PRELIMINARY STUDY OF COMPUTER MODELING OF THE DYNAMIC FUEL CONDITIONS IN WEAPON SYSTEM VULNERABILITY ANALYSIS

FINAL REPORT

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FOREWORD

This report summarizes the results of a study performed by Caywood-Schiller Division of A.T. Kearney, Inc. under U.S. Air Force Contract F33615-73-C-2078. The work was conducted between 1 July 1973 and 31 March 1974, under the direction of the Air Force Aero Propulsion Laboratory, with Mr. G. W. Gande (AFAPL/SFH) acting as Project Engineer.

Work was sponsored by JTCG/AS as part of the 3-year TEAS (Test and Evaluation, Aircraft Survivability) program. The TEAS program was funded by DDR&E/ODDT&E. The effort was conducted under the direction of the JTCG/AS Vulnerability Assessment Subgroup, as part of TEAS element 5.1.6.6, Development of Models for Assessment of the Vulnerability of Aircraft Fuel Systems.

A study was conducted to develop a dynamic model of the vulnerability of an aircraft fuel system to threats posed by hostile weapons. Improvement was achieved in treating fuel system vulnerability. Further development of the fuel system model is recommended.

DISCLAIMER

Estimates in this report are not to be construed as an official position of any of the Services or of the Joint AMC/NMC/AFLC/AFSC Commanders.

NOTE

Information and data contained in this document are based on reports available at the time of preparation, and the results may be subject to change.

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### Abstract

See reverse side.
Air Force Aero Propulsion Laboratory


This report presents the results of a study to develop a dynamic model of the vulnerability of an aircraft fuel system to the threats posed by hostile weapons. A Monte Carlo model was developed to calculate the probability of hit along segments of a specified flight profile at each point where a specified weapon system could pose a threat to the fuel system. An Air Force developed computer model (Well-Stirred Fuel Tank Model) is used to compute fuel state in each fuel tank under study at increments along the flight path. These are used as inputs to the Monte Carlo model.

Given that a hit takes place, the probable trajectories (liquid-air, liquid-liquid, and air-air) are calculated, and the probabilities of lethal outcomes (explosion, internal fire, external fire, leak) are computed. The model ranks the most likely events, and a hazard index is generated which portrays the most important threats to the fuel system on the specified flight path.

The resulting model gives an improved measure of the impact of fuel state on the vulnerability of a fuel system on aircraft vulnerability. It does not incorporate consideration of the effects of fuel slosh, vibration, or vent geometry. Further refinement and development is recommended.
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INTRODUCTION

PURPOSE:

This report presents the results of an exploratory study to develop a dynamic representation of the vulnerability of an aircraft fuel system to hostile threats.

BACKGROUND

Some analytical studies use gross aggregation in representing the vulnerability of an aircraft fuel system. Typically, a fixed percentage of fuel is assumed, empty and external fuel tanks ignored, and the wide variation in probability of a reaction within the various kinds of fuel tanks is compressed to a single probability of fire given a hit. Also, distinction in hazard between liquid fuel and tank ullages, influence of tank wall and liquid temperatures on the ullage composition, tank overpressure caused by internal fires, and effect of venting are largely ignored. Analyses conducted under these simplifying assumptions are valid, and study results are reliable and important; but more precise representation is required for test planning, fuel system design, and detailed examination of the fuel system vulnerability area. The greater accuracy of a dynamic fuel system vulnerability model will be beneficial in future aircraft development studies because delineation of specific vulnerabilities and more precise measurement of previously identified vulnerability will be possible.

In performing this background study, the WSFT (Well-Stirred Fuel Tank) computer program, developed for the Air Force by Dynamic Science, Inc., was considered the most accurate representation of internal fuel state. The WSFT program does not consider the hostile threats; therefore, a vulnerability model was constructed to combine the WSFT program fuel states with anticipated threats.

WSFT PROGRAM

GENERAL

The WSFT program, which is an integral part of the fuel vulnerability model, was developed under a prior AFAPL study\(^1\). The program determines the fuel-to-air ratio in the ullage space of a fuel tank as a function of time for a particular input mission profile and describes the state of fuel and vapor space in fuel tanks, accounting for mass and energy transport due to:

1. fuel evaporation
2. venting effects
3. heat transfer between ullage, tank walls, and liquids
4. outgassing as dissolved air is removed from the liquid as the aircraft climbs.

The program does not consider interaction of a fuel tank and an ignition source, such as in an incendiary projectile. The fuel vulnerability model developed in this study combined the interaction of threat and fuel tank.

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INPUTS REQUIRED

Basic inputs required by the WSFT program are:

1. Altitude profile of aircraft
2. Liquid temperature history
3. Skin and structure temperature
4. Vapor pressure relations of liquid fuels
5. Ullage volume and exposed surface area schedule
6. Vent size
7. Internal heat transfer coefficients between ullage and tank structure.

Standard FORTRAN IV NAMELIST is used for all input data to the WSFT program. The variable list and definitions for the input data under the NAMELIST name DATA are presented in Table 1. An example of a set of inputs to the program is provided in Figure 1.

OUTPUT

The normal output of the WSFT program is a report for each print time throughout the mission profile. Each report describes the state of the fuel and vapor space at that particular time in terms of air and fuel partial pressures, fuel vapor pressure, fuel-to-air ratio, and mass and mass flux of fuel vapor that has been vented, evaporated, outgassed, or condensed. In addition to these parameters, the altitude, speed, and amount of fuel used are printed out. An example of the printout of this report is shown in Figure 2. The WSFT output parameters used for the vulnerability model were the fuel-to-air ratio and the amount of fuel used as a function of time. Tables of fuel-to-air ratios and the percent of fuel remaining in each tank as a function of time were generated. These tables were stored on magnetic tape and used as input to the fuel vulnerability model.

INHERENT ASSUMPTIONS AND LIMITATIONS

The WSFT program assumes a homogenous mixture of fuel vapor and air. The mixing of air and vapor is assumed to occur rapidly with no appreciable difference in fuel-to-air ratio within the ullage volume. The program is particularly applicable for shallow tanks or tanks where the ratio of ullage volume to liquid fuel surface is small. It was considered beyond the scope of this study to develop a new model which would incorporate the concept of a stratified ullage space of different fuel-to-air ratios.

The effects of vibration and slosh on the fuel-to-air ratio are not included in the WSFT program. One of the inputs required is the liquid temperature history of the fuel in the tank. This information must be provided by the user; it is important because aerodynamic heating or cooling may have a significant influence on the temperature of the fuel and heat sources within the aircraft. These factors should be considered in the development of more sophisticated models for determining fuel-to-air ratios.
Table 1. Variable Names and Definitions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDATA</td>
<td>Ident of data block</td>
<td></td>
</tr>
<tr>
<td>RGAS</td>
<td>Universal gas constant</td>
<td>ft-lbm/lb-mole °R</td>
</tr>
<tr>
<td>EMWA</td>
<td>Mass of air</td>
<td>lbm/lbm-mole</td>
</tr>
<tr>
<td>EMWF</td>
<td>Mass of fuel</td>
<td>lbm/lbm-mole</td>
</tr>
<tr>
<td>CPA</td>
<td>Specific heat of air</td>
<td>BTU/lbm °R</td>
</tr>
<tr>
<td>CPF</td>
<td>Specific heat of fuel</td>
<td>BTU/lbm °R</td>
</tr>
<tr>
<td>TA</td>
<td>Temperature of the ullage</td>
<td>°F</td>
</tr>
<tr>
<td>HJ(J)</td>
<td>H&lt;sub&gt;J&lt;/sub&gt; heat transfer film coefficient</td>
<td>BTU/ft&lt;sup&gt;2&lt;/sup&gt; hr °R</td>
</tr>
<tr>
<td></td>
<td>J=1, to fuel surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>J=2, to side of tank</td>
<td></td>
</tr>
<tr>
<td></td>
<td>J=3, to top of tank</td>
<td></td>
</tr>
<tr>
<td>ZOG</td>
<td>1 Set equal to one</td>
<td>None</td>
</tr>
<tr>
<td>DV</td>
<td>Diffusion coefficient</td>
<td>ft&lt;sup&gt;2&lt;/sup&gt;/hr</td>
</tr>
<tr>
<td>CDELT A</td>
<td>Characteristic length for evaporation</td>
<td>ft</td>
</tr>
<tr>
<td>KTANK</td>
<td>0 Set equal to zero</td>
<td>None</td>
</tr>
<tr>
<td>GALO</td>
<td>Initial volume of fuel</td>
<td>gal</td>
</tr>
<tr>
<td>BETA</td>
<td>Bunsen coefficient</td>
<td></td>
</tr>
<tr>
<td>CON1</td>
<td>Outgassing coefficient</td>
<td>hr&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>CON2</td>
<td>Solution coefficient</td>
<td>hr&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>TVENT</td>
<td>If TVENT=0, incoming air will be calculated from altitude and Mach number</td>
<td></td>
</tr>
<tr>
<td></td>
<td>schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>If TVENT≠0, all incoming air will have temperature=TVENT</td>
<td></td>
</tr>
<tr>
<td>TF(1,1)</td>
<td>Table of time values corresponding to fuel temperature table</td>
<td>hrs</td>
</tr>
</tbody>
</table>
Table 1. Variable Names and Definitions (Continued).

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>TF(1,2)</td>
<td>Table of fuel temperatures at times corresponding to TF(1,1)</td>
<td>°F</td>
</tr>
<tr>
<td>TSIDE(1,1)</td>
<td>Table of time values corresponding to tank side temperature table</td>
<td>hrs</td>
</tr>
<tr>
<td>TSIDE(1,2)</td>
<td>Table of tank side temperatures at times corresponding to TSIDE(1,1)</td>
<td>°F</td>
</tr>
<tr>
<td>TTOP(1,1)</td>
<td>Same as TSIDE except applies to top of the tank</td>
<td></td>
</tr>
<tr>
<td>TTOP(1,2)</td>
<td>Table of tank side temperature at times corresponding to TTOP(1,1)</td>
<td></td>
</tr>
<tr>
<td>ALT(1,1)</td>
<td>Table of times corresponding to altitude schedule table</td>
<td>hrs</td>
</tr>
<tr>
<td>ALT(1,2)</td>
<td>Table of altitudes at times corresponding to ALT(1,1)</td>
<td>KFT</td>
</tr>
<tr>
<td>GALDOT(1,1)</td>
<td>Table of time values corresponding to fuel usage</td>
<td>hrs</td>
</tr>
<tr>
<td>GALDOT(1,2)</td>
<td>Table of fuel usage at times corresponding to GALDOT(1,1)</td>
<td>gal/hr</td>
</tr>
<tr>
<td>EMINF(1,1)</td>
<td>Table of time values corresponding to flight Mach number schedule</td>
<td>hrs</td>
</tr>
<tr>
<td>EMINF(1,2)</td>
<td>Table of flight Mach numbers at times corresponding to EMINF(1,1)</td>
<td>None</td>
</tr>
<tr>
<td>PVAP(1,1)</td>
<td>Table of temperatures corresponding to fuel vapor pressure</td>
<td>°F</td>
</tr>
<tr>
<td>PVAP(1,2)</td>
<td>Table of fuel vapor pressure corresponding to PVAP(1,1)</td>
<td>psia</td>
</tr>
<tr>
<td>TO</td>
<td>Initial time for start of integration</td>
<td>hrs</td>
</tr>
<tr>
<td>TMAX</td>
<td>Final integration time</td>
<td>hrs</td>
</tr>
<tr>
<td>DT</td>
<td>Time step for integration</td>
<td>hrs</td>
</tr>
<tr>
<td>DTPRNT</td>
<td>Print time interval</td>
<td>hrs</td>
</tr>
<tr>
<td>AV</td>
<td>Area of the vent</td>
<td>ft²</td>
</tr>
<tr>
<td>DELHF</td>
<td>Heat of formation of fuel</td>
<td>BTU/lbm</td>
</tr>
</tbody>
</table>
Table 1. Variable Names and Definitions (Continued).

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULLG</td>
<td>Ullage length</td>
<td>ft</td>
</tr>
<tr>
<td>ULWID</td>
<td>Ullage width</td>
<td>ft</td>
</tr>
<tr>
<td>ULHT</td>
<td>Ullage height</td>
<td>ft</td>
</tr>
<tr>
<td>S</td>
<td>End</td>
<td></td>
</tr>
</tbody>
</table>

SDATA
RGAS=1545,
EMWA=28.966,EMWF=72,
CPA=0.24,CPF=0.49,
TA=60,
HJ=3.2,
ULLGH=10.0,ULWID=10.0,ULHT=0.55,
DELHF=1,
ZOG=1,
AV=0.16,
DV=0.3,
CDELT=0.01,
KTANK=0,
GALO=5573,
BETA=0.16,
CON1=1000,CON2=0,
TVENT=70,
TF(1,1)=0.1,2,3,4,5,6,7,8,9,10,11,12,
TF(1,2)=60,60,68,48,48,45,15,20,25,110,130,120,
TSIDE(1,1)=0,12,TSIDE(1,2)=70,70,
TTOP(1,1)=0,12,TTOP(1,2)=70,70,
ALT(1,1)=0,1,3,5,1,4,5,6,8,8,3,12,
ALT(1,2)=0,8,20,22,22,20,18,20,22,25,25,
GALD(1,1)=0,8,3,8,31,10,3,10,31,12,
GALD(1,2)=0,8,2779,2779,0,0,
PVAP(1,1)=17,41,67,96,129,166,PVAP(1,2)=.35,.60,1.1,2.0,4.0,8.0,
EMINF(1,1)=0.5,12,EMINF(1,2)=0.85,85,
TO=0,TMAX=11,DTPMAX=.25,DT=.001$

*A header card must be present for each run on the WSFT program. The subsequent data cards contain the variable names and corresponding values required by the model. The data is punched on cards beginning in column two.

Figure 1. Example of a Set of Inputs for WSFT Program.
Time hrs = 1.7500
Mach number = .85000
Vent velocity = 1.6085 (ft/hr) (positive into tank)
Integration error total mass-percent = -1.6841

Air partial pressure = .77882E+03
Fuel partial pressure = .13494E+03
Fuel vapor pressure = .13486E+03
Air-fuel ratio = .23219E+01

<table>
<thead>
<tr>
<th>Altitude</th>
<th>.21500E+05 (ft)</th>
<th>Derivative</th>
<th>-.66667E+03 (ft/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>.91376E+03 (psf)</td>
<td></td>
<td>.25775E+02 (psf/hr)</td>
</tr>
<tr>
<td>Temperature</td>
<td>.52590E+03 (°R)</td>
<td></td>
<td>-.91200E+00 (°R/hr)</td>
</tr>
<tr>
<td>Volume</td>
<td>.5500E+02 (ft³)</td>
<td></td>
<td>0. (ft³/hr)</td>
</tr>
<tr>
<td>Gallons used</td>
<td>0.</td>
<td></td>
<td>0. (gal/hr)</td>
</tr>
</tbody>
</table>

| Vented        | -.99572E+01        | Mass flux,  |
|               |                   | slugs/hr    |
| Evaporated    | .19764E+01         | .62984E-01  |
| Outgassed     | .55206E+01         | -.25420E-01 |
| Condensed     | 0.                | 0.           |
| Total         | .21486E+01         | .37564E-01  |

Figure 2. Example of WSFT Program Normal Output Report.
VULNERABILITY MODEL

UTILITY

The vulnerability model was designed to ascertain the most hazardous phases of a designated flight profile, given a specific aircraft and a specified set of hostile weapons. It is intended for use in support of laboratory testing, both to reduce the number of tests required and to eliminate unnecessary tests.

INPUTS

To prepare for model runs, it is necessary to have input information in several categories (i.e., mission, weapons, and aircraft). See the Appendix for program listing and sample case.

In addition to the input from the WSFT program, the vulnerability model requires input information regarding ignition and detonation probabilities as functions of residual penetrator energy, and hydraulic ram probability as a function of impact kinetic energy. It also requires a geometric description of the fuel system and the hostile weapons under consideration.

Mission

The flight profile must be selected; which includes altitude, velocity, and time of the target aircraft during the period when hostile weapons may be expected.

Weapons

The model will accept any mixture of kinetic energy penetrators or fragmenting warhead weapons in a sector of attack determined by a range of permissible azimuth and elevation angles for each hostile weapon system.

Kinetic Energy Weapons. The parameters which characterize the kinetic energy penetrators (e.g., ball, AP*, and API) are: mass of the penetrator, time of incendiary ignition and incendiary burnout (relative to initial contact), muzzle velocity, drag coefficient, and a table of mil aiming errors as a function of target velocity. For each shot, the azimuth and elevation angles are taken from uniform distributions within the prescribed limits for the firing weapon system. The probable aiming error is calculated from the table of mil errors. A particular DM (miss distance) is chosen from a normal distribution characterized by this probable error. A point is chosen at random on the circumference of a circle having a radius equal to the DM and lying in the plane perpendicular to the relative velocity vector. This point and the relative velocity vector determine the trajectory. If the trajectory intersects any of the fuel tanks, a hit is said to occur on that tank. If a hit takes place, the geometry of the situation and the conditions within the fuel tank determine whether a particular damage mechanism occurs.

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*Armor-piercing and armor-piercing incendiary.
FRAGMENTING WARHEAD WEAPONS. The parameters which characterize the fragmenting warhead weapons are: (1) average fragment mass, (2) fragment static emission velocity, (3) fragment slowdown constant, (4) static fragment spray limits, (5) average static fragment density/steradian, (6) muzzle velocity of projectile, (7) slowdown constant of projectile, (8) aiming sigma, and (9) fuzing sigma. For each shot, a trajectory is chosen as with the solid shot weapons. using the aiming sigma in place of the table of mil errors. A burst point is chosen along the trajectory from a normal distribution using the fuzing sigma. For each fuel tank, the travel-time equation of the fragments is solved using an iterative procedure. The expected number of hits on each tank is calculated; this number and the conditions in the tank determine the probability of a particular damage mechanism.

Aircraft

The target aircraft is represented as a set of fuel tanks. Each tank is a rectangular parallelepiped characterized by the coordinates of its center, and by its length, width, and height. Constants, which must be supplied by the user, are stored; they represent, for the aspect of each tank, whether an external ignition source is present, and the distance of that aspect from the skin of the aircraft. The target is further characterized by the target velocity and by the energy levels required to produce penetration of each fuel tank and hydraulic ram effects.

PROGRAM OUTPUT

There are two reports generated by the program. Report 1 is a summary of fuel states for each tank as a function of time. (See Table 2). Report 2 is a summary of each non-zero hazard incident. (See Table 3.) It shows the fuel state at the time of the incident, summarizes the probable trajectories through the tank if impact occurs, and presents probabilities of no effect, leak, external fire, destructive ram, and internal fire/explosion. These probabilities are calculated as the average over several Monte Carlo trials for each combination of fuel tank, weapon, and time intervals resulting in a non-zero $P_h$ (probability of a hit) on the fuel tank. A summary of all Report 2 outputs is made, arranging hazards in descending order.

For solid shot weapons, the probabilities of liquid and vapor exit are given. On the basis of all these probabilities, a hazard index is calculated; which indicates, on a scale of zero through one, the relative likelihood of lethal damage occurring to the aircraft as a result of this encounter.

COORDINATE SYSTEM AND AZIMUTH-ELEVATION CONVENTION

The coordinate system used in this model has its origin at the center of gravity of the target aircraft; therefore, it is a moving coordinate system. The $X$ axis is positive in the direction of travel. (See Figure 3.) The $Y$ axis is positive in the direction of the left wing, and the $Z$ axis is positive in an upward direction.

In the analysis, the orientation of certain vectors with respect to certain axes is sometimes expressed in terms of direction cosines and in terms of azimuth-elevation; thus, conversion between these terms is required. The sign convention for azimuth-elevation needs definition because all users do not use identical conventions.
Table 2. Fuel Tank Vulnerability Model (Report 1).
Vehicle Test

<table>
<thead>
<tr>
<th>TIME INTO MISSION</th>
<th>TANK 1 F/A RATIO</th>
<th>TANK 1 PCT. FUEL REMAINING</th>
<th>TANK 2 F/A RATIO</th>
<th>TANK 2 PCT. FUEL REMAINING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.174764</td>
<td>100.00</td>
<td>0.174764</td>
<td>100.00</td>
</tr>
<tr>
<td>0.250</td>
<td>0.310226</td>
<td>100.00</td>
<td>0.310431</td>
<td>100.00</td>
</tr>
<tr>
<td>0.500</td>
<td>0.444017</td>
<td>100.00</td>
<td>0.444072</td>
<td>100.00</td>
</tr>
<tr>
<td>0.750</td>
<td>0.457327</td>
<td>100.00</td>
<td>0.457327</td>
<td>100.00</td>
</tr>
<tr>
<td>1.000</td>
<td>0.457327</td>
<td>100.00</td>
<td>0.457327</td>
<td>100.00</td>
</tr>
<tr>
<td>1.250</td>
<td>0.448503</td>
<td>100.00</td>
<td>0.448495</td>
<td>100.00</td>
</tr>
<tr>
<td>1.500</td>
<td>0.439516</td>
<td>100.00</td>
<td>0.439310</td>
<td>100.00</td>
</tr>
<tr>
<td>1.750</td>
<td>0.430690</td>
<td>100.00</td>
<td>0.430684</td>
<td>100.00</td>
</tr>
<tr>
<td>2.000</td>
<td>0.422020</td>
<td>100.00</td>
<td>0.422014</td>
<td>100.00</td>
</tr>
<tr>
<td>2.250</td>
<td>0.394664</td>
<td>100.00</td>
<td>0.394632</td>
<td>100.00</td>
</tr>
<tr>
<td>2.500</td>
<td>0.366976</td>
<td>100.00</td>
<td>0.366947</td>
<td>100.00</td>
</tr>
<tr>
<td>2.750</td>
<td>0.340186</td>
<td>100.00</td>
<td>0.340157</td>
<td>100.00</td>
</tr>
<tr>
<td>3.000</td>
<td>0.314242</td>
<td>100.00</td>
<td>0.314213</td>
<td>100.00</td>
</tr>
<tr>
<td>3.250</td>
<td>0.303331</td>
<td>100.00</td>
<td>0.303332</td>
<td>100.00</td>
</tr>
<tr>
<td>3.500</td>
<td>0.297901</td>
<td>100.00</td>
<td>0.297901</td>
<td>100.00</td>
</tr>
<tr>
<td>3.750</td>
<td>0.295495</td>
<td>100.00</td>
<td>0.295495</td>
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<td>27</td>
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Table 3. Fuel Tank Vulnerability Model (Report 2).

Solid Shot Weapon

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>TIME INTO MISSION (HRS)</td>
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<tr>
<td>PROBABILITY OF HIT ON FUEL TANK</td>
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</tr>
<tr>
<td>AVERAGE STRIKING VELOCITY (FPS)</td>
<td>2569.2</td>
</tr>
<tr>
<td>AVERAGE SLANT RANGE (FT)</td>
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<tr>
<td>AIRCRAFT ALTITUDE (FT)</td>
<td>250.00</td>
</tr>
<tr>
<td>AIRCRAFT SPEED (FPS)</td>
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<tr>
<td>VEHICLE type</td>
<td>Test</td>
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<tr>
<td>FULL TANK</td>
<td>AFT INTERMEDIATI</td>
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<td>THREAT</td>
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<td>PERCENT FUEL REMAINING</td>
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<tr>
<td>PROBABILITY OF VAPOR EXIT</td>
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</tr>
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<td>GIVEN VAPOR ENTRY</td>
<td></td>
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<tr>
<td>PROBABILITY OF LIQUID EXIT</td>
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<td>PROBABILITY OF VAPOR EXIT</td>
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PROBABILITIES OF FUEL TANK DAMAGE

GIVEN A HIT

<table>
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<th>Event</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
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<td>P (NO EFFECT)</td>
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</tr>
<tr>
<td>P (LEAK WITHOUT FIRE)</td>
<td>0.666667</td>
</tr>
<tr>
<td>P (LEAK AND EXTERNAL FIRE)</td>
<td>0.333333</td>
</tr>
<tr>
<td>P (DESTRUCTIVE RAM)</td>
<td>0.000000</td>
</tr>
<tr>
<td>P (INTERNAL FIRE/EXPLOSION)</td>
<td>0.000000</td>
</tr>
</tbody>
</table>
Consider the X, Y, and Z axes and the $\vec{V}_{SH}$ (shell velocity) having direction cosines $\mu_X$, $\mu_Y$, and $\mu_Z$. The El (elevation angle) is the angle between the vector and the XY plane. It is considered positive if the vector has an upward component, and negative if it has a downward component. The Az (azimuth angle) is the angle between the projection of the vector on the XY plane and the negative X axis. It is considered positive if the vector has a component in the -Y direction.

The relations between the direction cosines and azimuth-elevation can be derived by resolving the unit $\vec{V}_{SH}$ into its components along the coordinate axes. The magnitude of the Z axis component is $|\sin El|$, while the projection in the XY plane is $|\cos El|$. The latter component may be projected on the X axis to yield $\cos El \cos Az$ and on the Y axis to yield $\cos El \sin Az$. Thus, the unit vector has components along the X, Y, and Z axes whose magnitudes are $|\cos El \cos Az|$, $|\cos El \sin Az|$, and $|\sin El|$. Taking the sign conventions into account:

$$\mu_X = -\cos El \cos Az$$  \hspace{1cm} (1)
$$\mu_Y = -\cos El \sin Az$$  \hspace{1cm} (2)
$$\mu_Z = \sin El$$  \hspace{1cm} (3)

These equations permit calculation of the direction cosines if Az and El are given.
TRAJECTORY

For a single shot, it is assumed that $Az$ and $El$ are uniformly distributed between the limits $Az_{MIN}$, $Az_{MAX}$, $El_{MIN}$, and $El_{MAX}$. $El$ is found by selecting an $r_u$ (random number) uniformly distributed between zero and one and using it in:

$$El = El_{MIN} + r_u(El_{MAX} - El_{MIN})$$  \hspace{1cm} (4)

$Az$ is found by selecting another $r_u$ for use:

$$Az = Az_{MIN} + r_u(Az_{MAX} - Az_{MIN})$$  \hspace{1cm} (5)

The direction cosines $\mu_X$, $\mu_Y$, and $\mu_Z$ can be calculated from equations (1), (2), and (3).

The $\vec{V}_{SH}$ has magnitude $V_{SH}$ and is expressed in equation (6), where $\hat{i}$, $\hat{j}$, and $\hat{k}$ represent the unit vectors in the $X$, $Y$, and $Z$ directions, respectively. The $\vec{V}_T$ (target velocity) has magnitude $V_T$, is in the $X$ direction, and appears in equation (7):

$$\vec{V}_{SH} = V_{SH} \mu_X \hat{i} + V_{SH} \mu_Y \hat{j} + V_{SH} \mu_Z \hat{k}$$  \hspace{1cm} (6)

$$\vec{V}_T = V_T \hat{i}$$  \hspace{1cm} (7)

The $\vec{V}_R$ (relative velocity) has magnitude $V_R$, and is defined and evaluated as follows:

$$\vec{V}_R = \vec{V}_{SH} - \vec{V}_T = (V_{SH} \mu_X - V_T) \hat{i} + V_{SH} \mu_Y \hat{j} + V_{SH} \mu_Z \hat{k}$$  \hspace{1cm} (8)

$$V_R = \sqrt{V_{SH}^2 - 2 V_{SH} V_T \mu_X + V_T^2}$$  \hspace{1cm} (9)

Let $A$, $B$, and $C$ be the direction cosines of $\vec{V}_R$ with respect to the $X$, $Y$, and $Z$ axes.

$$A = \frac{V_{SH} \mu_X - V_T}{V_R}$$  \hspace{1cm} (10)

$$B = \frac{V_{SH} \mu_Y}{V_R}$$  \hspace{1cm} (11)

$$C = \frac{V_{SH} \mu_Z}{V_R}$$  \hspace{1cm} (12)

The $D_M$ is the closest approach distance of the trajectory to the aim point which in this case, is the center of gravity of the target. The method used to choose a value for $D_M$ depends on the weapon type.
For the weapons with fragmenting warheads, an $\sigma_A$ (aiming sigma) is an input. The value of $D_M$ is chosen randomly from a normal distribution having mean zero and standard deviation $\sigma_A$.

The solid shot weapons are characterized by a table of mil errors as a function of target velocity. The $E_M$ (probable aiming error expressed in mils) can be found for any $V_T$ by interpolation in this table. Let the altitude of the target be $H$, and the $R_S$ (slant range) is given by:

$$R_S = \frac{H}{\sin (\theta)}$$  \hspace{1cm} (13)

The $E_p$ (probable aiming error expressed in units of linear measure) can be calculated from:

$$E_p = 0.001 \times R_S \times E_M$$  \hspace{1cm} (14)

For normal distribution, the $E_p$ is equal to 0.675 standard deviation units. Thus, for the aiming error:

$$\sigma_A = \frac{E_p}{0.675}$$  \hspace{1cm} (15)

Given the aiming error, the $D_M$ defines the radius of a circle in the plane perpendicular to the $V_R$ and centered at the aiming point. The following procedure chooses a point $(X_0, Y_0, Z_0)$ at random on the circumference of the circle. This point and the $V_R$ defines the trajectory for a single shot.

Select an $r_u$ uniformly distributed between zero and one. Let $\phi = 2\pi r_u$. $A$, $B$, and $C$ are the direction cosines of $V_R$ as calculated from equations (10), (11), and (12). If $C \neq 0$, let:

$$\cos \psi = -\frac{A}{\sqrt{A^2 + B^2}}$$

$$\sin \psi = \frac{B}{\sqrt{A^2 + B^2}}$$

Then,

$$X_0 = |D_M| \left[ C \cos \phi \cos \psi + \sin \phi \sin \psi \right]$$  \hspace{1cm} (16)

$$Y_0 = |D_M| \left[ -C \cos \phi \sin \psi + \sin \phi \cos \psi \right]$$  \hspace{1cm} (17)

If $C = 0$,

$$Z_0 = |D_M| \cos \phi$$  \hspace{1cm} (18)

Otherwise,

$$Z_0 = (-AX_0 - BY_0)/C$$  \hspace{1cm} (19)
If \( C = 1 \), the following equations apply:

\[
\begin{align*}
X_0 &= |D_M| \cos \phi \\
Y_0 &= |D_M| \sin \phi \\
Z_0 &= 0
\end{align*}
\] (20)

GEOMETRY OF SOLID SHOT ENCOUNTER

For solid shot weapons, a hit is said to occur if the trajectory intersects any fuel tank. Consider the case of one tank having dimensions LT, WT, and HT, and centroid located at \((X_{CG}, Y_{CG}, Z_{CG})\). For a given trajectory there are, at most, three faces of the tank through which it is possible for the shell to enter. These can be determined from the direction cosines of the \( \overrightarrow{VR} \) as shown:

<table>
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<tr>
<th>(&lt;0)</th>
<th>=0</th>
<th>&gt;0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>No intercept with front or rear</td>
<td>Rear</td>
</tr>
<tr>
<td>Left</td>
<td>No intercept with side</td>
<td>Right</td>
</tr>
<tr>
<td>Top</td>
<td>No intercept with top or bottom</td>
<td>Bottom</td>
</tr>
</tbody>
</table>

The procedure for determining whether a hit occurs is to find the coordinates of the points which represent the intersection of the trajectory with those planes (taken from Table 2) in which the faces of the tank lie. These points are examined to determine whether they fall within the bounds which form the faces of the tank. For example, the planes which contain the top and bottom faces of the tank are parallel to the XY plane, and their equations are, respectively:

\[
\begin{align*}
Z &= Z_{CG} + HT/2 \\
Z &= Z_{CG} - HT/2
\end{align*}
\] (23) (24)

The equation of the trajectory is:

\[
\frac{X - X_0}{A} = \frac{Y - Y_0}{B} = \frac{Z - Z_0}{C}
\] (25)

Let \((X_{IN}, Y_{IN}, Z_{IN})\) be the intersection point of the trajectory with whichever plane, (23) or (24), is encountered by the shell first. Then, using Table 1 and equations (23) and (24):

\[
\begin{align*}
Z_{IN} &= Z_{CG} + HT/2, \ C < 0 \\
Z_{IN} &= Z_{CG} - HT/2, \ C > 0
\end{align*}
\]
Substituting this value of $Z_{IN}$ into equation (25):

$$X_{IN} = \frac{A}{C} (Z_{IN} - Z_0) + X_0$$
$$Y_{IN} = \frac{B}{C} (Z_{IN} - Z_0) + Y_0$$

If $C$ is equal to zero, the trajectory is parallel to the top and bottom faces and the point $(X_{IN}, Y_{IN}, Z_{IN})$ does not exist. This point indicates a hit on the top or bottom face of the tank if the following conditions are satisfied:

$$X_{CG} - LT/2 \leq X_{IN} \leq X_{CG} + LT/2$$
$$Y_{CG} - WT/2 \leq Y_{IN} \leq Y_{CG} + WT/2$$

If a hit is not found on the top or bottom face, the sides and the front/rear faces are checked by a procedure similar to the above. If a valid entry point is found for one of the three possible faces, the other three faces are checked to determine the exit point. Based on the percent of fuel remaining, it is determined whether the entry and exit points are above or below the fuel.

**GEOMETRY OF FRAGMENTING WARHEAD ENCOUNTER**

The method of treating the fragmenting warhead is to determine the burst point and solve, using an iterative procedure, the equation which relates distance and time traveled for the fragments. Having solved this equation, and knowing the fragment density, it is possible to calculate the expected number of hits on a tank and the probability of a kill.

The standard deviation of the fuzing error along the trajectory is $\sigma_F$. The aiming point for this type of weapon is not assumed to be the center of gravity, but is input as $(X_{FUSE}, Y_{FUSE}, Z_{FUSE})$. The error along the trajectory due to fuzing is taken from the point of closest approach to $(X_{FUSE}, Y_{FUSE}, Z_{FUSE})$. This error, $D_F$, is chosen at random from a normal distribution having mean of zero and standard deviation $\sigma_F$. For a burst point located by $X^*, Y^*, Z^*$:

$$X^* = X_0 + Y_{FUSE} + D_F (\mu_X \cdot \frac{VT}{VSH})$$
$$Y^* = Y_0 + Y_{FUSE} + D_F \mu_Y$$
$$Z^* = Z_0 + Z_{FUSE} + D_F \mu_Z$$

The explosion of a static fragment warhead yields a characteristic spectrum of fragment mass, angular density, and emission velocity. The explosion of a moving fragment warhead alters this spectrum by virtue of the velocity of the velocity of the projectile. It is necessary to determine the interaction of this altered spectrum with the target. The relationship between speed and direction of the projectile, and the speed and direction of an emitted fragment are derived using Figure 4. The $V_F$ (fragment emission velocity) and the angle $\theta$ are those observed in a static explosion; while, through vector addition, $V_O$ (observed fragment velocity) and angle $\gamma$ occur in a dynamic explosion.
The law of cosines applied to Figure 4 yields a quadratic equation for $V_O$:

$$V_O = V_{SH} \cos \gamma \pm \sqrt{(V_{SH} \cos \gamma)^2 + V_E^2 - V_{SH}^2}$$

If $V_{SH} < V_E$, as is usually true, the negative root leads to a negative velocity which is ruled out. Thus, equation (26) is valid and emission velocity is single-valued for a given $\gamma$ when $V_{SH} \leq V_E$:

$$V_O = V_{SH} \cos \gamma + \sqrt{(V_{SH} \cos \gamma)^2 + V_E^2 - V_{SH}^2}$$  \hspace{1cm} (26)

Another relationship results from Figure 4 by summing vector components in the $\vec{V}_{SH}$ direction:

$$\cos \theta = \frac{V_O \cos \gamma \cdot V_{SH}}{V_E}$$  \hspace{1cm} (27)

The fragment ballistics must be considered. A stationary $x, y, z$ coordinate system is employed. This coordinate system is defined to coincide with the $X, Y, Z$ system at the $t=0$ (time of the explosion). The explosion point in the $x, y, z$ system is at $(x^*, y^*, z^*)$, where:

- $x^* = X^*$
- $y^* = Y^*$
- $z^* = Z^*$
The target is represented by a set of fuel tanks, and the location of each tank is designated by the coordinates of its center of gravity. It must be determined whether each tank is hit by the fragment spray, and if so, what the expected number of hits will be.

Using this procedure for one tank, consider a tank located at point \((X_{CG}, Y_{CG}, Z_{CG})\). At \(t=0\), the tank coordinates in the stationary system are \((x, y, z) = (X_{CG}, Y_{CG}, Z_{CG})\). The tank is moving in the +x direction; therefore, the hit point occurs one time-of-flight later at point \((x, y, z) = x_H, Y_{CG}, Z_{CG}\). At this point the fragment has traveled a distance \(L\), where:

\[
x_H = X_{CG} + V_T t
\]

\[
L = \sqrt{(x_H - x^*)^2 + (Y_{CG} - y^*)^2 + (Z_{CG} - z^*)^2}
\]

The direction cosines, with respect to the \(x, y, z\) axes, of the line from explosion point to hit point are \(\beta_x, \beta_y, \text{and} \beta_z:\)

\[
\beta_x = \frac{x_H - x^*}{L}
\]

\[
\beta_y = \frac{Y_0 - y^*}{L}
\]

\[
\beta_z = \frac{Z_0 - z^*}{L}
\]

With the direction cosines of each vector known, the angle \(\gamma\) (Figure 4) is given by taking the scalar product of the vectors:

\[
\cos \gamma = \mu_x \beta_x + \mu_y \beta_y + \mu_z \beta_z
\]

The distance-time relationship, which describes the fragment travel, can be derived. By equating the inertial and drag forces for geometrically similar bodies, it can readily be shown that the logarithmic derivative of velocity with travel is proportional to the air density, and inversely proportional to any characteristic length of the body. The proportionality constant is determined by the drag coefficient, the mass density of the body, and the geometrical shape. Thus, for fragments having some characteristic mass spectrum, a sea level slowdown constant \((k)\) may be introduced whose value will be independent of mass:

\[
\frac{d \ln V}{d L} = -m^{1/3}
\]

\[
\text{where } V \text{ is the velocity of a fragment after traveling a distance } L, \rho \text{ is the relative air density, and } m \text{ is the fragment mass. This may be integrated at constant drag coefficient to yield the velocity-distance equation for fragments, where } V_O \text{ is the initial fragment speed:}
\]

\[
\ln \left( \frac{V}{V_O} \right) = -k \rho L/m^{1/3}
\]
This equation is integrated once more to obtain the desired result:

\[ B \, V_0 t = e^{B L} - 1 \]  

(34)

where

\[ B = k \rho / m^{1/3} \]

The criterion for a hit and all corresponding properties are determined by simultaneous solution of equations (26), (28), (29), (30), (31), (32), and (34). No analytic solution to this system has been found, but an iterative numerical solution can be employed.

The numerical method is the Newton-Raphson technique. The formulation of this method, as applied to fragments, has been tested and found to give rapid convergence even with inputs which were known to be troublesome by previous methods. The Newton-Raphson method obtains the roots of \( F(t) = 0 \).

The classical method takes the \( J \)th estimate of the root \( t_J \) and extracts the \( (J+1) \) estimate \( t_{(J+1)} \) by means of equation (35):

\[ t_{(J+1)} = t_J - \frac{F(t_J)}{F'(t_J)} \]  

(35)

The procedure is repeated until successive estimates are considered to differ negligibly. Application of this method to the fragment ballistics required suitable choice of \( F(t) \). The travel-time relation (34) is chosen and rewritten as the \( F \) function:

\[ F(t) = \ln (1 + B \, V_0 \, t) - B \, L \]  

(36)

Differentiation yields the time derivative:

\[ \dot{F}(t) = B \left[ \frac{V_0 + V_0 \, t}{1 + B \, V_0 \, t} - \dot{L} \right] \]  

(37)

The two time derivatives in equation (37) must be evaluated from the other relations that must be satisfied.

Differentiation of equation (26) at constant \( V_E \) yields:

\[ \dot{V}_o = \left[ -\frac{V_o \, V_{SH} \sin \gamma}{V_o - V_{SH} \cos \gamma} \right] \]  

(38)

Differentiation of equation (28) yields:

\[ \dot{x}_H = V_T \]  

(39)

Differentiation of equation (29), and use of (30) and (39) yields:

\[ \dot{L} = \beta_x \, V_T \]  

(40)
It can be seen that while \( L \) is known in terms of non-derivatives, \( \dot{V}_o \) is known in terms of \( \dot{\gamma} \). Thus, to complete the evaluation of equation (37), it is necessary to calculate \( \dot{\gamma} \).

Differentiation of equations (30), (31), and (32), and using (39) yields:

\[
\dot{\beta}_x = \frac{V_T - \beta_x I}{L} \quad (41)
\]

\[
\dot{\beta}_y = \frac{-\beta_y I}{L} \quad (42)
\]

\[
\dot{\beta}_z = \frac{-\beta_z I}{L} \quad (43)
\]

Differentiation of equation (33) and employing (41), (42), and (43) gives:

\[
\dot{\gamma} = \frac{\dot{L} \cos \gamma - \mu_x V_T}{L \sin \gamma} \quad (44)
\]

The final results are obtained by eliminating \( \dot{L} \) and \( \dot{\gamma} \) between equations (37), (38), (40), and (44):

\[
\ddot{F}(t) = B \left[ \frac{V_o + \dot{V}_o t}{1 + B V_o t} \right] \beta_x V_\gamma \quad (45)
\]

\[
\dot{V}_o = \left[ \frac{V_o V_{SH} V_T}{L} \right] \left[ \frac{\mu_x - \beta_x \cos \gamma}{V_o - V_{SH} \cos \gamma} \right] \quad (46)
\]

Thus, the Newton-Raphson method for fragment ballistics employs the system of equations (35), (36), (45), and (46).

The method used to determine the hit point of a given fuel tank for a fragment of a given mass is:

a. Estimate time-of-flight (t).

b. Calculate hit point coordinate (\( x_H \)) from equation (28).

c. Calculate fragment travel (L) from equation (29).

d. Calculate direction cosines (\( \beta_x \), \( \beta_y \), and \( \beta_z \)) of fragment velocity from equations (30), (31), and (32).

e. Calculate dynamic fragment emission angle (\( \gamma \)) from equation (33).

f. Calculate dynamic fragment emission velocity (\( V_o \)) from equation (26).
g. Calculate \( F(t) \) from (26) and \( \dot{V}_0 \) from equation (46).

h. Calculate \( \ddot{F}(t) \) from equation (45). If \( \ddot{F}(t) < 0 \), there is no hit point and the fragment has missed the fuel tank.

i. Make new estimate of time-of-flight \( t \) using equation (35). If the new \( t < 0 \), score a miss; otherwise, compare with the previous value of \( t \). If two successive values are in agreement (e.g., result in a difference of less than 0.5 foot in the hit point), the process is considered to have converged and the most recent value of \( t \) is saved as the solution. Otherwise, iterate again at step c.

It is important to make a good estimate of the time-of-flight for step a. The method used for the first estimate is to take the analytic solution for the case of zero fragment slowdown.

The distance-time relationship for the zero slowdown case is:

\[
L = V_0 t
\]  
(47)

With a substantial amount of algebraic manipulation, equation (48) is combined with (26), (28), (29), (30), (31), (32), and (33) to yield:

\[
K_1 t^2 + K_2 t + K_3 = 0
\]  
(48)

where

\[
K_1 = V_T^2 - V_{E}^2
\]

\[
K_2 = -2 V_{SH} \left[ \left( \frac{x_{CG} - x^*}{V_{SH}} \right) + \mu_y (Y_{CG} - y^*) + \mu_z (Z_{CG} - z^*) \right]
\]

\[
K_3 = (X_{CG} - x^*)^2 + (Y_{CG} - y^*)^2 + (Z_{CG} - z^*)^2
\]

The solution to this equation is:

\[
t = \frac{-K_2 \pm \sqrt{K_2^2 - 4K_1 K_3}}{2K_1}
\]

The smaller positive value of \( t \) from the above solution is used as the initial estimate for the iterative procedure.

When the iterations have been found to converge for a particular fuel tank, the value of \( \cos \theta \) is determined from equation (27). This value is compared with the limits of the static fragment spray. If the value lies outside these limits, the shot is scored as a miss. If \( \cos \theta \) lies within the bounds of the static fragment spray limits, it is necessary to calculate the fragment density resulting from the dynamic explosion.
The model assumes that the fragment density resulting from a static explosion is uniform between the fragment spray limits. Let \( \xi \) be this density expressed in fragments per steradian. As a result of the rotation of velocity vectors due to the projectile motion, the fragment density in the static case at angle \( \theta \) is not equal to the dynamic density at angle \( \gamma \). This effect may be calculated using the geometry of Figure 4.

The solid angle subtended by the conical shell between \( \theta \) and \( \theta + d\theta \) is \( d\omega_\theta \):

\[
d\omega_\theta = \frac{[V_E \, d\theta \, 2\pi \, V_E \sin \theta]}{V_E^2} = 2\pi \sin \theta \, d\theta
\]

Similarly, the solid angle of the conical shell between \( \gamma \) and \( \gamma + d\gamma \) is \( d\omega_\gamma \):

\[
d\omega_\gamma = \frac{[V_O \, d\gamma \, 2\pi \, V_O \sin \gamma]}{V_O^2} = 2\pi \sin \gamma \, d\gamma
\]

Assuming that adjacent rays satisfy the geometry of Figure 1, the number of fragments in each of these conical shells is the same; thus, \( E \) is a measure of the change in fragment density, where:

\[
E = \frac{d\omega_\gamma \, \sin \gamma \, d\gamma}{d\omega_\theta \, \sin \theta \, d\theta}
\]

\[
\xi_{\text{DYN}} = \frac{E}{\xi}
\]

To calculate the value of \( \xi_{\text{DYN}} \), \( E \) must be derived for use in equation (50).

The speed ratio \( G \) is defined as:

\[
G = \frac{V_E}{V_{\text{SH}}}
\]

Elimination of \( V_O \) between equations (26) and (27) gives:

\[
\cos^2 \gamma + G^2 - 1 = \frac{G \cos \theta + 1}{\cos \gamma} \cdot \cos \gamma
\]

Squaring and rearranging terms yields:

\[
\cos^2 \gamma = \frac{(1 + G \cos \theta)^2}{(G^2 + 2G \cos \theta + 1)}
\]
Differentiating equation (51) results in:

\[
\frac{d\gamma}{d\theta} = \frac{G^2 \sin \theta (1 + G \cos \theta) (G + \cos \theta)}{\cos \gamma \sin \gamma (G^2 + 2G \cos \theta + 1)^2}
\]

Substituting this result in equation (40):

\[
E = \frac{G^2 (1 + G \cos \theta) (G + \cos \theta)}{\cos \gamma (G^2 + 2G \cos \theta + 1)^{3/2}}
\]  \hspace{1cm} (52)

Further simplification results by eliminating \(\cos \gamma\) between equations (51) and (52). Based on the geometry of the situation, it is concluded that \(E\) is non-negative.

\[
E = \frac{G^2 |C + \cos \theta|}{(G^2 + 2G \cos \theta + 1)^{3/2}}
\]  \hspace{1cm} (53)

**PROBABILITY OF FRAGMENT DAMAGE TO FUEL TANKS**

The fuel tank is treated as a rectangular parallelepiped; therefore, there are a maximum of three faces that can be hit due to one explosion. Identification of the three faces can be achieved by the use of relative velocities.

\(V_{\text{HIT}}\) (fragment speed at the time of the hit) is found to be:

\[
V_{\text{HIT}} = V_0 e^{-BL}
\]

The striking fragment, target, and relative \(\vec{V}_{\text{NET}}\) velocities can now be expressed:

\[
\vec{V}_{\text{HIT}} = V_{\text{HIT}} \beta_x \hat{i} + V_{\text{HIT}} \beta_y \hat{j} + V_{\text{HIT}} \beta_z \hat{k}
\]

\[
\vec{V}_{\text{T}} = \vec{V}_{\text{T}}
\]

\[
\vec{V}_{\text{NET}} = \vec{V}_{\text{HIT}} - \vec{V}_{\text{T}} = (V_{\text{HIT}} \beta_x - V_T) \hat{i} + V_{\text{HIT}} \beta_y \hat{j} + V_{\text{HIT}} \beta_z \hat{k}
\]

The \(V_{\text{NET}}\) (net striking speed) is the magnitude of the velocity \(\vec{V}_{\text{NET}}\):

\[
V_{\text{NET}} = \sqrt{V_{\text{HIT}}^2 - 2V_T V_{\text{HIT}} \beta_x + V_T^2}
\]
The signs of the $\vec{v}_{NET}$ components identify the struck aspects as follows:

- $\beta_z$: Top
- $\beta_y$: Left
- $\beta_x - \frac{V_T}{V_{HIT}}$: Front

The number of fragment hits on each of the three aspects remains to be calculated. Calculation of the fragment density in target coordinates appears tedious and possibly difficult. Therefore, the approximation is made that the number of hits can be calculated on a static target. This should be an excellent approximation if $V_{HIT} \gg V_T$ and probably not too bad for most cases to be encountered. Using the static target concept, Table 2 is modified, replacing $V_T/V_{HIT}$ by zero.

Consider a static target placed in a constant density pulsed beam of particles emitted from a static point source. To be definite, consider the right-left aspect only. The actual area of the aspect is $A_y$, while the area component normal to the beam is $A_y|\beta_y|$. The solid angle viewed by the point source is approximately $A_y|\beta_y|/L^2$. If the separation $L$ is quite small, this will give a large overestimate of the solid angle, but this is not important since kill will be achieved for small $L$. Thus, the number of hits on the aspect is $n_i = \frac{EDYN \cdot A_y |\beta_y|/L^2}{E L^2}$. From this and equation (50), the following result is generalized for the $i^{th}$ aspect:

$$n_i = \frac{\xi A_i |\beta_i|}{E L^2}$$  \hspace{1cm} (54)

where $n_i$ is the number of hits on the $i^{th}$ aspect.

If $N$ is the total number of fragments emitted by the warhead, the probability that a fragment selected at random scores a hit on the $i^{th}$ aspect is:

$$p_i = \frac{n_i}{N}$$

Considering each fragment to be independent of other fragments in hitting a fuel tank, the $PH$ based on the appropriate three faces can be formulated by:

$$1-PH = \Pi(1-p_j)^N = \Pi(1-p_j)(1-p_i)(-n_j)$$

three faces

$$\simeq \Pi e^{-n_i} = e^{-\Sigma n_i}$$

three faces
where the approximation is good only for \( p_i \ll 1 \). Substituting from equation (54), the final form is:

\[
P_{1I} = 1 - e^{-\sum \frac{\xi A_i \beta_i}{E L^2}}
\]

(55)

Similarly, the \( P_{BF} \) (probability of a hit below the fuel level) and the \( P_{AF} \) (probability of a hit above the fuel level) can be calculated from:

\[
P_{BF} = 1 - e^{-\sum \frac{\xi A_i^\prime \beta_i}{E L^2}}
\]

(56)

\[
P_{AF} = 1 - e^{-\sum \frac{\xi A_i^\prime \beta_i}{E L^2}}
\]

(57)

where \( A_i^\prime \) represents that portion of the \( i^{th} \) aspect area which is below the fuel level, and \( A_i^\prime \) represents that portion of the \( i^{th} \) aspect area which is above the fuel level.

The probability of a leak is considered to be equal to the \( P_{BF} \). The \( P_{EF} \) (probability that an external fire occurs given that a leak exists) is calculated from:

\[
P_{EF} = P_{BF} D_{EF}
\]

(58)

\( D_{EF} \) is a degradation factor which is dependent upon the altitude at which the encounter takes place and the temperature of the fuel in the tank:

\[
D_{EF} = \begin{cases} 
0.3 & H > 60,000, \text{ or } H < 10,000 \text{ and } T < 0, \text{ or } T > 45 \\
0.3(T/45) & H > 60,000, \text{ or } H < 10,000 \text{ and } 0 \leq T \leq 45 \\
0.3(1.2 - 0.00002H) & 10,000 \leq H \leq 60,000 \text{ and } T < 0, \text{ or } T > 45 \\
0.3(T/45) (1.2 - 0.00002H) & 10,000 \leq H \leq 60,000 \text{ and } 0 \leq T \leq 45 
\end{cases}
\]

where \( T \) is the fuel temperature in degrees Fahrenheit, and \( H \) is the altitude in feet. This relationship for the degradation factor is based on limited data for wet hit test results\(^2\).

The \( P_{FE} \) (probability of an internal fire/explosion) is considered to be zero unless the fuel-to-air ratio in the ullage space is within the flammability limits for the particular fuel being used. If the fuel-to-air ratio lies within the flammability limits (e.g., 0.013 to 0.08 for JP-4), this probability is given by:

\[
P_{FE} = P_{AF} D_{FE}
\]

(59)

where

\[
D_{FE} = \begin{cases} 
.00000769m^{1/2} V_{NET} & H < 10,000 \\
.00000769m^{1/2} V_{NET} (2.5e^{-0.00092H}) & H \geq 10,000 
\end{cases}
\]

This relationship was derived by fitting curves to data supplied by BRL.

---

\(^2\)Ballistic Research Laboratory. *Fragment Firings Against Aircraft Fuels at Simulated Altitude*, by W.R. Harris. Aberdeen Proving Ground, MD, BRL, October 1953. (BRL TN 828, publication UNCLASSIFIED.)
The last type of damage mechanism which is considered by the model is damage due to hydraulic ram. This mechanism is treated from an energy density standpoint. If the energy density of the fragment spray on a particular fuel tank is above a threshold value, ram is said to occur on this tank for this explosion. The energy density of the spray is calculated from the relationship:

\[ E_{RAM} = \left[ \frac{mV^2}{2} \right] \left[ \frac{\xi}{EL^2} \right] \]

**APPLICATIONS**

The model can be used to examine variations in the type and intensity of threat as the mission profile changes. The vulnerability characteristics of the aircraft vary with time, maneuver history, threat, and threat exposure. For example, aircraft which penetrate and/or deliver ordnance at low altitude may be exposed to a greater variety of hostile weapons than high altitude bombers. Any given weapon system may be exposed to a wide variation in lethal threat as its flight profile is changed. Exercise of the model will reveal the relative severity of the threats and indicate potential phases for laboratory testing.

In the case of a large bomber, for example, it is not immediately obvious whether concern should be directed at air-to-air missiles in the cruise-out phase, or at light AAA weapons in the low altitude approach. At high altitude, ullage spaces tend to be oxygen-poor and quite cool, which inhibits propagating fires. At low altitude, the fuel-air mix, particularly immediately following descent, may reach near-optimum flammability, and even an otherwise minor threat may become lethal. Aerodynamic heating late in a low altitude phase may produce flammable mixtures.

**CONCLUSIONS**

The vulnerability model presents a system for studying the dynamic interaction between fuel state and hostile threat. Previous systems have studied the fuel system statistically, with dynamic treatment of wetons only.

There are several limitations in this model. Ullage spaces were assumed to be homogeneous. The effects of vent geometry, slosh, vibration, and splash caused by impact were not treated. There was no integration of the fuel system into the aircraft structure (masking and shielding by other components). Secondary ignition sources were only crudely treated. Tank geometry was limited to rectangular shapes. Round breakup and ricochet were not treated.

This project was exploratory in nature. The results achieved represent an improvement in treating fuel system vulnerability. Vulnerability can now be calculated as a function of the mission style, as opposed to the single point computations previously possible. This represents a large increase in the realism of vulnerability computations.
Appendix

PROGRAM LISTING AND SAMPLE CASE
WSFT PROGRAM

JOBWSFT,CM50000,1160,I0100,P6. FTON(OPTN=0) LBD(*=TNK1 ATAL0G(TNK1,TKN1,RP=10,KN=1) 9 END OF RECOMD

PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)

COMMON/TITL/CIBU(12)
COMMON/CSR/ KGAS,LMWA,LMWF,CPA,CPF,HJ(3),ULLGH,ULMID,ULMT,
1DLHF,ZOG,AV,CP,EMW,UV,CUELT,KTANK,GALE,TVENT
COMMON/ULIN/ DUMMY(9),EM,TSA,EMO,EMEG,EMEG,EMCD,V,GAL
COMMON/OUTGAS/ CON1,CON2, CONHOLE,LMUI5,TURMO,ENDOUT
1,UVL,LMUI5,EMUI5
COMMON/LIMIT/TF0,UTRPRNT,UPRNT,TIME,M&S
COMMON/TABLES/TAB(100,2),NTAB(6),NSAVE(8)
COMMON/F6ILE7/FAR(250),FLER(250),FTEMP(250),HT(250),VT(250),
1,PRINT,GALX, TINC

DIMENSION TF(100,2),TSIUL(100,2),TTOP(100,2) DUM(1)

EQUIVALENCE (TB(1,1,2)= TF(1,1) )

S(TAB(1,1,4)= TSIUL(1,1) )

S(TAB(1,1,5)= ALI(1,1) )

S(TAB(1,1,6)= GALUD(1,1) )

S(TAB(1,1,7)= PVAP(1,1) )

S(TAB(1,1,8)= EMINF(1,1) )

S(DUM(1), TAB(1,1,1) )

NAMELIST/CEGA,EMWA,EMWF,CPA,CPF,HJ,ULLGH,ULMID,
S ULMT,DLHF,ZOG,AV,UV,CUELT,KTANK,GALE,BETA,CON1,CON2

S+VLEN

S+TF,TSIUL,TTOP,AL,GAUSDPVAP,EMINF

S+TMT,UPRNT

DATA MURI,HTF,SHTSIJL,4HTTOP,3MALT,6HGALDOT,4HPVAP,1

1 SHMINF /

DO 5 =1,1,1600

DUM(1)=-992.1

5 CONTINUE

1 I1PRNT=0

IPRT=0

50 READ(5,900)C10

900 (OKMAT(12AB)

IF(COF(5))1000,10

10 READ(5,DATA)

TINC=UPRNT

GALX=GAL

TIME=T0

UPRNT= TU +UPRNT

DT= AMIN(J1,UPT,1,OE-8)

TUL= AMAX(J1,0.034UT+1.0E-8)

WRITE(*,910)

910 (OKMAT1,1H+20X+12HINPUT TABLES)

UO 75 152.8

WHITL(6+920) MURI(1)

920 (OKMAT(1)H+25X+10HTABLE (OK, A6/)

NSAVE(1)=1

DO 74 J=1,100

IF( TAB(J+1,1)EG=-992.1 AND JTAB(J+1,1),EQ=-992.1)GO TO 75

WHITL(6+930) JTAB(J+1,1)+TAB(J+1,1)

75 CONTINUE

930 (OKMAT(1)X+15X+2L17,7) NTAB(1)=0
SUBROUTINE LINI(X,Y,NN,ARG,YARG,NSAVE)

C       LINEAR INTERPOLATION ROUTINE

DIMENSION X(1), Y(1)

NN=NN

XV=ARG

IF (XV.GE.X(1)) GO TO 40

IF (XV.LE.X(1)) GO TO 50

J= NSAVE

IF (J .LT. 1 .OR. J .GT. NN) J=1

K= SIGN(1,J+(XV-X(J)))

J=J*K

IF (XV-X(J)) .EQ. 0.0 ) GO TO 10

10 IF(K.EQ.-1)J=J+1

I=J-1

C       INTERPOLATION CALC

H=X(J)-X(I)

UX=XV-X(I)

DY=Y(J)-Y(I)

YARG= Y(I) + UX*DY/H

NSAVE=1

RETURN

30 YARG=Y(J)

NSAVE=0

RETURN

40 YARG=Y(1)

RETURN

50 YARG=Y(NN)

RETURN

END
I: (ABC(DET) .EQ. 0.) GO TO 50
C COMPUTE DETERMINANT
UU 40 I=1,N 
*40 UET = UET*A(I:I)*S(1)
C HACK SUBSTITUTE
50 A1 = A(N,N)
DO 70 J=1,N 
JJ = N+J
X(N+J) = A(N,JJ)/A1
IF(N .LT. 1) GO TO 70
UU 65 I=2,N
K = M+1
A2 = A(K,K)
IF(ABC(A2) .LE. 1.0E-10) GO TO 110
B = A(K,JJ)
LL = K+1
UU 60 L=LL+N
60 B = B-A(K,L)*X(L,J)
65 X(K+J) = B/A2
70 CONTINUE
LA = O
RETURN
100 LA = 1
RETURN
110 LA = -1
RETURN
END

REAL FUNCTION LIN(ARG,N)
COMMON/TABS/TAB(100+2+8), NTAB(B),NSAVE(B)
CALL LI11(TAB1(1:1,N)+TAB1(2:1,N)+TAB(N)+ARG+NSAVE(N) )
LIN = Y
RETURN
END
SUBROUTINE LESK(A,X,B,N1,M1,N2,M2,DET,LA)
  DIMENSION A(N1+1),X(N1+1),B(N2)
  C THIS ROUTINE IS A SINGLE PRECISION LINEAR EQUATION C SOLVER, IN ORDER TO CONVERT TO COMPLEX OR DOUBLE-
  C PRECISION, REMOVE THE FOLLOWING CARD.*
  A(B) = ABS(A)
  C THEN, IF DOUBLE-PRECISION IS DESIRED, REMOVE C THE COL 1 L IN EACH OF THE NEXT TWO CARDS.*
  C DOUBLE PRECISION A*X+1+S*UET+AS*AI,AK+K
  C A(B) = DBS(A)
  C IF INSTEAD COMPLEX IS DESIRED, REMOVE THE COL 1 C IN EACH OF THE NEXT TWO CARDS.*
  C COMPLEX A*+DET+AI,AK+K
  C A(B) = CABS(A)
  N = N1
  M = M1
  MN = N+1
  NM = N+M
  C GET SCALE FACTORS
  DO 10 I=1,N
   S(I) = ABS(A(I+1))
  DO 20 J=1,N
   DA = ABS(A(I,J))
   IF(UA .LE. SKI)) GO TO 5
    S(I) = DA
  CONTINUE
  IF(S(I) .LE. 0.) GO TO 100
  CONTINUE
  C SCAL ALL ROWS
  DO 15 J=1,N
   AS = 1./S(I)
  DO 25 J=1,NM
   A(I,J) = AS*A(I,J)
  C START TRIANGULARIZATION PROCESS
  IF(N .LE. 1) GO TO 35
   NO = N-1
  DO 30 I=1,NO
   K = I+1
   DA = ABS(A(I+1))
  DO 40 J=1,N
   DB = ABS(A(J,I))
   IF(UA .LE. DA) GO TO 18
    K = J
    UA = UB
  CONTINUE
  IF(UA .EQ. 0.) GO TO 30
  IF(K .LE. 1) GO TO 22
  DO 20 J=1,NM
   B = A(K,J)
   A(K,J) = A(I,J)
   C A(I,J) = B
   DET = -DET
  II = I+1
  DO 29 J=II,N
   R = A(J+1,I)/A(I+1)
  DO 28 K=II,NM
   A(J+K) = A(J+K)-R*A(I+K)
  CONTINUE
  30 CONTINUE
  IF(ABC(A(N+1)) .LE. 1.0-10) GO TO 110

N = N1
M = M1
MN = N+1
NM = N+M
C GET SCALE FACTORS
DO 10 I=1,N
  S(I) = ABS(A(I+1))
DO 20 J=1,N
  DA = ABS(A(I,J))
  IF(UA .LE. SKI)) GO TO 5
   S(I) = DA
CONTINUE
IF(S(I) .LE. 0.) GO TO 100
CONTINUE
C SCALL ALL ROWS
DO 15 J=1,N
  AS = 1./S(I)
DO 25 J=1,NM
  A(I,J) = AS*A(I,J)
C START TRIANGULARIZATION PROCESS
IF(N .LE. 1) GO TO 35
  NO = N-1
DO 30 I=1,NO
  K = I+1
  DA = ABS(A(I+1))
DO 40 J=1,N
  DB = ABS(A(J,I))
  IF(UA .LE. DA) GO TO 18
   K = J
   UA = UB
CONTINUE
IF(UA .EQ. 0.) GO TO 30
IF(K .LE. 1) GO TO 22
DO 20 J=1,NM
  B = A(K,J)
  A(K,J) = A(I,J)
  C A(I,J) = B
  DET = -DET
II = I+1
DO 29 J=II,N
  R = A(J+1,I)/A(I+1)
DO 28 K=II,NM
  A(J+K) = A(J+K)-R*A(I+K)
CONTINUE
IF(ABC(A(N+1)) .LE. 1.0-10) GO TO 110

31
JTCG/AS-74-V-011

SUMMUG = U0, 0.
VER = 0.
EMUG = U0.
EMUG = U0.
GAL = U0.
TA = TA + 54.7
IF( KTANK .LE. 1) GO TO 100
V = ULLGH/ULLLHT
GO TO 200
100 V = 3.1*159265*ULMD4/ULLLHT = GAL = 0.231/1728.
200 ALT = ALT + 1000, 0
CALL ATMUS(ALT, TAM, RHU, EMWA, UUM1, UUM2)
 TF = LINTIME(1)
 PVAP = LIN( TF + 7)
 TF = TF + 459.7
PPFUEL = PVAP + 144.
PPAIR = PR - PPFUEL
RHU = (PPFUEL*EMWA + PPAIR*EMWA)/(RGAS*TA)
EM = RHU*V
Z = PPAIR*EMWA/(RHU*RGAS*TA)
VL100 = GAL/231/1728.
EM100 = EMWA
EMISO = (BETA*EM100*VL100*PPAIR)/(1.797*453.1*2116.224)
C
WRITE(6,CKINPT)
C
RETURN
END
SUBROUTINE EULER
COMMUN/LIMITS/10,TMAX,UT,TPRN1,UTPRN1,TIME,M16
DIMENSION X(9),XDOT(9)
COMMUN/EULLH/ XDOT X
COMMUN/OUTLIN/ULTA+CUN1+LON2+KHULIG+EMUIS0+SUMMDO+EMDOT
1+VLIG+EMUIS+EMUIS
C
DU 1 1 = 1,9
X(1) = X(1) + XDOT(1)*DT
CONTINUE
SUMMU0 = SUMMDO + EMDOU* DT
C
RETURN
END

SUBROUTINE FUNCT
COMMUN/STIR/ RGS,EMW,EMWF,CPA,CPF,HUJ(3),ULLGH,ULWID,ULHT,
1ULELH+ZOG+AV+CP+EM+UV,CUELTA,ATANK,GALD,TVENT

COMMUN/EULIN/ MDOT,TDOT,ZDOT, MDOTV, MDOTEV, MDOTCD, VDOT-
16GALU0,
2EM,TA+Z,EMV,EMOG,EMEV,EMCD,V,GAL
COMMUN/ETC/ ALT,AJI(3),TJ(3),RHOD,PR,PPAIR,PPFUEL,PPFLQ,
1AMACH, DALTUT,PDOT,OF,MASRAT,UVENT
COMMUN/OUTGAS/ BETA,CON1,CON2,HHOLIG,EMUIS0, SUMMDO, EMDOU
1,VLIG, EMUIS, EMUIS
COMMUN/LIMITS/10,TMAX, UT, TPKNT, UTPRN1,TIME,M16
REAL MD,T,MDOTV,MDOTEV,MDOTCD,MDOTG,MASRAT
NAMELIST/ANG/ TIME,ALT, MDOT,TDOT,ZDOT, MDOTV, MDOTG, MDOTEV,
1 MDOTCD, VDOTGALU0,EM,TA+Z,EMV,EMOG,EMEV,EMCD,V,GAL,PR,POOT,
2PPAIR,PPFUEL,PPFLQ,UVENT,OF,MASRAT
C
50 CALL EULER
TIME=TIME+DT
CALL DERIV
C
RETURN
END

33
ELZ = ELH*G/G0
DMOZ = 0.0
EM  = WMO

C CHECK TMS SLOPE AND CALCULATE PRESSURE
IF (ELH < EW < 0.0) GO TO 5

C NON-ZERO SLOPE PRESSURE EQUATION
A(4) = PM(J)*(TM(J)/TMS)**(GMRS/ELH)
GO TO 9

C ZERO SLOPE PRESSURE EQUATION
A(4) = PM(J)*GMRS*(MH(J)-H)/TMS
GO TO 9

C TMS LINEAR WITH Z, SEARCH MATRIX
6 DO 7 I = 2:14
J = I + 8
K = I + 1
IF (ZM(I) < TL) GO TO 8
STOP
CONTINUE

C CALCULATE TMS, SLOPE, AND STUFF
8 ELZ = (TM(J+1) - TM(J))/(ZM(K+1) - ZM(K))
TMS = TM(J) + ELZ*(Z - ZM(K))
DMOZ = (WM(K+1) - WM(K))/(ZM(K+1) - ZM(K))
EM  = WM(K) + DMOZ*(Z - ZM(K))
ZLZ = Z - TMS/TLZ

C PRESSURE EQUATION FOR TMS LINEAR WITH Z
1 A(4) = PM(J)*GMRS/ELZ*(NU/(K0+ZLZ)**2*(Z-ZM(K)))
2 1/(K0/(K0+ZLZ)) TO 6

C CALCULATE SOUND SPEED AND DERIVATIVE
9 A(1) = 49.022164*GMRS/258.26864
A(2) = 0.5*ELZ/TMS

C CALCULATE DENSITY, DERIVATIVE, AND PRESSURE DERIVATIVE
A(6) = GMRS*A(4)/G0/TMS
A(7) = -(A(6)+A(1)+ELZ/TMS)
A(5) = A(1)+A(6)

C CALCULATE TEMPERATURE, DERIVATIVE, AND LEAVE
A(8) = EM*TMS/WMO
A(9) = (EM*ELZ + TMS*DMOZ)/WMO

10 A6 = A(8)
A4 = A(4)
A1 = A(1)
A6 = A(6)
A5 = A(5)
RETURN
END
SUBROUTINE ATMOS(AS,AN,AL,AL,AL,AL,AL)
C THIS ROUTINE CALCULATES ATMOSPHERIC PROPERTIES OF THE
C US STANDARD ATMOSPHERE: 1962. ASSUMING AN INVERSE SQUARE
C GRAVITATIONAL FIELD, THIS ASSUMPTION YIELDS DATA THAT
C AGREES WITH THE CRISTA DOCUMENT WITHIN 1 PER CENT AT
C ALL ALTITUDES UP TO 700 KILOMETERS (2290588 FEET). THE
C DATA IS ARRANGED IN THE ATMOSPHERE AS AT AS AT
C FOLLOWS
C A(1) = CS, SPEED OF SOUND, FT/SEC
C A(2) = (1/CS)(U/L)(D/P), SOUND DERIVATIVE, 1/FT
C A(3) = Z, GEOMETRIC ALTITUDE, FT (GIVEN)
C A(4) = P, PRESSURE, LB/FT3
C A(5) = D/P, PRESSURE DERIVATIVE, LB/FT3
C A(6) = RHO, DENSITY, SLUGS/FT3
C A(7) = (1/TH4)(U/L)(D/P), DENSITY DERIVATIVE, 1/FT
C A(8) = T, TEMPERATURE, DEG RANKINE
C A(9) = UT/U, TEMPERATURE DERIVATIVE, DEG RANKINE/FT
C VARIOUS CONSTANTS USED
C EARTH RADIUS = 2089055 FT
C SPECIFIC HEAT HATU FOR AIR = 1.4
C SEA LEVEL VALUES
C UNAVITATIONAL ACCELERATION = 32.1740484 FT/SEC2
C MOLLELLAK WEIGHT = 28.9644
C GO*K0/K0 = 0.01874348 DEG RANK/FT
C DIMENSION AS AT AS AT AS AT AS
C SET CONSTANTS AND CONSTANT VALUES
C DATA GO,40,0.6,32.1740484,28.9644,0.01874348,2089055,0.
C 1,0.01874348/164044,0.0
C 536389,156317,104987,154199,170604,200131
C 2,259186,291160,1/295276,328084
C 3,36894,393701,492126,524934,557743,623560
C 734953,984252,1312536,1554200,1966504
C 6,2296589,2965018,28.9644,28.9644,28.9644
C 7,20.0726,92.2466,24.125,24.7,23.7,22.66,19.94
C 8,19.94,16.84,14.75,12.66,10.57,7.487
C DATA 14/77,17,518.63,389.7389.97,411.57
C 1,4871.17,4871.17,454.77,525.17,525.17,379.17,469.17
C 2,6417.17,1729.17,1999.17,2179.17,2431.17,2791.17
C 3,5295.17,3869.17,4357.17,4663.17,4861.17,542
C 4,3711.17,7839.2116,165.72,67563.11434314
C 5,1412655.2,5162176,1234197,5.5050279E-01
C 6,2,167532L-02,3.3431348E-03,1.62773411E-04,1.553490
C 7,9.4E-04,5.726142E-05,1.0561806E-05,7.7083076E-06
C 8,5.826151L-06,3.5159854E-06,1.9020255E-06,1.392909
C 9,6.5E-07,6.030242E-08,2.035256E-08,7.187548E-09
C A(3) = AS
C CALCULATE U, Z, AND CHECK
C Z = A(3)
C K = GO*(K0/(K0+2))**2
C IF (Z + K, 295276.0) GOTO 6
C TMS LINEAR WITH GEOPOTENTIAL, CALCULATE H AND SEARCH
C H = KU*Z/(KU+Z)
C UO 3 1 = *10
C UO 1 = 1 - 1
C UU (H/G) UU H UU 4
C CONTINUE
C CALCULATE TMS SLOPE TMS, AND SET MOL WT STUFF
C ELH = (TM(J+1) - TM(J))/(H(G(J+1) - H(GJ))
C TMS = TM(J) + ELH*(H - H(G))
\begin{align*}
A(2,1) &= \frac{1}{EM} \\
A(2,2) &= \frac{1}{TA} \\
A(2,3) &= EM \cdot (1/EM - 1) \\
A(2,4) &= 0 \\
A(3,1) &= \frac{1}{LM} \\
A(3,2) &= \frac{1}{TA} \\
A(3,3) &= (\Delta \gamma / \gamma) \cdot (CPA - CPF - RGAS \cdot (1/EM)A - 1) \\
A(3,4) &= -CPV \cdot TV / E \\
A(4,1) &= 1 \\
A(4,2) &= 0 \\
A(4,3) &= 0 \\
A(4,4) &= -1 \\
Y(1) &= MUOTOG \cdot ZOG / EM \\
Y(2) &= PUOT / PR + VDOT / V \\
HTRANS &= 0 \\
DU 300 \ I = 1.3 \\
300 \ HTRANS &= HTRANS + HJ(I) \cdot AJ(I) \cdot (T(J(I)) - TA) \\
Y(3) &= (MDOTEV \cdot CPF \cdot TF + MDOTUR \cdot CPF \cdot TP - MDOTCD \cdot (CPF \cdot TA - 1) \cdot ELLHF) + HTRANS / E \\
Y(4) &= MDOTEV + MDOTUG + MUOTCD \\
C \\
CALL \ LESK (C.X,DUMMY,4,1,4,0,LA) \\
IF (MOTPVE \ EQ. 0.) \ GO \ TO \ 375 \\
IF (MOTPVE / MOTOV) \ EQ. 350, 350, 375 \\
350 \ NCYC = NCYC + 1 \\
IF (NCYC EQ. 10) \ GO \ TO \ 140 \\
WHITE (6,900) \\
STOP \\
375 \ IF (LA.EQ.0.) \ GO \ TO \ 400 \\
WHITE (6,800) \\
STOP \\
400 \ CONTINUE \\
800 \ FORMAT (30H,UE(1ICIENT, MATRIX, IS, SINGULAR) \\
900 \ FORMAT(30H,UE(CALCULATION, IS, CYCLING) \\
RETURN \\
END
\end{align*}
75  T(J(1)) = LIN( M(1)+4)  
T(J(2)) = LIN( M(1)+3)  
T(J(3)) = LIN( M(1)+2)  
PVAP = LIN( T(1)+7)  
UU 100  I = 1,5  
100  T(J(1)) = T(J(1)) + 459.7  
C  CALCULATE  MUOTOG,  MUOTCV,  MUOTEV  
C  
MUOTCV = 0.0  
KHUNT = PK*EMW  
P PaiN = 2*KHONT/EMWA  
PFPFUEL = PK - PPAIK  
PFPFLGS = PVAP*144.  
IF(PFPFLGS .GE. 0.99*PR) GO TO 120  
MUOTEV = 0.0  
PFPALGS = PK - PFPFLGS  
IFABS((PPAIR-PPALGS)+LT,1,LT,-10) GO TO 130  
PAM = (PPAIR - PPALGS)/ALOG(PPAIR/PPALGS)  
CKG = UV*PH/(RGAS*TA*PAM*CUELTA)  
MUOTEV =AU(3)*CKG*(PFPFLGS - PFPFLG)*EMW  
GO TO 130  
120  WRITE(6,65)  
65  (FORMATE//28H(ULL BOILING MUOTLV CONSTANT)  
C  TEMPORARY  CALCULATION  OF  AMOUNT  OF  DISSOLVEDGAS  
130  EMUG = EMWA  
VLIP = (GALD*GAL)/231./1728.  
EMUISE = (BLTA*EMUG*VL1Q*PPAIR)/(1.797*253*2116.224)  
EMUIS = EMUISD - EMO = SUMMUD  
IF(LMUIS  ,LT, 0. ) WRITE(6,55)  
55  (FORMATE(0AMOUNT  DISSOLVED  GAS  IS  NEGATIVE)  
CON = CON1  
IF(LMUIS=EMUHSE  ,LT, 0. ) CON = CON2  
MUOTOG = CON1*(EMUHSE-EMUHSE)  
EMUHOT = LMUIS*GALUOT*231./VL1Q/1728.  
IF( TIME  +LU.  TO ) MUOTV = MUOT.  
140  IF(MUOTV  .LE. 0.0) GO TO 150  
C  VENTING  
C  
CPV = CP  
TV = TA  
ZV = Z  
LMWV = LMW  
GO TO 200  
C  FILLING  
C  
15.  CPV= CPA  
TV = TALT*(1.  + SQRT(0.72)*0.2*AMACH**2)  
IF(TVENT  .LT, 0. ) TV = TVENT  
ZV = 1.0  
EMW = EMWA  
200  RHUV = PRE*EMWA/(RGAS*TV)  
MUOTUL = MUOTV  
C  
A(1,1) = Z/LM  
A(1,2) = 0.0  
A(1,3) = 1.0  
A(1,4) = -ZV/EM  
C
SUBROUTINE OLEIV
COMMUN/LIMITS/T0,MAX,UT,IPRNT,OPRNL,TIME,M16,
COMMUN/STK,/HGA5,EMWA,LF,PA,CPF,HU(3),ULLGH,ULWID,ULHT,
10,LMF,125,AV,CP,LMW,UP,CUETAL,TANK,GAL0,TENT
COMMUN/ULIN/ MUOT,TUOT,ZDOT, MUOTV, MOOTEG, MOOTV, MOOTCU,VDOT,
10,ALUUT,
2LM,TA,LMV,EMUG,LMUL,LMULM,ULW
COMMUN/UTC/ AL,TAJ(3),IJ(3),MHUV,PR,PPAIR,PPFUEL,PPFLUS,
1 AMALU,ULUT,PUOTUP,DF,MAKAT,UVENT
COMMUN/OUT/ASUET/CON1,CON2,KHOIQ,EMUISO,SUMGSU,EMOUT
1,VLW,EMUS,EMUSE
REAL LINH(I1)
REAL MUOT,MUOTV,MUOTU,MUOTUG,MUOTVL
DIMENSION A(4,5),Y(4),C(4),X(4),DUMMY(4)
EQUIVALENCE (A,C), (C,Y,17), (X,MUOT), (TJ(3),F)
NAMELLIST/ULU/ PPAULS,AJ,TJ,MUOV,CP,DLTAUT,CPV,TV,2V,EMMV,Z,ZDOT
NAMELLIST/CLF/A,Y,MTANS

NCYC = 1
M(I) = TIME
AMACH = LIN(K(I),I)
CP = (1.-Z)*CPF + Z*CPA
LMH = 1. / (EMWA + (1.-Z)*EMF)
GAMMA = 1. / (HGS/(EMWA*CP)=778.1)
E = LM*CP*TA/GAMMA
CP0G = (1. - Z0G)*CPF + Z0G*CPA
ALT = LIN(0(I),5)
ALT = ALT + 1000.0
DUT= UT
IF( TIME +DT ,GL, TMAX ) DUT = UT
TPULL = TME +TTT1
ALT1 = LIN(TPULL,5)
ALT1 = ALT + 1000.0
ALT1 = ALT / DULT
ALT1 = ALT1 / DULT
CALL ATMS (ALT,TALT,PH,DUMM,DUMM1,DPUALT)
PUOT = UPDALT*ULALT
GALUUT = LIN(M(I),6)
VUOT = GALUUT*231.1728
IF( TANK ,EQ, 1) GO TO 75

C HECTANGULAR TANK
C CALC AI S I TJ S 1= TOP ; 2 = 4 SIDES ; 3= FUEL SURFACE
C
ULHT = V/(ULWIU*ULLGH)
AJ(1) = ULWID*ULLGH
AJ(2) =2.ULHT*(ULWIU + ULLGH)
AJ(3) = AJ(1)
GO TO 75

C CYLINDRICAL TANK - AXIS HORIZONTAL
C 1 = TOP ; 2 = 2 CIRCULAR SIDES ; 3 = FUEL SURFACE, DIAMETER = ULWID
C
50 GALNOW = (GAL0 - GAL) * 231.1728
THLT = 8.4*GALNOW/(ULWIU#2*ULLGH)
AJ(1) = (3.14159265 - THET/2.)* ULWID*ULLGH
AJ(2) = ULWID#2*THLT/4.
AJ(3) = ULWID*ULLGH*SIN(THET/2.)

38
74 CONTINUE
75 CONTINUE
CALL INITIL
CALL DERIV
CALL PRINT
C C ENTER INTEGRATION LOOP
C M16= 0
100 M16= M16+1
CALL FUNCT
IF( IPNT .EQ. 0) GO TO 200
C C LAST TIME STEP WAS TO PRINT STATION
C 150 TIME= TPRNT
CALL PRINT
TPKNT= TPRNT + DTPKNT
IF( TIME .GE. TMAX) GO TO 1001
DI= UTSV
IPRT=0
200 CONTINUE
C C CHECK FOR PRINT STATION
C CK= TIME + UT+ TOL
IF( TIME .GE. TMAX) GO TO 1001
IF( CK .GE. TMAX) IPKNT=TMAX
IF( CK .LT. TPRNT) GO TO 100
IPRT=1
UTSV= UT
DT= TPRNT- TIME
IF( UT .LE. TOL) GO TO 150
GO TO 100
1000 STOP
1001 GALX=GAL0
WRITE(7)(FAR(I)+1,I=1,1253)
GO TO '50
END
SUBROUTINE PRINT
COMM/JUN/TRNL/CD12)
COMM/LIMITS/T0,TMAX,UT,ITRNL,ITRNL,TIME,M16
COMM/STM/ RAS,LMF,CFP,CPH,ULMAX,ULWD,ULMAX,
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INPUT DATA FOR WSFT B-1 FORWARD FUSELAGE TANK TEST CASE

9 END OF RECORD
9 END OF RECORD

DATA

END OF RECORD

FUSELAGE TANK TEST CASE FOR

END OF RECORD

INPUT DATA

END OF RECORD

JTCG/AS-74-V-011

9 END OF RECORD
9 END OF RECORD
PATH TAPE CREATOR PROGRAM

PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6,TAPE7,TAPE8,TAPE9,TAPE10,TAPE11,TAPE12,TAPE13,TAPE14,TAPE15,TAPE16)
COMMON /SAVE/ HT(250),VT(250),FAK(250),JFLEFT(250,10)
COMMON /FILE7/ FA(250),FL(250),FT(250),H(250),V(250),NTP,GAL,TIN
INTEGER GAL
READ(5,1000)NTP
READ(7,FA(1),1=1,1253)
UO 1 I=1,NTP
HT(I)=H(I)
VT(I)=V(I)
FA(I)=FA(I)
FL(I)=FL(I)
FLEFT(I)=FLEFT(I)
NT=NTP
HT0=NTP
TINC=TIN
GAL(I)=GALX
IF(NTP.EQ.1) GO TO 4
IEND=6+NTP
K=1
READ(1)(FA(J),J=1,1253)
IF(H(J).NE.HT(J)) GO TO 5
UO 2 J=1,NTP
IF(V(J).NE.VT(J)) GO TO 5
FA(J)=FA(J)
FTEMP(J,K)=FT(J)
FLEFT(J,K)=FL(J)
GAL(K)=GALX
WRITE(6)(H(J),J=1,NTP)
STOP
5 PRINT 2000
STOP
1000 FORMAT(15)
2000 FORMAT(* DENT (LIGHT PROFILES (OR TWO TANKS*))
END
9 1
9

42
VULNERABILITY PROGRAM

PROGRAM FVMN(INPUT,OUTPUT,TAPE6)
COMON /COUNTER/ VSCUM(10),RSCUM(10),INIT(10),IEF(10),IEN(10),
     IP ARM(10),IFE(10),ILEAK(10)
COMON /WEAPONS/ VZERO(32),PENM(32),CDRAG(32),13ORF(32),AZMIN(32),
     A2MAX(32),ELMIN(32),EMAX(32),NSHOTS(32),TIGN(32),TASH(32),IME(32),
COMON /TANKS/ DSKIN(610),ILG(610),XGC(10),ZGC(10),
     X1(10),Y1(10),Z1(10),X2(10),Y2(10),Z2(10),HMIN(10),FULLPC(10)
COMON /INOUT/ ABM,ISP,ASP,XML,YN,ZOUT,YOUT,ZOUT,ENTRY,
     IAFEN,AFEX,10,10,20
COMON /PROFILE/ K(250),AMACH(250),FAR(250),PFUEL(250)
     IFERM(250),GAL(10),NNTANKS,NTINC
COMON /AIP/ ATANK(210),AWEAP(32),ASOL(2),ATARG
COMON /EDITOR/ EML(32*32)
COMON /FRAGS/ VE(32),PSI(32),COSMAX(32),COSMIN(32),CD(32),SF(32),
     1DF(32),YF(32),ZF(32)
DIMENSION CEF(10),CLEAK(10),CNE(10),PHC(10),PAF(10),PF(10)
EQUIV(CEF1),IEF1),(CEF1),IFE1),ICL(1),IHE(1),
     IPH(1),1AFEX(1)
LOGICAL ENTRY,NOH,EFEN,AFEX
INTEGER VAL,XSTNEWEAP(250)
DATA TWOPIDT,E strengths,0.017453293932,172/
     DATA AMACH,ASOL/10HFRAGMENTIN,10HGWARHEAD,10H SOLID SHO,10HT WEAP
10N /
CALL REPT1
READ 200,NWEAPS,XST,HKAM,KATMIN,KATMAX
READ 201,NWEAPS(1),1=1,NTP
READ 202,(ISOFK(I),IEH(I),NSHOTS(I),AZMIN(I),AZMAX(I),ELMIN(I),
     1ELMAX(I),XF(I),YF(I),ZF(I),I=1,NWEAPS)
READ 203,(TIGN(I),TASH(I),VZERO(I),PENM(I),CDRAG(I),I=1,NWEAPS)
READ 207,(VE(I),PSI(I),COSMAX(I),COSMIN(I),CD(I),SF(I),
     1I=1,NWEAPS)
READ 204,(EMIL(I,J),I=1,32),J=1,NWEAPS)
READ 205,(XGCG(I),XGC(1),ZGC(I),X1(I),Y1(I),Z1(I),X2(I),Y2(I),Z2(I),
     I=1,NNTANKS)
READ 206,(XGCG(I),XGC(1),ZGC(I),X1(I),Y1(I),Z1(I),X2(I),Y2(I),Z2(I),
     I=1,NNTANKS)
READ 207,(X1(I),Y1(I),Z1(I),X2(I),Y2(I),Z2(I),I=1,NNTANKS)
READ 208,(AWEAP(I),1=1,NWEAPS)
CU 103 ITIME=1,NTP
TIME=TIME+1 1TIME=1
VE=DEMACH(AMACH(ITIME),H(H(ITIME))
DELTA=0.0/VT
ALT=H(1TIME)
DO 102 IWEAP=1,NWEAPS
IF(A(AND(NWEAP=I),2**2(IWEAP-1)),NE.2**2(IWEAP-1)) GO TO 102
SLUGS=PENM(IWEAP)/3000,0.066E6
VE=VE(IWEAP)
BD=CU(IWEAP)
COSTX=COSMAX(IWEAP)
COSTX=COSMIN(IWEAP)
PSI=PSX(IWEAP)
FM=PENM(IWEAP)
SIG=SF(IWEAP)
XFUSE=XLIFEAP)
YFUSE=YLIFEAP)
ZFUSE=ZF(IWEAP)
T1=TIGN(IWEAP)
43
T2=TASH(IWEAP)
IVT=VT
I=IVT/100+1
IF (I,G.1,30) GO TO 1
LKM=MIL(I,IWEAP)+(0.01*VT-I+1.0)*(EMIL(I+1,IWEAP)-EMIL(I,IWEAP))
GO TO 2
1 LKM=MIL(I+1,IWEAP)
2 NOHE=.TRUL.
   IF (IHL(IWEAP),GT,0) NOHE=.FALSE.
   NSH=NSHOTS(IWEAP)
   GO TO 500
500 VSCUM(I)=0.0
   DO 100 ISHT=1,NSH
      AZ=AZMIN(IWEAP)+RANF(XST)*(AZMAX(IWEAP)-AZMIN(IWEAP))
      EL=ELMIN(IWEAP)+RANF(XST)*(ELMAX(IWEAP)-ELMIN(IWEAP))
      AZ=AZ*DTOR
      EL=EL*DTWR
      CUS=CUSCEL
      XMU=COS*AZ
      YMU=SIN*AZ
      KS=ABS(CALT/ZMU)
      IF (ISORF(IWLAP),GT,1) GO TO 3
      SIGMA=t(S*EK'K/0.671+5)
      GO TO 4
3 SIGMA=ERH
4 DM=ALGSIGAUS(SIGMA)
   THLTA=RANF(XST)*TWOPI
   COSTH=COS THLTA
   SIGT=1.0-A*A+B*B
      IF (SIGT.LT.0.0) GO TO 7
   SIGT=ALGS(wrt(1/0-A*A)YMU)
6 C=0.0
   GO TO 8
7 C=ALGS(wrt(C, ZMU)
   IF (ABS(C),LT,1.0) GO TO 9
   U=SQRT(A*A+B*B)
   COSPSI=-A/U
   SINSPI=8/0
   XO=DM*(C*COSTH*COSPSI+SINTH*SINPSI)
   YO=DM*(-C*LUSTH*SINPSI+SINTH*COSPSI)
   ZO=-(A*XO+B*YO)/C
   GO TO 10
8 XO=DM*B*COS
   YO=DM*A*SINT
   ZO=DM*COSTH
   GO TO 10
9 XO=DM*COSTH
   YO=DM*SINTH
   ZO=0.0
10 IF(ISORF(IWEAP),GT,1) GO TO 50
   ENTHY=FALSE.
   UU 11 ITANK=I+INTANKS
   CALL IN(XC(ITANK),YCG(ITANK),ZCG(ITANK),X1(ITANK),Y1(ITANK),
1211 ITANK = 0.01*PFUEL(ITIME, ITANK) + FULLPC(ITANK)
11 IF (*N01. ENTRY) GO TO 11
12 CALL OUT(XCG(ITANK), YCG(ITANK), ZCG(ITANK), X1(ITANK), Y1(ITANK),
          Z1(ITANK), U01*PFUEL(ITIME, ITANK) + FULLPC(ITANK))
13 GO TO 14
11 CONTINUE
12 IF (*N01. ENTRY) GO TO 11
13 CALL OUT(XCG(ITANK), YCG(ITANK), ZCG(ITANK), X1(ITANK), Y1(ITANK),
          Z1(ITANK), U01*PFUEL(ITIME, ITANK) + FULLPC(ITANK))
14 CONTINUE
15 GO TO 100
14 I1TANK = HIT(ITANK) + 1
15 KAT10 = FAR(ITIME, ITANK)
16 RSCUM(ITANK) = RSCUM(ITANK) + RS
17 VSCUM(ITANK) = VSCUM(ITANK) + VSH
18 ENERGY = ENERGY + J1G*VSH*VSH
19 U1 = USKIN(IASP, ITANK)
20 IF (ENERGY < HRAM) GO TO 15
21 IF (AFEN) GO TO 25
22 IF (ENERGY < HRAM) GO TO 15
23 IRAM(ITANK) = IRAM(ITANK) + 1
24 GO TO 100
25 D2 = D1 + 2.0*X1(ITANK)
26 D2 = D1 + 2.0*Y1(ITANK)
27 D2 = D1 + 2.0*Z1(ITANK)
28 IF ( VSH > Y1, GT, D2 ) GO TO 22
29 IF ( VSH > Y1, LT, U1 ) GO TO 22
30 IF ( VSH > Y1, LT, U1 ) GO TO 22
31 IF ( VSH > Y1, U1 ) GO TO 22
32 IEF(ITANK) = IEF(ITANK) + 1
33 GO TO 100
34 ILEAK(ITANK) = ILEAK(ITANK) + 1
35 GO TO 100
36 IF ( AFEXB ) GO TO 17
37 ILEAK(ITANK) = ILEAK(ITANK) + 1
38 IF ( I1G(IASP, ITANK), GT, U ) GO TO 16
39 GO TO 100
40 IEF(ITANK) = IEF(ITANK) + 1
41 GO TO 100
42 IAFEXB(ITANK) = IAFEXB(ITANK) + 1
43 IF ( KAT10, LT, KATMIN ) GO TO 22
44 IF ( KAT10, LT, KATMAX ) GO TO 22
45 GO TO 100
46 ILEAK(ITANK) = ILEAK(ITANK) + 1
47 GO TO 100
48 IAFEN(ITANK) = IAFEN(ITANK) + 1
49 IF ( KAT10, LT, KATMIN ) GO TO 28
50 IF ( KAT10, LT, KATMAX ) GO TO 28
51 GO TO 100
52 D2 = D1 + 2.0*X1(ITANK)
53 D2 = D1 + 2.0*Y1(ITANK)
54 D2 = D1 + 2.0*Z1(ITANK)
55 GO TO 27
56 D2 = D1 + 2.0*Y1(ITANK)
57 GO TO 27
58 D2 = D1 + 2.0*Z1(ITANK)
59 D2 = D1 + 2.0*Z1(ITANK)
60 IF ( VSH > Y1, D1, D2 ) GO TO 28
IF(VSMST2*LI.U1) GO TO 28
IF(AFEX) IAFEXA(ITANK)=IAFEXA(ITANK)+1
GO TO 100
28 IF(.NOT.AFLX) GO TO 29
IAFEXA(ITANK)=IAFEXA(ITANK)+1
GO TO 100
29 IF(ENERGY.LT.HKAN) GO TO 30
IRAM(ITANK)=IRAM(ITANK)+1
GO TO 100
30 ILEAK(ITANK)=ILEAK(ITANK)+1
IF(IITG>JAK+ITANK).UT.0. IIEF(ITANK)=IEF(ITANK)+1
GO TO 100
50 TF=GAUS(SIGF/VSH)
XSTAR=X0+TF*(VSH*XMU*VT)+XFUSE
YSTAR=Y0+TF*VSH*YM*TFUSE
ZSTAR=Z0+TF*VSH*ZMU+ZFUSE
DO 61 ITANK=1,ITANKS
YT=YCG(ITANK)-YSTAR
ZT=ZCG(ITANK)-ZSTAR
XT=XCG(ITANK)-XTAR
C1=VI=VR-VE=VEM
C2=VSH*(XMU*VT+VSH*XT+YM*YT+ZMU*ZT)/C1
C3=XT+Y1+YT+ZT+C1
DISCR=SQR((C2*C2-C3/C1)
T=C2/DISCR
IF(T>T,UT.) T=C2+DISCR
ITER=0
51 IF(ITER.GT.25) GO TO 61
XT=XT+VT*T
XL=SQR1(XT+YT+YT+ZT+ZT)
IF(XL.EQ.0.0) GO TO 61
BETAX=XT/XL
BLTAY=YT/XL
COSTH=XMU*BETAY+YMU*BETAY+ZMU*BETAY
VOUT=VSH*(XMU*BETAY+VSH+VSH*VSH)*COSGAM+VEM*VEM+VSH*VSH)
FODT=1.0+(V0+V0D*T)/1.0+8*V0+V0T)-BETAY*VT)
IF(FD0T.LE.0.0) GO TO 61
F=ALOQ(l.0+B0*V0+V0T)-BB*XL
THEWT=F/FD0T
IF(AABS(TNEW-T).LE.DELTA)  GO TO 52
T=TNEW
ITER=ITER+1
GO TO 51
52 IF(XL.GT.500) GO TO 61
COSTH=V0*COSGAM-VSH)/VEM
IF(COSTH.LT.COSTMX) GO TO 61
IF(COSTH.GT.COSTMN) GO TO 61
INITITANK=INITITANK+1
E=AA*ABS(AA+COSTH)/(AA+AA+2.0+AA*COSTH+1.0)**1.5
PSICPSIST/(E*XL*XL)
VHIT1=VU*EXP(-BB*XL)
VNET=SQR1(VHIT1-VHIT2*2.0*VT*VHIT*8ETH*VT+VT)
EDENS=0.5*SlUS*VHIT/VNET*PSIC
IF(EDENS.GE.0) IRAM(ITANK)=IRAM(ITANK)+1
ATB=0.A11ITANK)+Y1(IITANK)
ASS=4.0*XI(IITANK)+Z1(IITANK)
AFR=4.0*Y1(IITANK)+Z1(IITANK)
SAR = ABS(BETA_X) * AFH + ABS(BETA_Y) * ASS
TAR = SAR + ABS(BETA_Z) * ATB
PHCUM(ITANK) = PHCUM(ITANK) + 1.0 * EXP(-PSIC * TAR)
ARBF = 0.01 * FUEL(ITIME, ITANK) * 0.01 * FULLPC(ITANK) * SAR
ARAF = ARBF
IF (BETA_Z) 55 = 55.54
53 ARAF = ARAF + BETA_Z * ATB
GO TO 55
54 ARBF = ARBF + BETA_Z * ATB
55 PHITAF = 1.0 * EXP(-PSIC * ARAF)
PHITAF = 1.0 * EXP(-PSIC * ARAF)
TMP = TEMP(ITIME, ITANK)
IF (ALT <= 10000.0) GO TO 56
AFAC = 2.5 * EXP(-0.000092 * ALT)
IF (ALT <= 60000.0) GO TO 56
IF (TMP <= 0.0) GO TO 58
IF (TMP > 45.0) GO TO 57
DF = TMP * 45.0 * (1.2 - 0.00002 * ALT)
GO TO 60
56 AFAC = 1.0
IF (TMP <= 0.0) GO TO 58
IF (TMP > 45.0) GO TO 59
DF = TMP / 45.0
GO TO 60
57 DF = 1.2 - 0.00002 * ALT
GO TO 60
58 DF = 0.0
GO TO 60
59 DF = 1.0
60 CEF(ITANK) = CEF(ITANK) + 0.3 * DF * PHITBF
CLEAK(ITANK) = CLEAK(ITANK) + PHITBF * (1.0 - 0.3 * DF)
MATIQ = MATIQ (ITIME, ITANK)
IF (MATIQ <= 0.1) GO TO 62
IF (MATIQ <= 0.5) GO TO 62
CFL(ITANK) = CFL(ITANK) * 0.0000769 * SQHT(FM) * VNIT* AFAC * PHITAF
62 VSCUM(ITANK) = VSCUM(ITANK) + VSCUM
KSCUM(ITANK) = KSCUM(ITANK) + KS
61 CONTINUE
100 CONTINUE
IF (ISUMF(IWEAP), GT, 1) GO TO 108
100 101 ITANK = 1, NITANK
IF (IINIT(IITANK), EQ, 0) GO TO 101
VSAVE = VSCUM(ITANK) / IINIT(IITANK)
PAFE.XA = (1.0 * IAFIT.XA(ITANK)) / IINIT(IITANK)
IF (IINIT(IITANK), EQ, 0) GO TO 106
PAFE.XA = (1.0 * IAFIT.XA(ITANK)) / IAFIT.XA(ITANK)
GO TO 105
104 PAFEXA = 0.0
PAFX.B = (1.0 * IAFIT.XB(ITANK)) / IINIT(IITANK)
GO TO 107
105 IF (IINIT(IITANK), EQ, 0) GO TO 106
PAFX.B = (1.0 * IAFIT.XB(ITANK)) / (IINIT(IITANK) - IAFIT.IITANK)
GO TO 107
106 PAFEX.B = 0.0
107 PEAK = (1.0 * ILEAK(ITANK) - IEF(ITANK)) / IINIT(IITANK)
PFE = (1.0 * IPE(ITANK)) / IINIT(IITANK)
PEF = (1.0 * IEF(ITANK)) / (IINIT(IITANK) - IAFIT.IITANK)
RSAVL = RSCUM(ITANK) / IINIT(IITANK)
PHIT = (1.0 * IINIT(IITANK)) / NSH
PRAM = (1.0 * IRAM(ITANK)) / IINIT(IITANK)
PNUEF=1.0+PLEAK*PRAM*PFE*PEF
P6PEN=1.0-P6PEN
PEFEXA=1.0-P6FEXA
P6FEXB=1.0-P6FEXB
PKAM=1000+ASUL+ATAG+(ATANK(1,ITANK)=1=1,2)
PKAM=10U+TIM+AEAP(IWEAP)+P6PEN
PKFUE=1002+PHII+PFUEL(IITIME,ITANK)
PKHIT=1003+VsAVE+FTEMP(IITIM,ITANK)+P6FEXB
PKHIT=1004+HSAVE+FAK(IITIME,ITANK)+P6FEXB
PKHIT=1005+H(IITIME)+VT*P6PEN
PKHIT=1006+P6FEXA+P6FEXA
PKHIT=1007+PNUEF+PLEAK*PRAM*PFE
101 CONTINUE
GO TO 102
100 GO TO 109 ITANK=1,NTANKS
IF(P6CUM(1,ITANK)=EQ.0,0) GO TO 109
VSAVE=VSUM(ITANK)/HINIT(1,ITANK)
P6LEAK=UFL(1,ITANK)/HINIT(1,ITANK)
P6FEXA=UFLEAK*(HINIT(1,ITANK))/HINIT(1,ITANK)
P6FEXB=(1.0-HFAM(1,ITANK))/HINIT(1,ITANK)
PKHIT=1000+AWAK,ATH10(1,ITANK),1=1,2
PKHIT=1013+TIM+AEAP(IWEAP)
PKHIT=1008+P6HIT+PFUEL(IITIME,ITANK)
PKHIT=1009+VSAVE+FTEMP(IITIME,ITANK)
PKHIT=1010+SIGMA+FAR(IITIME,ITANK)
PKHIT=1011+ALT+VT
PKHIT=1012+P6LEAK*PRAM*PFE
109 CONTINUE
102 CONTINUE
103 CONTINUE
STOP
1000 IF(UMAT=1.5*(*UFL TANK VULNERABILITY MODEL)/625*REPORT 2/*0,
1500 A10*/*A10*/*AIF*/*A10*/*F9.6)
1001 IF(UMAT=1.5*(*HIT IN MISSION(HK)=*,/F7.2*/*F9.6*/*F9.6)
1002 IF(UMAT=1.5*(*HIT ON UFL TANK=*,/F7.2*/*F9.6*/*F9.6)
1003 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1004 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1005 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1006 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1007 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1008 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1009 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
1010 IF(UMAT=1.5*(*HIT ON IDEFRY=*,/F7.2*/*F9.6*/*F9.6)
SUBROUTINE IN(XT,Y1,Y2,Y3,Y4,Y5,Y6)
LOGICAL ENTRY, AREF
REAL LT
COMMON / INOUT/ A+B+C+IASP+JASP+XIN+XIN,XOUT,YOUT,ZOUT,ENTRY,
AREF+AFEX,X0,Y0,Z0
IF (C)1=2
1 IASP=5
ZIN=ZT+HT
GO TO 3
2 IASP=6
ZIN=ZT-HT
3 YIN=A/(C*(ZIN-Z0)+YO
XIN=A/(C*(ZIN-Z0)+YO
IF (ABS(YIN-Y1),GT,WT) GO TO 4
IF (ABS(YIN-X1),GT,LT) GO TO 4
GO TO 12
4 IF (A)5=6
5 IASP=3
YIN=YT+XT
GO TO 7
6 IASP=4
YIN=YU-WT
7 ZIN=A/(E*(YIN-YU)+ZO
XIN=A/(E*(YIN-YU)+ZO
IF (ABS(ZIN-ZT),GT,HT) GO TO 8
IF (ABS(ZIN-X1),GT,LT) GO TO 8
GO TO 12
8 IF (A)9=17
9 IASP=1
XIN=XT+LT
GO TO 11
10 IASP=2
XIN=XT-LT
11 ZIN=A/(E*(XIN-X0)+ZO
YIN=B/A*(XIN-X0)+YO
IF (ABS(ZIN-ZT),GT,HT) RETURN
IF (ABS(YIN-Y1),GT,WT) RETURN
12 ENTRY=.TRUE.
IF (PFUEL)17=16+13
13 IF (PFUEL)EQ.100.0) GO TO 15
IF (IASP)5=14+16+15
14 IF (SO.0,(ZIN-ZT+HT)/XT,GT,PFUEL) GO TO 16
15 AFEX=.FALSE.
RETURN
16 AFEX=.TRUE.
17 RETURN
END
JTCG/AS-74-V-011

SUBROUTINE UUT(XU, YU, ZU, LT, WT, HT, PFUEL)
LOGICAL AFEX
REAL LT
COMMON /INOUT/ A, B, C, IXASP, JASP, XIN, YIN, ZIN, XOUT, YOUT, ZOUT, ENTRY,
AFEX, AFEX, XO, YO, Z0
IF (C) 1, 4, 2
1 JASP=6
    ZOUT=ZT-HT
    GO TO 3
2 JASP=5
    ZOUT=ZT+HT
3 YOUT=C/B*(ZOUT-ZU)+YO
    XOUT=A/C*(ZOUT-ZU)+XU
    IF (ABS(YOUT-YT), GT, WT) GO TO 4
    IF (ABS(XOUT-XT), GT, LT) GO TO 4
    GO TO 13
4 IF (B) 5, 6, 16
5 JASP=4
    YOUT=YT-WT
    GO TO 7
6 JASP=3
    YOUT=YT+HT
7 ZOUT=C/B*(ZOUT-ZU)+Z0
    XOUT=A/C*(ZOUT-ZO)+X0
    IF (ABS(ZOUT-ZT), GT, HT) GO TO 8
    IF (ABS(XOUT-XT), GT, LT) GO TO 8
    GO TO 13
9 IF (A) 12, 10
A JASP=2
9 XOUT=XT-LT
    GO TO 11
10 JASP=1
    XOUT=XT+LT
11 ZOUT=C/A*(XOUT-XO)+Z0
    YOUT=B/A*(XOUT-XO)+YO
    IF (ABS(ZOUT-ZT), GT, HT) GO TO 12
    IF (ABS(YOUT-YT), GT, WT) GO TO 12
    GO TO 13
12 PRINT 1000
STOP
13 IF (PFUEL.EQ.0.0) GO TO 15
    IF (PFUEL.EQ.100.0) GO TO 14
    IF (JASP.EQ.6) GO TO 14
    IF (50.0*(ZOUT-ZT+HT)/HT, GT, PFUEL) GO TO 15
14 AFEX=FALSE.
RETURN
15 AFEX=TRUE.
RETURN
1000 (UNHAT* ENTRY BUT NO EXIT*)
END
FUNCTION UEMACH(AMACH, HT)
    IF (HT, LT, 3609, 0) GO TO 1
    UEMACH=968.452*AMACH
RETURN
1 (UEMACH=9, 0.40772, SQRT(518.688-0.00356616*HT)*AMACH
RETURN
END
SUBROUTINE NEPT1
COMMON /PROFILE/ HT(250), VT(250), FAR(250, 10), FLEFT(250, 10),
IFTEM(250, 10), GAL(10), NTANKS, NTP, TINC
COMMON /ALPHA/ ATANK(250), ATANK(250), ATANK(250), ATARK(250), ASOL(2), ATARG
INTEGER GAL
REAL (6) (MT(I), I=1, 10)
REAL 2000.1 ((ATANK(1+i), i=1, 2), j=1, NTANKS), ATARG
REAL 1.1
IST=1
1 IENU=IEN+4
ILEFT=ILEFT-5
IF (ILEFT.GT.0) GO TO 2
IENU=IENU+ILEFT
2 LINE=0
NTPS=1
3 IF (MTU(I), LINE(60), GT.0) GO TO 4
PRINT 1000, ATANK(1+i), i=1, 2), 1=IST, IENU)
PRINT 1001, (GAL(1), 1=IST, IENU)
PRINT 1002
LINE=LINE+12
4 TINC=TINC*(NTPS-1)
PRINT 1003, (FAR(NTPS, 1), FLEFT(NTPS, 1), 1=IST, IENU)
LINE=LINE+1
NTPS=NTPS+1
IF (MTU(LINE, NTP, GT.0) GO TO 5
IF (ILEFT.LE.0) RETURN
IST=IENU+1
GO TO 1
1001 (UMAT(11X, 5(3X, 21(----)) / 11X, 5(16, +, GALLON CAPACITY))
1002 (UMAT(11X, 5(3X, 21(----)) / 5 TIME INTO + 515X, * PCT. (UEL) /
1# MILESIGN +5(*. F/A RATIO R1MAINING))
1003 (UMAT(1X, 10, 3, 5(12, 6, (12, 2))
2000 (UMAT(5A10))
END

FUNCTION GAUS(SIGMA)
GAUS=0.0
DO 1 I=1, 12
1 GAUS=GAUS+RAINF(0.0)
GAUS=SIGMA*GAUS+6.0)
RETURN
END
9 END OF RECORD
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A Textron Co.
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Fairchild Republic Co.
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Baltimore, MD 21204
  Attn: W.J. Douglass, Jr.

Falcon Research and Development Co.
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Albuquerque, NM 87108
  Attn: W.L. Baker

Fiber Science, Inc.
7006 Sea Cliff Rd.
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  Attn: R.N. Flath

Firestone Coated Fabrics Co.
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San Diego, CA 92138
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  Attn: J.P. Waszczak

General Dynamics Corp.
Fort Worth Division
Grants Lane, P.O. Box 748
Fort Worth, TX 76101
  Attn: P.R. deTonnancour/G.W. Bowen

General Electric Co.
Aircraft Engine Group
1000 Western Ave.
West Lynn, MA 01905
  Attn: E.L. Richardson
  Attn: J.M. Wannemacher
General Electric Co.
Aircraft Engine Group
Evendale Plant
Cincinnati, OH 45215
Attn: AEG Technical Information Center (J.J. Brady)

Goodyear Aerospace Corp.
1210 Massillon d.
Akron, OH 44315
Attn: J.E. Wells (D/959)
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Attn: T.L. Shubert (D/910)

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Bethpage, NY 11714
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Irvine, CA 92664
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Rockwell International Corp.
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Attn: Technical Information Center (D.Z. Cox)

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International Airport
Los Angeles, CA 90009
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Russell Plastics Tech.
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Lindenhurst, NY 11757
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Sikorsky Aircraft
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Attn: J.B. Faulk
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P.O. Drawer 28510
San Antonio, TX 78284
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San Diego, CA  92112  
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Wichita Division  
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This report presents the results of a study to develop a dynamic model of the vulnerability of an aircraft fuel system to the threats posed by hostile weapons. A Monte Carlo model was developed to calculate the probability of hit along segments of the fuel system. The results are presented in tabular form and provide guidance for system designers. The model is based on realistic assumptions and incorporates the latest technology in fuel system design.

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specified flight profile at each point where a specified weapon system could pose a threat to the fuel system. An Air Force developed computer model (Well-Stirred Fuel Tank Model) is used to compute fuel state in each fuel tank under study at increments along the flight path. These are used as inputs to the Monte Carlo model.

Given that a hit takes place, the probable trajectories (liquid-air, liquid-liquid, air-liquid, and air-air) are calculated, and the probabilities of lethal outcomes (explosion, internal fire, external fire, leak) are computed. The model ranks the most likely events, and a hazard index is generated which portrays the most important threats to the fuel system on the specified flight path.

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The resulting model gives an improved measure of the impact of fuel state on the vulnerability of a fuel system on aircraft vulnerability. It does not incorporate consideration of the effects of fuel slosh, vibration, or vent geometry. Further refinement and development is recommended.
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