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THE GENERALIZED TRAJECTORY SIMULATION SYSTEM. VOLUME V. WEIGHT ESTIMATION MODELS FOR SIZING APPLICATIONS

Charles C. DeBilzan

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Aerospace Corporation

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Prepared for:

Space and Missile Systems Organization Air Force Rocket Propulsion Laboratory

21 November 1975

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Volume V: Weight Estimation Models for Sizing Applications

TRAJECTORY ANALYSIS PROGRAMMING DEPARTMENT Information Processing Division Engineering Science Operations The Aerospace Corporation El Segundo, Calif. 90245

21 November 1975

Final Report

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> > Prepaied for

AIR FORCE ROCKET PROPULSION LABORATORY AIR FORCE SYSTEMS COMMAND Edwards Air Force Bass, Calif. 98528





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SPACE AND MISSILE SYSTEMS ORGANIZATION AIR FORCE SYSTEMS COMMAND Los Angeles Air Force Station P.O. Box 92960, Worldway Postal Center Los Angeles, Calif. 90009 This report was prepared by The Aerospace Corporation, El Segundo, California, under Contract F04701-75-C-0076 with the Space and Missile Systems Organization (AFSC), P.O. Box 92960, Worldway Postal Center, Los Angeles, California 90009. The work was sponsored by the Air Force Rocket Propulsion Laboratory (AFSC), Edwards AFB, California 93523, with Capt. Francis Lymburner as project officer. This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

Approved by

Sims, Director R.

Mathematics and Programming Subdivision Information Processing Division Engineering Science Operations

This technical report has been reviewed and is approved for publication.

Gerhard E. Aichinger Technical Advisor Contracts Management Office

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Chief, Contracts Management Office

REPORT DOCUMENTATION PAG	E	READ INSTRUCTIONS
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AUTHOR(a)		S. CONTRACT OR GRANT NUMBER(+)
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Information Processing Division		F04701-75-C-0076
Engineering Science Operations		
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The Aerospace Corporation		
El Segundo, California 90245		
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Air Force Rocket Propulsion Laborate	OTV	
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20. ABSTRACT (Continued)

objectives. Additionally, the GTS system contains an extensive vehicle sizing capability and a state-of-the-art optimization capability.

This volume documents the GTS library of weight estimation models which provide a vehicle sizing capability for space and missile vehicles that utilize solid propellant rocket motors. Liquid propelled vehicles can also be accommodated within the sizing procedure; however, they require the development of specialized weight estimation models to represent particular characteristics of the desired liquid propellant system.

Primary applications include preliminary design studies, booster subsystem trade-off studies, and growth studies of existing systems, including the analysis of advanced propellant technology or new launch concepts.

PREFACE.

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This volume, the fifth of five volumes that describe the Generalized Trajectory Simulation System (GTS), documents the GTS library of weight estimation models utilized for sizing applications. The remaining volumes are:

Volume 1: <u>GTS Overview</u>. This document provides the user with an overview of GTS, including a summary of the major operational capabilities and structural design of the GTS system.

Volume II: <u>GTS Usage Guide</u>. This volume serves as a general usage guide to GTS and includes a set of example problems, a comprehensive description of the Generalized Trajectory Language, and a discussion of the trajectory simulation control. In addition, this volume contains a master reference list for all volumes and supplementary information to aid the user in defining his problem.

Volume III: <u>GTS Flight Dynamic Models</u>. This report concerns the GTS library of flight mechanics and flight dynamics models utilized for trajectory simulations.

Volume IV: <u>GTS Numerical Operators</u>. This publication deals with the GTS library of numerical operators, including integration, optimization, and interpolation operators.

This report was prepared by Charles C. DeBilzan. The author acknowledges the beneficial contributions and suggestions made by A. D. Hemenover, F. R. Henry, J. R. McLaughlin, D. S. Meder, J. Milligan, W. T. Milloway, ri. E. Pickett, and J. L. Searcy.

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1. INTRODUCTION

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1.0.1 Program Description

The solid rocket motor weight estimation models presented within this volume, combined with a general purpose optimization scheme (Vol. 1V) and trajectory simulation capability (Vol. III), form a generalized vehicle sizing program for solid rockets. The program, normally utilized in preliminary design level studies, estimates performance sensitive component weights which will determine a propulsion system configuration consistent with realistic vehicle geometry, performance and mission constraints. Specifically, it sizes each major rocket component, bases weight predictions on past and present experience, recognizes actual hardware and system constraints, and permits the inclusion of technology changes. It is valid for propulsion system weights between 3000 and 2,000,000 lbs. and does not require the generation of reference designs prior to generating results. It should be noted that the program does not replace the design, weight, and performance processes associated with hard point design studies. However, it has proven a valuable tool when sufficient data, funding, or time is not available for such a design effort.

1.0.2 Program Applications

The propulsion system configuration generated by this program has served as a reference vehicle design for:

- booster subsystem trade-off studies;
- preliminary design of major new missile weapon and space system concepts;
- growth studies of existing boost and post-boost vehicles;
- determining the effects of advanced propellent technology on missile systems;
- determining effects of new launch concepts on missile systems.

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1.1 SUMMARY OF WEIGHT ESTIMATION METHODOLOGY

This section summarizes the principal methods used for derivation of the weight prediction equations and gives some general comments on the accuracy to be expected. For a detailed exposition of the methodology for specific applications, and the derivation of many of the weight prediction equations used, see reference 8.

There are three principal methods of weight analysis associated with the development of the weight estimation models within this volume. The first two listed below, actual and hard point design, served as the data base for the development of the weight scaling equations used by this program.

- 1. Actual weight analysis--determination of the measurements and weights of existing rockets.
- 2. Hard point design analysis--development of detailed mathematical models of the geometry and physics of a specific proposed rocket system.
- 3. Preliminary design analysis using weight scaling--development of simple mathematical models using weight scaling equations derived by analysis of the physical and statistical properties of existing rockets. The resulting design, using estimated weights, serves as a reference vehicle which may require further perturbation for analysis of a specific rocket system. The primary scaling methods used are:
 - theoretical weight scaling
 - statistical weight scaling
 - parametric weight scaling

1.1.1 Theoretical Weight Scaling

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Theoretical weight scaling equations are developed by generating a simple mathematical model of the physics and geometry, which includes only elements common to a wide range of rockets.

The scaling equation is an analytical equation expressed in terms of design parameters which are either performance sensitive or basic quantities of the subsystem being modeled.

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^{1.} Kimble, J. E. "Parametric Weight Scaling Equations for Solid Propellent Launch Vehicles," TR-669(6560)-2, The Aerospace Corp., El Segundo, Calif., April 1966 (U).

The principal advantage of theoretical scaling is that the analytical approach assists in determining the significant design parameters and, since the fundamental physics and geometry are being modeled, weight trends due to design parameter perturbations can be predicted with confidence. However, due to the simple universal models employed, the absolute weights predicted may be considerably different than the actual subsystem weight.

The principal steps in developing a theoretical weight scaling model are:

- 1. Collect data. The data may include weights and design parameters of both existing rockets and hard point designs.
- 2. Derive a theoretical equation for the weight of the subsystem using physical properties. Select significant design parameters and re-express the weight equation as a function of these design parameters.
- 3. Compare the theoretical equation results with the data.
- 4. Repeat steps 2 and 3 until the comparison is satisfactory.

1.1.2 Statistical Weight Scaling

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Statistical weight scaling equations are developed by generating a mathematical model using statistical analysis of existing rockets.

The scaling equation and scaling parameters are both statistical in nature, chosen to give a "best fit" to the data.

When compared with the data from which they are derived, statistical equations yield better estimates of absolute component weights than the theoretical scaling equations described above. Further, for complex subsystems where a simple theoretical model may not be feasible, statistical scaling may be required. However, since both the equation and parameters do not reflect the physics of the subsystems being modeled, weight trends due to perturbation of design parameters cannot be predicted with confidence.

The principal steps in developing a statistical weight scaling model are:

- 1. Collect data. The data may include weights and design parameters of both existing rockets and hard point designs.
- 2. Determine both the form of the weight estimation function and the statistical parameters by analysis of the mathematical properties of the data.

- 3. Determine coefficient and exponent values which result in a "best fit" curve.
- 4. Perform correlation analysis.
- 5. Repeat steps 2 through 4 until errors are acceptable.

1.1.3 Parametric Weight Scaling

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Parametric weight scaling equations are developed by generating a mathematical model which combines both statistical weight scaling and theoretical weight scaling techniques.

The scaling equation is statistical in form, using elements of the theoretical equation as statistical parameters. As with theoretical weight scaling, design parameters are either performance sensitive or basic quantities of the subsystem being modeled.

Parametric weight scaling attempts to combine the advantages of both theoretical and statistical scaling methods. The analytical approach yields insight into selection of significant design parameters and is a basis for good weight trend predictions, whereas the statistical fitting yields realistic absolute weights by accounting for weight contributions not predicted by the theoretical equation. Whenever possible, the weight models documented within this volume use parametric weight scaling for predicting rocket component weights.

The principal steps in developing a parametric weight scaling model are:

- 1. Collect data. The data may include weights and design parameters of both existing rockets and hard point designs.
- 2. Derive a theoretical equation for the weight of the subsystem using physical properties. Select significant design parameters and re-express the weight equation as a function of these design parameters.
- 3. Compare the theoretical equation results with the data. Particular emphasis is placed on weight trend results since the statistical fitting in the following steps will account for bias in the absolute weights predicted.
- 4. Repeat steps 2 and 3 until the comparison is satisfactory.
- 5. Determine the form of the weight estimation function to be used for the statistical analysis. Rearrange the theoretical equation such that the elements serve as statistical parameters.

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6. Determine coefficient and exponent values which result in a "best fit" curve.

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- 7. Perform correlation analysis.
- 8. Repeat steps 2 through 7 until errors are acceptable.

1.1.4 Accuracy of Weight Scaling Results

For studies coordinated with competent weight prediction personnel, the following general statements may be made for the accuracy of the results using the weight estimation models presented within this volume.

- 1. Weight predictions do not include the effects of design philosophy, program funding, or technological advances difficult to evaluate or forecast.
- 2. The subsystems can be manufactured with the predicted weight.
- 3. Weight trends resulting from design parameter perturbations can be predicted with higher confidence than absolute weights. Weights of complex subsystems will have reduced accuracy.
- 4. The stage structure factor (ratio of stage burnout weight to stage gross weight) will be within 15%.
- 5. Statistical weight scaling models cannot be u ed for subsystem tradeoff studies.
- b. The geometrical configuration produced is of secondary importance and requires considerable interpretation for correlation with geometrical configurations produced by a "hard point design" analysis.

1.2 USE OF GTS FUNCTION GENERATORS TO SOLVE THE SIZING PROBLEM

Two principal components of the GTS system are a "model library" and a set of "program control executive models" (referred to as "function generators"), which select and control the execution of the subset of library models required for solution of a particular problem. Specifically, three subsets of the model library are pertinent for sizing applications: optimization numerical operator models (which are documented in Volume IV), weight estimation models (which are documented within this volume), and trajectory simulation models (which are documented in Volume III). In addition, to control these models, three function generators are required: OPTSYS, for control of the optimization numerical operator models; SIZE, for control of the weight estimation models; and TRAJCEM, for control of the trajectory simulation models.

This section will illustrate the general techniques utilized for solving sizing problems using the appropriate function generators and models. For specific model requirements, refer to the pertinent GTS volume, and for a detailed discussion of the input language, including the precise method and syntax required to implement the function generators and models, see Volume II.

1, 2, 1 Statement of the Sizing Problem

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In general, the sizing problem is to estimate the "best" rocket weight breakdown which will result in a propulsion system configuration which is consistent with realistic vehicle geometry, performance, and mission constraints.

The problem may be stated as three distinct, but not normally independent, subproblems:

- 1. The optimization subproblem. Determine the variable values which extremize the objective function subject to a set of equality and inequality constraints or determine the values of N variables which satisfy N equality constraints.
- 2. The weight estimation subproblem. Given a set of variable values, determine the vehicle geometry, propulsion, and weights.
- 3. The trajectory simulation subproblem. Given a set of variable values and vehicle parameters, determine the trajectory profile.

It must be noted that this problem statement completely separates the determination of variable values, constraint solving, and objective function maximization or minimization from the evaluation of the vehicle and trajectory quantities. This is not only required for a valid solution to the theoretical problem, it will be shown within the following sections that this method of breaking down the problem renders itself to natural, flexible, and efficient methods of solution using GTS function generators and GTS models.

1.2.2 Pertinent Function Generators

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A GTS function generator is the principal executive subprogram which controls the execution of the set of models required to solve a class of problems. The function generator will, in turn, call a lower level executive model (usually via a "definition" model type) to solve a specific problem within the class.

That is, a function generator is used to solve a particular type of problem.

A problem, which has been partitioned into distinct, functional, subproblems, may be solved by linking function generators, each type of subproblem solved by a specific function generator.

The pertinent function generators for sizing applications are OPTSYS, SIZE, and TRAJCEM.

OPTSYS - Optimization System Program Control Executive Model.

For sizing applications, OPTSYS normally executes UOPTIM or UBEST (or USCHN for special problem applications involving only trajectory quantities) via the optimization problem definition model type PROBDEF. Both UOPTIM and UBEST are general purpose optimization schemes designed for solving problems incorporating an objective function and a very large number of variables, equality constraints and inequality constraints. USCHN is a special purpose optimization scheme designed for efficiently solving search problems by satisfying equality constraints.

SIZE - Weight Estimation Program Control Executive Model.

For the current set of available weight estimation models, SIZE executes VHDM1, a vehicle definition model which controls the evaluation of the geometry, propulsion, and weight equations for a sequentially staged vehicle.

TRAJCEM - Trajectory Program Control Executive Model.

TRAJCEM executes TRJDM1, the trajectory definition model which controls the trajectory simulation. (TRJDM1 is a default model and is normally not of concern to the program user.)

Interaction of Function Generators 1.2.3

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As mentioned above, the sizing problem may be set up as three distinct (but dependent) subproblems, each subproblem solved by a particular function generator (i.e., OPTSYS is responsible for determining variable values, solving constraints, etc., SIZE is responsible for evaluating the weight estimation equations, and TRAJCEM is responsible for evaluating the trajectory equations). To solve the real problem, the function generators must be linked together by the program user in a manner which insures that the major dependencies are satisfied correctly. For example, generally, a valid optimization problem may have only a single objective function. If a multi-case setup is being utilized where the vehicle parameters are optimized within the first case by extremizing a part mar objective function. then the resulting vehicle is flown in the second case extremizing a second objective function, it is the responsibility of the program user to insure that the "two" optimization problems are not dependent.

Due to the nature of the sizing problem, the engineering design cycle for an application will frequently involve repeated computer runs using alternate function generator linkages. The repeated runs may be required to investigate a specific subsystem prior to sizing the total vehicle and mission, the alternate linkages may be required for the initial subsystem analysis cr to minimize computer charges. The latter becomes especially important for applications where many vehicles are being sized. This section will illustrate the various function generator linkages useful for sizing applications.

1. Evaluate Vehicle Configuration and Simulate Trajectory (no optimization).

Figure 1 illustrates two examples where SIZE and TRAJCEM are used in a "stand alone" mode without optimization. The first example illustrated is a two case job. The first case executes SIZE directly, which in turn calls a vehicle definition model (e.g., VHDM1) to evaluate the vehicle geometry, weight and propulsion quantities. The second case, which is optional, executes TRAJCEM, which simulates the trajectory using the vehicle parameters determined in case I. The second example illustrated is a single case job. TRAJCEM is executed directly and SIZE is executed from a trajectory initialization model type when vehicle parameters are required as input to the trajectory models.

Since there is no optimization and associated constraint solving, the above function generator linkages are not frequently used. The program user must furnish input data values which will satisfy the vehicle geometry constraints. Generally, these values, especially for the grain geometry, are not known apriori.

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2. Optimize Vehicle Configuration, Then Optimize Trajectory.

Figure 2 illustrates a two case setup which optimizes the vehicle configuration and trajectory separately. The first case executes OPTSYS which estimates vehicle variable values and, when a function evaluation is required for constraint solving or extremizing the objective function, calls SIZE. After the vehicle optimization problem is solved, the second case is executed if desired. OPTSYS estimates variable values and, when a function evaluation is required, TRAJCEM uses the optimization determined trajectory variable values, together with the vehicle parameters determined within the first case to simulate the trajectory. an dhi sha

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In practice, this function generator setup is used frequently. However, since the "two" optimization problems solved may not be independent, it must be used with extreme caution. The solution should be verified by rerunning the final job with the function generator setup illustrated in Figure 3 and described below.

3. Optimize Vehicle Configuration and Trajectory.

Figure 3 illustrates a single case function generator setup which optimizes the combined vehicle configuration and trajectory. OPTSYS estimates vehicle and trajectory variables and, when a function evaluation is required, TRAJCEM is executed from OPTSYS. TRAJCEM in turn calls SIZE out of a trajectory initialization model type when vehicle data is required.

Since the optimization dependencies are always valid, this is the preferred setup for sizing applications. No distinction is made between vehicle and trajectory quantities since both sets of equations are evaluated simultaneously with respect to the optimization. The only disadvantage is that for some problems, many trajectories will be medlessly generated for solving the set of vehicle constraints which are independent of the trajectory. Normally, it is not recommended that the user attempt to determine dependencies of this nature and economize by splitting the optimization problem into two parts. The dependencies are very subtle and results are usually not valid. However, some important, frequently used, basic sizing applications may be formulated such that the vehicle optimization problem is independent of the trajectory optimization problem.



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> Fig. 1.2.3-1 Typical Function Generator Interaction. Determine Vehicle Configuration and Simulate Trajectory. (No Optimization)

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Fig. 1.2.3-2. Typical Function Generator Interaction. Optimize Vehicle Configuration, Then Optimize Trajectory. (Optimization Problems Must Be Uncoupled.)

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EXECUTE OPTSYS Determine variable values which optimize the system. Call TRAJCEM when a function evaluation is required. TRAJCEM stage

TRAJCEM

Simulate trajectory by calling SIZE directly (via a trajectory initialization model type) when stage weights, thrust, etc., are required as input data to the trajectory models.

SIZE

Evaluate vehicle, weights, geometry, and propulsion equations when requested by TRAJCEM.

Fig. 1.2.3-3

Typical Function Generator Interaction. Optimize System by Combining Vehicle and Trajectory. (Optimization Problem May Have Interdependent Vehicle and Trajectory Quantities.)

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1.3 CLASSIFICATION AND PURPOSE OF WEIGHT ESTIMATION MODELS.

The weight estimation models within this volume are organized functionally into three major classifications:

vehicle definition models weight models geometry, internal ballistics, and propulsion models

Except for the vehicle definition models, which are presented first, the individual model writeups are ordered alphabetically within this document starting with Section 10.

1.3.1 Vehicle Definition Models

The vehicle definition model is an executive model (called by the SIZE function generator) which controls the execution of the individual models required to evaluate a specific application. The documentation for each vehicle definition model (Section 10) lists the applicable model types and serves as a guide for selecting models when setting up a new data deck.

1.3.2 Weight Models

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There are two types of weight models--scaling models and synthesis models.

Scaling models predict subsystem weights using weight scaling equations which are a function of design parameters selected when the weight scaling equations were developed. Whenever possible, parametric weight scaling is utilized. However, because of subsystem complexity, insufficient data, etc., statistical weight scaling and theoretical weight scaling are used for some component weights. Typical design parameters include:

> length to diameter ratios volumetric loading efficiency propellent weight burn time nowle expansion ratio chamber pressure specific impulse

> > Preceding page blank

Synthesis models are used to combine subsystem weights, evaluated by scaling models or other synthesis models, to form composite subsystems.

In addition to component weights peculiar to the subsystem being modeled, each weight model outputs a general expended component weight breakdown (for performance evaluation) of the following form:

$$w = w_{PP} + w_{X} + w_{NX}$$
$$w_{X} = w_{XI} + w_{XT}$$

where

| w               | is the total subsystem weight.                                                  |
|-----------------|---------------------------------------------------------------------------------|
| W <sub>PP</sub> | is the primary propellent weight component associated with the subsystem.       |
| w <sub>x</sub>  | is the total expended weight component associated with the subsystem.           |
| W <sub>NX</sub> | is the total non-expended weight component associated with the subsystem.       |
| w <sub>XI</sub> | is the expended (non-thrust producing) weight component associated with $W_X^*$ |
| w <sub>xt</sub> | is the expended (thrust producing) weight component associated with $W_X$ .     |

# 1.3.3 Geometry, Internal Ballistic and Propulsion Models

The <u>SOLE</u> purpose of the geometry, internal ballistic, and weight models is to determine the design parameter values required by the weight scaling models. Note that what constitutes a "design parameter" is specified by the weight model, NOT the geometry, internal ballistics or propulsion model.

The geometrical configuration produced is of secondary importance and requires considerable interpretation for correlation with geometrical configurations produced by a "hard point design" analysis.

# 2. NOMENCLATURE CONVENTIONS

The following conventions have been established to facilitate symbol identification within the weight estimation models. It must be emphasized that these are conventions, not rigid rules, and that exceptions will occur.

Except for ratios and factors:

the symbol

P<sub>SS</sub><sub>XXX</sub>

corresponds to the mnemonic **PSSXXX** 

where

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| P   | designates the primary attribute of the quantity                                  |
|-----|-----------------------------------------------------------------------------------|
| SS  | designates the secondary attribute of the quantity                                |
| xxx | designates an identifier which makes the quantity unique (up to three characters) |

For ratios:

the symbol RPPSSSS

corresponds to the mnemonic RPPSSSS

where

| R   |           | designates a vatio quantity                                                    |
|-----|-----------|--------------------------------------------------------------------------------|
| the | first P   | designates the numerator primary attribute                                     |
| the | second P  | designates the denominator primary attribute<br>(if different from first P)    |
| the | first SS  | designates the numerator secondary attribute                                   |
| the | second SS | designates the denominator secondary attribute<br>(if different from first SS) |

For factors:

| the | symbol      | <sup>K</sup> pssxxx |  |
|-----|-------------|---------------------|--|
| лę  | 8 y 111 DOL | **PSSXXX            |  |

corresponds to the mnemonic KPSSXXX

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|      | K designates a factor quantity  |                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      | PSSXXX                          | designates the left hand member of the equation containing the factor                                                                                                                                                                                                                                                                                                                                           |
| Exan | nples of p                      | rimary attributes are:                                                                                                                                                                                                                                                                                                                                                                                          |
| P =  | A B C D I K L N P Q R S T V W Y | Plane area (in <sup>2</sup> )<br>Burn rate (in/sec)<br>Constant (N. D.)<br>Diameter (in)<br>Impulse<br>Factor, coefficient or bias<br>Length (measured parallel to centerline) (in)<br>Number of (N. D.)<br>Pressure (psia)<br>Associative quantity<br>Ratio (N. D.)<br>Surface area (in <sup>2</sup> )<br>Thickness (in), time (sec), temperature<br>Volume (in <sup>3</sup> )<br>Weight (lb)<br>Centroid (in) |

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Examples of secondary attributes are:

| SS = | СН  | Chamber            |
|------|-----|--------------------|
|      | CS  | Case               |
|      | GN  | Grain              |
|      | IN  | Insulation         |
|      | IT  | Interstage         |
|      | IT  | Toint              |
|      | MT  | Motor              |
|      | N7  | Nozzla             |
|      |     | Davland            |
|      |     | Pauload reation    |
|      |     |                    |
|      | PP  | Primary propenent  |
|      | PS  | Propulsion system  |
|      | PT  | Port               |
|      | SG  | Stage              |
|      | SH  | Shroud             |
|      | SK  | Skirt              |
|      | SL  | Slot               |
|      | SS  | Substage           |
|      | ST  | Structure          |
|      | тн  | Throat             |
|      | ТТ  | Thrust termination |
|      | TV  | Thrust vector      |
|      | 4 T |                    |

Examples of identifiers which make a quantity unique:

XXX =Aft Α Forward F CL or C Closure CH Closure hole CY or Y Cylinder Н Hole I O Inside Outside

Some examples using the conventions:

| DCSO   | D <sub>CSO</sub>             | Outside case diameter                  |
|--------|------------------------------|----------------------------------------|
| DCSI   | D <sub>CS</sub> I            | Inside case diameter                   |
| WNZ    | w <sub>NZ</sub>              | Total nozzle weight                    |
| LNZ    | L <sub>NZ</sub>              | Total nozzle length                    |
| LNZCV  | L <sub>NZCV</sub>            | Length of convergent portion of nozzle |
| LNZDV  | L <sub>NZ<sub>DV</sub></sub> | Length of divergent portion of nozzle  |
| ANZTH  | A <sub>NZ</sub> TH           | Nozzle throat area                     |
| ANZEXT | A <sub>NZ</sub> EXT          | Nozzle exit area                       |
| ANZENT | A <sub>NZ</sub> ENT          | Nozzle entrance area                   |
| DNZTH  | D <sub>NZ</sub> TH           | Nozzle throat diameter                 |
| DNZEXT | D <sub>NZ</sub> EXT          | Nozzle exit diameter                   |
| DNZENT | D <sub>NZ</sub> ENT          | Nozzle entrance diameter               |

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| LNZB    | LNZB              | Buried nozzle length                       |
|---------|-------------------|--------------------------------------------|
| KLNZB   | <sup>K</sup> LNZB | Buried nozzle factor                       |
| RLDGNCY | RLDGNCY           | Cylindrical grain length to diameter ratio |

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VEHICLE DEFINITION

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MODEL TYPE: VEHDEF (VEHicle DEFinition)

MODEL NAME:

VHDM1 (Sequential stages with payload)

### DESCRIPTION:

VHDM1 (VeHicle Definition Model number 1) is an executive model which defines a rocket configuration consisting of a single propulsion system (i.e., boost vehicle), with sequential stages, and a single payload section (i.e., post-boost vehicle). The rocket is comprised of the following major components, each of which has a separate data block for input of its models and associated data (see figure 1).

The <u>"vehicle"</u> is comprised of a single "propulsion system" and a single "payload section". The "vehicle" data is input within the same data block as the vehicle definition model. In addition to the vehicle definition model type, VEHDEF, the following model types are applicable.

| VEHG | Vehicle | geometry |
|------|---------|----------|
| VEHW | Vehicle | weight   |

The <u>"propulsion system"</u> (i.e., boost vehicle) is comprised of up to ten sequential "stages". Data is input using the data block specified by DBPS(1) (see Intra-Model Input). The following model types are applicable.

| PROSYSG | Propulsion | system | geometry |
|---------|------------|--------|----------|
| PROSYSW | Propulsion | system | weight   |

A <u>"stage"</u> is comprised of a single "substage" and a single "interstage". "Stage" data is input using the data block specified by DBSG(i), i = 1, 10, where i is the stage number. Stages are numbered consecutively, from the bottom to the top, starting with any integer less than, or equal to, 10. The following model types are applicable.

| STAGEG | Scage | geometry |
|--------|-------|----------|
| STAGEW | Stage | weight   |

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# DESCRIPTION (Cont.):

A "substage" is comprised of the motor and nozzle associated with a "stage". "Substage" data is input using the data block specified by DBSS (i), i = 1, 10, where i is the stage number. The following model types are applicable.

| CASEG 2 | Case geometry                     |
|---------|-----------------------------------|
| CASEW   | Case weight                       |
| GRAING  | Grain geometry                    |
| IBGAS   | Internal ballistics, gas          |
| IBFLOW  | Internal ballistics, flow         |
| IBPERF  | Internal ballistics, performance  |
| INSULG  | Internal insulation geometry      |
| INSULW  | Internal insulation weight        |
| MISCMTW | Miscellaneous motor weight        |
| MOTORG  | Motor geometry                    |
| MOTORW  | Motor weight                      |
| NOZZLEG | Nozzle geometry                   |
| NOZZLEW | Nozzle weight                     |
| PROPELW | Propellent weight                 |
| PROPUL  | <b>Propulsion</b> characteristics |
| SUBSTGG | Substage geometry                 |
| SUBSTGW | Substage weight                   |
| TVCG    | Thrust vector control geometry    |
| TVCW    | Thrust vector control weight      |
| TTERMG  | Thrust termination geometry       |
| TTERMW  | Thrust termination weight         |

An "interstage" is comprised of the structure to join either "substages" or a "substage" and the "payload" (i.e., payload adapter). The "interstage" associated with a "stage" is on top of (forward of) the "substage" associated with that "stage". "Interstage" data is input using the data block specified by DBIT(i), i = 1, 10. The following model types are applicable.

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# VEHICLE DEFINITION

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# DESCRIPTION (Cont.):

| INTINSW | Interstage | external insulation weight |
|---------|------------|----------------------------|
| INTSTGG | Interstage | geometry                   |
| INTSTGW | Interstage | weight                     |
| INTSTRW | Interstage | structure weight           |

The "payload section" (i.e., post-boost vehicle) is comprised of a single payload. "Payload section" data is input using the data block specified by DBPL(1). The following model types are applicable.

| PAYSECG | Payload section geometry |
|---------|--------------------------|
| PAYSECW | Payload section weight   |
| SHROUDW | Shroud weight            |

"Payload" data is input using the data block specified by DBPA(1). The following model types are applicable.

| PAYLODG | Payload geometry |
|---------|------------------|
| PAYLODW | Payload weight   |

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Fig. 10, 1-1 Major Components and Data Block Designation for a Typical Three Stage Rocket

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# INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user.

| Mnemonic | Symbol  | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                     |
|----------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DBIT(i)  | DBIT(i) | Name of data block containing interstage data<br>for the interstage associated with the i-th<br>stage. $i = 1$ , 10 where i is the stage number.<br>The data block name is arbitrary (i.e., user<br>defined), except that it cannot be a previously<br>mentioned user-defined symbol or an existing<br>GTS symbol. |
|          |         | e.g., $DBIT(1) = [INTSTG1];$                                                                                                                                                                                                                                                                                       |
|          |         | N. D.                                                                                                                                                                                                                                                                                                              |
| DBPA(!)  | DBPA(1) | Name of data block containing payload data.<br>The data block name is arbitrary (i.e., user<br>defined), except that it cannot be a previously<br>mentioned user-defined symbol or an existing<br>GTS symbol.                                                                                                      |
|          |         | e.g., $DBPA(1) = [PAYLOD];$                                                                                                                                                                                                                                                                                        |
|          |         | N. D.                                                                                                                                                                                                                                                                                                              |
| DBPL(1)  | DBPL(1) | Name of data block containing payload section<br>(i.e., post-boost vehicle) data. The data<br>block name is arbitrary (i.e., user defined),<br>except that it cannot be a previously mentioned<br>user-defined symbol or an existing GTS symbol.                                                                   |
|          |         | e.g., DBPL(1) = [PAYSEC];                                                                                                                                                                                                                                                                                          |
|          |         | N. D.                                                                                                                                                                                                                                                                                                              |
| DBPS(1)  | DBPS(1) | Name of data block containing propulsion<br>system (i.e., boost vehicle) data. The data<br>block name is arbitrary (i.e., user defined),<br>except that it cannot be a previously mentioned<br>user-defined symbol or an existing GTS symbol.                                                                      |
|          |         | e.g., DBPS(1) = [PROSYS];                                                                                                                                                                                                                                                                                          |
|          |         | N. D.                                                                                                                                                                                                                                                                                                              |

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## INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol  | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                                                                                                                   |
|----------|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DBSG(i)  | DBSG(i) | Name of data block containing stage data for<br>the i-th stage. i = 1, 10 where i is the stage<br>number. Note that stages are numbered<br>consecutively, from the bottom to the top,<br>starting with any integer less than, or equal<br>to, 10. The data block name is arbitrary<br>(i.e., user defined), except that it cannot be<br>a previously mentioned user-defined symbol<br>or an existing GTS symbol. |
|          |         | e.g., DBSG(1) = [STAGE1];                                                                                                                                                                                                                                                                                                                                                                                        |
|          |         | N. D.                                                                                                                                                                                                                                                                                                                                                                                                            |
| DBSS(i)  | DBSS(i) | Name of data block containing substage data<br>for the substage associated with the i-th<br>stage, i = 1, 10 where i is the stage number.<br>The data block name is arbitrary (i.e., user<br>defined), except that it cannot be a previously<br>mentioned user-defined symbol or an existing<br>GTS symbol.                                                                                                      |
|          |         | e.g., DBSS(1) = [SUBSTGI];                                                                                                                                                                                                                                                                                                                                                                                       |
|          |         | N. D.                                                                                                                                                                                                                                                                                                                                                                                                            |

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. | (Int.) Units | Model Type |
|----------|--------|-------------------|--------------|------------|
|          | _ /    |                   | • • • •      |            |

None

### VEHICLE DEFINITION

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## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

Description; Ext. (Int.) Units Mnemonic Symbol

None

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MODEL TYPE: CASEG (CASE Geometry)

MODEL NAME: CSGMl (Metal case)

### DESCRIPTION:

CSGM1 (CaSe Geometry Model number 1) determines the pertinent geometry for a solid rocket motor metal case subject to internal pressure. This model does not account for buckling or aerodynamic loads.

As illustrated by Figure 1, the basic case geometry is comprised of a cylindrical section with forward and aft closure sections. The inside and outside surfaces of a closure section form concentric hemi-ellipsoids having coincident equatorial planes and, normally, unequal head ratios. The closures may have cylindrical holes, centered on the hemi-ellipsoid axis of revolution, for modeling geometry associated with the igniter, submerged nozzles and TVC systems. Generally, the geometry may be degenerated for simulating spherical motors, etc.

It should be noted that since the model does not include raceways or external protrusions associated with segmented cases, the outside case diameter is not necessarily the maximum diameter of the motor. If such protrusions exist, they would be evaluated by the models specified for the MOTORG (motor geometry) or SUBSTGG (substage geometry) model types.

### **PROCEDURE:**

Prior to entering CSGM1, the models specified by the IBGAS and NOZZLEG model types have determined the average chamber pressure and buried nozzle diameter.

Upon the first entrance to CSGM1, the thickness, closure lengths, diameters, head ratios, and closure hole geometry associated with a metal motor case are evaluated.

The models specified for the INSULG and GRAING model types then evaluate the remaining principal motor component geometry, the insulation and the grain.

After determining the grain geometry, CSGM1 is re-entered (second entrance) and quantities associated with the total case length are evaluated.

### EQUATIONS, FIRST ENTRANCE:

Case thickness, cylindrical section.

$$T_{CS_{CY}} = \left[ \frac{C_1 K_{FS} P_{MEO} D_{CS_O}}{2 K_{UTS}} \right] K_{CS_1} + K_{CS_2}$$
(1)

Case thickness, center of aft closure.

$$T_{CS_{CLA}} = (C_2 T_{CS_{CY}}) K_{CS_3} + K_{CS_4}$$
(2)

Case thickness, center of forward closure.

$$^{T}CS_{CLF} = \begin{pmatrix} C_{3} & T_{CS_{CY}} \end{pmatrix} K_{CS_{5}} + K_{CS_{6}}$$
(3)

Case inside diameter.

$$D_{CS_{I}} = D_{CS_{O}} - 2 T_{CS_{CY}}$$
(4)

Outside equatorial diameter for case closures.

$$D_{CS_{CLO}} = D_{CS_{O}}$$
(5)

Inside equatorial diameter for case closures.

$$^{D}CS_{CLI} = ^{D}CS_{I}$$
(6)

Outside longth of aft case closure.

$$L_{CS}_{CLAO} = \frac{R_{DCSCAO}}{2} D_{CS}_{CLO}$$
(7)

Inside length of aft case closure.

$$L_{CS}_{CLAI} = L_{CS}_{CLAO} - T_{CS}_{CLA}$$
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### CASE GEOMETRY

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### EQUATIONS, FIRST ENTRANCE (Cont.):

Inside head ratio of aft closure.

$$R_{DCSCAI} = 2 \frac{D_{CS_{CLAI}}}{D_{CS_{CLI}}}$$
(9)

Outside length of forward closure.

$$L_{CS}_{CLFO} = \frac{R_{DCSCFO} D_{CS}_{CLO}}{2}$$
(10)

Inside length of forward closure.

$$L_{CS_{CLFI}} = L_{CS_{CLFO}} - T_{CS_{CLF}}$$
(11)

Inside head ratio of forward closure.

$$R_{DCSCFI} = \frac{\frac{2 L_{CS}}{D_{CS}}}{\frac{D_{CS}}{CLI}}$$
(12)

Diameter of hole in aft outside case closure surface.

$$^{D}CS_{HAO} = K_{CS_{7}} D_{NZ_{B}} + K_{CS_{8}}$$
(13)

Diameter of hole in aft inside case closure surface.

$$^{\rm D}{\rm CS}_{\rm HAI} = {^{\rm D}{\rm CS}}_{\rm HAO}$$
(14)

Diameter of hole in forward outside case closure surface.

$$^{D}CS_{HFO} = ^{K}CS_{9} ^{D}CS_{CLO} + ^{K}CS_{10}$$
<sup>(15)</sup>

Diameter of hole in forward inside case closure surface.

$$^{\rm D}_{\rm CS}_{\rm HFI} = {}^{\rm D}_{\rm CS}_{\rm HFO}$$
(16)

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### EQUATIONS, FIRST ENTRANCE (Cont.):

Diameter ratio. Aft outside case hole diameter to outside case closure diameter.

$$R_{DCSHAO} = \frac{D_{CS}_{HAO}}{D_{CS}_{CLO}}$$
(17)

Outside length of aft case closure, adjusted for hole.

$$L_{CS}_{CHAO} = L_{CS}_{CLAO} \sqrt{1 - R_{DCSHAO}^2}$$
(18)

Diameter ratio. Aft inside case hole diameter to inside case closure diameter.

$$R_{DCSHAI} = \frac{D_{CS}_{HAI}}{D_{CS}_{CLI}}$$
(19)

Inside length of aft case closure, adjusted for hole.

$$L_{CS}_{CHAI} = L_{CS}_{CLAI} \sqrt{1 - R_{DCSHAI}^2}$$
(20)

Diameter ratio. Forward outside case hole diameter to outside case closure diameter.

$$R_{DCSHFO} = \frac{D_{CS}}{D_{CS}}$$
(21)

Outside length of forward case closure, adjusted for hole.

$$L_{CS}_{CHFO} = L_{CS}_{CLFO} \sqrt{1 - R_{DCSHFO}^2}$$
(22)

Diameter ratio, forward inside case hole diameter to inside case closure diameter.

$$R_{DCSHFI} = \frac{D_{CS}_{HFI}}{D_{CS}_{CLI}}$$
(23)

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### CASE GEOMETRY

### EQUATIONS, FIRST ENTRANCE (Cont.):

Inside length of forward case closure, adjusted for hole.

$$L_{\rm CS}_{\rm CHFI} = L_{\rm CS}_{\rm CLFI} \sqrt{1 - R_{\rm DCSHFI}^2}$$
(24)

Length of hole in aft case closure.

$$L_{CS}_{HA} = L_{CS}_{CHAO} - L_{CS}_{CHAI}$$
(25)

Length of hole in forward case closure.

$$L_{CS_{HF}} = L_{CS_{CHFO}} - L_{CS_{CHFI}}$$
(26)

Case cross sectional area.

$$A_{\rm CS} = \left(\frac{\pi}{4}\right) D_{\rm CS}^2 \tag{27}$$

Head ratio for use of models which define a single head ratio for forward and aft closures.

$$R_{DCSCHO} = R_{DCSCAO}$$
(27-a)

Associative quantities. The following quantities are intended solely for optional utilization by the program user. Their primary usage within this model is for forming constraint quantities.

| Q <sub>DI1</sub> | = K <sub>QDI1</sub> D <sub>CS</sub> | (28) |
|------------------|-------------------------------------|------|
|                  |                                     |      |

 $Q_{DI2} = K_{QDI2} D_{CS_{I}}$ (29)

$$Q_{DI3} = K_{QDI3} D_{CS_{I}}$$
(30)

$$Q_{\text{DOI}} = K_{\text{QDOI}} D_{\text{CS}}$$
(31)

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### CASE GEOMETRY

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## EQUATIONS, FIRST ENTRANCE (Cont.):

 $Q_{DO2} = K_{QDO2} D_{CS_{O}}$   $Q_{DO3} = K_{QDO3} D_{CS_{O}}$  (3.) (3.) (3.)

## EQUATIONS, SECOND ENTRANCE:

Length of cylindrical case section.

$$L_{CS_{CY}} = L_{GN_{CY}}$$
(34)

Total case length.

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$$L_{CS} = L_{CS}_{CY} + L_{CS}_{CHAO} + L_{CS}_{CHFO}$$
(35)

Cylindrical case length to diameter ratio.

$$R_{LDCSCY} = \frac{D_{CS_{O}}}{D_{CS_{O}}}$$
(36)

Total case length to diameter ratio.

$$R_{LDCS} = \frac{L_{CS}}{D_{CS_O}}$$
(37)

## 20.1-6

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### CASE GEOMETRY

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## INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol            | Description; Ext. (Int.) Units                                                                                                                     | Preset                        |  |
|----------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--|
| CCSG1    | C,                | Constant for TCSCY computation;                                                                                                                    |                               |  |
|          | •                 | N. D.                                                                                                                                              | 1.05                          |  |
| CCSG2    | c <sup>2</sup>    | Proportionality constant relating the case<br>thickness at the center of the aft closure to<br>the case thickness of the cylindrical section;      |                               |  |
|          |                   | N. D.                                                                                                                                              | 0.5                           |  |
| CCSG3    | c3                | Proportionality constant relating the case<br>thickness at the center of the forward<br>closure to the case thickness of the cylindric<br>section; |                               |  |
|          |                   | N. D.                                                                                                                                              | 0.5                           |  |
| DCSO     | D <sub>CSO</sub>  | Motor case outside diameter. Ou<br>diameter of pressure vessel cylin<br>section. Does not include raceway<br>protrusions, etc.;                    | ntside<br>ndrical case<br>ys, |  |
|          |                   | in Fig. 1                                                                                                                                          | 0                             |  |
| KCS1     | K <sub>C3</sub> . | Coefficient for TCSCY computation                                                                                                                  | on;                           |  |
|          | υı                | N. D.                                                                                                                                              | 1                             |  |
| KCS2     | ĸcs               | Bias for TCSCY computation;                                                                                                                        |                               |  |
|          | 2                 | in                                                                                                                                                 | 0                             |  |
| KCS3     | K <sub>CS</sub>   | Coefficient for TCSCLA computat                                                                                                                    | ion;                          |  |
|          | 3                 | N. D.                                                                                                                                              | 1                             |  |
| KCS4     | K <sub>CS</sub>   | Bias for TCSCLA computation;                                                                                                                       |                               |  |
|          | 4                 | in                                                                                                                                                 | 0                             |  |

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# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                                     | Preset    |
|----------|------------------------------|------------------------------------------------------------------------------------|-----------|
| KCS5     | <sup>K</sup> cs <sub>5</sub> | Coefficient for TCSCLF computation N. D.                                           | ;         |
| KCS6     | <sup>K</sup> cs <sub>6</sub> | Bias for TCSCLF computation;<br>in                                                 | 0         |
| KCS7     | к <sub>сs</sub>              | Coefficient for DCSHAO computation;<br>N. D.                                       | 1         |
| KCS8     | <sup>к</sup> сs <sub>8</sub> | Bias for DCSHAO computation;<br>in                                                 | 0         |
| KCS9     | к <sub>сs,</sub>             | Coefficient for DCSHFO computation;<br>N. D.                                       | 1         |
| KCS10    | к <sub>сs10</sub>            | Bias for DCSHFO computation;<br>in                                                 | 0         |
| KCSFS    | K <sub>FS</sub>              | Case factor of safety. Ratio of minin pressure to maximum expected opera pressure; | num burst |
|          |                              | N. D.                                                                              | 1         |
| KCSUTS   | KUTS                         | Ultimate tensile strength for metal ca<br>material;                                | ase       |
|          |                              | 1b/in <sup>2</sup>                                                                 | 0         |
| KQDCSII  | K <sub>QDII</sub>            | Associative quantity coefficient for Q computation;                                | DCSII     |
|          |                              | N. D.                                                                              | 0         |
| KQDCSI2  | K <sub>QDI2</sub>            | Associative quantity coefficient for Q computation;                                | DCS12     |
|          |                              | N. D.                                                                              | 0         |

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## INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                   | Preset                                                               |  |
|----------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|--|
| KQDCSI3  | K <sub>QDI3</sub>   | Associative quantity coefficient for QDCSI3 computation;                                                                                                                                                                                                                                                         |                                                                      |  |
|          |                     | N. D.                                                                                                                                                                                                                                                                                                            | 0                                                                    |  |
| KQDCSO1  | K <sub>QDO1</sub>   | Associative quantity coefficient for QDCSOI computation;                                                                                                                                                                                                                                                         |                                                                      |  |
|          |                     | N. D.                                                                                                                                                                                                                                                                                                            | 0                                                                    |  |
| KQDCSO2  | K <sub>QDO2</sub>   | Associative quantity coefficient for QDCSO2 computation;                                                                                                                                                                                                                                                         |                                                                      |  |
|          |                     | N. D.                                                                                                                                                                                                                                                                                                            | 0                                                                    |  |
| KQDCSO3  | K <sub>QDO3</sub>   | Associative quantity coefficient for QDCSO3 computation;                                                                                                                                                                                                                                                         |                                                                      |  |
|          |                     | N. D.                                                                                                                                                                                                                                                                                                            | 0                                                                    |  |
| RDCSCAO  | R <sub>DCSCAO</sub> | Head ratio of the ellipsoid associated<br>aft outside case closure surface. Ra<br>of twice the closure length to the clos<br>diameter, i.e., the aft outside case of<br>surface is an oblate spheroid. The h<br>is the ratio of the axis of revolution (<br>axis) to the equatorial diameter (majo               | with the<br>tio<br>ure<br>closure<br>ead ratio<br>minor<br>pr axis); |  |
|          |                     | N. D.                                                                                                                                                                                                                                                                                                            | 1                                                                    |  |
| RDCSCFO  | R <sub>DCSCFO</sub> | Head ratio of the ellipsoid associated<br>forward outside case closure surface<br>of twice the closure length to the clos<br>diameter, i.e., the forward outside<br>closure surface is an oblate spheroid<br>head ratio is the ratio of the axis of r<br>(minor axis) to the equatorial diamete<br>(major axis); | with the<br>Ratio<br>ure<br>case<br>The<br>evolution<br>er           |  |
|          |                     | <b>N.</b> D.                                                                                                                                                                                                                                                                                                     | 1                                                                    |  |

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### CASE GEOMETRY

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### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                                                                        | Model Type                         |
|----------|-----------------|-------------------------------------------------------------------------------------------------------|------------------------------------|
| DNZB     | D <sub>NZ</sub> | Buried nozzle diameter;                                                                               |                                    |
|          | В               | in                                                                                                    | NOZZLEG                            |
| рснмео   | PMEO            | Maximum expected operating cl<br>pressure;                                                            | namber                             |
|          |                 | psia                                                                                                  | IBGAS                              |
| LGNCY    | LGNCY           | Length of cylindrical grain sect<br>all adjustments for submerged<br>displaced propellent, cutouts, e | tion. Includes<br>nozzle,<br>etc.; |
|          |                 | in                                                                                                    | GRAING                             |

### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | <u>Symbol</u><br>A <sub>CS</sub> | Descriptio                                             | Description; Ext. (Int.) Units                                            |                                                       |  |  |
|----------|----------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------|--|--|
| ACS      |                                  | Motor cas<br>pressure<br>Does not i<br>in <sup>2</sup> | e cross sectional area<br>vessel cylindrical case<br>nclude raceways, pro | a. Area of<br>e section.<br>trusions, etc.;<br>Eq. 27 |  |  |
| DCSCLI   | D <sub>CS<sub>CLI</sub></sub>    | Equatorial<br>by the insi<br>case closu                | diameter of the ellipside surfaces of the for<br>tre sections;            | soids formed<br>ward and aft                          |  |  |
|          |                                  | in                                                     | Fig. 1                                                                    | Eq. 6                                                 |  |  |
| DCSCLO   | D <sub>CS<sub>CLO</sub></sub>    | Equatorial<br>by the out<br>case closu                 | diameter of the ellipside surfaces of the four section;                   | soids formed<br>rward and aft                         |  |  |
|          |                                  | in                                                     | Fig. 1                                                                    | Eq. 5                                                 |  |  |

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| OUTPUT DAT.                           | A (Cont.):                      |                                                                                                                                                                          |                                                                                                                |                                                                                                                     |                                                  |
|---------------------------------------|---------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|
| Mnemonic                              | Symbol                          | Descripti                                                                                                                                                                | on; Ext. (Int.)                                                                                                | Units                                                                                                               |                                                  |
| DCSHAI                                | D <sub>CS</sub> HAI             | Diameter of circular hole, for the nozzle,<br>centered on the axis of revolution of the hen<br>ellipsoid formed by the inside surface of the<br>aft case closure;        |                                                                                                                |                                                                                                                     |                                                  |
|                                       |                                 | in                                                                                                                                                                       | Fig. 1                                                                                                         | L .                                                                                                                 | Eq. 14                                           |
| DCSHAO                                | D <sub>CS</sub> HAO             | Diameter<br>centered<br>ellipsoid<br>aft case c                                                                                                                          | of circular ho<br>on the axis of :<br>formed by the<br>closure;                                                | le, for the noz:<br>revolution of th<br>outside surface                                                             | zle,<br>e hemi-<br>e of the                      |
|                                       |                                 | in                                                                                                                                                                       | Fig. 1                                                                                                         |                                                                                                                     | Eq. 13                                           |
| DCSHFI D <sub>CS</sub> <sub>HFI</sub> |                                 | Diameter of circular hole, for the igniter,<br>centered on the axis of revolution of the hemi-<br>ellipsoid formed by the inside surface of the<br>forward case closure; |                                                                                                                |                                                                                                                     |                                                  |
|                                       |                                 | in                                                                                                                                                                       | Fig. 1                                                                                                         | i                                                                                                                   | Eq. 16                                           |
| DCSHFO                                | D <sub>CS</sub> HFO             | Diameter of circular hole, for the igniter,<br>centered on the axis of revolution of the hem<br>ellipsoid formed by the outside surface of th<br>forward case closure:   |                                                                                                                |                                                                                                                     | ter,<br>e hemi-<br>e of the                      |
|                                       |                                 | in                                                                                                                                                                       | Fig. 1                                                                                                         | l                                                                                                                   | Eq. 15                                           |
| DCSI                                  | D <sub>CS-</sub>                | Case insi                                                                                                                                                                | de diameter, o                                                                                                 | ylindrical sect                                                                                                     | ion;                                             |
|                                       | 1                               | in                                                                                                                                                                       | Fig. 1                                                                                                         | L                                                                                                                   | Eq. 4                                            |
| LCS                                   | L <sub>CS</sub>                 | Total cas<br>forward b<br>associate<br>surface to<br>frustum a<br>surface.                                                                                               | e length. Dist<br>base of the hem<br>d with the forw<br>o the aft base o<br>associated with<br>Includes all ac | ance between the<br>ni-ellipsoid frue<br>vard outside clo<br>of the hemi-elli<br>the aft outside<br>djustments to g | ne<br>stum<br>osure<br>psoid<br>closure<br>rain; |
|                                       |                                 | in                                                                                                                                                                       | Fig. 1                                                                                                         |                                                                                                                     | Eq. 35                                           |
| LCSCHAI                               | <sup>L</sup> CS <sub>CHAI</sub> | Length of<br>forms the<br>closure.                                                                                                                                       | hemi-ellipsoid<br>inside surface<br>Includes adjust                                                            | dal frustum whi<br>e of the aft case<br>tment for nozzl                                                             | ich<br>e<br>e hole;                              |
|                                       |                                 | in                                                                                                                                                                       | Fig. 1                                                                                                         |                                                                                                                     | Eq. 20                                           |

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| OUTPUT DA | TA (Cont.):                     |                                                                                                                                             |                                                                                                                                            |                                |  |  |
|-----------|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--|--|
| Mnemonic  | Symbol                          | Description                                                                                                                                 | ; Ext. (Int.) Units                                                                                                                        |                                |  |  |
| LCSCHAO   | L <sub>CS</sub> CHAO            | Length of he<br>forms the o<br>closure. In                                                                                                  | Length of hemi-ellipsoidal frustum which<br>forms the outside surface of the aft case<br>closure. Includes adjustment for nozzle hole:     |                                |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 18                         |  |  |
| LCSCHFI   | L <sub>CS</sub> CHFI            | Length of he<br>forms the in<br>closure. Inc                                                                                                | Length of hemi-ellipsoidal frustum which<br>forms the inside surface of the forward case<br>closure. Includes adjustment for igniter hole: |                                |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 24                         |  |  |
| LCSCHFO   | L <sub>CS</sub> CHFO            | Length of hemi-ellipsoidal frustum which<br>forms the outside surface of the forward case<br>closure. Includes adjustment for igniter hole; |                                                                                                                                            |                                |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 22                         |  |  |
| LCSCLAI   | <sup>L</sup> CS <sub>CLAI</sub> | Length of the axis of revolut<br>ellipsoid formed by the insid<br>aft case closure section;                                                 |                                                                                                                                            | of the hemi-<br>urface of the  |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 8                          |  |  |
| LCSCLAO   | L <sub>CS</sub> CLAO            | Length of the axis of revolution of<br>ellipsoid formed by the outside su<br>aft case closure section;                                      |                                                                                                                                            | of the hemi-<br>surface of the |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 7                          |  |  |
| LCSCLFI   | <sup>L</sup> CS <sub>CLFI</sub> | Length of th<br>ellipsoid fo:<br>forward cas                                                                                                | ne axis of revolution<br>rmed by the inside s<br>re closure section;                                                                       | of the hemi-<br>urface of the  |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 11                         |  |  |
| LCSCLFO   | <sup>L</sup> CS <sub>CLFO</sub> | Length of th<br>ellipsoid fur<br>forward cas                                                                                                | e axis of revolution<br>rmed by the outside<br>e closure section;                                                                          | of the hemi-<br>surface of the |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 10                         |  |  |
| LCSCY     | LCSCY                           | Length of cy<br>adjustments                                                                                                                 | ylindrical case secti<br>to grain;                                                                                                         | on. Includes all               |  |  |
|           |                                 | in                                                                                                                                          | Fig. 1                                                                                                                                     | Eq. 34                         |  |  |

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## OUTPUT DATA (Cont.):

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| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                   |                  |  |  |
|----------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|--|--|
| LCSHA    | L <sub>CS<sub>HA</sub></sub> | Length of the cylindrical hole, for the nozzle, in the aft case closure;                                                                                                                                                                                                                                         |                  |  |  |
|          |                              | in Fig. 1                                                                                                                                                                                                                                                                                                        | Eq. 25           |  |  |
| LCSHF    | L <sub>CSHF</sub>            | Length of the cylindrical hole,<br>in the forward case closure;                                                                                                                                                                                                                                                  | for the igniter, |  |  |
|          |                              | in Fig. 1                                                                                                                                                                                                                                                                                                        | Eq. 26           |  |  |
| QDCSI1   | Q <sub>DI1</sub>             | Associative quantity, inside c<br>(see DCSI);                                                                                                                                                                                                                                                                    | ase diameter     |  |  |
|          |                              | in                                                                                                                                                                                                                                                                                                               | Eq. 28           |  |  |
| QDCSI2   | Q <sub>DI2</sub>             | Associative quantity, inside c<br>(see DCSI);                                                                                                                                                                                                                                                                    | ase diameter     |  |  |
|          |                              | in                                                                                                                                                                                                                                                                                                               | Eq. 29           |  |  |
| QDCS13   | Q <sub>DI3</sub>             | Associative quantity, inside case (<br>(see DCSI);                                                                                                                                                                                                                                                               |                  |  |  |
|          |                              | in                                                                                                                                                                                                                                                                                                               | Eq. 30           |  |  |
| QDCSO1   | Q <sub>DO1</sub>             | Associative quantity, outside<br>(see DCSO);                                                                                                                                                                                                                                                                     | case diameter    |  |  |
|          |                              | in                                                                                                                                                                                                                                                                                                               | Eq. 31           |  |  |
| QDCSO2   | Q <sub>DO2</sub>             | Associative quantity, outside<br>(see DCSO);                                                                                                                                                                                                                                                                     | case diameter    |  |  |
|          |                              | IN                                                                                                                                                                                                                                                                                                               | Eq. 32           |  |  |
| QDCSO3   | Q <sub>DO3</sub>             | Associative quantity, outside<br>(see DCSO);                                                                                                                                                                                                                                                                     | case diameter    |  |  |
|          |                              | in                                                                                                                                                                                                                                                                                                               | Eq. 33           |  |  |
| RDCSCAI  | RDCSCAI                      | Head ratio of the ellipsoid associated with the aft inside case closure surface. Ratio of two the closure length to the closure diameter, i.e., the aft inside case closure surface is oblate spheroid. The head ratio is the ratio the axis of revolution (minor axis) to the equatorial diameter (major axis); |                  |  |  |
|          |                              | N. D.                                                                                                                                                                                                                                                                                                            | Eq. 9            |  |  |

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## CASE GEOMETRY

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## OUTPUT DATA (Cont.):

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| Mnemonic                   | Symbol              | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                                  |                                       |                   |  |
|----------------------------|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|-------------------|--|
| RDCSCFI                    | <sup>R</sup> DCSCF1 | Head ratio of the ellipsoid associated<br>forward inside case closure surface.<br>twice the closure length to the closur<br>diameter, i.e., the forward inside c<br>closure surface is an oblate spheroic<br>head ratio is the ratio of the axis of<br>revolution (minor axis) to the equator<br>diameter (major axis);<br>N.D. | l with<br>Rat<br>ase<br>l. Th<br>rial | the<br>io of<br>e |  |
| RDCSHAT                    | Ø                   | Diamatan natio, hole diamatan te an                                                                                                                                                                                                                                                                                             |                                       | ~ <b>-</b> - 1    |  |
| RDCSHAI                    | <b>^DCSHAI</b>      | diameter, inside surface of aft case                                                                                                                                                                                                                                                                                            | closu                                 | al<br>re;         |  |
|                            |                     | N. D.                                                                                                                                                                                                                                                                                                                           | Eq.                                   | 19                |  |
| R DCSHAO                   | <sup>R</sup> DCSHAO | Diameter ratio, hole diameter to equatorial diameter, outside surface of aft case closure;                                                                                                                                                                                                                                      |                                       |                   |  |
|                            |                     | N. D.                                                                                                                                                                                                                                                                                                                           | Eq.                                   | 17                |  |
| RDCSHFI <sup>R</sup> DCSHF |                     | Diameter ratio, hole diameter to equatorial<br>diameter, inside surface of forward case<br>closure;                                                                                                                                                                                                                             |                                       |                   |  |
|                            |                     | N. D.                                                                                                                                                                                                                                                                                                                           | Eq.                                   | 23                |  |
| RDCSHFO                    | <sup>R</sup> dCshfo | Diameter ratio, hole diameter to equ<br>diameter, outside surface of forward<br>closure;                                                                                                                                                                                                                                        | atori<br>l case                       | al                |  |
|                            |                     | N. D.                                                                                                                                                                                                                                                                                                                           | Eq.                                   | 21                |  |
| RDCSCHO                    | RDCSCHO             | Head ratio for usage by models whic<br>a single head ratio for forward and a<br>closures;                                                                                                                                                                                                                                       | h defi<br>ft                          | ne                |  |
|                            |                     | N. D.                                                                                                                                                                                                                                                                                                                           | Eq.                                   | 27-a              |  |
| RLDCS                      | RLDCS               | Length to diameter ratio, total case;<br>N. D.                                                                                                                                                                                                                                                                                  | Eq.                                   | 37                |  |
| RLDCSCY                    | RLDCSCY             | Length to diameter ratio, cylindrica section;                                                                                                                                                                                                                                                                                   | l case                                | 9                 |  |
|                            |                     | N. D.                                                                                                                                                                                                                                                                                                                           | Eq.                                   | 36                |  |

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|---|----|----|----|------|--------|----|
|---|----|----|----|------|--------|----|

| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                        |                                                                                                   |                                              |
|----------|--------------------------------|-------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------------------------------------------|
| TCSCLA   | TCSCLA                         | Case thick<br>Distance b<br>hemi-ellip<br>axis of rev | ness at center of aft o<br>etween the aft inside<br>soid surfaces, measu<br>volution;             | case closure.<br>and outside<br>ared on the  |
|          |                                | in                                                    | Fig. 1                                                                                            | Eq. 2                                        |
| TCSCLF   | <sup>T</sup> CS <sub>CLF</sub> | Case thick<br>closure.<br>inside and<br>measured      | ness at center of forv<br>Distance between the<br>outside hemi-ellipsoi<br>on the axis of revolut | vard case<br>forward<br>id surfaces,<br>ion; |
|          |                                | in                                                    | Fig. 1                                                                                            | Eq. 3                                        |
| TCSCY    | TCS                            | Case thick                                            | ness, cylindrical sec                                                                             | tion;                                        |
|          | СУ                             | in                                                    | Fig. 1                                                                                            | Eq. l                                        |

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

|         |         |         | CASEC       | CSGM          | CASE GEOMET | RY      |
|---------|---------|---------|-------------|---------------|-------------|---------|
| CCSGL   | CCSG2   | CCSC3   | ۲¥          |               |             | •       |
| ACS     | DCSCLI  | DCSCLO  | ¢*          | DCSHAT        | DCSHAO      | DCSHFT  |
| DCSHFO  | DCSI    | DCSO    | *           |               |             | 4 11222 |
| KCSI    | KCS2    | Kcs3    | \$ <b>*</b> | KCS4          | KCS5        | KCSŃ    |
| KCS7    | KCS8    | KCS9    | ,¥          | KCSIO         |             |         |
| KCSFS   | KCSUTS  | KedcsIl | 6¥          | KODCSI2       | Kedcsia     | Kabcsol |
| KQDCSO2 | KQDCS03 | LCS     | *10         | LCSHA         | LCSHF       | LCSCHAT |
| LCSCHAO | LCSCHFI | LCSCHPO | 11*         | LCSCLAT       | LCSCLAO     | LUSCIEL |
| LCSCLFO | LCSCY   | QDCSI1  | *12         | <b>ODCSI2</b> | ancs13      | oncson  |
| QDCS02  | opcso3  | RDCSCAI | *13         | RDCSCAO       | RDCSCFI     | RDCSCPO |
| RDCSCHO | RDCSHAI | RDCSHAO | +14         | RDCSHFI       | RDCSHPO     | RLDCS   |
| RLDCSUY | TCSCLA  | TCSCLF  | <b>*1</b> 5 | TCSCY         |             |         |
|         |         |         |             |               |             |         |

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### CASE GEOMETRY

CSGM2

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MODEL TYPE: CASEG (CASE Geometry)

MODEL NAME: CSGM2 (Glass case)

### DESCRIPTION:

CSCM2 (ÇaSe Geometry Model number 2) determines the pertinent geometry for a solid rocket motor fiberglass case subject to internal pressure. This model does not account for buckling or aerodynamic loads.

As illustrated by Figure 1, the basic case geometry is comprised of a cylindrical section with forward and aft closure sections. The inside and outside surfaces of a closure section form concentric hemi-ellipsoids having coincident equatorial planes and, normally, unequal head ratios. The closures may have cylindrical holes, centered on the hemi-ellipsoid axis of revolution, for modeling geometry associated with the igniter, submerged nozzles and TVC systems. Generally, the geometry may be degenerated for simulating spherical motors, etc.

It should be noted that, since the model does not include raceways or external protrusions associated with segmented cases, the outside case diameter is not necessarily the maximum diameter of the motor. If such protrusions exist, they would be evaluated by the models specified for the MOTORG (motor geometry) or SUBSTGG (substage geometry) model types.

### **PROCEDURE:**

Prior to entering CSGM2, the models specified by the IBGAS and NOZZLEG model types have determined the average chamber pressure and buried nozzle diameter.

Upon the first entrance to CSGM2, the thickness, closure lengths, diameters, head ratios, and closure hole geometry associated with a fiberglass motor case are evaluated.

The models specified for the INSULG and GRAING model types then evalu the remaining principal motor component geometry, the insulation and the grain.

After determining the grain geometry, CSGM2 is re-entered (second entrance) and quantities associated with the total case length are evaluated.

### CASE GEOMETRY

CSGM2

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### EQUATIONS, FIRST ENTRANCE:

Case thickness, cylindrical section.  

$$T_{CS}_{CY} = \begin{bmatrix} \frac{C_4 K_{FS} P_{MEO} (D_{CS}_0)^{C_5}}{2 K_{UTS}} \end{bmatrix} K_{CS}_{11} + K_{CS}_{12}$$
(1)

Case thickness, center of aft closure.

$$T_{CS_{CLA}} = \begin{pmatrix} C_6 & T_{CS_{CY}} \end{pmatrix} K_{CS_{13}} + K_{CS_{14}}$$
(2)

Case thickness, center of forward closure.

$$^{T}CS_{CLF} = (^{C}_{7} ~^{T}CS_{CY}) ~^{K}CS_{15} + ~^{K}CS_{16}$$
 (3)

Case inside diameter.

$$D_{\rm CS_1} = D_{\rm CS_0} \sim 2 T_{\rm CS_{\rm CY}}$$
(4)

Outside equatorial diameter for case closures.

$$D_{CS_{CLO}} = D_{CS_{O}}$$
(5)

Inside equatorial diameter for case closures

$$D_{CS_{CLI}} = D_{CS_{I}}$$
(6)

Outside length of aft case closure.

$$L_{CS}_{CLAO} = \frac{R_{DCSCAO}}{2} D_{CS}_{CLO}$$
(7)

Inside length of aft case closure.

$$L_{CS}_{CLAI} = L_{CS}_{CLAO} - T_{CS}_{CLA}$$
(8)

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### CASE GEOMETRY

EQUATIONS, FIRST ENTRANCE (Cont.):

Inside head ratio of aft closure.

$$R_{\Gamma CSCAI} = 2 \frac{D_{CS}_{CLAI}}{D_{CS}_{CLI}}$$
(9)

Outside length of forward closure.

$$L_{CS}_{CLFO} = \frac{R_{DCSCFO} D_{CS}_{CLO}}{2}$$
(10)

Inside length of forward closure.

$$L_{CS}_{CLFI} = L_{CS}_{CLFO} - T_{CS}_{CLF}$$
(11)

Inside head ratio of forward closure.

$$R_{DCSCFI} = \frac{\frac{2 C_{CS} C_{LFI}}{D_{CS} C_{LI}}}$$
(12)

Diameter of hole in aft outside case closure surface.

$$D_{CS_{HAO}} = K_{CS_{17}} D_{NZ_B} + K_{CS_{18}}$$
 (13)

Diameter of hole in aft inside case closure surface.

$$^{\rm D}_{\rm CS}_{\rm HAI} = ^{\rm D}_{\rm CS}_{\rm HAO}$$
(14)

Diameter of hole in forward outside case closure surface.

$$D_{CS_{HFO}} = K_{CS_{19}} D_{CS_{CLO}} + K_{CS_{20}}$$
 (15)

Diameter of hole in forward inside case closure surface.

$$D_{CS_{HFI}} = D_{CS_{HFO}}$$
(16)

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### CASE GEOMETRY

CSGM2

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### EQUATIONS, FIRST ENTRANCE (Cont.):

Diameter ratio. Aft outside case hole diameter to outside case closure diameter.

$$R_{\text{DCSHAO}} = \frac{D_{\text{CS}_{\text{HAO}}}}{D_{\text{CS}_{\text{CLO}}}}$$
(17)

Outside length of aft case closure, adjusted for hole.

$$L_{\rm CS}_{\rm CHAO} = L_{\rm CS}_{\rm CLAO} \sqrt{1 - R^2_{\rm DCSHAO}}$$
(18)

Diameter ratio. Aft inside case hole diameter to inside case closure diameter.

$$R_{\text{DCSHAI}} = \frac{D_{\text{CS}_{\text{HAI}}}}{D_{\text{CS}_{\text{CLI}}}}$$
(19)

Inside length of aft case closure, adjusted for hole.

$$L_{CS}_{CHAI} = L_{CS}_{CLAI} \sqrt{1 - R_{DCSHAI}^2}$$
(20)

Diameter ratio. Forward outside case hole diameter to outside case closure diameter.

$$R_{\text{DCSHFO}} = \frac{D_{\text{CS}_{\text{HFO}}}}{D_{\text{CS}_{\text{CLO}}}}$$
(21)

Outside length of forward case closure, adjusted for hole.

$$L_{CS}_{CHFO} = L_{CS}_{CLFO} \sqrt{1 - R_{DCSHFO}^2}$$
(22)

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### CASE GEOMETRY

CSGM2

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### EQUATIONS, FIRST ENTRANCE (Cont.):

Diameter ratio, forward inside case hole diameter to inside case closure diameter.

$${}^{R}_{DCSHFI} = \frac{D_{CS}_{HFI}}{D_{CS}_{CLI}}$$
(23)

Inside length of forward case closure, adjusted for hole.

$$L_{CS}_{CHFI} = L_{CS}_{CLFI} \sqrt{1 - R_{DCSHFI}^2}$$
(24)

Length of hole in aft case closure.

$${}^{L}CS_{HA} = {}^{L}CS_{CHAO} - {}^{L}CS_{CHAI}$$
(25)

Length of hole in forward case closure.

$$L_{CS}_{HF} = L_{CS}_{CHFO} - L_{CS}_{CHFI}$$
(26)

Case cross sectional area.

$$A_{CS} = \left(\frac{\pi}{4}\right) D_{CS_{O}}^{2}$$
(27)

Head ratio for usage by models which define a single head ratio for the forward and aft closures.

$$^{R}DCSCHO = ^{R}DCSCAO$$
(27-a)

Associative quantities. The following quantities are intended solely for optional utilization by the program user. Their primary usage within this model is for forming constraint quantities.

$$Q_{D11} = K_{QD11} D_{CS_{T}}$$
(28)

$$Q_{D12} = K_{QD12} D_{CS_1}$$
(29)

$$Q_{DI3} = K_{QDI3} D_{CS_{I}}$$
(30)

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### CASE GEOMETRY

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## EQUATIONS, FIRST ENTRANCE (Cont.):

| $Q_{DO1} = K_{QDO1} D_{CS}$     |   | (31) |
|---------------------------------|---|------|
| $Q_{DO2} = K_{QDO2} D_{CS_O}$   | : | (32) |
| $Q_{DO3} = K_{QDO3} D_{CS_{O}}$ | , | (33) |

## EQUATIONS, SECOND ENTRANCE:

Length of cylindrical case section.

$$L_{CS} = L_{GN}$$
(34)

Total case length.

$$L_{CS} = L_{CS}_{CY} + L_{CS}_{CHAO} + L_{CS}_{CHFO}$$
(35)

Cylindrical case length to diameter ratio.

$$R_{LDCSCY} = \frac{D_{CS_{OY}}}{D_{CS_{OY}}}$$
(36)

Total case length to diameter ratio.

$$R_{LDCS} = \frac{L_{CS}}{D_{CS_0}}$$
(37)

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### CASE GEOMETRY

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## INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                                                      | Preset                                         |
|----------|-------------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| CCSG4    | C4                            | Constant for TCSCY computation;<br>N. D.                                                                            | 1.18                                           |
| CCSC5    | с <sub>5</sub>                | Constant for TCSCY computation; N. D.                                                                               | 1.16                                           |
| CCSG6    | c <sub>6</sub>                | Proportionality constant relating thickness at the center of the aft of the case thickness of the cylindric         | the case<br>losure to<br>al section;           |
|          |                               | N. D.                                                                                                               | 0.5                                            |
| CCSG7    | C <sub>7</sub>                | Proportionality constant relating thickness at the center of the forw closure to the case thickness of the section; | the case<br>vard<br>ne cylindrical             |
|          |                               | N. D.                                                                                                               | 0.5                                            |
| DCSO     | D <sub>CSO</sub>              | Motor case outside diameter. Ou<br>of pressure vessel cylindrical cas<br>Does not include raceways, protre          | tside diameter<br>le section.<br>usions, etc.; |
|          |                               | in Fig. 1                                                                                                           | 0                                              |
| KCSII    | <sup>K</sup> cs <sub>11</sub> | Coefficient for TCSCY computatio                                                                                    | n;<br>1                                        |
| KCS12    | K <sub>CS12</sub>             | Bias for TCSCY computation;<br>in                                                                                   | 0                                              |
| KCS13    | K <sub>CS13</sub>             | Coefficient for TCSCLA computat<br>N. D.                                                                            | icn;<br>1                                      |
| KCS14    | <sup>K</sup> cs <sub>14</sub> | Bias for TCSCLA computation;<br>in                                                                                  | 0                                              |

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### CASE GEOMETRY

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## INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                                   | Preset    |
|----------|-------------------------------|--------------------------------------------------------------------------------------------------|-----------|
| KCS15    | <sup>K</sup> cs <sub>15</sub> | Coefficient for TCSCLF computation N. D.                                                         | ; 1       |
| KCS16    | κ <sub>cs<sub>16</sub></sub>  | Bias for TCSCLF computation;<br>in                                                               | 0         |
| KCS17    | к <sub>сs17</sub>             | Coefficient for DCSEAO computation N. D.                                                         | ;<br>1    |
| KCS18    | <sup>к</sup> cs <sub>18</sub> | Bias for DCSHAO computation;<br>in                                                               | 0         |
| KCS19    | к <sub>сs19</sub>             | Coefficient for DCSHFO computation N. D.                                                         | ı;<br>1   |
| KCS20    | <sup>к</sup> сs <sub>20</sub> | Bias for DCSHFO computation;<br>in                                                               | 0         |
| KCSFS    | K <sub>FS</sub>               | Case factor of safety. Ratio of min-<br>burst pressure to maximum expecte<br>operating pressure; | imum<br>d |
|          |                               | N. D.                                                                                            | 1         |
| KCSUTS   | K <sub>UTS</sub>              | Ultimate tensile strength for fibergl filament case material;                                    | .255      |
|          |                               | lb/in <sup>2</sup>                                                                               | 0         |
| KQDCSII  | K <sub>QDII</sub>             | Associative quantity coefficient for computation;                                                | QDCSII    |
|          |                               | N. D.                                                                                            | 0         |
| KQDCS12  | K <sub>QL I2</sub>            | Associative quantity coefficient for computation;                                                | QDCS12    |
|          |                               | N. D.                                                                                            | 0         |

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## CASE GEOMETRY

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## INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol            | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                                         | Preset                                                                |
|----------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| KQDCSI3  | K <sub>QDI3</sub> | Associative quantity coefficient for QI computation;                                                                                                                                                                                                                                                                                   | DCSI3                                                                 |
| KQDCSOl  | K <sub>QDO1</sub> | Associative quantity coefficient for QI computation;                                                                                                                                                                                                                                                                                   | DCSO1                                                                 |
|          |                   | N. D.                                                                                                                                                                                                                                                                                                                                  | 0                                                                     |
| KQDCSO2  | K <sub>QDO2</sub> | Associative quantity coefficient for QI computation;                                                                                                                                                                                                                                                                                   | DCSO2                                                                 |
|          |                   | <b>N.</b> D.                                                                                                                                                                                                                                                                                                                           | 0                                                                     |
| KQDCSO3  | K <sub>QDO3</sub> | Associative quantity coefficient for Q<br>computation;                                                                                                                                                                                                                                                                                 | DCSO3                                                                 |
|          |                   | N. D.                                                                                                                                                                                                                                                                                                                                  | 0                                                                     |
| RDCSCAO  | RDCSCAO           | Head ratio of the ellipsoid associated<br>the aft outside case closure surface.<br>of twice the closure length to the clos<br>diameter, i.e., the aft outside case of<br>surface is an oblate spheroid. The he<br>is the ratio of the axis of revolution (n<br>axis) to the equatorial diameter (majo<br>N. D.                         | with<br>Ratio<br>ure<br>losure<br>ad ratio<br>minor<br>or axis);<br>l |
| RDCSCFO  | RDCSCFO           | Head ratio of the ellipsoid associated<br>the forward outcide case closure surf<br>Ratio of twice the closure length to th<br>closure diameter, i.e., the forward of<br>case closure surface is an oblate sphe<br>The head ratio is the ratio of the axis<br>revolution (minor axis) to the equator<br>diameter (major axis);<br>N. D. | with<br>ace.<br>e<br>outside<br>eroid.<br>of<br>ial<br>1              |

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### CASE GEOMETRY

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### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                                                                           | Model Type                      |
|----------|--------------------|----------------------------------------------------------------------------------------------------------|---------------------------------|
| DN Z B   | D <sub>NZ</sub>    | Buried nozzle diameter;                                                                                  |                                 |
|          | В                  | in                                                                                                       | NOZZLEG                         |
| PCHMEO   | PMEO               | Maximum expected operating ch pressure;                                                                  | amber                           |
|          |                    | psia                                                                                                     | IBGAS                           |
| LGNC Y   | L <sub>GN</sub> CY | Length of cylindrical grain secti<br>all adjustments for submerged m<br>displaced propellent, cutouts, e | on. Includes<br>lozzle,<br>tc.; |
|          |                    | in                                                                                                       | GRAING                          |

### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol              | Descriptic                                                                                       | on; Ext. (Int.) Units                                               |                                                       |
|----------|---------------------|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------|
| ACS      | A <sub>CS</sub>     | Motor case cross sectio<br>pressure vessel cylindr<br>Does not include racewa<br>in <sup>2</sup> |                                                                     | a. Area of<br>e section.<br>trusions, etc.;<br>Eq. 27 |
| DCSCLI   | D <sub>CS</sub> CLI | Equatorial<br>by the inst<br>case closu                                                          | i diameter of the ellip<br>ide surfaces of the for<br>are sections; | soids formed<br>rward and aft                         |
|          |                     | in                                                                                               | Fig. 1                                                              | Eq. 6                                                 |
| DCSCLO   | D <sub>CS</sub> CLO | Equatorial<br>by the out<br>case closu                                                           | l diameter of the ellip<br>side surfaces of the fo<br>are sections; | soids formed<br>orward and aft                        |
|          |                     | in                                                                                               | Fig. l                                                              | Eq. 5                                                 |

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| OUTPUT DA                 | <u> </u>                        |                                                                                  |                                                                                                                                                 |                                                                                              |
|---------------------------|---------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| Mnemonic                  | Symbol                          | Description                                                                      | ; Ext. (Int.) Units                                                                                                                             |                                                                                              |
| DCSHAI                    | D <sub>CS</sub> HAI             | Diameter o<br>centered on<br>ellipsoid fo<br>aft case clo                        | f circular hole, for the the axis of revolution rmed by the inside sosure;                                                                      | the nozzle,<br>on of the hemi-<br>urface of the                                              |
|                           |                                 | in                                                                               | Fig. 1                                                                                                                                          | Eq. 14                                                                                       |
| DCSHAO                    | D <sub>CS</sub> HAO             | Diameter o<br>centered or<br>ellipsoid fo<br>aft case clo                        | f circular hole, for the the axis of revolution rmed by the outside osure;                                                                      | the nozzle,<br>on of the hemi-<br>surface of the                                             |
|                           |                                 | in                                                                               | Fig. l                                                                                                                                          | Eq. 13                                                                                       |
| dcshfi d <sub>cshfi</sub> | D <sub>CS</sub> HFI             | Diameter o<br>centered on<br>ellipsoid fo<br>forward cas                         | f circular hole, for the the axis of revolution rmed by the inside state closure;                                                               | the igniter,<br>on of the hemi-<br>urface of the                                             |
|                           |                                 | in                                                                               | Fig. 1                                                                                                                                          | Eq. 16                                                                                       |
| dcshfo d <sub>cshfo</sub> |                                 | Diameter o<br>centered or<br>ellipsoid fo<br>forward ca                          | f circular hole, for a<br>the axis of revolution<br>rmed by the outside<br>se closure;                                                          | the igniter,<br>on of the hemi-<br>surface of the                                            |
|                           |                                 | in                                                                               | Fig. 1                                                                                                                                          | Eq. 15                                                                                       |
| DCSI                      | D <sub>CS</sub>                 | Case inside                                                                      | e diameter, cylindric                                                                                                                           | cal section;                                                                                 |
|                           |                                 | in                                                                               | Fig. 1                                                                                                                                          | Eq. 4                                                                                        |
| LCS                       | L <sub>CS</sub>                 | Total case<br>forward ba<br>associated<br>surface to<br>frustum as<br>surface. I | length. Distance be<br>se of the hemi-ellips<br>with the forward out<br>the aft base of the he<br>sociated with the aft<br>ncludes all adjustme | tween the<br>oid frustum<br>side closure<br>mi-ellipsoid<br>outside closure<br>nts to grain; |
|                           |                                 | in                                                                               | Fig. 1                                                                                                                                          | Eq. 35                                                                                       |
| LCSCHAI                   | <sup>L</sup> CS <sub>CHAI</sub> | Length of h<br>the inside a<br>Includes ad                                       | emi-ellipsoidal frus<br>surface of the aft cas<br>justment for nozzle                                                                           | tum which forms<br>e closure.<br>hole;                                                       |
|                           |                                 | in                                                                               | Fig. l                                                                                                                                          | Eq. 20                                                                                       |

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CASE GEOMETRY

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## OUTPUT DATA (Cont.):

| Mnemonic | Symbol                          | Description                                                                                                                     | ; Ext. (Int.) Units                                                      |                                              |
|----------|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------------------------------|
| LCSCHAO  | <sup>L</sup> CS <sub>CHAO</sub> | Length of he<br>forms the o<br>closure. Ir                                                                                      | emi-ellipsoidal frust<br>utside surface of the<br>acludes adjustment fo  | am which<br>aft case<br>r nozzle hole;       |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 18                                       |
| LCSCHFI  | <sup>L</sup> CS <sub>CHFI</sub> | Length of h<br>forms the is<br>closure. In                                                                                      | emi-ellipsoidal frust<br>nside surface of the f<br>icludes adjustment fo | um which<br>orward case<br>or igniter hole;  |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 24                                       |
| LCSCHFO  | <sup>L</sup> CS <sub>CHFO</sub> | Length of h<br>forms the o<br>closure. In                                                                                       | emi-ellipsoidal frust<br>utside surface of the<br>ncludes adjustment fo  | um which<br>forward case<br>or igniter hole; |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 22                                       |
| LCSCLAI  | <sup>L</sup> CS <sub>CLAI</sub> | Length of the axis of revolution of the hemi-<br>ellipsoid formed by the inside surface of the<br>aft case closure section;     |                                                                          |                                              |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 8                                        |
| LCSCLAO  | <sup>L</sup> CS <sub>CLAO</sub> | Length of the axis of revolution of the hemi-<br>ellipsoid formed by the outside surface of the<br>aft case closure section;    |                                                                          | of the hemi-<br>surface of the               |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 7                                        |
| LCSCLFI  | <sup>L</sup> CS <sub>CLFI</sub> | Length of the axis of revolution of the hemi-<br>ellipsoid formed by the inside surface of the<br>forward case closure section; |                                                                          | of the hemi-<br>urface of the                |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 11                                       |
| LCSCLFO  | <sup>L</sup> CS <sub>CLFO</sub> | Length of the ellipsoid for forward ca                                                                                          | he axis of revolution<br>rmed by the outside s<br>se closure section;    | of the hemi-<br>urface of the                |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 10                                       |
| LCSCY    | LCSCY                           | Length of c<br>all adjustm                                                                                                      | ylindrical case secti<br>ents to grain;                                  | on. Includes                                 |
|          |                                 | in                                                                                                                              | Fig. 1                                                                   | Eq. 34                                       |

## CASE GEOMETRY

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## OUTPUT DATA (Cont.):

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                                          |  |
|----------|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| LCSHA    | L <sub>CS<sub>HA</sub></sub> | Length of the cylindrical hole, for the nozzle,<br>in the aft case closure;                                                                                                                                                                                                                                                             |  |
|          |                              | in Fig. 1 Eq. 25                                                                                                                                                                                                                                                                                                                        |  |
| LCSHF    | Los <sub>HF</sub>            | Length of the cylindrical hole, for the igniter in the forward case closure;                                                                                                                                                                                                                                                            |  |
|          |                              | in Fig. 1 Eq. 26                                                                                                                                                                                                                                                                                                                        |  |
| QDCSII   | Q <sub>DI1</sub>             | Associative quantity, inside case diameter<br>(see DCSI);                                                                                                                                                                                                                                                                               |  |
|          |                              | in Eq. 28                                                                                                                                                                                                                                                                                                                               |  |
| QDCSI2   | Q <sub>DI2</sub>             | Associative quantity, inside case diameter<br>(see DCSI);                                                                                                                                                                                                                                                                               |  |
|          |                              | in Eq. 29                                                                                                                                                                                                                                                                                                                               |  |
| QDCSI3   | Q <sub>DI3</sub>             | Associative quantity, inside case diameter<br>(see DCSI);                                                                                                                                                                                                                                                                               |  |
|          |                              | in Eq. 30                                                                                                                                                                                                                                                                                                                               |  |
| QDCSO1   | Q <sub>DO1</sub>             | Associative quantity, outside case diameter<br>(see DCSO);                                                                                                                                                                                                                                                                              |  |
|          |                              | in Eq. 31                                                                                                                                                                                                                                                                                                                               |  |
| QDCSO2   | Q <sub>DO2</sub>             | Associative quantity, outside case diameter<br>(see DCSO);                                                                                                                                                                                                                                                                              |  |
|          |                              | in Eq. 32                                                                                                                                                                                                                                                                                                                               |  |
| QDCSO3   | Q <sub>DO3</sub>             | Associative quantity, outside case diameter<br>(see DCSO);                                                                                                                                                                                                                                                                              |  |
|          |                              | in Eq. 33                                                                                                                                                                                                                                                                                                                               |  |
| RDCSCAI  | RDCSCAI                      | Head ratio of the ellipsoid associated with the<br>aft inside case closure surface. Ratio of twice<br>the closure length to the closure diameter,<br>i.e., the aft inside case closure surface is an<br>oblate spheroid. The head ratio is the ratio<br>the axis of revolution (minor axis) to the<br>equatorial diameter (major axis); |  |
|          |                              | N. D. Eq. 9                                                                                                                                                                                                                                                                                                                             |  |

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CASE GEOMETRY

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
|----------|----------------------|--|--|
| RDCSCFI | ^R ·DCSCFI | Head ratio of the ellipsoid associat
forward inside case closure surfac
twice the closure length to the clos
diameter, i.e., the forward inside
closure surface is an oblate sphere
head ratio is the ratio of the axis o
revolution (minor axis) to the equat
diameter (major axis); | ed with the
e. Ratio of
ure
case
oid. The
f
torial |
| | | N. D. | Eq. 12 |
| RDCSHAI | R _{DCSHAI} | Diameter ratio, hole diameter to e
diameter, inside surface of aft cas | quatorial
e closure; |
| | | N. D. | Eq. 19 |
| RDCSHAO | R _{DCSHAO} | Diameter ratio, hole diameter to e
diameter, outside surface of aft ca | quatorial
se closure; |
| | | N. D. | Eq. 17 |
| RDCSHFI | ^R DCSHFI | Diameter ratio, hole diameter to e
diameter, inside surface of forwa:
closure; | equatorial
rd case |
| | | N. D. | Eq. 23 |
| RDCSHFO | ^R DCSHFO | Diameter ratio, hole diameter to e
diameter, outside surface of forwa
closure; | equatorial
ard case |
| | | N. D. | Eq. 21 |
| RDCSCHO | ^R DCSCHO | Head ratio for usage by models wh
a single head ratio for forward and | ich define
 aft closures; |
| | | N. D. | Eq. 27-a |
| RLDCS | RLDCS | Length to diameter ratio, total cas
N. D. | e;
Eq. 37 |
| RLDCSCY | RLDCSCY | Length to diameter ratio, cylindric section; | cal case |
| | | N. D. | Eq. 36 |

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CASE GEOMETRY

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Descriptio | on; Ext. (Int.) Units | |
|----------|--------------------------------|---|---|--|
| TCSCLA | T _{CS} CLA | Case thick
Distance t
hemi-ellip
axis of re- | mess at center of aft o
between the aft inside
bsoid surfaces, measu
volution; | case closure.
and outside
ured on the |
| | | in | Fig. 1 | Eq. 2 |
| TCSCLF | ^T cs _{clf} | Case thick
closure.
inside and
measured | ness at center of forv
Distance between the
outside hemi-ellipsoi
on the axis of revolut | vard case
forward
id surfaces,
ion; |
| | | in | Fig. 1 | Eq. 3 |
| TCSCY | T _{CS} | Case thick | ness, cylindrical sec | tion; |
| | CY | in | Fig. 1 | Eq. 1 |

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CASE GEOMETRY

CSGM2

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| Jusur | CASEC | CSSN2 | CASE GEOMET | RY |
|---------------|----------|----------------|---------------|---------|
| 05200 | 24 | | | |
| DCSCILO | * | DCSHAI | DCSHAO | DCSHFI |
| DCSO | 7* | | | |
| KCS13 | L# | KCS14 | KCS15 | KCS16 |
| KCS19 | ₽
₽ | KCS20 | | |
| KQDCSIJ | £ | KQDCSI2 | K (DCSI3 | KCDCSO1 |
| LCS | *10 | LCSHA | LCSHP | LCSCHAI |
| LCSCHPO | tt* | LCSCLAI | LCSCLAD | LCSCLF |
| ODCSI1 | 21* | ODCSI2 | (DCSI3 | opcsol |
| RDCSCAI | *13 | RDCSCAO | RDCSCFI | RDCSCFO |
| RDCSHAO | 414 | RDCSHFI | RDCSHPO | RLLCS |
| TCSCLF | *15 | TCSCY | | |

20. 2-17
CASE WEIGHT

CSWM1

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MODEL TYPE: CASEW (CASE Weight)

MODEL NAME: CSWM1 (Metal Case, Parametric Scaling)

DESCRIPTION:

CSWM1 (CaSe Weight Model number 1) utilizes parametric weight scaling equations to determine the weight of a solid rocket motor, unjointed or jointed, metal case. See references 8 and 34 for a description of the equations and scaling coefficient rationale.

The model is applicable for performance parameters within the following limits (see Input Data, Inter-Model).

500 < PCHMEO < 1950 psia 0.6 < RDCSCHO < 1.0 0.25 < RLDGNCY < 8.0 3000 < WPPMT < 2,000,000 lb.

PROCEDURE:

Prior to entering CSWM1, the models specified by the PROPELW and IBGAS model types have evaluated the propellent and gas properties. The models specified by the CASEG, GRAING and MOTORG have evaluated the motor geometry.

The CSWM1 model is then executed and the motor case weight is evaluated using parametric weight scaling equations. In addition, the case weight is broken down into expended and non-expended components.

These expended and non-expended case weight components will later be used by the model specified for the MCTORW model type to determine the motor weights and mass fractions.

CASE WEIGHT

CSWM1

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EQUATIONS:

Total case weight, no joints.

$$\kappa_{1} = \frac{R_{LDGNCY} + C_{1} \left[\left(|R_{DCSCHO} - C_{2}| \right)^{-3} + C_{4} \right]}{\left(\frac{R_{DCSCHO}}{(3)} \right) + C_{5} R_{LDGNCY}}$$

$$W_{CS_{NOJT}} = K_{WCSNOJ} \left\{ \frac{C_{CSG1} W_{PP_{MT}} P_{MEO} K_{FS} P_{CS} K_{1}}{K_{UTS} P_{PP_{MT}} \eta_{MT}} + \frac{C_{6} P_{CS} R_{DCSCHO} D_{CS_{O}}^{2}}{W_{PP_{MT}} \sqrt{\frac{K_{FS} W_{PP_{MT}}}{K_{UTS}}}} \right\}$$

Case weight penalty per joint.

$$W_{JT_{CSU}} = K_{WJTCSU} \left\{ \frac{K_{FS} P_{MEO} D_{CS_{O}}^{2}}{K_{UTS}} \right\} C_{14}$$
(2)

Total joint weight penalty.

$$W_{JT_{CS}} = N_{JT_{CS}} W_{JTU}$$
(3)

Total case weight.

$$\mathbf{w}_{\mathrm{CS}} = \mathbf{K}_{\mathrm{WCS}} \left(\mathbf{w}_{\mathrm{CS}}_{\mathrm{NOJT}} + \mathbf{w}_{\mathrm{JT}}_{\mathrm{CS}} \right)$$
(4)

Total non-expended case weight component.

$$W_{CS_{NX}} = K_{WCSNX} W_{CS}$$
 (5)

Total expended case weight component.

$$W_{CS_{X}} = 0$$
 (6)

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CASE WEIGHT

CSWMI

EQUATIONS (Cont.):

Expended (non-thrust producing) case weight component.

$$W_{CS_{XI}} = 0$$
(7)

Expended (thrust producing) case weight component.

$$W_{CS_{XT}} = 0$$
 (8)

INPUT DATA, INTRA-MODEL:

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The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Unite | Preset |
|----------|----------------|--------------------------------------|---------|
| CCSW1 | c ₁ | Scaling constant for WCS computat | tion; |
| | | N. D. | 0.5 |
| CCSW2 | c ₂ | Scaling constant for WCS computation | tion; |
| | - | N. D. | 0.77 |
| CCSW3 | C ₃ | Scaling constant for WCS computation | tion; |
| | 5 | N. D. | 1.3 |
| CCSW4 | C | Scaling constant for WCS computed | tion; |
| | | N. D. | 0.856 |
| CCSW5 | C | Scaling constant for WCS computation | tion; |
| | 2 | N. D. | 0.5 |
| CCSW6 | 34 | Scaling constant for WCS computation | tion; |
| | U | N. D. | 9.0712 |
| CCSW7 | C7 | Scaling constant for WCS compute | tion; |
| | • | N. D. | 0.20288 |

CASE WEIGHT

CSWMI

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INPUT DATA, INTRA-MODEL (Ccnt.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset | |
|----------|---------------------|--|------------|--|
| CCSW14 | C ₁₄ | Chaling constant for WJTCSU computation; | | |
| | | N. D. | 7.7 | |
| NJTCS | NJT | Number of joints in motor case; | , | |
| | - CS | N. D. | 0 | |
| ĸwcs | Kwcs | Proportionality factor for total ca
includes joint penalty; | se weight, | |
| | | N. D. | 1 | |
| KWCSNOJ | ^K wcsnoj | Proportionality factor for total ca
does not include joint penalty; | øe weight, | |
| | | N. D. | 1 | |
| KWCSNX | Kwcsnx | Proportionality factor for case no weight, includes joint penalty; | n-expended | |
| | | N. D. | 1 | |
| KWJTCSU | ^K wjtcsu | Proportionality factor for the weig joint; | ght of a | |
| | | N. D. | 1 | |
| RHOCS | PCS | Density of metal case material; | | |
| | | $1b/in^3$ | 0 | |

INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|--------|--------------------------------|-------------|
| CCSG1 | CCSGI | Constant for case thickness co | omputation; |
| | 001 | N. D. | CASEG |

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CASE WEIGHT

INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|-----------|--------------------|--|--------------------------------------|
| DCSO | D _{CSO} | Motor case outside diameter;
in | CASEG |
| KCSFS | K _{FS} | Case factor of safety;
N. D. | CASEG |
| KCSUTS | ^K uts | Ultimate tensile strength for me
material;
lb/in ² | etal case
CASEG |
| PCHMEO | PMEO | Maximum expected operating ch
pressure;
psia | amber
IBGAS |
| RDCSCHO | RDCSCHO | Case closure outside surface he
N. D. | ad ratio;
CASEG |
| R LDGNC Y | RLDGNCY | Ratio, cylindrical grain length t
diameter, Includes all adjustm
N. D. | to grain
ents to grain;
GRAING |
| RHOPPMT | р _{рр} мт | Propellent density;
lb/in ³ | PROPEL |
| RVPPMT | η _{MT} | Motor volumetric loading efficie
N. D. | ency;
MOTORG |
| WPPMT | W _{PP} MT | Propellent weight;
lb | PROPELW |

OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
|----------|-----------------|--|--|
| wcs | ^w cs | Total case weight, includes joint penalty; | |
| | - | lb Eq. 4 | |

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CASE WEIGHT

CSWMI

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | |
|----------|---------------------------------|--|----------|--|
| WCSNOJT | ^w cs _{nojt} | Total case weight, no joints;
lb | Eq. 1 | |
| WCSNX | w _{cs_{NX}} | Total non-expended case weight, inc.
joint penalty; | ludes | |
| | | 1b | Eq. 5 | |
| WCSX | ^w cs _x | Total expended case weight; | _ / | |
| | | 16 | Eq. 6 | |
| WCSXI | ^w cs _{x1} | Expended (non-thrust producing) case component; | e weight | |
| | | Іь | Eq. 7 | |
| WCSXT | w _{cs} xt | Expended (thrust producing) case we component; | ight | |
| | | 1ь | Eq. 8 | |
| WJTCS | w _{t T} | Total joint weight penalty; | | |
| | J CS | 1ь | Eq. 3 | |
| WJTCSU | WTT | Case weight penalty per joint; | | |
| | 'CSU | lb | Eq. 2 | |

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CASE WEIGHT

CSWMI

PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| CSWAL CASE WEIGHT | WCSXI MCSXI | CCSW4 CCSW5 CCSW6 | | KUCSNX XHJTCSU RHOCS | |
|-------------------|-------------|-------------------|--------|----------------------|---------|
| CASEN | Ŧ | ¥ | Ŧ | ŧ | ¥ |
| | WCSX | CCSH3 | | KMCSNOJ | NUTCSU |
| | WCSNDX | CCSH2 | CCSH12 | KINCS | NJTCS |
| | NCS | CCSM | CCSW7 | NJTCS | NCSNOJT |

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CASE WEIGHT

CSWM2

SALAN DESCRIPTION

30, 2

MODEL TYPE: CASEW (CASE Weight)

MODEL NAME: CSWM2 (Glass Case, Parametric scaling)

DESCRIPTION:

CSWM2 (<u>CaSe</u> Weight Model number $\underline{2}$) utilizes parametric weight scaling equations to evaluate the weight of a solid rocket motor (unjointed or jointed) fiberglass motor case.

The basic assumptions used to develop the equations were as follows:

- 1. Bosses are made from aluminum with a minimum ultimate tensile strength of 70 ksi.
- 2. Bolts used for the attachment of the igniter and nozzle to the bosses are heat treated 170 ksi (minimum).
- 3. Forward and aft boss diameters are 20% and 50% of the case diameter, respectively.
- 4. Equal margins of safety are maintained at all points on the composite shell.

The most important point for the engineer preparing input data is that KCSUTS is a representative strength for the fiber under consideration. For example, KCSUTS would be 350,000 psi for type S-901 (S-944) fibers.

See references 41-42 for a description of the unjointed case weight equation. The joint penalty is described in reference 44.

This model is applicable for performance parameters within the following limits (see Input Data, Inter-Model).

600 < PCHMEO < 1950 psia 3000 < WPPMT < 2,000,000 lb.

CASE WEIGHT

CSWM2

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PROCEDURE:

Prior to entering CSWM2, the models specified by the PROPEL and IBGAS model types have evaluated the propellent and gas properties. The models specified by the CASEG, GRAING and MOTORG have evaluated the motor geometry.

The CSWM2 model is then executed and the motor case weight is evaluated using parametric weight scaling equations. In addition, the case weight is broken down into expended and non-expended components.

These expended and non-expended case weight components will later be used by the model specified for the MOTORW model type to determine the motor weights and mass fractions.

EQUATIONS:

Total case weight, no joints.

$$\kappa_{1} = \frac{\rho_{CS} \kappa_{FS} P_{MEO}(D_{CS_{O}})^{C_{\delta}}}{\kappa_{UTS}} \left[\frac{C_{9} W_{PP_{MT}}}{\rho_{PP_{MT}} \eta_{PP_{MT}}} + C_{10} L_{M'T_{SKA}} D_{CS_{O}}^{2} \right]$$
(1)

$$K_2 = C_{11} D_{CS_0}^3 (1. C_{12} P_{MEO} K_{FS})$$

$$W_{CS_{NOJT}} = K_{WCSNOJ} (K_1 + K_2)$$

Case weight penalty per joint.

$$W_{JT}_{CSU} = K_{WJTCSU} \left(\frac{K_{FS} P_{MEO} D_{CS}^{2}}{K_{UTS}} \right) C_{13}$$
(2)

Total joint weight penalty.

$$W_{JT_{CS}} = N_{JT} W_{JT_{CSU}}$$
(3)

Total case weight.

$$\mathbf{w}_{\mathrm{CS}} = \mathbf{K}_{\mathrm{WCS}} \left(\mathbf{w}_{\mathrm{CS}_{\mathrm{NOJT}}} + \mathbf{w}_{\mathrm{JT}_{\mathrm{CS}}} \right)$$
(4)

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 CASE WEIGHT

CSWM2

EQUATIONS (Cont.):

CASEW

Total non-expended case weight component.

$${}^{W}CS_{NX} = {}^{K}WCSNX {}^{W}CS$$
⁽⁵⁾

Total expended case weight component.

$$W_{\rm CS_{\rm X}} = 0 \tag{6}$$

Expended (non-thrusting producing) case weight component.

$$W_{CS_{XI}} = 0$$
(7)

Expended (thrust producing) case weight component.

$$W_{CS_{XT}} = 0$$
 (8)

INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|-----------------|----------------------------------|------------|
| CCSWE | c ₈ | Scaling constant for WCSNOJT co | mputation; |
| | | N. D. | 0.16 |
| CCSW9 | Cq | Scaling constant for WCSNOJT con | mputation; |
| | , | N. D. | 2.62 |
| CCSW10 | C,0 | Scaling constant for WCSNOJT con | mputation; |
| | | N. D. | 6.09 |
| CCSW11 | с ₁₁ | Scaling constant for WCSNOJT con | mputation; |
| | | N. D. | 0.000016 |
| CCSW12 | C ₁₂ | Scaling constant for WCSNOJT cos | mputation; |
| | | N. D. | 0.01 |

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CASE WEIGHT

CSWM2

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset | |
|-----------------------|---------------------|--|-----------------|--|
| CCSW13 | C ₁₃ | Scaling constant for WJTCSU computation; | | |
| | | N. D. | 7.7 | |
| NJTCS | NJT | Number of joints in motor case; | | |
| | - CS | N. D. | 0 | |
| kwcs k _{wcs} | | Proportionality factor for total case weight, includes joint penalty; | | |
| | | N. D. | 1 | |
| KWCSNOJ | Kwcsnoj | Proportionality factor for case weight, does not include joint penalty; | | |
| | | N. D. | 1 | |
| KWCSNX | KWCSNX | Proportionality factor for case non-expende
weight component, includes joint penalty; | | |
| | | N. D. | 1 | |
| KWJTCSU | ^K witcsu | Proportionality factor for the weig | ght of a joint; | |
| | | N. D. | 1 | |
| RHOCS | ρ _{CS} | Density of composite glass case n | naterial; | |
| | 00 | $1b/in^3$ | 0 | |

INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|-----------------|--------------------------------|------------|
| DCSO | D _{CS} | Outside case diameter; | |
| | 000 | in | CASEG |

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CASEW

CASE WEIGHT

CSWM2

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type | |
|-------------------------|---------------------|--|----------------------------------|--|
| KCSFS | к _{fs} | Case factor of safety; | | |
| | | N. D. | CASEG | |
| kcsuts k _{uts} | | Ultimate tensile strength for fiberglass filament case material; | | |
| | | lb/in ² | CASEG | |
| LMTSKA | L _{MT} ska | Aft motor skirt length. The m
that the fore and aft skirts have | odel assumes
e equal lengths; | |
| | | in | MOTORG | |
| PCHMEO | PMEO | Maximum expected operating cl | namber pressure; | |
| | Mile | psia | IBGAS | |
| RHOPPMT | | Propellent density; | | |
| | MT | lb/in ³ | PROPELW | |
| RVPPMT | η _{PP} | Motor volumetric loading effici | ency; | |
| | - MT | N. D. | MOTORG | |
| WPPMT | W _{PP} | Propellent weight; | | |
| | MT | 1b | PROPELW | |

OUTPUT DATA:

The following data is output by this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | |
|----------|--------|--|-------|--|
| wcs | wcs | Total case weight, includes joint penalty; | | |
| | | 1b | Eq. 4 | |
| WCSNOJT | WCS | Total case weight, no joints; | | |
| | NOJT | 1ъ | Eq. l | |

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CASE WEIGHT

CSWM2

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
|----------|-------------------------------|--|------|-----|--|
| WCSNX | w _{cs_{NX}} | Total non-expended case wright component.
Includes joint penalty; | | | |
| | | ІЬ | Eq. | 5 | |
| WCSX | W _{CS} | Total expended case weight component; | | | |
| | X | 1ь | Eq. | 6 | |
| WCSXI | ^w cs _{XI} | Expended (non-thrust producing) case component; | weig | yht | |
| | | lb | Eq. | 7 | |
| WCSXT | wcs _{xt} | Expended (thrust producing) case weight component; | | | |
| | | 16 | Eq. | 8 | |
| WJTCS | W _{TT} | Total joint weight penalty; | | | |
| | °^CS | 1b | Eq. | 3 | |
| WJTCSU | W _{TT} | Case weight penalty per joint; | | | |
| | CSU | 1b | Eq. | 2 | |

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CASE WEIGHT

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MODEL TYPE: GRAING (GRAIN Geometry)

MODEL NAME: GNGM1 (cylindrical central perforate)

DESCRIPTION:

GNGM1 (GraiN Geometry Model number1) evaluates the pertinent geometry for a solid rocket propellent grain to be enclosed within a motor case having a cylindrical section with hemi-ellipsoidal closures and a single nozzle. The port is a cylindrical central perforate with provision for lateral slot cutouts, lateral motor joint cutouts, and a cone frustum section to accommodate a submerged nozzle. Provision is also made for a cylindrical grain length penalty for the propellent displacement due to internal insulation in the forward and aft hemi-ellipsoid closures.

Reference 52, "Some Useful Theorems Associated With Hemi-Ellipsoids" is the basis for the derivation of the equations.

PROCEDURE:

Prior to entering GNGM1, the models specified by the NOZZLEG and CASEG model types have determined the nozzle and case geometry. The model specified by the INSULG model type has determined (first entrance) the pertinent internal insulation quantities required for interfacing between the case and grain.

Upon the first entrance to GNGMI, the basic grain geometry is determined and then adjusted for nozzle subinergence. The propellent surface area is computed and the model specified by the IBFLOW model type is executed to determine the slot length penalty.

GNGM1 is then entered for the second time and the grain is adjusted to account for the slot and joint volumes. Using this corrected grain geometry, the model specified for the INSULG model type (second entrance) evaluates the internal insulation geometry within the grain envelope.

Upon the third entrance to GNGM1, the cylindrical grain length is adjusted to include the propellent displaced by the internal insulation, and the remaining grain geometry quantities are evaluated.

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PROCEDURE (Cont.):

After completing the grain geometry, the model specified for the INSULG model type is entered for the third time and the internal insulation geometry is completed.

A block diagram illustrating the inter-model coupling with the grain geometry is included in the documentation of the model specified for the INSULG model type.

NOTATION CONVENTIONS:

The following notation conventions are used within this model whenever possible.

First character

- A Plane area. (in^2)
- D Diameter, measured normal to centerline. (in)
- K Coefficient or bias.
- L Length, measured parallel to centerline. (in)
- Q Associative quantity.
- R Ratio. Next character(s) will be L or D to indicate diameter or length ratio. (N. D.)
- S Surface area. (in²)
- T Thickness. (in)
- V Volume. (in³)

Next two characters.

GN Grain PT Port

Next character(s)

| Α | Aft |
|---------|-------------------------------|
| C or CL | Closure |
| СН | Insulation liner closure hole |
| CY or Y | Cylinder |
| E | Ellipsoid |
| F | Forward |
| н | Insulation liner hole |
| PD | Propeilent displaced |
| PP | Propellent |
| NS | Nozzle submergence |
| NZ. | Nozzle |

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EQUATIONS, FIRST ENTRANCE:

GENERAL GRAIN AND BASIC PORT COMPUTATIONS:

Diameter of cylindrical grain section. (Figures 2, 6)

$$D_{GN} = D_{IL_{T}}$$
(1)

Diameter of basic cylindrical port section. (Figures 2, 3, 4, 6)

$$D_{\text{PT}} = K_{\text{DPT}_1} D_{\text{GN}} + K_{\text{DPT}_2}$$
(2)

Cross-sectional area of basic cylindrical port section. (Figure 6)

$$A_{PT} = \left(\frac{\pi}{4}\right) D_{PT}^2$$
(3)

Area ratio, basic cylindrical port section area to nozzle throat area.

$$R_{APTTH} = \frac{7 PT}{A_{NZ}}$$
(4)

Propellent web thickness for cylindrical grain and basic cylindrical port sections. (Figures 2, 3, 6)

$$T_{PP_{WEB}} = \left(\frac{D_{GN} - D_{PT}}{2}\right)$$
(5)

Propellent web cross-sectional area for cylindrical grain and basic cylindrical port sections. (Figure 6)

$$A_{PP_{WEB}} = \left(\frac{\pi}{4}\right) \left(D_{GN}^2 - D_{PT}^2\right)$$
(6)

BASIC CLOSURE SECTIONS (FORWARD / DAFT):

Equatorial diameter of grain closures. (Figures 2, 3, 4)

$$D_{GN_{CL}} = D_{GN}$$
(7)

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EQUATIONS, FIRST ENTRANCE (Cont.):

BASIC CLOSURE SECTIONS (FOR WARD AND AFT)(Cont.):

Diameter ratio, basic cylindrical port section diameter to grain closure equatorial diameter.

$$R_{DPTCL} = \frac{D_{PT}}{D_{GN_{CL}}}$$
(8)

BASIC FOR WARD CLOSURE SECTION:

Head ratio of ellipsoid associated with the forward grain closure section.

$$R_{\text{DGNCLF}} = R_{\text{DILCFI}} \tag{9}$$

Length of hemi-cllipsoid associated with the forward grain closure section. (Figures 2, 3)

$$L_{GN_{CLF}} = L_{IL_{CLFI}}$$
(10)

Volume of hemi-ellipsoid associated with the forward grain closure section. (Figure 3)

$$V_{GN_{CLF}} = \left(\frac{\pi}{6}\right) L_{GN_{CLF}} D_{GN_{CL}}^2$$
(11)

Length of cylindrical portion of basic port within the hemi-ellipsoid associated with the forward grain closure section. (Figure 3)

$$L_{\text{PT}_{\text{YCLF}}} = L_{\text{GN}_{\text{CLF}}} \sqrt{1 - R_{\text{DPTCL}}^2}$$
(12)

Volume of cylindrical portion of basic port within the hemi-ellipsoid associated with the forward grain closure section. (Figure 3)

$$\mathbf{V}_{\mathbf{PT}_{\mathbf{YCLF}}} = \left(\frac{\pi}{4}\right) \mathbf{L}_{\mathbf{PT}_{\mathbf{YCLF}}} \mathcal{D}_{\mathbf{PT}}^2$$
(13)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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BASIC FORWARD CLOSURE SECTION (Cont.):

Length ratio. Length of cylindrical portion of basic port within the hemiellipsoid to the length of the hemi-ellipsoid, forward grain closure section.

$$^{R}_{LPTCYF} = \frac{^{L}_{PT}_{YCLF}}{L_{GN}_{CLF}}$$
(14)

Volume of ellipsoidal cap at base of cylindrical portion of basic port section, within the hemi-ellipsoid associated with the forward grain closure section. (Figure 3)

$$V_{PT} = \left(\frac{V_{GN}_{CLF}}{2}\right) \left(2 - 3 R_{LPTCYF} + R_{LPTCYF}^{3}\right)$$
(15)

Volume of basic port within the hemi-ellipsoid associated with the forward grain closure section. (Figure 3)

$$v_{\text{PT}_{\text{CLF}}} = v_{\text{PT}_{\text{ECLF}}} + v_{\text{PT}_{\text{YCLF}}}$$
(16)

Volume of propellent associated with the hemi-ellipsoid of the forward grain closure section. Note that this volume is an intermediate quantity and does not include corrections for insulation wedges, igniter, etc. (Figure 3)

$$v_{PP_{CLF}} = v_{GN_{CLF}} - v_{PT_{CLF}}$$
(17)

Length of hemi-ellipsoid frustum associated with the forward grain closure section. (Figures 2, 3)

$$L_{GN_{CHF}} = L_{IL_{CHFI}}$$
(18)

Diameter of forward base of hemi-ellipsoid frustum associated with the forward grain closure section. (Figures 2, 3)

$$D_{\rm GN}_{\rm HF} = D_{\rm IL}_{\rm HFI} \tag{19}$$

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EQUATIONS, FIRST ENTRANCE (Cont.):

BASIC FORWARD CLOSURE SECTION (Cont.):

Length ratio. Length of hemi-ellipsoida! frustum to length of hemi-ellipsoid, forward grain closure section.

$$R_{LGNCHF} = \frac{L_{GN}^{C}CHF}{L_{GN}^{C}CLF}$$
(20)

Volume of hemi-ellipsoid frustum associated with the forward grain closure section. (Figure 3)

$$V_{GN_{CHF}} = \left(\frac{V_{GN_{CLF}}}{2}\right) \left(3 R_{LGNCHF} - R_{LGNCHF}^{3}\right)$$
(21)

BASIC AFT CLOSURE SECTION:

Head ratio of ellipsoid associated with the aft grain closure section.

$$R_{\text{DGNCLA}} = R_{\text{DILCAI}}$$
(22)

Length of hemi-ellipsoid associated with the aft grain closure section. (Figures 2, 4)

$$L_{GN_{CLA}} = L_{IL_{CLAI}}$$
(23)

Volume of hemi-ellipsoid associated with the aft grain closure section. (Figure 5)

$$V_{GN_{CLA}} = \left(\frac{\pi}{6}\right) L_{GN_{CLA}} D_{GN_{CL}}^2$$
(24)

Length of cylindrical portion of basic port within the hemi-ellipsoid associated with the aft grain closure section. (Figure 4)

$$L_{\text{PT}_{\text{YCLA}}} = L_{\text{GN}_{\text{CLA}}} \sqrt{1 - R_{\text{DPTCL}}^2}$$
(25)

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EQUATIONS, FIRST ENTRANCE (Cont.):

BASIC AFT CLOSURE SECTION (Cont.):

Volume of cylindrical portion of basic port within the hemi-ellipsoid associated with the aft grain closure section. (Figure 5)

$$\mathbf{v}_{\mathbf{PT}_{\mathbf{YCLA}}} = \left(\frac{\pi}{4}\right) \ \mathbf{L}_{\mathbf{PT}_{\mathbf{YCLA}}} \ \mathbf{D}_{\mathbf{PT}}^{2} \tag{26}$$

Length ratio. Length of cylindrical portion of basic port within the hemiellipsoid to the length of the hemi-ellipsoid, aft grain closure section.

$$R_{LPTCYA} = \frac{L_{PT}_{YCLA}}{L_{GN}_{CLA}}$$
(27)

Volume of ellipsoidal cap at base of cylindrical portion of basic port section within the hemi-ellipsoid associated with the aft grain closure section. (Figure 5)

$$V_{\text{PT}_{\text{ECLA}}} = \left(\frac{V_{\text{GN}_{\text{CLA}}}}{2}\right) \left(2 - 3 R_{\text{LPTCYA}} + R_{\text{LPTCYA}}^{3}\right)$$
(28)

Volum \sim of basic port within the hemi-ellipsoid associated with the aft grain closure section. (Figure 5)

$$\mathbf{v}_{\mathbf{PT}_{\mathbf{CLA}}} = \mathbf{v}_{\mathbf{PT}_{\mathbf{ECLA}}} + \mathbf{v}_{\mathbf{PT}_{\mathbf{YCLA}}}$$
(29)

Volume of propellent associated with the hemi-ellipsoid of the aft grain closure section. Note that this volume is an intermediate quantity and does not include corrections for nozzle submergence, insulation wedges, etc. (Figure 5)

$$v_{PP_{CLA}} = v_{GN_{CLA}} - v_{PT_{CLA}}$$
(30)

Length of hemi-ellipsoid frustum associated with the aft grain closure section. (Figures 2, 4)

$$L_{\rm GN}_{\rm CHA} = L_{\rm I}L_{\rm CHAI}$$
(31)

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EQUATIONS, FIRST ENTRANCE (Cont.):

BASIC AFT CLOSURE SECTION (Cont.):

Diameter of aft base of hemi-ellipsoid frustum associated with the aft grain closure section. (Figures 2, 4)

$$D_{GN_{HA}} = D_{IL_{HAI}}$$
(32)

Length ratio. Length of hemi-ellipsoid frustum to length of hemi-ellipsoid, aft grain closure section.

$$R_{LGNCHA} = \frac{L_{GN}_{CHA}}{L_{GN}_{CLA}}$$
(33)

Volume of hemi-ellipsoid frustum associated with the aft grain closure section. (Figure 5)

$$V_{GN_{CHA}} = \left(\frac{V_{GN_{CLA}}}{2}\right) \left(3 R_{LGNCHA} - R_{LGNCHA}^{3}\right)$$
(34)

BASIC CYLINDRICAL GRAIN SECTION:

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Volume of propellent within basic cylindrical grain section. Does not include displaced propellent corrections for nozzle submergence or internal insulation.

$$V_{PP_{CY1}} = V_{PP_{MT}} - V_{PP_{CLF}} - V_{PP_{CLA}}$$
(35)

Length of basic cylindrical grain section. Does not include length penalties for nozzle submergence, slots, joints, or internal insulation. (Figure 2)

$$L_{GN_{CY1}} = \frac{V_{PP_{CY1}}}{A_{PP_{WEB}}}$$
(36)

Length of diameter ratio, basic cylindrical grain section. Does not include penalties for nozzle submergence, slots, joints, or internal insulation.

$$R_{LDGNY1} = \frac{L_{GN}_{CY1}}{D_{GN}}$$
(37)

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EQUATIONS, FIRST ENTRANCE (Cont.):

BASIC CYLINDRICAL PORT SECTION:

Total length of cylindrical portion of basic port. Does not include adjustments for nozzle submergence, slots, joints or internal insulation.

$$L_{PT_{CY1}} = L_{GN_{CY1}} + L_{PT_{YCLA}} + L_{PT_{YCLF}}$$
(38)

CORRECTIONS TO BASIC GRAIN FOR NOZZLE SUBMERGENCE:

Distance nozzle is submerged in port. (Figure 4)

$$L_{PT_{NS}} = L_{NZ_B} - L_{IL_{HA}} - L_{CS_{HA}}$$
(39)

Distance nozzle is submerged in cylindrical grain section. (Figure 4)

$$L_{GN_{NSCY}} = L_{PT_{NS}} - L_{GN_{CHA}}$$
(40)

Diameter ratio, port cone frustum section aft base diameter to grain closure equatorial diameter.

$$R_{DCFACL} = \frac{D_{PT}_{CFA}}{D_{GN}_{CL}}$$
(41)

Length of portion of port cone frustum section within aft grain closure section. (Figures 2, 4)

$$L_{\text{PT}_{\text{CFCA}}} = L_{\text{GN}_{\text{CLA}}} \sqrt{1 - R_{\text{DCFACL}}^2}$$
(42)

Submerged nozzle inlet allowance. (Figure 4)

$$L_{\text{PT}_{\text{NZI}}} = L_{\text{PT}_{\text{CFHA}}} - L_{\text{PT}_{\text{NS}}}$$
(43)

Length of portion of port cone frustum section within cylindrical grain section. (Figures 2, 4)

$$L_{\text{PT}_{\text{CFCY}}} = L_{\text{GN}_{\text{NSCY}}} + L_{\text{PT}_{\text{NZI}}}$$
(44)

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(48)

EQUATIONS, FIRST ENTRANCE (Cont.):

CORRECTIONS TO BASIC GRAIN FOR NOZZLE SUBMERGENCE (Cont.):

Total length of port cone frustum section. (Figures 2, 4, 6)

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$$L_{\text{PT}_{\text{CF}}} = L_{\text{PT}_{\text{CFCY}}} + L_{\text{PT}_{\text{CFCA}}}$$
(45)

Half-angle of port cone frustum section. (Figure 2)

$$\theta_{\rm CF} = \arctan\left(\frac{D_{\rm PT}_{\rm CFA} - D_{\rm PT}_{\rm CFF}}{2 L_{\rm PT}_{\rm CF}}\right)$$
(46)

Slant height of port cone frustum section. (Figure 4)

$$L_{\text{PT}_{\text{CFS}}} = \left(\frac{1}{2}\right) \sqrt{4 L_{\text{PT}_{\text{CF}}}^2 + \left(D_{\text{PT}_{\text{CFA}}} - D_{\text{PT}_{\text{CFF}}}\right)^2}$$
(47)

Total volume of port cone frustum section. (Figure 5)

$$\mathbf{v}_{\mathbf{PT}_{\mathbf{CF}}} = \left(\frac{\pi}{12}\right) \mathbf{L}_{\mathbf{PT}_{\mathbf{CF}}} \left(\mathbf{D}_{\mathbf{PT}_{\mathbf{CFA}}}^2 + \mathbf{D}_{\mathbf{PT}_{\mathbf{CFF}}}^2 + \mathbf{D}_{\mathbf{PT}_{\mathbf{CFA}}} \mathbf{D}_{\mathbf{PT}_{\mathbf{CFF}}} \right)$$

Length ratio, length of portion of port cone frustum section within aft grain closure section to length of aft grain closure section. (Figure 4)

$$R_{LCFCA} = \frac{L_{PT_{CFCA}}}{L_{GN_{CLA}}}$$
(49)

Volume of ellipsoidal cap at aft base of port cone frustum section within aft grain closure section. (Figure 5)

$$V_{\text{PT}_{\text{ECFA}}} = \left(\frac{V_{\text{GN}_{\text{CLA}}}}{2}\right) \left(2 - 3R_{\text{LCFCA}} + R_{\text{LCFCA}}^{3}\right)$$
(50)

Volume of basic port portion of port cone frustum section within cylindrical grain section. (Figure 5)

$$V_{PT}_{CFCY} = \left(\frac{\pi}{4}\right) L_{PT}_{CFCY} D_{PT}^{2}$$
(51)

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EQUATIONS, FIRST ENTRANCE (Cont.):

CORRECTIONS TO BASIC GRAIN FOR NOZZLE SUBMERGENCE (Cont.):

Volume of basic port section associated with nozzle submergence. (Figure 5)

$$V_{\text{PT}_{\text{CYCF}}} = V_{\text{PT}_{\text{CFCY}}} + V_{\text{PT}_{\text{CLA}}}$$
(52)

Volume of propellent displaced due to nozzle submergence. (Figure 5)

$$V_{PP} = V_{PT} + V_{PT} - V_{PT}$$
(53)

Cylindrical grain length penalty required for propellent displaced by nozzle submergence. (Figure 2)

$$L_{GN_{PDNS}} = K_{GN_1} \left(\frac{V_{PP_{PDNS}}}{A_{PP_{WEB}}} \right) + K_{GN_2}$$
(54)

Adjusted length of cylindrical grain section, includes nozzle submergence penalty. (Figure 2)

$$L_{GN_{CY2}} = L_{GN_{CY1}} + L_{GN_{PDNS}}$$
(55)

Length to diameter ratio, cylindrical grain section. Includes nozzle submergence penalty.

$$R_{LDGNY2} = \frac{D_{GN}}{D_{GN}}$$
(56)

Adjusted length of cylindrical port section. Includes nozzle submergence penalty. (Figure 6)

$$L_{\text{PT}_{\text{CY2}}} = L_{\text{PT}_{\text{CY1}}} - L_{\text{PT}_{\text{YCLA}}} - L_{\text{PT}_{\text{CFCY}}} + L_{\text{GN}_{\text{PDNS}}}$$
(57)

PROPELLENT BURNING SURFACE:

Port surface area component, lateral cylindrical port propellent surface area. (Figure 6)

$$S_{\text{PT}_{\text{CY2}}} = \pi D_{\text{PT}} L_{\text{PT}_{\text{CY2}}}$$
(58)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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PROPELLENT BURNING SURFACE (Cont.):

Port surface area component, lateral cone frustum port propellent surface area. (Figure 6)

$$S_{\text{PT}_{\text{CFS}}} = \left(\frac{\pi}{2}\right) L_{\text{PT}_{\text{CFS}}} \left(D_{\text{PT}_{\text{CFF}}} + D_{\text{PT}_{\text{CFA}}}\right)$$
(59)

Port surface area component, forward base of port cone frustum propellent surface area. (Figure 6)

$$S_{\text{PT}_{\text{CFB}}} = \left(\frac{\pi}{4}\right) \left(D_{\text{PT}_{\text{CFF}}}^2 - D_{\text{PT}}^2\right)$$
(60)

Propellent surface area associated with the port. Includes submerged nozzle corrections.

$$S_{PT_2} = S_{PT_CY2} + S_{PT_{CFS}} + S_{PT_{CFB}}$$
(61)

Initial propellent burning surface area, excluding slots. (Figure 6)

$$S_{BS_{PT}} = S_{PT_2}$$
(62)

EQUATIONS, SECOND ENTRANCE:

CORRECTIONS TO GRAIN FOR SLOTS AND JOINTS:

Cylindrical grain section length penalty for slots. (Figure 2)

$$L_{GN_{SL}} = K_{GN_3} L_{SL_{GN}} + K_{GN_4}$$
(63)

Adjusted length of cylindrical grain section, includes nozzle submergence and slot penalties. (Figure 2)

$$L_{GN_{CY3}} = L_{GN_{CY2}} + L_{GN_{SL}}$$
(64)

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EQUATIONS, SECOND ENTRANCE (Cont.):

CORRECTIONS TO GRAIN FOR SLOTS AND JOINTS (Cont.):

Length to diameter ratio, cylindrical grain section. Includes nozzle submergence and slot penalties.

$$R_{LDGNY3} = \frac{D_{GN}CY3}{D_{GN}}$$
(65)

Adjusted length of cylindrical grain section, includes nozzle submergence, slot and joint penalties. (Figure 2)

$$L_{GN_{CY4}} = L_{GN_{CY3}} + L_{JT_{CUT}}$$
(66)

Length to diameter ratio, cylindrical grain section. Includes nozzle submergence, slot and joint penalties.

$$R_{LDGNY4} = \frac{L_{GN}_{CY4}}{D_{GN}}$$
(67)

EQUATIONS, THIRD ENTRANCE:

CORRECTIONS TO GRAIN FOR INTERNAL INSULATION:

Cylindrical grain length penalty for propellent displaced by internal insulation. (Figure 2)

$$L_{GN_{PDIN}} = K_{GN_5} \left(\frac{V_{IN_{PD}}}{A_{PP_{WEB}}} \right) + K_{GN_6}$$
(68)

Adjusted length of cylindrical grain section, includes nozzle submergence, slot, joint, and internal insulation penalties. (Figure 2)

$$L_{GN_{CY5}} = L_{GN_{CY4}} + L_{GN_{PDIN}}$$
(69)

Length to diameter ratio, cylindrical grain section. Includes nozzle submergence, slot, joints, and internal insulation penalties.

$$R_{LDGNY5} = \frac{D_{GN}}{D_{GN}}$$
(70)

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EQUATIONS, THIRD ENTRANCE (Cont.):

TOTAL GRAIN GEOMETRY:

Length of cylindrical grain section. Includes nozzle submergence, slot, joint and internal insulation penalties. (Figure 2)

$$L_{GN_{CY}} = K_{GN_7} L_{GN_{CY5}} + K_{GN_8}$$
(71)

Length to diameter ratio, cylindrical grain section. Includer nozzle submergence, slot, joint and internal insulation penaltics.

$$R_{LDGNCY} = \frac{\frac{GN_{CY}}{D_{GN}}}$$
(72)

Volume of cylindrical grain section. Includes port, submerged nozzle penalty, slots, joints and internal insulation except liner.

$$\mathbf{V}_{\mathrm{GN}_{\mathrm{CY}}} = \left(\frac{\pi}{4}\right) \, \mathbf{L}_{\mathrm{GN}_{\mathrm{CY}}} \, \mathcal{D}_{\mathrm{GN}}^2 \tag{73}$$

Volume of grain envelope. Includes port, submerged nozzle penalty, slots, joints and all internal insulation except liner. Note that the grain closures are hemi-ellipsoid frustums, not hemi-ellipsoids.

$$V_{GN} = V_{GN} + V_{GN} + V_{GN}$$
(74)

Length of grain envelope. Includes nozzle submergence, slot, joint and internal insulation penalties. (Figure 2)

$$L_{GN} = L_{GN_{CY}} + L_{GN_{CHF}} + L_{GN_{CHA}}$$
(75)

ASSOCIATIVE QUANTITIES:

The following associative quantities are intended solely for optional utilization by the program user. Their primary usage is for optional intermodel coupling and for forming constraint quantities.

$$Q_{\text{DCFA1}} = K_{\text{QDCFA1}} D_{\text{PT}_{\text{CFA}}}$$
(76)

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| GRAING | GRAIN GEOMETRY | GNGM1 |
|--|-----------------------------------|-------|
| EQUATIONS, THIR | D ENTRANCE (Cont.): | |
| ASSOCIATIVE QUA | NTITIES (Cont.): | |
| Q _{DCFA2} = K _{QDCF} | A2 DPT _{CFA} | (77) |
| $Q_{DCFA3} = K_{QDCF}$ | A3 DPTCFA | (78) |
| Q _{DCFF1} = K _{QDCF} | FI DPT _{CFF} | (79) |
| Q _{DCFF2} = K _{QDCF} | F2 ^D PT _{CFF} | (80) |
| Q _{DCFF3} = K _{QDCF} | F3 DPT _{CFF} | (81) |
| Q _{DGN1} = K _{QDGN1} | D _{GN} | (82) |
| $Q_{DGN2} = K_{QDGN2}$ | D _{GN} | (83) |
| Q _{DGN3} = K _{QDGN3} | D _{GN} | (84) |
| Q _{DPT1} = K _{QDPT1} | D _{PT} | (85) |
| Q _{DPT2} = K _{QDPT2} | D _{PT} | (86) |
| Q _{DPT3} = K _{QDPT3} | ^D PT | (87) |
| Q _{RAPTH1} = K _{QRA} | PHI RAPTTH | (88) |
| Q _{RAPTH2} = K _{QRA} | PH2 RAPTTH | (89) |
| $Q_{RAPTH3} = K_{QRA}$ | PH3 RAPTTH | (90) |

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OPTIMIZATION CONSIDERATIONS:

Generally, the nature of the problem which would require usage of this model would also require that the following variables and constraints be set up by the program user.

Variables.

Suggested nominal values for initial estimates of the variable values and bounds are included for each optimization variable listed below. These values are only guidelines, applicable to a very wide class of problems, and values corresponding to the specific application (quantities within parenthesis) should be used if they are easily available.

| KDPTI | Port fraction. The following values will insure that a propellent web is always defined. | | | | |
|---------|--|--|--|--|--|
| | Upper bound: 0.9
Lower bound: 0.1
Initial estimate: 0.2 | | | | |
| DPTCFF | Diameter of forward base of port cone frustum section.
(Figures 2, 4) | | | | |
| | Upper bound: 500, (approximate case diameter)
Lower bound: 5.
Initial estimate: approximate port diameter | | | | |
| DPTCFA | Diameter of aft base of port cone frustum section.
(Figures 2, 4) | | | | |
| | Upper bound: 500. (approximate case diameter)
Lower bound: 5.
Initial estimate: approximate port diameter | | | | |
| LPTCFHA | Distance from forward base of port cone frustum section to aft base of grain envelope. (Figure 2) | | | | |
| | Upper bound: approximate length of case
Lower bound: zero
Initial estimate: approximate length nozzle is buried
within case | | | | |

Constraints.

The following set of inequality constraints are formulated such that the motor volumetric loading efficiency (see MOTORG model type) will be maximum if a minimum vehicle length (fixed diameter) objective function is being utilized. For other objective functions, some of these constraints may require implementation as equality constraints.

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OPTIMIZATION CONSIDERATIONS (Cont.):

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Constraints 91 through 96 are required for "shaping" the port cone frustum grain cutout utilized for submerged nozzle geometry. It should be noted that these constraints should always be set up, even if the nozzle is not submerged.

The forward base diameter of the port cone frustum section is greater than, or equal to, the port diameter. (Figures 2, 4)

D_{PT}_{CFF} ^{≥ D}_{PT} (91)

The aft base diameter of the port cone frustum section is less than, or equal to, the grain diameter. (Figures 2, 4)

$$D_{\text{PT}_{\text{CFA}}} \delta_{\text{GN}}$$
 (92)

The aft base diameter of the port cone frustum section is greater than, or equal to, the forward base diameter of the port cone frustum section. (Figures 2, 4)

$$D_{\text{PT}_{\text{CFA}}} \ge D_{\text{PT}_{\text{CFF}}}$$
(93)

The aft base diameter of the port cone frustum section is greater than, or equal to, the diameter of the hole in the aft closure required for the nozzle. (Figures 2, 4)

$${}^{D}PT_{CFA} \stackrel{\geq}{\to} {}^{D}GN_{HA}$$
(94)

Nozzle inlet allowance. Sufficient space must be provided forward of the nozzle inlet to allow flow from the port cone frustum section to the nozzle entrance. QDNZENT and QDNZTH are associative quantities which must be set up, by the program user, in the nozzle geometry model. (Figure 4)

$$L_{PT_{NZI}} \ge QDNZENT$$
 (95)

The cylindrical grain section length must be greater than, or equal to, zero for valid closure geometry. (Figure 2)

$$L_{GN_{CY}} \ge 0 \tag{97}$$

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OPTIMIZATION CONSIDERATIONS (Cont.):

The nozzle entrance must be within the port. (Figure 4)

| L _{PT} _{CFHA} ≰ | L _{GN} | (98) |
|-----------------------------------|-----------------|------|
| | | |

 $L_{\text{PT}_{\text{NS}}} \ge 0 \tag{99}$

Considerations of structural integrity of the grain and acceptable internal ballistics limit feasible values of the port fraction.

 $K_{\text{DPT1}} \ge 0.2 \tag{100}$

To avoid unacceptable nozzle erosion, a lower bound in placed upon the ratio of the cylindrical port section cross section area to the nozzle throat area. (Note that this constraint corresponds to a lower limit of port fraction.)

RAPTTH ≥ 1,15

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Fig. 40.1-3 Forward Grain Closure Geometry

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Fig. 40.1-4 Aft Grain Closure and Nozzle Submergence Geometry


Fig.A

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Fig. 40.1-5 Aft Grain Closure and Nozzle Submergence Volumes

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Fig. 40.1-6 Surface and Cross-sectional Areas

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INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

Due to the nature of this model, many of the following required user inputs will be optimization variables. See the "Optimization Considerations" section.

| Mnemonic | Symbol | Descript | ion; Ext. (Int.) Units | Preset |
|----------|--------------------------------|---|---|---|
| DPTCFA | ^D PT _{CFA} | Diamete:
section; | r of aft base of port co | one frustum |
| | | in | Figs. 2, 4, 6 | 0 |
| DPTCFF | D _{PT} cff | Diameter
frustum | r of forward base of posterion; | ort cone |
| | | in | Figs. 2, 4, 6 | 0 |
| KDPTI | ^K DPT1 | Coefficie
cylindric
of the cy
computat | ent relating the diamet
al section of the port
lindrical grain section
tion, equation 2. | er of the
to the diameter
a. See DPT |
| | | N. D. | | 0 |
| KDPT2 | к _{ррт} | Bias for DPT computation; | | |
| | 2 2 | in | | 0 |
| LJTCUT | ^L JT _{CUT} | Total len
grain sec
slot leng
joint; | igth of cutout, within t
ction, for joints. Due
the if a slot is being u | he cylindrical
s not include
tilized as a |
| | | in | Fig. 2 | 0 |
| LPTCFHA | L _{PT} CFHA | Distance
cone frug
hemi-ell
aft grain | from forward base of
stum section to the aft
ipsoid frustum associa
closure section; | the port
base of the
ated with the |
| | | in | Fige 2 4 | 0 |

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INPUT DATA, INTRA-MODEL (Cont.):

The following coefficient and bias quantities are made available for input. However, in normal applications, the preset values are used for most, if not all, of these quantities. Note that these coefficient quantities are preset (1) and the bias quantities are preset (0).

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|-------------------|--|---------------|
| KGN I | к _{GN} 1 | Coefficient for LGNPDNS compu
N. D. | itation;
l |
| KGN2 | κ _{gn2} | Bias for LGNPDNS computation;
in | 0 |
| KGN3 | K _{GN3} | Coefficient for LGNSL computat N. D. | ion;
l |
| KGN4 | к _{GN4} | Bias for LGNSL computation;
in | 0 |
| KGN5 | к _{GN5} | Coefficient for LGNPDIN compu
N. D. | tation;
l |
| KGN6 | к _{GN6} | Bias for LGNPDIN computation;
in | 0 |
| KGN7 | K _{GN7} | Coefficient for LGNCY computed N. D. | tion;
1 |
| KGN 8 | K _{GN8} | Bias for LGNCY computation; | 0 |

The following associative quantity coefficients are intended solely for optional utilization by the program user. Their primary usage is for optional inter-model coupling and for forming constraint quantities. Note that all associative quantity coefficients are preset (0).

| KQ DCFA1 | K _{QDCFA1} | Associative quantity coefficient for QDCFA1 computation; | |
|----------|---------------------|--|---|
| | | N. D. | 0 |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|---------------------|--|--------|
| KQDCFA2 | KQDCFA2 | Associative quantity coefficient for QDCFA2 computation; | |
| | | N. D. | 0 |
| KQDCFA3 | K _{QDCFA3} | Associative quantity coefficient for QDCFA3 computation; | |
| | | N. D. | 0 |
| KQDCFF1 | K _{QDCFF1} | Associative quantity coefficient for QDCFF1 computation; | |
| | | N. D. | 0 |
| KQDCFF2 | K _{QDCFF2} | Associative quantity coefficient for QDCFF2 computation; | |
| | | N.D. | 0 |
| KQDCFF3 | K _{QDCFF3} | Associative quantity coefficient for QDCFF3 computation; | |
| | | N. D. | 0 |
| KQDGNI | K _{QDGN1} | Associative quantity coefficient for QDGN1 computation; | |
| | | N. D. | 0 |
| KQDGN2 | K _{QDGN2} | Associative quantity coefficient for QDGN2 computation; | |
| | | N. D. | 0 |
| KQDGN3 | K _{QDGN3} | Associative quantity coefficient for QDGN3 computation; | |
| | | N. D. | 0 |
| KQDPT1 | K _{QDPT1} | Associative quantity coefficient for QDPT1 computation; | |
| | | N. D. | 0 |
| KQDPT2 | K _{QDPT2} | Associative quantity coefficient for QDPT2 computation; | |
| | | N. D. | С |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|-----------|---------------------|---|--------|
| KQDPT3 | K _{QDPT3} | Associative quantity coefficient for QDPT3 computation: | ! |
| | | N. D. | 0 |
| KQR APH1 | K _{QRAPH1} | Associative quantity coefficient for QRAPTH3 computation; | |
| | | N. D. | 0 |
| KQR A PH2 | K _{QRAPH2} | Associative quantity coefficient for QRAPTH2 computation; | |
| | | N. D. | 0 |
| KQR APH3 | K _{QRAPH3} | Associative quantity coefficient for QRAPTH3 computation; | |
| | | N. D. | 0 |

INPUT DATA, INTER-MODEL:

This model requires as input certair data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|--------------------------------|--|--|
| ANZTH | A _{NZ} | Nozzle throat area; | |
| | TE | in ² | NOZZLEG |
| DILHAI | ^D IL _{HAI} | Diameter of circular hole, for the nozzle,
within the inside surface of the insulation
liner associated with the aft closure sectior | |
| | | in | INSULG |
| DILHFI | D _{IL} HFI | Diameter of circular hole, for
within the inside surface of the
liner associated with the forwar
section; | the igniter,
insulation
rd closure |
| | | in | INSULG |

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type | |
|----------|---------------------------------|--|---|--|
| DILI | DILI | Inside diameter of the insulation liner within the case cylindrical section; | | |
| | | in | INSULG | |
| LCSHA | L _{CS_{HA}} | Length of hole, for the nozzle,
case associated with the aft cas
section; | within the
se closure | |
| | | in Figs. 2, 4 | CASEG | |
| LILCHAI | L _{IL} CHAI | Length of hemi-ellipsoid frustu
with the inside surface of the ir
liner within the aft case closur | m associated
nsulation
re; | |
| | | in | INSULG | |
| LILCHFI | L _{IL} CHFI | Length of hemi-ellipsoid frustum assoc
with the inside surface of the insulation
within the forward case closure section | | |
| | | in | INSULG | |
| LILCLAI | ^L il _{clai} | Length of the hemi-ellipsoid as
the inside surface of the insula
within the aft case closure sect | sociated with
tion liner
tion; | |
| | | in | INSULG | |
| LILCLFI | L _{IL} CLFI | Length of the hemi-ellipsoid as
with the inside surface of the in
within the forward case closure | sociated
isulation liner
section; | |
| | | in | INSU LG | |
| LILHA | Lir ^{ha} | Length of the hole, for the noz:
the insulation liner associated
aft case closure section; | zle, within
with the | |
| | | in Figs. 2, 4 | INSULG | |
| LNZB | LNZ | Distance nozzle is buried withi | n the case; | |
| | B | in Fig. 4 | NOZZLEG | |

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|------------------------------|--|------------|
| LSLGN | LSL | Total slot length; | |
| | GN | in | IBFLOW |
| RDILCAI | RDILCAI | Head ratio, inside surface of insulation line
associated with the aft case closure section | |
| | | N. D. | INSULG |
| RDILCFI | RDILCFI | Head ratio, inside surface of insulation
liner associated with the forward case
closure section; | |
| | | N. D. | INSULG |
| VINPD | v _{IN_{PD}} | Volume of propellent displaced b
insulation. excluding liner; | y internal |
| | | in ³ | INSULG |
| VPPMT | v _{pp_} | Propellent volume; | |
| | MT | in ³ | PROPW |

OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol | Descripti | on; Ext. (Int.) Unit | 8 | |
|----------|---------------------|--|-----------------------|---------------|--|
| APIWEB | A _{PP} web | Propellent web area. Cross sectional area
of propellent volume bounded by the
cylindrical grain section and basic
cylindrical port section; | | | |
| | | in^2 | Fig. 6 | Eq. 6 | |
| APT | ^A PT | Cross sec
section; | ctional area of basic | c cylindrical | |
| | | in ² | Fig. 6 | Eq. 3 | |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
|----------|---------------------|--|--|---|--|
| DGN | D _{CN} | Diamete | r of cylindrical grain s | ection; | |
| | | in | Figs. 2, 6 | Eq. l | |
| DGNC L | D _{GN} CL | Equatorial diameter of hemi-ellipsoids
associated with the forward and aft grain
closure sections; | | | |
| | | in | Figs. 2, 3, 4 | Eq. 7 | |
| DGNHA | D _{GN} HA | Diameter of aft base of the hemi-ellipsoid frustum associated with the aft grain closure section; | | | |
| | | in | Figs. 2, 4 | Eq. 32 | |
| DGNHF | D _{GN} HF | Diamete
ellipsoid
grain clo | r of forward base of the frustum associated wi poure section; | e hemi-
th the forward | |
| | | in | Figs. 2, 3 | Eq. 19 | |
| DPT | D _{PT} | Diamete | r of basic cylindrical p | ort section; | |
| | | in | Figs, 2, 3, 4, 6 | Eq. 2 | |
| LGN | L _{GN} | Length o
the forw
frustum
closure
hemi-ell
aft grain
penalties
joints an | of grain envelope. Dist
ard base of the hemi-en-
associated with the for
section and the aft base
ipsoid frustum associan
closure section. Inclu-
s for nozzle submergen
and internal insulation; | ance between
llipsoid
ward grain
e of the
ted with the
udes length
ce, slots, | |
| | | in | Fig. 2 | Eq. 75 | |
| LGNCHA | L _{GN} CHA | Length o
ellipsoid
grain clo | of the axis of revolution
frustum associated wi
osure section; | of the hemi-
th the aft | |
| | | in | Figs. 2, 4 | Eq, 31 | |

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| OUTPUT DAT | A (Cont.): | | | | | |
|------------|---------------------|---|---|---|--|--|
| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | | |
| LGNCHF | L _{GN} CHF | Length of
ellipsoid :
grain clos | Length of the axis of revolution of the hemi -
ellipsoid frustum associated with the forward
grain closure section: | | | |
| | | in | Figs. 2, 3 | Eq. 18 | | |
| LGNCLA | L _{GNCLA} | Length of
ellipsoid a
closure s | the axis of revolution associated with the a section; | on of the hemi-
aft grain | | |
| | | in | Figs. 2, 4 | Eq. 23 | | |
| LGNCLF | L _{GNCLF} | Length of
ellipsoid a
closure se | n of the hemi-
orward grain | | | |
| | | in | Figs. 2, 3 | Eq. 10 | | |
| LGNCY | LGNCY | Length of cylindrical gr
length penalties for noz
slots, joints, and inter | | ction. Includes
bmergence,
ulation; | | |
| | | in | Fig. 2 | Eq. 71 | | |
| LGNCYI | L _{GN} CY1 | Length of
Does not :
submerge
insulation | basic cylindrical gr
include length penalt
nce, slots, joints ar
; | rain section.
Nies for nozzle
Nd internal | | |
| | | in | Fig. 2 | Eq. 36 | | |
| LGNCY2 | L _{GN} CY2 | Length of cylindrical grain section. Includes
length penalty for nozzle submergence; | | | | |
| | | in | Fig. 2 | Eq. 55 | | |
| LGNCY3 | L _{GNCY3} | Length of
length per
and slots; | cylindrical grain se
nalties for nozzle su | ction. Includes
bmergence | | |
| | | in | Fig. 2 | Eq. 64 | | |
| LGNCY4 | L _{GNCY4} | Length of
length per
slots and | cylindrical grain se
nalties for nozzle su
joints; | ction. Includes
bmergence, | | |
| | | in | Fig. 2 | Eq. 66 | | |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Descripti | on; Ext. (Int.) Units | | |
|----------|-------------------------------|---|--|------------------------------|--|
| LGNCY5 | L _{GN} CY5 | Length of cylindrical grain section. Includes
length penalties for nozzle submergence,
slots, joints and internal insulation; | | | |
| | | in | Fig. 2 | Eq. 69 | |
| LGNNSCY | L _{GNNSCY} | Distance
grain sec | nozzle is submerged in
tion; | cylindrical | |
| | | in | Fig. 4 | Eq. 40 | |
| LGN PDIN | L _{GN} PDIN | Cylindrical grain section length penalty for propellent displaced by internal insulation; | | | |
| | | in | Fig. 2 | Eq. 68 | |
| LGNPDNS | LGNPDNS | Cylindrical grain section length penalty for propellent displaced by submerged nozzle; | | | |
| | | in | Fig. 2 | Eq. 54 | |
| LGNSL | ^L GN _{SL} | Cylindrical grain section length penalty for slot cutouts; | | penalty for | |
| | | in | Fig. 2 | Eq. 63 | |
| LPTCF | L _{PT} | Total len | gth of port cone frustur | n section; | |
| | CF | in | Figs. 2, 4, 6 | Eq. 45 | |
| LPTCFCA | L _{PT} cfca | Length of
section w | of the portion of the port cone frustum
within the aft grain closure section; | | |
| | | in | Figs. 2, 4 | Eq. 42 | |
| LPICFCY | L _{PT} CFCY | Length of
section w | the portion of the port
within the cylindrical gr | cone frustum
ain section; | |
| | | in | Figs. 2, 4 | Eq. 44 | |
| LPTCFS | | Slant hei | ght of port cone frustun | n section; | |
| | - CFS | in | Fig. 4 | Ea. 47 | |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | | | | | |
|----------|----------------------|---|---|------------------------|--|--|--|--|--|
| LPTCYI | L _{PT} CY1 | Total length of cylindrical portion of basic
port. Does not include adjustments for
nozzle submergence, slots, joints nor
internal insulation: | | | | | | | |
| | | in | Fig. 2 | Eq. 38 | | | | | |
| LPTCY2 | L _{PT} CY2 | Length of
nozzle su | cylindrical port sec
bmergence penalty; | tion. Includes | | | | | |
| | | in | Figs. 2, 6 | Eq. 47 | | | | | |
| LPTNS | L _{PT} | Distance | nozzle is submerged | into port; | | | | | |
| | NS | in | Fig. 4 | Eq. 39 | | | | | |
| LPTNZI | LPT | Submerged nozzle inlet allowance; | | | | | | | |
| | N ZI | in | Fig. 4 | Eq. 43 | | | | | |
| LPTYCLA | L _{PT} ycla | Length of cylindrical portion of the ba
port within the hemi-ellipsoid associa
the aft grain closure section; | | | | | | | |
| | | in | Fig. 4 | Eq. 25 | | | | | |
| LPTYCLF | L _{PT} YCLF | Length of cylindrical portion of the basic
port within the hemi-ellipsoid associated
with the forward grain closure section; | | | | | | | |
| | | in | | Eq. 12 | | | | | |
| QDCFA1 | Q _{DCFA1} | Associative quantity, port cone frustum section aft base diameter. See DPTCFA; | | | | | | | |
| | | in | | Eq. 76 | | | | | |
| QDCFA2 | Q _{DCFA2} | Associati
section at | ve quantity, port con
It base diameter. Se | e frustum
e DPTCFA; | | | | | |
| | | in | | Eq. 77 | | | | | |
| QDCFA3 | Q _{DCFA3} | Associati
section at | ve quantity, port con
It base diameter. Se | e frustum
e DPTCFA; | | | | | |
| | | in | | Eq. 78 | | | | | |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
|----------|--------------------|---|---------------|
| QDCFF1 | Q _{DCFF1} | Associative quantity, port core frust
section forward base diameter. See | um
DPTCFF; |
| | | in E | Cq. 79 |
| QDCFF2 | Q _{DCFF2} | Associative quantity, port cone frust section forward base diameter. See | um
DPTCFF; |
| | | in E | Cq. 80 |
| QDCFF3 | Q _{DCFF3} | Associative quantity, port cone frust section forward base diameter. See | um
DPTCFF; |
| | | in É | Cq. 81 |
| QDGN1 | Q _{DGN1} | Associative quantity, cylindrical gra
diameter. See DGN; | in section |
| | | in H | Eq. 82 |
| QDGN2 | Q _{DGN2} | Associative quantity, cylindrical gra
diameter. See DGN; | in section |
| | | in I | Eq. 83 |
| QDGN3 | Q _{DGN3} | Associative quantity, cylindrical gra
diameter. See DGN; | in section |
| | | in I | Cq. 84 |
| QDPT1 | Q _{DPT1} | Associative quantity, basic cylindric section diameter. See DPT; | al port |
| | | in I | Eq. 85 |
| QDPT2 | Q _{DPT2} | Associative quantity, basic cylindric section diameter. See DFT; | al port |
| | | in I | Eq. 86 |
| QDPT3 | Q _{DPT3} | Associative quantity, basic cylindric section diameter. See DPT; | al port |
| | | in I | Eq. 87 |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | <u> </u> |
|----------|-----------------------------|--|---|
| QRAPTH1 | Q _{RAPTH1} | Associative quantity, port to noz
area ratio. See RAPTTH; | zle throat |
| | | N. D. | Eq. 88 |
| QRAPTH2 | Q _{RAPTH2} | Associative quantity, port to noz
area ratio. See RAPTTH; | zle throat |
| | | N. D. | Eq. 89 |
| QRAPTH3 | Q _{RAPTH3} | Associative quantity, port to noz
area ratio. See RAPTTH; | zzle throat |
| | | N. D. | Eq. 90 |
| RAPTTH | ^R APT T H | Area ratio. Ratio of basic cylin
section cross sectional area to r
cross sectional area; | drical port
nozzle throat |
| | | N. D. | Eq. 4 |
| RDCFACL | R _{DCFACL} | Diameter ratio. Ratio of port c
section aft base diameter to gra
equatorial diameter; | one frustum
in closure |
| | | N. D. | Eq. 41 |
| RDGNCLA | R _{DGNCLA} | Head ratio of ellipsoid associate
aft grain closure section. Ratio
the closure length to the closure
diameter; | ed with the
o of twice
e equatorial |
| | | N. D. | Eq. 22 |
| RDGNCLF | RDGNCLF | Head ratio of ellipsoid associate
forward grain closure section.
twice the closure length to the c
equatorial diameter; | ed with the
Ratio of
losure |
| | | N. D. | Eq. 9 |
| RDPTCL | RDPTCL | Diameter ratio, Ratio of basic
port section diameter to grain c
rial diameter; | cylindrical
losure equato- |
| | | N. D. | Eq. 8 |

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| OUT | PUT | DATA | (Cont. |): |
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| | | | | |

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | | | | | |
|----------|----------------------|---|--|--|--|--|--|--|--|
| RLCFCA | RLCFCA | Length ratio. Ratio of length of portion of
port cone frustum section within aft grain
closure section to length of aft grain closure
section; | | | | | | | |
| | | N. D. | Eq. 49 | | | | | | |
| RLDGNCY | RLDGNCY | Length to diameter ratio, cylind:
section. Includes nozzle submer
joint and internal insulation pena | rical grain
gence, slot,
lties; | | | | | | |
| | | N. D. | Eq. 72 | | | | | | |
| RLDGNYI | RLDGNYI | Length to diameter ratio, basic of
grain section. Does not include
submergence, slot, joint and into
insulation penalties; | cylindrical
nozzle
ernal | | | | | | |
| | | N. D. | Eq. 37 | | | | | | |
| R LDGNY2 | R _{LDGN Y2} | Length to diameter ratio, cylind
section. Includes nozzle submer
penalty; | rical grain
gence | | | | | | |
| | | N. D. | Eq. 56 | | | | | | |
| RLDGNY3 | R _{LDGNY3} | Length to diameter ratio, cylind
section. Includes nozzle submer
slot penalties; | rical grain
gence and | | | | | | |
| | | N. D. | Eq. 65 | | | | | | |
| RL GNY4 | RLDGNY4 | Length to diameter ratio, cylind
section. Includes nozzle submer
and joint penalties; | rical grain
rgence, slot | | | | | | |
| | | N. D. | Eq. 67 | | | | | | |
| R LDGNY5 | R _{LDGN Y5} | Length to diameter ratio, cylind
section. Includes nozzle submer
joint and internal insulation pena | rical grain
rgence, slot,
lties; | | | | | | |
| | | N. D. | Eq. 70 | | | | | | |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; E | xt. (Int.) Units | | | | | | | |
|----------|--------------------------------|---|--|---|--|--|--|--|--|--|
| RLGNCHA | RLGNCHA | Length ratio, aft grain closure section.
Ratio of hemi-ellipsoid frustum length to
hemi-ellipsoid length; | | | | | | | | |
| | | N. D. | | Eq. 33 | | | | | | |
| RLGNCHF | RLGNCHF | Length ratio, 1
Ratio of hemi-
hemi-ellipsoid | forward grain closur
ellipsoid frustum len
length; | e section.
gth to | | | | | | |
| | | N. D. | | Eq. 20 | | | | | | |
| RLPTCYA | R _{LPTCYA} | Length ratio.
cylindrical por
the hemi-ellips
ellipsoid for th | Ratio of the length of
tion of the basic po-
soid to the length of t
se aft grain closure s | i the
rt within
he hemi-
ection; | | | | | | |
| | | N. D. | | Eq. 27 | | | | | | |
| RLPTCYF | RLPTCYF | Length ratio. Ratio of the length of the cylindrical portion of the basic port within the hemi-ellipsoid to the length of the hemi-ellipsoid for the forward grain closure section: | | | | | | | | |
| | | N, D. | | Sq. 14 | | | | | | |
| SBSPT | s _{bspt} | Initial propelle
excluding slots | ent burning surface a | rea, | | | | | | |
| | | in ² | Fig. 6 | Eq. 62 | | | | | | |
| SPT2 | s _{PT2} | Propellent sur
port. Includes | face area associated
submerged nozzle c | with the orrections; | | | | | | |
| | | in ² | | Eq. 61 | | | | | | |
| SPTCFB | ^S PT _{CFB} | Port surface a surface a forw | rea component, Prop
vard bane of port con | ellent
e frustum | | | | | | |
| | | in ² | Fig. 6 | Eq. 60 | | | | | | |
| SPTCFS | S _{PT} _{CF5} | Port surface a
surface associ
cone frustum s | rea component. Prop
ated with lateral area
section; | pellent
a of port | | | | | | |
| | | in ² | Fig. 6 | Eq. 59 | | | | | | |

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GRAIN GEOMETRY

GNGM1

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| out | PUT | DATA | (Cont.): | |
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| Mnemonic | Symbol | Descriptio | n; Ext. (Int.) Units | | | | | | |
|----------|-------------------------------|---|---|--|--|--|--|--|--|
| SPTCY2 | SPTCY2 | Port surface area component. Propellent
surface associated with the lateral area of
the cylindrical port section; | | | | | | | |
| | | in ² | Fig. 6 | Eq. 58 | | | | | |
| THETACF | $\theta_{\rm CF}$ | Half-angle | of port cone frustur | n section; | | | | | |
| | Ŭ. | deg (rad | l) Figs. 2, 4 | Eq. 46 | | | | | |
| TPPWEB | T _{PP} web | Propellent
grain in se
port are cy
between su
and surfac | web thickness. The
ection where both the
ylindrical. Radial d
urface of cylindrical
e of cylindrical grai | ickness of
grain and
istance
port section
n section; | | | | | |
| | | in | Figs. 2, 3, 6 | Eq. 5 | | | | | |
| VGN | ^V GN | Volume of
submerged
and all into
Note that t
envelope a
hemi-ellip
in ³ | grain envelope. Ind
I nozzle penalty, slo
ernal insulation exce
he grain closures of
re hemi-ellipsoid fr
soids; | cludes port,
ots, joints
ept liner.
the grain
oustums, not
Eq. 74 | | | | | |
| VGNCHA | v_{GN}_{CHA} | Volume of with the af | hemi-ellipsoid frus
it grain closure sect | tum associated
ion; | | | | | |
| | | in ³ | Fig. 5 | Eq. 34 | | | | | |
| VGNCHF | V _{GN_{CHF}} | Volume of hemi-ellipsoid frustum associated with the forward grain closure section; | | | | | | | |
| | | in ³ | Fig. 3 | Eq. 21 | | | | | |
| VGNCLA | V _{GN_{CLA}} | Volume of
the aft gra | hemi-ellipsoid asso
in closure section; | ciated with | | | | | |
| | | jn ³ | Fig. 5 | Eq. 24 | | | | | |
| VGNCLF | V _{GN} CLF | Volume of the forwar | hemi- ellipsoid ass
d grain closure sec | ociated with
tion; | | | | | |
| | | in ³ | Fig. 3 | Eq. 11 | | | | | |

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GRAIN GEOMETRY

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| Mnemonic | Symbol | Description | n; Ext. (Int.) Units | 3 | | | | |
|----------|------------------------------|---|---|--|--|--|--|--|
| VGNCY | v _{GN_{CY}} | Volume of cylindrical grain section.
Includes port, submerged nozzle penalty,
slots, joints and internal insulation except
liner; | | | | | | |
| | | in | | Eq. 73 | | | | |
| VPPCLA | V _{PP} CLA | Volume of propellent associated with the
hemi-ellipsoid of the aft grain closure
section. Note that this volume is an inter-
mediate quantity and does not include
corrections for nozzle submergence,
inculation worked at a inter- | | | | | | |
| | | in^3 | Fig. 5 | Eq. 30 | | | | |
| VPPCLF | V _{PP} CLF | Volume of
hemi-ellip
section. N
mediate qu
correction
etc.;
in ³ | propellent associa
soid of the forward
lote that this volum
lantity and does no
s for insulation we
Fig. 3 | ted with the
d grain closure
ne is an inter-
t include
edges, igniter,
Eq. 17 | | | | |
| VPPCY1 | v _{PP} CY1 | Volume of
grain secti
propellent
gence, slots
in ³ | propellent within h
ion. Does not incl
corrections for he
s, joints nor intern | basic cylindrica
ude displaced
zzle submer-
nal insulation;
Eq. 35 | | | | |
| VPPPDNS | V _{PP} PDNS | Volume of
nozzle sub | propellent displac
mergence; | ed due to | | | | |
| | | in ³ | Fig. 5 | Eq. 53 | | | | |
| VPTCF | v _{PT} | Total volu | me of port cone fri | ustum section; | | | | |
| | CF | in ³ | Fig. 5 | Eq. 48 | | | | |
| VPTCFCY | v _{pt} cfcy | Volume of
frustum se
grain secti | basic port portion
ction within the cy
ion; | of the port cone
lindrical | | | | |
| | | in ³ | Fig. 5 | Eq. 51 | | | | |

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OUTPUT DATA (Cont.):

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GRAIN GEOMETRY

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GNGM1

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| Mnemonic | Symbol | Description; Ext. (Int.) Units |
|-----------|---------------------------------|---|
| VPTCLA | V _{PT_{CLA}} | Volume of basic port within the hemi-ellipsoid
associated with the aft grain closure section;
in ³ Fig. 5 Eq. 29 |
| VPTCLF | V _{PT} CLF | Volume of basic port within the hemi-ellipsoid
associated with the forward grain closure
section;
in ³ Fig. 3 Eq. 16 |
| VPTCYCF | V _{PT} CYCF | Volume of basic port section associated with
nozzle submergence;
in ³ Fig. 5 Eq. 52 |
| VPTECFA | V _{PT} ecfa | Volume of ellipsoidal cap at aft base of port
cone frustum section within aft grain closure
section;
in ³ Fig. 5 Eq. 50 |
| V PTEC LA | V _{PT} ecla | Volume of ellipsoidal cap at base of cylindri-
cal portion of basic port section within the
hemi-ellipsoid associated with the aft grain
closure section;
in ³ Fig. 5 Eq. 28 |
| VPTECLF | ^V PT _{ECLF} | Volume of ellipsoidal cap at base of cylindri-
cal portion of the basic port section within
the hemi-ellipsoid associated with the
forward grain closure section;
in ³ Fig. 3 Eq. 15 |
| VPTYCLA | V _{PT} ycla | Volume of cylindrical portion of the basic
port within the hemi-ellipsoid associated
with the aft grain closure section;
in ³ Fig. 5 Eq. 26 |
| VPTYCLF | ^v pt _{yclf} | Volume of cylindrical portion of the basic
port within the hemi-ellipsoid associated
with the forward grain closure section;
in ³ Fig. 3 Eq. 13 |
| | | |

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Norminally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| PPMEB APT CRAING GRAING GGAING GRAING GGAING GRAING GGAING | | | | | • | | | | | | | | | - | | | | | | | |
|---|---------|-------|--------|--------|---------|----------------|------------|------------|----------|---------|--------------|--------------|----------|-------------|--------------|-------------|--------|-------------|-------------|--------------|--------|
| PPMEB APT DENCET CRAING GRAING CONCL DENCET *** KODFTAL | | DCNHF | TNDX | KGN7 | KQDCFF2 | KQDPT2 | LCNCHA | LGNCY2 | ILGNPONS | LPTCFHA | LPTYCLA | QDCFF2 | ZIAO | RDCFACL | RLDGNY1 | RLGNCHF | SPICES | VGNCHF | VPPCY1 | VPTCYCF | |
| PFWEB APT GRAING | METRY | | | | | | | | | | | | | | | | | | | | |
| PFWEB APT DENCR CRAING GRAING APT DENCRIA LI DENCL DENCRIA LI DENCL | AIN GEC | NHA | 222 | N6 | DCFF1 | ILLAO | z | ILIN | NICHN | TCFCY | IZNT | CFFL | E | HILL | DGNCY | GNCHA | TCFB | NCHA | PCLF | TCLF | TYCLE |
| PFWEB APT DCN GRAING GNGMC PT DPTCFA DPTCFF *1 DGNCL PT DPTCFA DPTCFF *2 KDPTL GN2 KGN3 KGN4 *3 KGN5 GN2 KGN3 KGN4 *3 KGN5 GN2 KGN3 KGN4 *7 KGN5 GN2 KGN3 KGN4 *7 KGN5 GN2 KQDFTAL KQDCFA2 *5 KQDCFA3 QDFT3 KQDCFA2 *14 KQDCFA3 KGN5 QDFT3 KQDCFA2 *14 KQDCFA3 KGN5 QDFT3 KQDCTA2 *14 KQDCFA3 KGN5 QDFT3 KQDCTA2 *11 KQDCFA3 KGN3 QDFT3 LGNCLA LCNCT2 *11 QDCFA3 QNCT3 LFTC7 *11 QDCFA3 QDCN3 DFT3 QDCN1 QDCTA2 *11 QDCFA3 DFT3 QDCN1 QDCN2 *11 QDCFA3 DFT3 QDCN1 QDCN2 *12 QDCN3 DFT3 QDCN1 QDCN2 *12 QDCN3 DFT3 QDCN1 QDCN2 *11 QDCN3 <t< td=""><th>GR</th><td>8</td><td>₽</td><td>KG</td><td>Å
Å</td><td>A
Q</td><td>3</td><td>3</td><td>3</td><td>E</td><td>5</td><td>9</td><td>ə</td><td>R</td><td>R</td><td>Ę</td><td>SP</td><td>5
S</td><td>5</td><td>5</td><td>ΥΡ</td></t<> | GR | 8 | ₽ | KG | Å
Å | A
Q | 3 | 3 | 3 | E | 5 | 9 | ə | R | R | Ę | SP | 5
S | 5 | 5 | ΥΡ |
| PPWEBAPTDGN*1DGNPTDPTCFADCN*1DGNPTDPTCFADCN*1DGNGN2KGN3KGN4*3KGNGN2KGN3KGN4*3KGNGN3KQDCFA2*4*4QDPT3KQDCFA2*4KQCQDPT3KQDGN1KQDCFA2*4QDPT3KQDGN1KQDGN2*6QDPT3KQDGN2*1LCNQDPT3KQDGN1KQDGN2*6QDPT3LCNCT4LCNCT5*10LATCUTLPTC72LLPTC72*11PTCFSQDGN1QDGN2*11QDCT73QDGN1QDGN2*11QDCT73QDGN1QDGN2*11QDCT73QDGN2*11QDGDPTC5LLPTC72*12QDGDPT3QDGN1QDGN2*11QDCT73QDGN2*12QDGDPT3QDGN1QDGN2*11PTC72LLPTC71LLPTC72*12DCT73QDGN2YPTGC1*11PTC72THEPACF*13PTC72YPTGC1*11PTC72YPTGC1*11PTC72YPTGC1*11PTC72YPTGC1*11PTC72YPTGC1YPTG1PTGC1AYPTGC1YPTG1PTGC1AYPTGC1YPTG1PTG1AYPTG1YPTG1YPTG1AYPTG1YPTG1AYPTG1YPTG | Ş | 5 | F | Ś | CFA3 | CN3 | APH3 | C, | NSCY | CFCA | NS | FA3 | EN | PTH3 | FCA | GNY5 | ç، | | CLA | CLA | YCLA |
| PFWEB APT DGN PT DPTCFA MT CN2 CGATMG **1 CN2 DPTCFA DPTCFA **2 GN3 KGN3 KGN4 **2 QDCFF3 KQDCFAL KQDCFAL **2 QDCFF3 KQDCFAL KQDCFAL **2 QDCFF3 KQDCFAL KQDCFAL **2 QDCFF3 KQDCFAL KQDCFAL **4 QDCFF3 KQDCFAL KQDCFAL **1 QDCFF3 KGN1 KQDCFAL **4 QDCFF3 KQDCFAL KQDCFAL **1 QDCFF3 KQDCFAL KQDCFAL **1 QDCFF3 LGNCLA LFPTCF **1 CNCL LFPTCF LPTCY2 **1 DFT3 QDCFF3 QDCFAL **12 DFT3 QDCFF3 QDCFAL **12 DFT3 QDCFF3 QDCFAL **12 DFT3 QDCFF3 QDCFAL **12 DFT3 QDCFF3 RLDCNY5 **13 DFT3 QDCFF3 RLDCNY5 **13 DFT3 COCNT QDCFAL **10 DFT3 COCNT YPPOCFAL **12 <tr< td=""><th>GNG</th><td>DGN</td><td>KDP</td><td>KGN</td><td>Q.</td><td>Υ^χ</td><td>KOR</td><td>LGN</td><td>LCN</td><td>IL I</td><td>E.</td><td>ð</td><td>ġ</td><td>ORA</td><td>RLC</td><td>RLD</td><td>SPT</td><td>NGN</td><td>VPP</td><td>TAV</td><td>Idn</td></tr<> | GNG | DGN | KDP | KGN | Q. | Υ ^χ | KOR | LGN | LCN | IL I | E. | ð | ġ | ORA | RLC | RLD | SPT | NGN | VPP | TAV | Idn |
| PPWEB AFT DGN
PT DFYCFA DFYCFF
GNZ KGN3 KGN4
GNB KGDCFA1 DFYCFF
GNB KGDCFA1 KGDCFA2
GDF73 KGDCFA1 KGDCFA2
GDF73 KGDCFA1 KGDCH2
GDF73 KGDCFA1 KGDCH2
GNCHF LGNC1A LGNC1F
LGNC1A LGNC1A LGNC1F
LCNC74 LLFYCY2
DF73 QDCFA1 QDCFA2
GDCF73 QDCFA1 QDCFA2
GDCF73 QDCFA1 QDCFA2
GDCF73 GNC1A LLFYCY2
FTCCF
DF73 QDCFA1 QDCFA2
GDCF73 GNC1F LFFYCY2
FTCCF
RDF71 GDCF73 GDCFA2
GDCF73 GNC1F KDPTCL
LDCNY2 RLDCNY3 KLDCNY4
RLDCNY2 RLDCNY3 KLDCNY4
RLDCNY2 RLDCNY3 SBSFT
FTCCY2 VGNC1F VGNCY
FFFDNS VFECLF VGNCY | ATNG | Ţ. | Ŷ | ۳
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| PPWEB APT DGN
PT CFF DGN
GNZ KGN3 KGN3 KGN4
GNB KQDCFAL DPTCFF KGN4
GNB KQDCFAL KQDCFAZ
QDCFF KGN1 KQDCNZ KQDCFAZ
QDCFF KQDCN1 KQDCNZ
GNCH LGNCTA LGNCTZ
LGNCTA LGNCTA LGNCTZ
DFT3 LJJTCUT LPTCF
LJCNCTA LJCNCT2 LPTCF
LJCNCTA LPTCY1 LPTCF
DPT3 QDCTAL QDCFAZ
QDCF73 QDCTAL QDCFAZ
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DDF73 RDGNCLF RDPTCL
LLDCNCZ RLDCNY3 RLDCNY4
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| PPWEB PAT DENCEA
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GDCFF3 KGDCTA LGNC
GDCFF3 LGNCLA LGNC
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LCNCT4 LGNC
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COCF73 QDCFA1 QDCFA
LCNCT4 LLPTCTF LDCVFF LDCV
PTCCFS RLDCV75 SESEP
RLDCV75 RLDCV75 SESEP
PTCC72 VCNCLF VCNC5 VPTC5
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PTCC72 VFTC5 VCNC5
PTCC74 VFTC5 VCNC5
PTCC72 VCNC12 VCNC5 VFTC6
PTCC74 VFTC5 VCNC5
PTCC74 VCNC12 VCNC5 VFTC6
PTCC74 VFTC5 VCNC5
PTC72 VFTC5 VCNC5
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PT Construction
of the construction | | DGN | DPICE | KGN4 | KODCF | KODGN | KQRAI | LCNCI | LGNCY | THE | LOTAL | EDCFA | ODGNE | ORAFI | RPPTC | RLDGN | SBSFI | InddT | VGNCY | VPTCI | VIPTEX |
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FTCCFA
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FTCCFA | | APT | DPICEA | KGN3 | KODCFA | KQDGNI | KORAPI | ICONCLA | LGNCY | LUTICUT | LPTCYJ | OCTAI | CINDON | ORAPTI | RDGNCI | RLDGNY | RLPICI | THETAC | VGNCILE | VPTCF | VPTECI |
| PPMEB
PT
GNZ
GNZ
GNZ
GNZ
GNZ
GNZ
PTCCLF
DCFF3
DPT3
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DPT | | | | | | | | | | | | | | | | | | | | | |
| | | PWEB | E. | SN2 | BNE | DCFF3 | -
Erado | SNCHE | SNCT3 | ISNE | PICES | PTYCLF | DCFF3 | DPT3 | CINCLA | LIDGNY2 | LPTCYA | PTCY2 | SNCLA | SNOLA | PTECFA |

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GRAIN GEOMETRY

GNGM1

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INFLOW

INTERNAL BALLISTICS, FLOW

IBFM1

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MODEL TYPE: IBFLOW (Internal Ballistics, FLOW)

MODEL NAME: IBFM1 (Cylindrical port, slot penalty)

DESCRIPTION:

IBFM1 (Internal Ballistics, Flow Model number 1) evaluates the burn rate and flow characteristics within a cylindrical ported grain to determine the effective slot volume required for a neutral pressure-time history. This required volume (grain length penalty) is sometimes sizable, thereby resulting in a significant degradation of the motor volumetric loading efficiency.

The slot volume requirement is independent of the number of slots and is basically determined by the gas flow requirements from the slots into the center perforate. The calculation of the length of the slots is based upon the following assumptions:

- 1. The grain is cylindrical;
- 2. The port burning surface is cylindrical;
- 3. The gas leaves the slots and enters the center perforate at a Mach number specified by the program user;
- 4. The pressure and temperature within the slot are equal to the pressure and temperature respectively within the center perforate;
- 5. The gas flow upstream of the nozzle throat is isentropic flow of a perfect gas.

In addition to the slot penalty, this model also evaluates the maximum and minimum burn rates. These are available as constraint quantities to insure that the web is not thicker than that allowed by the maximum burn rate and burn time or thinner than that allowed by the minimum burn rate and burn time. The model evaluates a set of associative quantities to facilitate setting up these constraints, if required.

An appreciation for the slot geometry may be gained by referring to Figure 1.

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PROCEDURE:

Prior to entering IBFM1, the models specified by the PROPELW, IBGAS and IBPERF model types have evaluated the propellent density, gas, and performance properties. The model specified by the GRAING model type then determined the geometry required to design a cylindrical ported grain, including accommodation for nozzle submergence.

The IBFM1 model is then executed and the burn rates and grain length penalty for slots is determined.

After executing IBFM1, the model specified by the GRAING model type will be reentered and the preliminary grain design will be corrected to account for the slot volume. The model specified by the INSULG model type may then utilize data from IBFM1 and the grain geometry to assess internal insulation requirements.

EQUATIONS:

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Burn rate at ignition.

$$B_{PP_{IGN}} = \frac{T_{PP_{WEB}}}{T_{B}}$$
(1)

Average burn rate.

$${}^{B}PP_{AVG} = {}^{K}{}_{BPPAVG} {}^{B}PP_{IGN}$$
⁽²⁾

Maximum burn rate.

$${}^{B}PP_{MAX} = {}^{K}BPPMAX {}^{P}{}^{a}AVG$$
(3)

Minimum burn rate.

$${}^{B}PP_{M'N} = {}^{K}BPPMIN {}^{P}{}^{b}AVG$$
(4)

Weight flow rate from port surface, excluding slots.

$${\stackrel{\bullet}{W}}_{PT} = {\stackrel{\rho}{PP}}_{MT} {\stackrel{S}{BS}}_{PT} {\stackrel{B}{PP}}_{AVG}$$
 (5)

INTERNAL BALLISTICS, FLOW

EQUATIONS (Cont.):

IBFLOW

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Weight flow rate required from all slots.

$$\mathbf{\hat{w}}_{SL_{REQ}} = \mathbf{\hat{w}}_{PP_{MT}} - \mathbf{\hat{w}}_{PT}$$
(6)

Area of one burning surface of a slot.

$$A_{BS}SL = A_{PP}WEB$$
(7)

Weight flow rate from a slot (two surfaces).

$$\tilde{W}_{SL} = 2 \rho_{PP_{MT}} A_{BS_{SL}} B_{PP_{AVG}}$$
(8)

Length of a slot.

$$L_{SL} = \frac{\bar{W}_{SL} C_{GAS}}{\pi D_{PT} H P_{AVG} M_{SL} g_{o}}$$
(9)

Number of slots required.

$$N_{SL_{REQ}} = \frac{W_{SL_{REQ}}}{W_{SL}}$$
(10)

Grain length penalty for slots cutouts.

$$L_{SL_{GIN}} = N_{SL_{REQ}} L_{SL}$$
(11)

Associative quantities. The following quantities are intended solely for optional utilization by the program user. Their primary usage within this model is for forming constraint quantities.

$$Q_{BI} = K_{QBI} B_{PP}$$
(12)

$$Q_{BA} = K_{QBA} B_{PP}$$
(13)

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INTERNAL BALLISTICS, FLOW

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EQUATIONS (Cont.):

$$Q_{BMX} = K_{QBMX} B_{PP_{MAX}}$$
(14)

 $Q_{BMN} = K_{QBMN} B_{PP_{MIN}}$

OPTIMIZATION CONSIDERATIONS:

Generally, the nature of the problem which would require usage of this model would also require that the following constraints be set up by the program user.

A maximum propellent burn rate constraint will insure that the propellent web is not too thick. (Note that this constraint corresponds to a lower limit on the port fraction.)

$$B_{PP_{AVG}} \stackrel{\epsilon}{=} B_{PP_{MAX}}$$
(16)

A minimum propellent burn rate constraint will insure that the propellent web is not too thin. (Note that this constraint corresponds to an upper limit on the port fraction.)

$$B_{PP_{AVG}} \ge B_{PP_{MIN}}$$
(17)

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 $L_{1} \rightarrow L_{SL} \rightarrow L_{2} \rightarrow L_{1} \rightarrow L_{SL} \rightarrow L_{2} \rightarrow L_$

Note that $L_1 + L_2 = L$ Where L is the length such that $S_{PT} = \pi L D_{PT}$

Fig. 50, 1-1 Slot Geometry

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INTERNAL BALLISTICS, FLOW

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INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|------------------------------|--|----------|
| EBPPMAX | a | Exponent for maximum radial prop
burn rate computation; | ellent |
| | | N. D. | 0.39 |
| EBPPMIN | Ъ | Exponent for minimum radial prope
burn rate computation; | ellent |
| | | N. D. | 0.27 |
| KBPPAVG | KBPPAVG | Coecient for average radial prop
burn rate computation; | ellent |
| | | N. D. | 1.0 |
| КВРРМАХ | K _{BPPMAX} | Coefficient for maximum radial proburn rate computation; | opellent |
| | | N. D. | 0.054 |
| KBPPMIN | K _{BPPMIN} | Coefficient for minimum radial pro
burn rate computation; | opellent |
| | | N. D. | 0.039 |
| KQBAVG | K _{QBA} | Associative quantity coefficient for QBPPAVG computation; | |
| | | N. D. | 0 |
| KQBIGN | κ _{qbi} | Associative quantity coefficient for QBPPIGN computation; | |
| | | N. D. | U |
| KQBMAX | ^к _{QBMX} | Associative quantity coefficient for QBPPMAX computation; | |
| | | N. D. | 0 |
| KQBMIN | K _{QBMN} | Associative quantity coefficient for QBPPMIN computation; | |
| | | N. D. | 0 |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symuol | Description; Ext. (Int.) Units | Preset |
|----------|-----------------|---|---------------|
| MSLEXT | M _{SL} | Macı. number of combustion pro
exit; | ducts at slot |
| | | N. D. | 0.2 |

INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|--|---|------------|
| APPWEB | A _{PP} web | Cross sectional web area;
in ² | GRAING |
| CGAS | CGAS | Speed of sound in gas;
ft/sec | IBGAS |
| DPT | D _{PT} | Port diameter;
in | GRAING |
| DWPPMT | [♥] _{PP} _{MT} | Propellent weight flow;
lb/sec | IBPERF |
| PCHAVG | PAVG | Average chamber pressure;
PSIA | IBGAS |
| RHOPPMT | ρ _{pp} mt | Propellent density;
lb/in ³ | PROPELW |
| RSPHT | н | Specific heat ratio;
N. D. | IBGAS |
| SBSPT | S _{BS} PT | Port burning surface area;
in ² | GRAING |

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|----------------|--------------------------------|------------|
| TBPPMT | Τ _Β | Propellent burn time; | |
| | D | sec | IBPER F |
| TPPWEB | Tpp | Web thickness; | |
| | 1 WEB | in | GRAING |

OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | |
|----------|---|--|--------------|---------|
| ABSSL | A _{BS} SL | Area of one burning surface of a slo
in ² | t;
Eq. | 7 |
| BPPAVG | B _{PP} AVG | Average radial propellent burn rate;
in/sec | Eq. | 2 |
| BPPIGN | B _{PP} IGN | Radial burn rate of propellent at ign | itio
Eq. | n;
1 |
| BPPMAX | ^B PP _{MAX} | Maximum radial propellent burn rat
in/sec | e;
Eq. | 3 |
| BPFMIN | ^B PP _{MIN} | Minimum radial propellent burn rate
in/sec | e;
Eq. | 4 |
| DWBSNSL | •
^W PT | Propellent weight flow rate from por
area, excluding slots; | rt s | urface |
| DWSLREQ | [●] ^W SL _{REQ} | Propellent weight flow rate required
slots for balanced motor flow; | eq.
l fro | om |
| | | lb/sec | Eq. | 6 |

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
|----------|--------------------------------|---|--|
| DWSL | w _{sl} | Propellent weight flow rate fro surfaces); | m a slot (two |
| | | lb/sec | Eq. 8 |
| LSL | L _{SL} | Length of a slot required for ba
flow; | alanced slot |
| | | in | Eq. 9 |
| LSLGN | | Grain length penalty for slot cu | itouts; |
| | GN | in | Eq. 11 |
| NSLR EQ | ^N SL _{REQ} | Number of slots required for b
flow. NSLREQ will normally b
number. Note the distinction b
NSLREQ and NISIH0, NISIH1,
to the internal insulation mode | palanced motor
be a fractional
between
which is input
l; |
| | | N. D. | Eq. 10 |
| QBPPAVG | Q _{BA} | Associative quantity, average
(see BPPAVG); | burn rate |
| | | in/sec | Eq. 13 |
| QBPPIGN | Q _{BI} | Associative quantity, burn rate
(see BPPIGN); | e at ignition |
| | | in/sec | Eq. 12 |
| QBPPMAX | Q _{BMX} | Associative quantity, max. bu:
(see BPPMAX); | rn rate |
| | | in/sec | Eq. 14 |
| QBPPMIN | Q _{BMN} | Associative quantity, min. bur
(see BPPMIN); | n rate |
| | | in/sec | Eq. 15 |

| KEY: | |
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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| LNTERNAL BALLISTICS, FLOW
BPPATH DMBSNSL
KBFPANG KBFPMAX
KQBATH LSL
GEPPTGN QBPPMAX |
|---|
| IBFNA
BPFNAX
EBPFNAX
KQBMAX
QBPFNVC |
| 1911
1912
1913
1914
1914
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1917
1917 |
| BPFICH
Kupmax
Kopang
NSLRBQ |
| BPPAVG
DMSLRBQ
KQBUCA
NSLLBUT |
| ABSSI.
DMSI.
KBPPMIN
LSICN
QBPMIN |

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MODEL TYPE: IBGAS (Internal Ballistics, GAS)

MODEL NAME: IBGM1 (Constant vacuum thrust)

DESCRIPTION:

IBGM1 (Internal Ballistics Gas Model number 1) evaluates the gas characteristics and chamber pressures associated with a constant vacuum thrust solid rocket motor.

EQUATIONS:

Average chamber pressure.

| PAVG = | KAVG P | (1 | [] |
|--------|--------|----|----|
| AVU | AVU | | |

Maximum expected operating pressure.

$$P_{MEO} = K_{MEO} P$$
(2)

Maximum chamber pressure.

$$P_{MAX} = P_{MEO}$$
(3)

Delivered characteristic velocity.

 $C^* = \xi C^*_{TH} \tag{4}$

Specific heat ratio constants.

$$H_1 = H + 1 \tag{5}$$

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INTERNAL BALLISTICS, GAS

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EQUATIONS (Cont.): $H_{2} = H - 1$ $H_{3} = \frac{H_{1}}{H_{2}}$ $H_{4} = \frac{H_{1}}{H}$ $H_{5} = \frac{H_{2}}{H}$ $H_{6} = \left(\frac{2}{H_{1}}\right)^{H_{3}}$ $H_{7} = \sqrt{\frac{H_{2} H_{6}}{2}}$

$$H_8 = \sqrt{\frac{2 H H_6}{H_5}}$$
 (12)

Gas constant.

$$R_{GAS} = \frac{H H_6 C^{2}}{T_C}$$
(13)

Speed of sound in gas.

$$C_{GAS} = \sqrt{H T_C R_{GAS}}$$
(14)

INTERNAL BALLISTICS, GAS

INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset | |
|--------------------------|------------------|---|---------|--|
| CVTH | C* _{TH} | Theoretical characteristic veloc | city; | |
| | | ft/sec | 0 | |
| KPCHAVG | KAVG | Coefficient, average chamber pr | essure; | |
| | AIG | N. D. | 1 | |
| KPCHMEO K _{MEO} | | Coefficient, maximum expected operating chamber pressure; | | |
| | | N. D. | 1 | |
| KCEF | É | Combustion efficiency factor; | | |
| | | N. D. | 1 | |
| PCH | P | Chamber pressure; | | |
| | | PSIA | 0 | |
| RSPHT | Н | Specific heat ratio; | | |
| | | N. D. | 0 | |
| TCPP | т _с | Propellent combustion temperat | ure; | |
| | v | °R | 0 | |

INPUT DATA, INTER-MODEL:

None

OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | |
|----------|------------------|---|-------------|----|
| CGAS | C _{GAS} | Speed of sound in gas;
ft/sec | Eq. | 14 |
| CVDELV | C* | Delivered characteristic velocity;
ft/sec | Eq. | 4 |
| KRGAS | RGAS | Gas constant;
ft ² /(sec ² - ^o R) | Eq. | 13 |
| PCHAVG | P _{AVG} | Average chamber pressure;
PSIA | Eq. | 1 |
| PCHMAX | PMAX | Maximum chamber pressure;
PSIA | Eq. | 3 |
| PCHMEO | PMEO | Maximum expected operating chan
pressure;
PSIA | nber
Eq. | 2 |
| RSPHTI | H ₁ | Specific heat ratio quantity;
N. D. | Eq. | 5 |
| RSPHT2 | H ₂ | Specific heat ratio quantity;
N. D. | Eq. | 6 |
| RSPHT3 | H ₃ | Specific heat ratio quantity;
N. D. | Eq. | 7 |
| RSPHT4 | H ₄ | Specific heat ratio quantity;
N. D. | Eq. | 8 |
| RSPHT5 | Н ₅ | Specific heat ratio quantity;
N. D. | Eq. | 9 |
| RSPHT6 | н ₆ | Specific heat ratio quantity;
N. D. | Eq. | 10 |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
|----------|----------------|--|--------|
| RSPHT7 | H ₇ | Specific heat ratio quantity;
N. D. | Eq. 11 |
| RSPHT8 | н ₈ | Sp cific heat ratio quantity;
N. D. | Eg. 12 |

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PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| INTERNAL BALLISTICS, GAS
KPCHAVG KPCHMED
FCHMED RSPHT
RSPHT5 RSPHT6 |
|--|
| I BGMI
KCEF
PCHMAX
RSPHT4 |
| 1196AS |
| CVTH
PCHAVG
RSPHT3
TYCPP |
| CVDELV
PCH
RSPHT2
RSPHT2 |
| CGAS
K.AGAS
RSPHTI
RSPHT7 |

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MODEL TYPE: IBPERF (Internal Ballistics, PERFormance)

MODEL NAME: IBPM1 (Conical nozzle divergence losses)

DESCRIPTION:

IBPM1 (Internal Ballistics Performance Model number 1) evaluates the propellent and nozzle dependent vacuum delivered performance quantities. The specific impulse is degraded to account for the nozzle half angle divergence loss (axial direction), due to the directional change of flow as the gas expands in a conical nozzle.

PROCEDURE:

Prior to entering IBPM1, the models specified for the PROPELW and IBGAS model types have evaluated the propellent weight and gas properties.

Upon the first entrance to IBPM1, the propellent weight flow is computed and the model specified by the NOZZLEG model type is executed to determine the nozzle geometry.

IBPM1 is then entered for the second time, the pressure ratio is solved iteratively using Newton's method, and the remainder of the internal ballistics performance dependent quantities are evaluated.

After the IBPM1 computations are completed, the motor geometry and weights are determined, the model specified for the PROPUL model type is executed, and the primary motor propulsion quantities are evaluated.

EQUATIONS (FIRST ENTRANCE):

Propellent weight flow.

$$\mathbf{\hat{w}}_{PP_{MT}} = \frac{\mathbf{w}_{PP_{MT}}}{\mathbf{T}_{B}}$$

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INTERNAL BALLISTICS, PERFORMANCE

EQUATIONS (SECOND ENTRANCE):

Pressure ratio, nozzle exit pressure to chamber pressure. (transcendental equation solved iteratively for R_p)

$$\epsilon_{NZ} = \frac{H_7}{R_P (1/H) \sqrt{1 - R_P^{H_5}}}$$
 (2)

Critical pressure ratio.

$$R_{PC} = \left(\frac{2}{H_1}\right)$$
(3)

Nozzle half angle divergence momentum loss.

$$\lambda = \frac{1 + \cos\left(\theta_{\rm NZ}\right)}{2} \tag{4}$$

Reference nozzle half angle loss.

$$\lambda_{\rm R} = \frac{1 + \cos\left(\theta_{\rm R}\right)}{2} \tag{5}$$

Vacuum thrust coefficient,

$$C_{V} = \lambda H_{8} \sqrt{1 - R_{P}^{H_{5}}} + \epsilon_{NZ} R_{P}$$
 (6)

Reference thrust coefficient (exit pressure = atmospheric pressure).

$$C_{R} = \lambda_{R} H_{8} \sqrt{1 - C_{1}^{H_{5}}}$$
(7)

Vacuum specific impulse.

$$I_{SP_{V}} = \begin{pmatrix} C_{V} \\ C_{R} \end{pmatrix} \quad I_{SP_{R}}$$
(8)

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IBPERF INTERNAL BALLISTICS, PERFORMANCE IF

EQUATIONS (SECOND ENTRANCE) (Cont.):

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Delivered vacuum specific impulse.

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$$I_{SP_{VD}} = K_{VD} I_{SP_{V}}$$

INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|------------------------------|---|----------|
| CIBPI | ci | Ratio of a reference nozzle exit pressure to
a reference chamber pressure. The
reference nozzle exit pressure must be equa-
to sea level pressure; | |
| | | N. D. | 0.014696 |
| ISPR | ^I SP _R | Specific impulse for the reference p
ratio CIBP1 and the reference nozzl
angle NZHAR; | |
| | | sec | 0 |
| KISPVD | к _{vd} | Nozzle efficiency factor; | |
| | | N. D. | 1 |
| NZHAR | θ_{R} | Reference nozzle half angle; | |
| | | deg | 0 |
| TBPPMT | Т _В | Propellent burn time; | |
| | - | sec | 0 |

INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

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INTERNAL BALLISTICS, PERFORMANCE

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Model Type |
|----------|-------------------|--|------------------|
| COSNZHA | cos θ
NZ | Cosine of nozzle half angle;
N. D. | NOZZLEG |
| RAEXTTH | "NZ | Nozzle expansion ratio at exit pl
N. D. | lane;
NOZZLEG |
| RSPHT | н | Specific heat ratio;
N. D. | IBGAS |
| RSPHT1 | H ₁ | Specific heat ratio quantity;
N. D. | IBGAS |
| RSPHT2 | H ₂ | Specific heat ratio quantity;
N. D. | IBGAS |
| RSPHT5 | н ₅ | Specific heat ratio quantity;
N. D. | IBGAS |
| RSPHT7 | H ₇ | Specific heat ratio quantity;
N. D. | IBGAS |
| RSPHT8 | н ₈ | Specific heat ratio quantity;
N. D. | IBGAS |
| WPPMT | w _{ppmt} | Propellent weight;
1b | PROPELW |

OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
|----------|--------|--------------------------------|-------|
| CFVAC | cv | Vacuum thrust coefficient; | |
| | · | N. D. | Ea. 6 |

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OUT PUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Un | its | |
|----------|-----------------|--|----------------------|--|
| CFR | с _R | Reference thrust coefficient correspon
the reference nozzle half angle NZHAR
the reference pressure ratio CIBP1.
reference nozzle exit pressure is sea
pressure; | | |
| | | N. D. | Eq. 7 | |
| DWPPMT | W.D.D. | Propellent weight flow; | | |
| | MT | lb/sec | Eq. 1 | |
| ISPVC | Isp | Vacuum specific impulse; | | |
| | V-V | sec | Eq. 8 | |
| ISPVD | ISP | Delivered vacuum specific impulse; | | |
| | UT VD | sec | Eq. 9 | |
| NZHAL | λ | Nozzle half angle loss; | | |
| | | N. D. | Eq. 4 | |
| NZHALR | λ _R | Reference nozzle half angle loss; | | |
| | | N. D. | Eq. 5 | |
| RPEPC | ^R P | Pressure ratio. Ratio of r
pressure to chamber press | nozzle exit
sure; | |
| | | N. D. | Eq. 2 | |
| RPEPCC | R _{PC} | Critical pressure ratio. F
at nozzle throat; | Pressure ratio | |
| | | N. D. | Eq. 3 | |

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PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

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ISPVC
RPEPC |
| INTERNAL
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NZHAR |
| I BPMI
DWPPMI
NZHALR |
| IBPERF
+ 1
+ 2
- 3
- 3 |
| CTBP1
NZHAL |
| CFVAC
KISPVD
TBPPMT |
| CFR
ISPVD
RPEPCC |

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MODEL TYPE: INSULG (internal INSULation Geometry)

MODEL NAME: INGM1 (geometric parameter)

DESCRIPTION:

INGM1 (internal INsulation Geometry Model number 1) evaluates the internal insulation geometry for a solid rocket motor case and propellent grain having a cylindrical section and oblate closures. The basic components may include:

insulation liner

ellipsoidal insulation wedges for the forward and aft closures

insulation required for unjointed grain designs

insulation required for jointed grain designs

The model includes provision for circular cutouts, "holes" in the forward and aft closures, required for the igniter and nozzle. See figures 1 and 2 for an illustration of the basic insulation components and the interface with the case, grain, nozzle, and igniter geometry. Whenever possible, the equations have been formulated such that the geometry for the basic components degenerate to basic geometric forms. In addition, user specified coefficient and bias terms (preset to nominal values) are provided for the principal independent quantities associated with each basic geometric form. Consequently, the actual insulation geometry capable of being simulated is to a large degree a function of the ingenuity of the program user.

The insulation liner, as illustrated in figures 3 - 6, interfaces between the inside case surface and the outside wedge surfaces or grain envelope. Within the cylindrical case section, the liner has constant thickness. Within the closures, the outside and inside liner surfaces are hemi-ellipsoids whose equatorial planes are coincident with the plane separating the closure and cylindrical sections. The liner holes in the forward and aft closures are cylindrical, centered on the axis of revolution of the liner surface hemi-ellipsoids. The principle purposes of the liner geometry are to determine a total volume for insulation weight computations and to specify the head ratios and cylindrical diameter of the basic grain envelope.

INTERNAL INSULATION GEOMETRY

INGM1

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DESCRIPTION (Cont.):

The insulation wedges (see figures 7 - 14) are associated with the forward and aft closures and interface between the insulation liner and the grain. The wedges may be completely within a closure, or may extend beyond a closure into the cylindrical section. Since the principle purpose of the wedge geometry is to determine an effective volume for weight evaluations, no corrective action, except for a warning diagnostic, is taken by the program if a wedge extends from within a closure beyond the cylindrical section.

If a wedge is completely within the closure (see figures 7, 13), the inside and outside wedge surfaces are hemi-ellipsoid frustums which are tangent at their bases (the "inside/outside wedge surface osculation plane"). The axis of revolution of these frustums are coincident and the equatorial plane of the hemi-ellipsoid associated with the outside frustum surface is coincident with the plane separating the case closure and case cylindrical sections. However, the "equatorial plane of the hemi-ellipsoid associated with the inside frustum surface" and the "inside/outside wedge surface osculating plane" are normally not coincident with each other or the "plane separating the case closure and case cylindrical sections".

If a wedge extends beyond a closure into the cylindrical section (see figures 9, 14), the outside wedge surface is comprised of a hemi-ellipsoid and a cylinder. The inside wedge surface is a hemi-ellipsoid tangent to the cylindrical portion of the outside wedge surface (the "inside/outside wedge surface osculation plane"). The axis of revolution of the inside and outside wedge surfaces are coincident and the "equatorial plane of the inside surface ellipsoid" is coincident with the "inside/outside wedge surface osculation plane". Further, the "equatorial plane of the hemi-ellipsoid associated with the outside wedge surface" is coincident with the "plane separating the case closure and case cylindrical section". However, normally the equatorial planes of the hemi-ellipsoids associated with the outside wedge surface and the inside wedge surface are not coincident.

The length of the forward closure wedge (figures 7, 9) is normally a function of the propellent web thickness. The igniter cutout is cylindrical, centered on the axis of revolution of the wedge surface hemi-ellipsoids.

The length of the aft closure wedge (figures 11, 13) is normally a function the cone frustum grain cutout half angle. The nozzle cutout is a cone frust having a half angle equal to the cone frustum grain cutout half angle.

For the purpose of this model, a slot has none or one burning surface inhibited, whereas a joint has both burning surfaces inhibited. The slot and joint insulation, as illustrated in figures 15 - 20, is comprised of the following components: ÿ

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DESCRIPTION (Cont.):

Port/Liner (PL) component. This component interfaces between the port and the liner. It has a rectangular cross section and its dimensions are normally a function of the maximum insulation thickness and the slot or joint length.

Port/Grain (PG) component. This component, which inhibits a burning surface, interfaces between the port and the grain. It normally has a trapezoid cross section (although it may be a pentagon, rectangle or triangle--see figures 16, 17) and its dimensions are primarily a function of the maximum insulation thickness, propellent web thickness, and a user specified base length. It should be noted that for joints, provision is made for "overlapping" PG components. However, for slots, except for a warning diagnostic, no corrective action is taken by the program if the PG component exceeds the slot cutout length.

Grain/Liner (GL) component. This component interfaces between the grain and the liner. It has a triangular cross section and its dimensions are normally a function of the maximum insulation thickness and the propellent web thickness. The GL component is associated with each non-inhibited slot burning surface.

The number of slots and joints, for insulation purposes, is specified by the program user and should not be a fractional number. The purpose of the slot and joint geometry is to determine an effective volume for insulation weight computations.

PROCEDURE:

INGM1 is a three-entrance model. Inter-model coupling is illustrated by figure 22.

Prior to the first entrance to INGM1, the models specified for the IBGAS, IBPERF, INSULW, and CASEG model types have evaulated the gas characteristics, insulation density and case geometry.

Upon the first entrance to INGM1, the basic insulation material properties are evaluated and, except for the length of the cylindrical section, the insulation liner geometry is determined.

The grain geometry model, GNGM1, then uses the inside liner surface to define the basic grain envelope. After adjusting the basic grain to account for submerged nozzle, slot, and joint penalties, program control is returned to INGM1.

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INGM1

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PROCEDURE (Cont.):

Upon the second entrance to INGM1, the insulation wedge geometry, associated with the forward and aft closures, is evaluated, the slot and joint geometry is determined, and the propellent displaced by the closure wedges and the slot/joint insulation components is computed.

The grain geometry model, GNGM1, is then reentered, the cylindrical grain length is adjusted to include the propellent displaced by the insulation, and the total grain geometry is evaluated.

Upon the third entrance to INGM1, the grain geometry has been completely determined and the cylindrical section of the liner is sized. After evaluating the residual insulation volume, the total internal insulation volume is computed.

After executing INGM1, the program evaluates the remaining substage geometry. The model specified by the INSULW model type then uses the volumes obtained in INGM1 as effective volumes to determine the internal insulation weight breakdown.

REFERENCES:

Reference 52, "Some Useful Theorems Associated With Hemi-Ellipsoids" is the basis for the derivations of the following equations:

11, 17, 19, 20, 23, 25, 26, 28, 36, 42, 44, 45, 47, 50, 51, 53, 68, 81, 85, 87, 88, 89, 92, 94, 96, 78, 100, 101, 104, 115, 131, 135, 137, 138, 140, 142, 144, 146, 147, 160.

Reference 54, "Some Useful Theorems Associated With Osculating Ellipses" contains the derivations for the following equations:

74, 75, 76, 126, 127, 128.

Reference 55, "Derivation of LIWCFI and DIWCAI for the GTS INGM1 Internal Insulation Model" contains the derivations and assumptions for the following equations:

107a, 107b, 107c, 107d, 107e, 117, 120, 121, 122, 123, 124.

Reference 56, "PG Internal Insulation Subcomponent for GTS INGM1 Internal Insulation Model" contains the derivations and rationale for equations 156 through 210.

Reference 57, "Derivation of VIWCAPD and VIWCFPD for the GTS DNGM1 Internal Insulation Model" contains the derivations and assumptions for equations 211 through 222.

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INTERNAL INSULATION GEOMETRY

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NOTATION:

The following notation convention is used within this model whenever possible.

First Character

- Plane area. (in^2) А
- С Constant or intermediate quantity.
- D Diameter (measured normal to centerline). (in)
- Κ Coefficient or bias.
- L Length (measured parallel to centerline). (in)
- R Ratio. Next characters will be D or L to indicate diameter or length ratios. (N.D.)
- Т Thickness. (in)
- v
- Volume. (in³) Centroid. (in) Y

Next two characters denote principal insulation component.

- Liner. IL
- IJ Joint.
- IN General.
- IS Slot.
- IW Wedge.

Next characters.

Aft. Α

- C or CL Closure.
- Closure Hole. CH
- Ε Ellipsoid.
- F Forward.
- H Hole.
- Propellent Displaced. PD

Final character.

Ι Inside surface.

THE R. LAND THE REAL STREET & TO BE STORE AND A DESCRIPTION OF A DESCRIPTI

0 Outside surface.

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INTERNAL INSULATION GEOMETRY

EQUATIONS, FIRST ENTRANCE:

Equations 1 through 56 are evaluated at the first entrance to the INGM1 model.

INSULATION PROPERTIES:

Approximate radiative heating rate.

$$Q_{IN_{H}} = C_{JN_{1}} \left(\frac{T_{C_{PP}}}{C_{IN_{2}}} \right)^{4} K_{IN_{1}} + K_{IN_{2}}$$
(1)

Maximum insulation thickness for closure wedges. (See equations 61, 108)

$$T_{IW_{MAX}} = \left(\frac{C_{IN_{3}} T_{B} Q_{IN_{H}}}{Q_{IN}^{*} \rho_{IW}}\right) K_{IW_{23}} + K_{IW_{24}}$$
(2-a)

Maximum insulation thickness for a slot cutout. (Figure 16)

$$T_{IS_{MAX}} = \left(\frac{C_{IN_3} T_B Q_{IN_H}}{Q_{IN}^* \rho_{IS}}\right) K_{IS_1} + K_{IS_2}$$
(2-b)

Maximum insulation thickness for a joint cutout. (Figure 17)

$$T_{IJ_{MAX}} = \begin{pmatrix} C_{IN_3} & T_B & Q_{IN_H} \\ \hline Q_{IN}^* & \rho_{IJ} \end{pmatrix} K_{IJ_1} + K_{IJ_2}$$
(2-c)

INSULATION LINER, CYLINDRICAL SECTION:

Outside diameter of the cylinder which is the outside surface of the insulation liner in the cylindrical case section. (Figure 2)

$$D_{IL_{O}} = D_{CS_{I}}$$
(3)

Inside diameter of the cylinder which is the inside surface of the insulation liner in the cylindrical case section. (Figure 2)

$$D_{IL_{\overline{I}}} = D_{IL_{O}} - 2 T_{IL_{CY}}$$
(4)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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INSULATION LINER, CLOSURE SECTIONS (FORWARD AND AFT):

Equatorial diameter of the ellipsoids formed by the outside surface of the insulation liner associated with the forward and aft case closure sections. (Figures 2, 3, 5)

$$D_{IL}CLO = D_{IL}O$$
(5)

Equatorial diameter of the ellipsoids formed by the inside surface of the insulation liner associated with the forward and aft case closure sections. (Figures 2, 3, 5)

$$D_{IL} = D_{IL}$$
(6)

INSULATION LINER, FORWARD CLOSURE SECTION:

Head ratio of the ellipsoid formed by the outside surface of the insulation liner within the forward case closure section.

$$^{R}DILCFO = ^{R}DCSCFI$$
(7)

Length of the axis of revolution of the hemi-ellipsoid formed by the outside surface of the insulation liner within the forward case closure section. (Figures 3, 4)

$$L_{IL}CLFO = \frac{R_{DILCFO} D_{IL}CLO}{2}$$
(8)

Diameter of circular hole, for the igniter, centered on the axis of revolution of the hemi-ellipsoid formed by the outside surface of the insulation liner within the forward case closure section. (Figures 2, 3)

$$D_{IL}_{HFO} = D_{CS}_{HFI} K_{IL}_{17} + K_{IL}_{18}$$
(9)

Diameter ratio, hole diameter to equatorial diameter, outside surface of the insulation liner within the forward case closure section. (Figure 3)

$$R_{\text{DILHFO}} = \frac{D_{\text{IL}_{\text{HFO}}}}{D_{\text{IL}_{\text{CLO}}}}$$
(10)

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INTERNAL INSULATION GEOMETRY

EQUATIONS, FIRST ENTRANCE (Cont.):

INSULATION LINER, FOR WARD CLOSURE SECTION (Cont.):

Length of hemi-ellipsoid frustum associated with the outside surface of the insulation liner within the forward closure section. (Figure 3)

$$L_{IL_{CHFO}} = L_{IL_{CLFO}} \sqrt{1 - R_{DILHFO}^2}$$
(11)

Thickness of insulation liner at center of forward case closure section. Distance between inside and outside hemi-ellipsoid surfaces of the insulation liner, measured on the axis of revolution. (Figure 3)

$$T_{IL_{CLF}} = T_{IL_{CY}} K_{IL_1} * K_{IL_2}$$
(12)

Length of the axis of revolution of the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section. (Figure 3)

$$L_{IL_{CLFI}} = L_{IL_{CLFO}} - T_{IL_{CLF}}$$
(13)

Head ratio of the ellipsoid formed by the inside surface of the insulation liner within the forward case closure section.

$$R_{\text{DILCFI}} = \frac{\frac{2 L_{\text{IL}}}{D_{\text{IL}}}}{D_{\text{IL}}}$$
(14)

Diameter of circular hole, for the igniter, centered on the axis of revolution of the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section. (Figure 3)

$$D_{IL} = D_{IL}$$
(15)

Diameter ratio, hole diameter to equatorial diameter, inside surface of the insulation liner within the forward case closure section. (Figure 3)

$$R_{\text{DILHFI}} = \frac{D_{\text{IL}}}{D_{\text{IL}}}$$
(16)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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INSULATION LINER, FORWARD CLOSURE SECTION (Cont.):

Length of hemi-ellipsoidal frustum associated with the inside surface of the insulation liner within the forward case closure. (Figure 3)

$$L_{\rm IL_{CHFI}} = L_{\rm IL_{CLFI}} \sqrt{1 - R^2_{\rm DILHFI}}$$
(17)

Length of the cylindrical hole, for the igniter, in the insulation liner within the forward case closure section. (Figure 3)

$$L_{\rm IL}_{\rm HF} = L_{\rm IL}_{\rm CHFO} - L_{\rm IL}_{\rm CHFI}$$
(18)

Volume of the hemi-ellipsoid formed by the outside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL_{CLFO}} = \left(\frac{\pi}{6}\right) L_{IL_{CLFO}} D_{IL_{CLO}}^2$$
(19)

Volume of the cylindrical section, associated with the igniter hole, within the hemi-ellipsoid formed by the outside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL_{HFOC}} = \left(\frac{\pi}{4}\right) L_{IL_{CHFO}} D_{IL_{HFO}}^{2}$$
(20)

Length ratio, hemi-ellipsoid frustum to hemi-ellipsoid, outside surface, insulation liner, forward case closure. (Figure 3)

$$R_{\text{LILCFO}} = \frac{L_{\text{IL}}}{L_{\text{IL}}}$$
(21)

Volume of ellipsoidal cap at forward base of the cylindrical section, associated with the ignitor cutout, within the hemi-ellipsoid formed by the outside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL}_{HFOE} = \left(\frac{V_{IL}_{CLFO}}{2}\right) \left(2 - 3R_{LILCFO} + R_{LILCFO}^{3}\right)$$
(22)

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INSULG INTERNAL INSULATION GEOMETRY

EQUATIONS, FIRST ENTRANCE (Cont.):

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INSULATION LINER, FORWARD CLOSURE SECTION (Cont.):

Volume of cylinder with ellipsoidal cap, associated with the igniter cutout, within the hemi-ellipsoid formed by the outside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL} = V_{IL} + V_{IL}$$
(23)

Volume of hemi-ellipsoid frustum with hole cutout associated with the outside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL} = V_{IL} - V_{IL}$$
(24)

Volume of the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL_{CLFI}} = \left(\frac{\pi}{6}\right) L_{IL_{CLFI}} D_{IL_{CLI}}^2$$
(25)

Volume of the cylindrical section, associated with the igniter hole, within the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL} = \left(\frac{\pi}{4}\right) L_{IL} D_{II}^{2}$$
(26)

Length ratio, hemi-ellipsoid frustum to hemi-ellipsoid, inside surface, insulation liner, forward case closure. (Figure 3)

$$R_{\text{LILCFI}} = \frac{L_{\text{IL}_{\text{CHFI}}}}{L_{\text{IL}_{\text{CLFI}}}}$$
(27)

Volume of ellipsoidal cap at forward base of the cylindrical section, associated with the igniter cutout, within the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL_{HFIE}} = \left(\frac{V_{IL_{CLFI}}}{2}\right) \left(2 - 3 R_{LILCFI} + R_{LILCFI}^{3}\right)$$
(28)

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EQUATIONS, FIRST ENTRANCE (Cont.);

INSULATION LINER, FORWARD CLOSURE SECTION (Cont.):

Volume of cylinder with ellipsoidal cap, associated with the igniter cutout, within the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL} = V_{IL} + V_{IL}$$
(29)

Volume of hemi-ellipsoid frustum with hole cutout associated with the inside surface of the insulation liner within the forward case closure section. (Figure 4)

$$V_{IL_{CHFI}} = V_{IL_{CLFI}} - V_{IL_{HFI}}$$
(30)

Volume of insulation liner within the forward case closure section. (Figure 4)

$$\mathbf{v}_{\mathrm{IL}_{\mathrm{CLF}}} = \left(\mathbf{v}_{\mathrm{IL}_{\mathrm{CHFO}}} - \mathbf{v}_{\mathrm{IL}_{\mathrm{CHFI}}}\right) \mathbf{K}_{\mathrm{IL}_{3}} + \mathbf{K}_{\mathrm{IL}_{4}}$$
(31)

INSULATION LINER, AFT CLOSURE SECTION:

Head ratio of the ellipsoid formed by the outside surface of the insulation liner within the aft case closure section.

$$R_{\text{DILCAO}} = R_{\text{DCSCAI}}$$

Length of the axis of revolution of the hemi-cllipsoid formed by the outside surface of the insulation liner within the aft case closure section. (Figures 5, 6)

$$L_{\rm IL_{CLAO}} = \frac{R_{\rm DILCAO} - D_{\rm IL_{CLO}}}{2}$$
(33)

Diameter of circular hole, for the nozzle, centered on the axis of revolution of the hemi-ellipsoid formed by the outside surface of the insulation liner within the aft case closure section. (Figure 5)

$$D_{IL} = D_{CS} K_{IL_5} + K_{IL_6}$$
(34)

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(32)

INTERNAL INSULATION GEOMETRY

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EQUATIONS, FIRST ENTRANCE (Cont.):

INSULATION LINER, AFT CLOSURE SECTION (Cont.):

Diameter ratio, hole diameter to equatorial diameter, outside surface of the insulation liner within the aft case closure section. (Figure 5)

$$R_{\text{DILHAO}} = \frac{D_{\text{IL}}}{D_{\text{IL}}}$$
(35)

Length of hemi-ellipsoidal frustum associated with the outside surface of the insulation liner within the aft case closure section. (Figure 5)

$$L_{\rm IL_{CHAO}} = L_{\rm IL_{CLAO}} \sqrt{1 - R_{\rm DILHAO}^2}$$
(36)

Thickness of insulation liner at center of aft case closure section. Distance between the inside and outside hemi-ellipsoid surfaces of the insulation liner, measured on the axis of revolution. (Figure 5)

$$T_{IL_{CLA}} = T_{IL_{CY}} \kappa_{IL_7} + \kappa_{IL_8}$$
(37)

Length of the axis of revolution of the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case closure section. (Figure 5)

$$L_{IL_{CLAI}} = L_{IL_{CLAO}} - T_{IL_{CLA}}$$
(38)

Head ratio of the ellipsoid formed by the inside surface of the insulation liner within the aft case closure section. (Figure 5)

$$R_{\text{DILCAI}} = \frac{\frac{2 L_{\text{IL}} C LAI}{D_{\text{IL}} C LI}}$$
(39)

Diameter of circular hole, for the nozzle, centered on the axis of revolution of the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case closure section. (Figures 2, 5)

$$D_{IL_{HAI}} = D_{IL_{HAO}}$$
(40)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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INSULATION LINER, AFT CLOSURE SECTION (Cont.):

Diameter ratio, hole diameter to equatorial diameter inside surface of the insulation liner within the aft case closure section. (Figure 5)

$$R_{\text{DILHAI}} = \frac{D_{\text{IL}}}{D_{\text{IL}}}$$
(41)

Length of hemi-ellipsoidal frustum associated with the inside surface of the insulation liner within the aft case closure. (Figure 5)

$$L_{IL}_{CHAI} = L_{IL}_{CLAI} \sqrt{1 - R_{DILHAI}^2}$$
(42)

Length of cylindrical hole, for the nozzle, in the insulation liner within the aft case closure section. (Figure 5)

$$L_{1L} = L_{1L} - L_{1L}$$
(43)

Volume of the hemi-ellipsoid formed by the outside surface of the insulation liner within the aft case closure section. (Figure 6)

$$\mathbf{v}_{\mathrm{IL}_{\mathrm{CLAO}}} = \left(\frac{\pi}{6}\right) \quad \mathbf{L}_{\mathrm{IL}_{\mathrm{CLAO}}} \quad \mathbf{D}_{\mathrm{IL}_{\mathrm{CLO}}}^{2} \tag{44}$$

Volume of the cylindrical section associated with the nozzle cutout, within the hemi-ellipsoid formed by the outside surface of the insulation liner within the aft case closure section. (Figure 6)

$$\mathbf{v}_{\mathrm{IL}_{\mathrm{HAOC}}} = \begin{pmatrix} -\frac{\pi}{4} \end{pmatrix} \mathbf{L}_{\mathrm{IL}_{\mathrm{CHAO}}} \mathbf{D}_{\mathrm{IL}_{\mathrm{HAO}}}^{2}$$
(45)

Length ratio, hemi-ellipsoid frustum to hemi-ellipsoid, outside surface, insulation liner, aft case closure. (Figure 5)

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$$R_{\text{LILCAO}} = \frac{L_{\text{IL}}^{\text{LIL}} CHAO}{L_{\text{IL}}^{\text{LL}} CLAO}$$
(46)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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INSULATION LINER, AFT CLOSURE SECTION (Cont.):

Volume of ellipsoidal cap at aft base of the cylindrical section, associated with the nozzle cutout, within the hemi-ellipsoid formed by the outside surface of the insulation liner within the aft case closure section. (Figure 6)

$$V_{IL}_{HAOE} = \left(\frac{V_{IL}_{CLAO}}{2}\right) \left(2 - 3 R_{LILCAO} + R_{LILCAO}^{3}\right)$$
(47)

Volume of cylinder with ellipsoidal cap, associated with the nozzle cutout, within the hemi-ellipsoid formed by the outside surface of the insulation liner within the aft closure section. (Figure 6)

$$V_{IL}_{HAO} = V_{IL}_{HAOE} + V_{IL}_{HAOC}$$
(48)

Volume of the hemi-ellipsoid frustum with hole cutout associated with the outside surface of the insulation liner within the aft case closure section. (Figure 6)

$$V_{IL}_{CHAO} = V_{IL}_{CLAO} - V_{IL}_{HAO}$$
(49)

Volume of the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case closure section. (Figure 6)

$$\mathbf{v}_{\mathrm{IL}_{\mathrm{CLAI}}} = \left(\frac{\pi}{6}\right) \ \mathbf{L}_{\mathrm{IL}_{\mathrm{CLAI}}} \ \mathbf{D}_{\mathrm{IL}_{\mathrm{CLI}}}^{2} \tag{50}$$

Volume of the cylindrical section, associated with the nozzle cutout, within the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case closure section. (Figure 6)

$$V_{IL}_{HAIC} = \left(\frac{\pi}{4}\right) L_{IL}_{CHAI} D_{IL}^{2}_{HAI}$$
(51)

Length ratio, hemi-ellipsoid frustum to hemi-ellipsoid, inside surface, insulation liner, aft case closure. (Figure 5)

$$R_{LILCAI} = \frac{L_{IL}CHAI}{L_{IL}CLAI}$$
(52)

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EQUATIONS, FIRST ENTRANCE (Cont.):

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INSULATION LINER, AFT CLOSURE SECTION (Cont.):

Volume of ellipsoidal cap at aft base of the cylindrical section, associated with the nozzle cutout, within the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case closure section. (Figure 6)

$$V_{IL_{HAIE}} = \left(\frac{V_{IL_{CLAI}}}{2}\right) \left(2 - 3R_{LILCAI} + R_{LILCAI}^{3}\right)$$
(53)

Volume of cylinder with ellipsoidal cap, associated with the nozzle cutout, within the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case section. (Figure 6)

$$V_{IL} = V_{IL} + V_{IL}$$
(54)

Volume of hemi-ellipsoid frustum with hole cutout associated with the inside surface of the insulation liner within the forward closure section. (Figure 6)

$$V_{IL} = V_{IL} - V_{IL}$$
(55)

Volume of insulation liner within the aft case closure section. (Figure 6)

$$\mathbf{V}_{\mathrm{IL}_{\mathrm{CLA}}} = \left(\mathbf{V}_{\mathrm{IL}_{\mathrm{CHAO}}} - \mathbf{V}_{\mathrm{IL}_{\mathrm{CHAI}}} \right) \mathbf{K}_{\mathrm{IL}_{9}} + \mathbf{K}_{\mathrm{IL}_{10}}$$
(56)

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INTERNAL INSULATION GEOMETRY

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EQUATIONS, SECOND ENTRANCE:

Equations 60 through 225 are evaluated at the second entrance to the INGM1 model.

INSULATION WEDGE, FORWARD AND AFT CLOSURE:

Equatorial diameter of the hemi-ellipsoids formed by the outside surface of the insulation wedges associated with the forward and aft closure sections. (Figures 7, 9, 11, 13)

 $D_{IW_{CLO}} = D_{IL_{CLI}}$ (60)

INSULATION WEDGE, FORWARD CLOSURE:

Maximum thickness of the insulation wedge associated with the forward closure. Measured parallel to the motor centerline.

$$T_{IW} = T_{IW} K_{IW} + K_{IW}$$
(61)

Diameter of the circular hole, for the igniter, centered on the axis of revolution of the hemi-ellipsoid formed by the outside surface of the insulation wedge associated with the forward case closure section. (Figures 7, 9)

$$D_{IW}_{HFO} = D_{IL}_{HFI} K_{IW_1} + K_{IW_2}$$
(62)

Diameter of the circular hole, for the igniter, centered on the axis of revolution of the hemi-ellipsoid formed by the inside surface of the insulation wedge associated with the forward case closure section. (Figures 7, 9)

$$D_{IW} = D_{IW}$$
(63)

Length of the cylindrical hole, for the igniter, within the insulation wedge of the forward case closure section. (Figures 7, 9)

$$L_{IW}_{HF} = T_{IW}_{FMAX} K_{IW_3} + K_{IW_4}$$
(64)

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, FOR WARD CLOSURE (Cont.):

Head ratio of the ellipsoid associated with the outside surface of the insulation wedge within the forward closure section.

$$R_{\text{DIWCFO}} = R_{\text{DILCFI}}$$
(65)

Length of the axis of revolution of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward closure section. (Figures 7, 9)

$$L_{IW_{CLFO}} = \frac{R_{DIWCFO} D_{IW_{CLO}}}{2}$$
(66)

Diameter ratic, hole diameter to equatorial diameter, outside surface of the insulation wedge in the forward case closure section. (Figures 7, 9)

$$R_{DIWHFO} = \frac{D_{IW}_{HFO}}{D_{IW}_{CLO}}$$
(67)

Length of the hemi-ellipsoid frustum associated with the outside surface of the insulation wedge in the forward case closure section. (Figures 7, 9)

$$L_{IW_{CHFO}} = L_{IW_{CLFO}} \sqrt{1 - R^2_{DIWHFO}}$$
(68)

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward closure to the inside base of the cylindrical hole cutout for the igniter within the insulation wedge in the forward closure. (Figures 7, 9)

$$L_{IW_{CHFI}} = L_{IW_{CHFO}} - L_{IW_{HF}}$$
(69)

Distance from the inside/outside wedge surface osculation plane to the inside base of the cylindrical hole cutout for the igniter. Note that the "inside/outside wedge surface osculation plane" may be within the forward case closure section or within the cylindrical case closure section. For the former case (see Figure 7), it is defined by the circle of osculation formed by the tangency points of the inside wedge surface hemi-ellipsoid and the outside wedge surface hemiellipsoid section. For the latter case (see Figure 9), it is defined by the circle of osculation formed by the tangency points of the inside wedge surface hemiellipsoid and the outside wedge surface cylindrical section. Note that the proportionality constant, K_{LIWFII} must be determined by the user.

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INTERNAL INSULATION GEOMETRY

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EQUATIONS, SECOND ENTRANCE (Cont.):

$\frac{\text{INSULATION WEDGE, FORWARD CLOSURE (Cont.):}}{L_{\text{IW}_{\text{HFI}}} = T_{\text{PP}_{\text{WEB}}} K_{\text{LIWFI1}} + K_{\text{LIWFI2}}}$ (70)

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure to the "inside/outside wedge surface osculation plane." Note that the insulation wedge is not completely within the forward closure section if L_{IW}_{CFI} is negative. (Figures 7, 9)

$$L_{IW_{CFI}} = L_{IW_{CHFI}} - L_{IW_{HFI}}$$
(71)

IWINFCL (Insulation Wedge IN Forward CLosure) is a logical variable which specifies if the insulation wedge associated with the forward closure is completely within the forward closure.

IWINFCL = .TRUE., wedge is completely within the forward closure. See Figure 7.
IWINFCL = .FALSE., wedge extends beyond the forward closure into the cylindrical section or extends to the intersection of the aft closure and cylindrical section. See Figure 9.

INSULATION WEDGE, COMPLETELY WITHIN FORWARD CLOSURE (IWINFCL = .TRUE.):

Equations 73 - 76 are evaluated if IWINFCL = . TRUE. (i.e., $L_{IW} > 0$) as illustrated in Figure 7.

Diameter of the circle of osculation formed by the tangency points of the inside wedge surface hemi-ellipsoid and the outside wedge surface hemi-ellipsoid (Figure 7). See equation 77 for an alternate expression.

$$D_{IW}_{CFI} = \frac{2 \sqrt{\frac{1}{1}W_{CLFO} - \frac{1}{1}W_{CFI}}}{R_{DIWCFO}}$$
(73)

EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, COMPLETELY WITHIN FORWARD CLOSURE

(IWINFCL = . TRUE.)(Cont.):

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Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward closure to the equatorial plane of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure. (Figure 7) See equation 78 for an alternate expression. (74)

$$L_{IW_{CFI}} = \frac{-L_{IW_{CFI}} \left[4 \left(L_{IW_{CFI}}^{2} - L_{IW_{CHFI}}^{2} \right)^{+ R} D_{IWCFO} \left(D_{IW_{CFI}}^{2} - D_{IW_{HFI}}^{2} \right) \right]}{8 L_{IW_{CFI}} L_{IW_{HFI}} - R_{DIWCFO} \left(D_{IW_{CFI}}^{2} - D_{IW_{HFI}}^{2} \right)}$$

Length of the axis of revolution of the hemi ellipsoid associated with the inside surface of the insulation wedge in the forward case closure. (Figure 7) See equation 81 for an alternate expression. (75)



Equatorial diameter of hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure. (Figure 7) See equation 79 for an alternate expression.

$$D_{IW_{EFI}} = \frac{\frac{2 L_{IW_{EFI}}}{R_{DIWCFO}}}{\sqrt{\frac{L_{IW_{CFI}}}{\frac{L_{IW_{C$$

Equations 77 - 81 are evaluated if IWINFCL = .FALSE. (i.e., $L_{IW} \leq 0$) as illustrated in Figure 9.

Diameter of the circle of osculation formed by the tangency points of the inside wedge surface hemi-ellipsoid and the outside wedge surface cylinder. (Figure 9) See equation 73 for an alternate expression.

$$D_{IW}CFI = D_{IW}CLO$$
(77)

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure to the equatorial plane of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure. (Figure 9) See equation 74 for an alternate expression.

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, EXTENDS BEYOND FORWARD CLOSURE

(IWINFCL = . FALSE.) (Cont.):

$$L_{IW_{CEFI}} = L_{IW_{CFI}}$$
(78)

Equatorial diameter of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure. (Figure 9) See equation 76 for an alternate expression.

$$D_{IW} = D_{IW} CLO$$
(79)

Diameter ratio, hole diameter to equatorial diameter, inside surface of insulation wedge in the forward case closure. (Figure 9)

$$R_{DIWHFI} = \frac{D_{IW}_{HFI}}{D_{IW}_{EFI}}$$
(80)

Length of the axis of revolution of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure. (Figure 9) See equation 75 for an alternate expression.

$$L_{IW}_{EFI} = \frac{L_{IW}_{HFI}}{\sqrt{1 - R_{DIWHFI}^2}}$$
(81)

INSULATION WEDGE, FOR WARD CLOSURE:

Head ratio of the ellipsoid associated with the inside surface of the insulation wedge in the forward case closure section.

$$R_{DIWCFI} = \left(\frac{2 L_{IW}_{EFI}}{D_{IW}_{EFI}}\right)$$
(81-a)

Distance from the pole of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward closure to the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward closure. Note that if the wedge extends beyond the closure into the cylindrical section, L_{IW} has a negative value (Figures 7, 9) L_{IW}

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, FORWARD CLOSURE (Cont.):

$$L_{IW_{CLFI}} = L_{IW_{EFI}} + (L_{IW_{CEFI}})$$
(82)

Distance from the pole of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward closure to the forward closure inside/outside surface osculation plane. Note that if the wedge extends beyond the closure into the cylindrical section, L_{IW} has a negative value. (Figures 7, 9)

$$L_{IW_{FI}} = L_{IW_{CLFI}} - (L_{IW_{CFI}})$$
(83)

Distance from the equatorial plane of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure to the inside base of the cylindrical hole cutout for the igniter within the insulation wedge in the forward closure. (Figures 7, 9)

$$L_{IW} = L_{IW} - L_{IW} + L_{IW}$$
(84)

Volume of the hemi-ellipsoid associated with the outside surface of the insulation wedge within the forward case closure. (Figures 7, 8, 9, 10)

$$\mathbf{v}_{\mathbf{IW}_{\mathsf{CLFO}}} = \left(\frac{\pi}{6}\right) \mathbf{L}_{\mathbf{IW}_{\mathsf{CLFO}}} \mathbf{D}_{\mathbf{IW}_{\mathsf{CLO}}}^2$$
(85)

Length ratio, hemi-ellipsoid frustum to hemi-ellipsoid, outside surface, insulation wedge, forward case closure section. (Figures 7, 9)

$$R_{LIWCF1} = \frac{L_{IW}}{L_{IW}}$$
(86)

Volume of ellipsoidal cap, at forward base of the cylindrical section associated with the igniter cutout, within the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure section. (Figures 8, 10)

$$v_{IW_{HFOE}} = \left(\frac{v_{IW_{CLFO}}}{2}\right) \left(2 - 3 R_{LIWCF1} + R_{LIWCF1}^{3}\right)$$
(87)

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, FORWARD CLOSURE (Cont.):

Volume of the cylindrical section, associated with the ignitor hole, within the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure section. (Figures 8, 10)

$$V_{IW}_{HFOC} = \left(\frac{\pi}{4}\right) L_{IW}_{CHFO} D_{IW}^{2}_{HFI}$$
(88)

INSULATION WEDGE, COMPLETELY WITHIN FORWARD CLOSURE (IWINFCL = . TRUE.):

Equations 89 - 93 are evaluated if the insulation wedge is completely within the forward closure, i.e., $L_{IW} > 0$. (See Figures 7, 8)

Volume of the cylindrical section, associated with the igniter hole, within the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure section. The bases of the cylindrical section are the equatorial plane of the hemi-ellipsoid and the "inside/outside wedge surface osculation plane". (Figures 7, 8)

$$V_{IW_{HFOL}} = \left(\frac{\pi}{4}\right) L_{IW_{CFI}} D_{IW_{HFI}}^2$$
(89)

Volume of the cylinder with ellipsoidal cap, associated with the igniter hole, within the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure section. The cylindrical base is the "inside/outside wedge surface osculation plane". (Figures 7, 8) See equation 95 for an alternate expression.

$$V_{IW} = V_{IW} + V_{IW} - V_{IW} + FOL$$
(90)

Length ratio, hemi-ellipsoid frustum (with equatorial and "inside/outside wedge surface osculation plane" bases) to hemi-ellipsoid, outside surface, insulation wedge, forward base closure section. (Figures 7, 8)

$$^{R}LI WCF2 = \frac{^{L}IW}{^{L}IW}CFI$$
(91)

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EQUATIONS, SECOND ENTRANCE (Cont.):

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INSULATION WEDGE, COMPLETELY WITHIN FOR WARD CLOSURE (IWINFCL = . TRUE.) (Cont.):

Volume of the ellipsoidal cap formed by the intersection of the "inside/ outside wedge surface osculation plane" and the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure section. (Figures 8, ?)

$$V_{IW_{CFOE}} = \left(\frac{V_{IW_{CLFO}}}{2}\right) \left(2 - 3R_{LIWCF2} + R_{LIWCF2}^{3}\right)$$
(92)

Volume of the ellipsoidal cap with hole cutout for the igniter, formed by the intersection of the "inside/outside wedge surface osculation plane" and the hemi-ellipsoid associated with the outside surface of the insulation wedge in the forward case closure section. (Figure 8) See equation 97 for an alternate expression.

$$V_{IW_{CHFO}} = V_{IW_{CFOE}} - V_{IW_{HFO}}$$
(93)

INSULATION WEDGE, EXTENDS 3 ZYOND FORWARD CLOSURE (IWINFCL = .FALSE.):

Equations 94 - 97 are evaluated if the insulation wedge is not completely within the forward closure, i.e., $L_{IW} \leq 0$. (See Figures 9, 10) IW_{CFI}

Volume of the cylindrical section, associated with the igniter hole, within the cylindrical case section associated with the outside surface of the insulation wedge in the forward case closure section. The bases of the cylindrical section are the equatorial plane of the hemi-ellipsoid and the "inside/outside wedge surface osculation plane". (Figures 9, 10) Note that this is a positive volume. See equation 90 for an alternate expression.

$$V_{IW_{HFOY}} = \left(\frac{\pi}{4}\right) \left(-L_{IW_{CFI}}\right) D_{IW_{HFO}}^{2}$$
(94)

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, EXTENDS BEYOND FORWARD CLOSURE (IWINFCL = .FALSE) (Cont.):

Volume of the cylinder, with ellipsoidal cap, associated with the igniter hole, in the hemi-ellipsoid and cylinder associated with the outside surface of the insulation wedge in the forward case closure section. (Figure 10) See equation 90 for an alternate expression.

$$V_{IW}_{HFO} = V_{IW}_{HFOE} + V_{IW}_{HFOC} + V_{IW}_{HFOY}$$
(95)

Volume of the cylindrical section associated with the outside surface of the insulation wedge in the forward case closure section. (Figures 9, 10) Note that this is a positive volume.

$$V_{IW} = \left(\frac{\pi}{4}\right) \left(-L_{IW}_{CFI}\right) D_{IW}^{2}$$
(96)

Volume of hemi-ellipsoid and cylinder, with hole cutout for the igniter, which forms the outside surface of the insulation wedge in the forward case closure section. (Figures 8, 10) See equation 93 for an alternate expression.

$$V_{IW}_{CHFO} = V_{IW}_{CLFO} + V_{IW}_{FOY} - V_{IW}_{HFO}$$
(97)

INSULATION WEDGE, FOR WARD CLOSURE:

Volume of the hemi-ellipsoid associated with the inside surface of the insulation wedge within the forward case closure section. (Figures 7, 9)

$$V_{IW_{EFI}} = \left(\frac{\pi}{6}\right) L_{IW_{EFI}} D_{IW_{EFI}}^{2}$$
(98)

Length ratio, hemi-ellipsoid frustum (with equatorial and inside cylindrical hole cutout for the igniter bases) to hemi-ellipsoid, inside surface, insulation wedge, forward case closure section. (Figures 7, 9)

$$R_{LIWCF3} = \frac{L_{IW}_{EHFI}}{L_{IW}_{EFI}}$$
(99)

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INTERNAL INSULATION GEOMETRY

EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, FORWARD CLOSURE (Cont.):

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Volume of ellipsoidal cap, at forward base of the cylindrical section associated with the igniter cutout, within the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure section. (Figures 8, 10)

$$V_{IW_{HFIE}} = \left(\frac{V_{IW_{EFI}}}{2}\right) \left(2 - 3 R_{LIWCF3} + R_{LIWCF3}^{3}\right)$$
(100)

Volume of the cylindrical section, associated with the igniter hole, within the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure section. (Figures 8, 10)

$$V_{IW}_{HFIC} = \left(\frac{\pi}{4}\right) L_{IW}_{EHFI} D_{IW}^{2}_{HFI}$$
(101)

Volume of the cylinder with ellipsoidal cap, associated with the igniter hole, in the hemi-ellipsoid associated with the inside surface of the insulation wedge in the forward case closure section. (Figures 8, 10)

$$V_{IW} = V_{IW} + V_{IW}$$
(102)

Length ratio, hemi-ellipsoid frustum (with equatorial and "inside/outside wedge surface osculation plane" bases) to hemi-ellipsoid, inside surface, insulation wedge, forward case closure section. (Figures 7, 9)

$$R_{LIWCF4} = \frac{\begin{pmatrix} L_{IW} & -L_{IW} \\ \hline L_{IW} & FI \end{pmatrix}}{L_{IW} & FI}$$
(103)

Volume of the ellipsoidal cap associated with the inside surface of the insulation wedge in the forward case closure section. If the insulation wedge extends beyond the closure, V_{IW} is the hemi-ellipsoid volume. (Figures 8, 10) EFIE

$$V_{IW_{EFIE}} = \left(\frac{V_{IW_{EFI}}}{2}\right) \left(2 - 3R_{LIWCF4} + R_{LIWCF4}^{3}\right)$$
(104)

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INSULG INTERNAL INSULATION GEOMETRY

EQUATIONS, SECOND ENTRANCE (Cont.):

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INSULATION WEDGE, FORWARD CLOSURE (Cont.):

Volume of the ellipsoidal cap, with hole cutout for the igniter, which forms the inside surface of the insulation wedge in the forward case closure section. (Figures 8, 10)

$$\mathbf{v}_{\mathbf{IW}_{\mathbf{CHFI}}} = \left(\mathbf{v}_{\mathbf{IW}_{\mathbf{EFIE}}} - \mathbf{v}_{\mathbf{IW}_{\mathbf{HFI}}}\right)$$
(105)

Volume of insulation material required for the insulation wedge associated with the forward case closure section. (Figures 8, 10)

$$V_{IW_{CLF}} = \left(V_{IW_{CHFO}} - V_{IW_{CHFI}}\right) K_{IW_{7}} + K_{IW_{8}}$$
(106)

INSULATION WEDGE, AFT CLOSURE, BOUNDS FOR AN ACCEPTABLE SOLUTION:

The following conditions must be satisfied for acceptable solutions in determining the insulation wedge volume requirements associated with the aft closure. If the conditions are not satisfied, a diagnostic is usually printed and computations of sizing quantities may be terminated. See Figures 11, 13 and the figures associated with the GRAING model type.

The forward base of the submerged nozzle cone frustum grain cutout must not be aft of the aft closure.

$$(-L_{CF_{CY}}) \leq L_{W_{CLAO}}$$
 (107-a)

If the forward base of the submerged nozzle cone frustum grain cutout is in the cylindrical section, its diameter may not exceed the diameter of the inside surface of the insulation liner within the cylindrical section.

For
$$\left(- L_{CF_{CY}} \right) \leq 0; \quad 0 < D_{CFF} \leq D_{IL_{I}}$$
 (107-b)

If the forward base of the submerged nozzle cone frustum grain cutout is in the closure section, its diameter may not exceed the diameter of the inside surface of the insulation liner within the closure section.

For
$$(-L_{CF_{CY}}) \ge 0$$
; $0 < (\frac{D_{CFF}}{2}) \le \left[\sqrt{\frac{L_{IL_{CLAI}}^2 - L_{CF_{CY}}^2}{R_{DILCAI}}}\right]$ (107-c)

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EQUATIONS, SECOND ENTRANCE (Cont.):

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INSULATION WEDGE, AFT CLOSURE. BOUNDS FOR AN ACCEPTABLE SOLUTION (Cont.):

The "inside/outside wedge surface osculation plane" must be forward of the forward base of the submerged nozzle cone frustum insulation wedge cutout. See Figures 11, 13.

$$L_{IW_{HAI}} > \left[L_{IW_{CHAI}} + L_{CF_{CY}} \right]$$
(107-d)

The forward base of the submerged nozzle cone frustum grain cutout must be forward of the aft base of the submerged nozzle cone frustum grain cutout.

$$-\left(\frac{\pi}{2}\right) < \theta_{\rm CF} < \left(\frac{\pi}{2}\right)$$
(107-e)

INSULATION WEDGE, AFT CLOSURE:

Maximum thickness of the insulation wedge associated with the aft closure. Measured parallel to the slant height of the cone frustum grain cutout. See Figures 11, 13.

$$T_{IW_{AMAX}} = T_{IW_{MAX}}K_{IW_{9}} + K_{IW_{10}}$$
 (108)

Diameter of the aft base of the cone frustum hole, for the nozzle cutout, centered on the axis of revolution of the hemi-ellipsoid formed by the outside surface of the insulation wedge associated with the aft case closure section. (Figures 11, 13)

$$D_{IW}_{HAO} = D_{IL}_{HAI} K_{IW_{11}} + K_{IW_{12}}$$
 (109)

Diameter of the forward base of the cone frustum hole, for the nozzle cutout, centered on the axis of revolution of the hemi-ellipsoid formed by the inside surface of the insulation wedge associated with the aft case closure section. (Figures 11, 13)

$$D_{IW_{HAI}} = \left[D_{IW_{HAO}} K_{IW_{13}} - \left[2 T_{IW_{AMAX}} \sin\left(\theta_{CF}\right) \right] K_{IW_{14}} \right] K_{IW_{15}} + K_{IW_{16}}$$
(110)

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INTERNAL INSULATION GEOMETRY

EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, AFT CLOSURE (Cont.):

Altitude of the cone frustum, for the nozzle cutout, within the insulation wedge of the aft case closure section. (Figures 11, 13)

$$L_{IW_{HA}} = \left[T_{IW_{AMAX}} \cos\left(\theta_{CF}\right)\right] K_{IW_{17}} + K_{IW_{18}}$$
(111)

Head ratio of the ellipsoid associated with the outside surface of the insulation wedge in the aft case closure section. See equation 39.

$$R_{\rm DIWCAO} = R_{\rm DILCAI}$$
(112)

Length of the axis of revolution of the hemi-ellipsoid associated with the outside surface of the insulation wedge in ther aft closure section. (Figures 11, 13)

$$L_{IW_{CLAO}} = \frac{R_{DIWCAO}^{D} W_{CLO}}{2}$$
(113)

Diameter ratio, aft base of cone frustum hole to equatorial diameter, outside surface of the insulation wedge in the aft case closure section. (Figures 11, 13)

$$R_{\text{DIWHAO}} = \frac{D_{\text{IW}}}{D_{\text{IW}}}$$
(114)

Length of the hemi-ellipsoid frustum associated with the outside surface of the insulation wedge in the aft case closure section. (Figures 11, 13)

$$L_{IW}_{CHAO} = L_{IW}_{CLAO} \sqrt{1 - R_{DIWHAO}^2}$$
(115)

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the aft case closure section to forward base of the cone frustum hole, for the nozzle cutout, within the insulation wedge in the aft case closure section. (Figures 11, 13)

$$L_{IW}_{CHAI} = L_{IW}_{CHAO} - L_{IW}_{HA}$$
(116)

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EQUATIONS, SECOND ENTRANCE (Cont.):

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DETERMINATION IF AFT CLOSURE WEDGE EXTENDS BEYOND THE CLOSURE:

To determine if the insulation wedge lies completely within the aft case closure section (see Figure 11), or extends beyond the aft closure section into the cylindrical section (see Figure 13), the following procedure is utilized.

L_{IW</sup>CAI is first evaluated using the cylindrical geometry of equation 117.}

| ^{If L} IWCAI ^{≤ 0} , | (i.e., IWINACL = .FALSE.),
the "inside/outside wedge surface osculation plane" lies
within the cylindrical section and equation 119 is used to
evaluate D _{IW} . See Figure 13.
CAI |
|--|--|
| If $L_{IWCAI} > 0$, | (i.e., IWINACL = .TRUE.),
the "inside (outside wedge surface osculation plane" lies |

the "inside/outside wedge surface osculation plane" lies within the aft closure section and the ellipsoidal geometry of equations 120 - 124 must be used to reevaluate L_{IW} and D_{IW} .

For a derivation of equations 117 - 124, and root selection rationale, see reference 55.

Distance from the "equatorial plane of the aft closure outside wedge surface hemi-ellipsoid" to the "inside/outside wedge surface osculation plane". Measured along the axis of revolution, positive sense aft. A positive value indicates that the wedge is completely within the aft closure. A negative value indicates that the wedge extends beyond the aft closure into the cylindrical section. See IWINACL, equation 118. See equation 124 for an alternate expression.

$$L_{IW_{CAI}} = \left(-L_{CF_{CY}} \right) - \left(\frac{1}{2} \right) \left(D_{IW_{CLO}} - D_{CFF} \right) \tan \left(\theta_{CF} \right)$$
(117)

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EQUATIONS, SECOND ENTRANCE (Cont.):

DETERMINATION IF AFT CLOSURE WEDGE EXTENDS BEYOND THE

CLOSURE (Cont.):

IWINACL (Insulation Wedge IN Aft CLosure) is a logical variable which specifies if the insulation wedge associated with the aft closure is completely within the aft closure.

| <pre>If IWINACL = . TRUE.;</pre> | the insulation wedge is completely within the aft closure. Equations 124, 123 are used to |
|----------------------------------|---|
| | evaluate $L_{IW_{CAT}}$ and $D_{IW_{CAT}}$. See Figures 11, 12. |
| | CAI CAI |

If IWINACL = .FALSE.; the insulation wedge extends beyond the aft closure into the cylindrical section, or extends to the intersection of the aft closure and cylindrical section. Equations 117, 119 are used to evaluate L_{IW} and D_{IW} . See Figures 13, 14. IW_{CAI}

For the following logical expression, L_{IW} is evaluated using equation 117.

$$IWINACL = L_{IW_{CAI}}. GT. O$$

(118)

INSULATION WEDGE, EXTENDS BEYOND AFT CLOSURE (IWINACL = .FALSE.):

Equation 119 is evaluated if the insulation wedge extends beyond the aft closure into the cylindrical section, i.e., $L_{IW} \leq 0$.

Note that L_{IW} is evaluated using equation 117 above.

Diameter of the "inside/outside osculation circle" associated with the aft closure insulation wedge. (Figure 15) See equation 123 for an alternate expression.

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|-----------------------|---|-------------------|-----|-----|
| INO ^{""} CAI | | ¹ "CLO | | - |

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, COMPLETELY WITHIN AFT CLOSURE (IWINACL = . TRUE.):

Equations 120 - 124 are evaluated if the insulation wedge lies completely within the aft closure, i.e., $L_{IW} > 0$ as evaluated by equation 117. CAI

Note that L_{IW} is reevaluated using equation 124.

Equations 120 - 122 are intermediate computations for D_{IW} as shown in reference 55.

$$C_{IW_{A}} = \tan^{2}(\theta_{CF}) + R^{2}_{DIWCAO}$$
(120)

$$C_{IW_{B}} = -\tan(\theta_{CF}) \left[2 \left(-L_{CF_{CY}} \right) + D_{CFF} \tan(\theta_{CF}) \right]$$
(121)
(122)

$$C_{IW_{C}} = L_{CF_{CY}}^{2} - L_{IW_{CLAO}}^{2} + \left(\frac{D_{CFF}}{2}\right) \tan\left(\theta_{CF}\right) \left[\left(\frac{D_{CFF}}{2}\right) \tan\left(\theta_{CF}\right) + 2\left(L_{CF_{CY}}\right)\right]$$

Diameter of the "inside/outside osculation circle" associated with the aft closure insulation wedge. Se IWINACL, equation 118 and Figure 11. See equation 119 for an alternate expression.

$$D_{IW_{CAI}} = \frac{-C_{IW_{B}} + \sqrt{C_{IW_{B}}^{2} - 4C_{IW_{A}}C_{IW_{C}}}}{C_{IW_{A}}}$$
(123)

Distance from the "equatorial plane of the aft closure outside wedge surface hemi-ellipsoid" to the "inside/outside wedge surface osculation plane". Measured along the axis of revolution, positive sense aft. Since the wedge is completely within the aft closure, the value will be positive. Se IWINACL, equation 118, and Figure 11. See equation 117 for an alternate expression.

$$L_{IW_{CAI}} = \left({}^{-L}CF_{CY} \right) - \left({}^{-1}_{-2} \right) \left({}^{D}_{IW_{CAI}} - {}^{D}_{CFF} \right) \tan \left({}^{\theta}CF \right)$$
(124)

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, AFT CLOSURE:

Distance from the "inside/outside wedge surface osculation plane" to the inside base of the cone frustum hole cutout of the insulation wedge for the nozzle. Note that the "inside/outside wedge surface osculation plane" may be within the aft case closure section or within the cylindrical case closure section. For the former case (see Figure 11), it is defined by the circle of osculation formed by the tangency points of the inside wedge surface hemiellipsoid and the outside wedge surface hemi-ellipsoid section. For the latter case (see Figure 13), it is defined by the circle of osculation formed by the tangency points of the inside wedge surface hemi-ellipsoid and the outside wedge surface cylindrical section.

$$L_{IW}_{HAI} = L_{IW}_{CHAI} - L_{IW}_{CAI}$$

INSULATION WEDGE, COMPLETELY WITHIN THE AFT CLOSURE (IWINACL = TRUE.):

Equations 126 - 128 are evaluated if the insulation wedge lies completely within the aft closure. See equations 129 - 131 if the wedge extends beyond the aft closure into the cylindrical section.

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the aft case closure section to the equatorial plane of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figure 11) See equation 129 for an alternate expression. (126)

$$L_{IW_{CEAI}} = \frac{-L_{IW_{CAI}} \left[4 \left(L_{IW_{CAI}}^2 - L_{IW_{CHAI}}^2 \right) + R_{DIWCAO}^2 \left(D_{IW_{CAI}}^2 - D_{IW_{HAI}}^2 \right) \right]}{8 L_{IW_{CAI}} L_{IW_{HAI}} - R_{DIWCAO}^2 \left(D_{IW_{CAI}}^2 - D_{IW_{HAI}}^2 \right)}$$

Length of the axis of revolution of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure. (Figure 11) See equation 131 for an alternate expression.

$$L_{IW_{EAI}} = \sqrt{\frac{-D_{IW_{HAI}}^{2} (L_{IW_{CAI}} - L_{IW_{CEAI}})^{2} + D_{IW_{CAI}}^{2} (L_{IW_{CHAI}} - L_{IW_{CEAI}})^{2}}{D_{IW_{CAI}}^{2} - D_{IW_{HAI}}^{2}}}$$

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, COMPLETELY WITHIN THE AFT CLOSURE

(IWINACL = . TRUE.)(Cont.):

Equatorial diameter of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figure 11) See equation 130 for an alternate expression.

$$D_{IW_{EAI}} = \left(\frac{2 L_{IW_{EAI}}}{R_{DIWCAO}}\right) \sqrt{\frac{L_{IW_{CAI}}}{\left(L_{IW_{CAI}} - L_{IW_{CEAI}}\right)}}$$
(128)

INSULATION WEDGE, EXTENDS BEYOND AFT CLOSURE (IWINACL = .FALSE,):

Equations 129 - 131 below are evaluated if the insulation wedge extends beyond the aft closure into the cylindrical section, as illustrated by Figure 13.

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the att case closure section to the equatorial plane of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figure 13) See equation 126 for an alternate expression.

$$L_{IW}_{CEAI} = L_{IW}_{CAI}$$
(129)

Equatorial diameter of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figure 13) See equation 128 for an alternate expression.

$$D_{IW} = D_{IW} CLO$$
(130)

Length of the axis of revolution of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figure 13) See equation 127 for an alternate expression.

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, AFT CLOSURE:

Head ratio of the ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section.

 $R_{\text{DIWCAI}} = \left(\frac{2 L_{\text{IW}}}{D_{\text{IW}}}\right)$ (131-a)

Distance from the pole of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft closure to the equatorial plane of the hemiellipsoid associated with the outside surface of the insulation wedge in the aft closure. Note that if the wedge extends beyond the closure into the cylindrical section, L_{IW} has a negative value. (Figures 11, 13)

$$L_{IW_{CLAI}} = L_{IW_{EAI}} + (L_{IW_{CEAI}})$$
(132)

Distance from the pole of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft closure to the aft closure "inside/outside wedge surface osculation plane". Note that if the wedge extends beyond the closure into the cylindrical section, L_{IW} has a negative value. (Figures 11, 13)

$$L_{IW_{AI}} = L_{IW_{CLAI}} - (L_{IW_{CAI}})$$
(133)

Distance from the equatorial plane of the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure to the inside base of the cone frustum cutout within the insulation wedge in the aft case closure section. (Figures 11, 13)

$$L_{IW} = L_{IW} - L_{IW} + L_{IW}$$
(134)

Volume of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the aft case closure section. (Figures 11, 13, 14)

$$\mathbf{v}_{\mathrm{IW}_{\mathrm{CLAO}}} = \left(\frac{\pi}{6}\right) \quad \mathbf{L}_{\mathrm{IW}_{\mathrm{CLAO}}} \quad \mathbf{D}_{\mathrm{IW}_{\mathrm{CLO}}}^{2} \tag{135}$$

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INTERNAL INSULATION WEDGE

EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, AFT CLOSURE (Cont.):

Length ratio, hemi-ellipsoid frustum to hemi-ellipsoid, outside surface, insulation wedge, aft case closure section. (Figures 11, 13)

$$R_{LIWCA1} = \frac{L_{IW}CHAO}{L_{IW}CLAO}$$
(136)

Volume of the ellipsoidal cap, at aft base of the cone frustum section associated with the nozzle cutout, within the heini-ellipsoid associated with the outside surface of the insulation wedge in the aft case closure section. (Figures 12, 14)

$$\mathbf{v}_{\mathrm{IW}_{\mathrm{HAOE}}} = \left(\frac{\mathbf{v}_{\mathrm{IW}_{\mathrm{CLAO}}}}{2}\right) \left(2 - 3 R_{\mathrm{LIWCA1}} + R_{\mathrm{LIWCA1}}^{3}\right)$$
(137)

Volume of the cylindrical section, associated with the nozzle cutout, within the hemi-ellipsoid frustum associated with the outside surface of the insulation wedge in the aft case closure section. (Figures 12, 14)

$$\mathbf{v}_{\mathrm{IW}_{\mathrm{HAOC}}} = \left(-\frac{\pi}{4}\right) \left(\mathbf{L}_{\mathrm{IW}_{\mathrm{CHAO}}} - \mathbf{L}_{\mathrm{IW}_{\mathrm{CAI}}}\right) \mathbf{D}_{\mathrm{IW}_{\mathrm{HAI}}}^{2}$$
(138)

INSULATION WEDGE, COMPLETELY WITHIN CLOSURE (IWINACL = . TRUE.):

Equations 139 - 141 are evaluated if the insulation wedge lies completely within the aft closure. See Figures 11, 12.

Length ratio, hemi-ellipsoid frustum (with equatorial and "inside/outside wedge surface osculation plane" bases) to hemi-ellipsoid, outside surface, insulation wedge, aft case closure section. (Figures 11, 12)

$$R_{LIWCA2} = \frac{L_{IW}_{CAI}}{L_{IW}_{CLAO}}$$
(139)

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, COMPLETELY WITHIN CLOSURE (IWINACL = .TRUE.)(Cont.):

Volume of the ellipsoidal cap formed by the intersection of the "inside/outside wedge surface osculation plane" and the hemi-ellipsoid associated with the outside surface of the insulation wedge in the aft case closure section. (Figure 12)

$$\mathbf{v}_{\mathrm{IW}_{\mathrm{CAOE}}} = \left(\frac{\mathbf{v}_{\mathrm{IW}_{\mathrm{CLAO}}}}{2}\right) \left(2 - 3 R_{\mathrm{LIWCA2}} + R_{\mathrm{LIWCA2}}^{3}\right)$$
(140)

Volume of the hemi-ellipsoid frustum, with cylindrical hole cutout, associated with the outside surface of the insulation wedge in the aft case closure section. (Figure 12) See equation 143 for an alternate expression.

$$V_{IW}_{CHAO} = V_{IW}_{CAOE} - V_{IW}_{HAOE} - V_{IW}_{HAOC}$$
(141)

INSULATION WEDGE, EXTENDS BEYOND AFT CLOSURE

Equations 142, 143, are evaluated if the insulation wedge extends beyond the aft closure into the cylindrical section. See Figures 13, 14.

Volume of the cylindrical section associated with the outside surface of the insulation wedge in the aft case closure section. (Figures 13, 14) Note that this is a positive volume.

$$V_{IW_{AOY}} = \left(\frac{\pi}{4}\right) \left(-L_{IW_{CAI}}\right) D_{IW_{CLO}}^{2}$$
(142)

Volume of the hemi-ellipsoid frustum, with cylindrical hole cutout, associated with the outside surface of the insulation wedge in the aft closure section. (Figure 14) See equation 141 for an alternate expression.

$$v_{IW}_{CHAO} = v_{IW}_{AOY} + v_{W}_{CLAO} - v_{IW}_{HAOE} - v_{IW}_{HAOC}$$
(143)

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INTERNAL INSULATION GEOMETRY

EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, AFT CLOSURE:

Volume of the hemi-ellipsoid associated with the inside surface of the insulation wedge within the aft case closure. (Figures 11, 13)

$$\mathbf{V}_{\mathbf{IW}_{\mathbf{EAI}}} = \left(\frac{\pi}{6}\right) \mathbf{L}_{\mathbf{IW}_{\mathbf{EAI}}} \mathbf{D}_{\mathbf{IW}_{\mathbf{EAI}}}^2$$
(144)

Length ratio, hemi-ellipsoid frustum (with equatorial base and inside nozzle cutout base) to hemi-ellipsoid, inside surface, insulation wedge, aft case closure section. (Figures 11, 13)

$$R_{LIWCA3} = \frac{L_{IW}_{EHAI}}{L_{IW}_{EAI}}$$
(145)

Volume of the ellipsoidal cap, at the aft base of the cone frustum section associated with the nozzle cutout, within the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figures 12, 14)

$$V_{IW}_{HAIE} = \left(\frac{V_{IW}_{EAI}}{2}\right) \left(2 - 3R_{LIWCA3} + R_{LIWCA3}^{3}\right)$$
(146)

Volume of the cylindrical section, associated with the nozzle cutout. within the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figures 12, 14)

$$V_{IW}_{HAIC} = \left(\frac{\pi}{4}\right) L_{IW}_{HAI} D_{IW}^{2}_{HAI}$$
(147)

Volume of the cylinder, with ellipsoidal cap, associated with the nozzle cutout cone frustum, in the hemi-ellipsoid associated with the inside surface of the insulation wedge in the aft case closure section. (Figures 12, 14)

$$V_{IW} = V_{IW} + V_{IW}$$
(148)

INTERNAL INSULATION GEOMETRY

EQUATIONS, SECOND ENTRANCE (Cont.):

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INSULATION WEDGE, AFT CLOSURE (Cont.):

Length ratio, hemi-ellipsoid frustum (with equatorial and "inside/outside wedge surface osculation plane" bases) to hemi-ellipsoid, inside surface, insulation wedge, aft case closure section. (Figures 11, 13)

$$R_{LIWCA4} = \frac{\begin{pmatrix} L_{IW}_{CAI} & L_{IW}_{CEAI} \end{pmatrix}}{L_{IW}_{EAI}}$$
(149)

Volume of the ellipsoidal cap associated with the inside surface of the insulation wedge in the aft case closure. If the insulation wedge extends beyond the closure, V_{IW} is the hemi-ellipsoid volume. (Figures 12, 14) I_{EAIE}

$$V_{IW}_{EAIE} = \left(\frac{V_{IW}_{EAI}}{2}\right) \left(2 - 3 R_{LIWCA4} + R_{LIWCA4}^{3}\right)$$
(150)

Volume of the ellipsoidal cap, with cylindrical hole cutout associated with the core frustum hole cutout for the nozzle, which forms the inside surface of the insulation wedge in the aft case closure section. (Figures 12, 14)

$$V_{IW}_{CHAI} = V_{IW}_{EAIE} - V_{IW}_{HAI}$$
(151)

Area of triangular section, associated with the cone frustum cutout for the nozzle, within the aft case closure section. (Figures 12, 14)

$$A_{IW}_{HAT} = \left(\frac{1}{4}\right) \left({}^{D}_{IW}_{HAO} - {}^{D}_{IW}_{HAI} \right) {}^{L}_{IW}_{HA}$$
(152)

Distance from axis of revolution to centroid of triangular section in insulation wedge, associated with the cone frustum cutout for the nozzle, within the aft case closure section. (Figures 11, 13)

$$Y_{IW_{HAT}} = \frac{-W_{HAI}}{3} + \left(\frac{1}{6}\right) D_{IW_{HAO}}$$
(153)

Volume of triangular section in the insulation wedge, associated with the cone frustum cutout for the nozzle, within the aft case closure section. (Figures 12, 14)

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EQUATIONS, SECOND ENTRANCE (Cont.):

INSULATION WEDGE, AFT CLOSURE (Cont.):

$$V_{IW} = 2 \pi Y_{IW} A_{IW} A$$

Volume of insulation material required for the insulation wedge associated with the aft case closure section. (Figures 12, 14)

$$\mathbf{v}_{\mathbf{IW}_{CLA}} = \left(\mathbf{v}_{\mathbf{IW}_{CHAO}} - \mathbf{v}_{\mathbf{IW}_{CHAI}} - \mathbf{v}_{\mathbf{IW}_{HAT}}\right) \mathbf{\kappa}_{\mathbf{IW}_{19}} + \mathbf{\kappa}_{\mathbf{IW}_{20}}$$
(155)

SLOT AND JOINT INSULATION, BOUNDS FOR ACCEPTABLE SOLUTIONS:

The following conditions must be satisfied for acceptable solutions in determining the insulation slot and joint volume requirements. If the conditions are not satisfied, a diagnostic is usually printed and computations of sizing quantities may be terminated. (Figures 16, 17)

| D _{IL₁} > T _{PP_{WEB}} | (156-a) |
|---|------------------|
| T _{PP} > 0
WEB | (156-Ъ) |
| ^T _{PP} _{WEB} ^{≥ T} IS _{MAX} | (156-c) |
| ^T _{PP} _{WEB} ^{≥ T} _{IJ} _{MAX} | (156-d) |
| ^T IS _{MAX} ≥ 0 | (156-e) |
| ^T IJ _{MAX} ≥ 0 | (156 <i>-</i> f) |
| L _{IS_{CUT} ≥ 0} | (156-g) |
| L _{JJ_{CUT} ≥ 0} | (156-h) |
| ^L IS _{PG1} ≥ 0 | (156-i) |
| L _{IJ} ≥ 0
PG1 | (156-j) |

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EQUATIONS, SECOND ENTRANCE (Cont.):

SLOT AND JOINT INSULATION, CUTOUT REQUIREMENTS:

Number of slot cutouts in grain to be insulated. Integer valued real number (floating point integer).

$$N_{IS_{CUT}} = N_{IS_{IH0}} + N_{IS_{IH1}}$$
(157)

CUTOUTS (CUT OUT in grain for Slot) is a logical variable which specifies if there are slot cutouts within the grain which require insulation.

| If CUTOUTS = . TRUE. ; | there is at least one slot cutout requiring
insulation. Either one or no slot burning surface
may be inhibited. |
|-----------------------------------|---|
| If CUTOUTS = . FALSE. ; | there are no slot cutouts requiring insulation. |
| CUTOUTS = N _{ISCUT} .GT. | O (157-a) |

CUTOUTJ (CUT OUT in grain for \underline{J} oint) is a logical variable which specifies if there are joint cutouts within the grain which require insulation.

If CUTOUTJ = . TRUE.; there is at least one joint cutout requiring insulation. Both burning surfaces of a joint are inhibited.

If CUTOUTJ = . FALSE, ; there are no joint cutouts requiring insulation.

 $CUTOUTJ = N_{IJ}CUT . GT. 0$ (157-b)

SLOT INSULATION, COMPONENT VOLUMES (CUTOUTS = . FALSE.):

If CUTOUTS = . FALSE.; there is no slot insulation and equations 158-160 are evaluated. See Figures 15, 16, 20. See equations 162, 164, 165, 170 for alternate expression

EQUATIONS, SECOND ENTRANCE (Cont.):

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SLOT INSULATION, COMPONENT VOLUMES (CUTOUTS = . FALSE.)(Cont.):

| v _{is_{pl}} | = 0 | (158) |
|------------------------------|-----|-------|
| v _{isgl} | = 0 | (159) |

$$\mathbf{V}_{\mathbf{IS}_{\mathbf{PG}}} = 0 \tag{160}$$

SLOT INSULATION, COMPONENT VOLUMES (CUTOUTS = . TRUE.):

If CUTOUTS = . TRUE.; equations 162 - 170 are evaluated to determine the slot insulation component volumes, as illustrated by Figures 15, 16, 20.

Length of a single slot cutout for insulation computations. (Figure 16)

$$L_{IS_{CUT}} = \begin{pmatrix} L_{SL_{GN}} \\ N_{IS_{CUT}} \end{pmatrix} K_{IS_3} + K_{IS_4}$$
(162)

Volume of port/liner insulation component for a slot cutout. (Figures 15, 16, 20) See equation 158 for an alternate expression.

$$\mathbf{v}_{\mathrm{IS}_{\mathrm{PL}}} = \left[\pi \left(\mathcal{D}_{\mathrm{IL}_{\mathrm{I}}} - \mathbf{T}_{\mathrm{IS}_{\mathrm{MAX}}} \right) \mathbf{L}_{\mathrm{IS}_{\mathrm{CUT}}} \mathbf{T}_{\mathrm{IS}_{\mathrm{MAX}}} \right] \mathbf{K}_{\mathrm{IS}_{5}} + \mathbf{K}_{\mathrm{IS}_{6}}$$
(163)

Volume of grain/liner insulation component for a slot cutout. (Figures 15, 16, 20) See equation 159 for an alternate expression.

$$\mathbf{v}_{\mathrm{IS}_{\mathrm{GL}}} = \left| \pi \left[\left(\frac{\mathbf{D}_{\mathrm{IL}_{\mathrm{I}}}}{2} \right) - \left(\frac{\mathbf{T}_{\mathrm{IS}_{\mathrm{MAX}}}}{3} \right) \right] \mathbf{T}_{\mathrm{PP}_{\mathrm{WEB}}} \mathbf{T}_{\mathrm{IS}_{\mathrm{MAX}}} \right| \mathbf{K}_{\mathrm{IS}_{7}} + \mathbf{K}_{\mathrm{IS}_{8}}$$
(164)

Volume of the port/grain insulation component for slot cutouts. See Figures 15, 16, 20. See equations 160, 170 for alternate expressions.



 $\mathbf{V}_{\mathbf{IS}_{\mathbf{PG}}} = \mathbf{0} \tag{165}$

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EQUATIONS, SECOND ENTRANCE (Cont.):

SLOT INSULATION, COMPONENT VOLUMES (CUTOUTS = . TRUE.)(Cont.):

If
$$N_{IS} > 0$$
, equations 166 - 170 are evaluated to determine V_{IS}_{PG}

Altitude of the polygon cross section associated with the port/grain insulation component for slot cutouts. (Figure 16)

$$T_{IS} = T_{PP} = T_{IS}$$
(166)

Length of outside base of the polygon cross section associated with the port/grain insulation component for slot cutouts. (Figure 16)

$$L_{IS_{PGO}} = \left(\frac{T_{IS_{MAX}}}{T_{PP_{WEB}}}\right) \left(T_{PP_{WEB}} - T_{IS_{MAX}} + L_{IS_{PGI}}\right)$$
(167)

Area of the polygon cross section associated with the port/grain insulation component for slot cutouts. (Figure 16)

$$A_{IS_{PG}} = \begin{pmatrix} T_{IS_{PGI}} \\ 2 \end{pmatrix} \begin{pmatrix} L_{IS_{PGI}} + L_{IS_{PGO}} \end{pmatrix}$$
(168)

Centroid, measured with respect to the motor centerline, of the polygon cross section associated with the port/grain insulation component for slot cutouts. (Figure 16)

$$Y_{IS}_{PG} = \left(\frac{D_{IL}}{2}\right) - T_{IS}_{MAX} - \left(\frac{T_{IS}_{PGI}}{3}\right) \left(\frac{2L_{IS}_{PGI} + L_{IS}_{PGO}}{L_{IS}_{PGI} + L_{IS}_{PGO}}\right)$$

Volume of the port/grain insulation component for slot cutouts. (Figures 15, 16, 20) See equations 160, 165 for alternate expressions.

$$V_{IS_{PG}} = \left[2 \pi Y_{IS_{PG}} A_{IS_{PG}} \right] K_{IS_{9}} + K_{IS_{10}}$$
(170)

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EQUATIONS, SECOND ENTRANCE(Cont.):

SLOT INSULATION, PORT/GRAIN COMPONENT POLYGON CLASSIFICATION:

The following logical expressions are used to classify the polygon cross section associated with the port/grain insulation component for slot cutouts.

If NISIH1= 0;there is no port/grain insulation component and all
elements of the PGIS logical valued array are . FALSE.If NISIH1> 0;one, and only one, of the elements of the PGIS logical
array must have a . TRUE. value for an acceptable
port/grain insulation component solution.If NISIH1> 0;and either all of the elements of PGIS evaluated using
equations 171, 177 are . FALSE., or more than one

element is . TRUE., the logical variable PGISBAD is set . TRUE.

See Figure 18 for a geometrical interpretation and "Optimization Considerations" of the REMARKS section for discontinuity considerations.

Vertical line solution.

$$\mathbf{PGIS(1)} = \left(\mathbf{T}_{\mathbf{IS}_{\mathbf{MAX}}}, \mathbf{EQ}, \mathbf{O}\right) \quad \mathbf{AND}, \quad \left(\mathbf{L}_{\mathbf{IS}_{\mathbf{PGI}}}, \mathbf{EQ}, \mathbf{O}\right)$$
(171)

Horizontal line solution.

$$PGIS(2) = \left({}^{T}_{PP} {}^{WEB} \cdot {}^{EQ} \cdot {}^{T}_{IS} {}^{MAX} \right)$$
(172)

Intermediate quantity, solution is not a line.

$$ISNOTLN = . NOT. \left[PGIS(1). OR. PGIS(2) \right]$$
(173)

Triangle solution.

$$PGIS(3) = ISNOTLN . AND. \begin{pmatrix} L_{IS} & EQ. O \\ & O \end{pmatrix}$$

$$AND. \begin{pmatrix} T_{IS} & GT. O \\ & O \end{pmatrix}$$
(174)

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EQUATIONS, SECOND ENTRANCE (Cont.):

SLOT INSULATION, PORT/GRAIN COMPONENT POLYGON CLASSIFICATION (Cont.):

Trapezoid solutions.

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$$PGIS(4) = ISNOTLN . AND. \begin{pmatrix} L_{IS} & LT. & L_{IS} \\ . & AND. & \begin{pmatrix} L_{IS} & GT. & O \end{pmatrix} \end{pmatrix}$$
(175)

(TIS_{MAX}. GT. O) PGIS(5) = ISNOTLN , AND.(176)· AND. $(^{T}_{IS}_{MAX}, ^{EQ. L}_{IS}_{PGI})$

$$PGIS(6) = ISNOTLN \cdot AND. \begin{pmatrix} L_{IS} & GT. & L_{IS} \\ PGI & PGO \end{pmatrix}$$
(177)

JOINT INSULATION, COMPONENT VOLUMES (CUTOUTJ = . FALSE.):

If CUTOUTJ = .FALSE., there is no joint insulation and equations 178, 179 are evaluated. See Figures 15, 17, 20, and equations 182, 195 for alternate definition if CUTOUTJ = . TRUE. .

$$\mathbf{V}_{\mathbf{IJ}_{\mathbf{PL}}} = \mathbf{0} \tag{178}$$

$$\mathbf{v}_{\mathbf{IJ}\mathbf{PG}} = \mathbf{0} \tag{179}$$

JOINT INSULATION, COMPONENT VOLUMES (CUTOUTJ = .TRUE.):

If CUTOUTJ = . TRUE., equations 181-195 are evaluated to determine the joint insulation component volumes as illustrated by Figures 15, 17, 20.

Length of a unit joint cutout for insulation computations. (Figure 17)

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$$L_{IJ_{GUT}} = \left(\frac{L_{JT_{CUT}}}{N_{IJ_{CUT}}}\right) \quad K_{IJ_3} + K_{IJ_4}$$
(181)

EQUATIONS, SECOND ENTRANCE (Cont.):

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JOINT INSULATION, COMPONENT VOLUMES (CUTOUTJ = . TRUE.)(Cont.):

Volume of port/liner insulation component for joint cutouts. (Figures 17, 20)

$$V_{IJ}_{PL} = \left(\pi \left(D_{IL} - T_{IJ}_{MAX} \right) L_{IJ}_{CUT} T_{IJ}_{MAX} \right) K_{IJ_5} + K_{IJ_6}$$
(182)

Intermediate quantity required for the determination of the outside base of the polygon cross section associated with the port/grain insulation component for joint cutouts. (Figure 17)

$$L_{IJ_{PG3}} = \begin{pmatrix} T_{IJ_{MAX}} \\ T_{PP_{WEB}} \end{pmatrix} \begin{pmatrix} T_{PP_{WEB}} - T_{IJ_{MAX}} + L_{IJ_{PGI}} \end{pmatrix}$$
(183)

PGIJLAP is a logical valued variable which indicates overlapping of the polygon cross sections associated with the port/grain insulation component for joint cutouts. (Figure 19)

PGIJLAP = . TRUE., PG components overlap.

PGIJLAP = . FALSE., PG components do not overlap.

$$PGIJLAP = L_{IJ}PG3 \cdot GT \cdot \left(\frac{L_{IJ}CUT}{2}\right)$$
(183-a)

Outside base of the polygon cross section associated with the port/grain insulation components for grain cutouts. (Figure 17)

If PGIJLAP = . FALSE.,
$$I_{IJ} = L_{IJ}$$
 (184)

If PGIJLAP = . TRUE.,
$$L_{IJ}_{PGO} = \begin{pmatrix} L_{IJ}_{CUT} \\ 2 \end{pmatrix}$$
 (185)

Component altitude of the polygon cross section associated with the port/grain insulation component for joint cutouts. (Figure 17)

$$T_{IJ}_{PG3} = T_{PP}_{WEB} - T_{IJ}_{MAX} + L_{IJ}_{PGI} - \left(\frac{T_{PP}_{WEB}}{T_{IJ}_{MAX}}\right) L_{IJ}_{PGO}$$
(186)

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EQUATIONS, SECOND ENTRANCE (Cont.):

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JOINT INSULATION, COMPONENT VOLUMES (CUTOUTJ = . TRUE.)(Cont.):

Component altitude of the polygon cross section associated with the port/grain insulation component for joint cutouts. (Figure 17)

$$T_{IJ}_{PGI} = \begin{pmatrix} T_{PP}_{WEB} \\ T_{IJ}_{MAX} \end{pmatrix} L_{IJ}_{PGO} - L_{IJ}_{PGI}$$
(187)

Area of the polygon cross section associated with the port/grain insulation component for joint cutouts. (Figure 17)

$$A_{IJ}_{PG} = \left(-\frac{T_{IJ}_{PGI}}{2}\right) \left(L_{IJ}_{PGI} + L_{IJ}_{PGO}\right) + T_{IJ}_{PG3} L_{IJ}_{PGO}$$
(188)

Centroid, measured with respect to the motor centerline, of the polygon cross section for joint cutouts. (Figure 17)

$$Y_{2} = \left(\frac{T_{IJ}^{2}PGI}{3}\right) \left(2 L_{IJ}PGI + L_{IJ}PGO\right)$$
(189)

$$\mathbf{Y}_{3} = \mathbf{T}_{IJ}_{PG1} \mathbf{T}_{IJ}_{PG3} \begin{pmatrix} \mathbf{L}_{IJ}_{PGI} + \mathbf{L}_{IJ}_{PGO} \end{pmatrix}$$
(190)

$$Y_4 = T_{IJ}^2 L_{PG3} L_{IJ}PGO$$
(191)

$$\mathbf{Y}_{5} = \mathbf{T}_{IJ}_{PG1} \begin{pmatrix} \mathbf{L}_{IJ}_{PGI} + \mathbf{L}_{IJ}_{PGO} \end{pmatrix} + \mathcal{Z} \mathbf{T}_{IJ}_{PG3} \quad \mathbf{L}_{IJ}_{PGO}$$
(192)

$$Y_1 = \frac{Y_2 + Y_3 + Y_4}{Y_5}$$
(193)

$$Y_{IJ}_{PG} = \left(\frac{D_{IL}}{2}\right) - T_{IJ}_{MAX} - Y_1$$
(194)

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EQUATIONS, SECOND ENTRANCE (Cont.):

JOINT INSULATION, COMPONENT VOLUMES (CUTOUTJ = . TRUE.) (Cont.):

Volume of a port/grain insulation component for slot cutouts. (Figure 20) See equation 179 for an alternate expression.

$$V_{IJ}_{PG} = \left[2 \pi Y_{IJ}_{PG} A_{IJ}_{PG} \right]^{K}_{IJ_{7}} + K_{IJ_{8}}$$
(195)

JOINT INSULATION, PORT/GRAIN COMPONENT POLYGON CLASSIFICATION:

The following logical expressions are used to classify the polygon cross section associated with the port/grain insulation component for joint cutouts.

| If CUTOUTJ = . FALSE., | there is no joint insulation and all elements of the PGIJ logical valued array are . FALSE. |
|------------------------|--|
| If CUTOUTJ = . TRUE. , | one, and only one, of the elements of the PGIJ
logical valued array must have a , TRUE. value
for an acceptable port/grain insulation component
solution. |
| If CUTOUTJ = . TRUE., | and either all of the elem nts of the PGIJ array
are false, or more than one element is true, the
logical variable PGIJBAD is set. TRUE. |

See Figure 19 for a geometrical interpretation and "Optimization Considerations" of the REMARKS section for discontinuity considerations.

Vertical line solution.

$$\mathbf{PGIJ(1)} = \begin{pmatrix} \mathbf{T}_{IJ}_{MAX}, EQ, O \end{pmatrix} \quad \text{AND.} \quad \begin{pmatrix} \mathbf{L}_{IJ}_{PGI}, EQ, O \end{pmatrix}$$
(196)

Horizontal line solution.

$$PGIJ(2) = \begin{pmatrix} T_{PP} & EQ & T_{IJ} \\ WEB & & IJ \end{pmatrix}$$
(197)

Intermediate quantity, solution is not a line.

IJNOTLN = .NOT. [PGIJ(1) . OR. PGIJ(2)](198)

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EQUATIONS, SECOND ENTRANCE (Cont.):

JOINT INSULATION, PORT/GRAIN COMPONENT POLYGON CLASSIFICATION (Cont.):

Triangle solution.

$$PGIJ(3) = (T_{IJ}_{PG3}, EQ, O) \quad AND. IJNOTIN$$
(199)
$$AND. (L_{IJ}_{PGI}, EQ, O) AND. (T_{IJ}_{MAX}, GT, O)$$

Trapezoid solutions.

$$PGIJ(4) = (T_{IJ}PG3} \cdot EQ \cdot O) \cdot AND. IJNOTLN$$
(200)
$$\cdot AND. (L_{IJ}PGI \cdot LT \cdot L_{IJ}PGO)$$
$$\cdot AND. (L_{IJ}PGI \cdot GT \cdot O)$$

$$PGIJ(5) = \begin{pmatrix} T_{1J} \\ PGI \end{pmatrix} \cdot EQ. \\ O \\ AND. \begin{pmatrix} I \\ IJ \\ MAX \end{pmatrix} \cdot GT. \\ O \\ AND. \begin{pmatrix} L_{IJ} \\ PGI \end{pmatrix} \cdot EQ. \\ T_{IJ} \\ MAX \end{pmatrix}$$
(20)

$$PGIJ(6) = \begin{pmatrix} T_{IJ} \\ PG3 \end{pmatrix} \cdot AND. IJNOTLN$$
(202)
$$AND. \begin{pmatrix} L_{IJ} \\ PG1 \end{pmatrix} \cdot GT. L_{IJ} PG0 \end{pmatrix}$$
(202)

$$PGIJ(7) = (T_{IJ}_{PG3}, GT, O) \cdot AND, (L_{IJ}_{PGI}, EQ, T_{IJ}_{MAX})$$
(203)

$$PGIJ(8) = (T_{IJ}_{PG3}, GT, O) \quad (AND, (L_{IJ}_{PGI}, EQ, O)) \quad (204)$$

$$AND, (T_{IJ}_{MAX}, GT, O) \quad (204)$$

Pentagon solution.

$$PGIJ(9) = (T_{IJ}_{PG3}, GT, O) \cdot AND, (L_{IJ}_{PGI}, GT, O)$$

$$AND, (L_{IJ}_{PGI}, LT, L_{IJ}_{PGO})$$

$$(205)$$

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EQUATIONS, SECOND ENTRANCE (Cont.):

SLOT AND JOINT VOLUMES:

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Volume of insulation for a slot with no sides inhibited. (Figure 20)

$$V_{IS_{IHO}} = \left[V_{IS_{PL}} + 2 V_{IS_{GL}} \right] K_{IS_{11}} + K_{IS_{12}}$$
(206)

Volume of insulation for a slot with one side inhibited. (Figure 20)

$$v_{IS_{IH1}} = [v_{IS_{PL}} + v_{IS_{GL}} + v_{IS_{PG}}] \kappa_{IS_{13}} + \kappa_{IS_{14}}$$
 (207)

Total volume of insulation required for slots.

$$\mathbf{v}_{IS} = \left[N_{IS}_{IH0} \quad \mathbf{v}_{IS}_{IH0} + N_{IS}_{IH1} \quad \mathbf{v}_{IS}_{IH1} \right] K_{IS_{15}} + K_{IS_{16}}$$
(208)

Volume of insulation required for a joint. (Figure 20)

$$\mathbf{V}_{IJ_{IH2}} = \begin{bmatrix} \mathbf{V}_{IJ_{PL}} + 2 \mathbf{V}_{IJ_{PG}} \end{bmatrix} \mathbf{K}_{IJ_{9}} + \mathbf{K}_{IJ_{10}}$$
(209)

Total volume of insulation required for joints.

$$V_{IJ} = N_{IJ}_{CUT} V_{IJ}_{IH2} K_{IJ}_{11} + K_{IJ}_{12}$$
 (210)

PROPELLENT DISPLACEMENT:

Volume of propellent displaced by the insulation wedge associated with the forward closure. (Figure 21)

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EQUATIONS, SECOND ENTRANCE (Cont.):

PROPELLENT DISPLACEMENT (Cont.):

Determination of propellent displaced by the insulation wedge associated with the aft closure.

- If $\theta_{CF} = 0$, the grain cone frustum is a cylinder and equation 212 is used to evaluate V_{IW} CAPD
- If $L_{CFCA} > 0$. and $\theta_{CF} \neq 0$, the grain cone frustum intersects the ellipsoid portion of the aft outside insulation wedge and equations 213 - 221 are used to evaluate V_{IW}_{CAPD} .
- If $L_{CFCA} \leq 0$, and $\theta_{CF} \neq 0$, the grain cone frustum intersects the cylindrical portion of the aft outside insulation wedge and equations 213 - 220, 222 are used to evaluate V_{IW}_{CAPD} .

Volume of propellent displaced by the insulation wedge associated with the aft closure (cylindrical grain cone frustum). See equations 221, 222 for alternate expressions. (Figure 21)

$$V_{IW_{CAPD}} = \left\{ V_{IW_{CLA}} - \left(\frac{\pi}{12}\right) \right\} R_{DIWCAO} \left[\left(D_{IW_{CLO}}^{2} - D_{IW_{HAO}}^{2} \right)^{\frac{3}{2}} - \left(D_{IW_{CLO}}^{2} - D_{CFA}^{2} \right)^{\frac{3}{2}} \right]$$

$$+ 3 L_{IW_{CEAI}} \left(D_{IW_{HAO}}^{2} - D_{CFA}^{2} \right)$$

$$+ R_{DIWCAI} \left[\left(D_{IW_{EAI}}^{2} - D_{CFA}^{2} \right)^{\frac{3}{2}} - \left(D_{IW_{EAI}}^{2} - D_{IW_{HAO}}^{2} \right)^{\frac{3}{2}} \right] \left\{ \left| K_{PD_{3}}^{+} K_{PD_{4}}^{+} \right|^{\frac{3}{2}} \right\} \right\}$$

Equations 213 - 220 are intermediate computations required for the evaluation of equations 221 and 222. They are evaluated if $\theta_{CF} \neq 0$.

$$L_{IW_{A1}} = L_{IW_{CHAO}} - \left(\frac{D_{IW_{HAO}}}{2}\right) \cot\left(\theta_{CF}\right)$$
(213)

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EQUATIONS, SECOND ENTRANCE (Cont.):

PROPELLENT DISPLACEMENT (Cont.):

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$$L_{IW_{A2}} = L_{CF_{CA}} - \left(\frac{D_{CFA}}{2}\right) \cot\left(\theta_{CF}\right)$$
(214)

$$D_{IW_{A1}} = \left(\frac{D_{CFA}}{2}\right) - L_{CF_{CA}} \tan\left(\theta_{CF}\right)$$
(215)

$$C_{IW_{AP}} = R_{DIWCAI}^{2} \tan^{2}(\theta_{CF}) + 1$$
(216)

$$C_{IW_{BP}} = 2 R_{DIWCAI}^{2} D_{IW_{A1}} \tan \left(\theta_{CF}\right) - 2 L_{IW_{CEAI}}$$
(217)

$$C_{IW_{CP}} = D_{IW_{A1}}^2 R_{DIWCAI}^2 - L_{IW_{EAI}}^2 + L_{IW_{CEAI}}^2$$
 (218)

Distance from the equatorial plane of the hemi-ellipsoid associated with the outside surface of the insulation wedge in the aft closure to the intersection of the grain cone frustum cutout with the inside surface of the insulation wedge in the aft closure. Measured parallel to centerline. (Figure 21)

$$L_{IW_{CFAI}} = \frac{-C_{IW_{BP}} + \sqrt{C_{IW_{BP}}^2 - 4 C_{IW_{AP}} C_{IW_{CP}}}}{\frac{2 C_{IW_{AP}}}{2 C_{IW_{AP}}}}$$
(219)

Diameter of the circle formed by the intersection of the grain cone frustum cutout with the inside surface of the insulation wedge associated with the aft closure section. (Figure 21)

$$D_{IW_{CFAI}} = 2 \left[D_{IW_{A1}} + L_{IW_{CFAI}} \tan \left(\theta_{CF} \right) \right]$$
(220)

Volume of propellent displaced by the insulation wedge associated with the aft closure $(L_{CFCA} > 0)$. See Figure 21. See equations 212, 222 for alternate expressions.

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PROPELLENT DISPLACEMENT (Cont.):

EQUATIONS, SECOND ENTRANCE (Cont.):

Volume of propellent displaced by the insulation wedge associated with the aft closure $L_{CF} \leq 0$. See Figure 21. See equations 212, 221 for alternate expressions.

$$V_{IW_{CAPD}} = \left(\frac{\pi}{12}\right) \left\{ 3 \left(L_{IW_{A2}} - L_{IW_{CEAI}} \right) \left(D_{CFA}^2 - D_{IW_{CFAI}}^2 \right) + \left(D_{CFA}^3 - D_{IW_{CFAI}}^3 \right) \right\} \left(\frac{D_{CFA}^2 - D_{IW_{CFAI}}^2}{16} + R_{DIWCAI} \left(D_{IW_{EAI}}^2 - D_{CFA}^2 - D_{IW_{CFAI}}^2 - D_{IW_{CFAI}}^2 \right) \right) \left\{ K_{PD_3}^{+} + K_{PD_4}^{+} + K_{PD_4}^{-} + K_{PD_4$$

Volume of propellent displaced by the insulation wedges associated with the forward and aft closures. (Figure 21)

$$v_{IW_{PD}} = (v_{IW_{CAPD}} + v_{IW_{CFPD}}) + \kappa_{PD_5} + \kappa_{PD_6}$$
(223)

EQUATIONS, SECOND ENTRANCE (Cart.):

PROPELLENT DISPLACEMENT (Cont.):

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Volume of propellant displaced by the grain/liner components of the slot insulation. (Figure 21)

$$\mathbf{v}_{\mathrm{IS}_{\mathrm{PD}}} = \left(2 \, \mathrm{N}_{\mathrm{IS}_{\mathrm{IH0}}} + \, \mathrm{N}_{\mathrm{IS}_{\mathrm{IH1}}} \right) \, \mathbf{v}_{\mathrm{IS}_{\mathrm{GL}}} \, \mathrm{K}_{\mathrm{PD}_{7}} + \, \mathrm{K}_{\mathrm{PD}_{8}}$$
(224)

Total volume of propellent displaced by the insulation wedges and slots. (Figure 21)

$$\mathbf{v}_{\mathbf{IN}_{PD}} = \left(\mathbf{v}_{\mathbf{IW}_{PD}} + \mathbf{v}_{\mathbf{IS}_{PD}} \right) \mathbf{\kappa}_{\mathbf{PD}_{9}} + \mathbf{\kappa}_{\mathbf{PD}_{10}}$$
(225)

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INTERNAL INSULATION GEOMETRY

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EQUATIONS, THIRD ENTRANCE:

Equations 226 - 230 are evaluated at the third entrance to the INGM1 model.

INSULATION LINER, CYLINDRICAL SECTION:

Length of insulation liner within the cylindrical case section. Includes length adjustment for submerged nozzle, slots and joints. (Figure 2)

$$L_{IL_{CY}} = L_{GN_{CY4}} K_{IL_{11}} + K_{IL_{12}}$$
(226)

Volume of cylindrical insulation liner section within the cylindrical case section.

$$V_{IL_{CY}} = \left(\frac{\pi}{4}\right) \left(D_{IL_{O}}^{2} - D_{IL_{I}}^{2}\right) L_{IL_{CY}} K_{IL_{13}} + K_{IL_{14}}$$
(227)

INSULATION LINER, TOTAL VOLUME:

Total volume of insulation material required for the insulation liner. Includes adjustment for igniter hole in forward closure, nozzle hole in aft closure, length penalty for submerged nozzle, slots, and joints in the grain.

$$\mathbf{V}_{\mathrm{IL}} = \left(\mathbf{V}_{\mathrm{IL}} + \mathbf{V}_{\mathrm{IL}} + \mathbf{V}_{\mathrm{IL}}\right) + \mathbf{V}_{\mathrm{IL}}_{\mathrm{CLF}} + \mathbf{V}_{\mathrm{IL}}_{\mathrm{CLA}}$$
(228)

RESIDUAL INSULATION:

Volume of residual insulation.

$$V_{IN_{R}} = T_{IN_{R}} \left(\frac{V_{IL}}{T_{IL_{CY}}} \right) K_{IN_{5}} + K_{IN_{6}}$$
(229)

TOTAL INSULATION VOLUME:

Total internal insulation volume. Includes liner, wedges in forward and aft closure, inhibited slots and joints. (Figures 1, 2)

$$V_{IN} = (V_{IL} + V_{IW}_{CLA} + V_{IW}_{CLY} + V_{IS} + V_{IJ}) K_{IN_{7}} + K_{IN_{8}}$$
(230)



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Fig. 80.1-2 Typical Insulation Liner and Wedge Geometry

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Fig. 80.1-4 Liner Within Forward Closure, Volumes

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Fig. 80.1-6 Liner Within Aft Closure, Volumes



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Fig. 80, 1-16 Slot Inculation Subcomponents and Geometry

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NOTE: CUTOUTS = . TRUE. N_{IS}H1





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SEE FIGURE 17 FOR DETAILED GEOMETRY. NOTE: CUTOUT J = . TRUE. T_{IJ}PG1 JPGI OR IJ PG0 IJ PGO PGIJ(1) = . TRUE. EQUATION 196 PGIJ(2) = . TRUE. EQUATION 197 PGIJ(3) = .TRUE.EQUATION 199 LIJPGI ^{'IJ}PGI ,T_{IJ}PG1 ,^TIJ_{PG1} T_{IJ}PG1 L ^{IJ}PG0 L IJ_{FG0} IJ PG0 PGIJ(4) = . TRUE. EQUATION 200 PGIJ(5) = . TRUE. EQUATION 201 PGIJ(6) = .TRUE.EQUATION 202 LIJPGI LIJPGI T_{IJ}PG3 T_{IJ}PG1 T_{IJ}PG3 NPG3 IJ_{PG3} LIJPG0 ^{IJ}PG0 IJPG0 PGIJ(7) = . TRUE. EQUATION 203 PGIJ(8) = . TRUE. EQUATION 204 PGIJ(9) = . TRUE. EQUATION 205



Acceptable Polygons for Joint Port/Grain Component

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Fig. 80, 1-20 Slot and Joint Insulation Volumes

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Fig. 80.1-21 Displaced Propellent

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Fig. 80.1-22 Inter-Model Coupling

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INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|--------------------------------|---|---------------------------------|
| CING1 | C _{IN} , | Constant for QINH computation. | |
| | 1 | | 0.43 |
| CING2 | C _{IN} | Constant for QINH computation. | |
| | 2 | | 1000. |
| CING3 | CIN3 | Constant for TIWMAX, TISMAX TIJMAX computations. | and |
| | | | 0.00868 |
| KLIWFII | K _{LIWFII} | Proportionality coefficient for L
computation; | WHFI |
| | | N. D. | 1 |
| KLIWF12 | K _{LIWF12} | Bias for LIWHFI computation; | |
| | | in | 0 |
| LIJPGI | L _{IJ} PGI | Inside base of the polygon cross
associated with the port/grain in
component for joint cutouts; | section
sulation |
| | | in Fig. 17 | . 1 |
| LISPGI | L _{IS} PGI | Inside base of the polygon cross
associated with the port/grain in
component for slot cutouts; | section
sulation |
| | | in Fig. 16 | , 1 |
| NIJCUT | ^N ij _{cut} | Number of joint cutouts having be
burning surfaces inhibited. Inte-
real number (floating point integ | oth grain
ger valued
er); |
| | | N. D. | 0 |
| NISIHO | N _{ISIH0} | Number of slot cutouts having no
burning surfaces inhibited. Inte-
real number (floating point integ | grain
ger valued
er); |
| | | N. D. | 0 |

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| INPUT DATA, | INTRA-MODE | L (Cont.): | | |
|-------------|------------------------------|---|---|---------------------------------|
| Mnemonic | Symbol | Description; In | nt. (Int.) Units | Preset |
| NISIHI | NISIH1 | Number of slo
burning surfac
real number (1 | t cutouts having o
ee inhibited. Integ
floating point integ | ne grain
ger valued
ger); |
| | | N. D. | | 0 |
| QINSTAR | Q [*] _{IN} | Effective heat insulation; | of ablation of inte | rnal |
| | | btu/lb | | 0 |
| TILCY | T _{IL} CY | Thickness of i cylindrical sec | nsulation liner in
ction; | the |
| | | in | Fig. 2 | 0 |
| TINR | TIN | Thickness of r | esidual insulation | ; |
| | - 'R | in | | . 1 |

Due to the nature of this model, a very large number of coefficient and bias quantities (mnemonic with first character K) are made available for input. However, in normal applications the preset values are used for most, if not all, of these quantities. Note that these coefficient quantities are preset (1) and the bias quantities are preset (0).

LINER INSULATION COEFFICIENTS AND BIAS

| KILI | K _{IL} | Coefficient for TILCLF computation; | | |
|------|------------------|--|---------|--|
| | 1 | N. D. | 1 | |
| KIL2 | κ _{il2} | Bias for TILCLF computation;
in | 0 | |
| KIL3 | κ _{IL3} | Coefficient for VILCLF computation N. D. | ı;
1 | |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|-------------------------------|--|----------|
| KIL4 | κ _{IL4} | Bias for VILCLF computation; in^3 | 0 |
| KIL5 | κ _{IL5} | Coefficient for DILHAO computation N.D. | on;
1 |
| KIL6 | κ _{IL6} | Bias for DILHAO computation;
in | 0 |
| KIL7 | K _{IL7} | Coefficient for TILCLA computation. D. | on;
l |
| KIL8 | κ _{IL8} | Bias for TILCLA computation;
in | 0 |
| KIL9 | κ _{IL9} | Coefficient for VILCLA computati
N. D. | on;
l |
| KIL10 | κ _{IL} 10 | Bias for VILCLA computation; in ³ | 0 |
| KILII | κ _{IL} | Coefficient for LILCY computation N. D. | n;
1 |
| KIL12 | K _{IL} ₁₂ | Bias for LILCY computation;
in | 0 |
| KILI 3 | κ _{IL} 13 | Coefficient for VILCY computation N. D. | n;
1 |
| KIL14 | K _{IL14} | Bias for VILCY computation;
in | 0 |

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IN PUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|------------------------------|---|-----------|
| KIL15 | κ _{IL₁₅} | Coefficient for VIL computation;
N. D. | 1 |
| KIL16 | KIL ¹⁶ | Bias for VIL computation; in ³ | 0 |
| KIL17 | κ _{1L} 11 | Coefficient for DILHFO computat
N.D. | ion;
1 |
| KIL18 | K _{IL} 18 | Bias for DILHFO computation;
in | 0 |

JOINT INSULATION COEFFICIENTS AND BIAS

| KIJI | K _{IJ1} | Coefficient for TIJMAX computation N. D. | ı;
1 |
|-------|------------------|--|---------|
| KIJ2 | κ _{IJ2} | Bias for TIJMAX computation;
in | 0 |
| KIJ3 | κ _{IJ3} | Coefficient for LIJCUT computation N.D. | ı;
1 |
| KIJ4 | κ _{IJ4} | Bias for LIJCUT computation;
in | 0 |
| ь:IJ5 | K _{IJ5} | Coefficient for VIJPL computation;
N.D. | 1 |
| KIJ6 | K _{IJ6} | Bias for VIJPL computation;
in ³ | 0 |

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|--------------|--------------------|---|--------|
| KIJ7 | κ _{IJ7} | Coefficient for VIJPG computation;
N.D. | 1 |
| KIJ8 | κ _{IJ8} | Bias for VIJPG computation;
in ³ | 0 |
| KI J9 | κ _{IJ9} | Coefficient for VIJIH2 computation;
N.D. | 1 |
| KIJ10 | κ _{IJ10} | Bias for VIJIH2 computation;
in ³ | 0 |
| KIJII | κ _{IJ} 11 | Coefficient for VIJ computation;
N. D. | 1 |
| KIJ12 | K _{IJ12} | Bias for VIJ computation;
in ³ | 0 |

INPUT DATA, INTRA-MODEL (Cont.):

GENERAL INSULATION COEFFICIENTS AND BIAS

| KINI | κ _{IN1} | Coefficient for QINH computation;
N. D. | 1 |
|------|------------------|--|---------|
| KIN2 | κ _{IN2} | Bias for QINH computation; | 0 |
| KIN3 | K _{IN3} | Coefficient for TINMAX computation N. D. | n;
1 |
| KIN4 | κ_{IN_4} | Bias for TINMAX computation;
in | 0 |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|------------------------------|---|--------|
| KIN5 | κ _{IN5} | Coefficient for VINR computation;
N. D. | 1 |
| KIN6 | ^K IN ₆ | Bias for VINR computation;
in ³ | 0 |
| KIN7 | κ _{IN} ⁷ | Coefficient for VIN computation;
N. D. | 1 |
| KIN8 | κ _{IN8} | Bias for VIN computation;
in ³ | 0 |

SLOT INSULATION COEFFICIENTS AND BIAS

| KISI | κ _{IS 1} | Coefficient for TISMAX computati
N. D. | on;
1 |
|------|------------------------------|---|----------|
| KIS2 | K _{IS2} | Bias for TISMAX computation;
in | 0 |
| KIS3 | K _{IS3} | Coefficient for LISCUT computation N.D. | on;
1 |
| KIS4 | ^K IS ₄ | Bias for LISCUT computation;
in | 0 |
| KIS5 | ^K IS ₅ | Coefficient for VISPL computation N.D. | ; |
| KIS6 | κ _{is6} | Bias for VISPL computation; in ³ | 0 |

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INPUT DATA, INTRA-MODEL (Cont.):

| <u>Mnemonic</u> | Symbol | Description; Ext. (Int.) Units | Preset |
|-----------------|-------------------------------|---|---------|
| KIS7 | K _{IS7} | Coefficient for VISGL computation N. D. | n;
1 |
| KIS8 | κ _{IS8} | Bias for VISGL computation;
in ³ | 0 |
| KIS9 | κ _{is,} | Coefficient for VISPG computation N. D. | n;
1 |
| KISI 0 | κ _{is₁₀} | Bias for VISPG computation;
in ³ | 0 |
| KISI I | ^K IS ₁₁ | Coefficient for VISIH0 computation N. D. | n;
1 |
| KIS12 | K _{IS12} | Bias for VISIH0 computation; in^3 | 0 |
| KISI 3 | κ _{IS13} | Coefficient for VISIH1 computation N.D. | n;
1 |
| KIS14 | K _{IS14} | Bias for VISIH1 computation;
in ³ | 0 |
| KIS15 | к _{IS15} | Coefficient for VIS computation;
N. D. | 1 |
| KIS16 | ^K IS ₁₆ | Bias for VIS computation;
in ³ | 0 |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Presct | |
|---------------|--------------------|-------------------------------------|--------|--|
| WEDGE INSULAT | ION COEFFICI | ENTS AND BIAS | | |
| KIWI | κ _{iw.} | Coefficient for DIWHFO computation; | | |
| | 21 | N. D. | 1 | |
| KIW2 | κ _{ιw} | Bias for DIWHFO computation; | | |
| | 2 | in | 0 | |
| KIW3 | K _{IW} | Coefficient for LIWHF computation | 13 | |
| | 2 | N. D. | 1 | |
| KIW4 | KIWA | Bias for LIWHF computation; | | |
| | - | in | 0 | |
| KIW7 | K _{IW7} | Coefficient for VIWCLF computation | on; | |
| | • | N. D. | 1 | |
| KIWti | κ _{IW} , | Bias for VIWCLF computation; | | |
| | · | in | 0 | |
| KIW'? | κ _{IWg} | Coefficient for TIWAMAX computat | ion; | |
| | | N. D. | 1 | |
| KIW10 | K _{IW10} | Bias for TIWAMAX computation; | | |
| | | in | 0 | |
| KIW11 | K _{JW} 11 | Coefficient for DIWHAO computation | on; | |
| | | N, D. | 1 | |
| KIW12 | K _{IW} 12 | Blas for DIWHAO computation; | 0 | |
| | | in | U | |
| KIW13 | K _{IW13} | Coefficient for DIWHAI computatio | n; | |
| | | N, D, | 1 | |

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset | | | |
|----------------|-------------------------------|-------------------------------------|-------------------------------------|--|--|--|
| KIW14 | ^K IW ₁₄ | Coefficient for DIWHAI computa | Coefficient for DIWHAI computation; | | | |
| | | N. D. | 1 | | | |
| KIW15 | KIW16 | Coefficient for DIWHAI computa | tion; | | | |
| | 10 | N. D. | 1 | | | |
| KIW16 | K _{TW} | Bias for DIWHAI computation; | | | | |
| | - 16 | in | 0 | | | |
| KIW17 | K., | Coefficient for LIWHA computat | ion; | | | |
| | ¹ ^w 17 | N. D. | 1 | | | |
| KIW18 | К | Bias for LIWHA computation: | | | | |
| | - ^{1W} 18 | in | 0 | | | |
| E1 1110 | V | Coefficient for WWCLA comput | ations | | | |
| KIW19 | ^r IW ₁₉ | N. D. | 1.
1. | | | |
| | | | | | | |
| KIW20 | KIW20 | Bias for VIWCLA computation;
. 3 | • | | | |
| | | in | 0 | | | |
| KIW21 | K _{IW} 21 | Coefficient for TIWFMAX comp | utation; | | | |
| | <u> </u> | N. D. | 1 | | | |
| KIW22 | K _{tw} | Bias for TIWFMAX computation; | | | | |
| | ~~~ 22 | in | 0 | | | |
| KIW23 | K _{7W} | Coefficient for TIWMAX computation: | | | | |
| | 1 1 23 | N. D. | 1 | | | |
| KIW24 | К | Bias for TIWMAX computation: | | | | |
| | ⁻¹ ^w 24 | | 0 | | | |

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|--------------------|--|-----------|
| Ki Dl | κ _{pd1} | Coefficient for VIWCFPD computat | ion;
1 |
| KPD2 | K _{PD2} | bias for VIWCFPD computation;
in ³ | 0 |
| KPD3 | K _{PD3} | Coefficient for VIWCAPD computat | ion;
1 |
| KPD4 | κ _{pd4} | Bias for VIWCAPD computation; | 0 |
| KPD5 | K _{PD5} | Coefficient for VIWPD computation N. D. | ;
1 |
| KPD6 | κ _{pd} | Bias for VIWPD computation;
in ³ | 0 |
| KPD7 | κ _{pd7} | Coefficient for VISPD computation;
N.D. | 1 |
| KPD8 | κ _{pd8} | Bias for VISPD computation;
in ³ | 0 |
| KPD9 | κ _{pdg} | Coefficient for VINPD computation N. D. | ;
1 |
| KPD10 | κ _{pd} 10 | Bias for VINPD computation;
in ³ | 0 |

INPUT DATA, INTRA-MODEL (Cont.):

INTERNAL INSULATION GEOMETRY

INPUT DATA, INTER-MODEL:

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This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; | Ext. (Int.) Units | Model Type | | |
|----------|-------------------------------|--|---|-------------------------------|--|--|
| DCSHAI | D _{CS_{HAI}} | Diameter of
closure surf | hole in aft inside ca
face; | inside case | | |
| | | in | Figs. 2, 22 | CASEG | | |
| DCSHFI | D _{CS} HFI | Diameter of
closure surf | hole in forward ins
face; | ide case | | |
| | | in | Figs. 2, 22 | CASEG | | |
| DCSI | D _{CS} | Inside case | diameter, cylindri | cal section; | | |
| | υJ | in | Figs. 2, 22 | CASEG | | |
| DPT | D _{PT} | Diameter of cylindrical section of port; | | | | |
| | | in | Figs. 2, 21, 22 | GRAING | | |
| DPTCFA | D _{CFA} | Aft base dia
section requ | Aft base diameter of the port cone frustum section required for nozzle submergence; | | | |
| | | in | Figs. 21, 22 | GRAING | | |
| DPTCFF | D _{CFF} | Forward bas
frustum sec
submergenc | se diameter of the p
tion required for no
e; | oort cone
ozzle | | |
| | | in | Figs. 11, 13, 21, 2 | 22 GRAING | | |
| LGNCY4 | LGNCY4 | Length of cy
Includes len
submergenc | vlindrical grain sect
gth penalty for nozz
e, joint cutouts and | tion.
tle
slot cutouts; | | |
| | | in | Figs. 2, 21, 22 | GRAING | | |
| LJTCUT | LIT | Total length | of cut in grain for | joints; | | |
| | ⁵ CUT | in | Fig. 22 | GRAING | | |

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Descriptio | n; Ext. (Int.) Units | Model Type | |
|----------|-------------------|---|---|--|--|
| LPTCFCA | L _{CFCA} | Length of
section, r
within the
closure eq | the portion of the por
equired for nozzle su
aft closure. Positive
uatorial plane toward | t cone frustum
ibmergence,
e sense from
is aft; | |
| | | in | Figs. 21, 22 | GRAING | |
| LPTCFCY | LCFCY | Length of
which is w | the portion of the por
ithin the cylindrical | t cone frustum
section; | |
| | | in | Figs. 11, 13, 21, | 22 GRAING | |
| LSLGN | LSI | Total slot | length; | | |
| | GN | in | Fig. 22 | IBFLOW | |
| RDCSCAI | RDCSCAL | Head ratio, aft inside case closure surface; | | | |
| | 200014 | N. D. | Fig. 22 | CASEG | |
| RDCSCFI | RDCSCFI | Head rations surface; | e closure | | |
| | | N. D. | Figs. 21, 22 | CASEG | |
| RHOIJ | | Density of insulation for joint cutouts; | | | |
| | 10 | lb/in ³ | Fig. 22 | INSULW | |
| RHOIS | ρ _{is} | Density of insulation for slot cutouts; | | | |
| | 15 | lb/in ³ | Fig. 22 | INSULW | |
| RHOIW | ρ _{tw} | Density of | insulation for closur | e wedges; | |
| | | lb/in ³ | Fig. 22 | INSULW | |
| TBPPMT | TB | Propellen | t burn time; | | |
| | J | sec | Fig. 22 | IBPERF | |

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units Model Type |
|----------|-----------------|---|
| TCPP | | Propellent combustion temperature; |
| | OPP | ^o R Fig. 22 IBGAS |
| THETACF | θ _{CF} | Half-angle of port cone frustum section; |
| | UI | deg (rad) Figs. 2, 11, 13, 21, 22 GRAING |
| TPPWEB | | Thickness of propellent web; |
| | WEB | in Figs. 2, 16, 17, 22 GRAING |

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INTERNAL INSULATION GEOMETRY

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OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol | Description; | Ext. (Int.) Units | | |
|----------|---------------------------------------|---|--|--|--|
| AIJPG | ^A IJ _{PG} | Area of the polygon cross section associated
with the port/grain insulation component for
joint cutouts; | | | |
| ATCPC | • | | - ·B· · · | | |
| AISPG | ^A IS _{PG} | with the port
slot cutouts; | t/grain insulation of | component for | |
| | | in ² | Fig. 16 | Eq. 168 | |
| AIWHAT | AIW HAT | Area of triangular wedge section, associated
with the cone frustum cutout for the nozzle,
within the aft case closure section; | | | |
| | | in ² | Figs. 12, 14 | Eq. 152 | |
| COSTCF | $\cos \left(\theta_{\rm CF} \right)$ | Cosine of Th | HETACF; | | |
| | | N. D. | | | |
| CUTOUTJ | CUTOUTJ | CUTOUTJ (CUT OUT in grain for Joint) is
a logical variable which specifics if there
are joint cutouts within the grain which
require insulation. | | | |
| | | . TR UE. ; | there is at least
cutout requiring
Both surfaces o
inhibited. | t one joint
; insulation.
f a joint are | |
| | | .FALSE.; | there are no joi
requiring insula | nt cutouts
ition; | |
| | | N. D. | | Eq. 157-b | |
| CUTOUTS | CUTOUTS | CUTOUTS (CUT OUT in grain for <u>Slot</u>) is a logical variable which specifies if there are slot cutouts within the grain which require insulation. | | for <u>S</u> lot) is a
s if there are
hich require | |

INTERNAL INSULATION GEOMETRY

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OUTPUT DATA (Cont.):

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| Mnemonic | Symbol | Description; Ext. (Int.) Units |
|----------|-------------------|--|
| | | .TRUE.; there is at least one slot cutou
requiring insulation. Either o
or no slot burning surface may
be inhibited. |
| | | .FALSE.; there are no slot cutouts requiring insulation. |
| | | N. D. Eq. 157 |
| CIWA | C _{IW} A | Intermediate computation for DIWCAI evaluation; |
| | | N.D. Eq. 120 |
| CIWAP | CIWAP | Intermediate computation for LIWCFAI evaluation; |
| | | N. D. Eq. 216 |
| CIWB | c _{iwb} | Intermediate computation for DIWCAI evaluation; |
| | | in Eq. 121 |
| CIWBP | CIWBP | Intermediate computation for LIWCFAI evaluation; |
| | | in Eq. 217 |
| CIWC | c _{iwc} | Intermediate computation for DIWCAI evaluation; |
| | | in ² Eq. 122 |
| CIWCP | CIWCP | Intermediate computation for LIWCFAI evaluation; |
| | | in ² Eq. 218 |
| DILCLI | DILCLI | Equatorial diameter of the ellipsoids formed
by the inside surface of the insulation liner
associated with the forward and aft case
closure sections; |
| | | in Figs. 3. 5 Eq. 6 |

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INTERNAL INSULATION GEOMETRY

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|---|----|---|----|-----|----|---------|----|
| _ | - | _ | | | | | |

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
|----------|---------------------------------|---|------------|--------|--|
| DILCLO | DILCLO | Equatorial diameter of the ellipsoids formed
by the outside surface of the insulation liner
associated with the forward and aft case
closure sections; | | | |
| | | in | Figs. 3, 5 | Eq. 5 | |
| DILHAI | D _{IL} HAI | Diameter of circular hole, for the nozzle,
centered on the axis of revolution of the
hemi-ellipsoid formed by the inside surface
of the insulation liner within the aft case
closure section; | | | |
| | | in | Figs. 2, 5 | Eq. 40 | |
| DILHAO | D _{IL} HAO | Diameter of circular hole, for the nozzle,
centered on the axis of revolution of the
hemi-ellipsoid formed by the outside surface
of the insulation liner within the aft
case closure section; | | | |
| | | in | Fig. 5 | Eq. 34 | |
| DILHFI | D _{IL} _{HFI} | Diameter of circular hole, for the ignitor,
centered on the axis of revolution of the hemi-
ellipsoid formed by the inside surface of the
insulation liner within the forward case
closure section: | | | |
| | | in | Fig. 3 | Eq. 15 | |
| DILHFO | D _{IL} _{HF} O | Diameter of circular hole, for the ignitor,
centered on the axis of revolution of the
hemi-ellipsoid formed by the outside surface
of the insulation liner within the forward
case closure section; | | | |
| | | in | Fig. 3 | Eq. 9 | |
| DILI | DILI | Inside diameter of the cylinder which is
the inside surface of the insulation liner in
the cylindrical case section; | | | |
| | | in | Fig. 2 | Eq. 4 | |
| DILO | D _{IL} O | Outside diameter of the cylinder which is
the outside surface of the insulation liner
in the cylindrical case section; | | | |
| | | in | Fig. 2 | Eq. 3 | |

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| OUTPUT DATA | A (Cont.): | | | | |
|--|----------------------|--|--|---|--|
| Mnemonic | Symbol | Descripti | on; Ext. (Int.) Units | | |
| DIWAL | DIWAI | Intermediate computation for LIWCFAI,
DIWCFAI evaluation; | | | |
| | | in | | Eq. 215 | |
| DIWCAI | DIWCAI | Diameter of the circle of osculation formed
by the tangency points of the inside aft
wedge surface hemi-ellipsoid and the outsid
aft wedge surface hemi-ellipsoid. See
IWINACL; | | | |
| | | in | Figs. 11, 15 | Eqs. 119,123 | |
| DIWCFAI | D _{IW} CFAI | Diameter of the circle formed by the inter-
section of the grain cone frustum cutout with
the inside surface of the insulation wedge
associated with the aft closure section: | | | |
| | | in | | Eq. 220 | |
| DIWCFI | D _{IW} CFI | Diameter of the circle of osculation formed
by the tangency points of the inside forward
wedge surface hemi-ellipsoid and the outside
forward wedge surface hemi-ellipsoid. See
IWINFCL: | | | |
| | | in | Figs. 7, 9 | Eqs. 73, 77 | |
| DIWCLO | DIWCLO | Equatorial diameter of the hemi-eliipsoids
formed by the outside surface of the insula-
tion wedges associated with the forward and
aft closure sections; | | | |
| | | in | Figs. 7, 9, 11, 1 | 3 Eq. 60 | |
| DIWEAI | D _{IW} EAI | Equatorial diameter of the hemi-ellipsoid
associated with the inside surface of the
insulation wedge in the aft case closure
section. See IWINACL; | | | |
| | | in | Figs. 11, 13 | Eqs. 128,130 | |
| DIWEFI D _{IW} EFI asso
insu
See | | Equatoria
associate
insulatior
See IWIN | al diameter of the he
d with the inside sur
n wedge in the forwa
FCL; | mi-ellipsoid
face of the
rd case closure. | |
| | | in | Figs. 7, 9 | Eqs. 76, 79 | |

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| OUTPUT DAT | A (Cont.): | | | | |
|------------|--------------------------------|---|---|--|--|
| Mnemonic | Symbol | Description | ; Ext. (Int.) Units | | |
| DIWHAI | D _{IWHAI} | Diameter of the forward base of the confrustum hole, for the nozzle cutout, centered on the axis of revolution of the hemi-ellipsoid formed by the inside su of the insulation wedge associated with aft case closure section; | | | |
| | | in | Figs. 11, 13 | Eq. 110 | |
| DIWHAO | ^D IW _{HAO} | Diameter of the aft base of the cone fru-
hole, for the nozzle cutout, centered on
axis of revolution of the hemi-ellipsoid
formed by the outside surface of the ins
wedge associated with the aft case closu
section; | | | |
| | | in | Figs. 11, 13 | Eq. 109 | |
| DIWHFI | DIWHFI | Diameter of the circular hole, for the
centered on the axis of revolution of t
ellipsoid formed by the inside surface
insulation wedge associated with the f
case closure section; | | for the ignitor,
on of the hemi-
urface of the
h the forward | |
| | | in | Figs. 7, 9 | Eq. 63 | |
| DIWHFO | D _{IW} HFO | Diameter of
centered on
ellipsoid for
insulation w
case closur | the circular hole,
the axis of revoluti
rmed by the outside
redge associated wit
e section; | for the ignitor,
on of the hemi-
surface of the
h the forward | |
| | | in | Figs. 7, 9 | Eq. 62 | |
| GOODPGJ | GOODPGJ | GOODPGJ i
indicates an
for the port
associated y | s a logical valued va
acceptable polygon
/grain insulation co
with the joint cutouta | ariable which
cross section
mponent
3. | |
| | | =. TRUE. ; | PG component for
tion is an acceptal
The particular pol
determined by ref | joint insula-
ble polygon.
lygon may be
erring to PGIJ. | |

INTERNAL INSULATION GEOMETRY

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| OUTPUT DATA | (Cont.): | | | |
|-------------|---------------------|--|---|--|
| Mnemonic | Symbol | Description | ; Ext. (Int.) Units | |
| | | =.FALSE.; | PG component for joint insula-
tion is not an acceptable
polygon. Joint insulation
geometry may be bad. | |
| | | N. D. | | |
| GOODPGS | GOODPGS | GOODPGS i
indicates an
for the port
associated v | GOODPGS is a logical valued variable which
indicates an acceptable polygon cross section
for the port/grain insulation component
associated with the slot cutouts: | |
| | | =. TRUE. , | PG component for slot insula-
tion is an acceptable polygon.
the particular polygon may be
determined by referring to
PGIS. | |
| | | =.FALSE., | PG component for slot insula-
tion is not an acceptable
polygon. Slot insulation
geometry may be bad; | |
| | | N. D. | | |
| IJNOT LN | IJNOT LN | Intermediat
computation | e logical quantity for PGIJ
1; | |
| | | N. D. | Eq. 198 | |
| ISNOTLN | ISNOTLN | Intermediat
computation | e logical quantity for PGIS | |
| | | N. D. | Eq. 173 | |
| IWINACL | Iwin _{ACL} | IWINACL (I
is a logical
insulation w
closure is c | nsulation Wedge IN Aft Closure)
variable which specifies if the
vedge associated with the aft
completely within the aft closure; | |
| | | =. TRUE. ; | the insulation wedge is
completely within the aft
closure. See Figs. 11, 12. | |

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| OUTPUT DAT | A (Cont.): | | | |
|------------|------------|---|--|---|
| Mnemonic | Symbol | Description; Ext. (Int.) Units | | |
| | | =. FALSE. ; | the insulation of
beyond the aft
cylindrical sec
to the intersec
closure and cy
See Figs. 13, | wedge extends
closure into the
tion, or extends
tion of the aft
lindrical section.
14; |
| | | N. D. | | Eq. 118 |
| IWINFCL | IWINFCL | IWINFCL (Insulation Wedge IN Forward
CLosure) is a logical variable which speci-
fies if the insulation wedge associated with
the forward closure is completely within the
forward closure; | | |
| | | =. TRUE. ; | wedge is comple
forward closure | etely within the
. See Fig. 7. |
| | | =. FALSE. ; | wedge extends b
closure into the
section or exten
section of the fo
and cylindrical
Fig. 9; | eyond the forward
cylindrical
ds to the inter-
rward closure
section. See |
| | | N. D. | | Eq. 72 |
| LIJCUT | LIJCUT | Length of a single joint cutout for computation; | | ut for insulation |
| | | in | Fig. 17 | Eq. 181 |
| LIJPG3 | LIJPG3 | Intermediate quantity required for the determination of the outside base of the polygon cross section associated with the port/grain insulation component for joint cutouts; | | |
| | | in | Fig. 17 | Eq. 183 |
| LIJPGO | LIJPGO | Outside base of the polygon cross secti
associated with the port/grain insulatio | | cross section
in insulation
s; |
| | | in | Fig. 17 | Eqs. 184,185 |

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INTERNAL INSULATION GEOMETRY

OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
|----------|---|--|--|-------------------------------------|--|
| LILCHAI | LILCHAI | Length of hemi-ellipsoidal frustum
associated with the inside surface of the
insulation liner within the aft case closure; | | | |
| | | in | Fig. 5 | Eq. 42 | |
| LILCHAO | LIL CHAO | Length of hemi-ellipsoidal frustum
associated with the outside surface of the
insulation liner within the aft case
closure section; | | | |
| | | in | Fig. 5 | Eq. 36 | |
| LILCHFI | L _{IL} CHFI | Length of the hemi-ellipsoidal frustum
associated with the inside surface of the
insulation liner within the forward case
closure; | | | |
| | | in | Figs. 2, 3 | Eq. 17 | |
| LILCHFO | L _{IL} CHFO | Length of hemi-ellipsoidal frustum
associated with the outside surface of th
insulation liner within the forward closu
section; | | | |
| | | in | Figs. 2, 3 | Eq. 11 | |
| LILCLAI | L _{IL} CLAI | Length of the axis of revolution of the
ellipsoid formed by the inside surface
insulation liner within the aft case clo
section; | | the hemi-
face of the
closure | |
| | | in | Fig. 5 | Eq. 38 | |
| LILCLAO | L _{IL} CLAO | Length of the axis of revolution of the h
ellipsoid formed by the outside surface
the insulation liner within the aft case
closure section; | | the hemi-
rface of
case | |
| | | in | Figs. 5, 6 | Eq. 33 | |
| LILCLFI | Length of the axis of revolu-
ILCLFI ellipsoid formed by the ins-
insulation liner within the f
closure section: | | axis of revolution of
ned by the inside sur
er within the forward
on; | the hemi-
face of the
case | |
| | | in | Fig. 3 | Eq. 13 | |
| | | | | | |

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INTERNAL INSULATION GEOMETRY

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| OUTPUT DAT. | A (Cont.): | | | | |
|-------------|------------|--|---|--|--|
| Mnemonic | Symbol | Description, Ext. (Int.) Units | | | |
| LILC LFO | LILCLFO | Length o
ellipsoid
the insul
closure i | Length of the axis of revolution of the hemi-
ellipsoid formed by the outside surface of
the insulation liner within the forward case
closure section; | | |
| | | in | Figs. 3, 4 | Eq. 8 | |
| LILCY | LILCY | Length of insulation liner within t
cylindrical case section. Include
adjustment for submerged nozzle,
and joints; | | in the
udes length
zle, slots | |
| | | in | Fig. 2 | Eq. 226 | |
| LILHA | | Length of cylindrical hole, for the nozzle,
in the insulation liner within the aft case
closure section; | | | |
| | | in | Fig. 5 | Eq. 43 | |
| LILHF | LILHE | Length of cylindrical hole, for the ign
in the insulation liner within the forw
case closure section; | | r the ignitor,
he forward | |
| | | in | Fig. 3 | Zq. 18 | |
| LISCUT | LISCUT | Length of a single slot cutout for computations; | | for insulation | |
| | | in | Fig. 16 | Eq. 162 | |
| LISPGO | LISPGO | Length o
section a
insulatio | f outside base of the p
associated with the po
n component for slot | polygon cross
rt/grain
cutouts; | |
| | | in | Fig. 16 | Eq. | |
| LIWAI | LIWAI | Distance from the pole of the hemi-el
associated with the inside surface of
insulation wedge in the aft closure to
closure "inside/outside surface wedg | | hemi-elliv
face of the
sure to the arr
ce wedge | |
| | | in | -
Figs. 11, 13 | Eq. 133 | |

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| Mnemonic | Symbol | Description; Ext. (Int.) Uni | ts | |
|----------|----------------------|---|--|--|
| LIWAI | L _{IWA1} | Intermediate computation for VIWCAPD evaluation; | | |
| | | in | Eq. 213 | |
| LIWA2 | LIWA2 | Intermediate computation for VIWCAPD evaluation; | | |
| | | in | Eq. 214 | |
| LÍWCAI | LIWCAI | Distance from the "equatorial plane of the
aft closure outside wedge surface hemi-
cllipsoid" to the "inside/outside wedge sur-
face osculation plane". Measured along the
axis of revolution, positive serse aft. A
positive value indicates that the wedge is
completely within the aft closure. A negative
value indicates that the wedge extends beyond
the aft closure into the cylindrical section.
See IWINACL; | | |
| | | in Figs. 11, 13 | Eqs. 117, 124 | |
| LIWCEAI | L _{IW} CEAI | Distance from the equatorial plane of the
hemi-ellipsoid associated with the outside
surface of the insulation wedge in the aft
case closure section to the equatorial plane
of the hemi-ellipsoid associated with the
inside surface of the insulation wedge in th
aft case closure section. See IWINACL; | | |
| | | in Figs. 11, 13 | Eqs. 126,129 | |
| LIWCEFI | L _{IW} cefi | Distance from the equatoria
hemi-ellipsoid associated w
surface of the insulation we
case closure to the equator
hemi-ellipsoid associated w
surface of the insulation we
case closure; | al plane of the
with the outside
edge in the forwar
ial plane of the
with the inside
edge in the forwar | |
| | | in Figs. 7. 9 | Eas. 74. 78 | |

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| OUTPUT DATA | A (Cont.): | | | |
|-------------|---------------------------------|--|---|--|
| Mnemonic | Symbol | Descriptio | on; Ext. (Int.) Units | |
| LIWCFAI | LIWCFAI | Distance from the equatorial plane of the
hemi-ellipsoid associated with the outside
surface of the insulation wedge in the aft
closure to the intersection of the grain con
frustum cutout with the inside surface of th
insulation wedge in the aft closure.
Measured parallel to centerline; | | |
| | | in | | Eq. 219 |
| LIWCFI | LIWCFI | Distance from the equatorial plane of the
hemi-ellipsoid associated with the outside
surface of the insulation wedge in the forwar
case closure to the "inside/outside wedge
surface osculation plane." Note that the
insulation wedge is not completely within the
forward closure section if LIWCFI is
negative. See IWINFCL; | | |
| | | in | Figs. 7, 9 | Eq. 71 |
| LIWCHAI | L _{IW} CHAI | Distance from the equatorial plane of the
hemi-ellipsoid associated with the outsid
surface of the insulation wedge in the aft
closure section to forward base of the co
frustum hole, for the nozzle cutout, with
the insulation wedge in the aft case closu
section: | | plane of the
the outside
in the aft case
e of the cone
utout, within
case closure |
| | | in | Figs. 11, 13 | Eq. 116 |
| LIWCHAO | LIW CHAO | Length of
associate
insulation
section; | the hemi-ellipsoid fr
d with the outside sur
wedge in the aft cas | rustum
rface of the
e closure |
| | | in | Figs. 11, 13 | Eq. 115 |
| LIWCHFI | ^L IW _{CHFI} | Distance
hemi-elli
surface o
closure to
hole cutor
insulation | from the equatorial p
psoid associated with
f the insulation wedge
o the inside base of th
at for the ignitor with
wedge in the forwar | plane of the
in the outside
in the forward
he cylindrical
hin the
d closure; |
| | | in | Figs. 7, 9 | Eq. 69 |

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| OUTPUT DATA | A (Cont.): | | | | |
|-------------|--|---|---|--|--|
| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
| LIWCHFO | L _{IW} CHFO | Length of the hemi-ellipsoid frustum
associated with the outside surface of the
insulation wedge in the forward case
closure section; | | | |
| | | in | Figs. 7, 9 | Eq. 68 | |
| LIWCLAI | LIW CLAI | Distance from the pole of the hemi-ellipsoi
associated with the inside surface of the
insulation wedge in the aft closure to the
equatorial plane of the hemi-ellipsoid
associated with the outside surface of the
insulation wedge in the aft closure; | | | |
| | | in | Figs. 11, 13 | Eq. 132 | |
| LIWCLAO | L _{IW} CLAO | Length of
ellipsoid a
of the ins
section; | the axis of revolution
associated with the o
ulation wedge in the a | ntion of the hemi-
le outside surface
he aft closure | |
| | | in | Figs. 11, 13 | Eq. 113 | |
| LIWCLFI | ^L IW _{CLFI} | Distance from the pole of the hemi-ellipso
associated with the inside surface of the
insulation wedge in the forward closure to
the equatorial plane of the hemi-ellipsoid
associated with the outside surface of the
insulation wedge in the forward closure; | | | |
| | | in | Figs. 7, 9 | Eq. 82 | |
| LIWCLFO | IWCLFO Length
IWCLFO ellipsoi
of the in
closure | | the axis of revolutio
associated with the o
ulation wedge in the f
ection; | n of the hemi-
utside surface
forward | |
| | | in | Figs. 7, 9 | Eq. 66 | |
| LIWEAI | L _{IW} EAI | Length of the axis of revolution of the h
ellipsoid associated with the inside surf
of the insulation wedge in the aft case
closure section: | | r of the hemi-
nside surface
aft case | |
| | | in | Figs. 11, 13 | Eqs. 127,131 | |

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INTERNAL INSULATION GEOMETRY

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| OUTPUT DATA | 4 (Cont.): | | | |
|-------------|---------------------------------|--|-----------------------|---|
| Mnemonic | Symbol | Descripti | on; Ext. (Int.) Units | |
| LIWEFI | L _{IWEFI} | Length of the axis of revolution of the hemi-
ellipsoid associated with the inside surface
of the insulation wedge in the forward case
closure. See IWINFCL; | | |
| | | in | Figs. 7, 9 | Eqs. 75, 81 |
| LIWEHAI | ^L IW _{EHAI} | Distance from the equatorial plane of the
hemi-ellipsoid associated with the inside
surface of the insulation wedge in the aft
case closure to the inside base of the cone
frustum cutout within the insulation wedge
the aft case closure section; | | |
| | | in | Figs. 11, 13 | Eq. 134 |
| LIWEHFI | ^L IW _{EHFI} | Distance from the equatorial plane of the
hemi-ellipsoid associated within the inside
surface of the insulation wedge in the forward
case closure to the inside base of the
cylindrical hole cutout for the ignitor within
the insulation wedge in the forward closure; | | |
| | | in | Figs. 7, 9 | Eq. 84 |
| LIWFI | L _{IW_{FI}} | Distance from the pole of the hemi-ellipsoid
associated with the inside surface of the
insulation wedge in the forward closure to
the forward closure inside/outside wedge
surface osculation plane; | | |
| | | in | Figs. 7, 9 | Eq. 83 |
| LIWHA | LIWHA | Altitude of the cone frustum, for the nozzle cutout, within the insulation wedge of the aft case closure section; | | |
| | | in | Fige. 11, 13 | Eq. 111 |
| LIWHAI | LIW _{HAI} | Distance from the "inside/outsi
surface osculation plane" to the
of the cone frustum hole cutout
insulation wedge for the nozzle: | | side wedge
he inside base
it of the
e; |
| | | in | Figs. 11, 13 | Eq. 125 |
INTERNAL INSULATION GEOMETRY

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
|----------|--------------------------------|--|---|---|--|
| LIWHF | ^L IW _{HF} | Length of the cylindrical hole, for the ignitor, within the insulation wedge of the forward case closure section: | | | |
| | | in | Figs. 7, 9 | Eq. 64 | |
| LIWHFI | ^L IW _{HFI} | Distance from the inside/outside wedge
surface osculation plane to the inside base
of the cylindrical hole cutout for the ignito | | | |
| | | in | Figs. 7, 9 | Eq. 70 | |
| NISCUT | ^N IS _{CUT} | Number of slot cutouts in grain to be insulated. Integer valued real number (floating point integer); | | | |
| | | N. D. | | Eq. 157 | |
| PGIJ(i) | PGIJ(i) | Logical va
particular
port/grain
with joint
PGIJ will
elements
indicating
(e.g., lin
for the PC
the key id | alue array which ide
polygon cross sector
insulation compone
cutouts. The i-the
have the value. TR
will be . FALSE.),
the particular poly
e, triangle, trapeze
Component. See I
entifying the i-th el | entifies the
tion of the
ent associated
element of
UE. (all other
thereby
gon shape
oid, pentagon)
Fig. 19 for
lement; | |
| | | N. D. | Fig. 19 | Eqs. 196-205 | |
| PGIJLAP | PGIJLAP | Logical va
overlappin
associated
componen | alued variable which
ng of the polygon cr
i with the port/grai
t for joint cutouts; | h indicates
coss sections
in insulation | |
| | | =. TRUE. | PG components of | overlap. | |
| | | =. FALSE | ; PG components of | do not overlap; | |
| | | N. D. | Fig. 19 | Eq. 183-a | |

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol | Description; Ext. (Int.) Ur | nits | |
|-----------------------------|---------------------|---|----------------------|--|
| PGIS(i) | PGIS(i) | Logical valued array which identifies the
particular polygon cross section of the
port/grain insulation component associated
with slot cutouts. If a slot burning surface
inhibited, the i-th element of PGIS will have
the value . TRUE. (all other elements will
be . FALSE.), thereby indicating the
particular polygon shape (e.g., line,
triangle, trapezoid) for the PG component.
See Fig. 18 for the key identifying the i-th
element;
N. D. Fig. 18 Eqs. 171- | | |
| QINH | Q _{IN} H | Approximate radiative he
N. D. | ating rate;
Eq. l | |
| RDILCAI | RDILCAI | Head ratio of the ellipsoid formed by the inside surface of the insulation liner within the aft case closure section; | | |
| | | N. D. | Eq. 39 | |
| RDILCAO | RDILCAO | Head ratio of the ellipsoid formed by the
outside surface of the insulation liner
within the aft case closure section: | | |
| | | N. D. | Eq. 32 | |
| RDILCFI ^R DILCFI | | Head ratio of the ellipsoid formed by the inside surface of the insulation liner within the forward case closure section; | | |
| | | N. D. | Eq. 14 | |
| RDILCFO | ^R dilcf0 | Head ratio of the ellipsoid formed by the
outside surface of the insulation liner
within the forward case closure section; | | |
| | | N. D. | Eq. 7 | |

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| OUTPUT DAT. | A (Cont.): | | |
|-------------|---------------------|--|---|
| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
| R DILHAI | ^R DILHAI | Diameter ratio, hole diameter t
diameter, inside surface of the
liner within the aft case closure | o equatorial
insulation
section; |
| | | N. D. | Eq. 41 |
| RDILHAO | ^R DILHAO | Diameter ratio, hole diameter t
diameter, outside surface of the
liner within the aft case closure | o equatorial
insulation
section; |
| | | N. D. | Eq. 35 |
| RDILHFI | ^R dilhfi | Diameter ratio, hole diameter t
diameter, inside surface of the
liner within the forward case cl | o equatorial
insulation
osure section |
| | | N. D. | Eq. 16 |
| RDILHFO | ^R DILHFO | Diameter ratio, hole diameter t
diameter, outside surface of the
liner within the forward case clu
section; | o equatorial
insulation
osure |
| | | N. D. | Eq. 10 |
| RDIWCAI | RDIWCAI | Head ratio of the ellipsoid assout
the inside surface of the insulat
in the aft closure section; | ciated with
ion wedge |
| | | N. D. | Eq, 131-a |
| RDIWCAO | RDIWCAO | Head ratio of the ellipsoid assoc
the outside surface of the insula
within the aft case closure secti | ciated with
tion wedge
on; |
| | | N. D. | Eq. 112 |
| RDIWCFI | R _{DIWCFI} | Head ratio of the ellipsoid association inside surface of the insulation forward closure section; | ciated with the wedge in the |
| | | N. D. | Eq. 81-a |

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | | |
|----------|----------------------|---|-----------------------|--|
| RDIWCFO | RDIWCFO | Head ratio of the ellipsoid associated with
the outside surface of the insulation wedge
within the forward case closure section; | | |
| | | N. D. | Eq. 65 | |
| RDIWHAO | ^R di whao | AO Diameter ratio, aft base of cone for
hole to equatorial diameter, outside
of the insulation wedge in the aft conclusion closure section; | | |
| | | N. D. | Eq. 114 | |
| RDIWHFI | R _{DIWHFI} | Diameter ratio, hole diameter to equatorial
diameter, inside surface of insulation wedge
in the forward case closure; | | |
| | | N. D. | Eq. 80 | |
| RDIWHFO | ^R diwhfo | O Diameter ratio, hole diameter to equatorial diameter, outside surface of the insulation wedge in the forward case closure section; | | |
| | | N. D. | Eq. 67 | |
| RIJLCAI | RLILCAI | Length ratio, hemi-ellipsoid fru
hemi-ellipsoid, inside surface,
liner, forward case closure; | stum to
insulation | |
| | | N. D. | Eq. 52 | |
| RLILCAO | RLILCAO | Length ratio, hemi-ellipsoid fru
hemi-ellipsoid, outside surface,
liner, aft case closure; | stum to
insulation | |
| | | N. D. | Eq. 46 | |
| RLILCFI | RLILCFI | Length ratio, hemi-ellipsoid fru
hemi-ellipsoid, inside surface,
liner, forward case closure; | stum to
insulation | |
| | | N. D. | Eq. 27 | |

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| OUTPUT DAT. | A (Cont.): | | |
|-------------|---------------------|---|---|
| Mnemonic | Symbol | Description; Ext. (Int.) Units | |
| RLILCFO | ^R LILCFO | Length ratio, hemi-ellipsoid fr
hemi-ellipsoid, outside surface
liner, forward case closure; | ustum to
e, insulation |
| | | N. D. | Eq. 21 |
| RLIWCAI | RLIWCAL | Length ratio, hemi-ellipsoid fr
hemi-ellipsoid, outside surfact
wedge, aft case closure section | ustum to
e, insulation
n; |
| | | N. D. | Eq. 136 |
| RLIWCA2 | RLIWCAZ | Length ratio, hemi-ellipsoid fr
equatorial and "inside/outside
osculation plane" bases) to hen
outside surface, insulation weo
closure section; | rustum (with
wedge surface
ni-ellipsoid,
lge, aft case |
| | | N. D. | Eq. 139 |
| RLIWCA3 | ^R LIWCA3 | Length ratio, hemi-ellipsoid fr
equatorial base and inside noza
base) to hemi-ellipsoid, inside
insulation wedge, aft case clos | rustum (with
tie cutout
surface,
ure section; |
| | | N. D. | Eq. 145 |
| RLIWCA4 | ^R LIWCA4 | Length ratio, hemi-ellipsoid fr
equatorial and "inside/outside
osculation plane" bases) to her
inside surface, insulation wedg
closure section; | rustum (with
wedge surface
ni~ellipsoid
ge, aft case |
| | | N. D. | Eq. 14 9 |
| RLIWCF1 | RLIWCFI | Length ratio, hemi-ellipsoid f
hemi-ellipsoid, outside surfac
wedge, forward case closure s | rustum to
e, insulation
ection; |
| | | N. D. | Eq. 86 |

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | : | |
|----------|-----------------------------------|---|---------------|--|
| RLIWCF2 | RLIWCF2 | Length ratio, hemi-ellipsoid frustum (with
equatorial and "inside/outside wedge surface
osculation plane" bases) to hemi-ellipsoid
outside surface, insulation wedge, forward
base closure section; | | |
| | | N. D. | Eq. 91 | |
| RLIWCF3 | R _{LIWCF3} | Length ratio, herai-ellipsoid frustum (with
equatorial and inside cylindrical hole cutout
for the ignitor bases) to hemi-ellipsoid,
inside surface, insulation wedge, forward
case closure section; | | |
| | | N. D. | Eq. 99 | |
| RLIWCF4 | ^R LIWCF4 | Length ratio, hemi-ellipsoid frustum (with
equatorial and "inside/outside wedge surface
osculation plane" bases) to hemi-ellipsoid,
inside surface, insulation wedge, forward
case closure section; | | |
| | | N. D. | Eq. 103 | |
| SINTCF | $\sin \left(\theta_{CF} \right)$ | Sin of THETACF;
N.D. | | |
| TANTCF | $	an\left(heta_{CF} ight)$ | Tangent of THETACF;
N.D. | | |
| ΤΙJΜΑΧ | T _{IJ} MAX | Maximum insulation thicknes
cutout; | s for a joint | |
| | | in Fig. 17 | Eq. 2-c | |
| TIJPGI | T _{IJ} PG1 | Component altitude of the polygon cross
section associated with the port/grain
insulation component for joint cutouts; | | |
| | | in Fig. 17 | Eq. 187 | |

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| OUTPUT DAT | A (Cont.) | | | | |
|------------|----------------------|--|--|--|--|
| Mnemonic | Symbol | Descriptio | on; Ext. (Int.) Units | | |
| TIJPG3 | T _{IJ} PG3 | Component altitude of the polygon cross
section associated with the port/grain
insulation component for joint cutouts; | | | |
| | | in | Fig. 17 | Eq. 186 | |
| TILCLA | T _{IL} CLA | Thickness of insulation liner a
case closure section. Diatance
the inside and outside hemi-el
of the insulation liner, measure
axis of revolution: | | at center of aft
ice between
illipsoid surfaces
ured on the | |
| | | in | Fig. 5 | Eq. 37 | |
| TILCLF | T _{IL} CLF | Thickness
forward c
between is
surfaces
on the axi | s of insulation liner
ase closure section
nside and outside he
of the insulation line
s of revolution; | at center of
. Distance
emi-ellipsoid
er, measured | |
| | | in | Fig. 3 | Eq. 12 | |
| TISMAX | T _{ISMAX} | Maximum insulation thickness for a slucutout; | | | |
| | | in | Fig. 16 | Eq. 2-b | |
| TISPGl | T _{IS} PG1 | Altitude o
associate
componen | f the polygon cross
d with the port/grai
t for slot cutouts; | section
n insulation | |
| | | in | Fig. 16 | Eq. 166 | |
| TIWMAX | T _{IW} MAX | Maximum
wedges (e | insulation thicknes
xcluding liner); | s for closure | |
| | | in | | Eq. 2-a | |
| TIWAMAX | T _{IW} AMAX | Maximum thickness of the insulation wedge
associated with the aft closure. Measured
parallel to the slant height of the cone
fructure grain cutout: | | | |
| | | in | | Eq. 108 | |

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|---|----|----|----|-----|------|-------|----|
|---|----|----|----|-----|------|-------|----|

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| Mnemonic | Symbol | Description; Ext. (Int.) Units | | | |
|----------|-------------------------------|--|---|--|--|
| TIWFMAX | TIW _{FMAX} | Maximum thickness of the insulation wedge
associated with the forward closure.
Measured parallel to the motor centerline
See LIWHF: | | | |
| | | in | | Eq. 61 | |
| VIJ | v _{IJ} | Total volume of insulation required for joints; | | | |
| | | in | | Eq. 210 | |
| VIЛH2 | V _{IJ} | Volume of insulation required for a joint; | | | |
| | IH2 | in ³ | Fig. 20 | Eq. 209 | |
| VIJPG | V _{IJ} _{PG} | Volume of a port/grain insulation component for slot cutouts; | | | |
| | | in ³ | Fiz. 20 | Dqs, 179,195 | |
| VIJPL | V _{IJ_{PL}} | Volume of port/liner insulation component for joint cutouts; | | | |
| | | in ³ | Figs. 17, 20 | Eqs. 178, 182 | |
| VIL | v _{IL} | Total volume
for the insul-
for ignitor h-
hole in aft cl
submerged n
. 3 | e of insulation ma
ation liner. Inclu
ole in forward clo
losure, length per
lozzle, slots and | terial required
ades adjustment
osure, nozzle
halty for
joints in grain; | |
| | | in | | Eq. 228 | |
| VILCHAI | v _{il} chai | Volume of he
cutout assoc
the insulation
closure sect | emi-ellipsoid frus
iated with the ins
n liner within the
ion; | stum with hole
ide surface of
aft case | |
| | | in ³ | Fig. 6 | Eq. 55 | |
| VILCHAO | v _{il} chao | Volume of th
hole cutout a
surface of th
aft case clos
in ³ | he hemi-ellipsoid
associated with the
ne insulation liner
oure section;
Fig. 6 | frustum with
e outside
within the
Eq. 49 | |
| | | | | | |

INTERNAL INSULATION GEOMETRY

OUTPUT DATA (Cont.): Description; Ext. (Int.) Units Mnemonic Symbol $v_{IL_{CHFI}}$ Volume of hemi-ellipsoid frustum with hole VILCHFI cutout associated with the inside surface of the insulation liner within the forward case closure section; in^3 Fig. 4 Eq. 30 v_{IL}_{Chfo} Volume of hemi-ellipsoid frustum with hole VILCHFO cutout associated with the outside surface of the insulation liner within the forward case closure section; in³ Eq. 24 Fig. 4 v_{il}cla VILCLA Volume of insulation liner within the forward case closure section; in³ Fig. 6 Ea. 50 $v_{IL_{CLAI}}$ VILC LAI Volume of the hemi-ellipsoid formed by the inside surface of the insulation liner within the aft case closure section; in^3 Fig. 6 Eq. 50 V_{IL}CLAO Volume of the hemi-ellipsoid formed by VILCLAO the outside surface of the insulation liner within the aft case closure section; in³ Fig. 6 Eq. 44 v_{IL}_{CLF} VILCLF Volume of insulation liner within the forward case closure section; in³ Fig. 4 Eq. 31 v_{IL}_{CLFI} VILC LFI Volume of the hemi-ellipsoid formed by the inside surface of the insulation liner within the forward case closure section; in^3 Fig. 4 Eq. 25 V_{IL}_{CLFO} Volume of the hemi-ellipsoid formed by the VILC LFO outside surface of the insulation liner within the forward case closure section; in³ Fig. 4 Eq. 19

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INTERNAL INSULATION GEOMETRY

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| OUTPUT DAT. | A (Cont.): | | | |
|-------------|----------------------|--|--|---|
| Mnemonic | Symbol | Descripti | on; Ext. (Int.) Unit | 8 |
| VILCY | v _{il} cy | Volume o
within the | f cylindrical insula
cylindrical case s | tion liner section
ection; |
| | | in ³ | | Eq. 227 |
| VILHAI | V _{IL} HAI | Volume o
associate
the hemi-
surface o
aft case s | f cylinder with ellip
d with the nozzle cu-
ellipsoid formed by
f the insulation line
section; | psoidal cap,
utout, within
y the inside
er within the |
| | | in ³ | Fig. 6 | Eq. 54 |
| VILHAIC | V _{IL} HAIC | Volume o
with the r
ellipsoid
the insula
closure s | f the cylindrical se
nozzle cutout, withi
formed by the insid
ation liner within th
ection; | ction, associated
n the hemi-
le surface of
e aft case |
| | | in ³ | Fig. 6 | Eq. 51 |
| VILHAIE | v _{il} haie | Volume of ellipsoidal cap at aft base of the
cylindrical section, associated with the
nozzle cutout, within the hemi-ellipsoid
formed by the inside surface of the insulation
liner within the aft case closure section: | | |
| | | in ³ | Fig. 6 | Eq. 53 |
| VILHAO | v _{ilhao} | Volume o
associate
the hemi-
surface o
closure s | f cylinder with ellip
d with the nozzle cu-
ellipsoid formed by
f the insulation line
ection; | psoidal cap,
utout, within
y the outside
er within the aft |
| | | in | Fig. 6 | Eq. 48 |
| VILHAOC | V _{IL} HAOC | Volume c
with the r
ellipsoid
the insula
closure s | of the cylindrical se
nozzle cutout, withi
formed by the outsi
ation liner within th
section; | ction associated
n the henui-
ide surface of
e aft case |
| | | in ⁵ | Fig. 6 | Eq. 45 |

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INTERNAL INSULATION GEOMETRY

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| OUTPUT DATA (| Cont.): | | | |
|---------------|---------------------------------|--|---|--|
| Mnemonic | Symbol | Description; | Ext. (Int.) Units | |
| VILHAOE | V _{IL} HAOE | Volume of ell
cylindrical se
nozzle cutout,
formed by the
insulation line
section;
in ³ | ipsoidal cap at aft ba
ection, associated wi
, within the hemi-ell
e outside surface of t
er within the aft case
Fig. 6 | the
ipsoid
the
closure
Eq. 47 |
| VILHFI | v _{IL_HTI} | Volume of cyl
associated wi
the hemi-elli
surface of the
forward case
in ³ | linder with ellipsoida
th the ignitor cutout,
psoid formed by the
insulation liner • .t
closure sectio,
Fig. 4 | al cap,
within
inside
hin the
Eq. 29 |
| VILHFIC | v _{il_{hfic}} | Volume of the
with the ignit
ellipsoid form
insulation lin
closure secti
in ³ | cylindrical section,
or hole, within the h
ned by the inside sur
er within the forward
on;
Fig. 4 | associated
emi-
face of the
d case
Eq. 26 |
| VILHFIE | v _{il_{hfi}fi} | Volume of ell
of the cylindr
the ignitor cu
formed by the
insulation lin
closure secti
in ³ | ipsoidal cap at forwa-
ical section, associa-
itout, within the hem
e inside surface of th
er within the forward
on;
Fig. 4 | ard base
ated with
i-ellipsoid
d case
Eq. 28 |
| VILHFO | v _{il} hfo | Volume of cy
associated wi
the hemi-elli
surface of the
forward case
in ³ | linder with ellipsoids
ith the ignitor cutout,
psoid formed by the
e insulation liner wit
closure section;
Fig. 4 | al cap,
within
outside
hin the
Eq. 23 |

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| OUTPUT DATA | (Cont.): | | | |
|-------------|-------------------------------|---|--|---|
| Mnemonic | Symbol | Description; Ext. | (Int.) Units | |
| VILHFOC | V _{IL} HFOC | Volume of the cyl
with the ignitor h
ellipsoid formed
the insulation line
closure section;
in ³ Fi | indrical sect
ole, within th
by the outside
er within the
g. 4 | ion, associated
he hemi-
e surface of
forward case
Eq. 20 |
| VILHFOE | V _{IL} hfoe | Jume of ellipsoidal cap at forward base
of the cylindrical section, associated with
the ignitor cutout, within the hemi-ellipsoid
formed by the outside surface of the
insulation liner within the forward case
closure section; | | |
| | | in ⁵ Fi | g. 4 | Eq. 22 |
| VIN | v _{IN} | Total internal ins
liner, wedges in
inhibited slots an
in ³ | ulation volum
forward and a
d joints; | ne. Includes
aft closures,
Eq. 230 |
| VINPD | v _{in_{pd}} | Total volume of p
closure insulation
grain/liner insula
in ³ | propellent dis
n wedges and
ation compone | placed by the
the slot
ents;
Eq. 225 |
| VINR | v _{IN_R} | Volume of residu
in ³ | al insulation; | Еq. 229 |
| VIS | v _{IS} | Total volume of i
in ³ | nsulation req | uired for slots;
Eq. 208 |
| VISGL | v _{is} gl | Volume of grain/
for slot cutout; | liner insulati | on component |
| | | in ³ Fi | gs.15,16,20 | Eqs. 159,164 |
| VISIH0 | V _{IS_{IH0}} | Volume of insulat
sides inhibited; | tion fo r a sl o | t with no |
| | | in ³ Fi | g. 20 | Eq. 20ó |

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| Mnemonic | Symbol                        | Description                                                                             | ; Ext. (Int.) Units                                                                                             |                                                                            |
|----------|-------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| VISIH1   | V <sub>ISIH1</sub>            | Volume of in<br>side inhibite                                                           | nsulation for a slot<br>ed;                                                                                     | with one                                                                   |
|          |                               | in                                                                                      | Fig. 20                                                                                                         | Eq. 207                                                                    |
| VISPD    | $v_{IS}_{PD}$                 | Volume of p<br>grain/liner                                                              | ropellent displaced<br>insulation compone                                                                       | l by the slot<br>ents;                                                     |
|          |                               | in <sup>3</sup>                                                                         |                                                                                                                 | Eq. 224                                                                    |
| VISPG    | v <sub>IS</sub> <sub>PG</sub> | Volume of the component f                                                               | he port/grain insul<br>for slot cutouts;                                                                        | ation                                                                      |
|          |                               | in <sup>3</sup>                                                                         | Figs. 15, 16, 20                                                                                                | <b>Eqs. 160, 165,</b><br>170                                               |
| VISPL    | $v_{IS}_{PL}$                 | Volume of p<br>for a slot cu                                                            | oort/liner insulation<br>utout;                                                                                 | n component                                                                |
|          |                               | in <sup>3</sup>                                                                         | Figs. 15, 16, 20                                                                                                | Eqs. 158,163                                                               |
| VIWAOY   | V <sub>IW</sub> AOY           | Volume of t<br>with the out<br>wedge in the                                             | he cylindrical sect<br>side surface of the<br>e aft case closure s                                              | ion associated<br>insulation<br>section;                                   |
|          |                               | in <sup>3</sup>                                                                         | Fig. 13                                                                                                         | Eq. 142                                                                    |
| VIWCAOE  | v <sub>iw</sub> caoe          | Volume of t<br>intersection<br>surface osc<br>ellipsoid as<br>of the insula<br>section; | he ellipsoidal cap i<br>of the "inside/out<br>ulation plane" and<br>sociated with the c<br>ation wedge in the a | formed by the<br>side wedge<br>the hemi-<br>outside surface<br>aft closure |
|          |                               | in <sup>3</sup>                                                                         | Fig. 12                                                                                                         | Eq. 140                                                                    |
| VIWCAPD  | V <sub>IW</sub> CAPD          | Volume of p<br>insulation w<br>closure;                                                 | oropellent displaced<br>vedge associated with                                                                   | d by the<br>ith the aft                                                    |
|          |                               | in <sup>3</sup>                                                                         |                                                                                                                 | Eqs. 212, 221<br>222                                                       |

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## OUTPUT DATA (Cont.):

| Mnemonic | Symbol               | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                               |
|----------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VIWCFOE  | v <sub>iw</sub> cfoe | Volume of the ellipsoidal cap formed by the<br>intersection of the "inside/outside wedge<br>surface osculation plane" and the hemi-<br>ellipsoid associated with the outside surface<br>of the insulation wedge in the forward case<br>closure section;<br>in <sup>3</sup> Figs. 8, 9 Eq. 92 |
| VIWCFPD  | V <sub>IW</sub> CFPD | Volume of propellent displaced by the insulation wedge associated with the forward closure; in <sup>3</sup> Eq. 211                                                                                                                                                                          |
| VIWCHAI  | v <sub>iw</sub> chai | Volume of the ellipsoidal cap, with<br>cylindrical hole cutout associated with the<br>cone frustum hole cutout for the nozzle, which<br>forms the inside surface of the insulation<br>wedge in the aft case closure section;                                                                 |
|          |                      | $1n^2$ Figs. 12, 14 Eq. 151                                                                                                                                                                                                                                                                  |
| VIWCHAO  | v <sub>iwchao</sub>  | Volume of the hemi-ellipsoid frustum, with<br>cylindrical hole cutout, associated with the<br>outside surface of the insulation wedge in<br>the aft closure section;<br>in <sup>3</sup> Figs. 12, 14 Eqs. 141, 143                                                                           |
| VIWCHFI  | v <sub>iwchfi</sub>  | Volume of the ellipsoidal cap, with hole<br>cutout for the ignitor, which forms the<br>inside surface of the insulation wedge in the<br>forward case closure section;                                                                                                                        |
|          |                      | in <b>Figs. 8,</b> 10 Eq. 105                                                                                                                                                                                                                                                                |
| VIWCHFO  | v <sub>iw</sub> chfo | Volume associated with the outside surface<br>of the insulation wedge in the forward case<br>closure section, adjusted for ignitor hole;<br>in <sup>3</sup> Figs. 8, 10 Eqs. 93, 97                                                                                                          |
| VIWCLA   | V <sub>IW</sub> CLA  | Volume of insulation material required for<br>the insulation wedge associated with the aft<br>case closure section;                                                                                                                                                                          |
|          |                      | in <sup>2</sup> Figs. 12, 14 Eq. 155                                                                                                                                                                                                                                                         |

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| OUTPUT DAT | A (Cont.):                     |                                                                 |                                                                                                                                |                                                                                              |  |
|------------|--------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|--|
| Mnemonic   | Symbol                         | Descriptio                                                      | on; Ext. (Int.) Units                                                                                                          |                                                                                              |  |
| VIWCLAO    | V <sub>IW</sub> CLAO           | Volume of<br>the outsid<br>in the aft                           | the hemi-ellipsoid as<br>e surface of the insula<br>case closure section;                                                      | he hemi-ellipsoid associated with<br>surface of the insulation wedge<br>ase closure section; |  |
|            |                                | in <sup>3</sup>                                                 | Fig. 14                                                                                                                        | Eq. 135                                                                                      |  |
| VIWCLF     | V <sub>IW</sub> CLF            | Volume of<br>the insula<br>forward c                            | insulation material r<br>tion wedge associated<br>ase closure section;                                                         | equired for<br>with the                                                                      |  |
|            |                                | in <sup>3</sup>                                                 | Figs. 8, 10                                                                                                                    | Eq. 106                                                                                      |  |
| VIWCLFO    | v <sub>iwclfo</sub>            | Volume of<br>the outsid<br>within the                           | f the hemi-ellipsoid as<br>e surface of the insula<br>forward case closure                                                     | ssociated with<br>ation wedge<br>;                                                           |  |
|            |                                | in <sup>3</sup>                                                 | Figs. 8, 10                                                                                                                    | Eq. 85                                                                                       |  |
| VIWEAI     | v <sub>iw<sub>eai</sub></sub>  | Volume of<br>the inside<br>within the                           | f the hemi-ellipsoid as<br>surface of the insulat<br>aft case closure;                                                         | ssociated with<br>tion wedge                                                                 |  |
|            |                                | in <sup>3</sup>                                                 |                                                                                                                                | Eq. 144                                                                                      |  |
| VIWEAIE    | v <sub>iw<sub>eaie</sub></sub> | Volume of<br>with the in<br>wedge in t<br>insulation<br>VIWEAIE | f the ellipsoidal cap as<br>nside surface of the in<br>the aft case closure.<br>wedge extends beyond<br>is the hemi-ellipsoid  | ssociated<br>sulation<br>If the<br>d the closure,<br>volume;                                 |  |
|            |                                | in <sup>3</sup>                                                 | Figs. 12, 14                                                                                                                   | Eq. 150                                                                                      |  |
| VIWEFI     | v <sub>iw<sub>efi</sub></sub>  | Volume o<br>with the i<br>wedge wit                             | f the hemi-eilipsoid as<br>nside surface of the ir<br>thin the forward case of                                                 | ssociated<br>isulation<br>closure section                                                    |  |
|            |                                | in <sup>3</sup>                                                 | Figs. 7, 9                                                                                                                     | Eq. 98                                                                                       |  |
| VIWEFIE    | v <sub>iw<sub>efie</sub></sub> | Volume o<br>the inside<br>the forwa<br>insulation<br>VIWEFIE    | f the ellipsoidal cap as<br>surface of the insulat<br>rd case closure section<br>wedge extends beyond<br>is the hemi-ellipsoid | ssociated with<br>tion wedge in<br>on. If the<br>d the closure,<br>volume;                   |  |
|            |                                | in <sup>3</sup>                                                 | Figs. 8, 10                                                                                                                    | Ea. 104                                                                                      |  |

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|-------------|----------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Mnemonic    | Symbol               | Descripti                                                                          | on; Ext. (Int.) Units                                                                                                            |                                                                           |
| VIWFOY      | v <sub>iw</sub> foy  | Volume o<br>with the o<br>wedge in                                                 | f the cylindrical section<br>outside surface of the<br>the forward case clos                                                     | on associated<br>insulation<br>oure section;                              |
|             |                      | in                                                                                 | Fig. 10                                                                                                                          | Eq. 96                                                                    |
| VIWHAI      | v <sub>iwhai</sub>   | Volume o<br>cap, asso<br>frustum,<br>with the i<br>wedge in                        | f the cylinder, with e<br>ociated with the nozzle<br>in the hemi-ellipsoid<br>nside surface of the i<br>the aft case closure s   | llipsoidal<br>e cutout cone<br>associated<br>nsulation<br>ection;         |
|             |                      | in <sup>3</sup>                                                                    | Figs. 12, 14                                                                                                                     | Eq. 148                                                                   |
| VIWHAIC     | V <sub>IW</sub> HAIC | Volume o<br>with the r<br>ellipsoid<br>of the ins<br>closure s<br>. 3              | f the cylindrical section<br>tozzle cutout, within the associated with the ir<br>ulation wedge in the a<br>ection;               | ion, associated<br>the hemi-<br>nside surface<br>aft case                 |
|             |                      | in                                                                                 | Figs. 12, 14                                                                                                                     | Eq. 147                                                                   |
| VIWHAIE     | V <sub>IW</sub> HAIE | Volume o<br>base of th<br>the nozzl<br>associate<br>insulation<br>section;         | f the ellipsoidal cap,<br>ne cone frustum assoc<br>e cutout, within the he<br>d with the inside surf<br>n wedge in the aft case  | at the aft<br>ciated with<br>emi-ellipsoid<br>ace of the<br>e closure     |
|             |                      | in <sup>3</sup>                                                                    | Figs. 12, 14                                                                                                                     | Eq. 146                                                                   |
| VIWHAOC     | v <sub>iw</sub> haoc | Volume o<br>with the r<br>ellipsoid<br>surface o<br>case clos                      | f the cylindrical sect<br>nozzle cutout, within f<br>frustum associated w<br>f the insulation wedge<br>ure section;              | ion, associated<br>the hemi-<br>ith the outside<br>in the aft             |
|             |                      | in <sup>3</sup>                                                                    | Figs. 12, 14                                                                                                                     | Eq. 138                                                                   |
| VIWHAOE     | V <sub>IW</sub> HAOE | Volume of<br>of the cor<br>the nozzl<br>associate<br>insulation<br>section;<br>. 3 | of the ellipsoidal cap,<br>ne frustum section as:<br>e cutout, within the hi<br>d with the outside sur<br>n wedge in the aft cas | at aft base<br>sociated with<br>emi-ellipsoid<br>face of the<br>e closure |
|             |                      | ın                                                                                 | Figs. 12, 14                                                                                                                     | Eq. 137                                                                   |

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# OUTPUT DATA (Cont.):

| Mnemonic | Symbol                        | Description; E                                                                                             | Ext. (Int.) Units                                                                                                             |                                                       |
|----------|-------------------------------|------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| VIWHAT   | V <sub>IWHAT</sub>            | Volume of tria<br>wedge, associ<br>cutout for the<br>closure sectio                                        | angular section, in in<br>ated with the cone fr<br>nozzle within the aft<br>n;                                                | nsulation<br>ustum<br>case                            |
|          |                               | in                                                                                                         | Figs. 12, 14                                                                                                                  | Eq. 154                                               |
| VIWHFI   | v <sub>iw<sub>hfi</sub></sub> | Volume of the<br>associated wit<br>ellipsoid asso<br>of the insulation<br>closure section                  | cylinder with ellips<br>th the ignitor hole, in<br>ciated with the inside<br>on wedge in the forw<br>on;                      | bidal cap,<br>n the hemi-<br>e surface<br>ard case    |
|          |                               | in <sup>3</sup>                                                                                            | Figs. 8, 10                                                                                                                   | Eq. 102                                               |
| VIWHFIC  | V <sub>IW</sub> HFIC          | Volume of the<br>with the ignito<br>ellipsoid asso<br>the insulation<br>closure sectio                     | cylindrica section,<br>or hole, within the he<br>ciated with the inside<br>wedge in the forward<br>on;                        | associated<br>mi-<br>e surface of<br>d case           |
|          |                               | in                                                                                                         | Figs. 8, 10                                                                                                                   | Eq. 101                                               |
| VIWHFIE  | v <sub>iw</sub> hfie          | Volume of elli<br>of the cylindri<br>the ignitor cut<br>associated wit<br>insulation wed<br>closure sectio | psoidal cap, at forw<br>cal section associate<br>out, within the hemi<br>th the inside surface<br>ge in the forward ca<br>on; | ard base<br>ed with<br>-ellipsoid<br>of the<br>se     |
|          |                               | in <sup>5</sup>                                                                                            | Figs. 8, 10                                                                                                                   | <b>Eq.</b> 100                                        |
| VIWHFO   | V <sub>IW</sub> HFO           | Volume of the<br>associated wit<br>ellipsoid and c<br>outside surfac<br>the forward ca                     | cylinder, with ellip<br>the ignitor hole, in<br>cylinder associated v<br>ce of the insulation v<br>ase closure section;       | soidal cap,<br>n the hemi-<br>vith the<br>vedge in    |
|          |                               | in <sup>3</sup>                                                                                            | Figs. 8, 10 Eq                                                                                                                | <b>s.</b> 90, 95                                      |
| VIWHFOC  | v <sub>iw</sub> hfoc          | Volume of the<br>with the ignito<br>associated wit<br>insulation wed<br>section;<br>. 3                    | cylindrical section,<br>or hole, within the he<br>th the outside surfac<br>lge in the forward ca                              | associated<br>emi-ellipsoid<br>e of the<br>se closure |
|          |                               | in″                                                                                                        | Figs. 8, 10                                                                                                                   | Eq. 88                                                |

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## INTERNAL INSULATION GEOMETRY

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| OUTPUT DATA | A (Cont.):                      |                                                                                                                                                                                                                                                                                      |                                                                                                                                |
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| Mnemonic    | Symbol                          | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                       |                                                                                                                                |
| VIWHFOE     | V <sub>IW</sub> hfoe            | Volume of ellipsoidal cap, at a<br>of the cylindrical section asso<br>ignitor cutout, within the hemi<br>associated with the outside su<br>insulation wedge in the forwar<br>section;                                                                                                | forward base<br>ciated with the<br>-ellipsoid<br>rface of the<br>d case closure                                                |
|             |                                 | in <sup>3</sup> Figs. 8, 10                                                                                                                                                                                                                                                          | Eq. 87                                                                                                                         |
| VIWHFOL     | <sup>v</sup> iw <sub>hfol</sub> | Volume of the cylindrical sect<br>with the ignitor hole, within the<br>ellipsoid associated with the o<br>of the insulation wedge in the<br>closure section. The bases of<br>section are the equatorial plan<br>ellipsoid and the "inside/outsi<br>surface osculation plane";        | ion, associated<br>he hemi-<br>utside surface<br>forward case<br>f the cylindrical<br>he of the hemi-<br>de wedge              |
|             |                                 | in <sup>3</sup> Figs. 7, 8                                                                                                                                                                                                                                                           | Eq. 89                                                                                                                         |
| VIWHFOY     | <sup>v</sup> i₩ <sub>hfoy</sub> | Volume of the cylindrical sect<br>with the ignitor hole, within the<br>case section associated with the<br>surface of the insulation wedge<br>case closure section. The base<br>cylindrical section are the equ<br>of the hemi-ellipsoid and the '<br>wedge surface osculation plane | ion, associated<br>ne cylindrical<br>he outside<br>e in the forward<br>ses of the<br>natorial plane<br>'inside/outside<br>e''; |
|             |                                 | in <sup>3</sup> Fig. 10                                                                                                                                                                                                                                                              | Eq. 94                                                                                                                         |
| VIWPD       | V <sub>IW</sub> PD              | Volume of propellent displaced<br>insulation wedges associated v<br>forward and aft closures;                                                                                                                                                                                        | d by the<br>vith the                                                                                                           |
|             |                                 | in                                                                                                                                                                                                                                                                                   | Eq. 223                                                                                                                        |
| YIJI        | Y <sub>1</sub>                  | Intermediate quantity for YIJF<br>in <sup>3</sup>                                                                                                                                                                                                                                    | PG computation;<br>Eq. 193                                                                                                     |
| YIJ2        | ¥,                              | Intermediate quantity for YIJF                                                                                                                                                                                                                                                       | G computation;                                                                                                                 |
|             | <i>u</i>                        | in <sup>3</sup>                                                                                                                                                                                                                                                                      | Eq. 189                                                                                                                        |

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| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                        |                                                                                          |                                                               |
|----------|-------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------|
| YIJ3     | Y <sub>3</sub>                | Intermediate q                                                        | luantity for YIJPG                                                                       | computation;                                                  |
|          |                               | in                                                                    |                                                                                          | Eq. 190                                                       |
| YIJ4     | Y <sub>4</sub>                | Intermediate q                                                        | luantity for YIJPG                                                                       | computation;                                                  |
|          |                               | in                                                                    |                                                                                          | Eq. 191                                                       |
| YIJ5     | Y <sub>5</sub>                | Intermediate q                                                        | uantity for YIJPG                                                                        | computation;                                                  |
|          |                               | in <sup>2</sup>                                                       |                                                                                          | Eq. 192                                                       |
| YIJPG    | Y <sub>IJ</sub> <sub>PG</sub> | Centroid, mea<br>centerline, of<br>joint cutouts;                     | sured with respective the polygon cross                                                  | t to the motor<br>section for                                 |
|          |                               | in                                                                    | Fig. 17                                                                                  | Eq. 194                                                       |
| YISPG    | Y <sub>IS</sub> PG            | Centroid, mea<br>centerline, of<br>associated wit<br>component for    | sured with respect<br>the polygon cross<br>h the port/grain is<br>slot cutouts;          | t to the motor<br>section<br>nsulation                        |
|          |                               | in                                                                    | Fig. 16                                                                                  | Eq. 169                                                       |
| YIWHAT   | Y <sub>IW</sub> HAT           | Distance from<br>of triangular s<br>associated wit<br>the nozzle, wit | axis of revolution<br>section in insulation<br>h the cone frustun<br>thin the aft case c | n to centroid<br>on wedge,<br>n cutout for<br>losure section; |
|          |                               | in                                                                    | Figs. 11, 13                                                                             | Eq. 153                                                       |

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PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

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| AP              | CIVB         | ¥                       | CIVBP        | CINC          | CINCP              |
| LIUO            | CUTOUTS      | ţ                       | DILCLI       | DILCIO        | DILIAI             |
| IAHAI           | DILHFO       | - <b>1</b><br>*         | IIII         | OIID          | LAWID              |
| WCPAI           | DINCFI       | \$ <b>*</b>             | DINCLO       | DIWEAL        | DIMENU             |
| <b>WHAO</b>     | LATHMIC      | ¥                       | DIMIFO       | COODPGJ       | CODPGS             |
| NTELON          | INTINACL     | L*                      | INTUFCI      | KIJ           | KIJ2               |
| 11              | KIJS         | 8 <b>*</b>              | XIJ6         | KIJ           | KLJ8               |
| otri            | LIUIN        | <b>\$</b>               | <b>KIJ12</b> | KIJTRUE       | <b>KIIN</b>        |
| [1]             | KTL4         | *10                     | KIL5         | KIL6          | KILT               |
| 61              | OTIIX        | <b>11</b>               | TTTIX        | <b>KILL2</b>  | KIL13              |
| <u>115</u>      | 911IX        | *12                     | LTTI X       | 8TTIX         | KIM                |
| ENJ             | 7NTX         | <b>*1</b> 3             | KINS         | KIIN6         | KIN7               |
| ISI             | KIS2         | <b>+</b> 14             | KIS3         | KIS4          | KIS5               |
| LS7             | KIS8         | <b>*1</b> 5             | KIS9         | <b>KISIO</b>  | KISII              |
| EI3             | <b>MISIN</b> | *16                     | KIS15        | KIS16         | KISTRUE            |
| CN2             | KIN3         | <b>*17</b>              | KIN4         | KIWT          | KIW8               |
| INTO            | KIWIJ        | <b>*1</b> 8             | <b>SINIX</b> | K TW13        | KIM 4              |
| IN16            | <b>KIWL</b>  | <b>*1</b> 9             | KIW18        | KIM19         | KIW2O              |
| IW22            | KTW23        | ¥20                     | K TW24       | KLIMIJI       | KLIWF12            |
| 202             | KPD3         | ភ្                      | Kapt         | KEPDS         | KPD6               |
| 8 <b>6</b> 2    | KPD9         | ş                       | <b>KPD10</b> | LIJCUT        | LUFGI              |
| LJPG3           | LILCHAI      | <b>*</b> 23             | LILCHAO      | LILCHT        | LILCHPO            |
| <b>ILCLA</b> O  | LILOULI      | <b>1</b> 77<br><b>*</b> | LILCLEO      | LILLO         | LTLHA              |
| ISCUT           | LISPOIL      | <del>ڈ</del> ئ          | LISPGO       | LIVAL         | LTWA2              |
| EWCAI           | LINCEAL      | <b>*</b> 26             | LINCEPI      | LINCFAL       | LINCFI             |
| <b>INCEAO</b>   | LINCHFI      | +27                     | LINCHPO      | LIWCLAI       | LINCLAD            |
| INCLIPO         | LIVEAL       | *28                     | LIVEPT       | LIWEHAI       | LINDALT            |
| ILWIA           | LIWHAI       | ₹¥                      | LIMHP        | LIMMIT        | NIJCUT             |
| OHISI           | THISIN       | •¥30                    | FGLJ(1)      | FGIJ(2)       | PGLJ(3)            |
| 3 <b>IJ(</b> 5) | FGIJ(6)      | *31                     | FGIJ(7)      | FGIJ(8)       | <b>FGLJ(9)</b>     |

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| *32                   | FGIS(3)       | PGIS(4)                                                                                                                                                                                                                                           | RIS(5)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| R *33                 | RDILCAI       | RDILCAO                                                                                                                                                                                                                                           | RULCFI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 1 <sup>2</sup> *      | RULLHFI       | OILITION                                                                                                                                                                                                                                          | RDIWCAI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *35                   | RDTWHAO       | LIHMICH                                                                                                                                                                                                                                           | <b>COLIMITOR</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *36                   | RLILCFO       | RUTHCAL                                                                                                                                                                                                                                           | RLIWCA2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <u>1</u> *37          | RLINCF2       | RLINCF3                                                                                                                                                                                                                                           | RL TWCF'4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *38                   | TJPGI         | TIJEG                                                                                                                                                                                                                                             | TILCLA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *39                   | TISMAX        | TISPGI                                                                                                                                                                                                                                            | TIWAMAX                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 01+                   | <b>VIJIH2</b> | orta                                                                                                                                                                                                                                              | <b>MUPL</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 0 *+T                 | VILCHFI       | VILCHPO                                                                                                                                                                                                                                           | VILCLA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *40                   | VILCLFI       | VILLELEO                                                                                                                                                                                                                                          | VILCY                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| E *tr3                | VILHAO        | VTLHAOC                                                                                                                                                                                                                                           | VILHAOE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 171 <b>*</b> 3        | VILHFO        | VILHFOC                                                                                                                                                                                                                                           | VILHPOE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| * <del>1</del> 5      | VIS           | <b>VISCL</b>                                                                                                                                                                                                                                      | OHISIA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 97*                   | VISPL         | VIMAOY                                                                                                                                                                                                                                            | VTWCAOE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Lt++ Q                | VINCHAI       | VIWCHAO                                                                                                                                                                                                                                           | VIWCHFI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| ,0 <b>*</b> 48        | VTNCLE        | VINCLED                                                                                                                                                                                                                                           | VIWEAL                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| E +49                 | VTWFOY        | LINHAI                                                                                                                                                                                                                                            | VTWHAIC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| E *50                 | VIWHAT        | LIHMLA                                                                                                                                                                                                                                            | VIMHFIC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| c *51                 | VTWHFOE       | VIMIPOL                                                                                                                                                                                                                                           | VIHHTV                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *52                   | X1J3          | 4CIX                                                                                                                                                                                                                                              | YIJ5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| *53                   |               |                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| - स००नन व सम 60सम्र * |               | FULLAT<br>FULLAT<br>FULLAT<br>FULLAT<br>FULLAT<br>FLINCF2<br>FLINCF2<br>FLINCF2<br>FLINCF2<br>FLINCF2<br>VIJHF2<br>VIJHF0<br>VILLAT<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF<br>VINCLF | FULD(3)<br>FULLCFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>FULLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEFO<br>VILLEF | FULD(13)FULD(13)FULD(14)RDILUFTRDILLATRDILLATRDIWHAORDILLFORDILLATRDIWFAORDILLFORDILLATRLIWCF2RLIWCF3RLIWCA2RLIWCF2RLIWCF3RLIWCA2RLIWCF2RLIWCF3RLIWCF4TIJFG1TIJFG3TILCF4TIJFG1TIJFG3TILCF4VIJIH2VILTG1VILCHF1VILCHF1VILCHF2VILCHF0VILCHF1VILCHF0VILCHF0VILLHC0VILCHF0VILCHF0VILLHC0VILCHF0VILCHF1VILCHF1VILCHF0VILCHF0VILCHF1VILCHF0VILCHF0VILCHF1VILCHF0VILCHF1VILCHF1VILCHF0VILCHF1VILCHF1VILCHF0VILCHF1VICHAIVILCHF0VILCHF1VICHF1VILCHF0VILCHF1VICHF1VILCHF0VILCHF1VILCHF1VILCHF0VILCHF1VILCHF1VILCHF0VILCHF1VILCHF1VILCHF0VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1VILCHF1 |

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INSULG

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## INTERNAL INSULATION GEOMETRY

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#### INTERNAL INSULATION WEIGHT

INWM1

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MODEL TYPE: INSULW (internal INSULation Weight)

MODEL NAME: INWM1 (Geometry dependent)

#### DESCRIPTION:

INWM1 (internal INsulation Weight Model number 1) uses volumes, determined by an insulation geometry model, to evaluate the internal insulation component weights for a solid rocket motor. The computed insulation weight breakdown may include the following components.

Insulation liner.

Insulation wedges associated with the forward and aft closures.

Joint insulation.

Slot insulation.

Residual insulation.

#### PROCEDURE:

This is a two entrance model. At the first entrance, the insulation densities are picked up and made available to define the insulation properties required for the insulation geometry computations. No equations are evaluated.

The internal insulation geometry is then evaluated by the model specified for the INSULG model type and the component volumes are evaluated.

The second entrance of INWM1 uses these volumes to evaluate the component weights, then uses these component weights to compute the internal insulation weight breakdown.

#### EQUATIONS:

Weight of insulation liner within forward case closure section.

 $W_{IL_{CLF}} = K_{WILCLF} \rho_{IL} V_{IL_{CLF}}$ (1)

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INSULW

#### INTERNAL INSULATION WEIGHT

INWM1

## EQUATIONS (Cont.):

Weight of insulation liner within aft case closure section.

$$W_{IL_{CLA}} = K_{WILCLA} \rho_{IL} V_{IL_{CLA}}$$
(2)

Weight of insulation liner within cylindrical case section.

$$W_{IL}_{CY} = K_{WILCY} \rho_{IL} V_{IL}_{CY}$$
(3)

Total weight of insulation liner. Includes forward closure, aft closure and cylindrical section components.

$$W_{IL} = K_{WIL} \rho_{IL} V_{IL}$$
(4)

Weight of insulation wedge associated with forward case closure section.

$$W_{IW_{CLF}} = K_{WIWCLF} \rho_{IW} V_{IW_{CLF}}$$
(5)

Weight of insulation wedge associated with aft case closure section.

$$W_{IW_{CLA}} = K_{WIWCLA} \rho_{IW} V_{IW_{CLA}}$$
(6)

Total weight of closure insulation wedges. Includes forward case closure and aft case closure components.

$$w_{IW} = \kappa_{WIW} \begin{pmatrix} w_{IW} + w_{IW} \end{pmatrix}$$
(7)

Weight of insulation for a single slot having no sides inhibited.

$$W_{IS_{IH0}} = K_{WISIH0} \rho_{IS} V_{IS_{IH0}}$$
(8)

Weight of insulation for a single slot having one side inhibited.

$$W_{IS_{IH1}} = K_{WISIH1} \rho_{IS} V_{IS_{IH1}}$$
(9)

#### INTERNAL INSULATION WEIGHT

#### INSULW

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## EQUATIONS (Cont.):

Total weight for slot insulation.

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$$W_{IS} = K_{WIS} \rho_{IS} V_{IS}$$
(10)

Weight of insulation for a single joint having both sides inhibited.

$$W_{IJ_{IH2}} = K_{WIJIH2} \rho_{IJ} V_{IJ_{IH2}}$$
(11)

Total weight for joint insulation.

$$W_{IJ} = K_{WIJ} \rho_{IJ} V_{IJ}$$
(12)

Density of residual internal insulation material.

$$\rho_{\rm R} = \kappa_{\rho_{\rm RL}} \rho_{\rm IL} + \kappa_{\rho_{\rm RJ}} \rho_{\rm IJ} + \kappa_{\rho_{\rm RW}} \rho_{\rm IW} + \kappa_{\rho_{\rm RS}} \rho_{\rm IS} + \kappa_{\rho_{\rm R}}$$
(12-a)

Total residual insulation weight.

$$W_{IN_{R}} = K_{WINR} \rho_{R} V_{IN_{R}}$$
(13)

Total internal insulation weight. Includes liner, closure wedge, slot, and joint components.

$$\mathbf{w}_{IN} = \mathbf{K}_{WIN} \left( \mathbf{w}_{IL} + \mathbf{w}_{IW} + \mathbf{w}_{IS} + \mathbf{w}_{IJ} \right)$$
(14)

Total non-expended internal insulation weight component.

$$W_{IN_{NX}} = K_{WINNX} W_{IN_{R}}$$
(15)

Total expended internal insulation weight component.

$$w_{IN_{X}} = \kappa_{WINX} \left( w_{IN} - w_{IN_{R}} \right)$$
(16)

Expended (thrust producing) internal insulation weight component.

$$W_{IN}_{XT} = K_{WINXT} W_{IN}_{X}$$
(17)

Expended (non-thrust producing) internal insulation weight component.

$$W_{IN_{XI}} = W_{IN_{X}} - W_{IN_{XT}}$$
(18)

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INWM1

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## INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic  | Symbol              | Description; Ext. (Int.) Units                     | Preset     |
|-----------|---------------------|----------------------------------------------------|------------|
| KRHOINR   | $\kappa_{\mu R}$    | Bias for RHOINR computation;<br>lb/in <sup>3</sup> | 0          |
| KR HOIR J | к <sub>рр J</sub>   | Coefficient for RHOINR computation N. D.           | tion;<br>0 |
| KRHOIRL   | κ <sub>ρr l</sub>   | Coefficient for RHOINR computation. D.             | tion;<br>1 |
| KR HOIR S | K <sub>PRS</sub>    | Coefficient for RHOINR computa<br>N. D.            | tion;<br>O |
| KRHOIR W  | κ <sub>ρrw</sub>    | Coefficient for RHOINR computa<br>N. D.            | tion;<br>O |
| KWIJ      | ĸ <sub>wij</sub>    | Coefficient for WIJ computation;<br>N. D.          | 1          |
| KWIJIH2   | K <sub>WIJIH2</sub> | Coefficient for WIJ1H2 computati<br>N. D.          | on;<br>l   |
| KWIL      | ĸ <sub>wil</sub>    | Coefficient for WIL computation;<br>N. D.          | 1          |
| KWILCLA   | K <sub>WILCLA</sub> | Coefficient for WILCLA computa<br>N. D.            | tion;<br>1 |
| KWILCLF   | KWILCLF             | Coefficient for WILCLF computa N. D.               | tion;<br>1 |
| KWILCY    | KWILCY              | Coefficient for WILCY computati                    | .on;<br>l  |
| KWIN      | κ <sub>win</sub>    | Coefficient for WIN computation;<br>N. D.          | 1          |

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# INTERNAL INSULATION WEIGHT

# INWM1

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# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                         | Preset      |
|----------|---------------------|------------------------------------------------------------------------|-------------|
| KWINR    | K. WINR             | Coefficient for WINR computation N. D.                                 | .;<br>1     |
| KWINNX   | <sup>K</sup> winnx  | Coefficient for WINNX computation N. D.                                | on;<br>1    |
| KWINX    | K <sub>WINX</sub>   | Coefficient for WINX computation N. D.                                 | i;<br>1     |
| KWINXT   | <sup>K</sup> winxt  | Coefficient for WINXT computation N. D.                                | on;<br>1    |
| KWIS     | ĸ <sub>wis</sub>    | Coefficient for WIS computation;<br>N. D.                              | 1           |
| KWISIH0  | K <sub>WISIH0</sub> | Coefficient for WISIH0 computation N. D.                               | on;<br>l    |
| KWISIHI  | KWISIHI             | Coefficient for WISIH1 computation N. D.                               | on;<br>1    |
| KWIW     | ĸwiw                | Coefficient for WIW computation;<br>N. D.                              | 1           |
| KWIWCLA  | KWIWCLA             | Coefficient for WIWCLA computa<br>N. D.                                | tion;<br>1  |
| KWIWCLF  | KWIWCLF             | Coefficient for WIWCLF computa N. D.                                   | tion;<br>1  |
| RHOIJ    | ρ <sub>IJ</sub>     | Density of internal insulation mat<br>for joints;                      | terial      |
| RHOIL    | ρ <sub>IL</sub>     | lb/in <sup>~</sup><br>Density of internal insulation may<br>for liner; | 0<br>terial |
|          |                     | lb/in <sup>-</sup>                                                     | 0           |

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### INTERNAL INSULATION WEIGHT

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## INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                                                 | Preset       |
|----------|-----------------|--------------------------------------------------------------------------------|--------------|
| RHOIS    | ρ <sub>IS</sub> | Density of internal insulation ma<br>for slots;<br>lb/in <sup>3</sup>          | aterial<br>0 |
| RHOIW    | ρ <sub>IW</sub> | Density of internal insulation ma<br>for closure wedges;<br>lb/in <sup>3</sup> | aterial<br>0 |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                                                                                              | Model Type                   |
|----------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------|------------------------------|
| VIJ      | $v_{IJ}$                       | Total volume of internal insul for joints;                                                                                  | ation required               |
|          |                                | in <sup>3</sup>                                                                                                             | INSULG                       |
| VIJIH2   | V <sub>IJ</sub> <sub>IH2</sub> | Volume of internal insulation<br>a single joint having both side                                                            | required for<br>s inhibited; |
|          |                                | in <sup>3</sup>                                                                                                             | INSULG                       |
| VIL      | v <sub>IL</sub>                | Total volume of internal insulation requir<br>for insulation liner. Includes cylindrical<br>section and closure components; |                              |
|          |                                | in <sup>3</sup>                                                                                                             | INSULG                       |
| VILCLA   | V <sub>IL</sub> CLA            | Volume of internal insulation the aft closure;                                                                              | liner within                 |
|          |                                | in <sup>3</sup>                                                                                                             | INSULG                       |
| VILC LF  | V <sub>IL</sub> CLF            | Volume of internal insulation the forward closure;                                                                          | liner within                 |
|          |                                | in <sup>3</sup>                                                                                                             | INSULG                       |

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| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                         | Model Type              |
|----------|-------------------------------|------------------------------------------------------------------------|-------------------------|
| VILCY    | V <sub>IL<sub>CY</sub></sub>  | Volume of internal insulation li<br>the cylindrical case section;<br>3 | ner within              |
|          |                               | in                                                                     | INSULG                  |
| VINR     | v <sub>IN</sub> R             | Volume of residual internal ins in <sup>3</sup>                        | ulation;<br>INSULG      |
| VIS      | v <sub>IS</sub>               | Total volume of internal insulat<br>for slots;                         | tion required           |
|          |                               | in <sup>3</sup>                                                        | INSULG                  |
| VISIH0   | v <sub>IS<sub>IH0</sub></sub> | Volume of internal insulation resingle slot having no sides inhibit    | equired for a<br>bited; |
|          |                               | in <sup>3</sup>                                                        | INSULG                  |
| VISIHI   | v <sub>ISIH1</sub>            | Volume of internal insulation real a single slot having one side in    | equired for<br>hibited; |
|          |                               | in <sup>3</sup>                                                        | INSULG                  |
| VIWCLA   | v <sub>iw</sub> cla           | Volume of internal insulation w associated with the aft closure;       | edge                    |
|          |                               | in <sup>3</sup>                                                        | INSULG                  |
| VIWCLF   | v <sub>iw</sub> clf           | Volume of internal insulation w<br>associated with the forward clo     | edge<br>sure;           |
|          |                               | in <sup>3</sup>                                                        | INSULG                  |

## INPUT DATA, INTER-MODEL (Cont.):

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## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol         | Description; Ext. (Int.) Units           |    |
|----------|----------------|------------------------------------------|----|
| RHOINR   | ρ <sub>R</sub> | Density of residual insulation material; |    |
|          |                | 1b Eq. 12                                | -a |

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## INTERNAL INSULATION WEIGHT

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| DUT | PUT | DATA | (Cont.): |
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| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                                                               |                    |              |
|----------|--------------------------------|----------------------------------------------------------------------------------------------|--------------------|--------------|
| WIJ      | W <sub>IJ</sub>                | Total weight for joint insulation;                                                           |                    |              |
|          |                                | lb                                                                                           | Eq.                | 12           |
| WIJIH2   | w <sub>IJ</sub> <sub>IH2</sub> | Weight of insulation for a single ,<br>both sides inhibited;                                 | joint ha           | aving        |
|          |                                | 1 <b>b</b>                                                                                   | Eq.                | 11           |
| WIL      | w <sub>IL</sub>                | Total weight of insulation liner.<br>forward closure, aft closure, an<br>section components; | Include<br>d cylin | es<br>drical |
|          |                                | ІЪ                                                                                           | Eq.                | 4            |
| WILCLA   | w <sub>il</sub> cla            | Weight of insulation liner within closure section;                                           | aít cas            | e            |
|          |                                | 1Ь                                                                                           | Eq.                | 2            |
| WILCLF   | W <sub>IL</sub> CLF            | Weight of insulation liner within case closure section;                                      | forwa <b>r</b>     | d            |
|          |                                | 1ь                                                                                           | Eq.                | 1            |
| WILCY    | w <sub>IL</sub> CY             | Weight of insulation liner within case section;                                              | cylindı            | rical        |
|          |                                | 1b                                                                                           | Eq.                | 3            |
| WIN      | w <sub>IN</sub>                | Total internal insulation weight.<br>liner, closure wedge, slot and jo<br>components;        | Incluc<br>oint     | les          |
|          |                                | 16                                                                                           | Eq.                | 14           |
| W INN X  | w <sub>IN<sub>NX</sub></sub>   | Total non expended internal insu weight exponent;                                            | lation             |              |
|          |                                | 1 <b>b</b>                                                                                   | Eq.                | 15           |
| WINR     | WTN                            | Weight of residual internal insula                                                           | ation;             |              |
|          | 1'R                            | 16                                                                                           | Eq.                | 13           |
| WINX     | w <sub>IN</sub> x              | Total expended internal insulatio component;                                                 | n weig             | ht           |
|          |                                | lb                                                                                           | Eq.                | 16           |

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## INTERNAL INSULATION WEIGHT

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# OUTPUT DATA (Cont.):

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                                                      |                        |
|----------|---------------------|-----------------------------------------------------------------------------------------------------|------------------------|
| WINXI    | w IN XI             | Expended (non-thrust producing)<br>insulation weight component;                                     | internal               |
|          |                     | lb                                                                                                  | Eq. 18                 |
| WINXT    | w <sub>in</sub> xt  | Expended (thrust producing) inte insulation weight component;                                       | rnal                   |
|          |                     | lb                                                                                                  | Eq. 17                 |
| wis      | WIS                 | Total weight for slot insulation;                                                                   |                        |
|          |                     | ١b                                                                                                  | Eq. 10                 |
| WISIH0   | w <sub>ISIH0</sub>  | Weight of insulation for a single having no sides inhibited;                                        | slot                   |
|          |                     | 1Ь                                                                                                  | Eq. 8                  |
| WI STH1  | w <sub>ISIH1</sub>  | Weight of insulation for a single<br>one side inhibited;                                            | slot having            |
|          |                     | 1Ъ                                                                                                  | Eq. 9                  |
| WIW      | w <sub>IW</sub>     | Total weight of insulation of insu<br>wedges. Includes forward case<br>aft case closure components; | ulation<br>closure and |
|          |                     | ІЪ                                                                                                  | Eq. 7                  |
| WIWCLA   | w <sub>IW</sub> cla | Weight of insulation wedge assoc<br>aft closure section;                                            | ciated with            |
|          |                     | 1Ъ                                                                                                  | Eq. 6                  |
| WIWCLF   | w <sub>IW</sub> clf | Weight of insulation wedge associon forward closure section;                                        | ciated with            |
|          |                     | lb                                                                                                  | Eq. 5                  |

PRINT BLOCK KEY:

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Norminally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

|          |         |          | MJUS NI     | TIMMUT   | INTERNAL   | INSULATION WEIGHT |
|----------|---------|----------|-------------|----------|------------|-------------------|
| NIM      | XNNITH  | XNITM    | <b>[</b> *  | IXNIM    | TXNIW      |                   |
| KRHOINR  | KRHOIRJ | K RHOIRL | çı<br>¥     | K RHOIRS | KRHOLRW    | <b>LINX</b>       |
| KWIJIHZ  | NWIL    | KUTICLA  | ÷           | KWILCLF  | KNILCY     | KUTN              |
| XNINTENX | KUTNR   | XNIMX    | <b>†</b> *  | KWINKT   | KWIS       | OHISIMX           |
| KUTSTHI  | NUMIN   | KWIWCLA  | \$ <b>*</b> | KUTUCLF  | RHOIJ      | RHOIL             |
| RHOINR   | RHOIS   | RHOITH   | \$<br>*     | VIJIHZ   | <b>LIU</b> | TEN               |
| WILCLA   | WILCLF  | WILLOY   | L*          | WINR     | SIW        | OHISIM            |
| THISIN   | MIM     | WINCLA   | 8<br>*      | WINCLF   |            |                   |

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INWM1

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INTSTGG

#### INTERSTAGE GEOMETRY

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MODEL TYPE: INTSTGG (INTerSTaGe Geometry)

MODEL NAME: ITGM1 (Cone frustum)

#### DESCRIPTION:

ITGM1 (InTerstage Geometry Model number 1) evaluates the geometry for a simple cone frustum or cylindrical interstage connecting either two substages (see figure 1) or the top substage and the payload (see figure 2).

#### PROCEDURE:

Prior to entering ITGM1, all substage and payload models have been executed.

ITGMl is then executed. If this is not the uppermost interstage in the propulsion system, the geometry requirements of the substage below and the substage above this interstage are used to determine the pertinent interstage geometry. If this is the uppermost interstage in the propulsion system, the substage below and the payload above are utilized to determine interstage geometry.

After leaving ITGM1, the weight models for this particular interstage are executed. After all interstages are sized, the stage models will be executed and, utilizing the interstage and substage data, the stage will be sized.

#### EQUATIONS:

Required interstage length component associated with the substage above this interstage. Figs. 1, 2

$$L_{IT}_{SSF} = \left( L_{SS}_{ITA} \right)_{above}$$
(1)

Required interstage length component associated with the substage below this interstage. Figs. 1, 2

$$L_{\rm IT}_{\rm SSA} = \left( L_{\rm SS}_{\rm ITF} \right)_{\rm below}$$
(2)

#### INTSTGG

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## INTERSTAGE GEOMETRY

ITGMI

## EQUATIONS (Cont.):

Interstage length. Figs. 1, 2

$$L_{IT} = L_{IT}_{SSA} + L_{IT}_{SSF} + L_{IT}_{S}$$
(3)

Forward interstage base diameter. Figs. 1, 2

$$D_{IT} = \left( D_{SS}_{ITA} \right)_{above}$$
(4)

Aft interstage base diameter. Figs. 1, 2

$$D_{IT_{A}} = \left( D_{SS_{ITF}} \right)_{below}$$
(5)

Interstage half angle. Figs. 1, 2

$$\theta_{\rm IT} = \arctan\left[\frac{D_{\rm IT} - D_{\rm IT}}{2} L_{\rm IT}\right]$$
(6)

Interstage slant height. Figs. 1, 2

$$L_{\rm IT} = \frac{L_{\rm IT}}{\cos \theta_{\rm IT}}$$
(7)

Interstage surface area.

$$S_{IT} = \left(\frac{\pi}{2}\right) L_{IT} \left(D_{IT} + D_{IT}\right)$$
(8)

Interstage aft base cross-sectional area.

$$A_{IT_{A}} = \left(\frac{\pi}{4}\right) D_{IT_{A}}^{2}$$
(9)

Interstage forward base cross-sectional area.

$$A_{IT} = \left(\frac{\pi}{4}\right) D_{IT}^2$$
(10)





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## INPUT DATA, INTRA-MODEL:

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The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol           | Description; Ext. (Int.) Units                             | Preset |
|----------|------------------|------------------------------------------------------------|--------|
| LITS     | L <sub>ITS</sub> | Spacing distance associated with interstage. (Figs. 1, 2); | the    |
|          |                  | in                                                         | 0      |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                                          | Model Type                                            |
|----------|-------------------------------|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| DSSITA   | D <sub>SS<sub>ITA</sub></sub> | Substage aft diameter for inters<br>Associated with the substage ab<br>of, the interstage;              | stage attachment<br>ove, or forward                   |
|          |                               | in                                                                                                      | SUBSTGG                                               |
| DSSITF   | D <sub>SS<sub>ITF</sub></sub> | Substage forward diameter for attachment. Associated with th below, or aft of, the interstage           | interstage<br>e substage<br>;                         |
|          |                               | in                                                                                                      | SUBSTGG                                               |
| LSSITA   | LSSITA                        | Length of interstage required for<br>above, or forward of, the inter<br>nozile protruding beyond aft su | or substage<br>stage. Includes<br>bstage skirt, etc.; |
|          |                               | in                                                                                                      | SUBSTGG                                               |
| LSSITF   | L <sub>SS<sub>ITF</sub></sub> | Length of interstage required for<br>below, or aft of, the interstage<br>closure protruding beyond forw | or substage<br>. Includes<br>ard skirt, etc.;         |
|          |                               | in                                                                                                      | SUBSTGG                                               |

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#### INTSTGG

## INTERSTAGE GEO'METRY

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic                                     | Symbol                       | Description;                                                                           | Ext. (Int.) Units                               |                        |  |
|----------------------------------------------|------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------|------------------------|--|
| AITA                                         | A <sub>IT</sub> A            | Cross-sectional area, interstage aft base<br>in <sup>2</sup> Ec                        |                                                 |                        |  |
| AITF                                         | A <sub>IT</sub> <sub>F</sub> | Cross-sectio<br>in <sup>2</sup>                                                        | nal area, interstage f                          | ore base;<br>Eq. 10    |  |
| DITA                                         | D <sub>IT</sub> <sub>A</sub> | Interstage af<br>in                                                                    | t (below) base diamete<br>Figs. 1, 2            | r;<br>Eq. 5            |  |
| DITF                                         | D <sub>IT</sub> <sub>F</sub> | Interstage fo<br>in                                                                    | rward (above) base dia<br>Figs. 1, 2            | Eg. 4                  |  |
| ITHA                                         | $\theta_{\rm IT}$            | Interstage ha<br>deg                                                                   | lf angle. (internal uni<br>Figs. 1, 2           | ts, radians);<br>Eq. 6 |  |
| LIT                                          | L <sub>IT</sub>              | Interstage length. Measured along centerline.<br>Altitude of cone frustum or cylinder; |                                                 |                        |  |
| LITL                                         | LITL                         | in<br>Interstage sl                                                                    | Figs. 1, 2<br>ant height;<br>Figs. 1, 2         | Eq. 3                  |  |
| LITSSA                                       | L <sub>IT</sub> SSA          | Required interstage length component<br>associated with the substage above (forward);  |                                                 |                        |  |
|                                              |                              | in                                                                                     | Figs. 1, 2                                      | Eq. 2                  |  |
| LITSSF                                       | L <sub>IT</sub> SSF          | Required inte<br>associated w                                                          | erstage length compon<br>ith the substage below | ent<br>(aft);          |  |
|                                              |                              | in                                                                                     | Figs. 1, 2                                      | Eq. l                  |  |
| SIT S <sub>IT</sub> Interstage surface area; |                              |                                                                                        | iríace area;                                    |                        |  |
|                                              | **                           | in                                                                                     | Figs. 1, 2                                      | Eq. 8                  |  |

PRINT BLOCK KEY:

Norminally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

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## INTERSTAGE GEOMETRY

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INTINSW INTERSTAGE EXTERNAL INSULATION WEIGHT ITIWM1

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| MODEL TYPE: | INTINSW | (INTerstage E  | xternal | <u>INS</u> ulation | Weight) |
|-------------|---------|----------------|---------|--------------------|---------|
| MODEL NAME: | ITIWMI  | (Geometry Depe | endent) |                    |         |

## **DESCRIPTION:**

ITIWM1 (InTerstage external Insulation Weight Model number  $\underline{l}$ ) uses a geometry dependent equation to evaluate the interstage external insulation weight as a function of the interstage surface area and the external insulation weight per unit area.

#### **PROCEDURE:**

Prior to entering ITIWM1, the model specified for the INTSTGG model type has determined the interstage surface area.

The ITIWM1 model uses the interstage surface area, together with the external insulation weight per unit area, to determine the external insulation weight breakdown.

After leaving ITIWM1, the model specified for the INTSTGW model type will use the external insulation weights to evaluate the interstage weights.

#### EQUATIONS:

Total interstage external insulation weight.

$$W_{IT_{IE}} = K_{WITIE} \left( K_{WITIE1} S_{IT} W_{IT_{IUA}} + K_{WITIE2} \right)$$
(1)

Total non-expended interstage external insulation weight component.

$$W_{IT_{IENX}} = K_{WITINX} W_{IT_{IE}}$$
(2)

Total expended interstage external insulation weight component.

$$W_{IT} = K_{WITIX} W_{IT}$$
(3)

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# EQUATIONS (Cont.):

Expended (non-thrust producing) interstage external insulation weight component.

$$W_{IT_{IEXI}} = W_{IT_{IEX}}$$
(4)

Expended (thrust producing) interstage external insulation weight component.

$$W_{IT} = 0$$
(5)

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                            | Preset  |
|----------|-------------------------------|---------------------------------------------------------------------------|---------|
| KWITIE   | κ <sub>witje</sub>            | Coefficient for WITIE computation;<br>N. D.                               | 1       |
| KWI71E1  | <sup>K</sup> witie1           | Coefficient for WITIE computation;<br>N. D.                               | 1       |
| KWITIE2  | <sup>K</sup> witie2           | Bias for WITLE computation;<br>lb                                         | 0       |
| KWITINX  | <sup>K</sup> witinx           | Coefficient for WITIENX computation N. D.                                 | n;<br>1 |
| KWITIX   | <sup>K</sup> witix            | Coefficient for WITIEX computation N. D.                                  | ;<br>0  |
| WITIUA   | w <sub>IT<sub>IUA</sub></sub> | Weight of interstage external insula<br>per unit interstage surface area; | tion    |
|          |                               | lb/in <sup>4</sup>                                                        | 0       |

INTINSW INTERSTAGE EXTERNAL INSULATION WEIGHT ITIWMI

# INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such ? source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units              | Model Type |
|----------|-----------------|---------------------------------------------|------------|
| SIT      | <sup>S</sup> IT | Interstage surface area;<br>in <sup>2</sup> | INTSTGG    |

#### OUTPUT DATA:

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The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                                               |               |  |  |
|----------|--------------------------------|------------------------------------------------------------------------------|---------------|--|--|
| WITIE    | w <sub>IT</sub> F              | Total interstage external insulation weight;                                 |               |  |  |
|          |                                | 16                                                                           | Eq. 1         |  |  |
| WITIENX  | W <sub>IT</sub> ienx           | Total non-expended interstage external insulation weight component;          |               |  |  |
|          |                                | lb                                                                           | Eq. 2         |  |  |
| WITIEX   | w <sub>it</sub> iex            | Total expended interstage external in weight component;                      | nsulation     |  |  |
|          |                                | lb                                                                           | Eq. 3         |  |  |
| WITIEXI  | w <sub>IT</sub> IEXI           | Expended (non-thrust producing) inte<br>external insulation weight component | erstage<br>t; |  |  |
|          |                                | 1ь                                                                           | Eq. 4         |  |  |
| WITIEXT  | W <sub>IT</sub> <sub>EXT</sub> | Expended (thrust producing) intersta<br>external insulation weight component | ge<br>t;      |  |  |
|          |                                | 16                                                                           | Eq. 5         |  |  |

PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| VEIGHT     |         |                  |
|------------|---------|------------------|
| INSULATION |         |                  |
| E EXTERNAL |         | AUTTIN           |
| INTERSTAG  |         | XUTTUX           |
| TWALTI     | DUILIN  | XNILLINX         |
| MSNILINI   | Ŧ       | ţ                |
|            | MITTEX  | <b>ZA LITINX</b> |
|            | XNELLIN | KULTTEL          |
|            | WITTE   | KUTTE            |

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| INTSTRW     | INTERSTAC | SE STRUCTURE WEIGHT           | ITSWMI |
|-------------|-----------|-------------------------------|--------|
| 120. 1      |           |                               |        |
| MODEL TYPE: | INTSTRW   | (INTerstage STRucture Weight) |        |
| MODEL NAME: | ITSWMI    | (Parametric weight scaling)   |        |

#### DESCRIPTION:

ITSWM1 (InTerstage Structure Weight Model number 1) utilizes a parametric weight scaling equation to determine the interstage structure weight. The actual flight loads are not used explicitly as parameters by this model. However, axial thrust loads are implicitly accounted for since the theoretical equation, upon which the correlation analysis is based, uses motor thrust as a loading parameter. See reference 8 for a description of the equation and scaling rationale.

The interstage structure includes all of the interstage except the external insulation.

The model is applicable for performance parameters within the following limits (see Input Data - Inter Model).

5 < RAEXTIH < 75 300 < PCHAVG < 1000 psia 40 < TBPPMT < 140 sec. 3000 < WPPMT < 2,000,000 lbs.

#### **PROCEDURE:**

Prior to entering ITSWM1, the geometry, weights, internal ballistics, and propulsion characteristics for all of the substages have been evaluated. For the substage immediately above this interstage, the models specified for the IBGAS, IBPERF, and NOZZLEG model types have evaluated the internal ballistics and nozzle geometry. For the substage immediately below this interstage, the models specified for the IBPERF and PROPELW model types have evaluated the internal ballistics and propellent characteristics.

The ITSWM1 model is then executed and the interstage structure weight is evaluated using parametric weight scaling equations. In addition, the interstage structure weight is broken down into expended and non-expended components.

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#### INTERSTAGE STRUCTURE WEIGHT

#### PROCEDURE (Cont.):

After leaving ITSWM1, these expended and non-expended components will be used by the model specified for the INSTGW model type to determine the interstage weights.

#### EQUATIONS:

Total interstage structure weight.

$$w_{IT_{ST}} = \kappa_{WITST} C_1 \left\{ \left[ \frac{W_{PP_{MT}} I_{SP_{VD}}}{T_B} \right]_{below} \right]^{C_2}$$
(1)

$$\left[ \frac{W_{PP_{MT}}}{V_{NZ}} - 1 \right] \sqrt{\frac{W_{PP_{MT}}}{V_{MT}}} \right]_{above}^{C^{*}}$$

Total non-expended interstage structure weight component.

$$W_{IT_{STNX}} = K_{WITSNX} W_{IT_{ST}}$$
(2)

Total expended interstage structure weight component.

$$W_{IT_{STX}} = 0$$
(3)

Expended (non-thrust producing) interstage structure weight component.

$$W_{IT} = 0$$
(4)

Expended (thrust producing) interstage structure weight component.

$$W_{I'\Gamma} = 0$$
(5)

#### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

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**INTSTRW** 

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# INTERSTAGE STRUCTURE WEIGHT IT

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# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                          | Preset             |  |
|----------|---------------------|-------------------------------------------------------------------------|--------------------|--|
| CITST1   | C,                  | Scaling constant for WITST compu                                        | tation;            |  |
|          | •                   | N. D.                                                                   | 0.00114            |  |
| CITST2   | c <sub>2</sub>      | Scaling constant for WITST compu                                        | tation;            |  |
|          | -                   | N. D.                                                                   | 0.665              |  |
| CITST3   | c3                  | Scaling constant for WITST compu                                        | WITST computation; |  |
|          | -                   | N. D.                                                                   | 0.828              |  |
| KWITST   | <sup>K</sup> witst  | Proportionality factor for total int structure weight;                  | erstage            |  |
|          |                     | N. D.                                                                   | 1                  |  |
| KWITSNX  | <sup>K</sup> witsnx | Proportionality factor for non-exp<br>stage structure weight component; | ended inter-       |  |
|          |                     | N. D.                                                                   | 1                  |  |

# INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol             | Description; Ext. (Int.) Unit                             | s Model Type      |
|----------|--------------------|-----------------------------------------------------------|-------------------|
| CVDELV   | с*                 | Delivered characteristic vel<br>above this interstage;    | ocity of substage |
|          |                    | ft/sec                                                    | IBGAS             |
| ISPVD    | I <sub>SP</sub> vd | Delivered vacuum specific impulse obelow this interstage; |                   |
|          |                    | 8 e C                                                     | IBPERF            |
| PCHAVG   | PAVG               | Average chamber pressure of this interstage;              | of substage above |
|          |                    | psia                                                      | IBGAS             |

INTSTRW

#### INTERSTAGE STRUCTURE WEIGHT

ITSWMI

# INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                   | Model Type    |
|----------|--------------------|--------------------------------------------------|---------------|
| RAEXTTH  | • <sub>NZ</sub>    | Expansion ratio of substage abo<br>interstage;   | ove this      |
|          |                    | N. D.                                            | NOZZLEG       |
| RLNZP    | RLNZP              | Protruding nozzle ratio of subs this interstage; | tage above    |
|          |                    | N. D.                                            | NOZZLEG       |
| TBPPM1   | т <sub>в</sub>     | Propellent lurn time of substag<br>interstage;   | ge above this |
|          |                    | sec                                              | IBPERF        |
| твррмт   | т <sub>в</sub>     | Propellent burn time of substag<br>interstage;   | ge below this |
|          |                    | 8ec                                              | IBPERF        |
| WPPMT    | w <sub>PP</sub> MT | Propellent weight of substage a interstage;      | above this    |
|          |                    | sec                                              | PROPELW       |
| WPPMT    | w <sub>pp</sub> mt | Propellent weight of substage b<br>interstage;   | elow this     |
|          |                    | 1ь                                               | PROPEL        |

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol            | Description; Ext. (Int.) Units                                                                |  |
|----------|-------------------|-----------------------------------------------------------------------------------------------|--|
| WITST    | w <sub>itst</sub> | Total interstage structure weight. Includes all interstage weight except external insulation; |  |
|          |                   | lb Eq. l                                                                                      |  |

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# INSTRW INTERSTAGE STRUCTURE WEIGHT ITSWM1

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# OUTPUT DATA (Cont.):

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| Mnemonic | Symbol               | Description; Ext. (Int.) Units                                   |                |
|----------|----------------------|------------------------------------------------------------------|----------------|
| WITSTNX  | w <sub>it</sub> stnx | Total non-expended interstage st<br>component;                   | ructure weight |
|          |                      | ĪP                                                               | <b>Eq.</b> 2   |
| WITSTX   | w <sub>itstx</sub>   | Total expended interstage structure component;                   |                |
|          |                      | lь                                                               | Eq. 3          |
| WITSTXI  | w <sub>itstxi</sub>  | Expended (non-thrust producing)<br>structure weight component;   | interstage     |
|          |                      | lb                                                               | Eq. 4          |
| WITSTXT  | w <sub>itstxt</sub>  | Expended (thrust producing) inter<br>structure weight component; | rstage         |
|          |                      | lb                                                               | Eq. 5          |

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PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given bylow may be printed or suppressed (see the section on output models for the details).

| INTERSTAGE STRUCTURE WEIGHT<br>WITSTRT |                      |
|----------------------------------------|----------------------|
| DXISLIN<br>DVISLIN                     |                      |
| I*I<br>*1                              | * *                  |
| XISLIM                                 | CINSTI 3             |
| XNLSLIM                                | CITISTI2<br>CITISTI2 |
| ISTIW                                  | LTSTID<br>CITSTI     |

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INTSTRW

#### INTERSTAGE STRUCTURE WEIGHT

ITSWM2

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| MODEL TYPE: | INTSTRW | (INTerstage STRucture Weight) |
|-------------|---------|-------------------------------|
| MODEL NAME: | ITSWM2  | (Geometry Dependent Weight)   |

#### **DESCRIPTION:**

ITSWM2 (InTerstage Structure Weight Model number 2) uses a geometry dependent equation to evaluate the interstage structure weight as a function of the interstage surface area and the weight per unit surface area. Although this model may be utilized for any interstage, its primary usage is for simulating the top interstage within the propulsion system (i.e., payload adapter).

The interstage structure includes all of the interstage except the external insulation.

#### **PROCEDURE:**

Prior to entering ITSWM2, the model specified for the INTSTGG model type has determined the interstage surface area.

The ITSWM2 model then uses the interstage surface area, together with the structure weight per unit surface area, to determine the interstage structure weight breakdown.

After leaving ITSWM2, the model specified for the INTSTGW model type will use the interstage structure weight to determine the interstage weight.

#### EQUATIONS:

Total interstage structure weight.

$$W_{IT_{ST}} = K_{WITST} \left( K_{WJTST1} S_{IT} W_{IT_{SUA}} + K_{WITST2} \right)$$
(1)

Total non-expended interstage structure weight component.

$$W_{IT}_{STNX} = W_{IT}_{ST}$$
(2)

Total expended interstage structure weight component.

$$W_{\rm IT_{\rm STX}} = 0 \tag{3}$$

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INTSTRW

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#### INTERSTAGE STRUCTURE WEIGHT

ITSWM2

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#### EQUATIONS (Cont.):

Expended (thrust producing) interstage structure weight component.

$$W_{IT_{STXT}} = 0$$
(4)

Expended (non-thrust producing) interstage structure weight component.

$$W_{\rm IT} = 0$$
(5)

#### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                      | Preset       |
|----------|---------------------|---------------------------------------------------------------------|--------------|
| KWITST   | <sup>K</sup> witst  | Coefficient for WITST computation;<br>N. D.                         | 1            |
| KWITSTI  | <sup>K</sup> witsti | Coefficient for WITST computation;<br>N. D.                         | 1            |
| KWITST2  | <sup>K</sup> witst2 | Bias for WITST computation;<br>lb                                   | 0            |
| WITSUA   | w <sub>itsua</sub>  | Interstage structure weight per unit<br>area;<br>lb/in <sup>2</sup> | surface<br>0 |

#### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. (Int.) Units  | Model Type |
|----------|--------|---------------------------------|------------|
| SIT      | Sir    | Interstage structure surface ar | ea;        |
|          | ••     | in <sup>2</sup>                 | INTSTGG    |

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# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic                    | Symbol              | Description; Ext. (Int.) Units                                                   |                |             |
|-----------------------------|---------------------|----------------------------------------------------------------------------------|----------------|-------------|
| WITST                       | w <sub>itst</sub>   | Total interstage structure weight, inc<br>interstage weight except external insu | lude:<br>latio | s all<br>n; |
|                             |                     | 1ь                                                                               | Eq.            | 1           |
| WITSTNX                     | w <sub>itstnx</sub> | Total non-expended interstage structu<br>weight component;                       | ıre            |             |
|                             |                     | 1ь                                                                               | Eq.            | 2           |
| WITSTX                      | w <sub>itstx</sub>  | Total expended interstage structure w component;                                 | eight          | t           |
|                             |                     | 1ь                                                                               | Eq.            | 3           |
| witstxi w <sub>itstxi</sub> |                     | Expended (non-thrust producing) inter<br>structure weight component;             | stag           | e           |
|                             |                     | 1ь                                                                               | Eq.            | 5           |
| WITSTXT                     | w <sub>itstxt</sub> | Expended (thrust producing) interstag structure weight component;                | e              |             |
|                             |                     | 1b                                                                               | Eq.            | 4           |

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PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| INTERSTAGE STRUCTURE WEIGHT<br>WITISDAT |
|-----------------------------------------|
| IXISI IM<br>ZWMSLI                      |
| †*<br>≥*<br>T*                          |
| AUSTIN                                  |
| ZISIIMX<br>XNSLIMX<br>XNLSLIM           |
| NTTST<br>KWITIST<br>KWITIST             |

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MODEL TYPE: INTSTGW (INTerSTaGe Weight)

MODEL NAME: IT WM1 (Weight Synthesis)

#### **DESCRIPTION:**

ITWM1 (InTerstage Weight Model number 1) is a weight synthesis model which evaluates the interstage weight breakdown. The interstage weight is comprised of the following subsystems:

Interstage structure

Interstage external insulation

#### PROCEDURE:

Prior to entering ITWM1, the models specified by the INTSTRW and INTINSW model types have evaluated the interstage structure and external insulation weights. In addition to evaluating subcomponent weights peculiar to their particular requirements, they have defined a set of component weights in terms of expended or non-expended attributes.

These expended and non-expended weight components are input to ITWM1. The ITWM1 model will combine these quantities to determine the interstage weight components.

After all of the interstages are sized, the model specified by the STAGEW model type will use the substage and interstage quantities to determine the stage weights and mass fractions.

#### EQUATIONS:

Total interstage weight.

 $\mathbf{w}_{\mathbf{IT}} = \kappa_{\mathbf{WIT}} \left( \mathbf{w}_{\mathbf{IT}_{\mathbf{ST}}} + \mathbf{w}_{\mathbf{IT}_{\mathbf{IE}}} \right)$ (1)

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## INTERSTAGE WEIGHT

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# EQUATIONS (Cont.):

Total non-expended interstage weight component.

$$W_{IT_{NX}} = K_{WITNX} \left( W_{IT_{STNX}} + W_{IT_{IENX}} \right)$$
(2)

Total expended interstage weight component.

$$\mathbf{w}_{\mathrm{IT}_{\mathbf{X}}} \stackrel{\simeq}{=} \stackrel{\mathrm{K}}{\mathrm{WIT}_{\mathbf{X}}} \left( \stackrel{\mathrm{W}}{\mathrm{IT}_{\mathrm{STX}}} \stackrel{+}{=} \stackrel{\mathrm{W}}{\mathrm{IT}_{\mathrm{IEX}}} \right)$$
(3)

Expended (thrust producing) interstage weight component.

$$\mathbf{w}_{\mathrm{IT}_{\mathrm{XT}}} = \mathbf{K}_{\mathrm{WITXT}} \begin{pmatrix} \mathbf{w}_{\mathrm{IT}_{\mathrm{STXT}}} + \mathbf{w}_{\mathrm{IT}_{\mathrm{IEXT}}} \end{pmatrix}$$
(4)

Expended (non-thrust producing) interstage weight component.

$$W_{IT_{XI}} = K_{WITXI} \left( W_{IT_{STXI}} + W_{IT_{IEXI}} \right)$$
(5)

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic                | Symbol             | Description; Ext. (Int.) Units                                           | Preset                   |
|-------------------------|--------------------|--------------------------------------------------------------------------|--------------------------|
| KWIT                    | Kwit               | Proportionality factor for total int weight;                             | erstage                  |
|                         |                    | N. D.                                                                    | 1                        |
| KWITNX                  | κ <sub>witnx</sub> | Proportionality factor for total no<br>interstage weight component;      | n-expended               |
|                         |                    | N. D.                                                                    | 1                        |
| kwitx k <sub>witx</sub> |                    | Proportionality factor for total ex<br>interstage weight component;      | pended                   |
|                         |                    | N. D.                                                                    | 1                        |
| KWITXI                  | ĸ <sub>witxi</sub> | Proportionality factor for expende<br>thrust producing) interstage weigh | ed (non-<br>t component: |
|                         |                    | N. D.                                                                    | 1                        |

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## INTERSTAGE WEIGHT

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INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                                          | Preset               |
|----------|--------------------|-------------------------------------------------------------------------|----------------------|
| KWITXT   | <sup>K</sup> witxt | Proportionality factor for expende<br>producing) interstage weight comp | d (thrust<br>conent; |
|          |                    | N. D.                                                                   | 1                    |

# INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this date, then it must be input directly with the intra-model input.

| Mnemonic              | Symbol               | Description; Ext. (Int.; Units                                  | Model Type       |
|-----------------------|----------------------|-----------------------------------------------------------------|------------------|
| WITIE W <sub>II</sub> | WIT <sub>IE</sub>    | Total interstage external insulation weight;                    |                  |
|                       | ***                  | 16                                                              | INTINSW          |
| WITIENX               | W <sub>IT</sub> ienx | Total non-expended interstage e insulation weight component;    | external         |
|                       |                      | Ъ                                                               | INTINSW          |
| WITIEX                | w <sub>IT</sub> IEX  | Total expended interstage exter weight component;               | nal insulation   |
|                       |                      | 16                                                              | INTINSW          |
| WITIEXI               | w <sub>IT</sub> IEXI | Expended (non-thrust producing insulation weight component;     | ) external       |
|                       |                      | 16                                                              | INTINSW          |
| WITIEXT               | w <sub>it</sub> iext | Expended (thrust producing) ext<br>insulation weight component; | ernal            |
|                       |                      | 16                                                              | INTINSW          |
| WITST                 | WIT                  | Total interstage structure weig                                 | ht;              |
|                       | I ST                 | Ъ                                                               | INTSTRW          |
| WITSTNX               | w <sub>itstnx</sub>  | Total non-expended interstage a component;                      | structure weight |
|                       |                      | 1ь                                                              | <b>INTSTRW</b>   |

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# INPUT DATA, INTER-MCDEL (Cont.):

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                               | Model Type    |
|----------|---------------------|--------------------------------------------------------------|---------------|
| WITSTX   | w <sub>itstx</sub>  | Total expended interstage stru<br>component;                 | cture weight  |
|          |                     | 1ь                                                           | INTSTR W      |
| WITSTXI  | <sup>w</sup> itstxi | Expended (non-thrust producin<br>structure weight component; | g) interstage |
|          |                     | Ъ                                                            | INTSTRW       |
| WITSTXT  | w <sub>itstxt</sub> | Expended (thrust producing) in structure weight component;   | terstage      |
|          |                     | 16                                                           | INTSTRW       |

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic                           | Symbol             | Description; Ext. (Int.) Units                                                                                |        |
|------------------------------------|--------------------|---------------------------------------------------------------------------------------------------------------|--------|
| WIT                                | W <sub>IT</sub>    | Total interstage weight. Includes structur<br>and external insulation;                                        | re     |
|                                    |                    | lb Eq.                                                                                                        | 1      |
| WITNX W <sub>IT<sub>NX</sub></sub> |                    | Total non-expended interstage weight component. Includes structure and extern insulation;                     | al     |
|                                    |                    | ib Eq.                                                                                                        | 2      |
| witx w <sub>itx</sub>              | w <sub>IT</sub> x  | Total expended interstage weight compone<br>Includes structure and external insulation;                       | nt.    |
|                                    |                    | lb Eq.                                                                                                        | 3      |
| WITXI                              | w <sub>IT</sub> XI | Expended (non-thrust producing) interstag<br>weight component. Includes structure and<br>external insulation; | e<br>1 |
|                                    |                    | lb Eq.                                                                                                        | 5      |

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| OUTPUT DA | I'A (Cont.):       |                                                                                                            |   |
|-----------|--------------------|------------------------------------------------------------------------------------------------------------|---|
| Mnemonic  | Symbol             | Description; Ext. (Int.) Units                                                                             |   |
| WITXT     | w <sub>IT</sub> XT | Expended (thrust producing) interstage<br>weight component. Includes structure and<br>external insulation; |   |
|           |                    | lb Eq.                                                                                                     | 4 |

PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| INTERSTAGE WEIGHT<br>WITXI<br>KUTTYT |   |
|--------------------------------------|---|
| DATTU<br>DATTU<br>DATTU              |   |
| C*<br>T*                             | , |
| XILIN<br>XILIN                       |   |
| XNTTNX<br>XNTTVX                     |   |
| NTT<br>KVTT                          |   |

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MISCELLANEOUS MOTOR WEIGHT

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| MODEL TYPE: | MISCMTW | (MISCellaneous MoTor Weight)                                 |
|-------------|---------|--------------------------------------------------------------|
| MODEL NAME: | MMWM1   | (Collective Miscellaneous Subsystems,<br>Parametric Scaling) |

#### DESCRIPTION:

MMWM1 (Miscellaneous Motor Weight Model number 1) utilizes a parametric scaling equation to determine collectively the weight of a set of miscellaneous solid rocket motor subsystems. The subsystems considered are:

Raceways

Base heat protection

Igniter

Ordnance

See reference 8 for a description of the equation and parametric scaling rationale.

The model is applicable for performance parameters within the following limits (see Input Data, Inter-Model and reference 8, figure 15).

1000 lb < WFPMT < 5,000,000 lb

#### PROCEDURE:

In addition to evaluating the miscellaneous motor weight, the MMWM1 model determines the weight breakdown in terms of expended and non-expended components.

These expended and non-expended component weights will later be used by the model specified for the MOTORW model type to determine the motor weights and mass fractions.

#### EQUATIONS:

Total miscellaneous motor weight.

$$w_{MM} = \kappa_{WMM} C_1 \left( W_{PP_{MT}} \right)^C 2$$
 (1)

Total non-expended miscellaneous motor weight component.

$$W_{MM_{NX}} = K_{WMMNX} W_{MM}$$
(2)

Total expended miscellaneous motor weight component.

$$W_{MM} = 0 \tag{3}$$

Expended (thrust producing) miscellaneous motor weight component.

$$W_{MM_{XI}} = 0$$
 (4)

Expended (non-thrust producing) miscellaneous motor weight component.

$$W_{MM} = 0$$
(5)

#### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol         | Description; Ext. (Int.) Units     | Preset  |
|----------|----------------|------------------------------------|---------|
| CMMWI    | C,             | Scaling constant for WMM comput    | ations; |
|          | -              | N. D.                              | 0,05    |
| CMMW2    | C <sub>2</sub> | Scaling constant for WMM computati |         |
|          | 2              | N. D.                              | 0.8     |

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## MISCELLANEOUS MOTOR WEIGHT

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# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol                      | Description; Ext. (Int.) Units                                         | Preset          |
|----------|-----------------------------|------------------------------------------------------------------------|-----------------|
| кумм     | <sup>к</sup> <sub>wmm</sub> | Proportionality factor for total mi motor weight;                      | scellaneous     |
|          |                             | N. D.                                                                  | 1               |
| KWMMNX   | <sup>K</sup> wmmnx          | Proportionality factor for non-exp<br>miscellaneous motor weight compo | ended<br>onent; |
|          |                             | N. D.                                                                  | 1               |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units | Model Type |
|----------|-----------------|--------------------------------|------------|
| WPPMT    | W <sub>PP</sub> | Propellent weight;             |            |
|          | MT              | 16                             | PROPELW    |

#### OUTPUT DATA:

The following data is output by this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                                                                      |                                        |  |
|----------|------------------------------|---------------------------------------------------------------------------------------------------------------------|----------------------------------------|--|
| WMM      | w <sub>MM</sub>              | Total miscellaneous motor weight, includes<br>weights of raceways, base heat protection,<br>igniters, and ordnance; |                                        |  |
|          |                              | ІЪ                                                                                                                  | Eq. 1                                  |  |
| WMMNX    | w <sub>MM<sub>NX</sub></sub> | Total non-expended miscellane<br>weight component, includes we<br>raceways, base heat protection<br>and ordnance;   | ous motor<br>fights of<br>h, igniters, |  |
|          |                              | 16                                                                                                                  | Eq. 2                                  |  |

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# OUTPUT DATA (Cont.):

| Mnemonic | Symbol                                                                                                                  | Description                                                                                                                                  | ; Ext. (Int.) Units                          |                                                      |
|----------|-------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|------------------------------------------------------|
| WMMX     | w <sub>MM</sub> X                                                                                                       | Total expen<br>component,<br>base heat p                                                                                                     | motor weight<br>f raceways,<br>and ordnance; |                                                      |
|          |                                                                                                                         | 1ь                                                                                                                                           |                                              | Eq. 3                                                |
| WMMXI    | w <sub>MM</sub> XI                                                                                                      | Expended (non-thrust producing) misce<br>KI motor weight component, includes weig<br>raceways, base heat protection, ignite<br>and ordnance; |                                              | ng) miscellaneous<br>udes weights of<br>n, igniters, |
|          |                                                                                                                         | ІЬ                                                                                                                                           |                                              | Eq. 4                                                |
| WMMXT    | W.MMXT Expended (thrust producing) weigh<br>MMXT includes weights of raceways, bas<br>protection, igniters, and ordnanc |                                                                                                                                              | eight component,<br>base heat<br>ance;       |                                                      |
|          |                                                                                                                         | Эр                                                                                                                                           | ŝ                                            | Eq. 5                                                |

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| KEY:  |  |
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| BLOCK |  |
| PRINT |  |

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| MISCELLANEOUS MOTOR WEIGHT | WMMXT |          |
|----------------------------|-------|----------|
| TIMMMW                     | IXWWM | XNNNMMYX |
| MISCHIW                    | Ŧ     | CU<br>*  |
|                            | XUMIN | KWWW     |
|                            | XNUMM | CIMINZ   |
|                            | Man   | CMMMD    |

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MOTOR GEOMETRY

MTGMI

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MODEL TYPE: MOTORG (MOTOR Geometry)

MODEL NAME: MTGMl (Solid Rocket Motor)

#### DESCRIPTION:

MTGM1 (MoTor Geometry Model number 1) evaluates the geometry of a basic solid rocket motor. The motor includes only the cylindrical case section, forward case closure section and aft case closure section. It may include diameter corrections for raceways, etc., but does not include the protruding portion of the nozzle, thrust termination ports, etc. The latter quantities are evaluated by the substage geometry model. The motor geometry is illustrated by figure 1.

#### PROCEDURE:

Prior to entering MTGM1, the models specified by the PROPELW, CASEG, and GRAING model types have evaluated the geometry of the major motor components.

MTGM1 then determines the basic motor geometry.

After executing MTGM1, the model specified by the SUBSTGG model type will utilize the motor geometry and nozzle geometry to determine the substage geometry.

#### EQUATIONS:

Length of forward motor closure. (Figure 1)

$$L_{MT_{CHF}} = K_{MT_1} L_{CS_{CHFO}} + K_{MT_2}$$
(1)

Length of aft motor closure. (Figure 1)

$$L_{MT_{CHA}} = K_{MT_3} L_{CS_{CHAO}} + K_{MT}.$$
 (2)

#### MOTOR GEOMETRY

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EQUATIONS (Cont.):

Length of motor cylindrical section. (Figure 1)

$$L_{MT_{CY}} = K_{MT_5} L_{CS_{CY}} + K_{MT_6}$$
(3)

Total motor length. (Figure 1)

$$L_{MT} = L_{MT_{CY}} + L_{MT_{CHF}} + L_{MT_{CHA}}$$
(4)

Total motor diameter. (Figure 1)

$$D_{MT} = K_{MT_7} D_{CS_0} + K_{MT_8}$$
<sup>(5)</sup>

Motor cross sectional area.

$$A_{MT} = \left(\frac{\pi}{4}\right) D_{MT}^2 \tag{6}$$

Ratio; motor length to case diameter.

$$R_{LDMTCS} = \frac{L_{MT}}{D_{CS_{O}}}$$
(7)

Ratio; motor length to motor diameter.

$$R_{LDMT} = \frac{L_{MT}}{D_{MT}}$$
(8)

Motor volume.

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$$v_{MT} = v_{GN}$$
(9)

Motor volumetric loading efficiency.

$$\eta_{\mathbf{PP}_{\mathbf{MT}}} = \frac{\mathbf{V}_{\mathbf{PP}_{\mathbf{MT}}}}{\mathbf{V}_{\mathbf{MT}}}$$
(10)

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# MOTOR GEOMETRY

MTGM1

# EQUATIONS (Cont.):

| Motor forward skirt length. (Figure 1)                                                         |      |
|------------------------------------------------------------------------------------------------|------|
| $L_{MT_{SKF}} = K_{MTSKF1} D_{CS_{O}} + K_{MTSKF2}$                                            | (11) |
| Motor aft skirt length. (Figure 1)                                                             |      |
| L <sub>MT<sub>SKA</sub> = <sup>K</sup>MTSKA1 <sup>D</sup>C<b>S</b>O <sup>+ K</sup>MTSKA2</sub> | (12) |

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MOTOR GEOMETRY

MTGM1

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Fig. 150, 1-1 Basic Motor Geometry

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#### MOTOR GEOMETRY

#### MTGMI

## INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                                               | Preset            |
|----------|---------------------|----------------------------------------------------------------------------------------------|-------------------|
| KMTSKAI  | <sup>K</sup> MTSKA1 | Proportionality factor relating the m<br>skirt length to the outside case diam               | otor aft<br>eter; |
|          |                     | N. D.                                                                                        | 0.1               |
| KMTSKA2  | K <sub>MTSKA2</sub> | Bias for motor aft skirt length comp                                                         | utation;          |
|          |                     | in                                                                                           | 0                 |
| KMTSKFI  | <sup>K</sup> MTSKF1 | Proportionality factor relating the m<br>forward skirt length to the outside ca<br>diameter; | otor<br>Ise       |
|          |                     | N. D.                                                                                        | 0.1               |
| KMTSKF2  | K <sub>MTSKF2</sub> | Bias for motor forward skirt length computation;                                             |                   |
|          |                     | in                                                                                           | 0                 |

The following coefficient and bias quantities are made available for input. However, in normal applications, the preset values are used for most, if not all, of these quantities. Note that these coefficient quantities are preset (1) and the bias quantities are preset (0).

| KMTI . | K <sub>MT1</sub> | Coefficient for LMTCHF computation.      | on;<br>l |
|--------|------------------|------------------------------------------|----------|
| КМТ2   | K <sub>MT2</sub> | Bias for LMTCHF computation;<br>in       | U        |
| КМТ3   | K <sub>MT3</sub> | Coefficient for LMTCHA computation N. D. | אי:<br>1 |
| KMT4   | K <sub>MT4</sub> | Bias for LMTCHA compu 'on;<br>in         | 0        |

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## MOTOR GEOMETRY

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MTGM1

| Mnemonic | Symbol           | Description; Ext. (Int.) Units              | Preset |
|----------|------------------|---------------------------------------------|--------|
| KMT5     | к <sub>мт5</sub> | Coefficient for LMTCY computation;<br>N. D. | 1      |
| KMT6     | к <sub>мт6</sub> | Bias for LMTCY computation;<br>in           | 0      |
| KMT7     | к <sub>мт7</sub> | Coefficient for DMT computation;<br>N.D.    | 1      |
| KMT8     | к <sub>мт8</sub> | Bias for DMT computation;<br>in             | 0      |

## INPUT DATA, INTRA-MODEL (Cont.):

# INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                          | Description; Ext. (Int.) Units         | Model Type |  |
|----------|---------------------------------|----------------------------------------|------------|--|
| DCSO     | D <sub>CSO</sub>                | Outside case diameter;                 |            |  |
|          |                                 | in Fig. 1                              | CASEG      |  |
| LCS      | L <sub>CS</sub>                 | Case length;                           | CASEC      |  |
|          |                                 |                                        | CADEC      |  |
| LCSCY    | LCSCY                           | Cylindrical case section length;<br>in | CASEG      |  |
| LCSCHAO  | L <sub>CS</sub> CHAO            | Aft case closure length;<br>in         | CASEG      |  |
| I.CSCHFO | <sup>L</sup> CS <sub>CHFO</sub> | Forward case closure length;           | CASEG      |  |
|          |                                 | 411                                    | 01.010     |  |

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## MOTOR GEOMETRY

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**MTGM1** 

## INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol             | Description; Ext. (Int.) Units               | Model Type |
|----------|--------------------|----------------------------------------------|------------|
| VGN      | v <sub>GN</sub>    | Volume of grain envelope;<br>in <sup>3</sup> | GRAING     |
| VPPMT    | v <sub>pp</sub> mt | Propellent volume;<br>in <sup>3</sup>        | PROPELW    |

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                                                      |        |       |  |
|----------|-------------------------------|---------------------------------------------------------------------------------------------------------------------|--------|-------|--|
| AMT      | A <sub>MT</sub>               | Motor cross sectional area. May include raceways and other protrusions;                                             |        |       |  |
|          |                               | in                                                                                                                  |        | Eq. 6 |  |
| DMT      | D <sub>MT</sub>               | Motor diameter. May include allowance for raceways and other protrusions;                                           |        |       |  |
|          |                               | in                                                                                                                  | Fig. 1 | Eq. 5 |  |
| LMT      | L <sub>MT</sub>               | Motor length. Does not include protruding<br>nozzle, outside igniter attachment, thrust<br>termination parts, etc.; |        |       |  |
|          |                               | in                                                                                                                  | Fig. 1 | Eq. 4 |  |
| LMTCHA   | L <sub>MT<sub>CHA</sub></sub> | Aft motor closure length;                                                                                           |        |       |  |
|          |                               | in                                                                                                                  | Fig. 1 | Eq. 2 |  |
| LMTCHF   | L <sub>MT</sub> CHF           | Forward motor closure length. Does not<br>include outside igniter attachments, thrust<br>termination ports, etc.;   |        |       |  |
|          |                               | in                                                                                                                  | Fig. 1 | Eq. l |  |
| LMTCY    | LMT                           | Motor cylinder length;                                                                                              |        |       |  |
|          | CY                            | in                                                                                                                  | Fig. 1 | Eq. 3 |  |

MOTORG MOTOR GEOMETRY

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OUTPUT DATA (Cont.):

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                                                                                           |                                                                                                                             |                     |  |
|----------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|---------------------|--|
| LMTSKA   | L <sub>MT</sub> SKA | Motor aft skirt length. Measured along<br>outside of skirt from intersection of<br>cylindrical motor section and aft closure<br>section; |                                                                                                                             |                     |  |
|          |                     | in                                                                                                                                       | <b>Fig.</b> 1                                                                                                               | Eq. 12              |  |
| LMTSKF   | L <sub>MT</sub> skf | Motor for<br>outside of<br>motor sec                                                                                                     | Motor forward skint length. Measured<br>outside of skirt from intersection of cy<br>motor section and forward motor section |                     |  |
|          |                     | in                                                                                                                                       | Fig. 1                                                                                                                      | Fq. 11              |  |
| RLDMT    | RLDMT               | Ratio, motor length to motor diameter;                                                                                                   |                                                                                                                             |                     |  |
|          |                     | N. D.                                                                                                                                    |                                                                                                                             | Eq. 8               |  |
| RLDMTCS  | RLDMTCS             | Ratio, motor length to case outside diameter;                                                                                            |                                                                                                                             |                     |  |
|          |                     | N. D.                                                                                                                                    |                                                                                                                             | Eq. 7               |  |
| RVPPMT   | η <sub>PPMT</sub>   | Motor volumetric loading efficiency. Ratio of propellent volume to motor volume;                                                         |                                                                                                                             | ncy. Ratio<br>lume; |  |
|          |                     | N. D.                                                                                                                                    |                                                                                                                             | Eq. 10              |  |
| YMT      | v <sub>MT</sub>     | Motor volume. Volume of grain envelope.<br>Excludes case liner;                                                                          |                                                                                                                             |                     |  |
|          |                     | in <sup>3</sup>                                                                                                                          |                                                                                                                             | Eq. 9               |  |

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| NOTOR GROMETRY | NATEL        | <b>IONTSKA2</b> | LIMICY   | L H      |
|----------------|--------------|-----------------|----------|----------|
|                | ETHON        | DCSICAL         | LMICHP   | RVPPMT   |
| MICHO          | <b>KINTZ</b> | STR<br>8        | LIMITCHA | RLINITCS |
| NOTORG         | Ŧ            | Ŷ               | £        | ¶#       |
|                | <b>LTHOM</b> | KNHL            |          | RLDNC    |
|                |              |                 | 2DSDO    | DSDA     |
|                | Ę            | SE SE           | KNESGI   | NSDAI    |

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MOTOR WEIGHT

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MODEL TYPE: MOTORW (MOTOR Weight)

MODEL NAME: MTWMl (Weight Synthesis)

#### DESCRIPTION:

MTWM1 (MoTor Weight Model number 1) is a weight synthesis model which evaluates the motor weight breakdown. The motor weight is comprised of the following subsystems.

#### Propellent

Case (includes joint weight penalty if applicable)

Thrust termination mechanism

Internal insulation

Thrust vector control system

Miscellaneous motor weight (includes raceways, base heat protection, igniters, and ordnance)

<u>Note that the above subsystems do NOT include the nozzle</u>. See the SUBSTGW model type for substage (motor plus nozzle) weight quantities.

#### **PROCEDURE:**

Prior to entering MTWM1, all of the models which evaluate motor subsystem weights have been executed. In addition to evaluating sub-component weights peculiar to its particular requirement, each model has defined a set of component weights in terms of expended or non-expended attributes.

These expended or non-expended subsystem weights are input to the MTWM1 model which, in turn, combines these quantities to determine the motor weight breakdown. The motor mass fractions are also evaluated.

After MTWM1 is executed, the model specified by the SUBSTGW model type will utilize these motor quantities, with the nozzle quantities, to determine the total substage weights and mass fractions.

#### MOTOR WEIGHT

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#### EQUATIONS:

Total motor weight.

$$W_{MT} = K_{WMT} \left( W_{PP_{MT}} + W_{CS} + W_{TT} + W_{MM} + W_{IN} + W_{TV} \right)$$
(1)

Total non-expended motor weight component.

$$w_{MT_{NX}} = \kappa_{WMTNX} \left( w_{CS_{NX}} + w_{TT_{NX}} + w_{MM_{NX}} + w_{IN_{NX}} + w_{TV_{NX}} \right)$$

Total expended motor weight component (excluding propellent).

$$w_{MT_{X}} = \kappa_{WMTX} \left( w_{CS_{X}} + w_{TT_{X}} + w_{MM_{X}} + w_{IN_{X}} + w_{TV_{X}} \right)$$
(3)

Expended (thrust producing) motor weight component.

$$W_{MT_{XT}} = K_{WMTXT} \left( W_{CS_{XT}} + W_{TT_{XT}} + W_{MM_{XT}} + W_{IN_{XT}} + W_{TV_{XT}} \right)$$
(4)

Expended (non-thrust producing) motor weight component.

$$w_{MT_{XI}} = \kappa_{WMTXI} (w_{CS_{XI}} + w_{TT_{XI}} + w_{MM_{XI}} + w_{IN_{XI}} + w_{TV_{XI}})$$
 (5)

#### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                                 | Preset      |
|----------|--------------------|----------------------------------------------------------------|-------------|
| KWMT     | ĸwmt               | Proportionality factor for total mo                            | tor weight; |
|          |                    | N. D.                                                          | 1           |
| KWMTNX   | <sup>K</sup> wmtnx | Proportionality factor for non-expe<br>motor weight component; | ended       |
|          |                    | N. D                                                           | 1           |

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MTWM1

# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol             | Description; Ext. (Lit.) Units                                                    | Preset            |
|----------|--------------------|-----------------------------------------------------------------------------------|-------------------|
| KWMTX    | <sup>к</sup> wmtx  | Proportionality factor for total ex<br>motor weight component;                    | pended            |
|          |                    | N. D.                                                                             | 1                 |
| KWMTXI   | <sup>K</sup> wmtxi | Proportionality factor for expended (non-throp producing) motor weight component; |                   |
|          |                    | N. D.                                                                             | 1                 |
| KWMTXT   | <sup>K</sup> wmtxt | Proportionality factor for expende producing) motor weight componer               | ed (thrust<br>nt; |
|          |                    | N. D.                                                                             | 1                 |

# INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                      | Model Type   |
|----------|------------------------------|-----------------------------------------------------|--------------|
| WCC      | 117                          | *                                                   |              |
| WCS      | <sup>w</sup> cs              | Case weight, total;                                 |              |
|          |                              | Ъ                                                   | CASEW        |
| WCSNX    | WCS                          | Case weight component, total no                     | on-expended; |
|          | UNX                          | 1b                                                  | CASEW        |
| wcsx     | W <sub>CS</sub>              | Case weight component, total ex                     | (pended;     |
|          | X                            | 1b                                                  | CASEW        |
| WCSXI    | w <sub>cs<sub>xi</sub></sub> | Case weight component, expend<br>thrust producing); | ed, (non-    |
|          |                              | 16                                                  | CASEW        |

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# INPUT DATA, INTER-MODEL (Cont.):

| <u>Mnemonic</u> | Symbol                       | Description; Ext. (Int.) Units                                          | Model Type      |  |
|-----------------|------------------------------|-------------------------------------------------------------------------|-----------------|--|
| WCSXT           | w <sub>cs<sub>xt</sub></sub> | Case weight component, expended, (thrust producing);                    |                 |  |
|                 |                              | 1b                                                                      | CASEW           |  |
| WIN             | W IN                         | Internal insulation weight, total                                       | ;               |  |
|                 |                              | lb                                                                      | INSULW          |  |
| WINNX           | w <sub>IN<sub>NX</sub></sub> | Internal insulation weight component non-expended;                      | onent, total    |  |
|                 |                              | lb                                                                      | INSULW          |  |
| WINX            | w <sub>IN</sub> X            | Internal insulation weight compo<br>expended;                           | onent, total    |  |
|                 |                              | Іь                                                                      | INSULW          |  |
| WINXI           | w <sub>in</sub> xi           | Internal insulation weight component, expended, (non-thrust producing); |                 |  |
|                 |                              | 1ь                                                                      | INSUL W         |  |
| WINXT           | w <sub>inxt</sub>            | Internal insulation weight component, expended, (thrust producing);     |                 |  |
|                 |                              | 1ъ                                                                      | INSULW          |  |
| WMM             | w <sub>MM</sub>              | Miscellaneous motor weight, total;                                      |                 |  |
|                 |                              | 1ъ                                                                      | MISCMTW         |  |
| WMMNX           | w <sub>MM</sub> NX           | Miscellaneous motor weight cor<br>non-expended;                         | nponent, total  |  |
|                 |                              | Іь                                                                      | MISCMTW         |  |
| WMMX            | w <sub>MM</sub> x            | Miscellaneous motor weight cor<br>total expended;                       | nponent,        |  |
|                 |                              | 1ь                                                                      | MISCMTW         |  |
| WMMXI           | w <sub>MM</sub> XI           | Miscellaneous motor weight cor expended, (non-thrust producing          | nponent,<br>g); |  |
|                 |                              | 1ь                                                                      | MISCMTW         |  |

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# INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol                                   | Description; Ext. (Int.) Units                                      | Model Type     |
|----------|------------------------------------------|---------------------------------------------------------------------|----------------|
| WMMXT    | w <sub>MM<sub>XT</sub></sub>             | Miscellaneous motor weight comp<br>expended, (thrust producing);    | ponent,        |
|          |                                          | lb                                                                  | MISCMTW        |
| WPPMT    | W <sub>DD</sub>                          | Propellent weight;                                                  |                |
|          | MT                                       | lb                                                                  | PROPELW        |
| WTT      | WTT                                      | Thrust termination weight, total;                                   |                |
|          | 11                                       | lb                                                                  | TTERMW         |
| WTTNX    | w <sub>tt</sub> nx                       | Thrust termination weight compo<br>non-expended;                    | nent, total    |
|          |                                          | 1ь                                                                  | TTERMW         |
| WTTX     | w <sub>TTx</sub>                         | Thrust termination weight compor<br>X expended;                     |                |
|          |                                          | 1ь                                                                  | TTERMW         |
| WTTXI    | w <sub>TT<sub>XI</sub></sub>             | Thrust termination weight compo<br>expended, (non-thrust producing) | nent,          |
|          |                                          | lb                                                                  | TTERMW         |
| WTTXT    | w <sub>TT<sub>XT</sub></sub>             | Thrust termination weight compo<br>expended, (thrust producing);    | nent,          |
|          |                                          | 1ъ                                                                  | TTERMW         |
| WTV      | WTW                                      | Thrust vector control weight, total;                                |                |
|          | ĨV                                       | 1ь                                                                  | TVCW           |
| WTVNX    | w <sub>tvnx</sub>                        | Thrust vector control weight con<br>non-expended;                   | ponent, total  |
|          |                                          | 1ъ                                                                  | TVCW           |
| WTVX     | <sup>w</sup> <sub>T</sub> ∨ <sub>x</sub> | Thrust vector control weight con expended;                          | nponent, total |
|          |                                          | 1b                                                                  | TVCW           |

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# MOTOR WEIGHT

MTWM1

# INPUT DATA, INTER-MODEL (Cont.):

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| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                    | Model Type      |
|----------|------------------------------|-------------------------------------------------------------------|-----------------|
| WTVXI    | w <sub>tv<sub>xi</sub></sub> | Thrust vactor control weight co<br>expended, (non-thrust producin | mponent,<br>g); |
|          |                              | 16                                                                | TVCW            |
| WTVXT    | w <sub>TV</sub> XT           | Thrust vector control weight co<br>expended, (thrust producing);  | omponent,       |
|          |                              | 1b                                                                | TVCW            |

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic      | Symbol            | Description; Ext. (Int.) Units                                                                                                                                                     |                                                                                         |  |
|---------------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--|
| WMT           | w <sub>MT</sub>   | Total motor weight. Include<br>case, thrust termination, m<br>internal insulation, and thru<br>subsystems. Does not inclu                                                          | ncludes propellent,<br>on, miscellaneous,<br>i thrust vector control<br>include nozzle; |  |
|               |                   | 1b                                                                                                                                                                                 | Eq. 1                                                                                   |  |
| WMTN <b>X</b> | w <sub>mtnx</sub> | Total non-expended motor weight compone<br>Includes case, thrust termination,<br>miscellaneous, internal insulation, and th<br>vector control subsystems. Does not incl<br>nozzle; |                                                                                         |  |
|               |                   | Jb                                                                                                                                                                                 | Eq. 2                                                                                   |  |
| WMTX          | w <sub>MT</sub> X | Total expended motor weigh<br>Includes case, thrust termin<br>miscellaneous, internal insu-<br>vector control subsystems,<br>propellent or nozzle;                                 | t component.<br>nation,<br>ulation and thrust<br>Does not include                       |  |
|               |                   | 1b                                                                                                                                                                                 | Eq. 3                                                                                   |  |

| MOTORW    |                              | MOTOR WEIGHT                                                                                                                                                           | MTWMI                                                            |
|-----------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| OUTPUT DA | TA (Cont.):                  |                                                                                                                                                                        |                                                                  |
| Mnemonic  | Symbol                       | Description; Ext. (Int.) Units                                                                                                                                         |                                                                  |
| WMTXI     | w <sub>mt</sub> xi           | Expended (non-thrust producing<br>component, Includes case, thr<br>miscellaneous motor, internal<br>thrust vector control subsystem<br>include nozzle;                 | ) motor weig<br>ust terminatio<br>insulation, ar<br>ns. Does not |
|           |                              | 16                                                                                                                                                                     | Eq. 5                                                            |
| WMTXT     | w <sub>mt<sub>xt</sub></sub> | Expended (thrust producing) mo<br>component. Includes case, thr<br>miscellaneous, internal insulat<br>thrust vector control subsysten<br>include propellent or nozzle; | otor weight<br>ust termination, and<br>ns. Does not              |
|           |                              | 1b                                                                                                                                                                     | Eq. 4                                                            |

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PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| MOTOR WEIGHT | TXTMA             | KUMERCE |
|--------------|-------------------|---------|
| MIMO         | IXIM              | IXIMIN  |
| MOTORN       | Ŧ                 | Ŷ       |
|              | Y.TWM             | YTMMY   |
|              | VIIIIIII VIIIIIII | VITLINU |
|              | KUMP.             |         |

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#### NOZZLE GEOMETRY

NZGM1

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MODEL TYPE: NOZZLEG (NOZZLE Geometry)

MODEL NAME: NZGM1 (Conical nozzle)

#### DESCRIPTION:

NZGM1 (NoZzle Geometry Model number 1) evaluates the geometrical expressions required for a simple conical nozzle design having circular convergent and transition section contours. Due to the requirement that the nozzle contour be smooth (continuous function and continuous first derivative) where the major sections join at the throat and transition planes, the conical section half angle is equal to the transition section arc angle.

The model assumes:

- 1. The length of the convergent section is directly proportional to the throat diameter.
- 2. The radius of curvature of the convergent section contour is directly proportional to the throat diameter.
- 3. The radius of curvature of the transition section contour is directly proportional to the throat diameter.
- 4. The conical section half angle is equal to the transition section arc angle.
- 5. The nozzle has zero thickness.

It should be noted that the placement of the buried nozzle plane with respect to the motor is not determined by this model. Although always associated with the outside surface of the aft case closure, the actual placement of the buried nozzle plane is normally specified by the model associated with the GRAING model type.

For an appreciation of the basic nozzle terminclogy used within this model, see figure 1. Figures 2 through 5 illustrate the nozzle geometry and are useful when referring to the symbol definitions and equations.

### NOZZLE GEOMETRY

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#### PROCEDURE:

Prior to entering NZGM1, the models specified by the IBGAS and IBPERF model types have evaluated the gas characteristics, chamber pressures and propellent weight flow for the solid rocket motor.

The NZGM1 is then executed and the conical nozzle geometry is evaluated.

After executing NZGM1, the model specified by the IBPERF model type is reentered (if required) to evaluate the performance quantities which are dependent upon the nozzle geometry.

#### EQUATIONS:

Nozzle throat area.

$$A_{NZ_{TH}} = \frac{W_{PP_{MT}}}{g_{o}P_{AVG}}$$
(1)

Nozzle throat diameter. (Figures 2, 3, 4, 5)

$$D_{NZ_{TH}} = \sqrt{\frac{4 A_{NZ_{TH}}}{\pi}}$$
(2)

Proportionality factor relating nozzle entrance diameter to nozzle throat diameter.

$$K_{\text{DENT}} = 1 + 2 \left( C_2 - \sqrt{C_2^2 - C_1^2} \right)$$
(3)

Porportionality factor relating nozzle transition diameter to nozzle throat diameter.

$$K_{\text{DTR}} = 1 + 2 C_3 \left[ 1 - \cos \left( \theta_{\text{NZ}} \right) \right]$$
(4)

Ratio, nozzle transition diameter to nozzle throat diameter.

$$R_{\text{DTRTH}} = K_{\text{DTR}}$$
(5)

Expansion ratio at nozzle transition plane.

$$\epsilon_{\rm TR} = \left( {\rm R}_{\rm DTRTH} \right)^2 \tag{6}$$

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# NOZZLE GEOMETRY

NZGM1

# EQUATIONS (Cont.):

Ratio, nozzle exit diameter to nozzle throat diameter.

 $R_{\text{DEXTTH}} = \sqrt{\epsilon_{\text{NZ}}}$ (7) Radius of curvature, convergent nozzle section. (Figure 3)  $R_{C_{CV}} = C_2 D_{NZ_{TH}}$ (8) Radius of curvature, transition nozzle section. (Figure 4)  $R_{C_{TR}} = C_3 D_{NZ_{TH}}$ (9) Nozzle entrance diameter. (Figure 3)  $D_{NZ_{ENT}} = K_{DENT} D_{NZ_{TH}}$ (10) Nozzle transition diameter. (Figure 4)  $D_{NZ_{TR}} = R_{DTRTH} D_{NZ_{TH}}$ (11)Nozzle exit diameter, (Figure 5) D<sub>NZ<sub>EXT</sub> - R<sub>DEXTTH</sub> D<sub>NZ<sub>TH</sub></sub></sub> (12)Nozzle entrance area. (Figure 3)  $A_{NZ_{ENT}} = \left(\frac{\pi}{4}\right) D_{NZ_{ENT}}^2$ (13) Nozzle transition area. (Figure 4)  $A_{NZ_{TR}} = \left(\frac{\pi}{4}\right) D_{NZ_{TR}}^2$ (14)

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## EQUATIONS (Cont.):

Nozzle exit area. (Figure 5)

$$A_{NZ_{EXT}} = \left(\frac{\pi}{4}\right) D_{NZ_{EXT}}^{2}$$
(15)

Convergent nozzle section length. (Figure 3)

$$L_{NZ_{CV}} = C_1 D_{NZ_{TH}}$$
(16)

Transition nozzle section length. (Figure 4)

$$L_{NZ} = R_{C_{TR}} \sin \left( \theta_{NZ} \right)$$
(17)

Conic nozzle section length. (Figure 5)

$$L_{NZ_{CN}} = \frac{\begin{pmatrix} D_{NZ_{EXT}} & D_{NZ_{TR}} \end{pmatrix}}{2 \tan(\theta_{NZ})}$$
(18)

Body nozzle section length. (Figure 2)

$$L_{NZ_{BDY}} = L_{NZ_{CV}} + L_{NZ_{TR}}$$
(19)

Divergent nozzle section length. (Figure 2)

$$L_{NZ_{DV}} = L_{NZ_{TR}} + L_{NZ_{CN}}$$
(20)

Total nozzle length. (Figure 2)

$$L_{NZ} = L_{NZ_{CV}} + L_{NZ_{DV}}$$
(21)

Buried nozzle section length. (Figure 2)

$$L_{NZ_{B}} = K_{LNZB} L_{NZ}$$
(22)

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#### NOZZLE GEOMETRY

# EQUATIONS (Cont.):

Protruding nozzle section length. (Figure 2)

$$L_{NZ_{P}} = L_{NZ} - L_{NZ_{B}}$$
(23)

Buried nozzle length ratio.

$$R_{LNZB} = \frac{L_{NZ}B}{L_{NZ}}$$
(23-a)

Protruding nozzle length ratio.

$$R_{LNZP} = \frac{L_{NZP}}{L_{NZ}}$$
(23-b)

Length buried in convergent nozzle section. (Positive sense towards entrance.) (Figure 4)

$$L_{NZ_{BCV}} = L_{NZ_{CV}} - L_{NZ_{B}}$$
(24)

Length buried in transition nozzle section. (Positive sense towards exit.) (Figure 4)

$$L_{NZ_{BTR}} = L_{NZ_{B}} - L_{NZ_{CV}}$$
(25)

Length buried in conic nozzle section. (Positive sense towards exit.) (Figure 5)

$$L_{NZ_{BCN}} = L_{NZ_{B}} - L_{NZ_{BDY}}$$
 (26)

Buried nozzle diameter evaluation:

If the buried nozzle plane is within the convergent nozzle section, (Figure 3)

$$D_{NZ_{B}} = D_{NZ_{TH}} + 2 \left( R_{C_{CV}} - \sqrt{R_{C_{CV}}^{2} - L_{NZ_{BCV}}^{2}} \right)$$
(27)

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## NOZZLE GEOMETRY

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# EQUATIONS (Cont.):

If the buried nozzle plane is within the transition nozzle section, (Figure 4)

$$D_{NZ_{B}} = D_{NZ_{TH}} + 2 \left( R_{C_{TR}} - \sqrt{R_{C_{TR}}^{2} - L_{NZ_{BTR}}^{2}} \right)$$
(28)

If the buried nozzle plane is within the conic nozzle section, (Figure 5)

$$D_{NZ_{B}} = D_{NZ_{TR}} + 2 L_{NZ_{BCN}} \tan\left(\theta_{NZ}\right)$$
(29)

Associative Quantities. The following quantities are intended solely for optional utilization by the program user. (Their primary usage within this model is for forming constraint quantities.)

$$Q_{DB} = K_{QDB} D_{NZ_{B}}$$
(30)

$$Q_{\text{DENT}} = K_{\text{QDEN}} D_{\text{NZ}_{\text{ENT}}}$$
(31)

$$Q_{\text{DEXT}} = K_{\text{QDEX}} D_{\text{NZ}_{\text{EXT}}}$$
(32)

$$Q_{LNZ} = K_{QL} L_{NZ}$$
(33)

 $Q_{LB} = K_{QLB} L_{NZ_{B}}$ (34)

$$Q_{\text{DTH}} = K_{\text{QDTH}} D_{\text{NZ}_{\text{TH}}}$$
(35)

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# INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol            | Description; Ext. (Int.) Units                                                                                                      | Preset                              |
|----------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| CNZI     | c,                | Proportionality factor relating convergent<br>nozzle section length to nozzle throat<br>diameter;                                   |                                     |
|          |                   | N. D.                                                                                                                               | . 4                                 |
| CNZ2     | c <sub>2</sub>    | Proportionality factor relating the radius<br>of curvature of the convergent nozzle<br>section contour to the nozzle throat diamete |                                     |
|          |                   | N. D.                                                                                                                               | 1                                   |
| CNZ3     | C3                | Proportionality factor relating t<br>curvature of the transition nozzl<br>contour to the nozzle throat dia                          | he radius of<br>e section<br>meter; |
|          |                   | N. D.                                                                                                                               | . 2                                 |
| KQDNZB   | K <sub>QDB</sub>  | Associative quantity coefficient :<br>QDNZB computation;                                                                            | for                                 |
|          |                   | N. D.                                                                                                                               | 0                                   |
| KQDNZEN  | KQDEN             | Associative quantity coefficient : QDNZENT computation;                                                                             | for                                 |
|          |                   | N. D.                                                                                                                               | 0                                   |
| KQDNZEX  | KQDEX             | Associative quantity coefficient :<br>QDNZEXT computation;                                                                          | for                                 |
|          |                   | N. D.                                                                                                                               | υ                                   |
| KQDNZTH  | K <sub>QDTH</sub> | Associative quantity coefficient :<br>QDNZTH computation;                                                                           | for                                 |
|          |                   | N. D.                                                                                                                               | 0                                   |
| KQLNZB   | K <sub>QLB</sub>  | Associative quantity coefficient :<br>QLNZB computation;                                                                            | lor                                 |
|          |                   | N. D.                                                                                                                               | 0                                   |
| KQLN Z   | K <sub>QL</sub>   | Associative quantity coefficient :<br>QLNZ computation;                                                                             | for                                 |
|          |                   | N. D.                                                                                                                               | 0                                   |

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#### NOZZLE GEOMETRY

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| INPUT DATA, | INTRA-MODE        | L (Cont. ):                                                                  |                                                                 |                                     |
|-------------|-------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------|
| KLNZB       | <sup>K</sup> LNZB | Proportionality factor relating buried nozzle length to total nozzle length; |                                                                 |                                     |
|             |                   | N. D.                                                                        |                                                                 | 0                                   |
| NZHA        | θ <sub>NZ</sub>   | Nozzle half angle;                                                           |                                                                 |                                     |
|             |                   | deg                                                                          | Figs. 2, 4, 5                                                   | 0                                   |
| RAEXTTH     | <sup>€</sup> NZ   | Nozzle ex<br>Ratio of r                                                      | <b>cpansior ratio</b> at nozz<br>nozzl <b>e exit</b> area to no | le exit plane.<br>zzle throat area; |
|             |                   | N. D.                                                                        |                                                                 | 0                                   |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                 | Description; Ext. (Int.) Units             | Model Type  |
|----------|------------------------|--------------------------------------------|-------------|
| CVDELV   | C*                     | Delivered characteristic velocit<br>ft/sec | y;<br>IBGAS |
| DWPPMT   | •<br>W <sub>PPMT</sub> | Propellent weight flow;<br>lt/sec          | IBPER F     |
| PCHAVG   | PAVG                   | Average chamber pressure;<br>PSIA          | IBGAS       |

#### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| <u>Mnemonic</u> | Symbol              | Description; Ext. (Int.) Unite           | 3      |
|-----------------|---------------------|------------------------------------------|--------|
| ANZENT          | ANZENT              | Nozzle entrance arca;<br>in <sup>2</sup> | Eq. 13 |
| AN <b>Z</b> EXT | A <sub>NZ</sub> EXT | Nozzle exit area;<br>in <sup>2</sup>     | Eq. 15 |

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| OUTPUT DATA | A (Cont.):                    |                                   |                                                                          |                              |
|-------------|-------------------------------|-----------------------------------|--------------------------------------------------------------------------|------------------------------|
| Mnemonic    | Symbol                        | Descrip                           | tion; Ext. (Int.) Units                                                  |                              |
| ANZTH       | A <sub>NZ</sub> TH            | Nozzle t<br>in <sup>2</sup>       | hroat area;                                                              | Eq. 1                        |
| ANZTR       | A <sub>NZ</sub> TR            | Nozzle t<br>in <sup>2</sup>       | ransition area;                                                          | Eq. 14                       |
| DNZB        | D <sub>NZ</sub> B             | Buried n<br>measure               | ozzle diameter. Noz:<br>ed at buried nozzle pla                          | zle diameter<br>ne;          |
|             |                               | in                                | Figs. 3, 4, 5                                                            | Eqs.27,<br>28, 29            |
| DNZENT      | D <sub>NZ</sub> ENT           | Nozzle (<br>nozzle r              | entrance diameter. D<br>neasured at nozzle ent                           | iameter of<br>trance plane;  |
|             |                               | in                                | Fig. 3                                                                   | Eq. 10                       |
| DNZEXT      | D <sub>NZ</sub> EXT           | Nozzle<br>measur                  | exit diameter. Diame<br>ed at nozzle exit plane                          | ter of nozzle<br>;           |
|             |                               | in                                | Fig. 5                                                                   | Eq. 12                       |
| DNZTH       | <sup>D</sup> NZ <sub>TH</sub> | Nozzle i<br>nieasuri              | threat diameter. Diam<br>ed at nozzle throat pla                         | neter of nozzlc<br>ne;       |
|             |                               | in                                | Fig. 2                                                                   | Eq. 2                        |
| DNZTR       | D <sub>NZ</sub> TR            | Nozzle (<br>nozzle r<br>transitio | transition diameter.<br>neasured at transition<br>on and conic sections; | Diameter of plane separating |
|             |                               | in                                | Fig. 4                                                                   | Eq. 11                       |
| KDNZENT     | K <sub>DENT</sub>             | Proport<br>entrance               | ionality factor relatin<br>e diameter to nozzle t                        | g nozzle<br>hroat diameter;  |
|             |                               | N. D.                             |                                                                          | Eq. 3                        |
| KDNZTR      | <sup>K</sup> <sub>DTR</sub>   | Proport<br>transiti               | ionality factor relatin<br>on diameter to nozzle                         | g nozzle<br>throat diameter; |
|             |                               | N. D.                             |                                                                          | Eq. 4                        |
| LNZ         | LNZ                           | Total no<br>entranc               | ozzle length. Distance<br>e plane to nozzle exit                         | e from nozzle<br>plant;      |
|             |                               | in                                | Fig. 2                                                                   | Eq. 21                       |

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NOZZLE GEOMETRY

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| OUTPUT DAT.   | A (Cont.):          |                                                                                             |                                                                               |                                                                                             |  |
|---------------|---------------------|---------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|--|
| Mnemonic      | Symbol              | Descript                                                                                    | ion; Ext. (Int.) Unit                                                         | 8                                                                                           |  |
| LNZ B         | LNZB                | Buried no<br>nozzle en                                                                      | ozzle section length.<br>trance plane to nozz                                 | Distance from<br>le buried plane;                                                           |  |
|               |                     | in                                                                                          | <b>Fig.</b> 2                                                                 | Eq. 22                                                                                      |  |
| LNZ BCN       | L <sub>NZ</sub> BCN | Length by<br>Distance<br>nozzle bu<br>towards e                                             | aried in conic nozzle<br>from nozzle transit<br>ried plane. (Positi<br>exit); | l in conic nozzle section.<br>n nozzle transition plane to<br>l plane. (Positive sense<br>; |  |
|               |                     | in                                                                                          | Fig. 5                                                                        | Eq. 26                                                                                      |  |
| LNZBCV LNZBCV |                     | Length bu<br>Distance<br>buried pl<br>entrance                                              | from nozzle throat<br>ane. (Positive sens                                     | nozzle section.<br>plane to nozzle<br>e towards                                             |  |
|               |                     | in                                                                                          | Fig. 3                                                                        | Eq. 24                                                                                      |  |
| LNZBDY        | L <sub>NZBDY</sub>  | Body nozzle section length. Distance from nozzle entrance plane to nozzle transition plane; |                                                                               |                                                                                             |  |
|               |                     | in                                                                                          | Fig. ?                                                                        | Eq. 19                                                                                      |  |
| LNZ BTR       | LNZBTR              | Length by<br>Distance<br>buried pl                                                          | uried in transition n<br>from nozzle throat<br>ane. ( <b>P</b> ositive sens   | ozzle section.<br>plane to nozzle<br>se towards exit);                                      |  |
|               |                     | in                                                                                          |                                                                               | Eq. 25                                                                                      |  |
| LNZCN         | LNZCN               | Conic no:<br>nozzle tr                                                                      | zzle section length.<br>ansition plane to no:                                 | Distance from<br>zzle exit plane;                                                           |  |
|               |                     | in                                                                                          | Fig. 5                                                                        | Eq. 18                                                                                      |  |
| LNZCV         | L <sub>NZCV</sub>   | Converge<br>from noz<br>plane;                                                              | ent nozzle section le<br>zle entrance plane t                                 | ngth. Distance<br>to nozzle throat                                                          |  |
|               |                     | in                                                                                          | Fig. 3                                                                        | Eq. 16                                                                                      |  |
| LN2 DV        | LNZDV               | Divergen<br>from noz                                                                        | t nozzle section len<br>zle throat plane to r                                 | gth. Distance<br>nozzle exit plane;                                                         |  |
|               |                     | in                                                                                          | Fig. 2                                                                        | Eq. 20                                                                                      |  |

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## NOZZLE GEOMETRY

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OUTPUT DATA (Cont. ):

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| Mnemonic | Symbol            | Description; Ext. (Int.) Units                                                                  |
|----------|-------------------|-------------------------------------------------------------------------------------------------|
| LNZP     | LNZP              | Protruding nozzle section length. Distance<br>from nozzle buried plane to nozzle exit plane;    |
|          |                   | in Fig. 2 Eq. 23                                                                                |
| LNZTR    | LNZTR             | Transition nozzle section length. Distance from nozzle throat plane to nozzle transition plane; |
|          |                   | in Fig. 4 Eq. 17                                                                                |
| QDNZB    | Q <sub>DB</sub>   | Associative quantity, buried nozzle diameter.<br>(See DNZB);                                    |
|          |                   | in Eq. 30                                                                                       |
| QDNZENT  | Q <sub>DENT</sub> | Associative quantity, nozzle entrance diameter. (See DNZENT);                                   |
|          |                   | in Eq. 31                                                                                       |
| QDNZEXT  | Q <sub>DEXT</sub> | Associative quantity, nozzle exit diameter.<br>(Sce DNZEXT);                                    |
|          |                   | in <b>Eq. 32</b>                                                                                |
| QUNZTH   | Q <sub>DTH</sub>  | Associative quantity, nozzle throat diameter.<br>(See DNZTH);                                   |
|          |                   | in Eq. 35                                                                                       |
| QLNZ     | Q <sub>L</sub>    | Associative quantity, total nozzle length.<br>(See LNZ);                                        |
|          |                   | in Eq. 33                                                                                       |
| QLNZB    | Q <sub>LB</sub>   | Associative quantity, buried nozzle length.<br>(See LNZB);                                      |
|          |                   | in Eq. 34                                                                                       |
| RATRTH   | ε <sub>TR</sub>   | Expansion ratio at transition plane. Ratio of nozzle transition area to nozzle throat area;     |
|          |                   | N. D. Eq. 6                                                                                     |

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# NOZZLEG NOZZLE GEOMETRY

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# OUTPUT DATA (Cont.):

| Mnemonic      | Symbol                       | Description; Fxt. (Int.) Units                                                        | <u></u>                       |
|---------------|------------------------------|---------------------------------------------------------------------------------------|-------------------------------|
| RCNZCV        | <sup>R</sup> C <sub>CV</sub> | Radius of curvature, convergen section contour;                                       | t nozzle                      |
|               |                              | in                                                                                    | Eq. 8                         |
| RCNZTR        | <sup>R</sup> C <sub>TR</sub> | Radius of curvature, transition section contour;                                      | nozzle                        |
|               |                              | in                                                                                    | Eq. 9                         |
| RDEXTTH       | <sup>R</sup> dextth          | Ratio, nozzle exit diameter to n<br>throat diameter;                                  | ozzle                         |
|               |                              | N. D.                                                                                 | Eq. 7                         |
| <b>ЧDTRTH</b> | <sup>R</sup> d <b>trt</b> h  | Ratio, nozzle transition diamete<br>throat diameter;                                  | er to nozzle                  |
|               |                              | N. D.                                                                                 | Eq. 5                         |
| R LN Z B      | R <sub>LNZB</sub>            | Buried nozzle length ratio. Rat<br>nozzle section length to total no                  | tio of buried<br>zzle length; |
|               |                              | N. D.                                                                                 | Eq. 23-a                      |
| RLNZP         | RLNZP                        | Protruding nozzle length ratio.<br>protruding nozzle section length<br>nozzle length; | Ratio of<br>to total          |
|               |                              | N. D.                                                                                 | Eq. 23-b                      |

PRINT BLOCK KEY:

170.1-18

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| LETHY<br>CNZ2<br>DNZTR<br>KQDNZEX<br>LNZBCH<br>LNZBCH<br>LNZDV<br>QDNZEZCT<br>RCNZCV<br>TANNZAA                   |
|-------------------------------------------------------------------------------------------------------------------|
| NOZZIJE GBOM<br>CNZJ<br>DNZTH<br>KQDNZEN<br>KQDNZEN<br>LAZCV<br>QDNZENT<br>RATHTH<br>RATHTH<br>ROTRATH<br>COSNZHA |
| NZCBAL<br>ANZTR<br>DNZEXT<br>DNZEXT<br>KQDNZB<br>LNZ<br>LNZCN<br>RAEXTTH<br>RAEXTTH<br>SLNZP<br>SLNZP             |
| N<br>1220<br>12<br>12<br>12<br>12<br>12<br>12<br>12<br>12<br>12<br>12<br>12<br>12<br>12                           |
| ANZTH<br>INZENT<br>KUNZB<br>KUNZB<br>KQLNZB<br>KQLNZB<br>RLNZB<br>RLNZB<br>BPTR<br>BPTR                           |
| ANZEKT<br>DNZB<br>DNZB<br>KONZTR<br>KOLNZ<br>LNZBDY<br>LNZTR<br>QLNZ<br>ROEXTTH<br>BPCV                           |
| ANZENT<br>CINZJ<br>KCINZJENT<br>KQINZTH<br>KQINZTH<br>LINZP<br>LINZP<br>LINZP<br>RCINZTH<br>RCINZTR<br>BPCIN      |

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NOZZLE WEIGHT

NZWM1

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MODEL TYPE: NOZZLEW (NOZZLE Weight)

MODEL NAME: NZWMI (Single, Ablative, Parametric Scaling)

#### DESCRIPTION:

NZWM1 (NoZzle Weight Model number 1) utilizes parametric weight scaling equations to determine the weight of a solid rocket motor fixed or gimballed nozzle. A detailed description of both the equations and parametric scaling rationale may be found in reference 8.

The model is applicable for performance parameters within the following limits

15 < NZHA < 30 deg
300 < PCHAVG < 1000 psia
5 < RAEXTTH < 75
30 < TBPPMT < 140 sec
500 < WPPMT < 2,000,000 lb</pre>

where NZHA is associated with the NOZZLEG model type and the remaining quantities are defined in the Input Data, Inter-Model section below.

#### PROCEDURE:

Prior to entering NZWM1, the models specified by the IBGAS and IBPERF model types have evaluated the gas and performance properties of the propellent, and the model specified by the NOZZLEG model type evaluated the nozzle geometry. The nozzle weight penalty due to gimballed or other thrust vector control systems has been determined by the model specified for the TVCW model type.

The NZWM1 model is then executed and the nozzle weight is evaluated using a parametric weight scaling equation. The expended weights, due to ablation during thrusting, are also computed.

After leaving NZWM1, the remaining component weights of the motor are evaluated. The NZWM1 output data will then be used by the models specified by the SUBSTGW and PROPUL model types to evaluate the substage weights and propulsion characteristics.

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# NOZZLE WEIGHT

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EQUATIONS:

Total nozzle weight.

$$W_{NZ} = K_{WNZ} K_{TVNZ} C_1 \begin{bmatrix} \frac{\left(W_{PP}C^*\right)^2 \epsilon^3}{C_4 C_5 C_6} \end{bmatrix}^{\prime}$$
(1)

Total expended nozzle weight component.

$$W_{NZ_{X}} = K_{WNZX} C_{8} \left( P_{AVG} T_{B} \right)^{C_{9}} W_{NZ}$$
(2)

Expended (non-thrusting producing) nozzle weight component.

$$W_{NZ_{XI}} = K_{WNZXI} W_{NZ_{X}}$$
(3)

Expended (thrust producing) nozzle weight component.

$$W_{NZ} = 0$$
(4)

Total non-expended nozzle weight component,

$$W_{NZ_{NX}} = K_{WNZNX} \begin{pmatrix} W_{NZ} - W_{NZ_{X}} \end{pmatrix}$$
(5)

# INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units  | Preset    |
|----------|--------|---------------------------------|-----------|
| CNZW1    | C,     | Scaling constant for WNZ comput | ation;    |
|          | -      | N. D.                           | 0.0000772 |

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# NOZZLE WEIGHT

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# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                                         | Preset             |
|----------|--------------------|------------------------------------------------------------------------|--------------------|
| CNZW2    | c2                 | Scaling constant for WNZ computa<br>N. D.                              | tion;<br>1.2       |
| CNZW3    | C3                 | Scaling constant for WNZ computa<br>N. D.                              | tion;<br>0. 7      |
| CNZW4    | C4                 | Scaling constant for WNZ computa<br>N. D.                              | tion;<br>0.8       |
| CNZW5    | C5                 | Scaling constant for WNZ computa N. D.                                 | tion;<br>0.6       |
| CNZW6    | c <sub>6</sub>     | Scaling constant for WNZ computa<br>N. D.                              | ution;<br>0.4      |
| CNZW7    | c <sub>7</sub>     | Scaling constant for WNZ computa<br>N. D.                              | tion;<br>0.916     |
| CNZW8    | C <sub>8</sub>     | Scaling constant for WNZX compu<br>N. D.                               | tation;<br>0.00032 |
| CNZW9    | C <sub>9</sub>     | Scaling constant for WNZX compu<br>N.D.                                | tation;<br>0.5     |
| KWNZ     | K <sub>WNZ</sub>   | Proportionality factor for total no<br>N. D.                           | zzle weight;<br>1  |
| KWNZNX   | K <sub>WNZNX</sub> | Proportionality factor for nozzle a weight component;                  | non-expended       |
|          |                    | N. D.                                                                  | 1                  |
| KWNZX    | K <sub>WNZX</sub>  | Proportionality factor for total ex weight component;                  | pended nozzle      |
|          |                    | N. D.                                                                  | 1                  |
| KWNZXI   | <sup>K</sup> wnzxi | Proportionality factor for non-thr<br>component of expended nozzle wei | ust producing ght; |
|          |                    | N. D.                                                                  | 1                  |

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## NOZZLE WEIGHT

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## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input,

| Mnemonic | Symbol            | Description; Ext. (Int.) Units               | Model Type |
|----------|-------------------|----------------------------------------------|------------|
| CVDELV   | с*                | Delivered characteristic velocity;<br>it/sec | IBGAS      |
| KTVNZ    | K <sub>TVNZ</sub> | Thrust vector control factor;<br>N. D.       | TVCW       |
| PCHAVG   | PAVG              | Average chamber pressure;<br>psia            | IBGAS      |
| RAEXTTH  | • <sub>NZ</sub>   | Nozzle expansion ratio;<br>N. D.             | NOZZLEG    |
| TANNZHA  | $\tan(\theta)$    | Tangent of nozzle half angle;<br>N. D.       | NOZZLEG    |
| твррмт   | т <sub>в</sub>    | Propellent burn time;<br>sec                 | IBFERF     |
| WPPMT    | W <sub>PP</sub>   | Propellent weight;<br>1b                     | PROPELW    |

## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimes ation routines.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units |       |
|----------|-----------------|--------------------------------|-------|
| WNZ      | W <sub>NZ</sub> | Total nozzle weight;           |       |
|          |                 | 1ь                             | Eq. 1 |

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# NOZZLE WEIGHT

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# OUTPUT DATA (Cont.):

| Mnemonic             | Symbol             | Description; Ext. (Int.) Units                             |       |      |  |
|----------------------|--------------------|------------------------------------------------------------|-------|------|--|
| WN ZN X              | W <sub>N7</sub>    | Total non-expended nozzle weight com                       | pone  | ent; |  |
|                      | NX                 | 1ь                                                         | Eq.   | 5    |  |
| WNZX W <sub>NZ</sub> |                    | Total expended nozzle weight compone                       | ent;  |      |  |
|                      | X                  | 1ь                                                         | Eq.   | 2    |  |
| WNZXI                | w <sub>NZ</sub> XI | Expended (non-thrust producing) nozzi<br>weight component; | le    |      |  |
|                      |                    | 1ъ                                                         | Eq.   | 3    |  |
| WNZXT                | w <sub>NZ</sub> XT | Expended (thrust-producing) nozzle we component;           | eight |      |  |
|                      |                    | 1Ъ                                                         | Eq.   | 4    |  |

180.1-5

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PRINT BLOCK KEY:

180.1-6

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| NOZZLE WEIGHT | UNZXT<br>CNZWS CNZW6 | KUNZNY          |
|---------------|----------------------|-----------------|
| DWRZN         | unzat<br>Cnzwł       | KNNZ            |
| NOZZLEN       | ቲ <sub>춘</sub>       | ÷               |
|               | CHZH3                | CNZN3           |
|               | CIVIZIVA<br>CIVIZIVA | CNZN8           |
|               | CH2ND                | CNZN7<br>KNNZXI |

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PAYLODG

PAYLOAD GEOMETRY

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MODEL TYPE: PAYLODG (PAYLOaD Geometry)

MODEL NAME: PAGMI (Single, Simple Payload)

#### DESCRIPTION:

PAGM1 (PAyload Geometry Model number  $\underline{1}$ ) evaluates the geometry for a simple single payload which may be defined in terms of its length and base diameter. See figure 1 and the figure associated with the model used as the top interstage (INTSTGG model type) for an appreciation of the pertinent geometry.

#### **PROCEDURE:**

Prior to entering PAGM1, all of the solid rocket motor substages have been sized.

PAGM1 then determines both the basic payload geometry and the payload requirements for interstage design.

After PAGMI is executed, the interstages will be sized. The top interstage for the propulsion system will use PAGMI output, together with the geometry of the top substage in the propulsion system, to determine its design requirements. After all of the interstages, stages, and the propulsion system have been sized, the payload geometry is used for sizing the payload section and shroud.

#### EQUATIONS:

Total payload length.

 $L_{PA} = L_{PA}_{SF} + L_{PA}_{B} + L_{PA}_{SA}$ (1)

Payload cross-sectional area.

 $A_{PA} = \left(-\frac{\pi}{4}\right) D_{PA_A}^2$ 

190, 1-1

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(2)

# EQUATIONS (Cont. ):

Payload aft diameter for interstage attachment.

$$D_{SS_{ITA}} = D_{PA_{A}}$$
(3)

Length of interstage required for the payload.

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$$L_{SS_{ITA}} = L_{PA_{SA}}$$
(4)



190.1-3

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#### PAYLODG

### PAYLOAD GEOMETRY

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                                                          | Preset |
|----------|-----------------|-----------------------------------------------------------------------------------------|--------|
| DPAA     | D <sub>PA</sub> | Payload base (i.e., aft) diameter, required for defining the aft interstage attachment; |        |
|          |                 | in                                                                                      | 0      |
| LPAB     | L <sub>PA</sub> | Basic prvload length component;                                                         |        |
|          | В               | in                                                                                      | 0      |
| LPASA    |                 | Payload aft spacing distance;                                                           |        |
|          | SA              | in                                                                                      | 0      |
| LPASF    |                 | Payload forward spacing diatance;                                                       |        |
|          | SF              | in                                                                                      | 0      |

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. | (Int.) Units | Model Type |
|----------|--------|-------------------|--------------|------------|
|----------|--------|-------------------|--------------|------------|

None

#### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                   |       |  |
|----------|-----------------|--------------------------------------------------|-------|--|
| АРА      | A <sub>PA</sub> | Payload cross-sectional area;<br>in <sup>2</sup> | Eq. 2 |  |
|  | PA | Y | LODG |
|--|----|---|------|
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## PAYLOAD GEOMETRY

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## OUTPUT DATA (Cont.):

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units         |                      |
|----------|-------------------------------|----------------------------------------|----------------------|
| DSSITA   | D <sub>SS<sub>ITA</sub></sub> | Payload aft diameter for interstage in | attachment;<br>Eq. 3 |
| LPA      | L <sub>PA</sub>               | Total payload length;<br>in            | Eq. 1                |
| LSSITA   | L <sub>SSITA</sub>            | Length of interstage required for th   | ne payload;<br>Eq. 4 |

190.1-5

PRINT BLOCK KEY:

190.1-6

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| OMETRY     | LPASF   |                |
|------------|---------|----------------|
| PAYLOAD GE | LPASA   |                |
| PAGM       | LPAB    |                |
| PAYLODG    | ť       | \$¥            |
|            | DESITIA |                |
|            | DPAA    | <b>ATTSSLI</b> |
|            | APA     | <b>NA</b> LI   |

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PAYLOAD WEIGHT

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## MODEL TYPE: PAYLODW (PAYLOaD Weight)

MODEL NAME: PAWM1 (Direct Input)

#### DESCRIPTION:

PAWM1 (PAyload Weight Model number  $\underline{l}$ ) is a simple payload weight model for which the payload weight is input directly by the program user.

# Note that the payload weight does NOT normally include the weight of the shroud, payload adapter, etc.

#### PROCEDURE:

Prior to entering PAWM1, the substages have been sized and the model specified for the PAYLODG model type has evaluated the payload geometry.

PAWM1 then defines the payload weight.

After leaving PAWM1, the interstages, stages, and propulsion system are sized. The model specified for the PAYSECW model types then uses the payload weight, together with the shroud weight, etc., to determine the payload section weight.

#### EQUATIONS:

Total payload weight.

$$W_{PA} = K_{WPA} W_{PAYLOD}$$
(1)

Total non-expended payload weight component.

$$W_{PA_{NX}} = W_{PA}$$
(2)

Total expended payload weight component.

$$W_{PA_{X}} = 0 \tag{3}$$

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## PAYLOAD WEIGHT

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## EQUATIONS (Cont.):

Expended (thrust producing) payload weight component.

$$W_{PA} = 0$$
(4)

Expended (non-thrust producing) payload weight component.

$$W_{PA_{XI}} = 0$$
(5)

#### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol  | Description; Ext. (Int.) Units   | Preset |
|----------|---------|----------------------------------|--------|
| KWPA     | KWPA    | Coefficient for WPA computation; |        |
|          | W 4 4 1 | N. D.                            | 1      |
| WPAYLOD  | WPAYLOD | Payload weight input by user;    |        |
|          |         | 16                               | 0      |

#### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext | t. (Int.) Units | Model Type |
|----------|--------|------------------|-----------------|------------|
|          |        |                  | , ,             |            |

None

#### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines. PAYLODW

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## PAYLOAD WEIGHT

| OUTPUT DA | TA (Cont.):        |                                                         |                                          |               |  |
|-----------|--------------------|---------------------------------------------------------|------------------------------------------|---------------|--|
| Mnemonic  | Symbol             | Description; Ext. (Int.) Units                          |                                          |               |  |
| WPA       | W <sub>PA</sub>    | Total payload weight;                                   |                                          |               |  |
|           |                    | lb                                                      | Eq.                                      | 1             |  |
| WPANX     | WPA                | Total non-expended payload weight co                    | mpon                                     | en <b>t</b> ; |  |
|           | - NX               | lb                                                      | Eq.                                      | 2             |  |
| WPAX      | W <sub>PA</sub>    | Total expended payload weight compo                     | Total expended payload weight component; |               |  |
|           | X                  | 1b                                                      | Eq.                                      | 3             |  |
| WPAXI     | w <sub>PA</sub> XI | Expended (non-thrust producing) payle weight component; | oad                                      |               |  |
|           |                    | lb                                                      | Eq.                                      | 5             |  |
| WPAXT     | w <sub>pa</sub> xt | Expended (thrust producing) payload weight component;   |                                          |               |  |
|           |                    | 1b                                                      | Eq.                                      | 4             |  |

200.1-3

PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| PAYLOAD WEIGHT<br>WPAXT |
|-------------------------|
| PAWAQ<br>WPAXT          |
| 5*<br>1*<br>NGOJYA      |
| MF-AX                   |
| WPANX<br>WPAYLOD        |
| NPA<br>KWPA             |

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# PAYLOAD WEIGHT

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#### PROPULSION CHARACTERISTICS

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MODEL TYPE: PROPUL (PROPULsion Characteristics)

MODEL NAME: PCM1 (Constant Thrust, Single Engine)

#### **DESCRIPTION:**

PCM1 (Propulsion Characteristics Modei number 1) evaluates the thrust and weight flow breakdown for a single constant thrust solid rocket engine. The engine is comprised of the following subsystems:

Motor

Nozzle

In addition to the thrust derived from the propellent, thrust components associated with the following subsystem expended weight components are evaluated.

Internal insulation

Thrust vector control

Nozzle

#### PROCEDURE:

Prior to executing PCM1, the model specified for the IBPE 3F model type has determined the propellent weight flow, burn time and specific impulse. The model specified for the NOZZLEG model type has determined the nozzle exit area and the models specified for the NOZZLEW and MOTORW model types have broken down the principle subsystem weight into expended components.

PCM1 is then executed and the expended subsystem weights are used to determine the inert and thrust producing weight flow components. These weight flow components are then used, together with the required specific impulses, to determine the vacuum nrust components. Finally, the vacuum thrust components are summed and the total engine vacuum thrust and sea-level thrust degradation are evaluated.

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## PROPULSION CHARACTERISTICS

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## PROCEDURE (Cont.):

After PCMl is executed, the remaining substages are sized and the propulsion characteristics for each engine within the vehicle are evaluated. After the entire vehicle is sized, the PCMl output data is input to the applicable weight and propulsion model for the mission simulation. See REMARKS.

## EQUATIONS:

Expended motor weight flow, excludes propellent.

$$\mathbf{\hat{w}}_{MT_{X}} = \frac{\mathbf{\hat{w}}_{MT_{X}}}{\mathbf{T}_{B}}$$
(1)

Expended (thrust producing) motor weight flow component, excludes propellent.

$$\mathbf{\hat{w}}_{MT} = \frac{\mathbf{\hat{w}}_{MT}}{T_{B}}$$
(2)

Expended (non-thrust producing) motor weight flow component.

$$\mathbf{\hat{w}}_{MT_{XI}} = \frac{\mathbf{\hat{w}}_{MT_{XI}}}{\mathbf{T}_{B}}$$
(3)

Expended nozzle weight flow.

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$$\hat{W}_{NZ_X} = \frac{W_{NZ_X}}{T_B}$$
(4)

Expended (thrust producing) nozzle weight flow component.

$$\hat{W}_{NZ_{XT}} = \frac{W_{NZ_{XT}}}{T_B}$$
(5)

Expended (non-thrust producing) nozzle weight flow component.

$$\mathbf{\hat{w}}_{NZ_{XI}} = \frac{\mathbf{\hat{w}}_{NZ_{XI}}}{T_{B}}$$
(6)

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## PROPULSION CHARACTERISTICS

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## EQUATIONS (Cont.):

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Weight flow associated with expended (thrust producing) internal insulation.

$$\hat{\mathbf{W}}_{\mathbf{IN}_{\mathbf{X}\mathbf{T}}} = \frac{\mathbf{W}_{\mathbf{IN}_{\mathbf{X}\mathbf{T}}}}{\mathbf{T}_{\mathbf{B}}}$$
(7)

Weight flow associated with expended (thrust producing) thrust vector control system material.

$$\mathbf{\hat{W}}_{TV} = \frac{\mathbf{\hat{W}}_{TV}}{\mathbf{T}_{B}}$$
(8)

Thrust producing engine weight flow component. (Includes propellent);

$$\dot{\mathbf{W}}_{\mathrm{EN}_{\mathrm{T}}} = \mathbf{K}_{\mathrm{DWENT}} \left( \mathbf{W}_{\mathrm{PP}} + \dot{\mathbf{W}}_{\mathrm{MT}_{\mathrm{XT}}} + \dot{\mathbf{W}}_{\mathrm{NZ}_{\mathrm{XT}}} \right)$$
(9)

Inert (non-thrust producing) engine weight flow component,

$$W_{EN_{I}} = K_{DWENI} ( W_{MT_{XI}} + W_{NZ_{XI}} )$$
(10)

Total engine weight ilow.

$$\hat{\mathbf{w}}_{\mathrm{EN}} = \kappa_{\mathrm{DWEN}} \left( \hat{\mathbf{w}}_{\mathrm{EN}_{\mathrm{T}}} + \hat{\mathbf{w}}_{\mathrm{EN}_{\mathrm{I}}} \right)$$
(11)

Vacuum thrust component associated with the propellent.

$$F_{V_{PP}} = K_{FVPP} I_{SP_{VD}} \overset{\bullet}{W}_{PP}$$
(12)

Vacuum thrust component associated with expended (thrust producing) internal insulation.

$$F_{V_{IN}} = K_{FVIN} I_{SP_{IN}} \tilde{W}_{IN_{XT}}$$
(13)

210.1-3

### PCM1

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#### PROPULSION CHARACTERISTICS

EQUATIONS (Cont.):

<del>ಕಾರ್ಯವರ್ಷವಾಗಿದ್ದುವು ಎಂದಿ ಇತ್ತು ಅವರ ಸ್ವಾರ್</del>ಕ ಕಾರ್ಯಕ್ರಿಯ ದಾಗಿ ಮುಂಗ ಸ್ವಾಮಿಗಳು

Vacuum thrust component associated with expended (thrust producing) thrust vector control material.

$$\mathbf{F}_{\mathbf{V}_{\mathbf{T}\mathbf{V}}} = \mathbf{K}_{\mathbf{F}\mathbf{V}\mathbf{T}\mathbf{V}} \quad \mathbf{I}_{\mathbf{SP}_{\mathbf{T}\mathbf{V}}} \quad \mathbf{\hat{W}}_{\mathbf{T}\mathbf{V}_{\mathbf{X}\mathbf{T}}}$$
(14)

Vacuum thrust component associated with expended (thrust producing) nozzle material.

$$F_{V_{NZ}} = K_{FVNZ} I_{SP_{NZ}} \tilde{W}_{NZ_{XT}}$$
(15)

Engine vacuum thrust.

$$\mathbf{F}_{\mathbf{V}_{\mathbf{EN}}} = \mathbf{K}_{\mathbf{F}\mathbf{V}\mathbf{F}\mathbf{N}} \left( \mathbf{F}_{\mathbf{V}_{\mathbf{PP}}} + \mathbf{F}_{\mathbf{V}_{\mathbf{IN}}} + \mathbf{F}_{\mathbf{V}_{\mathbf{T}\mathbf{V}}} + \mathbf{F}_{\mathbf{V}_{\mathbf{N}\mathbf{Z}}} \right)$$
(16)

Engine thrust degradation due to atmospheric pressure.

$$\Delta F_{EN} = \kappa_{DELFEN} C_1 A_{NZ_{EXT}}$$
(17)

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol  | Description; Ext. (Int.) Units                                                      | Preset    |
|----------|---------|-------------------------------------------------------------------------------------|-----------|
| CPCI     | $c_1$   | Constant for DELFEN computation.<br>Corresponds to atmospheric sea-le-<br>pressure; | vel       |
|          |         | 1b/(in <sup>-</sup> )                                                               | 4. 695972 |
| KDELFEN  | KDELFEN | Coefficient for DELFEN computation;                                                 |           |
|          |         | N. D.                                                                               | 1         |
| KDWEN    | KDWEN   | Coefficient for DWEN computation;                                                   |           |
|          | 2211    | N, D.                                                                               | 1         |

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# INPUT DATA, INTRA-MODEL, (Cont.):

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                       | Preset     |
|----------|-------------------------------|----------------------------------------------------------------------|------------|
| KDWENI   | K <sub>dweni</sub>            | Coefficient for DWENI computation;<br>N. D.                          | 1          |
| KDWENT   | K <sub>dwent</sub>            | Coefficient for DWENT computation;<br>N. D.                          | 1          |
| KFVEN    | K <sub>FVEN</sub>             | Coefficient for FVEN computation;                                    | 1          |
| KFVIN    | K <sub>fvin</sub>             | Coefficient for FVIN computation;<br>N. D.                           | 1          |
| KFVNZ    | K <sub>fvnz</sub>             | Coefficient for FVNZ computation;<br>N. D.                           | 1          |
| KFVPP    | K <sub>FVPP</sub>             | Coefficient for FVPP computation;<br>N. D.                           | 1          |
| KFVTV    | K <sub>FVTV</sub>             | Coefficient for FVTV computation; N. D.                              | 1          |
| ISPIN    | <sup>1</sup> SP <sub>IN</sub> | Specific impulse of expended (thrust internal insulation material;   | producing) |
|          |                               | Sec.                                                                 | 0          |
| IS PN Z  | ISPNZ                         | Specific impulse of expended (thrust norsile material;               | producing) |
|          |                               | 89C                                                                  | 0          |
| ISPTV    | I <sub>SP</sub> TV            | Specific impulse of expended (thrust thrust vector control material; | producing) |
|          |                               | foc                                                                  | 0          |

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#### PROPULSION CHARACTERISTICS

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                               | Model Type      |
|----------|---------------------|--------------------------------------------------------------|-----------------|
| ANZEXT   | A <sub>NZ</sub> EXT | Nozzle exit area;<br>in <sup>2</sup>                         | NOZZLEG         |
| DWPPMT   | ₩ <sub>PP</sub> mt  | Propellent weight flow;<br>lb/sec                            | IBPERF          |
| ISPVD    | I <sub>SPVD</sub>   | Vacuum delivered specific im <sub>r</sub><br>sec             | ilse;<br>IBPERF |
| ТВРРМТ   | т <sub>в</sub>      | Propellent burn time;<br>sec                                 | IBPERF          |
| WINXT    | w <sub>in</sub> xt  | Expended (thrust producing) int insulation weight component; | ernal           |
|          |                     | 16                                                           | INTINSW         |
| WMTX     | <sup>w</sup> мт     | Total expended motor weight co                               | mponent;        |
|          | X                   | 1ь                                                           | MOTORW          |
| WMTXI    | w <sub>MTXI</sub>   | Expended (non-thrust producing weight component;             | ) motor         |
|          |                     | 1ь                                                           | MOTORW          |
| WMTXT    | w <sub>MTxt</sub>   | Expended (thrust producing) mc<br>component;                 | otor weight     |
|          |                     | 1b                                                           | MOTORW          |
| WNZX     | W <sub>NZ</sub>     | Total expended nozzle weight component;                      |                 |
|          | N <sup>2</sup> X    | lb                                                           | NOZZLEW         |
| WNZXI    | w <sub>NZXI</sub>   | Expended (non-thrust producing weight component;             | ) nozzle        |
|          |                     | 1b                                                           | NOZZLEW         |

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## PROPULSION CHARACTERISTICS

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| INPUT DATA, INTER-MODEL (Cont.): |                   |                                                              |             |  |
|----------------------------------|-------------------|--------------------------------------------------------------|-------------|--|
| Mnemonic                         | Symbol            | Description; Ext. (Int.) Units                               | Model Type  |  |
| WNZXT                            | w <sub>NZXT</sub> | Expended (thrust producing) no:<br>component;                | zzle weight |  |
|                                  |                   | lb                                                           | NOZZLEW     |  |
| w <sub>TV</sub> xT               | w <sub>tvxt</sub> | Expended (thrust producing) thr<br>control weight component; | ust vector  |  |
|                                  |                   | 1b                                                           | TVCW        |  |

## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                                                           | Description; Ext. (Int.) Units                                                                                                                              |                       |
|----------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| DELFEN   | ∆f <sub>en</sub>                                                 | Engine sea-level thrust degra<br>DELFEN corresponds to DEL<br>trajectory simulation models;                                                                 | idation.<br>F in the  |
|          |                                                                  | ІЪ                                                                                                                                                          | Eq. 17                |
| DWEN     | VEN WEN Total engine weight flow. In propellent, motor, and nozz |                                                                                                                                                             | ludes<br>weight flow; |
|          |                                                                  | lb/sec                                                                                                                                                      | Eq. 11                |
| DWENI    | •<br>w <sub>eni</sub>                                            | Inert (non-thrust producing) engine<br>flow component (includes motor an                                                                                    |                       |
|          |                                                                  | lb/sec                                                                                                                                                      | Eq. 10                |
| DWENT    | ₩ <sub>EN</sub> T                                                | Thrust producing engine weight flow comp<br>(Includes propellent, motor, and nozzle.)<br>DWENT corresponds to DWVAC in the<br>trajectory simulation models; |                       |
|          |                                                                  | 1b/ <b>se</b> c                                                                                                                                             | Eq. 9                 |
| DWINXT   | •<br>w <sub>inxt</sub>                                           | Motor weight flow associated with exper<br>(thrust producing) internal insulation m                                                                         |                       |
|          |                                                                  | lb/sec                                                                                                                                                      | Ea. 7                 |

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| OUTPUT DA | TA (Cont.):                                   |                                                                                                    |                        |
|-----------|-----------------------------------------------|----------------------------------------------------------------------------------------------------|------------------------|
| Mnemonic  | Symbol                                        | Description; Ext. (Int.) Units                                                                     |                        |
| DWMTX     | •<br>w <sub>MT</sub> X                        | Expended motor weight flow. Exclue propellent and nozzle;                                          | des                    |
|           |                                               | lb/sec                                                                                             | Eq. 1                  |
| DWMTXI    | <sup>•</sup><br><sup>w</sup> мт <sub>XI</sub> | Expended (non-thrust producing) mo<br>flow component, excludes nozzle;                             | tor weight             |
|           |                                               | lb/sec                                                                                             | Eq. 3                  |
| DWMTXT    | <sup>•</sup><br><sup>w</sup> мт <sub>хт</sub> | Expended (thrust producing) motor w<br>flow component. Excludes propeller<br>nozzle;               | veight<br>nt and       |
|           |                                               | lb/sec                                                                                             | Eq. 2                  |
| DWNZX     | W <sub>NZ</sub>                               | Expended nozzle weight flow;                                                                       |                        |
|           | ····x                                         | lb/sec                                                                                             | Eq. 4                  |
| DWNZXI    | •<br><sup>w</sup> NZ <sub>XI</sub>            | Expended (non-thrust producing) noz<br>flow component;                                             | zle weight             |
|           |                                               | lb/sec                                                                                             | Eq. 6                  |
| DWNZXT    | <sup>w</sup> NZ <sub>XT</sub>                 | Expended (thrust producing) nozzle v<br>flow component;                                            | weight                 |
|           |                                               | lb/sec                                                                                             | Eq. 5                  |
| DWTVXT    | <sup>₩</sup> TV <sub>XT</sub>                 | Motor weight flow associated with ex<br>(thrust producing) thrust vector cont<br>material;         | kpended<br>trol system |
|           |                                               | 1b/sec                                                                                             | Eq. 8                  |
| FVEN      | FVEN                                          | Total engine vacuum thrust, FVEN<br>corresponds to FVAC in the trajecto<br>simulation models;      | ry                     |
|           |                                               | 1ь                                                                                                 | Eq. 16                 |
| FVIN      | F <sub>V</sub> IN                             | Vacuum thrust component associated<br>expended (thrust producing) internal<br>insulation material; | i with the             |
|           |                                               | 1ь                                                                                                 | Eq. 13                 |

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# PROPULSION CHARACTERISTICS

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| OUTPUT DAT | FA (Cont.):                  |                                                                                                                                                                          |
|------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mnemonic   | Symbol                       | Description; Ext. (Int.) Units                                                                                                                                           |
| F V N Z    | F <sub>V<sub>NZ</sub></sub>  | Vacuum thrust component associated with the expended (thrust producing) nozzle material.<br>Note that this is not associated with the nozzle half angle divergence loss; |
|            |                              | 1b Eq. 15                                                                                                                                                                |
| FVPP       | <sup>F</sup> v <sub>PP</sub> | Vacuum thrust component associated with the propellent;                                                                                                                  |
|            |                              | 1ь                                                                                                                                                                       |
| FVTV       | Fv <sub>TV</sub>             | Vacuum thrust component associated with the expended (thrust producing) thrust vector control system material;                                                           |
|            |                              | 1b Eq. 14                                                                                                                                                                |

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PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| I CHARACTERISTICS | TOKINTING | DANZXT   | MIN     | NEWDI   |        |       |
|-------------------|-----------|----------|---------|---------|--------|-------|
| PROPULSING        | TNEWD     | IXZNHQ   | FVPP    | NEWDA   | ZNASI  |       |
| Dica              | INSIMO    | XZINHO   | ZNVY    | KUMENT  | NIASI  |       |
| PROFUL            | Ŧ         | ¥        | Ŧ       | 7*      | \$*    | ¥     |
|                   | NEINO     | DUNCTION | NIN     | INSIMON | VIVDI  |       |
|                   | DELFEN    | DUDING   | PVISN   | NUMBR   | THAT   |       |
|                   | าววา      | XUMO     | TXV THO | NORFEN  | NT WIZ | ALISI |

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## PAYLOAD SECTION CEOMETRY

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MODEL TYPE: PAYSECG (PAYload SECtion Geometry)

MODEL NAME: PLGM1 (Single Payload, No Shroud Geometry)

#### DESCRIPTION:

PLGM1 (PayLoad section Geometry Model number 1) evaluates the geometry for a simple payload section comprised of a single payload without shroud geometry. Although provision is made for defining a payload section length bias, Intra-Model Input is not normally required for this model. See figure 1 and the figures associated with the payload model utilized (PAYLODG model type) for an appreciation of the payload section geometry.

Note that this model is not applicable if a shroud geometry model (see SHROUDG model type) is utilized. However, this model may be used if a non-geometry dependent shroud weight model (see SHROUDW model type) is used.

#### PROCEDURE:

Prior to entering PLGM1, all vehicle subsystems within the propulsion system have been sized and the model specified for the PAYLODG model type has determined the payload geometry.

PLGM1 then uses the payload geometry to determine the payload section geometry.

After PLGM1 is executed, the payload section weight will be determined. The total vehicle geometry is then evaluated using the payload section geometry and propulsion system geometry.

#### EQUATIONS:

Payload section length. Figure 1

 $L_{PL} = L_{PA} + L_{PL}_{SF}$ 

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# PAYLOAD SECTION GEOMETRY

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# EQUATIONS (Cont. ):

Payload section diameter. Figure 1

$$D_{PL} = D_{PA}$$
(2)

Payload section cross-sectional area.

$$A_{\rm PL} = \left(\frac{\pi}{4}\right) D_{\rm PL}^2 \tag{3}$$



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Fig. 220, 1-1 Phyload Section Geometry

220, 1-3

## PAYLOAD SECTION GEOMETRY

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#### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnernonic | Symbol | Description ; Ext. (Int.) Units Preset    |
|-----------|--------|-------------------------------------------|
| LPLSF     | LPL    | Payload section forward spacing distance; |
|           | - SF   | in Fig. 1 0                               |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol  | Description;  | Ext. (Int.) Units | Model Type |
|----------|---------|---------------|-------------------|------------|
| DPAA     | DPA     | Payload aft d | iameter;          |            |
|          | · · · A | in            |                   | PAYLODG    |
| LPA      | LPA     | Total payload | l length;         |            |
|          |         | in            | Fig. 1            | PAYLODG    |

## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                      | _   |   |
|----------|-----------------|-----------------------------------------------------|-----|---|
| APL      | A <sub>PL</sub> | Payload section cross-sectional area;               |     |   |
|          |                 | in                                                  | Eq. | 3 |
| DPL      | D <sub>PL</sub> | Payload section disinctor at interstage attachment; | 9   |   |
|          |                 | in                                                  | Eq. | 2 |
| LPL      | LPL             | Payload section length;                             |     |   |
|          |                 | in                                                  | Eq. | 1 |

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PRINT BLOCK KEY:

Norminally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be wrinted or suppressed (see the section on output models for the details).

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#### PAYLOAD SECTION WEIGHT

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MODEL TYPE: PAYSECW (PAYload SECtion Weight)

MODEL NAME: PLWM1 (Single Payload, no Shroud)

#### DESCRIPTION:

PLWM1 (PayLoad section Weight Model number 1) is a weight synthesis model which evaluates the weight breakdown for a simple payload section comprised of a single payload without a shroud.

#### **PROCEDURE**:

Prior to entering PLWM1, all vehicle subsystems within the propulsion system have been sized and the model specified for the PAYLODW model type has evaluated the payload weight breakdown.

PLWMI uses the payload weight breakdown to evaluate the payload section weight breakdown.

After PLWM1 is executed, the payload section weight breakdown, together with the propulsion system weight breakdown, will be utilized by the model specified for the VEHW model type to determine vehicle weight quantities.

#### EQUATIONS:

Total payload section weight.

 $W_{PL} = K_{WPL} W_{PA}$ (1)

Total non-expended payload section weight component.

$$W_{PL_{NX}} = K_{WPLNX} W_{PA_{NX}}$$
<sup>(2)</sup>

Total expended payload section weight component.

$$W_{PL_{X}} = K_{WPLX} W_{PA_{X}}$$
(3)

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## PAYLOAD SECTION WEIGHT

## EQUATIONS (Cont.):

Expended (non-thrust producing) payload section weight component.

$${}^{W}PL_{XI} = {}^{K}WPLXI {}^{W}PA_{XI}$$
(4)

Expended (thrust producing) payload section weight component,

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$$W_{PL_{XT}} = K_{WPLXT} W_{PA_{XT}}$$
(5)

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units              | Preset |
|----------|--------------------|---------------------------------------------|--------|
| KWPL     | K <sub>WPL</sub>   | Coefficient for WPL computation;<br>N. D.   | 1      |
| KWPLNX   | K <sub>wplnx</sub> | Coefficient for WPLNX computation;          | 1      |
| KWPLX    | KWPLX              | Coefficient for WPLX computation;<br>N. D.  | 1      |
| KWPLXI   | K <sub>WPLXI</sub> | Coefficient for WPLXI computation;<br>N. D. | 1      |
| KWPLXT   | K <sub>wplxt</sub> | Coefficient for WPLXT computation;<br>N, D. | 1      |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

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## PAYLOAD SECTION WEIGHT

## **PLWMI**

## INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                   | Model Type     |
|----------|--------------------------------|--------------------------------------------------|----------------|
| WPA      | W <sub>PA</sub>                | Total payload weight;                            |                |
|          |                                | lb                                               | PAYLODW        |
| WPANX    | <sup>₩</sup> ₽ <sup>A</sup> NX | Total non-expended payload wei                   | ght component; |
| WPAX     | WPA                            | Total expended payload weight component;         |                |
|          | ···x                           | 1b                                               | PAYLODW        |
| WPAXI    | W <sub>PA<sub>XI</sub></sub>   | Expended (non-thrust producing weight component; | ) payload      |
|          |                                | 1ь                                               | PAYLODW        |
| WPAXT    | w <sub>PA</sub> XT             | Expended (thrust producing) pay component;       | yload weight   |
|          |                                | 16                                               | PAYLODW        |

## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                        | Dee~~iption; Ext. (Int.) Units                  |        |   |
|----------|-------------------------------|-------------------------------------------------|--------|---|
| WPL      | W <sub>PL</sub>               | Total payload section weight;                   |        |   |
|          |                               | 1ь                                              | Eq.    | 1 |
| WPLNX    | <sup>W</sup> PL <sub>NX</sub> | Total non-expended payload section w component; | reight |   |
|          |                               | 1ъ                                              | Eq.    | 2 |
| WPLX     | w <sub>PL</sub> x             | Total expended payload section weigh component; | t      |   |
|          |                               | 16                                              | Eq.    | 3 |

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| OUTPUT DATA (Cont.): |                    |                                                            |                |  |  |
|----------------------|--------------------|------------------------------------------------------------|----------------|--|--|
| Maemonic             | Symbol             | Description; Ext. (Int. ) Units                            |                |  |  |
| WPLXI                | w <sub>PL</sub> XI | Expended (non-thrust producin<br>section weight component; | ag) payload    |  |  |
|                      |                    | 1Ъ                                                         | Eq. 4          |  |  |
| WPLXT                | W <sub>PL</sub> XT | Expended (thrust producing) pa<br>weight component;        | hyload section |  |  |
|                      |                    | 16                                                         | Eq. 5          |  |  |

PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on withut models for the details).

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## PAYLOAD SECTION WEIGHT

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MODEL TYPE: PAYSECW (PAYload SECtion Weight)

MODEL NAME: PLWM2 (Single payload, shroud)

#### DESCRIPTION:

PLWM2 (PayLoad section Weight Model number 2) is a weight synthesis model which evaluates the payload section weight breakdown. The model is applicable for a payload section comprised of the following subsystem:

> Payload Shroud

#### PROCEDURE:

Prior to entering PLWM2, all vehicle subsystems within the propulsion system have been sized and the models specified for the PAYLODW and SHROUDW model types have evaluated the payload and shroud weight breakdown.

PLWM2 uses these payload and shroud weights to evaluate the payload section weight breakdown.

After PLWM2 is executed, the payload section weight breakdown, together with the propulsion system weight breakdown, will be utilized by the model specified for the VEHW model type to determine vehicle weight quantities.

#### EQUATIONS:

Total payload section weight.

$$W_{PL} = K_{WPL} \left( W_{PA} + W_{SH} \right)$$
(1)

Total non-expended payload section weight component.

$$W_{PL_{NX}} = K_{WPLNX} \left( W_{PA_{NX}} + W_{SH_{NX}} \right)$$
(2)

## PAYLOAD SECTION WEIGH

## EQUATIONS (Cont.):

Total expended payload section weight component.

$$W_{PL_{X}} = K_{WPLX} \left( W_{PA_{X}} + W_{JH_{X}} \right)$$
(3)

Expended (non-thrust producing) payload section weight component.

$$W_{PL_{XI}} = K_{WPLXI} \left( W_{PA_{XI}} + W_{SH_{XI}} \right)$$
(4)

Expended (thrust producing) payload section weight component.

$$W_{PL_{XT}} = K_{WPLXT} \left( W_{PA_{XT}} + W_{SH_{XT}} \right)$$
(5)

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units              | Preset |
|----------|--------------------|---------------------------------------------|--------|
| KWPL     | K <sub>wpl</sub>   | Coefficient for WPL computation;<br>N. D.   | 1      |
| KWPLNX   | K <sub>WPLNX</sub> | Coefficient for WPLNX computation;<br>N. D. | 1      |
| KWPLX    | Kwplx              | Coefficient for WPLX computation;<br>N. D.  | 1      |
| KWPLXI   | K <sub>wplxi</sub> | Coefficient for WPLXI computation;<br>N. D. | 1      |
| KWPLXT   | <sup>K</sup> wplxt | Coefficient for WPLXT computation;<br>N. D. | 1      |

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## INFUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                   | Model Type     |
|----------|-------------------------------|--------------------------------------------------|----------------|
| WPA      | ₩ <sub>₽A</sub>               | • Total payload weight;                          | PAYLODW        |
|          |                               |                                                  | I AI LOD       |
| WPANX    | W <sub>PLNX</sub>             | Total non-expended payload wei                   | ght component; |
|          |                               | 1b                                               | PAYLODW        |
| WPAX     | W <sub>PA</sub>               | Total expended payload weight o                  | component;     |
|          | <sup>r</sup> x                | lb                                               | PAYLODW        |
| WPAXI    | w <sub>PA</sub> XI            | Expended (non-thrust producing weight component; | ) payload      |
|          |                               | lb                                               | PAYLODW        |
| WPAXT    | w <sub>PA</sub> XT            | Expended (thrust producing) pay component;       | load weight    |
|          |                               | lb                                               | PAYLODW        |
| WSH      | w <sub>sH</sub>               | Total shroud weight;                             |                |
|          | 011                           | 1b                                               | SHROUDW        |
| WSHNX    | w <sub>su</sub>               | Total non-expended shroud weig                   | ght component; |
|          | on'nx                         | lb                                               | SHROUDW        |
| wshx     | Wcu                           | Total expended shroud weight c                   | omponent;      |
|          | ST X                          | lb                                               | SHROUDW        |
| WSHXI    | w <sub>sh</sub> xi            | Expended (non-thrust producing weight component; | ) shroud       |
|          |                               | 16                                               | SHROUDW        |
| WSHXT    | <sup>w</sup> sн <sub>хт</sub> | Expended (thrust producing) sh component;        | roud weight    |
|          |                               | 1ь                                               | SHROUDW        |

## PAYLOAD SECTION WE'GHT

PLWM2

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## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                                                               |              |
|----------|--------------------|----------------------------------------------------------------------------------------------|--------------|
| WPL      | w <sub>pl</sub>    | Total payload section weight. Includes payload and shroud;                                   |              |
|          |                    | 1b                                                                                           | Eq. l        |
| WPLNX    | w <sub>pl</sub> nx | Total non-expended payload section weight component. Includes payload and shroud;            |              |
|          |                    | 1b                                                                                           | Eq. 2        |
| WPLX     | w <sub>PL</sub> x  | Total expended payload section weight component. Includes payload and shroud;                |              |
|          |                    | lb                                                                                           | Eq. 3        |
| WPLXI    | w <sub>pl</sub> xi | Expended (non-thrust producing) paylor section weight component. Includes paylor and shroud; | ad<br>yload  |
|          |                    | 15                                                                                           | Eq. 4        |
| WPLXT    | W <sub>PL</sub> XT | Expended (thrust producing) payload se<br>weight component. Includes payload as<br>shroud;   | ection<br>nd |
|          |                    | 1b                                                                                           | Eq. 5        |

PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| THOIR WEIGHT |          |               |  |
|--------------|----------|---------------|--|
| PAYLOAD SE   | TXTIAN   | IXITAWN       |  |
| 2MH74        | DCLAW    | <b>KUPLXI</b> |  |
| PAYSECW      | <b>F</b> | ¥             |  |
|              | XTIAM    | KUPLX         |  |
|              | XINTIAM  | XINTIAMX      |  |

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# PAYLOAD SECTION WEIGHT

PLWM2

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## PROPELLENT WEIGHT

**PPWMI** 

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## MODEL TYPE: PROPELW (PROPELlent Weight)

MODEL NAME: PPWM1 (Direct input of propellent weights)

#### DESCRIPTION:

PPWMI (ProPellent Weight Model number 1) determines the basic propellent properties (weight, volume, density) of a solid rocket motor for which the propellent weight is specified directly.

### EQUATIONS:

Propellent volume.

 $v_{PP_{MT}} = \frac{w_{PP_{MT}}}{\rho_{PP_{MT}}}$ (1)

## INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units            | Preset |
|----------|-------------------------------|-------------------------------------------|--------|
| RHOPPMT  | ρ <sub>PP</sub> MT            | Propellent density;<br>lb/in <sup>3</sup> | 0      |
| WPPMT    | <sup>₩</sup> ₽₽ <sub>МТ</sub> | Propellent weight;                        | •      |
|          |                               | lb                                        | 0      |

INPU'I DATA, INTER-MODEL:

None

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PROPLW

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### PROPELLENT WEIGHT

## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units        |
|----------|--------------------|---------------------------------------|
| VPPMI    | v <sub>pp</sub> mt | Propellent volume;<br>in <sup>3</sup> |

|            | PROPELW                                                          | PROPELLENT WEIGHT | PPWMI |
|------------|------------------------------------------------------------------|-------------------|-------|
| Ō          |                                                                  |                   |       |
|            | e line number will be<br>ted or suppressed                       | PROFELLENT WEIGHT |       |
|            | e left of th<br>ay be prin                                       | Dunda             |       |
| ( .        | n asterisk to the<br>s given below m<br>or the details).         | L*                | ·     |
|            | se lines with a<br>any of the lines<br>output models f           | TMIT              |       |
|            | T BLOCK KEY<br>ally, only tho<br>d. By input,<br>he section on o | TMETODA           |       |
| <b>4</b> . | PRINT<br>Nomin<br>printe<br>(see th                              | DATAM             |       |
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PROSYSG

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#### PROPULSION SYSTEM GEOMETRY

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#### MODEL TYPE:

PROSYSG (PROpulsion SYStem Geometry)

and the second 
MODEL NAME: PSGM1 (Sequential Stages)

#### DESCRIPTION:

PSGM1 (<u>Propulsion System Geometry Model number 1</u>) evaluates the geometry for a propulsion system comprised of sequential stages. See figure 1 for an illustration of the geometry associated with a typical propulsion system.

#### PROCEDURE:

Prior to entering PSGM1, all of the stages have been sized and the models specified for the STAGEG model types have determined the stage lengths for all stages comprising this propulsion system.

PSGM1 then sums these stage lengths and determines the total propulsion system length.

After PSGM1 has determined the propulsion system geometry, the propulsion system weight is evaluated. After all of the propulsion systems have been sized, the model specified for the VEHG model type will use the propulsion system geometry, together with the payload section geometry, to determine the total vehicle geometry. After the total vehicle geometry is evaluated, a final pass is made through all of the models and any remaining quantities dependent upon the total propulsion system length are evaluated.

#### EQUATIONS:

Total propulsion system length.

 $L_{PS} = \sum L_{SG}$ 

(1)

Where the summation includes all stages within the propulsion system.

# PROPULSION SYSTEM GEOMETRY

PSGM1



Fig. 250.1-1 Typical Three Stage Boost Vehicle

250.1-2
PROSYSG

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#### PROPULSION SYSTEM GEOMETRY

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## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|--------|--------------------------------|--------|
|          |        |                                |        |

None

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol | Description; Ext. (Int.) Units                     | Model Type  |
|----------|--------|----------------------------------------------------|-------------|
| LSG      | LSG    | Stage length for each stage com propulsion system; | prising the |
|          |        | in                                                 | STAGEG      |

#### OUTPUT DATA

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units  |       |
|----------|-----------------|---------------------------------|-------|
| LPS      | L <sub>PS</sub> | Total propulsion system length; |       |
|          | 10              | ft                              | Eq. l |

250.1-3

PSGM1

PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

PROPULSION SYSTEM GEOMETRY

PSGM

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LPS

PSGM)

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PROSYSW

## **PROPULSION SYSTEM WEIGHT**

PSWM1

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MODEL TYPE: PROSYSW (PROpulsion SYStem Weight)

MODEL NAME: PSWM1 (W

PSWM1 (Weight Synthesis)

#### DESCRIPTION:

PSWM1 (Propulsion System Weight Model number 1) is a weight synthesis model which evaluates the propulsion system weights. The propulsion system is comprised of the following subsystems.

Stages

#### PROCEDURE:

Prior to entering PSWM1, the models specified for the STAGEW model type have evaluated the stage weights and mass fractions which are not dependent upon the propulsion system or vehicle weights.

PSWM1 then uses the pertinent stage weight to determine the propulsion system weight quantities.

After leaving PSWM1, the total vehicle geometry and weights are evaluated. After the vehicle has been sized, the model specified for the STAGEW model type (and other major subsystem model types if required) is reentered and mass fractions dependent upon propulsion system quantities are evaluated.

#### EQUATIONS:

In the equations below, the summation includes all stages within the propulsion system.

Total propellent weight associated with the propulsion system.

$$W_{PP} = \Sigma W_{PP}$$
(1)

Total propulsion system weight.

 $w_{PS} = \Sigma w_{SG}$ (2)

PROSYSW

#### **PROPULSION SYSTEM WEIGHT**

PSWM1

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# EQUATIONS (Cont.):

Total non-expended propulsion system weight component.

$$W_{PS_{NX}} = \sum W_{SG_{NX}}$$
(3)

Total expended propulsion system weight component.

$$W_{PS_{X}} = \sum W_{SG_{X}}$$
(4)

Expended (non-thrust producing) propulsion system weight component.

$$w_{PS_{XI}} = \Sigma w_{SG_{XI}}$$
(5)

Expended (thrust producing) propulsion system weight component.

$$W_{PS_{XT}} = \Sigma W_{SG_{XT}}$$
(6)

## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. I: a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. (Int.) Units | Preset |
|----------|--------|--------------------------------|--------|
|          |        |                                |        |

None

#### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                           | Model Type   |
|----------|--------------------|----------------------------------------------------------|--------------|
| WPPSG    | w <sub>PP</sub> SG | Propellent weight for each stage this propulsion system; | e comprising |
|          |                    | 1ь .                                                     | STAGEW       |

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PSWM1

# INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                    | Model Type      |
|----------|------------------------------|-------------------------------------------------------------------|-----------------|
| WSG      | w <sub>sG</sub>              | Total stage weight for each stage compris this propulsion system; |                 |
|          |                              | 16                                                                | STAGEW          |
| WSGNX    | W <sub>SG</sub>              | Total non-expended stage weight component;                        |                 |
|          | UCNX                         | 16                                                                | STAGEW          |
| WSGX     | <sup>w</sup> sg <sub>x</sub> | Total expended stage weight component;                            |                 |
|          |                              | 16                                                                | STAGEW          |
| WSGXI    | w <sub>sgxi</sub>            | Expended (non-thrust producin<br>component;                       | g) stage weight |
|          |                              | 16                                                                | STAGEW          |
| WSGXT    | w <sub>sgxt</sub>            | Expended (thrust producing) st component;                         | age weight      |
|          |                              | ІЪ                                                                | STAGEW          |

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                                                                             |                                               |  |
|----------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|--|
| WPPPS    | <sup>₩</sup> ₽₽ <sub>₽S</sub> | Total propellent weight associated with the propulsion system. Includes propellent weights of all stages comprising the propulsion system; |                                               |  |
|          |                               | 1ь                                                                                                                                         | Eq. l                                         |  |
| WPS      | w <sub>PS</sub>               | Total propulsion system weigh<br>propellent, non-expended and t<br>weight components for all stag<br>the propulsion system;                | t. Includes<br>otal expended<br>es comprising |  |
|          |                               | 16                                                                                                                                         | Eq. 2                                         |  |

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# OUTPUT DATA (Cont.):

| Mnemonic              | Symbol                       | Description; Ext. (Int.) Units                                                                                                       |                                                                                |  |
|-----------------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--|
| WPSNX                 | w <sub>psnx</sub>            | Total non-expended propulsi<br>component. Includes non-ex<br>components for all stages co<br>propulsion system;                      | on system weight<br>opended weight<br>comprising the                           |  |
|                       |                              | 16                                                                                                                                   | Eq. 3                                                                          |  |
| wpsx w <sub>psx</sub> |                              | Total expended propulsion s<br>component. Includes expend<br>components for all stages co<br>propulsion system. Exclude<br>weight;   | ystem weight<br>ded weight<br>omprising the<br>es propellent                   |  |
|                       |                              | 1ь                                                                                                                                   | Eq. 4                                                                          |  |
| WPSXI                 | w <sub>PS</sub> XI           | Expended (non-thrust produce<br>system weight component.<br>thrust producing weight com<br>stages comprising the propu               | cing) propulsion<br>Includes non-<br>ponents for all<br>ilsion system;         |  |
|                       |                              | 16                                                                                                                                   | Eq. 5                                                                          |  |
| WPSXT                 | w <sub>PS<sub>XT</sub></sub> | Expended (thrust prc-lucing)<br>weight component. Includes<br>weight components for all st<br>the propulsion system. Exc<br>weights; | propulsion system<br>thrust producing<br>tages comprising<br>cludes propellent |  |
|                       |                              | 16                                                                                                                                   | <b>Eq.</b> 6                                                                   |  |

PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of .he line number will be printed. By input, any of the lines given below may be puncted or suppressed (see the section on output models for the details). PROPULSION SYSTEM WEIGHT

PROPULSION SYSTEM WEIGHT WPSRT WPPPS

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STAGE GEOMETRY

SGGMI

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MODEL TYPE: STAGE (STAGE Geometry)

MODEL NAME: SGGM1 (Single Sequential Stage and Interstage)

#### DESCRIPTION:

SGGM1 (StaGe Geometry Model number 1) evaluates the geometry for a stage comprised of a single substage and interstage as illustrated in figure 1. By inputting coefficients and bias terms, considerable flexibility is provided for specifying the stage length, diameter, and cross-sectional area. However, since the Intra-Model Input Data is preset to the nominal stage configuration, user input data is not normally required for this model.

#### PROCEDURE:

Prior to entering SGGM1, the models specified for the SUBSTGG and INTSTGG model types have determined the final geometry for the substage and interstage.

SGGM1 (first entrance) then uses these primary component diameters and lengths to determine the overall stage geometry.

After leaving SGGM1, the weight for this particular stage is evaulated. After all the stages are sized, the models specified for the PROSYSG and VEHG model types will be executed and, utilizing the stage geometry together with their individual requirements, the overall propulsion system and vehicle is sized.

SGGM1 is then entered for the second time and stage fractions dependent upon propulsion system and vehicle quantities are evaluated.

#### EQUATIONS (FIRST ENTRANCE):

Stage length. Fig. 1

$$L_{SG} = K_{LSG1} \quad L_{SS} + K_{LSG2} \quad L_{IT_{S}} + K_{LSG3}$$

270.1-1

(1)

## STAGEG

# STAGE GEOMETRY

SGGM1

# EQUATIONS (FIRST ENTRANCE) (Cont.):

Stage diameter.

$$D_{SG} = K_{DSG1} D_{SS} + K_{DSG2} D_{ITA} + K_{DSG3} D_{ITF} + K_{DSG4}$$
(2)

Stage cross-sectional area.

$$A_{SG} = K_{ASG1} A_{SS} + K_{ASG2} A_{ITA} + K_{ASG3} A_{ITF} + K_{ASG4}$$
(3)

Stage length to stage diameter ratio.

$$R_{LDSG} = \frac{L_{SG}}{D_{SG}}$$
(4)

# EQUATIONS (SECOND ENTRANCE):

Propulsion system length to stage diameter ratio.

$$R_{LDPSSG} = \frac{L_{PS}}{D_{SG}}$$
(5)

Vehicle length to stage diameter ratio.

$$R_{LDVHSG} = \frac{L_{VH}}{D_{SG}}$$
(6)

STAGEG

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SGGM1



Fig. 270.1-1 Stage Geometry

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# STAGE GEOMETRY

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# INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol            | Description; Ext. (Int.) Units                      | Preset                   |
|----------|-------------------|-----------------------------------------------------|--------------------------|
| KASG1    | K <sub>ASG1</sub> | Coefficient for stage area computa<br>N. D.         | ation;<br>1              |
| KASG2    | KASG2             | Coefficient for stage area comput:<br>N. D.         | ation;<br>O              |
| KASG3    | K <sub>ASG3</sub> | Coefficient for stage area computa<br>N. D.         | ation;<br>0              |
| KASG4    | KASG4             | Bias for stage area computation;<br>in <sup>2</sup> | 0                        |
| KDSG1    | <sup>K</sup> DSG1 | Coefficient f <b>or stage</b> diameter cor<br>N. D. | n <b>putat</b> ion;<br>l |
| KDSG2    | K <sub>DSG2</sub> | Coefficient for stage diameter cor<br>N. D.         | nputation;<br>0          |
| KDSG3    | K <sub>DSG3</sub> | Coefficient for stage diameter cor<br>N. D.         | nputation;<br>0          |
| KDSG4    | K <sub>DSG4</sub> | Bias for stage diameter computat                    | ion;<br>O                |
| KLSGI    | K <sub>LSG1</sub> | Coefficient for stage length compu<br>N. D.         | itation;<br>1            |
| KLSG2    | KLSG2             | Coefficient for stage length compu<br>N. D.         | itation;<br>1            |
| KLSG3    | KLSC3             | Bias for stage length computation in                | ;<br>0                   |

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# STAGE GEOMETRY

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# INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                     | Model Type              |
|----------|------------------------------|----------------------------------------------------|-------------------------|
| AITA     | A <sub>IT</sub> A            | Cross-sectional area, interstag<br>in <sup>2</sup> | e aft base;<br>INTSTGG  |
| AITF     | A <sub>IT</sub> F            | Cross-sectional area, interstag<br>in <sup>2</sup> | e fore base;<br>INTSTGG |
| ASS      | A <sub>SS</sub>              | Cross-sectional area, substage<br>in <sup>2</sup>  | ;<br>SUBSTGG            |
| DITA     | D <sub>IT</sub> A            | Diameter, interstage aft base;<br>in               | INTSTGG                 |
| DITF     | D <sub>IT</sub> <sub>F</sub> | Diameter, interstage fore base;<br>in              | ;<br>INTSTGG            |
| DSS      | D <sub>SS</sub>              | Outside diameter, substage;<br>in                  | SUBSTGG                 |
| LITS     | LITS                         | Spacing distance associated wit interstage;        | h the                   |
|          |                              | in Fig. 1                                          | INTSTGG                 |
| LPS      | L <sub>PS</sub>              | Total propulsion system length;<br>in              | PPOSYSG                 |
| LSS      | Lss                          | Total substage length;                             |                         |
|          | 55                           | in Fig. 1                                          | SUBSTGG                 |
| LVH      | L <sub>VH</sub>              | Total vehicle length;                              |                         |
|          | V                            | in                                                 | VEHG                    |

# STAGE GEOMETRY

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                       |                   |  |
|----------|-----------------|------------------------------------------------------|-------------------|--|
| ASG      | A <sub>SG</sub> | Stage cross-sectional area;<br>in <sup>2</sup>       | Eq. 3             |  |
| DSG      | D <sub>SG</sub> | Stage diameter;<br>in                                | Eq. 2             |  |
| LSG      | L <sub>SG</sub> | Stage length;<br>in Fig. l                           | Eq. l             |  |
| RLDPSSG  | RLDPSSG         | Propulsion system length to stage<br>ratio;<br>N. D. | diameter<br>Eq. 5 |  |
| RLDSG    | RLDSG           | Stage length to stage diameter rati<br>N. D.         | o;<br>Eq. 4       |  |
| RLDVHSG  | RLDVHSG         | Vehicle length to stage diameter r                   | atio;<br>Eq. 6    |  |

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PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| STRY       | KASG4 | KLS72        |         |
|------------|-------|--------------|---------|
| STACE GBOM | KASG3 | <b>KLSG1</b> | RLDVHSG |
| SOGMI      | KASG2 | KDSC1        | RLDSC   |
| STAGEG     | ľ,    | ţ,           | ÷       |
|            | KASGI | KDGG3        | RLDPSSG |
|            | DSG   | KDSG2        | 1°SC    |
|            | ASG   | KDSCI        | KLSG3   |

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STAGE WEIGHT

SGWM1

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MODEL TYPE: STAGEW (STAGE Weight)

MODEL NAME: SGWMl (Single substage and interstage)

#### DESCRIPTION:

SGWM1 (StaGe Weight Model number 1) is a weight synthesis model which evaluates the stage weight breakdown and stage mass fractions for a stage having a single substage and interstage. The stage weight is comprised of the following subsystems:

Substage

Interstage

#### PROCEDURE:

Prior to entering SGWM1, the models specified by the SUBSTGW and INTSTGW model types have evaluated the substage and interstage weights. In addition to evaluating subcomponent weights peculiar to their particular requirements, they have defined a set of component weights in terms of expended or non-expended attributes.

Upon the first entrance to SGWM1, these expended and non expended, substage and interstage, weight components are used in determining the stage weight breakdown. In addition, mass fractions which are not dependent upon propulsion system or vehicle quantities are evaluated.

The remainder of the stages are then sized and the models specified for the PROSYSW and VEHW model types will determine the propulsion system and vehicle weights.

After the entire vehicle has been sized, a second entrance is made to SGWM1 and the stage mass fractions which are dependent upon propulsion system and vehicle quantities are evaluated.

# STAGE WEIGHT

SGWM1

# EQUATIONS (FIRST ENTRANCE):

Weight of propellent associated with this stage.

$$w_{PP_{SG}} = w_{PP_{SS}}$$
(1)

Total stage weight.

$$W_{SG} = K_{WSG} \left( W_{SS} + W_{IT} \right)$$
<sup>(2)</sup>

Total non-expended stage weight component.

$$w_{SG_{NX}} = \kappa_{WSGNX} \left( w_{SS_{NX}} + w_{IT_{NX}} \right)$$
(3)

Total expended stage weight component.

$$W_{SG_{X}} = K_{WSGX} \left( W_{SS_{X}} + W_{IT_{X}} \right)$$
<sup>(4)</sup>

Expended (thrust producing) stage weight component.

$$\mathbf{w}_{SG_{XT}} = \mathbf{K}_{WSGXT} \left( \mathbf{w}_{SS_{XT}} + \mathbf{w}_{IT_{XT}} \right)$$
(5)

Expended (non-thrust producing) stage weight component.

$$\mathbf{w}_{\mathrm{SG}_{\mathbf{XI}}} = \mathbf{K}_{\mathrm{WSGXI}} \left( \mathbf{w}_{\mathrm{SS}_{\mathbf{XI}}} + \mathbf{w}_{\mathrm{IT}_{\mathbf{XI}}} \right)$$
(6)

Total weight of stage expendables.

$${}^{W}SG_{XX} = {}^{K}WSGXX \left( {}^{W}PP_{SG} + {}^{W}SG_{X} \right)$$
<sup>(7)</sup>

Total stage expended inert weight flow.

$$\hat{\mathbf{W}}_{SG_{\mathbf{I}}} = \mathbf{K}_{DWSGI} \quad \hat{\mathbf{W}}_{EN_{\mathbf{I}}}$$
(8)

Stage propellent neass fraction.

$$K_{SG_{PMF}} = \frac{W_{PP_{SG}}}{W_{SG}}$$
(9)

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EQUATIONS (FIRST ENTRANCE)(Cont.):

Stage expended mass fraction.

$$K_{SG_{XMF}} = \frac{W_{SG_{X}}}{W_{SG}}$$
(10)

Stage structure mass fraction.

$$K_{SG_{SMF}} = \frac{W_{SG_{NX}}}{W_{SG}}$$
(11)

#### EQUATIONS (SECOND ENTRANCE):

Stage weight proportion

$$R_{WSGPS} = \frac{W_{SG}}{W_{PS}}$$
(12)

Stage propellent weight proportion.

$$P_{WPSGPS} = \frac{W_{PP}SG}{W_{PP}SG}$$
(13)

## INPUT DATA, INTRA-MODEL:

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The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                          | Preset      |
|----------|--------------------|---------------------------------------------------------|-------------|
| KDWSGI   | K <sub>DWSGI</sub> | Coefficient for DWSGI computation                       | ;           |
|          |                    | N. D.                                                   | -1          |
| KWSG     | KWSG               | Proportionality <i>i</i> actor for total stage weight;  |             |
|          |                    | N. D.                                                   | 1           |
| KWSGNX   | K <sub>WSGNX</sub> | Proportionality factor for non-exp<br>weight component; | ended s:age |
|          |                    | N, D.                                                   | 1           |

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## STAGE WEIGHT

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# INPUT DATA, INTRA-MODEL (Cont.):

| Mnemonic | Symbol | Description: Ext. (Int.) Units                                                         | Preset           |
|----------|--------|----------------------------------------------------------------------------------------|------------------|
| KWSGX    | ĸwsgx  | Proportionality factor for total ex<br>weight component;                               | pended stage     |
|          |        | N. D.                                                                                  | 1                |
| KWSGXI   | Kwsgxi | Proportionality factor for expended (non-<br>thrust producing) stage weight component; |                  |
|          |        | N. D.                                                                                  | 1                |
| KWSGXT   | Kwsgxt | Proportionality factor for expende<br>producing) stage weight componen                 | ed (thrust<br>t; |
|          |        | N. D.                                                                                  | 1                |
| KWSGXX   | KWSCXX | Coefficient for WSGXX computation                                                      | on;              |
|          | WOUXX  | N. D.                                                                                  | 1                |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol            | Description; Ext. (Int.) Units                | Model Type   |
|----------|-------------------|-----------------------------------------------|--------------|
| DWENI    | W <sub>EN-</sub>  | Inert engine weight flow;                     |              |
|          | I                 | 16                                            | PROPUL       |
| WIT      | w <sub>it</sub>   | Total interstage weight;                      |              |
|          |                   | 1b                                            | INTSTGW      |
| WITNX    | w <sub>itnx</sub> | Total non-expended interstage v<br>component; | veight       |
|          |                   | 16                                            | INTSTGW      |
| WITX     | w <sub>tr</sub>   | Total expended interstage weigh               | t component; |
|          | · · ):            | lb                                            | INTSTGW      |

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INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                      | Model Type              |
|----------|------------------------------|---------------------------------------------------------------------|-------------------------|
| WITXI    | w <sub>ITX</sub>             | Expended (non-thrust producing) : weight component;                 | interstage              |
|          |                              | Ъ                                                                   | INTSTGW                 |
| WITXT    | w <sub>IT<sub>XT</sub></sub> | <b>Expended (thrust</b> producing) inter weight component;          | stage                   |
|          |                              | 1ь                                                                  | INTSTGW                 |
| WPPPS    | W <sub>PP</sub> PS           | Weight of propellent associated w propulsion system;                | ith the                 |
|          |                              | 1ь                                                                  | PROSYSW                 |
| WPPSS    | w <sub>PP</sub> ss           | Weight of propellent associated w substage;                         | ith the                 |
|          |                              | Ъ                                                                   | SUBSTGW                 |
| WPS      | W <sub>PS</sub>              | Total propulsion system weight;                                     |                         |
|          | 10                           | 1ь                                                                  | PROSYSW                 |
| wss      | W <sub>SS</sub>              | Total substage weight. Includes                                     | propellent;             |
|          |                              | 1ь                                                                  | SUBSTGW                 |
| WSSNX    | <sup>w</sup> ss              | Total non-expended substage weig                                    | ght component;          |
|          | NX                           | 16                                                                  | SUBSTGW                 |
| WSSX     | <sup>w</sup> ss <sub>x</sub> | Total expended substage weight c<br>does not include propellent;    | omponent,               |
|          |                              | 1ъ                                                                  | SUBSTGW                 |
| WSSXI    | w <sub>ssx1</sub>            | Expended (non-thrust producing) weight component;                   | substage                |
|          |                              | 1ь                                                                  | SUBSTGW                 |
| WSSXT    | w <sub>ssxt</sub>            | Expended (thrust producing) subs<br>component, does not include pro | tage weight<br>pellent; |
|          |                              | 1b                                                                  | SUBSTGW                 |

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# STAGE WEIGHT

**SGWM1** 

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# OUTPUT DATA:

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The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic      | Symbol                         | Description; Ext. (Int.) Units                                                                                                                                                       |               |
|---------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| DWSGI         | <sup>ŵ</sup> sс <sub>I</sub>   | Total stage expended inert weight flow. A<br>negative value indicates weight loss from the<br>stage (see KDWSGI). DWSGI corresponds to<br>DWINERT in the trajectory simulation model | ;<br>)<br>[8; |
|               |                                | 1b/sec Eq. 8                                                                                                                                                                         |               |
| KSGPMF        | к <sub>sg</sub> рмf            | Stage propellent mass fraction. Ratio of propellent weight to stage weight;                                                                                                          |               |
|               |                                | N. D. Eq. 9                                                                                                                                                                          |               |
| KSGSMF        | <sup>K</sup> SG <sub>SMF</sub> | Stage structure mass fraction. Ratio of non-<br>expended stage weight to total stage weight;                                                                                         | •             |
|               |                                | N. D. Eq. 1                                                                                                                                                                          | 1             |
| KSGXMF        | <sup>к</sup> sc <sub>xmf</sub> | Stage expended mass fraction. Ratio of expended stage weight (excluding propellent) to total stage weight;                                                                           |               |
|               |                                | N. D. Eq. 10                                                                                                                                                                         | C             |
| RWSGPS RWSGPS |                                | Stage weight proportion. Ratio of stage weig<br>to propulsion system weight;                                                                                                         | ;ht           |
|               |                                | N. D. 12                                                                                                                                                                             |               |
| R W PSG PS    | Rwpsgps                        | Stage propellent weight proportion. Ratio of propellent weight associated with the stage to the propellent weight associated with the propulsion system;                             | D             |
|               |                                | N. D. Eq. 1.                                                                                                                                                                         | 3             |
| W.PPSG        | w <sub>pp</sub> sc             | Weight of propellent associated with this stage;                                                                                                                                     |               |
|               |                                | lb Eq. l                                                                                                                                                                             |               |
| WSG           | <sup>w</sup> sg                | Total stage weight. Includes substage and interstage;                                                                                                                                |               |
|               |                                | 1b Eq. 2                                                                                                                                                                             |               |

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STAGE WEIGHT

SGWM1

| OUTPUT | DATA | (Cont.): |
|--------|------|----------|
|        |      |          |

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                                                                                                             |                                                                  |
|----------|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| WSGNX    | w <sub>sgnx</sub>             | Total non-expended stage weight<br>Includes substage and interstage<br>corresponds to WTSTS in the tra<br>simulation models;                                               | component.<br>WSGNX<br>jectory                                   |
|          |                               | 1b                                                                                                                                                                         | Eq. 3                                                            |
| WSGX     | wsgx                          | Total expended stage weight com<br>Includes substage and interstage<br>include propellent;                                                                                 | ponent.<br>. Does not                                            |
|          |                               | 1b                                                                                                                                                                         | Eq. 4                                                            |
| WSGXI    | <sup>w</sup> sg <sub>xi</sub> | Expended (non-thrust producing)<br>component. Includes substage a                                                                                                          | stage weight<br>nd interstage;                                   |
|          |                               | lb                                                                                                                                                                         | <b>Eq.</b> 6                                                     |
| WSGXT    | w <sub>sgxt</sub>             | Expended (thrust producing) stag<br>component. Includes substage a<br>Does not include propellent;                                                                         | e weight<br>nd interstage.                                       |
|          |                               | 1b                                                                                                                                                                         | Eq. 5                                                            |
| WSGXX    | <sup>w</sup> sg <sub>XX</sub> | Total weight of stage expendable<br>propellent, expended thrust proc<br>expended non-thrust producing s<br>components. WSGXX correspon<br>in the trajectory simulation mod | s. Includes<br>lucing, and<br>tage weight<br>ds to WTANK<br>els; |
|          |                               | 1Ъ                                                                                                                                                                         | Eq. 7                                                            |

280.1-7

PRINT BLOCK KEY:

280.1-8

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| r<br>WPPSC<br>KWSCXX<br>RWPSGPS            |
|--------------------------------------------|
| STAGE WEIGHT<br>WSGXT<br>KTMSGXT<br>KDMSGI |
| IDSMQ<br>IXDSMX<br>IXDSM<br>TWMDS          |
| STAGEW<br>*1<br>*2<br>*3                   |
| WSGX<br>KVBSCX<br>KSCXONF                  |
| WSGNX<br>KWSGNX<br>KSGSMF                  |
| WSG<br>KWSG<br>KSGPMF                      |

SHROUDW

SHROUD WEIGHT

SHWM1

290.1

MODEL TYPE: SHROUDW (SHROUD Weight)

MODEL NAME: SHWM1 (Direct Input)

#### **DESCRIPTION:**

SHWM1 (<u>SH</u>roud Weight Model number 1) is a simple non-geometry dependent shroud weight model for which the shroud weight is input directly by the program user. It should be noted that shroud simulations will normally require a shroud weight model but not a shroud geometry model.

See the PAYSECW model type for payload section weight models which are applicable if this shroud weight model is used.

#### PROCEDURE:

Prior to executing SHWM1, all vehicle subsystems within the propulsion system have been sized and the model specified for the PAYLODW model type has evaluated the payload weight breakdown.

SHWM1 is then executed and the shroud weight is evaluated.

After SHWMl is executed, the model specified for the PAYSECW model type will use the payload and shroud weights to evaluate the payload section weight breakdown.

#### EQUATIONS:

Total shroud weight.

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Total non-expended shroud weight component.

| W <sub>SHNX</sub> | = | $w_{SH}$ | {2} | ) |
|-------------------|---|----------|-----|---|
| 1478              |   |          |     |   |

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(1)

## EQUATIONS (Cont.):

Total expended shroud weight component.

$$W_{SH_X} = 0$$
 (3)

Expended (non-thrust producing) shroud weight component.

$$W_{SH_{XI}} = 0$$
(4)

Expended (thrust producing) shroud weight component.

$$W_{SH_{XT}} = 0$$
 (5)

# INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol  | Description; Ext. (Int.) Units            | Preset |
|----------|---------|-------------------------------------------|--------|
| KWSH     | ĸwsh    | Coefficient for WSH computation;<br>N. D. | 1      |
| WSHROUD  | WSHROUD | Shroud weight input by user;<br>lb        | 0      |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic Symbol | Description; Ext. (Int.) Units | Model Type |
|-----------------|--------------------------------|------------|
|-----------------|--------------------------------|------------|

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SHROUD WEIGHT

SHWM1

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | <u>Symbol</u>                  | Description; Ext. (Int.) Units                         |                                 |   |  |
|----------|--------------------------------|--------------------------------------------------------|---------------------------------|---|--|
| WSH      | <sup>w</sup> sн                | Total shroud weight;                                   |                                 |   |  |
|          |                                | ІЪ                                                     | Eq.                             | 1 |  |
| WSHNX    | W <sub>SH</sub>                | Total non-expended shroud weight                       | weight component;               |   |  |
|          | S. NX                          | lb                                                     | Eq.                             | 2 |  |
| WSHX     | W <sub>SH</sub> Total exp      | Total expended shroud weight com                       | pended shroud weight component; |   |  |
|          | x                              | 1b                                                     | Eq.                             | 3 |  |
| WSHXI    | w <sub>SH</sub> XI             | Expended (non-thrust producing) s<br>weight component; | hroud                           |   |  |
|          |                                | 1b                                                     | Eq.                             | 4 |  |
| WSHXT    | <sup>w</sup> sh <sub>x</sub> ™ | Expended (thrust producing) shrou component;           | d weight                        | ; |  |
|          |                                | 1b                                                     | Eq.                             | 5 |  |

PRINT BLOCK KEY:

290.1-4

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| SHROUD WEIGHT<br>WSHXT |
|------------------------|
| IXHSM<br>TMMHS         |
| SHROUDW<br>*1<br>*2    |
| XHSM                   |
| UUDAHSW<br>XNHSW       |
| HSMX<br>HSM            |

SHROUDW

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SUBSTGG

SUBSTAGE GEOMETRY

SSGM1

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## MODEL TYPE: SUBSTGG (SUBSTaGe Geometry)

MODEL NAME: SSGM1 (Single Solid Rocket Motor)

#### DESCRIPTION:

SSGM1 (SubStage Geometry Model number 1) evaluates the geometry of a complete solid rocket motor substage, including the motor case, protruding nozzle and spacing required ahead of the forward closure for the igniter attachment, thrust termination, etc. Since this is the final geometry model executed in the substage geometry design, substage requirements for interstage design are also evaluated. See figure 1.

#### **PROCEDURE:**

Prior to entering SSGM1, the models specified for the CASEG, NOZZLEG and MOTORG model types have determined the final geometry for the case, nozzle and basic motor.

SSGM1 then uses these primary component diameters and lengths to determine the overall substage geometry, including interstage requirements.

After leaving SSGM1, the weight and propulsion models for this particular substage are sized. After all substages are sized, the interstage models will be executed and, utilizing the substage geometry data together with satisfying their individual requirements, the interstages are sized.

#### EQUATIONS:

Intersubstage spacing distance.

$$L_{SS_{S}} = K_{LS1} + K_{LS2} D_{CS_{O}} + L_{TT_{MT}}$$
(1)

Total substage length.

$$L_{SS} = L_{SS_S} + L_{MT} + L_{NZ_P}$$
(2)

## SUBSTAGE GEOMETRY

SSGMI

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# EQUATIONS (Cont.):

Substage outside diameter.

$$D_{SS} = K_{D1} + K_{D2} D_{MT}$$
(3)

Substage cross sectional area.

$$A_{SS} = \left(\frac{\pi}{4}\right) D_{SS}^2$$
(4)

Ratio, total substage length to case diameter.

$$R_{LDSSCS} = \frac{L_{SS}}{D_{CS_O}}$$
(5)

Substage diameter for forward interstage attachment.

$$D_{SS_{ITF}} = D_{SS}$$
(6)

Substage diameter for aft interstage attachment.

$$D_{SS_{ITA}} = D_{SS}$$
(7)

Length of interstage required (forward) for this substage.

$$L_{SS_{ITF}} = L_{MT_{CHF}} + L_{SS_{S}} - L_{MT_{SKF}}$$
(8)

Length of interstage required (aft) for this substage.

$$L_{SS_{ITA}} = L_{MT_{CHA}} + L_{NZ_{P}} - L_{MT_{SKA}}$$
(9)

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SSGM1



Fig. 300.1-1 Substage Geometry

## SUBSTGG

## SUBSTAGE GEOMETRY

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## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                                                                                                                                 | Preset       |
|----------|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| KLSSS1   | KLS1            | Bias for inter-substage spacing distanc<br>computation. Does not include thrust<br>termination;                                                                |              |
|          |                 | in                                                                                                                                                             | 0            |
| KLSSS2   | KLS2            | Proportionality factor relating a component<br>of the inter-substage spacing distance to the<br>outside case diameter. Does not include<br>thrust termination; |              |
|          |                 | N. D.                                                                                                                                                          | 0            |
| KDSS1    | κ <sub>D1</sub> | Bias for substage diameter compu                                                                                                                               | itation;     |
|          |                 | in                                                                                                                                                             | 0            |
| K DSS2   | к <sub>D2</sub> | Coefficient for substage diameter                                                                                                                              | computation; |
|          |                 | in                                                                                                                                                             | 1            |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units | Model Type |
|----------|-----------------|--------------------------------|------------|
| DCSO     | D <sub>CS</sub> | Outside motor case diameter;   |            |
|          | 000             | in                             | CASEG      |
| DMT      | D <sub>MT</sub> | Motor diameter;                |            |
|          | ••• -           | in                             | MOTORG     |
| LMT      | LMT             | Motor length;                  |            |
|          | <b>A</b>        | in                             | MOTORG     |

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# INPUT DATA, INTER-MODEL:

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units        | Model Type  |
|----------|-------------------------------|---------------------------------------|-------------|
| LMTCLA   | L <sub>MT</sub> cla           | Length of motor aft closure;<br>in    | MOTORG      |
| LMTCLF   | L <sub>MT</sub> CLF           | Length of motor forward closure<br>in | ;<br>MOTORG |
| LMTSKA   | L <sub>MT<sub>SKA</sub></sub> | Length of inotor aft skirt;<br>in     | MOTORG      |
| LMTSKF   | L <sub>MT</sub> skf           | Length of motor forward skirt;<br>in  | MOTORG      |
| LNZP     | L <sub>NZ</sub> P             | Protruding nozzle length;<br>in       | NOZZLEG     |
| LTTMT    | L <sub>TTMT</sub>             | Length, thrust termination;<br>in     | TTERMG      |

# OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol              | Description; Ext. (Int.) Units                                         |              |  |
|----------|---------------------|------------------------------------------------------------------------|--------------|--|
| ASS      | ASS                 | Substage cross sectional area;                                         |              |  |
|          | 60                  | in                                                                     | Eq. 4        |  |
| DSS      | D <sub>SS</sub>     | Substage outside diameter. May include raceways and other protrusions; |              |  |
|          |                     | in                                                                     | Eq. 3        |  |
| DSSITA   | D <sub>SS</sub> ITA | Substage aft diameter for attachment;                                  | • interstage |  |
|          |                     | in                                                                     | Eq. 7        |  |

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SUBSTAGE GEOMETRY

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OUTPUT DATA:(Cont.):

| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                 |                                          |  |
|----------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|--|
| DSSITF   | D <sub>SS<sub>ITF</sub></sub>  | Substage forward diameter for interstage attachment;                                                                                                                                                                                                                                                           |                                          |  |
|          |                                | in                                                                                                                                                                                                                                                                                                             | Eq. 6                                    |  |
| LSS      | L <sub>S3</sub>                | Total substage length. Includes motor,<br>protruding nozzle, and required spacing<br>distance forward of the forward closure;                                                                                                                                                                                  |                                          |  |
|          |                                | in                                                                                                                                                                                                                                                                                                             | Eq. 2                                    |  |
| LSSITA   | <sup>L</sup> ss <sub>ITA</sub> | Length of interstage required (aft) for this substage;                                                                                                                                                                                                                                                         |                                          |  |
|          |                                | in                                                                                                                                                                                                                                                                                                             | Eq. 9                                    |  |
| LSSITF   | <sup>L</sup> SS <sub>ITF</sub> | Length of interstage required (forward) for this substage);                                                                                                                                                                                                                                                    |                                          |  |
|          |                                | in                                                                                                                                                                                                                                                                                                             | Eq. 8                                    |  |
| LSSS     | L <sub>SSS</sub>               | Inter-substage spacing distance. Substage<br>distance, measured along vehicle centerline,<br>forward of fore motor closure. Used primarily<br>for thrust termination equipment and any<br>other spacing distance required between this<br>substage and the nozzle of the substage<br>forward of this substage; |                                          |  |
|          |                                | in                                                                                                                                                                                                                                                                                                             | Eq. 1                                    |  |
| RLDSSCS  | RLDSSCS                        | Length to diameter rat<br>substage length to outs                                                                                                                                                                                                                                                              | io. Ratio of total<br>ide case diameter; |  |
|          |                                | N. D.                                                                                                                                                                                                                                                                                                          | Eq. 5                                    |  |

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PRINT BLOCK KEY:

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| <b>GEOMETRY</b> | KDSS2  | ILSSS   |         |
|-----------------|--------|---------|---------|
| SUBSTAGE        | KDSSI  | LISSI   |         |
| SSGM            | DISSUL | LSSITA  |         |
| SUBSTICC        | Ţ      | Ŷ       | ~^<br>* |
|                 | DSSITA | SSI     |         |
|                 | DSS    | KLSSS22 |         |
|                 | ASS    | KLSSSI  | RLDSSCS |

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SUBSTAGE WEIGHT

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| MODEL TYPE: | SUBSTG | W (SUBSTaGe Weight)                            |
|-------------|--------|------------------------------------------------|
| MODEL NAME: | SSWM1  | (Weight Synthesis, Single Motor<br>and Nozzle) |

#### DESCRIPTION:

SSWM1 (Substage Weight Model number 1) is a weight synthesis model which evaluates the substage weight breakdown and substage mass fractions for a substage having a single solid rocket motor and nozzle. The substage weight is comprised of the following subsystems.

Motor

Nozzle

Note that the above subsystems do NOT include the interstage. See the STAGEW model for stage (substage plus interstage) weight quantities.

#### **PROCEDURE:**

Prior to entering SSWM1, the models specified by the NOZZLEW and MOTORW model types have evaluated the nozzle and motor weights. In addition to evaluating subcomponent weights peculiar to their particular requirements, they have defined a set of component weights in terms of expended or non-expended attributes.

These expended and non-expended motor and nozzle weights are input to SSWM1. The SSWM1 model will combine these quantities to determine the substage weight components and mass fractions.

After the SSWM1 model is executed, the interstage geometry and weights are determined. The model specified by the STAGEW model type will then use the substage and interstage quantities to determine the stage weights and mass fractions.

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#### SUBSTAGE WEIGHT

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## EQUATIONS:

Weight of propellent associated with the substage.

$$W_{PP_{SS}} = W_{PP_{MT}}$$
(1)

Total substage weight.

$$w_{SS} = K_{WSS} (W_{MT} + W_{NZ})$$
<sup>(2)</sup>

Total non-expended substage weight component.

$$W_{SS_{NX}} = K_{WSSNX} (W_{MT_{NX}} + W_{NZ_{NX}})$$
(3)

Total expended substage weight component (excluding propellent).

$$W_{SS_X} = K_{WSSX} (W_{MT_X} + W_{NZ_X})$$
(4)

Expended (thrust producing) substage weight component (excluding propellent),

$$W_{SS}_{XT} = K_{WSSXT} (W_{MT}_{XT} + W_{NZ}_{XT})$$
(5)

Expended (non-thrust producing) substage weight component.

$$W_{SS_{XI}} = K_{WSSXI} (W_{MT_{XI}} + W_{NZ_{XI}})$$
(6)

Substage propellent mass fraction.

$$K_{SS}_{PMF} = \frac{W_{PP}_{SS}}{W_{SS}}$$
(7)

Substage expended mass fraction.

$$K_{SS}_{XMF} = \frac{W_{SS}_X}{W_{SS}}$$
(8)

Substage structure mass fraction.

$$\kappa_{SS_{SMF}} = \frac{W_{SS_{NX}}}{W_{SS}}$$
(9)

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## INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic                     | Symbol           | Description; Ext. (Int.) Units                                         | Preset                 |
|------------------------------|------------------|------------------------------------------------------------------------|------------------------|
| KWSS                         | к <sub>wss</sub> | Proportionality factor for total su                                    | bstage weight;         |
|                              |                  | N. D.                                                                  | 1                      |
| KWSSNX                       | Kwssnx           | <b>Proportionality factor for total no substage weight component;</b>  | n-expended             |
|                              |                  | N. D.                                                                  | 1                      |
| KWSSX                        | ĸwssx            | Proportionality factor for total expended substage weight component;   |                        |
|                              |                  | N. D.                                                                  | 1                      |
| KWSSXI KWSSXI Propo<br>produ |                  | Proportionality factor for expende<br>producing) substage weight compo | d (non-thrust<br>nent; |
|                              |                  | N. D.                                                                  | 1                      |
| KWSSXT                       | Kwssxt           | Proportionality factor for expende producing) substage weight compo    | d (thrust<br>nent;     |
|                              |                  | N. D.                                                                  | 1                      |

## INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units | Model Type    |
|----------|-----------------|--------------------------------|---------------|
| WMT      | W <sub>MT</sub> | Motor weight, total;           |               |
|          |                 | 1ь                             | MOTORW        |
| WMTNX    | w <sub>мт</sub> | Motor weight component, total  | non-expended; |
|          | M NX            | 1b                             | MOTORW        |

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# INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                        | Model Type    |
|----------|--------------------|-------------------------------------------------------|---------------|
| WMTX     | W <sub>MT</sub> .  | Motor weight component, total e                       | expended;     |
|          | X                  | 16                                                    | MOTORW        |
| WMTXI    | w <sub>MT</sub> XI | Motor weight component, expen-<br>thrust producing);  | ded, (non-    |
|          |                    | 1b                                                    | MOTORW        |
| WMTXT    | w <sub>MT</sub> xt | Motor weight component, expen producing);             | ded, (thrust  |
|          |                    | 16                                                    | MOTORW        |
| WNZ      | W <sub>N7</sub>    | Nozzle weight, total;                                 |               |
|          | IN Z               | 16                                                    | NOZZLEW       |
| WNZNX    | W <sub>N7</sub>    | Nozzle weight component, total                        | non-expended; |
|          | N <sup>2</sup> NX  | 16                                                    | NOZZLEW       |
| WNZX     | W <sub>N7</sub>    | Nozzle weight component, total                        | expended;     |
|          | <sup>N2</sup> X    | 16                                                    | NOZZLEW       |
| WNZXI    | w <sub>NZXI</sub>  | Nozzle weight component, expent<br>thrust producing); | nded, (non-   |
|          |                    | 1b                                                    | NOZZLEW       |
| WNZXT    | w <sub>NZ</sub> xt | Nozzle weight component, exper<br>producing);         | nded, (thrust |
|          |                    | lb                                                    | NOZZLEW       |
| WPPMT    | W <sub>DD</sub>    | Propellent weight;                                    |               |
|          | MT                 | lb                                                    | PROPELW       |

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### SUBSTAGE WEIGHT

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### OUTPUT DATA:

The following data is output from this model. It is available for use as inter-model input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                         | Description; Ext. (Int.) Units                                                        |
|----------|--------------------------------|---------------------------------------------------------------------------------------|
| KSSPMF   | K <sub>SS</sub> PMF            | Substage propellent mass fraction. Includes motor and nozzle;                         |
|          |                                | N. D. Eq. 7                                                                           |
| KSSSMF   | к <sub>sssmf</sub>             | Substage structure mass fraction. Includes motor and nozzle;                          |
|          |                                | N. D. Eq. 9                                                                           |
| KSSXMF   | <sup>K</sup> ss <sub>xmf</sub> | Substage expended mass fraction. Includes motor and nozzle;                           |
|          |                                | N. D. Eq. 8                                                                           |
| WPPSS    | w <sub>PP</sub> ss             | Weight of propellent associated with the substage;                                    |
|          |                                | lb Eq. l                                                                              |
| WSS      | wss                            | Total substage weight. Includes motor and nozzle;                                     |
|          |                                | lb Eq. 2                                                                              |
| WSSNX    | w <sub>ss<sub>nx</sub></sub>   | Total non-expended substage weight component.<br>Includes motor and nozzle;           |
|          |                                | lb Eq. 3                                                                              |
| WSSX     | w <sub>ss</sub> x              | Total expended substage weight component.<br>Includes motor and nozzle;               |
|          |                                | lb Eq. 4                                                                              |
| WSSXI    | <sup>w</sup> ss <sub>xi</sub>  | Expended (non-thrust producing) substage weight component. Includes motor and nozzle; |
|          |                                | lb Eq. 6                                                                              |
| WSSXT    | w <sub>ssxt</sub>              | Expended (thrust producing) substage weight component. Includes motor and nozzle;     |
|          |                                | lb Eq. 5                                                                              |

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| SUBSTAGE WATCHT | SSIGM | KSSPMP |        |
|-----------------|-------|--------|--------|
|                 | WSSW  | IXSSMI |        |
| SSWAL           | IXSSM | IXSSMI |        |
| SUBSTICH        | Ŧ     | Ŷ      | ÷      |
|                 | MSSM  | KNSSX  |        |
|                 | XNSSM | KNSSNX | KSSXMF |
|                 | SSM   | KWSS   | KSSSMF |

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والأفراض والمتعادة والمتعادما والمتعاولة فاستعادهم والمحاج وتقارحه تحاجم والمتعادية والمتعالي والمعالي والمروم

SUBSTAGE WEIGHT

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MODEL TYPE: TTERMG (Thrust TERMination Geometry)

MODEL NAME: TTGM1 (Motor Centerline spacing Distance)

#### DESCRIPTION:

TTGM1 (Thrust Termination Geometry Model number 1) evaluates the spacing distance required, forward of the fore motor closure, for the thrust termination mechanism.

#### PROCEDURE:

Prior to executing TTGMl, the model specified for the CASEG model type has determined the case outside diameter.

TTGM1 then uses the case diameter to evaluate the spacing distance required for the thrust termination mechanism.

The thrust termination spacing distance will later be used by the model specified for the SUBSTGG model type to determine the required intersubstage spacing distance.

#### EQUATIONS:

Thrust termination spacing length.

 $L_{TT_{MT}} = K_{LTTMT} C_1 D_{CS_O}$ 

#### INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

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| <b>NPUT</b> | DATA, | INTRA-MODEL (Cont.) | ): |
|-------------|-------|---------------------|----|
|             |       |                     | ,  |

| Mnemonic | Symbol             | Description; Ext. (Int.) Units           | Preset  |
|----------|--------------------|------------------------------------------|---------|
| CTTGl    | c,                 | Constant for LTTMT computation;<br>N. D. | 0.01    |
| KLTTMT   | <sup>K</sup> lttmt | Coefficient for LTTMT computation N. D.  | ı;<br>1 |

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description; Ext. (Int.) Units | Model Type |
|----------|-----------------|--------------------------------|------------|
| DCSO     | D <sub>CS</sub> | Outside case diameter;         |            |
|          | 0               | in                             | CASEG      |

### OUTPUT DATA:

The following data is output by this model. It is available for usage as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                                                                                                                         |
|----------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LTTMT    | L <sub>TT<sub>MT</sub></sub> | Thrust termination spacing length. Distance<br>measured along motor centerline forward of<br>the fore motor closure, required for the<br>thrust termination mechanism; |
|          |                              |                                                                                                                                                                        |

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Nominally, only those lines with an asterisk to the lcft of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

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MODEL TYPE: TTERMW (Thrust TERMination Weight)

MODEL NAME: TTWM1 (Parametric Scaling)

#### DESCRIPTION:

TTWM1 (Thrust Termination Weight Model number 1) utilizes a parametric scaling equation to determine the weight of the thrust termination mechanism for a solid rocket motor. See reference 8 for a description of the equation and parametric scaling rationale.

This model is applicable for performance parameters within the following limits (see Input Data, Inter-Model).

300 < PCHAVG < 1000 psia.</li>
40 < TBPPMT < 140 sec.</li>
3000 < WPPMT < 2,000,000 lb.</li>

#### PROCEDURE:

In addition to evaluating the thrust termination weight, the 'TTWM1 model determines the total weight breakdown in terms of expended and non-expended components.

These expended and non-expended component weights will later be used by the model specified for the MOTORW model type to determine the motor weights and mass fractions.

#### EQUATIONS:

Total thrust termination weight.

$$W_{TT} = K_{WTT} C_1 \left( \frac{W_{PP}}{P_{AVG} T_B} \right)^{C_2}$$
(1)

### TTERMW

### THRUST TERMINATION WEIGHT

TTWMI

### EQUATIONS (Cont.):

Total non-expended thrust termination weight component.

$$W_{TT_{NX}} = K_{WTTNX} W_{TT}$$
(2)

Total expended thrust termination weight component.

$$W_{TT_{X}} = 0$$
(3)

Expended (non-thrust producing) thrust termination weight.

$$W_{TT_{XI}} \approx 0$$
 (4)

Expended (thrust producing) thrust termination weight.

$$W_{TT_{XT}} = 0$$
(5)

### INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units                           | Preset        |
|----------|--------------------|----------------------------------------------------------|---------------|
| CTTWI    | c,                 | Scaling constant for WTT comput                          | ation;        |
|          | ^                  | N. D.                                                    | 170           |
| CTTW2    | c <sub>2</sub>     | Scaling constant for WTT comput                          | ation;        |
|          | -                  | N. D.                                                    | 1.45          |
| XWTT     | K <sub>WTT</sub>   | Proportionality factor for thrust weight;                | terminatior   |
|          |                    | N. D.                                                    | 1             |
| KWTTNX   | <sup>K</sup> wttnx | Proportionality factor for non-ex<br>termination weight; | pended thrust |
|          |                    | N. D.                                                    | 1             |

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# INPUT DATA, INTER-MODEL:

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This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                                   | Description; Ext. (Int.) Units    | Model Type |
|----------|------------------------------------------|-----------------------------------|------------|
| PCHAVG   | PAVG                                     | Average chamber pressure;<br>psia | IBGAS      |
| TBPPMT   | т <sub>в</sub>                           | Propellent burn time;<br>sec      | IBPERF     |
| WPPMT    | <sup>₩</sup> <sub>PP</sub> <sub>MT</sub> | Propellent weight;<br>lb          | PROPE      |

### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                               |                             |
|----------|------------------------------|--------------------------------------------------------------|-----------------------------|
| WTT      | w <sub>rr</sub>              | Total thrust termination subs                                | ystem weight;               |
|          | • •                          | 1b                                                           | Eq. 1                       |
| WTTNX    | w <sub>TT<sub>NX</sub></sub> | Total non-expended thrust ter<br>subsystem weight component; | mination                    |
|          |                              | 16                                                           | Eq. 2                       |
| WTTX     | w <sub>TT</sub> x            | Total expended thrust termin weight component;               | ation subsystem             |
|          |                              | 15                                                           | Eq. 3                       |
| WTTXI    | w <sub>tt</sub> xi           | Expended (non-thrust produci<br>termination subsystem weigh  | ing) thrust<br>t component; |
|          |                              | 1b                                                           | Eq. 4                       |
| WTTXT    | w <sub>TT</sub> xt           | Expended (thrust producing) (<br>termination subsystem weigh | thrust<br>t component;      |
|          |                              | 1b                                                           | Eq. 5                       |

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| Т     | TERMW                                  | THRUST TERMINATION WEIGHT | TTWMI |             |
|-------|----------------------------------------|---------------------------|-------|-------------|
|       |                                        |                           |       | Ũ           |
|       |                                        | TGHT                      |       |             |
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TVCG

TVGM1

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MODEL TYPE: TVCG (Thrust Vector Control Geometry)

MODEL NAME: TVGM1 (Gimballed nozzle)

#### DESCRIPTION:

TVGM1 (Thrust Vector Geometry Model number 1) evaluates the geometry required for the simulation of a gimballed nozzle. The gimbal point is located on the nozzle centerline and may be forward (see figure 1) or aft (see figure 2) of the nozzle throat plane.

#### PROCEDURE:

Prior to entering TVGM1, the model specified for the NOZZLEG model type has evaluated the nozzle geometry.

TVGM1 then uses this nozzle geometry to determine the gimballed nozzle envelope geometry.

EQUATIONS:

Gimballed nozzle length ratio. (Positive value if gimbal point is aft of nozzle throat plane.)

$$R_{LGB} = K_{RLGB1} + \frac{K_{RLGB2}}{\sqrt{\epsilon_{NZ}}}$$
(1)

Distance from nozzle throat plane to nozzle gimbal point. (Positive sense from nozzle throat plane towards nozzle exit plane.) (Figs. 1, 2)

$$L_{GB_{TH}} = R_{LGB} L_{NZ_{DV}}$$
(2)

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### THRUST VECTOR CONTROL GEOMETRY

### EQUATIONS (Cont.):

Distance from nozzle gimbal point to nozzle exit plane. (Figs. 1, 2)

$$L_{GB_{EXT}} = L_{IIZ_{DV}} - L_{GB_{TH}}$$
(3)

Nozzle gimbal envelope half angle for zero gimbal angle. (Figs. 1, 2)

$$\theta_{GB_2} = \arctan\left(\frac{D_{NZ}_{EXT}}{2L_{GB}_{EXT}}\right)$$
 (4)

Nozzle gimbal envelope half angle. (Figs. 1, 2)

. ...

$${}^{\theta}\mathbf{GB}_{1} = {}^{\theta}\mathbf{GB}_{2} + {}^{\theta}\mathbf{GB}$$
<sup>(5)</sup>

Distance from nozzle gimbal point to edge of nozzle exit cone. (Figs. 1, 2)

$${}^{L}_{GB}{}_{EDGE} \sqrt[2]{\left(\frac{D_{NZ}}{2}\right)^{2}} + {}^{L}_{GB}{}_{EXT}$$
(6)

Diameter of gimballed nozzle envelope. (Figs. 1, 2)

$${}^{D}_{GB}{}^{=2} {}^{L}_{GB}{}^{e}_{EDGE} {}^{sin} \left( {}^{\theta}_{GB}{}^{h}_{1} \right)$$
(7)



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FORWARD NOZZLE THROAT PLANE GIMBAL POINT LGBTH AFT LNZDV θGB2. GIMBAL LGBEXT ENVELOPE <sup>θ</sup>GB<sub>1</sub>-<sup>θ</sup>GĘ <sup>₿</sup>GB NOZZLE EXIT PLANE Ë XIT CONE EDGE -DNZEXT-DGBENV





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### DIPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol              | Description; Ext. (Int.) Units Prese         |
|----------|---------------------|----------------------------------------------|
| KR LGB1  | <sup>K</sup> rlgbi  | Bias for RLGB computation;<br>N. D. 0        |
| KRLGB2   | <sup>K</sup> R LGB2 | Coefficient for RLGB_computation;<br>N. D. 0 |
| GBANGLE  | <sup>θ</sup> GB     | Nozzle gimbal angle;<br>deg Figs. 1, 2 0     |

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol            | Description; Ext. (Int.) Units   | Model Type     |  |
|----------|-------------------|----------------------------------|----------------|--|
| DNZEXT   | D <sub>N7</sub>   | Nozzle esit diameter;            |                |  |
|          | <sup>N2</sup> EXT | in Figs. 1, 2                    | NOZZLEG        |  |
| LNZDV    | LNZ               | Divergent nozzle section length; |                |  |
|          | DV                | in Figs. 1, 2                    | NOZZLEG        |  |
| RAEXTTH  | ε <sub>N7</sub>   | Nozzle expansion ratio at nozz   | le exit plane; |  |
|          |                   | N. D.                            | NOZZLEG        |  |

TVCG

### THRUST VECTOR CONTROL GEOMETRY

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## OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                         | Descriptio                                                     | on; Ext. (Int.) Units                                                                     |                                               |  |
|----------|--------------------------------|----------------------------------------------------------------|-------------------------------------------------------------------------------------------|-----------------------------------------------|--|
| DGBENV   | DGB                            | Diameter of gimballed nozzle envelope;                         |                                                                                           |                                               |  |
|          | ENV                            | in                                                             | Figs. 1, 2                                                                                | Eq. 7                                         |  |
| GBENHA   | <sup><i>θ</i></sup> GВ.        | Nozzle gin                                                     | nbal envelope half an                                                                     | gle;                                          |  |
|          | 1                              | deg                                                            | Figs. 1, 2                                                                                | Eq. 5                                         |  |
| GBENHAZ  | $\theta_{GB_2}$                | Nozzle gimbal envelope half angle for zero gimbal angle;       |                                                                                           |                                               |  |
|          |                                | deg                                                            | Figs. 1, 2                                                                                | Eq. 4                                         |  |
| LGBEDGE  | L <sub>GB</sub> EDGE           | Distance from nozzle gimbal point to edge of nozzle exit cone; |                                                                                           |                                               |  |
|          |                                | in                                                             | Figs. 1, 2                                                                                | Eq. 6                                         |  |
| LGBEXT   | <sup>L</sup> GB <sub>EXT</sub> | Distance from nozzle gimbal point to nozzle exit plane;        |                                                                                           |                                               |  |
|          |                                | in                                                             | Figs. 1, 2                                                                                | Eq. 3                                         |  |
| LGBTH    | L <sub>GB</sub> TH             | Distance :<br>gimbal po<br>positive s<br>towards n             | from nozzle throat pl<br>int. Measured on no<br>ense from nozzle thr<br>ozzle exit plane; | ane to nozzle<br>zzle centerline<br>oat plane |  |
|          |                                | in                                                             | Figs. 1, 2                                                                                | Eq. 2                                         |  |
| RLGB     | RLGB                           | Gimballed<br>LGBTH to<br>gimbal po                             | l nozzle length ratio.<br>LNZDV. Positve si<br>int is aft of nozzle th                    | Ratio of<br>gn indicates<br>roat plane;       |  |
|          |                                | N. D.                                                          | Figs. 1, 2                                                                                | Eq. l                                         |  |
|          |                                |                                                                |                                                                                           |                                               |  |

| THRUST VECTOR CONTROL GEOMETRY                 | TVGMI                          |
|------------------------------------------------|--------------------------------|
| THRUST VECTOR CONTROL GEOMETHY<br>KRLGB2 LGBTH |                                |
| TVCMI<br>KRLGBL<br>RLGB                        |                                |
| 50 T *                                         |                                |
| GBENHAZ<br>LGBENT                              |                                |
| <b>GBENHA</b><br>DGBENV                        |                                |
| GBANGLE<br>LGBEDGE                             |                                |
|                                                | THRUST VECTOR CONTROL GEOMETRY |

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TVCW

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MODEL TYPE: TVCW (Thrust Vector Control Weight

MODEL NAME: TVWM1 (Gimballed nozzle or integral omnivector, statistical scaling)

#### DESCRIPTION:

TVWMI (Thrust Vector control Weight Model number 1) utilizes a statistically derived equation to determine the weight of a gimballed nozzle thrust vector control system. In addition, a nozzle weight factor is determined for assessing the required nozzle weight penalty.

(See REMARKS for the simulation of an integral omnivector TVC system.) The subsystems considered within the TVC system weight are:

Actuators Hydraulic pressurization system Plumbing Valves Roll control system

It should be noted that since the TVC weight equation is based upon a purely statistical analysis, the model is intended for usage only in total sizing and optimization studies. This model cannot be used for subsystem trade off studies. See reference 8 for a description of the equations and statistical scaling rationale.

This model is applicable for performance parameters within the following limits,

# 15 < NZHA < 30 deg 300 < PCHAVG < 1000 PSIA 5 < RAEXTTH < 75 30 < TBPPMT < 140 sec

500 < WPPMT < 2,000,000 lbs

where NZHA and RAEXTTH are associated with the NOZZLEG model type, PCHAVG is associated with the IBGAS model type, TBPPMT is associated with the IBPERF model type, and WPPMT is associated with the PROPELW model type.

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#### TVWM1

#### **PROCEDURE:**

This is a two entrance model. Up on the first entrance to TVWM1, the nozzle weight penalty factor is evaluated. The model specified for the NOZZLEW model type is then executed to determine the nozzle weight.

TVWM1 is then entered for the second time, the TVC system weight is evaluated as a function of the nozzle weight, and the TVC system weight breakdown is determined.

#### EQUATIONS (FIRST ENTRANCE):

TVC nozzle weight penalty factor.

$$K_{TV_{NZ}} = \frac{C_1 K_{TVNZ1}}{(\epsilon_{NZ})^2} + K_{TVNZ2}$$
(1)

EQUATIONS (SECOND ENTRANCE):

Total thrust vector control weight.

$$W_{TV} = K_{WTV} C_3 (W_{NZ})^{C_4}$$
(2)

Total non-expended thrust vector control weight component.

$$W_{TV_{NX}} = W_{TV}$$
(3)

Total expended thrust vector control weight component.

$$W_{T}V_{X} = 0.$$
 (4)

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### EQUATIONS (SECOND ENTRANCE) (Cont.):

Expended (non-thrust producing) thrust vector control weight component.

$$W_{T}V_{XI} = 0.$$
 (5)

Expended (thrust producing ) thrus: vector control weight component.

$$W_{TV_{XT}} = 0.$$
 (6)

### INPUT DATA, INTRA-MODEL:

The following data is input directly to this model by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol             | Description; Ext. (Int.) Units           | Preset        |
|----------|--------------------|------------------------------------------|---------------|
| CTVWI    | c <sub>1</sub>     | Constant for KTVNZ computation N. D.     | ;<br>2, 1     |
| CTVW2    | c2                 | Constant for KTVNZ computation N.D.      | ;<br>0.116    |
| CTVW3    | C3                 | Constant for WNZ computation;<br>N. D.   | 2.7           |
| CTVW4    | C <sub>4</sub>     | Constant for WNZ computation;<br>N. D.   | 0.60 <b>4</b> |
| KTVNZI   | <sup>K</sup> TVNZ1 | Coefficient for KTVNZ computati<br>N. D. | on;<br>1      |
| KTVNZ2   | K <sub>TVNZ2</sub> | Coefficient for KTVNZ computati<br>N. D. | on;<br>0      |
| KWTV     | ĸ <sub>wtv</sub>   | Coefficient for WTV computation N. D.    | ;<br>1        |

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

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| INPUT | DATA, | INTER-MODEL: |
|-------|-------|--------------|
|       |       |              |

| Mnemonic | Symbol          | Description; Ext. (Int.) Units                         | Model Type               |
|----------|-----------------|--------------------------------------------------------|--------------------------|
| RAEXTTH  | <sup>ϵ</sup> NZ | Nozzle expansion ratio at nozzl                        | e exit plane;<br>NOZZLEG |
| WNZ      | w <sub>NZ</sub> | Total nozzle weight. Includes due to TVC requirements; | weight penalty           |
|          |                 | 1Ъ                                                     | NOZZLEW                  |

### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol                        | Description; Ext. (Int.) Units                                                               |                                |
|----------|-------------------------------|----------------------------------------------------------------------------------------------|--------------------------------|
| KTVNZ    | <sup>K</sup> TV <sub>NZ</sub> | Coefficient used by the nozzle<br>to assess a nozzle weight pena<br>TVC system requirements; | weight model<br>lty to satisfy |
|          |                               | N. D.                                                                                        | Eq. l                          |
| WTV      | w <sub>TV</sub>               | Total thrust vector control we                                                               | ight;                          |
|          |                               | lb                                                                                           | Eq. 2                          |
| WTVNX    | <sup>w</sup> tv <sub>nx</sub> | Total non-expended thrust vec<br>weight component;                                           | tor control                    |
|          |                               | 1b                                                                                           | Eq. 3                          |
| WTVX     | w <sub>T</sub> v <sub>x</sub> | Total expended thrust vector c component;                                                    | control weight                 |
|          |                               | 1Ъ                                                                                           | Eq. 4                          |
| WTVXI    | w <sub>tv<sub>xi</sub></sub>  | Expended (non-thrust producin<br>vector control weight compone                               | g) thrust                      |
|          |                               | 16                                                                                           | Eq. 5                          |
| WTVXT    | w <sub>tv<sub>xt</sub></sub>  | Expended (thrust producing) th<br>control weight component;                                  | rust vector                    |
|          |                               | 16                                                                                           | Eq. 6                          |
|          |                               |                                                                                              |                                |

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TVCW

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### THRUST VECTOR CONTROL WEIGHT

TVWM1

### REMARKS:

This model is applicable for simulating an integral omnivector TVC system by inputting the following coefficients for the nozzle weight penalty factor.

KTVNZ1 = 0

KTVN7.2 = 1.05



PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| THRUST VECTOR CONTROL WEIGHT<br>WIVXT |
|---------------------------------------|
| TVWA<br>WTVXI<br>CTVW4<br>KWTV        |
| TVCW<br>* 1<br>* 3                    |
| WTVX<br>CTVH3<br>KTVNZ2               |
| WTVNX<br>CTVW2<br>KTVNZ1              |
| WTV<br>CTVW1<br>KTVNZ                 |

TVCW

TVWMI

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VEHG

VEHICLE GEOMETRY

VHGMI

360.1

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MODEL TYPE: VEHG (VEHicle Geometry)

MODEL NAME:

VHCM1 (Single Propulsion System and Payload Section)

#### DESCRIPTION:

VHGM1 (VeHicle Geometry Model number  $\underline{1}$ ) evaluates the geometry for a vehicle comprised of a single propulsion system and a single payload section. See figure 1 for an illustration of the geometry for a typical vehicle comprised of three stages, a payload and a shroud.

#### PROCEDURE:

Prior to entering VHGM1 all of the major vehicle subsystems have been sized and the models specified for the PROSYSG and PAYSECG model types have determined the pertinent propulsion system and payload section geometry.

VHGM1 is then executed and the vehicle geometry evaluated.

After VHGM1 is executed, the vehicle weight breakdown is evaluated by the model specified for the VEHW model type. The vehicle has then been completely sized. However, another pass will be made through all of the models to evaluate length and weight fractions dependent upon total vehicle geometry and weight quantities.

#### EQUATIONS:

Total vehicle length. Figure 1.

 $L_{VH} = L_{PS} + L_{PL}$ 

(1)

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VHGM1

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Fig. 360.1-1 Vehicle Geometry

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### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol | Description; Ext. | (Int.) | ) Units | Preset |
|----------|--------|-------------------|--------|---------|--------|
|          |        |                   | 1      |         |        |

None

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol          | Description                   | h; Ext. (Int.) Units | Model Type |  |
|----------|-----------------|-------------------------------|----------------------|------------|--|
| LPL      | L <sub>PI</sub> | Total payload section length; |                      |            |  |
|          |                 | in                            | Fig. 1               | PAYSECG    |  |
| LPS      | L <sub>PS</sub> | Total propu                   | 1;                   |            |  |
|          |                 | in                            | Fig. 1               | PROSYSG    |  |

### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

| Mnemonic | Symbol          | Description | n; Ext. (Int.) Units |       |
|----------|-----------------|-------------|----------------------|-------|
| LVH      | L <sub>VH</sub> | Total vehic | le length;           |       |
|          | ¥ • •           | in          | Fig. 1               | Eq. l |

PRINT BLOCK KEY:

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Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

VEHG VHGMI VEHICLE GEOMETRY \*1

LVH

VEHG

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VHGMI

VEHW

VHWMI

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MODEL TYPE: VEHW (VEHicle Weight)

MODEL NAME:

VHWM1 (Single Propulsion system and payload section.)

#### DESCRIPTION:

VHWM1 (VeHicle Weight Model number 1) is a weight synthesis model which evaluates the vehicle weight breakdown and mass fractions for a vehicle having a single propulsion system and a single payload section. The vehicle weight is comprised of the following subsystems:

Propulsion System

Payload Section

#### PROCEDURE:

Prior to entering VHWM1, the models specified for the PROSYSW and PAYSECW model type have evaluated the propulsion system and payload section weights. In addition to evaluating subcomponent weights peculiar to their particular requirements, they have defined a set of component weights in terms of expended or non-expended attributes.

VHWM1 then uses these expended and non-expended, propulsion system and payload section, weight components to determine the vehicle weight breakdown. In addition, the vehicle growth factor is evaluated.

After VHWMl is executed, the vehicle has been completely sized. However, another pass will be made through all of the models to evaluate subsystem weight fractions dependent upon the vehicle weight breakdown.

#### EQUATIONS:

Total vehicle weight.

 $W_{VH} = K_{WVH} (W_{PS} + W_{PL})$ 

(1)

#### VEHW

### VEHICLE WEIGHT

VHWM1

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### EQUATIONS (Cont.):

Total non-expended vehicle weight component.

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$$W_{VH_{NX}} = K_{WVHNX} (W_{PS_{NX}} + W_{PL_{NX}})$$
(2)

Total expended vehicle weight component.

$$w_{VH_{X}} = \kappa_{WVHX} \left( w_{PS_{X}} + w_{PL_{X}} \right)$$
(3)

Expended (non-thrust producing) vehicle weight component.

$$W_{VH_{XI}} = K_{WVHXI} \left( W_{PS_{XI}} + W_{PL_{XI}} \right)$$
(4)

Expended (thrust producing) vehicle weight component.

$$\mathbf{w}_{\mathbf{VH}_{\mathbf{X1}}} = \mathbf{K}_{\mathbf{W}\mathbf{V}\mathbf{H}\mathbf{XT}} \left( \mathbf{w}_{\mathbf{PS}_{\mathbf{XT}}} + \mathbf{w}_{\mathbf{PL}_{\mathbf{XT}}} \right)$$
(5)

Total propellent weight associated with the vehicle.

$$W_{PP} = W_{PP}$$
(6)

Vehicle growth factor.

$$K_{\rm VH_{\rm GF}} = \frac{W_{\rm VH}}{W_{\rm PA}}$$
(7)

### INPUT DATA, INTRA-MODEL:

The following data is input to this model directly by the program user. If a value is not input, the preset value is used.

| Mnemonic | Symbol           | Description; Ext. (Int.) Units   | Preset |
|----------|------------------|----------------------------------|--------|
| кшлн     | к <sub>wvн</sub> | Coefficient for WVH computation; |        |
|          |                  | N. D.                            | 1      |

#### Mnemonic Symbol Description; Ext. (Int.) Units Preset κ<sub>wvhnx</sub> Coefficient for WVHNX computation; KWVHNX N. D. 1 ĸ<sub>wvhx</sub> KWVHX Coefficient for WVHX computation; N.D. 1 KWANI Coefficient for WVHXI computation; KWVHXI N. D. 1 KWVHXT KWVHXT Coefficient for WVHXT computation; N. D. 1

### INPUT DATA, INTRA-MODEL (Cont.):

### INPUT DATA, INTER-MODEL:

This model requires as input certain data which is usually output from a model of the specified model type. If the user has not specified such a source for this data, then it must be input directly with the intra-model input.

| Mnemonic | Symbol                       | Description; Ext. (Int. ) Units                      | Model Type |  |
|----------|------------------------------|------------------------------------------------------|------------|--|
| WPA      | <sup>W</sup> ₽A              | Total payload weight;                                |            |  |
|          |                              | 16                                                   | PAYLODW    |  |
| WPL      | WPL                          | Total payload section weight;                        |            |  |
|          |                              | <sup>-</sup> ს                                       | PAYSECW    |  |
| WPLNX    | W <sub>PL<sub>NX</sub></sub> | Total non-expended payload section weight component; |            |  |
|          |                              | 15                                                   | PAYSECW    |  |
| WPLX     | w <sub>PL</sub> X            | Total expended payload section weight component;     |            |  |
|          |                              | 16                                                   | PAYSECW    |  |

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### VEHICLE WEIGHT

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# INPUT DATA, INTER-MODEL (Cont.):

| Mnemonic                             | Symbol                       | Description; Ext. (Int.) Units                                    | Model Type                                                 |  |
|--------------------------------------|------------------------------|-------------------------------------------------------------------|------------------------------------------------------------|--|
| WPLXI                                | w <sub>pl<sub>XI</sub></sub> | Expended (non-thrust producing) payload section weight component; |                                                            |  |
|                                      |                              | ІЪ                                                                | PAYSECW                                                    |  |
| WPLXT                                | WPLXT                        | Expended (thrust producing) payload section weight component;     |                                                            |  |
|                                      |                              | 1ъ                                                                | PAYSECW                                                    |  |
| WPPPS                                | W <sub>PP</sub> PS           | Weight of propellent associated propulsion system;                | with the                                                   |  |
|                                      |                              | ib                                                                | PROSYSW                                                    |  |
| WPS                                  | W <sub>PS</sub>              | Total propulsion system weight;                                   |                                                            |  |
|                                      | 10                           | 1ъ                                                                | PROSYSW                                                    |  |
| WPSNX                                | w <sub>psnx</sub>            | Total non-expended propulsion system weight component;            |                                                            |  |
|                                      |                              | ІЪ                                                                | PROSYSW                                                    |  |
| WPSX                                 | w <sub>PS</sub> x            | Total expended propulsion system weight component;                |                                                            |  |
|                                      |                              | 1ь                                                                | PROSYSW                                                    |  |
| WPSXI WPSXI Expended<br>SXI system w |                              | Expended (non-thrust producing system weight component;           | led (non-thrust producing) propulsion<br>weight component; |  |
|                                      |                              | 1ъ                                                                | PROSYSW                                                    |  |
| WPSXT                                | w <sub>PS</sub> xr           | Expended (thrust producing) propulsion system weight component;   |                                                            |  |
|                                      |                              | 1ь                                                                | PROSYSW                                                    |  |

### OUTPUT DATA:

The following data is output from this model. It is available for use as intermodel input to other models and to print, plot, and optimization routines.

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VEHW

VEHICLE WEIGHT

VHWM1

# OUTPUT DATA (Cont.):

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| Mnemonic | Symbol                       | Description; Ext. (Int.) Units                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                 |           |
|----------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------|
| KVHGF    | к <sub>vн<sub>gf</sub></sub> | Vehicle growth factor. Ratio of tota<br>weight to payload weight;<br>N. D.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | al vehic<br>Eo. | cle<br>7  |
| WPPVH    | w <sub>ppvh</sub>            | Total propellent weight associated with the vehicle;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                 |           |
|          |                              | 1b                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Eq.             | 6         |
| WVH      | w <sub>vH</sub>              | Total vehicle weight;<br>lb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Eq.             | 1         |
| WVHNX    | w <sub>vh</sub> nx           | Total non-expended vehicle weight of the set | compon<br>Eq.   | ent;<br>2 |
| WVHX     | w <sub>vh</sub> x            | Total expended vehicle weight comp<br>lb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | oonent;<br>Eq.  | 3         |
| WVHXI    | w <sub>vh</sub> xi           | Expended (non-thrust producing) vehicle weight component;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                 |           |
|          |                              | lb                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Eq.             | 4         |
| WVHXT    | w <sub>vh</sub> xt           | Expended (thrust producing) vehicle weight component;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                 |           |
|          |                              | 1ь                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Eq.             | 5         |

370.1-5

PRINT BLOCK KEY:

370.1-6

Nominally, only those lines with an asterisk to the left of the line number will be printed. By input, any of the lines given below may be printed or suppressed (see the section on output models for the details).

| WEIGHT  | HVYTW | KVHGP   |
|---------|-------|---------|
| VEHICLE | TXHVW | TXHVWX  |
| NHWA    | IXHVH | IXHAMX  |
| VEHN    | Ŧ     | ¢≀<br>* |
|         | XHVW  | KWVHX   |
|         | XNHVW | KWANNX  |
| ļ       | H>M   | HVW     |

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