AFWAL-TR-88-3101

Automated Structural Optimization System (ASTROS) User Training Workshop

AF WRIGHT AERONAUTICAL LABORATORIES

E.H. Johnson
D.J. Neill
Northrop Corporation
Aircraft Division
Hawthorne, CA 90250-3277

D.L. Herendeen
Universal Analytics, Inc.
Playa del Rey, CA 90293-8495

R.A. Canfield
U.S. Air Force
Wright-Patterson AFB, OH 45433-6523

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Flight Dynamics Laboratory
Wright Research and Development Center
Air Force Systems Command
Wright-Patterson AFB, OH 45433-6523

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R. A. Canfield
ROBERT A. CANFIELD, Capt, USAF
Project Engineer
Design and Analysis Methods Group

Nelson D. Wolf
NELSON D. WOLF, Technical Manager
Design and Analysis Methods Group
Analysis and Optimization Branch

FOR THE COMMANDER

John T. Ach
JOHN T. ACH, Chief
Analysis and Optimization Branch

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01	01	03

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The ASTROS (Automated Strucutral Optimization System) procedure provides multidisciplinary analysis and design capability for aerospace structures. The engineering analysis capabilities in the system include structural analysis (static and dynamic), aeroelastic analysis (static and dynamic) and automated design. A specifically designed data base and executive system were implemented to maximize the system's efficiency, flexibility, and maintainabilit The charts used in the ASTROS User Training Workshop, conducted by the Air Force and Northro are presented in this report.

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Capt R. A. Canfield	(513) 255-6992	WRDC/FIBRA

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FOREWORD

Contract F33615-83-C-3232, entitled "Automated Strength-Aeroelastic Design of Aerospace Structures," was initiated by the Analysis and Optimization Branch (FDSR) of the Air Force Wright Aeronautical Laboratories. The objective of this contract was to develop a computer procedure which can assist significantly in the preliminary automated design of aerospace structures. This report consists of materials used at the ASTROS User Workshop.

Northrop Corporation, Aircraft Division, was the primary contractor for this program with Universal Analytics, Inc. (UAI) and Kaman AviDyne acting as subcontractors. The principal contributors to this report were: E. H. Johnson, the overall Program Manager at Northrop D. J. Neill, Project Co-Principal investigator, D. L. Herendeen, the Project Manager at UAI, and R. A. Canfield, the Air Force Project Engineer.

Capt R. A. Canfield was the Air Force Project Manager while Dr V. B. Venkayya initiated the program at the Air Force and provided overall program direction. The work reported on in this report was performed from 01 July 1983 through 24 June 1988.

The authors would like to acknowledge those who acted as instructors at the ASTROS User Training Workshop held at Wright-Patterson AFB from 20 June to 24 June, 1988:

Capt Robert Canfield	Flight Dynamics Laboratory
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Dr Erwin Johnson	Northrop
Mr Raymond Kolonay	Flight Dynamics Laboratory
Mr Doug Neill	Northrop
Lt Bruce Snyder	Flight Dynamics Laboratory
Mr Richard Swift	Universal Notre Dame
Mrs Victoria Tischler	Flight Dynamics Laboratory
Dr Vipperla Venkayya	Flight Dynamics Laboratory
Mr Les Whitford	ASD Computer Center

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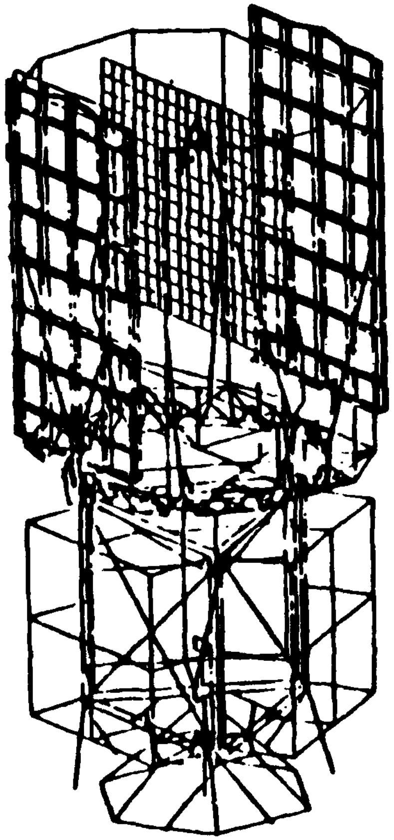
20–24 June 1988



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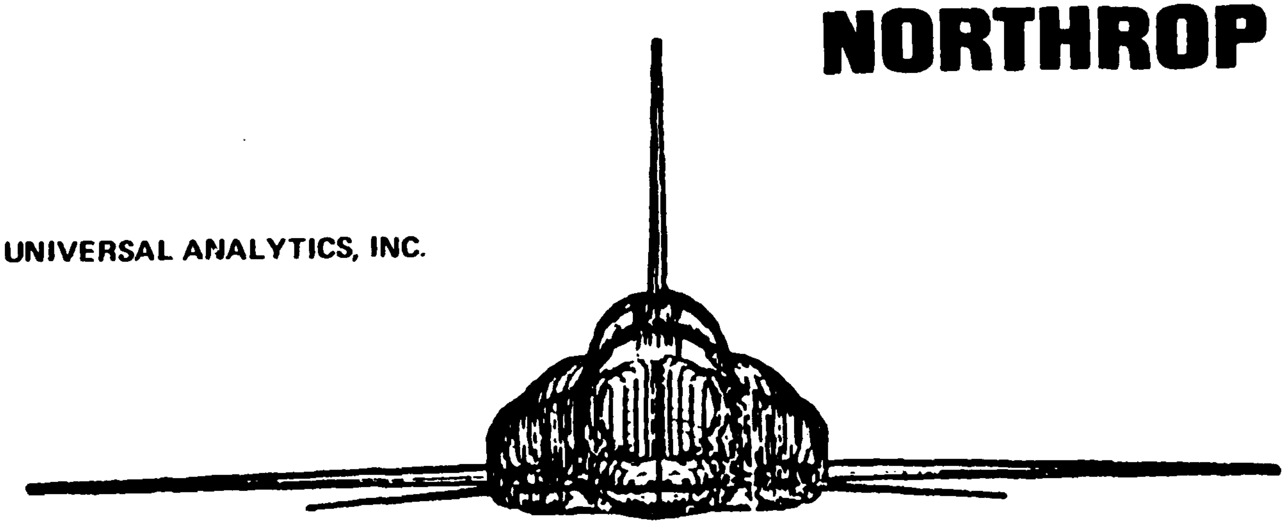

Overview

AUTOMATED STRENGTH – AEROELASTIC DESIGN OF AEROSPACE STRUCTURES

CONTRACT NUMBER:	F33615-83-C-3232
SPONSOR:	AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
PROJECT ENGINEER:	CAPT. R. CANFIELD
CONTRACTOR:	NORTHROP CORPORATION, AIRCRAFT DIVISION
SUBCONTRACTORS:	UNIVERSAL ANALYTICS, INC. KAMAN AVIDYNE
PERFORMANCE PERIOD:	JULY 1983 – JULY 1988

85-50003
3K, 10A

OBJECTIVES AND PAYOFFS

OBJECTIVES

- AN AUTOMATED TOOL FOR PRELIMINARY STRUCTURAL DESIGN
- EMPHASIZE INTERDISCIPLINARY FEATURES OF THE DESIGN TASK
- PROVIDE A NATIONAL RESOURCE

PAYOFFS

- IMPROVED COMMUNICATION AMONG DESIGN TEAM MEMBERS
- IMPROVED DESIGN
- REDUCED DESIGN TIME

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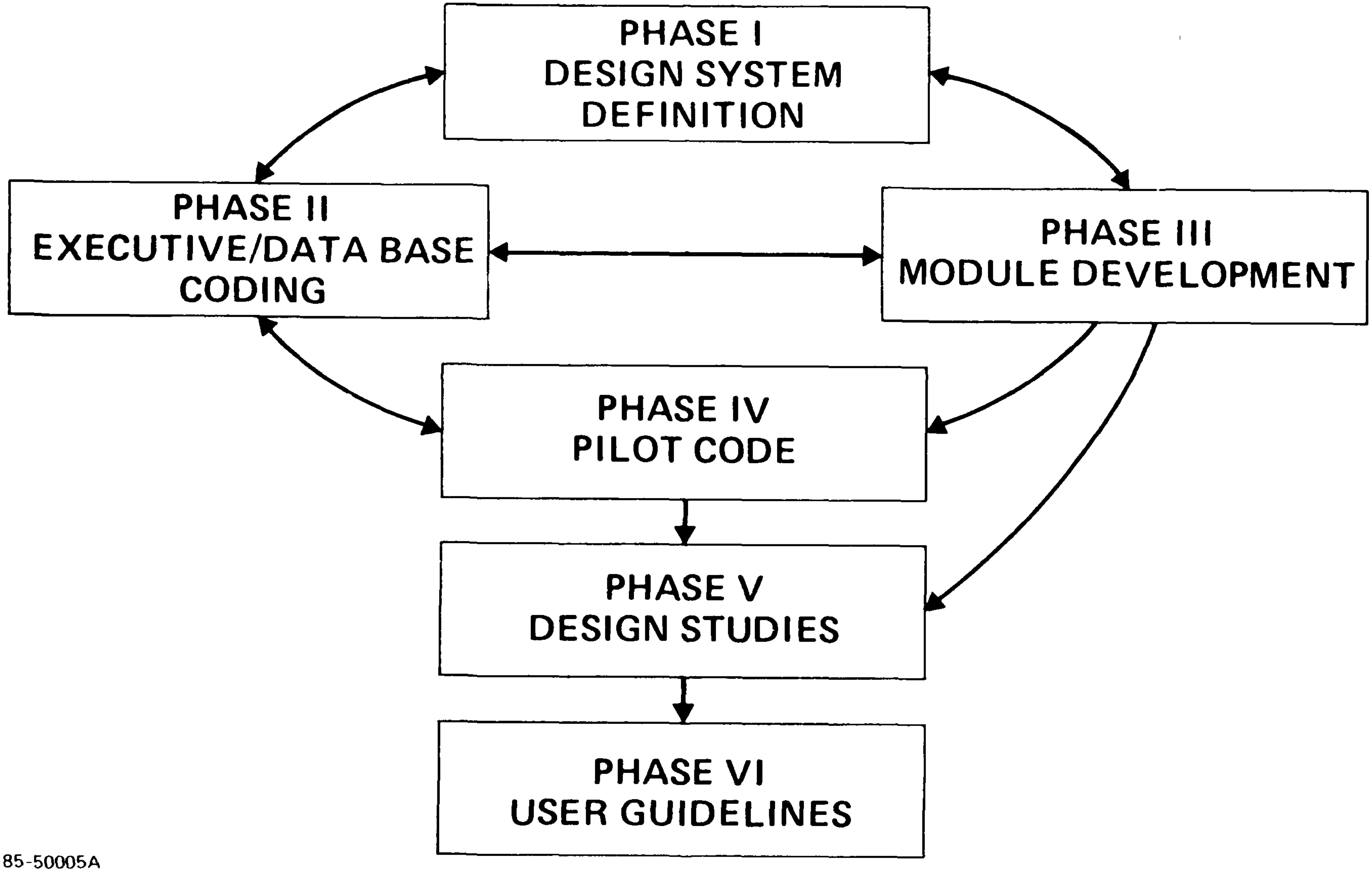
5B

ASTROS PHASES



PHASE I
DESIGN SYSTEM
DEFINITION

PHASE II
EXECUTIVE/DATA BASE
CODING

PHASE III
MODULE DEVELOPMENT

PHASE IV
PILOT CODE

PHASE V
DESIGN STUDIES

PHASE VI
USER GUIDELINES

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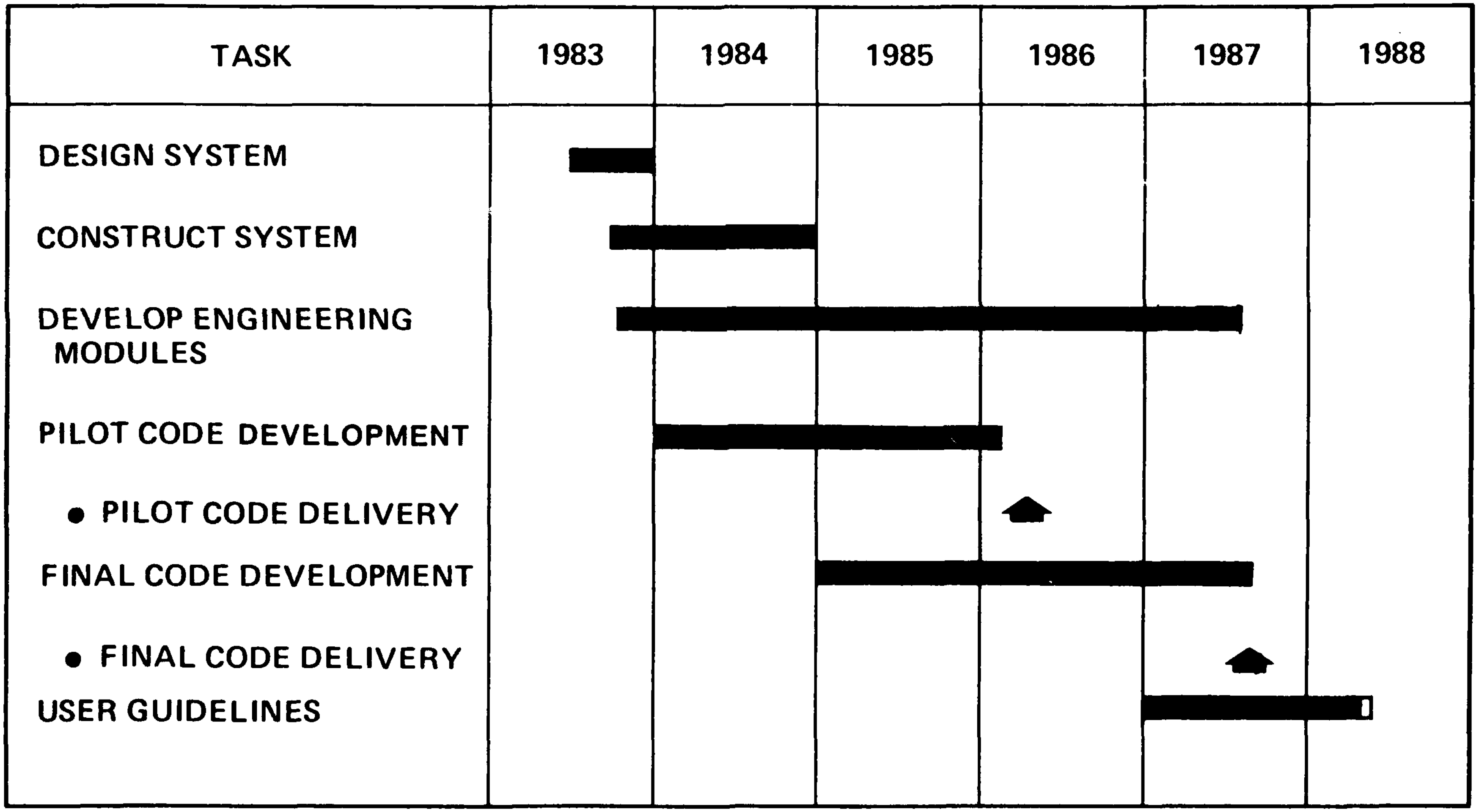
KEY ASTROS MILESTONES



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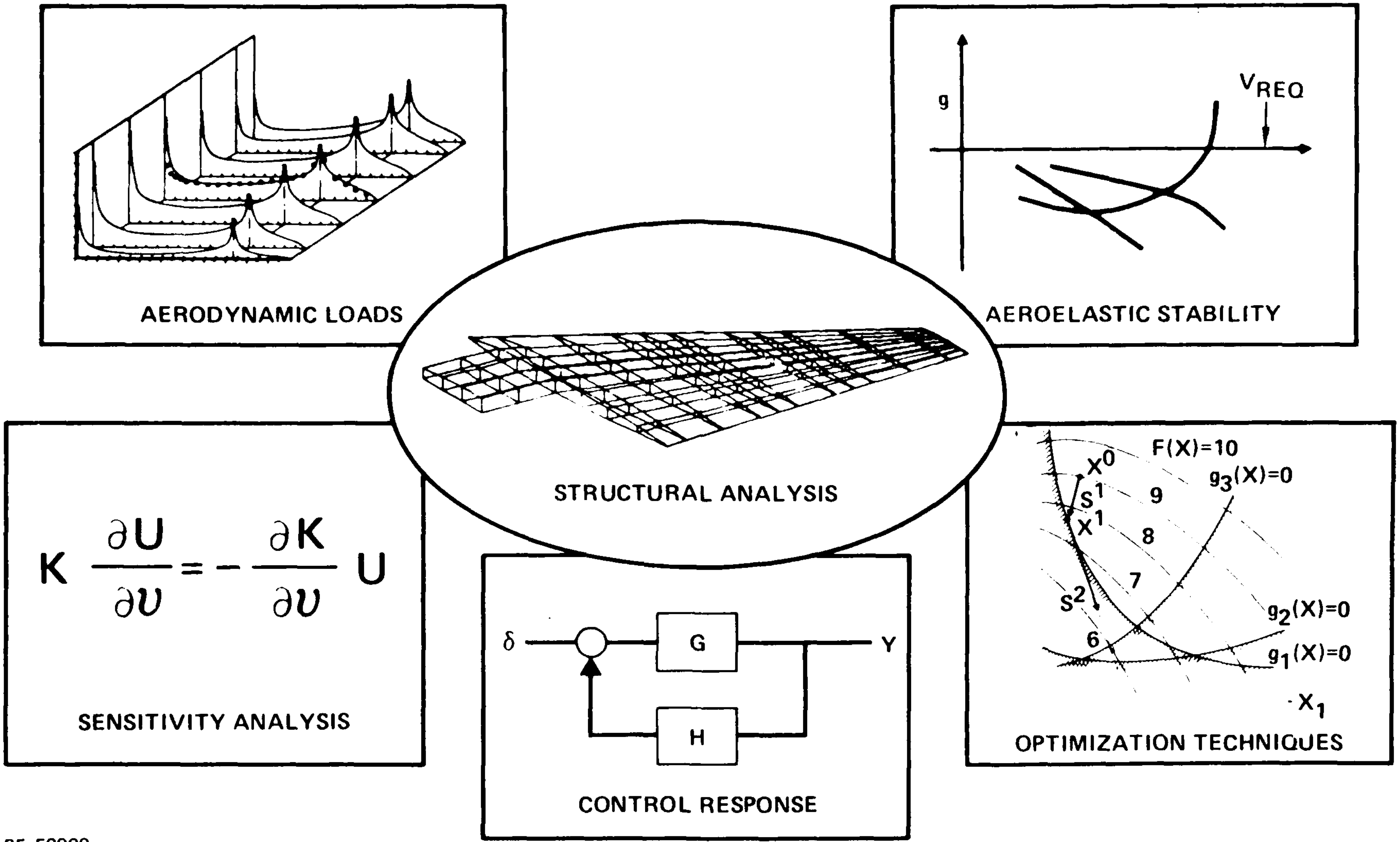
ENGINEERING DISCIPLINES



AERODYNAMIC LOADS

AEROELASTIC STABILITY

STRUCTURAL ANALYSIS

$$K \frac{\partial U}{\partial v} = - \frac{\partial K}{\partial v} U$$

SENSITIVITY ANALYSIS

CONTROL RESPONSE

OPTIMIZATION TECHNIQUES

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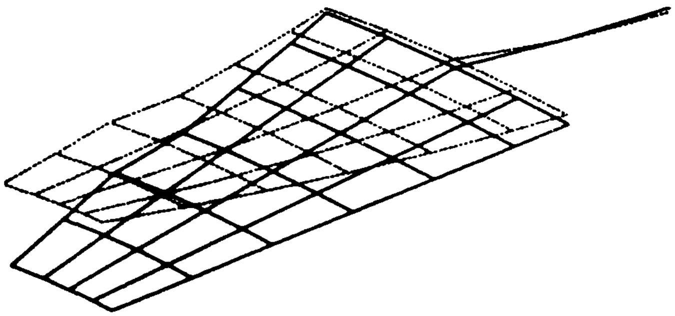
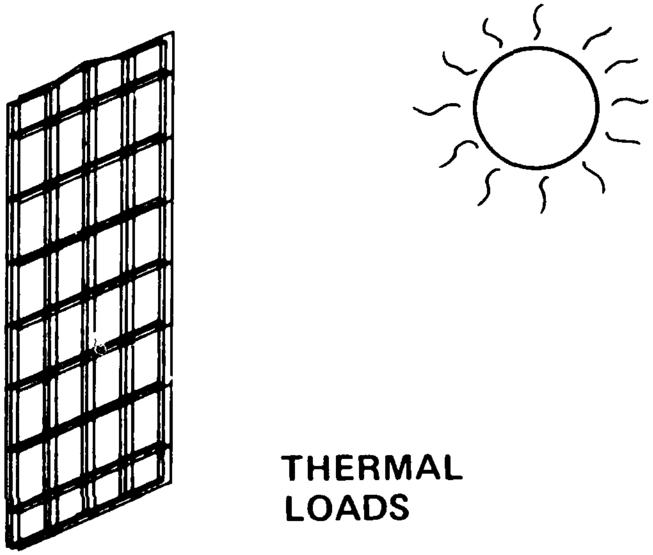
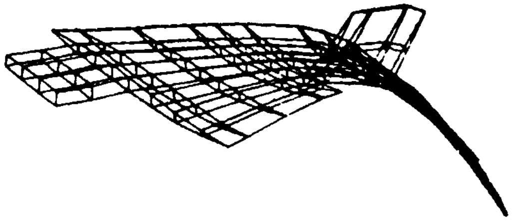
STRUCTURAL ANALYSES



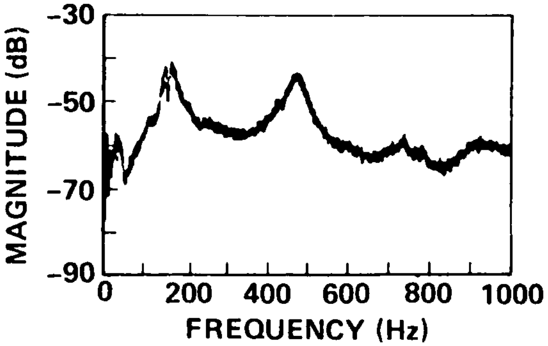
STATIC ANALYSIS



THERMAL
LOADS



EIGENVALUE ANALYSIS



DYNAMIC ANALYSIS

Software Resources for ASTROS

Structural Analysis — NASTRAN

Static Aerodynamic Loads — USSAERO

Unsteady Aerodynamic Loads — Doublet Lattice
CPM

Optimization Algorithms — MDOT

DESIGN PARAMETERS

DESIGN VARIABLES

- ROD AREAS
- SHEAR ELEMENT THICKNESSES
- MEMBRANE ELEMENT THICKNESSES
- BARS
- CONCENTRATED MASSES

CONSTRAINTS

- STRESS-STRAIN
- DISPLACEMENT
- MODAL FREQUENCY
- AEROELASTIC EFFECTS
  - LIFT EFFECTIVENESS
  - AILERON EFFECTIVENESS
  - DIVERGENCE SPEED
- FLUTTER RESPONSE

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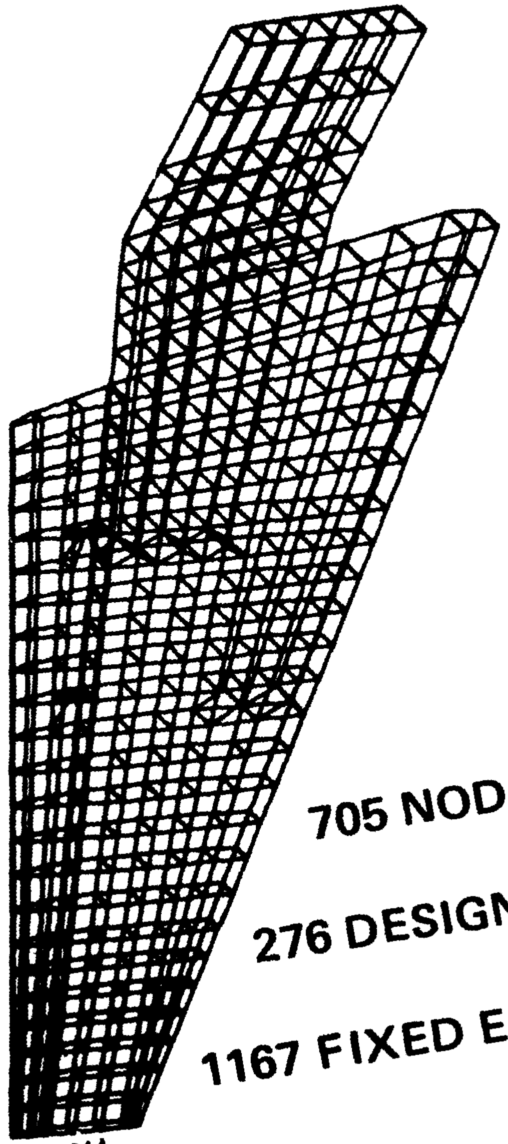
AN ARCHETYPICAL ASTROS APPLICATION



GIVEN:
- STRUCTURAL CONFIGURATION
- MATERIAL PROPERTIES
- DESIGN FLIGHT CONDITIONS
- DESIGN ALLOWABLES

DETERMINE
- THICKNESSES OF DESIGNED ELEMENTS
- OPTIONALLY – MASS BALANCE VALUES

POSSIBLE DESIGN CONSIDERATIONS
- MULTIPLE BOUNDARY CONDITIONS
- MULTIPLE FLIGHT CONDITIONS
- MULTIPLE STORE LOADINGS

705 NODES

276 DESIGNED ELEMENTS

1167 FIXED ELEMENTS

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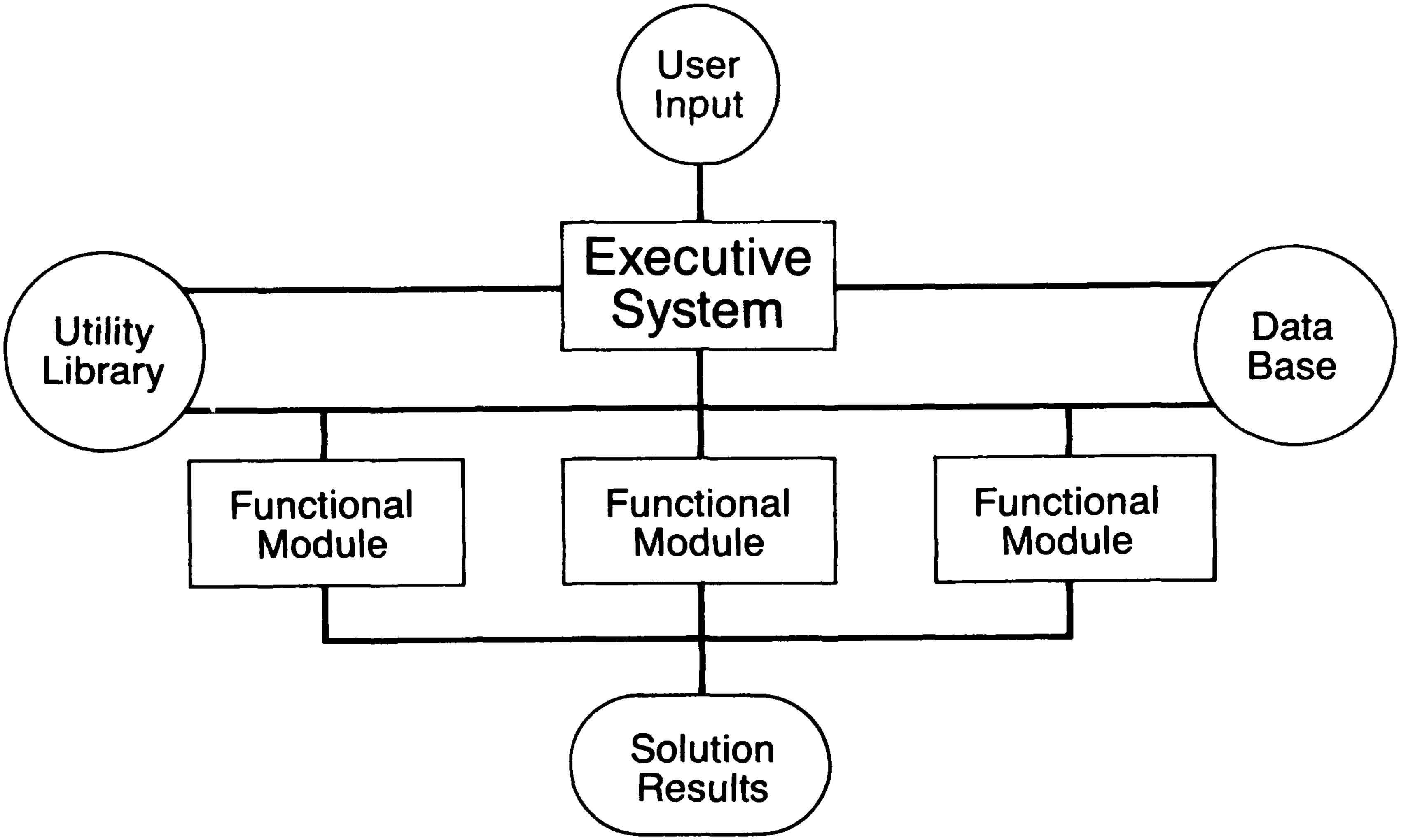
ASTROS Architecture



User Input

Executive System

Utility Library

Data Base

Functional Module

Functional Module

Functional Module

Solution Results

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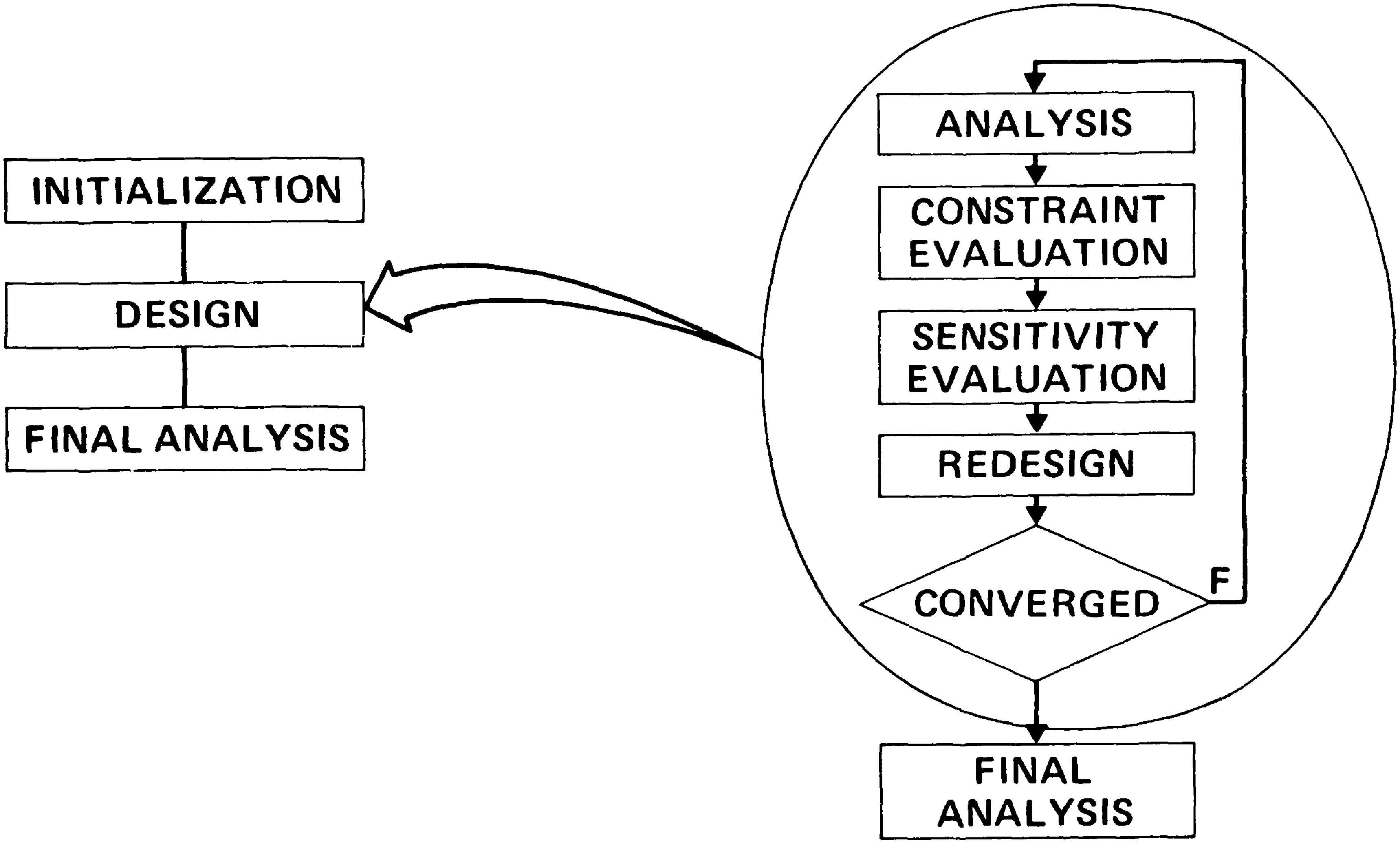
BASIC ASTROS SEGMENTS



INITIALIZATION

DESIGN

FINAL ANALYSIS

ANALYSIS

CONSTRAINT EVALUATION

SENSITIVITY EVALUATION

REDESIGN

CONVERGED

F

FINAL ANALYSIS

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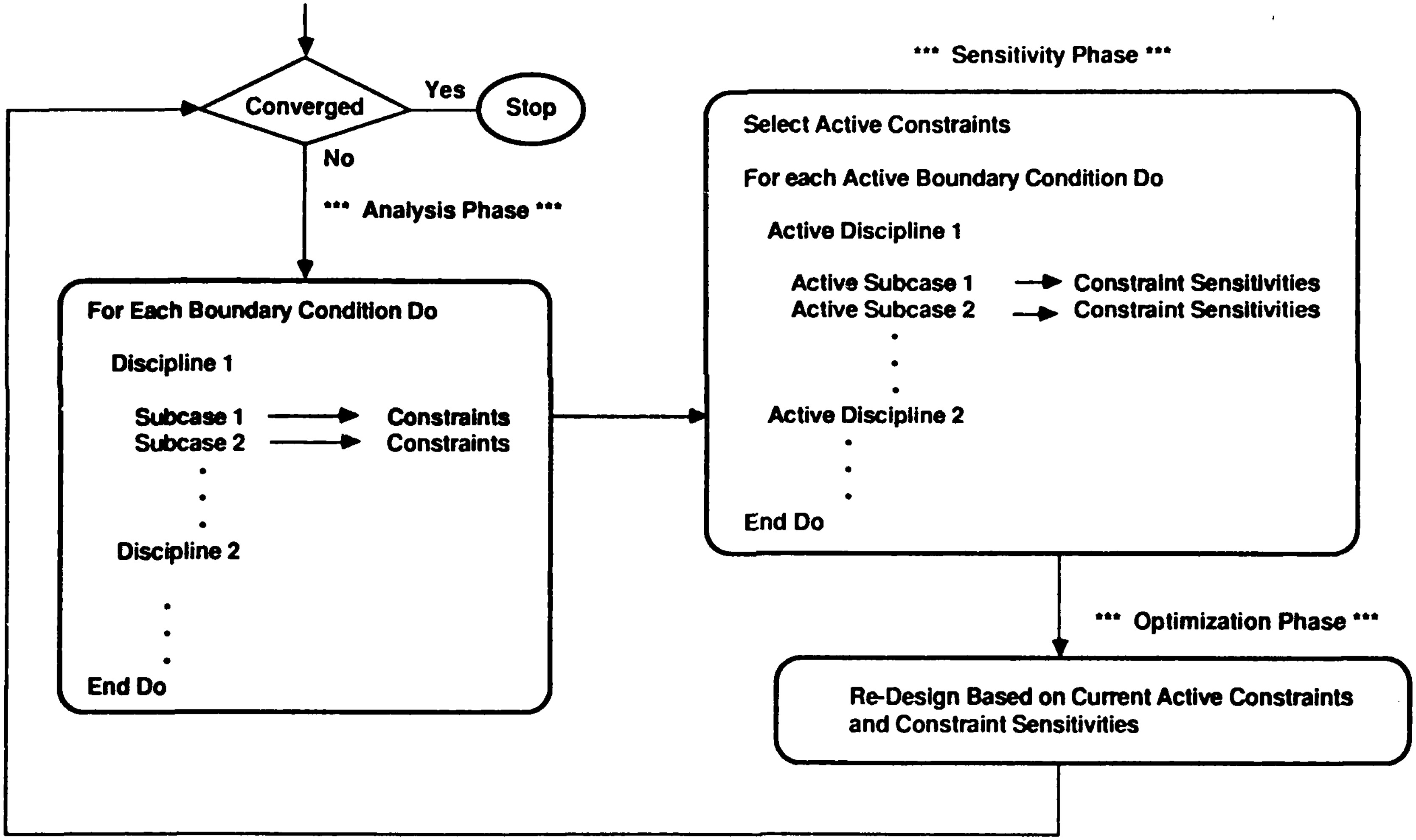
Multidisciplinary Optimization



Converged

Yes

Stop

No

*** Analysis Phase ***

For Each Boundary Condition Do

Discipline 1

Subcase 1 → Constraints
Subcase 2 → Constraints

.
.
.

Discipline 2

.
.
.

End Do

*** Sensitivity Phase ***

Select Active Constraints

For each Active Boundary Condition Do

Active Discipline 1

Active Subcase 1 → Constraint Sensitivities
Active Subcase 2 → Constraint Sensitivities

.
.
.

Active Discipline 2

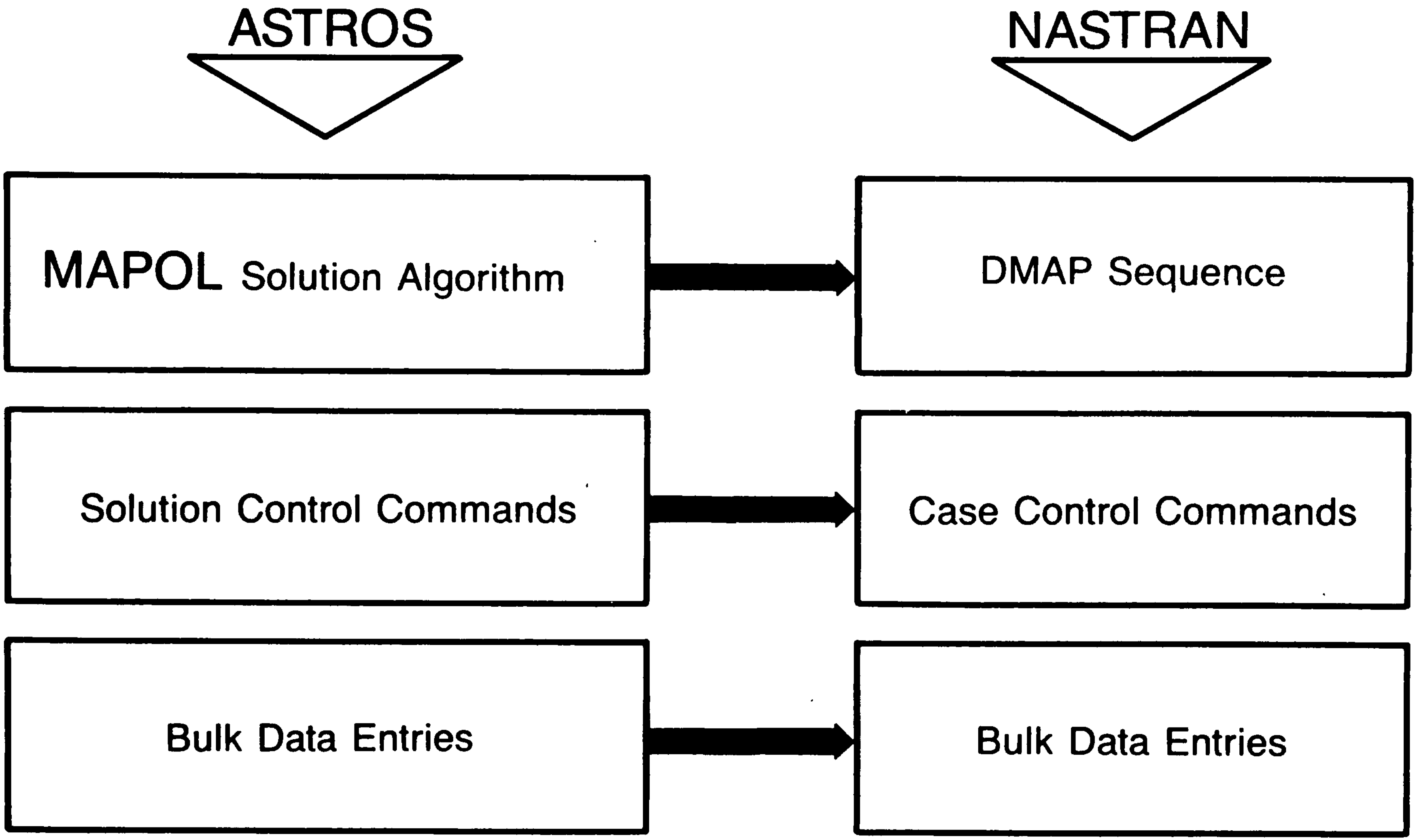
.
.
.

End Do

*** Optimization Phase ***

Re-Design Based on Current Active Constraints
and Constraint Sensitivities

User Input Data Stream



ASTROS

NASTRAN

MAPOL Solution Algorithm

DMAP Sequence

Solution Control Commands

Case Control Commands

Bulk Data Entries

Bulk Data Entries

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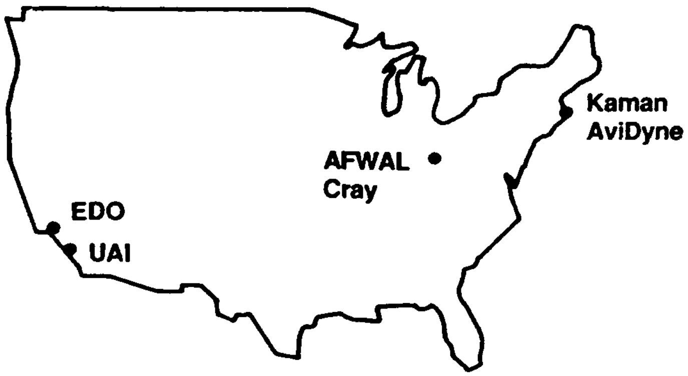
Astros Integration/Development Environment

The NORTHROP MicroVAX is the Central ASTROS Processor



Comunication with Central Processor		
Entity	**From**	**To**
AFWAL	Floppy	Floppy + CT + MT
UAI	Direct Line (IBM)	Direct Line (IBM)
Kaman AviDyne	Floppy	Floppy + MT
EDO	Floppy + MT	N/A
Astros + LV	Direct Line (VAX)	Direct Line (VAX)
Astros (IBM)	Floppy + MT=> CT	Floppy + CT => MT
Cray	N/A	? (AFWAL)

Ten Engineering Contributions of ASTROS

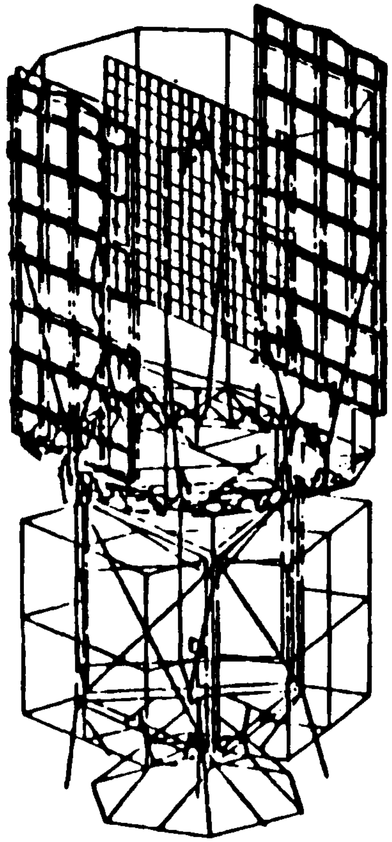
- Multidisciplinary Analysis and Design
- Analytical Sensitivity Analysis
- Approximation Concepts in a Production Code
- QUAD4 Element in the Public Domain
- Improved Supersonic Unsteady Aerodynamics
- Innovative Flutter Design Technique
- Nuclear Blast Analysis with Finite Elements and Advanced Aerodynamics
- Advanced Methods of Dynamic Reduction
- Design Variable Linking
- Aerodynamic Influence Coefficients For Static Aeroelasticity

Ten Software Contributions of ASTROS

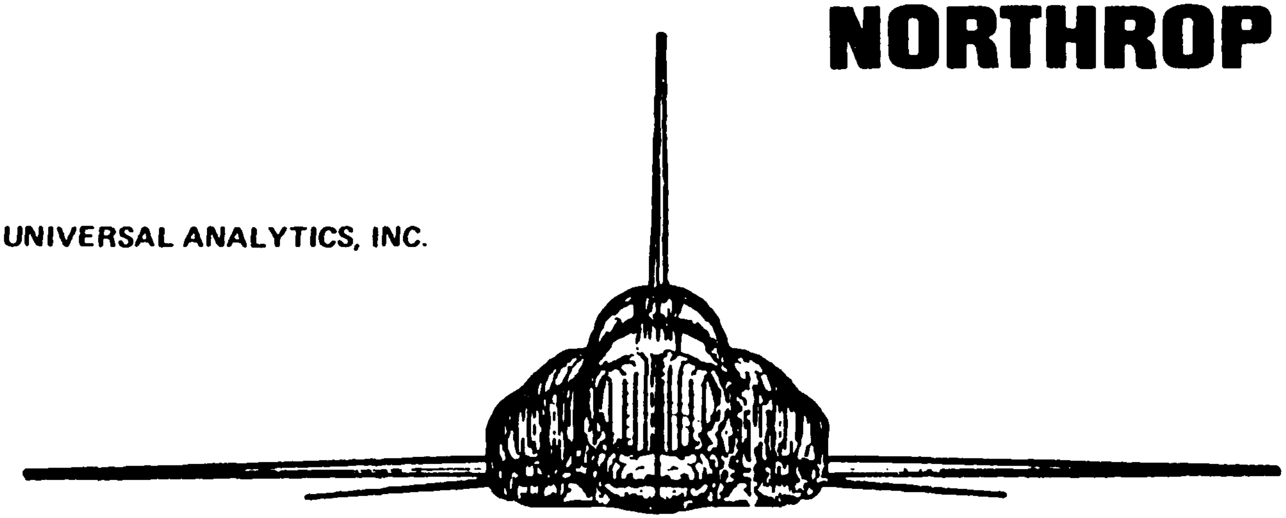
- Framework For Multidisciplinary Analysis and Design
- Engineering Data Base
- High Level Executive System
- Obsolescence of Rigid Formats
- Unlimited Problem Size
- Exploitation of Microcomputers
- Built in Maintenance Features
- Improved Special Purpose Utilities
- Balanced Approach to Software Design
- Integration of Dispersed Development Team

ASTROS User Training Workshop

20–24 June 1988



NORTHROP



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Theory

Agenda For Theoretical Discussion

- Introduction / Background
- Multidisciplinary Analysis and Design Concepts
- Finite Elements
- Static / Normal Modes Analyses
- Aerodynamic Analyses
- Automated Design
- Miscellaneous Analyses

Background - TSO

- **Developed By General Dynamics for the AFFDL**
- **Applies Rayleigh Ritz Analysis to a Trapezoidal Plate Model**
- **Includes in Design**
    - Strength
    - Flutter
    - Frequency
    - Lift Effectiveness
    - Control Effectiveness
- **Additional Analyses Available in Final Analysis**
    - Plots of Thicknesses and Response
    - Drag Polars
    - Detailed Analyses

Background - TSO

- **Strengths**

  Has a Extremely Efficient Analysis Procedure at Its Core

  Provides Basic Multidisciplinary Design

- **Weaknesses**

  Structural Analysis Simplistic

  Single Boundary Condition

  Only Three Composite Layers

- **Impact on ASTROS Significant**

Background - FASTOP

- **Developed for the AFFDL By Grumman**
- **Uses Finite Element Methods for the Structural Analysis**
- **Performs Strength / Flutter Design in Sequential Stages**
  - Fully Stressed Design Criteria Used for Strength
  - Flutter Sensitivity Criteria Used for Flutter
- **Strengths**
  - Detailed Structural Analysis
  - Efficient Resizing Algorithm
- **Weaknesses**
  - Sequential Design Not Necessarily Optimal
  - Limited Capability

Background - Further Motivation For a New Procedure

- Improved Optimization Techniques
- New Software Concepts
- Data Base Concepts
- FORTRAN 77
- New Computer Hardware

Promotes Maintenance and Enhancement

ASTROS Documentation

- **Theoretical Manual**

  Describes ASTROS Methods
  Emphasizes Innovative Features

- **User's Manual**

  Input and Output Description
  Techniques to Obtain Additional Output
  Creation and Modification of MAPOL Sequences

- **Application Manual**

  Documentation Resources
  Modeling Guidelines
  Sample Cases

- **Programer's Manual**

  Code Installation
  Module Description
  Data Base Calls
  Utility Calls

The Design Task

Minimize an Objective

$F(v)$

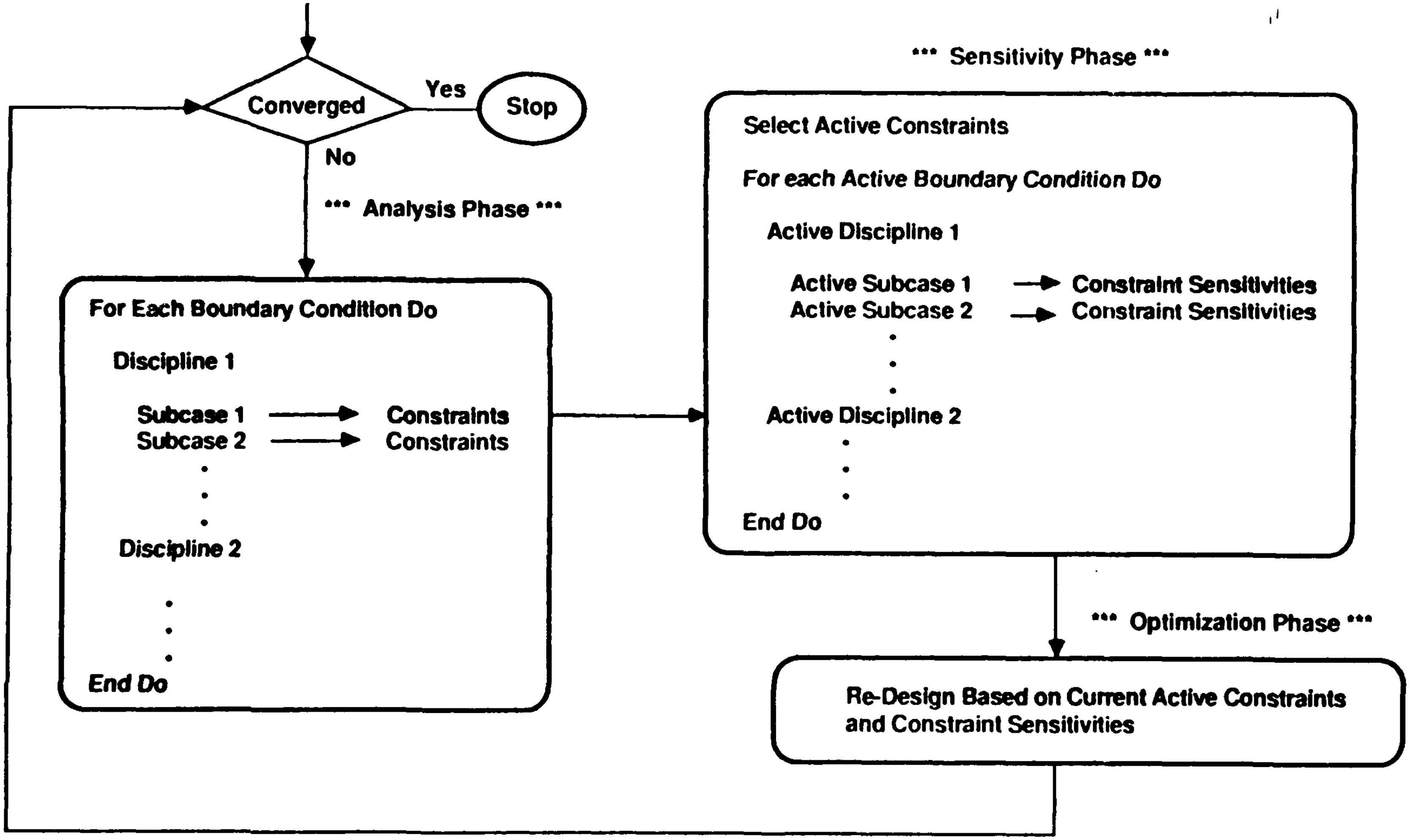
Subject to Constraints

$g_j(v) \leq 0 \qquad j = 1, \text{ncon}$

$v_i^{\text{lower}} \leq v_i \leq v_i^{\text{upper}} \qquad n = 1, \text{ndv}$

In ASTROS, the Objective is Always Weight

Multidisciplinary Optimization



Converged

Yes

Stop

No

*** Analysis Phase ***

For Each Boundary Condition Do

Discipline 1

Subcase 1 → Constraints
Subcase 2 → Constraints

.
.
.

Discipline 2

.
.
.

End Do

*** Sensitivity Phase ***

Select Active Constraints

For each Active Boundary Condition Do

Active Discipline 1

Active Subcase 1 → Constraint Sensitivities
Active Subcase 2 → Constraint Sensitivities

.
.
.

Active Discipline 2

.
.
.

End Do

*** Optimization Phase ***

Re-Design Based on Current Active Constraints and Constraint Sensitivities

Physical Design Variables

ELEMENT	DESIGN VARIABLE
CROD	Area
CSHEAR	Thickness
CQDMEM	Thickness (es)
CTRMEM	Thickness (es)
CQUAD4	Membrane Thickness (es)
CBAR	Area
CONM2	Mass
CELAS1 , 2	Stiffness
CMASS1 , 2	Mass

Physical Design Variables

- Mass and Stiffness Matrices are a Linear Function of the Design Variable
- Bar Element an Exception

$$I_1 = R_1 A^{\alpha}$$
$$I_2 = R_2 A^{\alpha}$$

- Bending Effects are Ignored for Two-Dimensional Elements
- Each Ply Direction Can Be a Separate Local Variable

Design Variable Linking Options

$$\underset{\substack{\text{Local}\\ \text{Variables}}}{\{\, t \,\}} \quad = \quad \underset{\substack{\text{Linking}\\ \text{Matrix}}}{[\, P \,]} \quad \underset{\substack{\text{Global}\\ \text{Variables}}}{\{\, v \,\}}$$

1) Unique Physical Linking

$t_i = P_{ii} \, v_i$ Local Variable Is Global Variable

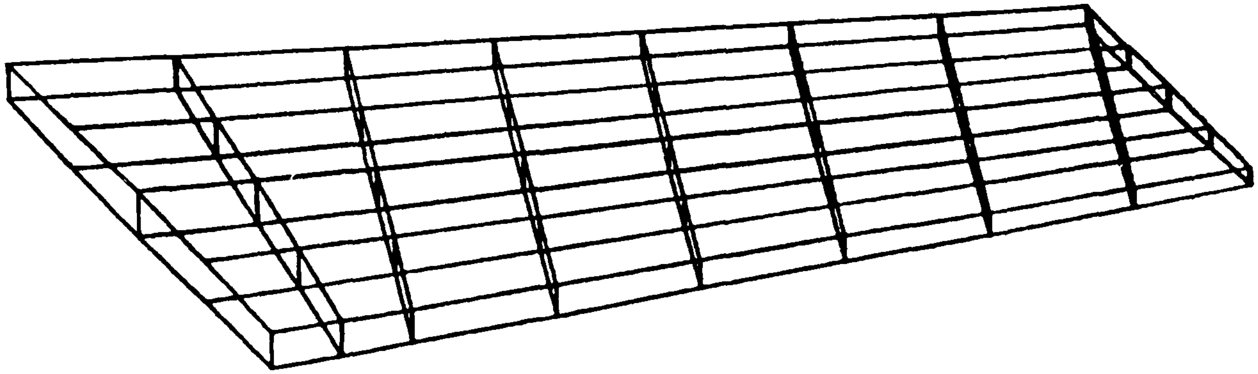
2) Physical Linking

$\{\, t_n \,\} = \{\, P_{ni} \,\} \, V_i$ Many Local Variables Linked to One Global Variable

3) Shape Function Linking

$\{\, t \,\} = [\, P \,] \{\, v \,\}$ Columns of [P] Are Reduced Basis Vectors

NO. OF NODES	NO. OF ELEMENTS		NO. OF DOF'S	
88	39	RODS	294	CONSTRAINED
	55	SHEAR PANELS	234	UNCONSTRAINED
	62	QUADRILATERAL MEMBRANE	528	TOTAL
	2	TRIANGULAR MEMBRANE		
	158	TOTAL		



Linking Options for Cover Skins

Unique Linking	-	256 Design Variables
Physical Linking By Ribs	-	64 Design Variables
Shape Function Linking	-	16 Design Variables

Constant Chordwise + Spanwise Taper

Thickness Constraints

- **Side Constraints**
  - Used for Unique and Physical Linking
  - Aplied to the Global Design Variable
  - Defined By Physical Limits, Manufacturing Considerations or Factors Not Analyzed in ASTROS
- **Thickness Constraints**
  - Used for Shape Function Linking
  - Explicitly Applied as a Property or Connectivity Attribute
- **Move Limits**
  - Restrain Movement of the Approximate Problem
  - Imposed Internally in ASTROS

STRESS/STRAIN CONSTRAINTS
TWO BASIC TYPES OF CONSTRAINTS:

VON MISES

$$G = \left[\left(\frac{\sigma_x}{X}\right)^2 + \left(\frac{\sigma_y}{Y}\right)^2 - \left(\frac{\sigma_x \sigma_y}{X\ Y}\right) + \left(\frac{\tau_{xy}}{S}\right)^2\right]^{1/2} - 1.0$$

WHERE X, Y AND S ARE ALLOWABLES

FOR AN ISOTROPIC MATERIAL:

- X AND Y ARE THE SAME
- SEPARATE TENSION AND COMPRESSION ALLOWABLES
- MAT1 DATA ENTRY USED FOR INPUT

FOR AN ORTHOTROPIC MATERIAL:

- SEPARATE X AND Y ALLOWABLES
- SEPARATE TENSION AND COMPRESSION ALLOWABLES
- MAT8 DATA ENTRY USED FOR INPUT

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10A, 3K

STRESS/STRAIN CONSTRAINTS

PRINCIPAL STRAIN

$$G_1 = \frac{1}{\varepsilon_{all}} \left[\frac{1}{2} (\varepsilon_x + \varepsilon_y) + \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2} \right)^2 + \left(\frac{\varepsilon_{xy}}{2} \right)^2} \right] - 1.0$$

$$G_2 = \frac{1}{\varepsilon_{all}} \left[\frac{1}{2} (\varepsilon_x + \varepsilon_y) - \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2} \right)^2 + \left(\frac{\varepsilon_{xy}}{2} \right)^2} \right] - 1.0$$

Compression or tension allowable is used based on the sign of the principal strain value

Two constraints are generated for each laminate

Stress/Strain Constraints (Concluded)

Tsai - Wu

For Two-Dimensional Elements the Tsai - Wu Criteria States Failure Occurs When

$$F_{11}\sigma_1^2 + 2F_{12}\sigma_1\sigma_2 + F_{22}\sigma_2^2 + F_1\sigma_1 + F_2\sigma_2 + F_{66}\tau_{12}^2 = 1.0$$

A Ratio, R , is Determined That Will Uniformly Modify a Given Stress State to Reach the Failure Boundary

The Tsai - Wu Constraint is Defined in ASTROS as:

$$g = \frac{1.0}{R} - 1.0$$

Stiffness Constraints

Constraint	Pos	Neg	Upper	Lower
Displacement	x	x	x	x
Frequency	x	NM	x	x
Flutter	x	x	x	NM
Lift Effectiveness	x	x	x	x
Aileron Effectiveness	x	x	x	x

NM - Not Meaningful

Sensitivity Analysis

- Gradient Information Required for Automated Design

$$\frac{\partial F}{\partial V_i} \quad , \quad \frac{\partial g_j}{\partial V_i} \qquad \begin{array}{l} i = 1 , ndv \\ j = 1 , ncon \end{array}$$

- Gradients of the Objective are Invariant
- Gradients of the Constrained are All Computed Analytically
  - Key to Performing the Approximate Problem
  - Computations Can Be Intricate

Architectural Highlights

- **Executive System**
  - Provides High Level Control
  - Enables Multidisciplinary Design
- **Database**
  - Customized for Engineering Analysis and Design
  - Necessitated Major Recoding of Software Resources
- **Dynamic Memory**
  - Enables Unrestricted Problem Size
  - Provides Programmer with Precise, Explicit Control

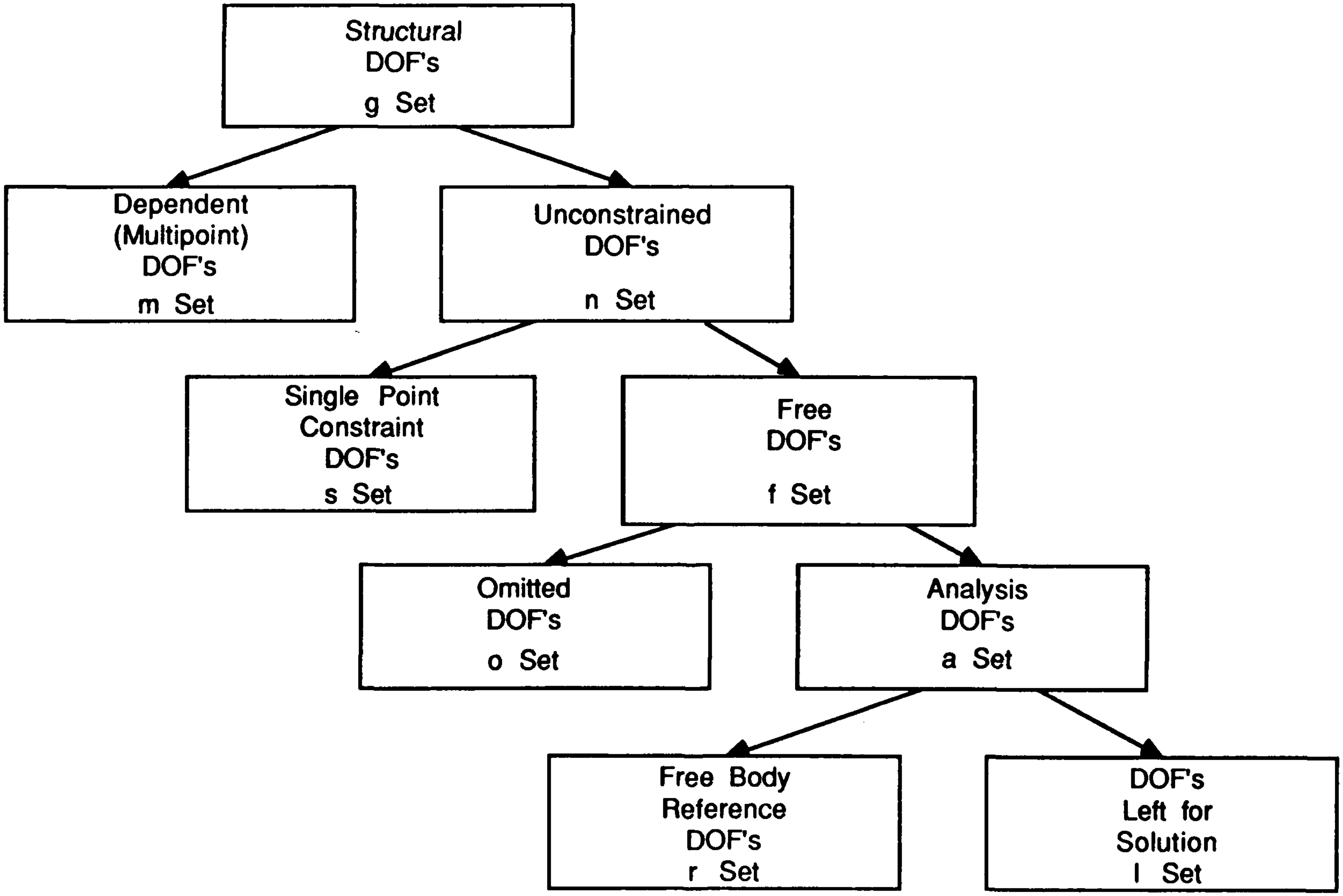
Architectural Highlights - Concluded

- **Utility Library**
  - Special Purpose Routines Required By Modules (Sort, Search, etc.)
  - Emphasis Placed on High Quality, Robust, Self Documented Algorithms
  - Machine Dependent Functions Isolated
- **Modules**
  - Distinction Between Functional and Utility Modules Blurred
  - Each Module :
    - Establishes Base Address in Memory
    - Opens Required Data Base Entities
    - Closes All Data Base Entities Prior to Exit
    - Frees All Memory Blocks Prior to Exit
  - Intermodular Communication is Through the Data Base

Large Matrix Utilities

UTILITY	FUNCTION
PARTN	$[A] \rightarrow \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$
MERGE	$[A] \leftarrow \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$
SDCOMP	$[A] \rightarrow [L][D][L]^T$
FBS	$[X] = ([L][D][L]^T)^{-1} [B]$
DECOMP	$[A] \rightarrow [L][U]$
GFBS	$[X] = ([L][U])^{-1} [B]$
MXADD	$[C] = \alpha[A] + \beta[B]$
MPYAD	$[D] = [A][B] + [C]$
TRNSPOSE	$[B] = [A]^T$
REIG	$[K - \lambda M][\phi] = [0]$

Hierarchy Of Displacement Sets



Structural
DOF's
g Set

Dependent
(Multipoint)
DOF's
m Set

Unconstrained
DOF's
n Set

Single Point
Constraint
DOF's
s Set

Free
DOF's
f Set

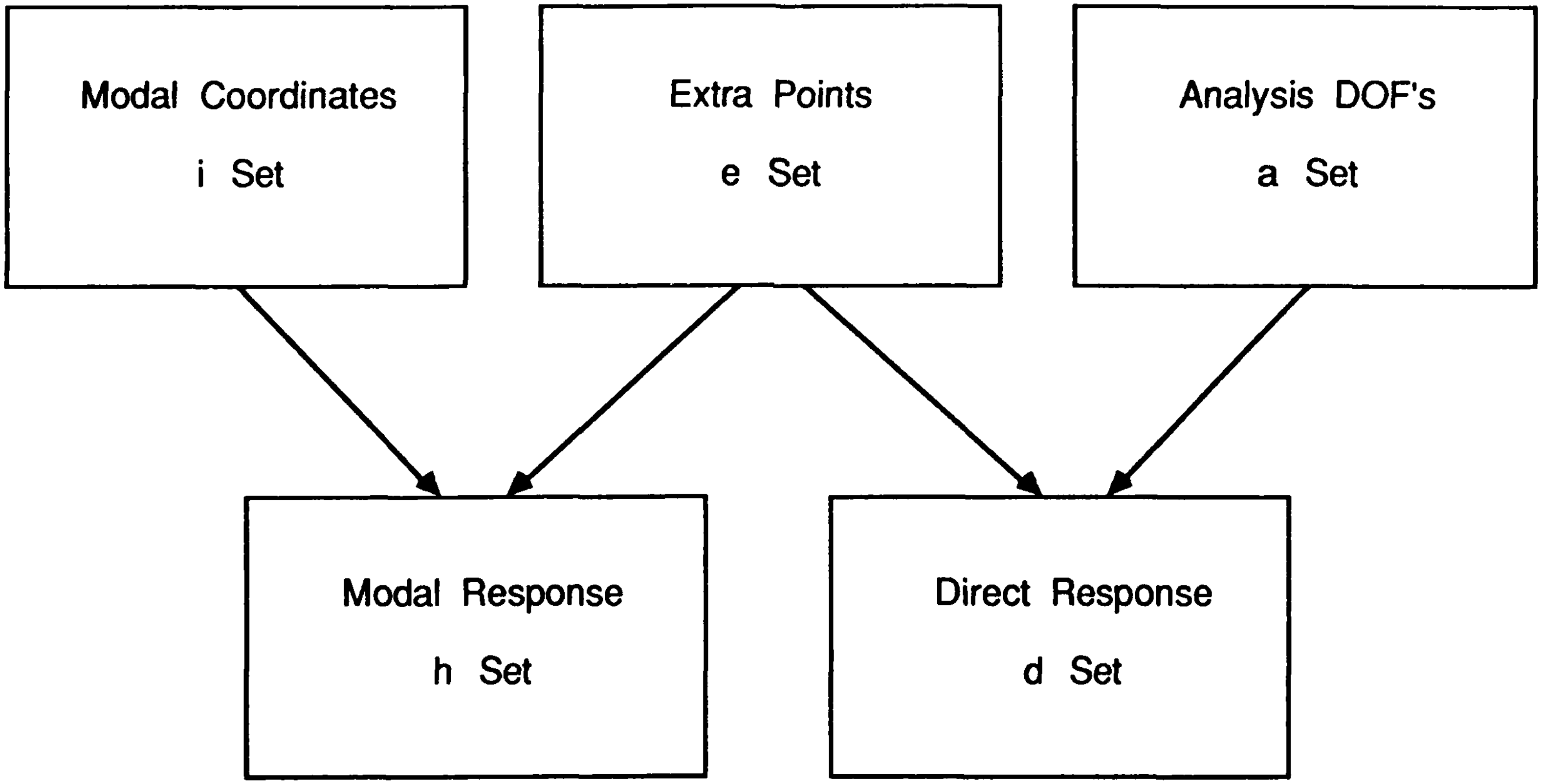
Omitted
DOF's
o Set

Analysis
DOF's
a Set

Free Body
Reference
DOF's
r Set

DOF's
Left for
Solution
l Set

Relation Of Dynamic Analysis Sets



Modal Coordinates

i Set

Extra Points

e Set

Analysis DOF's

a Set

Modal Response

h Set

Direct Response

d Set

Matrix And Vector Notation

TERM	(M)ATRIX OR (V)ECTOR	DESIGNATION
B	M	Damping
D	M	Rigid body transformation
G	M	Transformation matrix, including spline matrices for steady aerodynamics
K	M	Structural stiffness
M	M	Mass
m	M	Rigid body mass
P	V/M	Applied load
t	V	Local thickness variables
u	V/M	Displacement
UG	M	Unsteady aerodynamic spline
v	V	Global design variables
YS	V	Enforced displacements

Finite Elements - Concentrated Mass

- **Contain Mass Without Stiffness**
  - Used to Develop Mass Model
  - Can Be Used as " TUNING " Masses in Design
- **Two Input Forms**
  - Entire Mass Matrix at a Designated Grid Point (CONM1)
  - Mass and Inertias Input at a Point Relative to a Grid Point (CONM2)
  - Only the CONM2 Allows Design

Finite Element - Scalar Elements

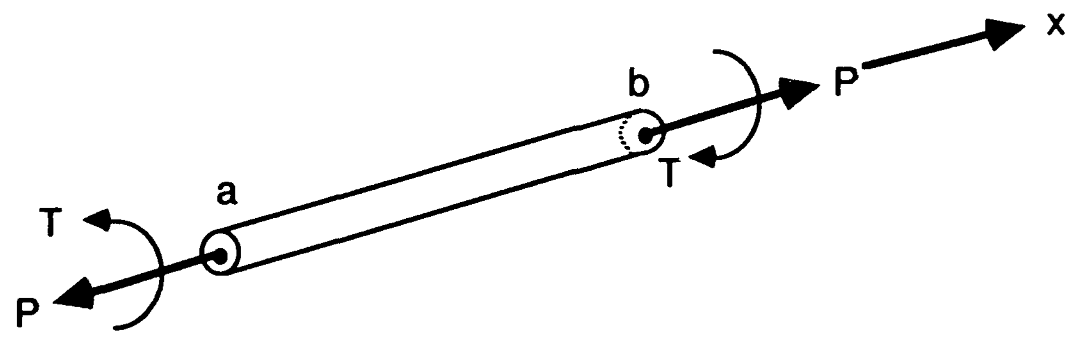
- ASTROS Has Implemented the NASTRAN CELAS and CMASS Elements:

$$[k] = \bar{k} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

- Both Elements Can Be Designed

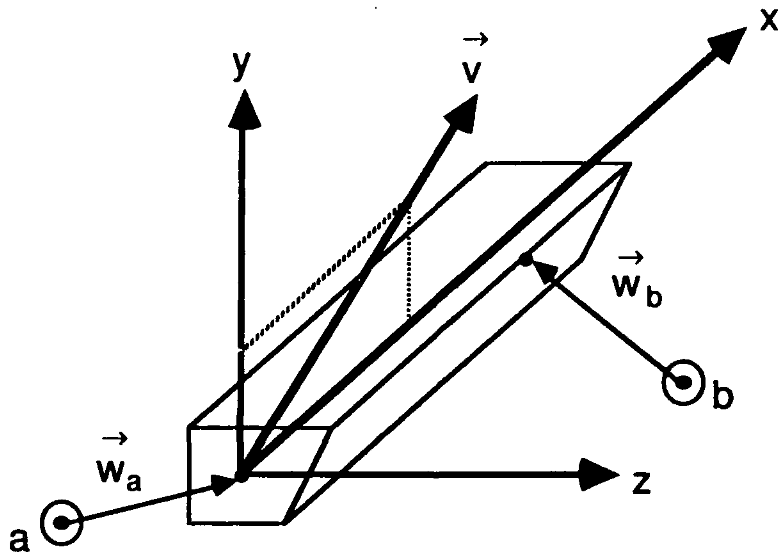
- Elements Have No Explicity Associated Constraints

Finite Elements - The Rod Element

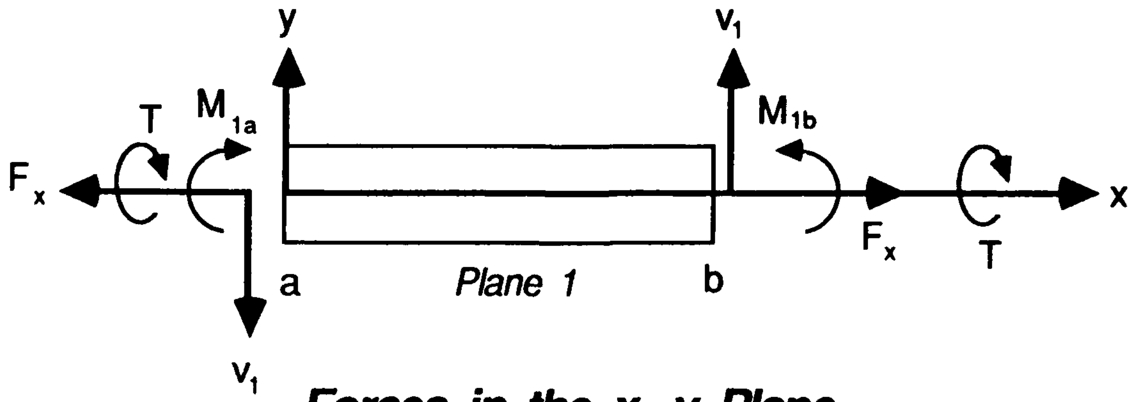


- **Two Degrees of Freedom at Each Node**
- **Design Variable is Rod Area. If the Element is Designed :**
  - Torsional Stiffness is Ignored
  - Non - Structural Mass is Ignored

Finite Elements - The Bar Element



The Element Coordinate System



Forces in the x - y Plane

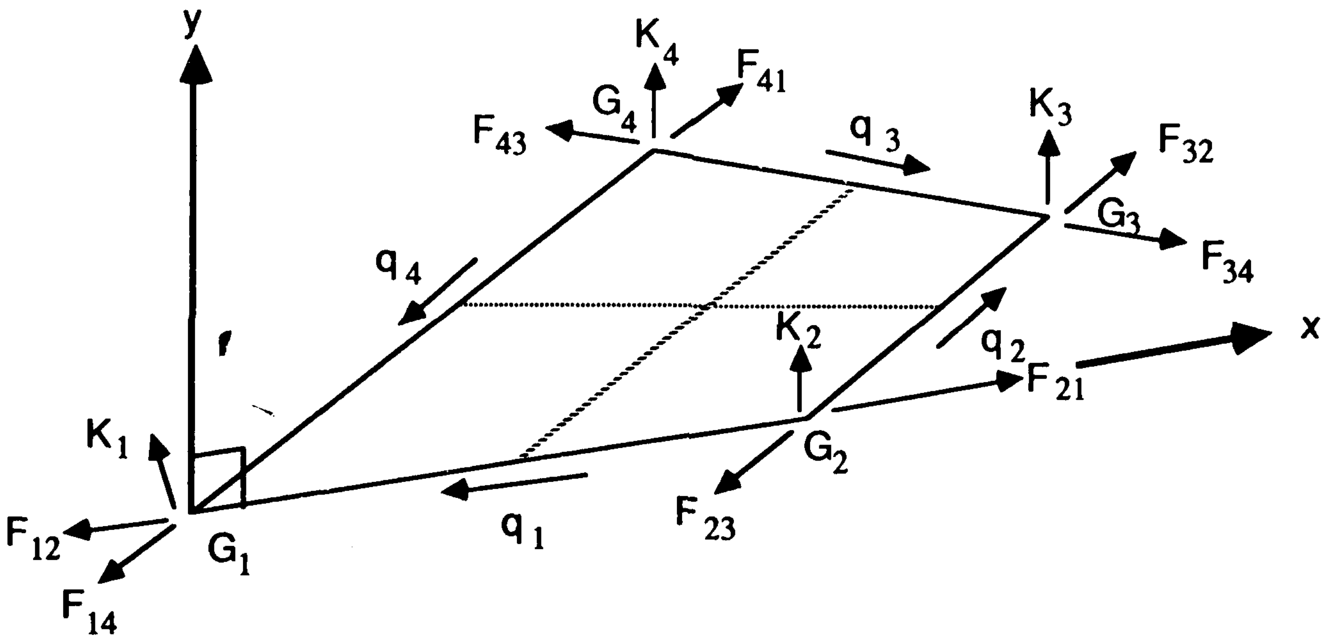
Finite Elements - The Bar Element

- **Neutral Axis May Be Offset**
- **Pinned Connections May Be Defined**
- **Stress Calculated at Four Points at Each Node**
- **Design Variable is Bar Area. - Inertias Related By**

$$I_1 = r_1^2 A^{\alpha}$$
$$I_2 = r_2^2 A^{\alpha}$$

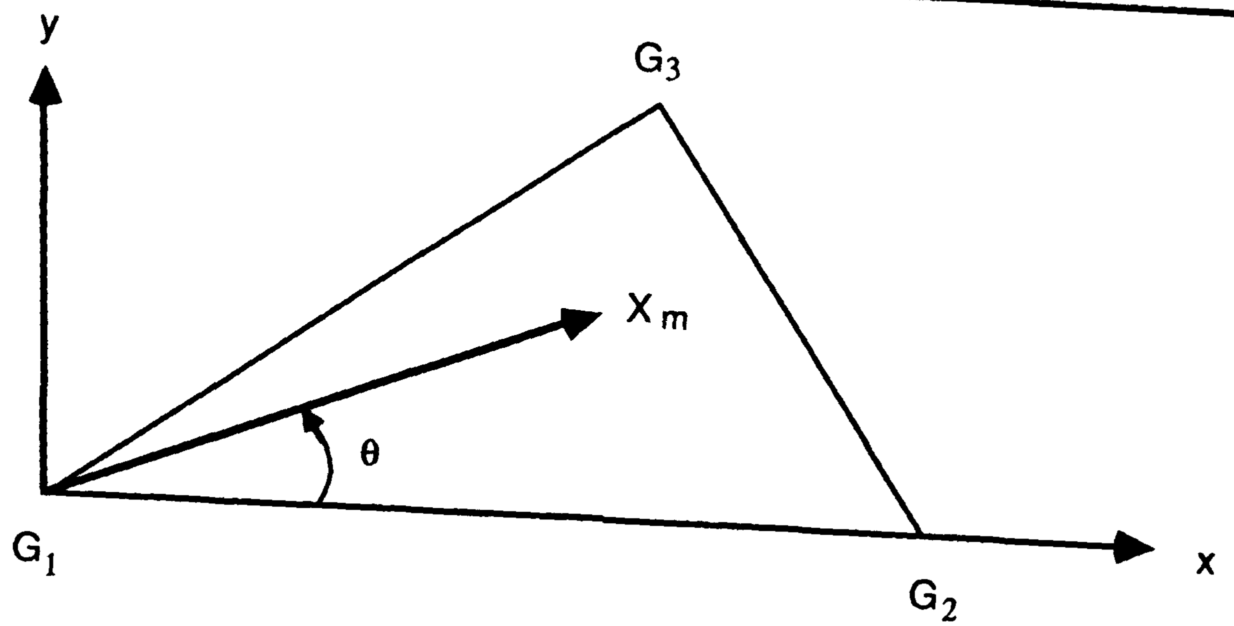
- **If the Element is Designed :**
  - Torsional Stiffness is Ignored
  - Non - Structural Mass is Ignored
  - Pin Connection and Offset Not Supported

Finite Elements - The Quadrilateral Shear Element



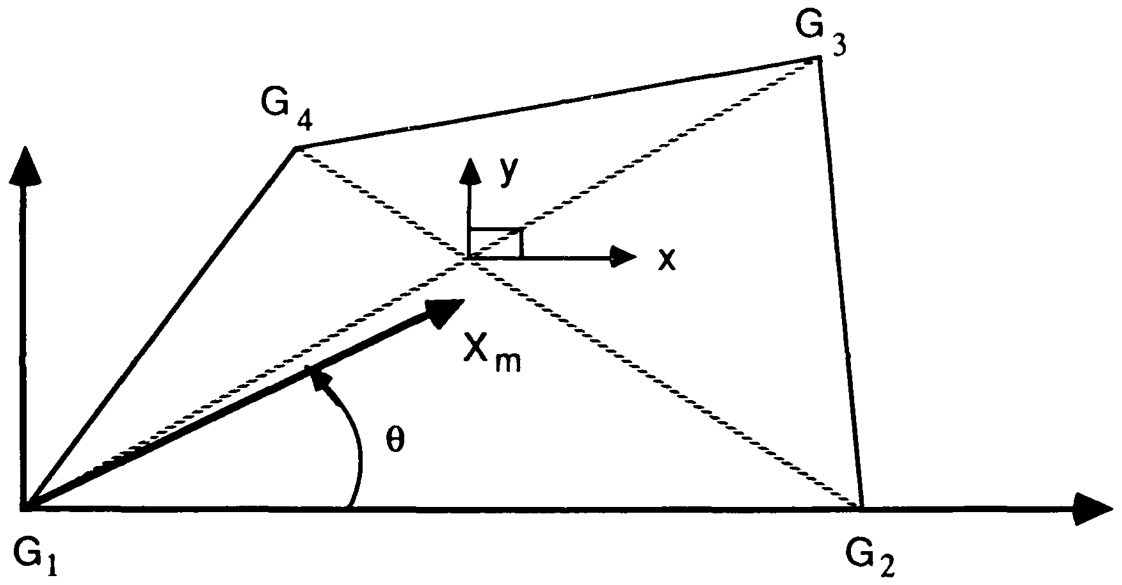
- Garvey Shear Panel Implemented
- Only Isotropic Materials Supported
- Design Variable is Element Thickness
- Stress Constraint Based on the Average Shear Stress at the Four Nodes

Finite Elements - The Triangular Membrane Element



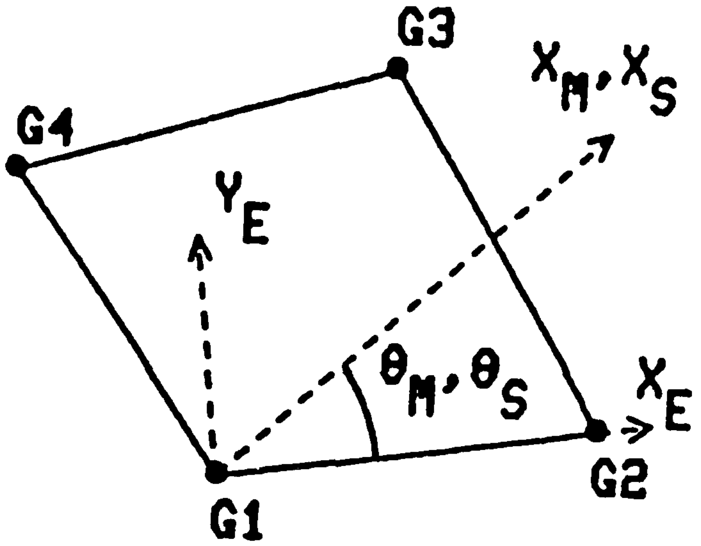
- Element Resists Only In - Plane Forces
- Linear Displacement Field ⟹ Constant Strain
- Anisotropic Materials Supported
- Design Variable is Element Thickness
  - Ply Direction Can Be Independently Designed
  - Orientation Angle Not a Design Variable
  - Ply Order Effect Not Accounted For

Finite Elements - The Isoparametric Quadrilateral Membrane Element



- Element Resists Only In - Plane Forces
- Equivalent to NASTRAN's CQDMEM1
- Element Warping is Allowed
- Anisotropic Materials Supported
- Design Variable is Element Thickness
    - Comments from Triangular Element Apply

Finite Elements - The Quadrilateral Shell Element



- Element Includes Efrects of Membrane, Bending, Transverse Shear with Coupling Effects
- Capable of Representing Laminate Composite Elements
- Design Variable is Element Thickness
  - Only Membrane Effects Considered in Design
  - Comments from Triangular Element Apply

COMPARISON OF QUAD4 ELEMENTS

ASTROS, MSC/NASTRAN[1] AND COSMIC NASTRAN

TEST DESCRIPTION	ELEMENT LOADING		ELEMENT SHAPE	ASTROS	MSC	COSMIC
	IN-PLANE	OUT-OF-PLANE				
1. PATCH TEST	X		IRREGULAR	A	A	A
2. PATCH TEST		X	IRREGULAR	A	A	D
3. STRAIGHT BEAM, EXTENSION	X		ALL	A	A	A
4. STRAIGHT BEAM, BENDING	X		REGULAR	B	B	F
5. STRAIGHT BEAM, BENDING	X		IRREGULAR	F	F	F
6. STRAIGHT BEAM, BENDING		X	REGULAR	A	A	B
7. STRAIGHT BEAM, BENDING		X	IRREGULAR	A	B	B
8. STRAIGHT BEAM, TWIST			ALL	B	B	D
9. CURVED BEAM	X		REGULAR	C	C	F
10. CURVED BEAM		X	REGULAR	B	B	D
11. TWISTED BEAM	X	X	REGULAR	A	A	F
12. RECTANGULAR PLATE (N=4)		X	REGULAR	A	B	C
13. SCORDELIS-LO ROOF (N=4)	X	X	REGULAR	B	B	D
14. SPHERICAL SHELL (N=8)	X	X	REGULAR	A	A	A
15. THICK-WALLED CYLINDER	X		REGULAR	B	F	F

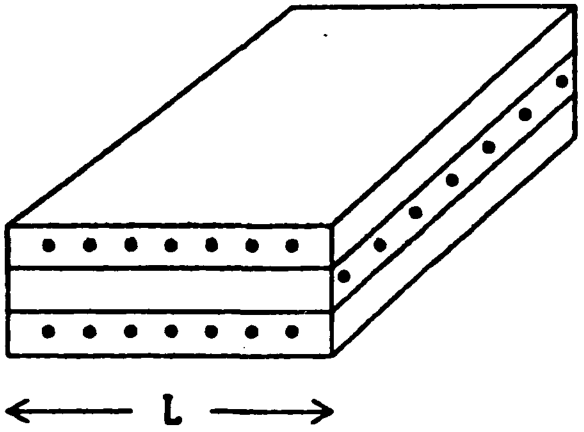
[1] MSC/NASTRAN IS A SERVICE AND TRADEMARK OF MACNEAL-SCHWENDLER CORP.

[2] MSC REPORTED ERROR EXCEEDS 50%, THUS GRADE SCORE IS CORRECTED TO "F".

GRADE SCORES ARE DEFINED BY:
A - ERROR LESS THAN 2%
B - ERROR BETWEEN 2% AND 10%
C - ERROR BETWEEN 10% AND 20%
D - ERROR BETWEEN 20% AND 50%
F - ERROR EXCEEDS 50%

ISOPARAMETRIC QUADRILATERAL ELEMENT

SAMPLE TEST PROBLEM FOR LAMINATED COMPOSITE PLATE



REGULAR SYMMETRIC
CROSS-PLY LAMINATE

SIMPLY SUPPORTED
UNIFORM LOAD

$T_1 = T_2 = T_3 = 0.06667$

$E_1 = 2.0E7$ $L = 1.0$

$E_1 = 5.0E5$ $P = 1.0E-4$

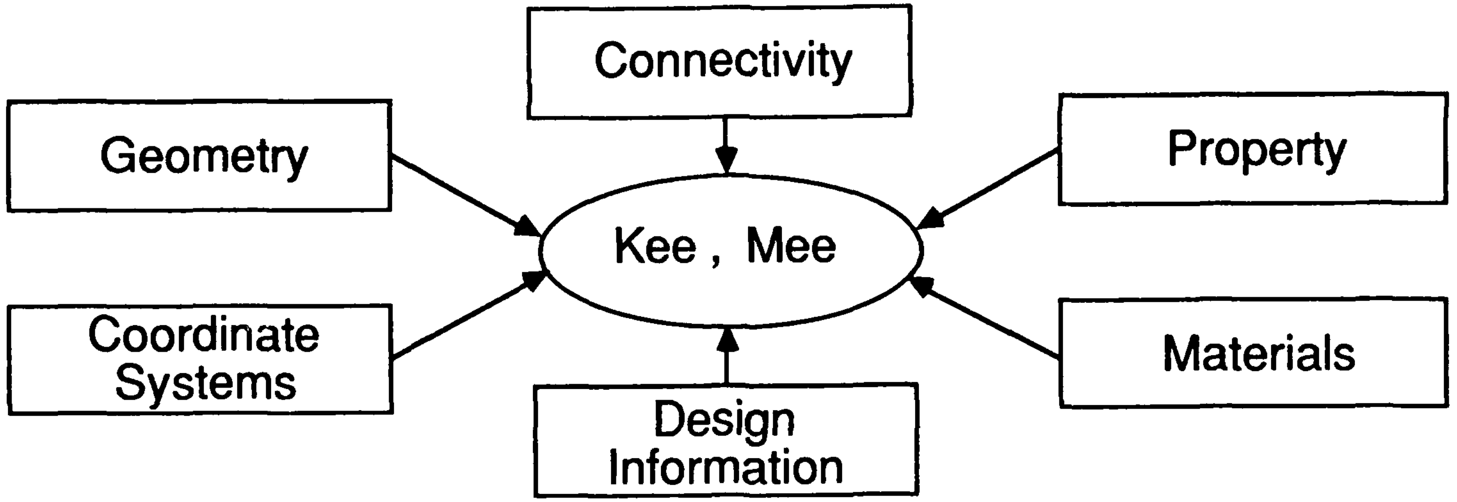
$NU_{12} = 0.25$ $\theta_1 = \theta_3 = 0.0°$

$G_{12} = 2.5E5$ $\theta_2 = 90°$

STRESS RESULTS		
LAYER 1&3	ASTROS Q4	THEORY
σ_1	53.6	58.6
σ_2	1.4	1.8
τ_{12}	-.04	-.06

Matrix Assembly - Stage One

- **Matrices are Assembled at the Element Level**



- **Performed as a Preface Operation**

Matrix Assembly - Stage Two

- **Design Sensitivity Matrices are Assembled**

$$[DKV]_i = \sum_{j=1}^{nle} p_{ij}\,[KEE]_j$$

$$[DMV]_i = \sum_{j=1}^{nle} p_{ij}\,[MEE]_j$$

nle = Number of Linked Elements

- **Performed as a Preface Operation**
- **These Matrices are Basic to ASTROS Sensitivity Analysis**

Matrix Assembly - Stage Three

- **Global Matrices are Assembled**

$$[K_{gg}] = \sum_{i=0}^{ndv} v_i \, [DKV]_i + \sum_{j=1}^{ndv} v_j^{\alpha j} \, [DKBV]_j$$

$$[M_{gg}] = \sum_{i=0}^{ndv} v_i \, [DMV]_i$$

- **Assembly is Performed Inside the Design Loop**

Static Loads - Capability

- **Mechanical Loads**
  - Discrete Forces and Moments at Grids
  - Pressure Loads Defined by Three or Four Grids
- **Gravity Loads**
  - User Defined Acceleration Vector
  - Can Be Design Dependent

$$\{DPGR\}_i = [DMV]_i \{a_g\}$$

- **Thermal Loads**
  - Temperature Specified at Grid Points
  - Can Be Design Dependent

$$\{DPTH\}_i = \sum_{j=1}^{nle} p_{ij} [T_{ee}]_j \{T_{GRID} - T_{REF}\}_j$$

Static Loads - Assembly

- **ASTROS Allows For the Combination of Simple Loads**

$$\{P_g\} = S_0 \sum_i S_i \{L\}_i$$

- **Final Assembly is Performed Inside the Design and Boundary Condition Loops**
  - Allows for Combining of Simple Loads
  - Accommodates Design Dependent Loads

Static Analysis - Equations Of Motion

- **Equilibrium Equation in the g - set :**

$$[K_{gg}]\,\{u_g\} + [M_{gg}]\,\{\ddot{u}_g\} = \{P_g\}$$

- **NASTRAN Formulation Followed For MPC, SPC and Guyan Reduction**

- **Support Reduction Aligned with NASTRAN's Static Aeroelastic Analysis**
    - Deformations are Constrained To Be Orthogonal to Rigid Body Mode Shapes

$$[D \quad I]^T \begin{bmatrix} M_{\ell\ell} & M_{\ell r} \\ M_{r\ell} & M_{rr} \end{bmatrix} \begin{Bmatrix} u_\ell \\ u_r \end{Bmatrix} = 0$$

Where

$$[D] = -[K_{\ell\ell}]^{-1}\,[K_{\ell r}]$$

Static Analysis - Solution And Recovery

- **With Rigid Body Degrees of Freedom :**

$$\begin{bmatrix} K_{\ell\ell} & K_{\ell r} & M_{\ell\ell} D + M_{\ell r} \\ D^T M_{\ell\ell} + M_{r\ell} & D^T M_{\ell r} + M_{rr} & 0 \\ 0 & 0 & m_r \end{bmatrix} \begin{Bmatrix} u_\ell \\ u_r \\ \ddot{u}_r \end{Bmatrix} = \begin{Bmatrix} P_\ell \\ 0 \\ D^T P_\ell + P_r \end{Bmatrix}$$

- **Otherwise :**

$$[K_{aa}]\{u_a\} = \{P_a\}$$

- **Recovery to g - set is Standard**

Static Analysis - Strength Constraint Evaluation

Element	Von - Mises	Tsai - Wu	Principal Strain
BAR	X		
QDMEM1	X	X	X
QUAD4	X	X	X
ROD	X		X
SHEAR	X		X
TRMEM	X	X	X

- **ASTROS Computes a Design Invariant Matrix Which Relates Stress / Strain to Global Displacements**

$$\{\sigma\} = [SMAT]^T \{u_g\}$$

Static Analysis - Strength Constraint Example

- **For the Triangular Membrane Element at Each Node**

  $$[S_i] = [G]\,[C_i]\,[E]^T\,[T_i] \qquad i = 1,2,3$$

  [G] - Stress / Strain
  [C] - Strain - Displacement
  [E] - Basic to Element Coordinate Transformation
  [T] - Basic to Global Coordinate Transformation

- **Then the Element Stress is**

  $$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \sum_{i=1}^{3} [S_i]\,\{U_{gi}\}$$

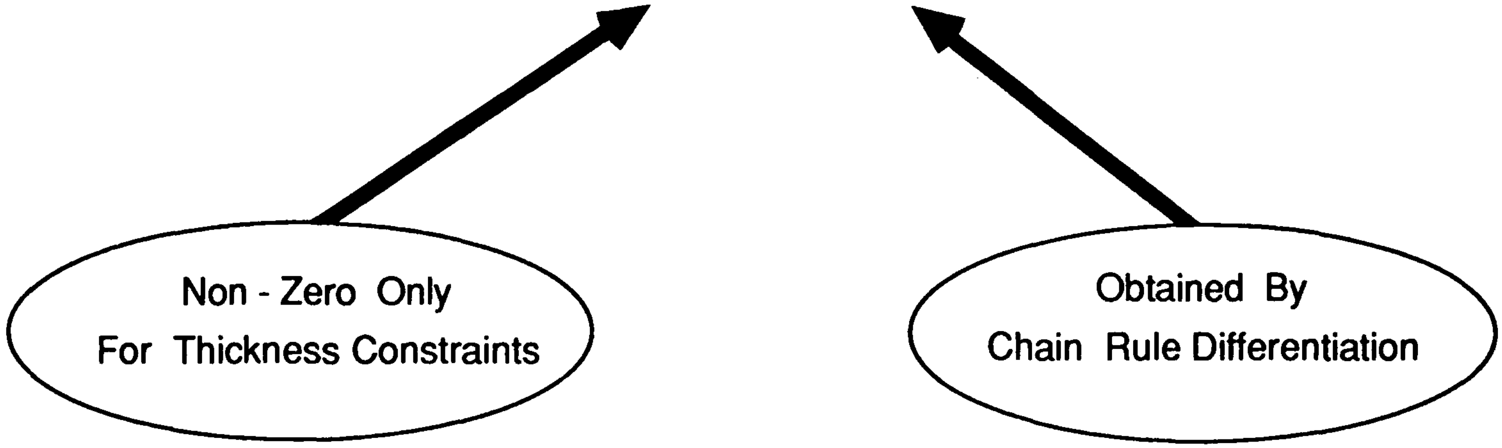
Static Analysis - Strength Constraint Sensitivity

- **Constraints are a Function of Design Variables and Structural Deformation**

$$g = f(u, v)$$

- **Sensitivity to a Design Variable is :**

$$\frac{\partial g_j}{\partial v_i} = \frac{\partial f_j}{\partial v_i} + \frac{\partial f_j^T}{\partial u} \frac{\partial u}{\partial v_i}$$



Non - Zero Only
For Thickness Constraints

Obtained By
Chain Rule Differentiation

Gradient Method For Sensitivity Analysis - Overview

- Solves

$$[K]\left\{\frac{\partial u}{\partial v}\right\} = \left\{\frac{\partial P}{\partial v}\right\} - \left[\frac{\partial K}{\partial v}\right]\{u\}$$

- Forms

$$\frac{\partial g}{\partial v} = \frac{\partial f}{\partial u}^{T} \frac{\partial u}{\partial v}$$

- Number of Forward - Backward Substitutions Equal to the Number of Design Variables Times the Number of Load Cases

- Method is General

Virtual Load Method For Sensitivity Analysis

- Solves

$$[K]\{w\} = \{\frac{\partial f}{\partial u}\}$$

- Forms

$$\frac{\partial g}{\partial v} = \{w\}^T \left[\{\frac{\partial P}{\partial v}\} - [\frac{\partial K}{\partial v}]\{u\}\right]$$

- Number of Forward - Backward Substitutions Equal to the Number of Constraints
- Method Not Applicable With Inertia on Aerodynamic Terms

Sensitivity Analysis - Gradient Method

- The Gradient of the Equilibrium Equation Gives

$$[K_{gg}]\{\frac{\partial u_g}{\partial v}\} + [M_{gg}]\left\{\frac{\partial \ddot{u}_g}{\partial v}\right\} = \{\frac{\partial P_g}{\partial v}\} - [\frac{\partial K_{gg}}{\partial v}]\{u_g\} - [\frac{\partial M_{gg}}{\partial v}]\{\ddot{u}_g\}$$

- Terms on the Right Hand Side are Known

$$\left\{\frac{\partial P_g}{\partial v_i}\right\} = \{DPGR\}_i + \{DPTH\}_i$$

$$\left[\frac{\partial K_{gg}}{\partial v_i}\right] = [DKV]_i + \alpha v_i^{(\alpha-1)}[DKBV]_i$$

$$\left[\frac{\partial M_{gg}}{\partial v_i}\right] = [DMV]_i$$

- These are Pseudo - Load Vectors that are Designated DP_g

Sensitivity Analysis - Gradient Method (Continued)

- **With Support, Gradient of Orthogonality Constraint Gives :**

$$[\,D \quad I\,]^T \begin{bmatrix} M_{\ell\ell} & M_{\ell r} \\ M_{r\ell} & M_{rr} \end{bmatrix} \begin{Bmatrix} DU_\ell \\ DU_r \end{Bmatrix} = -[\,D \quad I\,]^T \begin{Bmatrix} DMU_\ell \\ DMU_r \end{Bmatrix}$$

Where

$$DU = \partial u / \partial v$$

$$DMU = \left[\frac{\partial M}{\partial v}\right] \{u\}$$

- **Leads to Sensitivity Equations Similar to the Analysis Equations**

$$\begin{bmatrix} K_{\ell\ell} & K_{\ell r} & M_{\ell\ell} D + M_{\ell r} \\ D^T M_{\ell\ell} + M_{r\ell} & D^T M_{\ell r} + M_{rr} & 0 \\ 0 & 0 & m_r \end{bmatrix} \begin{Bmatrix} DU_\ell \\ DU_r \\ DUD_r \end{Bmatrix}_i = \begin{Bmatrix} DP_\ell \\ D^T DMU_\ell + DMU_r \\ D^T DP_\ell + DP_r \end{Bmatrix}_i$$

Sensitivity Analysis - Gradient Method (Concluded)

- Gradients of Displacements in the f - set are Recovered From Gradients of Displacements and Accelerations in the a - set

- Sensitivity of Constraints With Respect to g - set Displacements are Reduced to the f - set

- This Results in Fewer Terms in the Vector Multiply to Obtain Constraint Gradients

$$\frac{\partial g_j}{\partial v_i} = \frac{\partial f_j}{\partial u_f}^T \frac{\partial u_f}{\partial v_i}$$

Modal Analysis

- **Determines Structural Eigenvalues and Eigenvectors**

$$[K_{aa} - \lambda M_{aa}]\{\Phi_a\} = 0$$

- **Useful in Its Own Right, But Also :**
  - Basis For Frequency Constraints
  - Flutter and Blast Analyses Always Use Modal Coordinates
  - Transient, Frequency and Gust Analysis Can Use Modal Formulation

- **Given's (Tridiagonal) Method of Eigenanalysis Employed**

- **Problem Size is Typically Reduced**
  - Guyan Reduction
  - Dynamic Reduction

Dynamic Reduction

- Reduces the Number of Freedom Without the Explicit Selection of Retained Degrees of Freedom

- Gives Comparable or Better Accuracy for Modal Analysis With Fewer Degrees of Freedom

- Generalized Dynamic Degrees of Freedom are Made up of Any or All of the Following:

    1) Physical Degrees of Freedom
    2) Inertia Relief Shapes
    3) Approximate Mode Shapes

Dynamic Reduction - Approximate Mode Shapes

- **Subspace Vectors are Generated Using Iteration**

$$[K - \lambda_s M] \{u_{i+1}\} = \frac{1}{c_i} [M] \{u_i\}$$

- **Process Converges to the Eigenvector Whose Eigenvalue is Closed to λ_s**
- **Previous Iterates Contain Nearby Eigenvectors**
- **Algorithm Performance Dependent on Specification of**
  - Starting Vector
  - Number of Iterates
  - Shift Point
  - Rejection of Parallel Vectors

Dynamic Reduction - Approximate Mode Shapes (Concluded)

- **Reduction is Performed Using**

$$\{u_f\} = [G_{fk}]\{u_k\}$$

u_k - Generalized Degree of Freedom

G_{fk} - Matrix of Approximate Eigenvectors

- **ASTROS Applications Have Produced Excellent, But Limited Results**

Frequency Constraint Evaluation

Constraints on Frequency Can Be Upper Bound

$$g_j = 1.0 - \frac{\left(2 \pi f_{high}\right)^2}{\lambda_j}$$

Or Lower Bound

$$g_j = \frac{\left(2 \pi f_{low}\right)^2}{\lambda_j} - 1.0$$

Structural Frequencies Can Be Squeezed Into a Range But Not Squeezed Out

Frequency Constraint Sensitivity

For Upper Bound Constraint

$$\frac{\partial g_j}{\partial v_i} = \frac{(2\pi f_{HIGH})^2}{\lambda^2_j} \frac{\partial \lambda_j}{\partial v_i} = \frac{(1.0 - g_j)}{\lambda_j} \frac{\partial \lambda_j}{\partial v_i}$$

Where

$$\frac{\partial \lambda_j}{\partial v_i} = \{\phi_j\}^T \left[\frac{\partial K}{\partial v_i} - \lambda_j \frac{\partial M}{\partial v_i}\right] \{\phi_j\} / (\{\phi_j\}^T [M] \{\phi_j\})$$

Steady Aerodynamics

- **ASTROS Has Incorporated the USSAERO - C Computer Code**

- **Features Include**
  - Subsonic and Supersonic Analyses
  - Symmetric and Antisymmetric Analyses
  - Multiple Lifting Surfaces
  - Body Elements for Fuselage and Pods
  - Thickness and Camber Effects
  - Aerodynamic Influence Coefficients
  - Multiple Mach Numbers

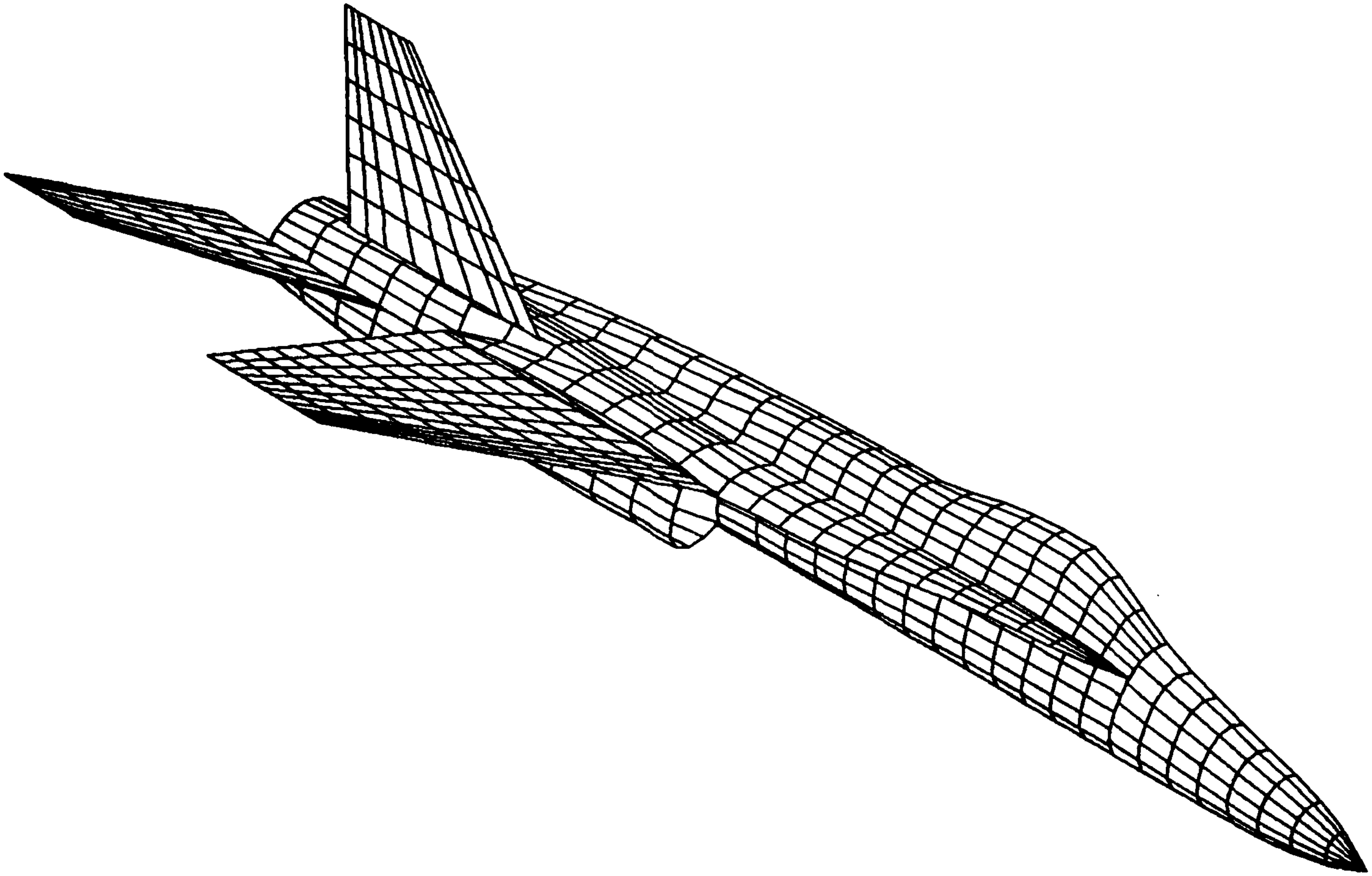
Steady Aerodynamics

- Aircraft Configuration is Modeled By Discrete Panels
- Singularities at Panels are Solved For as a Function of the Boundary Condition

$$\begin{bmatrix} A_{bb} & A_{bw} \\ A_{wb} & A_{ww} \end{bmatrix} \begin{Bmatrix} \sigma \\ \gamma \end{Bmatrix} = \begin{Bmatrix} \omega_b \\ \omega_w \end{Bmatrix}$$

- Singularities $\Longrightarrow$ Velocities $\Longrightarrow$ Pressures $\Longrightarrow$ Forces
- Rigid Aerodynamic Forces are Computed For a Series of Boundary Conditions
- Aerodynamic Influence Coefficient Matrix Based on Linearized Pressure Computation

Steady Aerodynamics - Paneling Example



Unsteady Aerodynamics

- **Two Paneling Methods Have Been Implemented :**

  Doublet Lattice For Subsonic Aerodynamics
  Constant Pressure Method For Supersonic Aerodynamics
  A Common Geometric Definition is Utilized

- **Features Include**

  Symmetric, Antisymmetric and Asymmetric Analyses
  Slender Bodies and Interference Panels For Subsonic Aerodynamics
  No Bodies For Supersonic Aerodynamics
  Multiple Lifting Surfaces

Unsteady Aerodynamics

Preface Aerodynamics Compute Three Basic Matrices

A - Computes Downwash For Given Pressures

$$w = [A]\,P$$

D - Computes Downwash For Given Displacements

$$w = [D]\,U$$

S - Computes Forces For Given Pressures

$$F = [S]\,P$$

Subsequent Disciplines Require Different Matrices

Fluttered Gust : $[Q_{hh}] = [\phi\, G^T\, SA^{-1}\, DG\phi]$

Gust : $[Q_{hj}] = [\phi\, G^T\, SA^{-1}]$

Blast: $[A]^{-1}$

Design Independent Calculations are Performed Only Once

Connection Between Aerodynamic And Structural Models

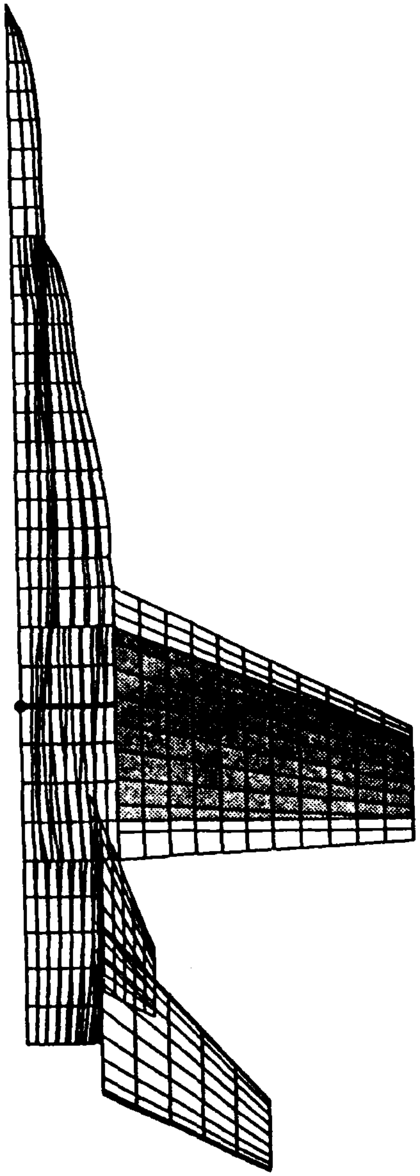
- **Aerodynamic and Structural Points are Typically Not Coincident**
- **Two Techniques are Available for Transfer of Deformations and Forces**
    - Surface Spline Technique
    - Equivalent Force Transfer

Surface Spline

- Developed By Harder and Desmaris and Applied in NASTRAN
- Solves Equation For an Infinite Plate to Provide Deformations of a Continuous Surface Based on Deformations at a Discrete Set of Points

UNSTEADY	***STEADY***
$\{w_a\} = [UG]\{w_s\}$	$\{\alpha_a\} = [GS]\{w_s\}$
$\{F_s\} = [UG]^T\{F_a\}$	$\{F_s\} = [G]\{F_a\}$
w - Deformation	a - Aero Model
α - Slope	s - Structural Model

Equivalent Load Transfer



Used When No Underlying Structural Model Exists For Aerodynamic Components

Geometrically Based Transfer :

$$\{F\}_R = \sum_{i=1}^{NBOX} \{F\}_i$$

$$\{M\}_R = \sum_{i=1}^{NBOX} [R]_i \{F\}_i$$

Where

$$[R]_i = \begin{bmatrix} 0 & -(z_i - z_R) & (y_i - y_R) \\ (z_i - z_R) & 0 & -(x_i - x_R) \\ -(y_i - y_R) & (x_i - x_R) & 0 \end{bmatrix}$$

Static Aeroelastic Analysis

The Aerodynamic Loads Contain a Rigid Portion

$$[PA_f] = \bar{q}\ [G_{jf}]^T\ [AIRFRC]$$

And a Portion Related Structural Deformation

$$[AICS_{ff}] = \bar{q}\ [G_{jf}]^T\ [AIC]\ [GS_{jf}]$$

The Equilibrium Equation is Then

$$[K_{ff} - AICS_{ff}]\{u_f\} + [M_{ff}]\{\ddot{u}_f\} = [PA_f]\ \{\delta\}$$

A New Matrix Combines Structural and Aerodynamic Stiffnesses

$$[KA_{ff}] = [K_{ff} - AICS_{ff}]$$

Static Aeroelastic Analysis

The Solution of the Aeroelastic Equations Resembles That of Static Analysis

$$\left[\begin{array}{cc|c} KA_{\ell\ell} & KA_{\ell r} & M_{\ell\ell}D+M_{\ell r} \\ D^TM_{\ell\ell}+M_{r\ell} & D^TM_{\ell r}+M_{rr} & 0 \\ \hline D^TKA_{\ell\ell}+KA_{r\ell} & D^TKA_{\ell r}+KA_{rr} & m_r \end{array}\right] \left\{\begin{array}{c} u_\ell \\ u_r \\ \hline \ddot{u}_r \end{array}\right\} = \left[\begin{array}{c} PA_\ell \\ 0 \\ \hline D^TPA_\ell+PA_r \end{array}\right] \{\delta\}$$

A Notational Change Gives

$$\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} \{\delta\}$$

The First Equation is Solved for u_1 and Substituted Into the Second to Give

$$[K_{22} - K_{21}K_{11}^{-1}K_{12}]\{u_2\} = [P_2 - K_{21}K_{11}^{-1}P_1]\{\delta\}$$

This is the Basic Equation For Static Aeroelastic Analysis

Static Aeroelastic Analysis - Symmetric Trim

For Symmetric Analysis, the δ Vector Has Four Components

o - Thickness and Camber Effects
δ_e - Pitch Control Surface
q - Pitch Rate
α - Angle of Attack

Single Equation Trim :

Lift Equation is Balanced
Pitch Rate and Pitch Control are Ignored

u_2 is a Scalar Equal to $g\,n_z$
α is Determined That Provides Required Lift

Static Aeroelastic Analysis - Symmetric Trim

Two Equation Trim

Lift and Pitching Moment are Balanced

Pitch Acceleration is Zero

Vertical Acceleration is $g\,n_z$

$$q = \frac{g\,(n_z - 1)}{V}$$

α and δ_e are Determined

Given u_2 and δ, Recovery of Displacements and Stresses is Straightforward

Lift Effectiveness Constraint

Bounds are Placed on the Flexible to Rigid Lift Curve Slope

$$\epsilon_{min} \leq \frac{C_{L_{\alpha_f}}}{C_{L_{\alpha_R}}} \leq \epsilon_{max}$$

Flexible Derivatives are Obtained From Basic Equation

$$\frac{\bar{q}S}{2}\left\{\begin{matrix} C_{L_{\alpha_f}} \\ cC_{m_{\alpha_f}} \end{matrix}\right\} = [m_r][K_{22}-K_{21}K_{11}^{-1}K_{12}]^{-1}[P_2-K_{21}K_{11}^{-1}P_1]\{\delta_\alpha\} \Leftarrow$$

Unit α
Other Components
Zero

Includes Inertia Relief and Aeroelastic Effects

Rigid Derivatives are Obtained From

$$\frac{\bar{q}S}{2}\left\{\begin{matrix} C_{L_{\alpha_R}} \\ \hline cC_{m_{\alpha_R}} \end{matrix}\right\} = [P_2]\{\delta_\alpha\}$$

Lift Effectiveness Constraint (Concluded)

Effectiveness Affected By Dynamic Pressure But is Independent of Trim Requirements

A Positive Lower Bound Limit on Effectiveness Creates the Constraint

$$g = 1.0 - \epsilon / \epsilon_{REQ}$$

Upper Bound, Negative and Zero Requirements Can Also Be Specified

Antisymmetric Aeroelastic Analysis

For Antisymmetric Analysis, the δ Vector Has Two Components

δ_a - Roll Control Surface
p - Roll Pitch Rate

Analysis Computes Aircraft Roll Effectiveness

$$\epsilon_{eff} = -\left(C_{\ell_{\delta a}}\right)_f / \left(C_{\ell_{\frac{pb}{2V}}}\right)_f$$

Measures Steady State Roll Achievable for a Unit Aileron Deflection

Roll Effectiveness Constraint

Flexible Derivatives are Calculated From

$$\frac{\bar{q}Sb}{2} C_{\ell_{\delta a}} = [P_2 - K_{21}K_{11}^{-1}P_1] \begin{Bmatrix} 1.0 \\ 0.0 \end{Bmatrix}$$

$$\frac{\bar{q}Sb^2}{4} C_{\ell_{\frac{pb}{2V}}} = [P_2 - K_{21}K_{11}^{-1}P_1] \begin{Bmatrix} 0.0 \\ 1.0 \end{Bmatrix}$$

Constraint Form and Capabilities Similar to Lift Effectiveness

Static Aeroelasticity - Sensitivity Analysis

Similar to Sensitivity of Static Analysis Without Aerodynamics

- Aerodynamic Matrices are Invariant with Respect to Design Variables
- Calculation Varies Depending on the Condition

Basic Equation is

$$\left[\begin{array}{cc|c} KA_{\ell\ell} & KA_{\ell r} & M_{\ell\ell}D+M_{\ell r} \\ D^{T}M_{\ell\ell}+M_{r\ell} & D^{T}M_{\ell r}+M_{rr} & 0 \\ \hline D^{T}KA_{\ell\ell}+KA_{r\ell} & D^{T}KA_{\;\;r}+KA_{rr} & m_{r} \end{array}\right] \left\{\begin{array}{c} Du_{\ell} \\ Du_{r} \\ \hline DUD_{r} \end{array}\right\}_{i} = \left[\begin{array}{c} PA_{\ell} \\ 0 \\ \hline D^{T}PA_{\ell}+PA_{r} \end{array}\right] \{DDEL\}_{i}$$

$$+ \left\{\begin{array}{c} DP_{\ell} \\ D^{T}DMU_{\ell}+DMU_{r} \\ \hline D^{T}DP_{\ell}+DP_{r} \end{array}\right\}$$

Static Aeroelasticity - Sensitivity Analysis

For Trim Sensitivity

Acceleration is Invariant

Compute Change in Trim Settings

Change in Displacements Then Extracted

For Lift Effectiveness Sensitivity

Configuration Parameters are Invariant

Changes in Accelerations and Displacement are Computed

For Roll Effectiveness Sensitivity

Configuration Parameters are Invariant

Acceleration is Invariant and Zero

Changes in Displacement are Computed

Flutter Analysis

p − k METHOD OF FLUTTER ANALYSIS EMPLOYED

$$\left[p^2 \left(\frac{V}{b}\right)^2 M_{HH} + K_{HH} - \rho \frac{V^2}{2} \left(\frac{p}{k} Q^I_{HH} + Q^R_{HH} \right) \right] \{v\} = 0$$

WHERE

$$p = k\ (\gamma + i)$$

$$M_{HH} = \Phi^T M \Phi$$

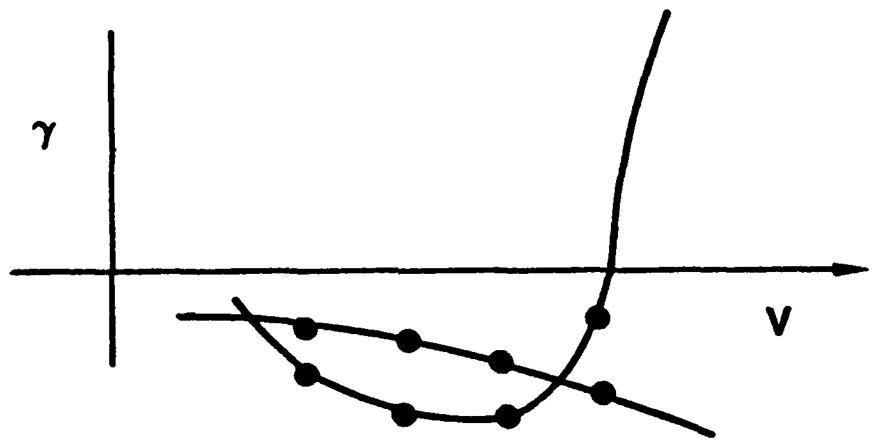
$$K_{HH} = \Phi^T K \Phi$$

$$Q_{HH} = \Phi^T G^T S A^{-1} D G \Phi$$

THE EQUATION REPRESENTS A SYNTHESIS OF NASTRAN AND FASTOP

Flutter Analysis

p – k METHOD SOLVES FOR p AT A SET OF SPECIFIED VELOCITIES



FASTOP ALGORITHM EMPLOYED TO SOLVE EQUATION
MULLER'S METHOD WITH DEFLATION
MODIFIED TO EXTRACT REAL ROOTS

GIVEN p:

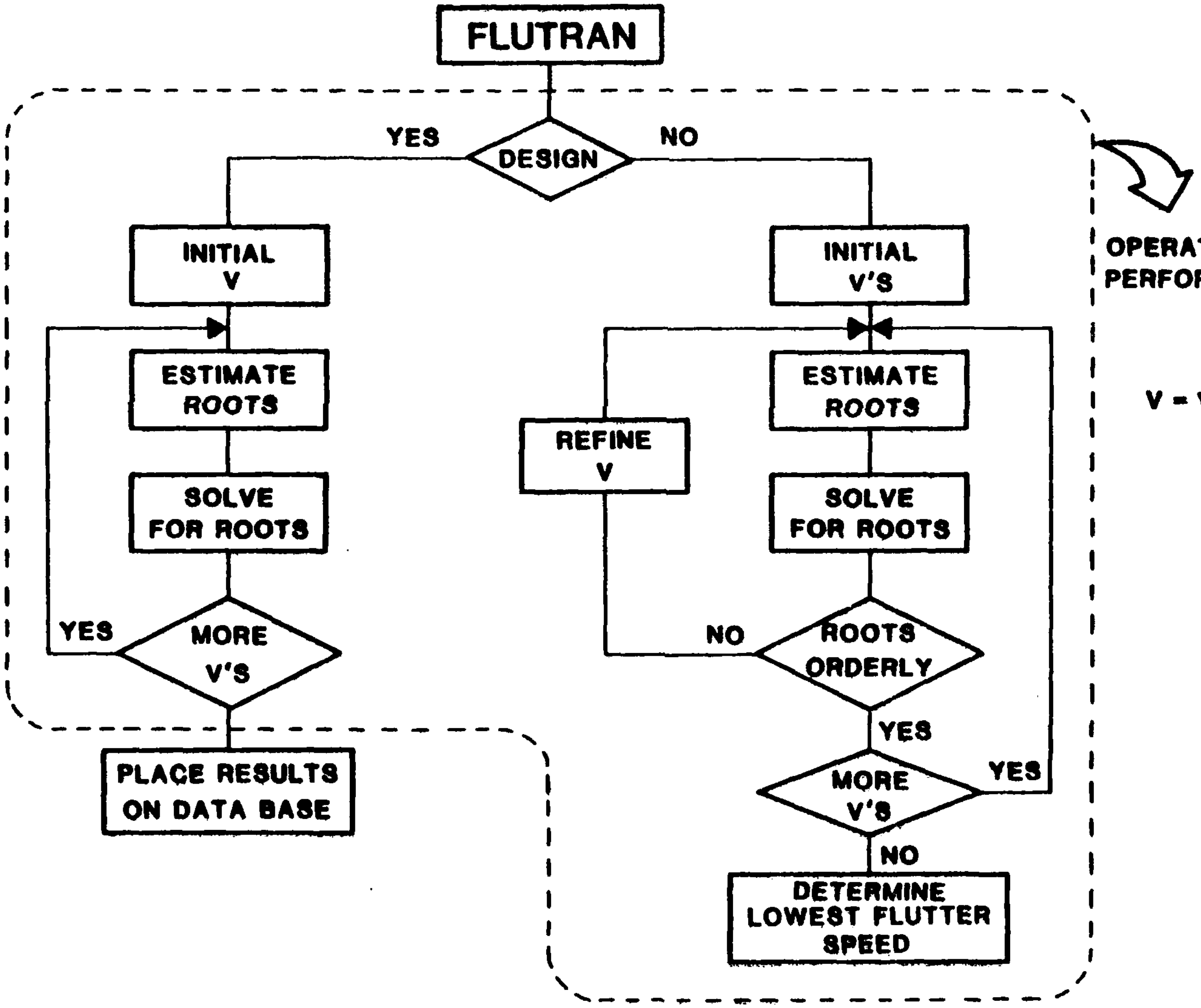
$k = \text{Imag}(p)$

$\gamma = \text{Real}(p)/k$

Flutter Analysis - Aerodynamic Interpolation

- Aerodynamics Have Been Computed at a Discrete Set of Reduced Frequencies
- p - k Method Assumes Aerodynamics are Available as a Continuous Function of Reduced Frequency
- A Cubic Spline Fit of the Aerodynamics, Adapted From NASTRAN, is Used for Interpolation
- Quality of the Interpolation is Assessed By the Procedure

Flutter Analysis Algorithms



OPERATIONS PERFORMED IN CORE

V = VELOCITY

Flutter Constraint Form

$$g = \frac{\gamma - \gamma_{REQ}}{GFACT} \leq 0.0$$

Where

γ - Extracted Damping Value

$$= \frac{Re(p)}{k} \quad \text{For Oscillatory Roots}$$

$$= \frac{p}{\ell n\, 2} \quad \text{For Real Roots}$$

γ_{REQ} - Required Damping Value Which Can Be a Function of Velocity

GFACT - Normalization Factor

NOTE : IT IS NOT NECESSARY TO KNOW THE FLUTTER SPEED

Flutter Constraint Properties

- Computation of the Flutter Speed Not Required
- Constraint Evaluated Only at Velocities of Interest
- " Hump " Mode Behavior is Addressed
- Typically, Only a Few Constraints Require Gradients

Flutter Constraint Sensitivity

The Gradient of the Flutter Constraint is Given By

$$\frac{\partial g}{\partial v_i} = \frac{1}{\text{GFACT}} \frac{\partial \gamma_{j1}}{\partial v_i}$$

The Gradient of the Damping Value is Given By

$$\frac{\partial \gamma_{j1}}{\partial v_i} = \frac{1}{k} \left(\frac{\partial \text{Re}(p)}{\partial v_i} - \gamma_j \frac{\partial \text{Im}(p)}{\partial v_i} \right)$$

Gradient is Computed Analytically

Sensitivity of the Normal Modes is Not Required

- Adjoint Flutter Vector Utilized
- Similar to Frequency Constraint Sensitivity

Procedure is Conceptually Straightforward But Algebraically Complex

Automated Design - Methods Of Solution

Mathematical Programming

Search for the Optimum Based on Currently Available Information

General in Application

Computationally Intensive

Fully Stressed Design

Redesigns Based on an Optimality Criterion

Computationally Efficient

Limited in Application

Mathematical Programming

ASTROS Employs the MICRO - DOT Code

Combines Features of Feasible Directions and Generalized Reduced Gradient

One-Dimensional Search Based on Polynomial Interpolation with Bounds

Other Algorithms Could Be Readily Substituted

Reduction In The Number Of Design Variables

- **Design Variable Linking**
    - Reduces Size of the Design Task
    - Allows Consideration of Physical Limitations
- **There are No Fixed Limits on the Number of Design Variables**
    - Computer Resources a Nonlinear Function at Design Variables and Constraints
    - Practical Limits a Function of Computer Utilized and User's Tolerance Level
    - 200 - 300 Variables Taxing for a Micro Computer

Reduction In The Number Of Constraints

- **The Majority of the Constraints Do Not Affect the Redesign Task**
- **Motivation for Reduction**
  - Eases the Sensitivity Analysis Task
  - Streamlines the Redesign Task
- **Constraints are Included in Redesign if**
  - They are Greater Than $\in$
  - At Least NRFAC x ndv Constraints are Always Retained
- **Deletion of Constraints Can Result in**
  - Inactive Boundary Conditions
  - Inactive Disciplines
  - Inactive Subcases

The Approximate Design Problem

- **A Major Efficiency Results From Approximating Quantities Required in Redesign Rather Than Computing Them Explicity**
- **Five Basic Pieces of Information are Supplied to the Design Task :**

F_o - Current Value of the Objective

$\{v_o\}$ - Current Values of the Design Variables

$\{g_o\}$ - Current Values of the Retained Constraints

$\{\partial F/\partial v_i\}$ - Gradient of the Objective with Respect to the Design Variables

$[A]$ - Current Value of the Gradient of the Active Constraints with Repect to the Design Variables

The Approximate Design Problem

- **Assumption is Made That Constraint Gradients are Invariant with Respect to Changes in the Design Variables**
- **Quality of This Assumption is Enhanced By the Use of Inverse Design Variables**
  - $x_i = 1/v_i$
  - Motivation is that Strength Constraints are Inversely Proportional to Structural Thickness
  - Applicable to Unique and Physical Linking

Redesign Using Inverse Design Variables

Objective and Constraints are Computed as

$$F = \sum_{i=1}^{ndv} \frac{1}{x_i} \frac{\partial F}{\partial v_i}$$

$$g_j = g_{oj} - \sum_{i=1}^{ndv} \frac{A_{ji} (x_i - x_{oi})}{x_{oi}^2}$$

Gradients of the Objective and Constraints

$$\frac{\partial F}{\partial x_i} = - \frac{1}{x_i^2} \frac{\partial F}{\partial v_i}$$

$$\frac{\partial g_j}{\partial x_i} = - \frac{1}{x_{oi}^2} A_{ji}$$

Move Limits are Imposed on the Design Variables During Redesign

$$\frac{x_{oi}}{MOVLIM} \leq x_i \leq MOVLIM \cdot x_{oi}$$

Redesign Using Direct Design Variables

Inverse Design Variables are Not Applicable with Shape Function Linking

- Physical Significance Not Clear
- Direct Variables Can Be Zero

Objective and Constraints are Computed as

$$F = \sum_{i=1}^{ndv} v_i \frac{\partial F}{\partial v_i}$$

$$g_j = g_{oj} + \sum_{i=1}^{ndv} A_{ji} v_i$$

Gradients of the Objective and Constraints are

$$\frac{\partial F}{\partial v_i} = \frac{\partial F}{\partial v_i}$$

$$\frac{\partial g_j}{\partial v_i} = A_{ji}$$

Termination Criteria

- **MICRO - DOT Designates Approximate Problem Converged When Either**

$|\Delta F| \leq$ DABOBJ (.001)

$|\Delta F / F| \leq$ DELOBJ (.001)

In Two Sucessive Iterations

- **ASTROS Tentatively Designates Design Converged if**

$|\Delta F| \leq .005$

$|\Delta F / F_o| \leq$ 0.1 CNVLIM (.005)

Termination Criteria (Concluded)

- Check Must Be Made if Constraints are Satisfied
- Design is Analyzed and Designated Converged When

$$2.0 \cdot CTL < g_{max} < 3.0 \cdot CTLMIN$$

g_{max} - Maximum Constraint Value

CTL - Active Constraint Identifier (D = -.003)

CTLMIN - Violated Constraint Identifier (D = .0005)

Fully Stressed Design Option

- **Resize Local Design Variables Based on a Simple Stress Ratio**

$$t_{i_{new}} = \max\left\{\left({}^{\sigma}/\sigma_{all}\right)^{\alpha} \cdot t_{i_{old}},\ t_{i_{min}}\right\}$$

- **Simple Stress Ratio Obtained from Existing Stress Constraints**

$${}^{\sigma}/\sigma_{all} = G + 1.0$$

- **Determine New Global Variable Value from Linking Relation**

$$t_i = P_{ij}\ V_j$$

$V_{j_{new}} = \max\left\{{}^{t_{i_{new}}}/{}^{P_{ij}}\right\}$ over all t_i for j th V

Fully Stressed Design Option (Concluded)

- User Selects FSD Through Solution Control Optimization Strategy
- User Can Select the Number of FSD Cycles Performed Before Switching to Math Programming
- FSD is not Supported for Shape Function Design Variable Linking

Dynamic Response Analysis

- **All Dynamic Response Disciplines are Based on an Equation of the Form :**

$$[M]\,\{\ddot{u}\} + [B]\,\{\dot{u}\} + [K - qQ]\,\{u\} = \{P(t)\} + \{C\}$$

- **Transient Response, Frequency Response and Flutter**
    - Gust Analysis
    - Fast Fourier Transform Techniques
- **Direct and Modal Formulations Available**

Dynamic Matrix Assembly
Direct Forms

$$[M_{dd}] = [M^1_{dd}] + [M^2_{dd}]$$

$$[B_{dd}] = [B^2_{dd}] + \frac{g}{\omega_3}[K^1_{dd}]$$

$$[K_{dd}]^t = [K^1_{dd}] + [K^2_{dd}]$$

$$[K_{dd}]^f = (1 + ig)\ [K^1_{dd}] + [K^2_{dd}]$$

Superscripts: 1 Denotes Matrices Obtained Through Assembly of Element Matrices

2 Denotes Direct Input Matrices

Dynamic Matrix Assembly
Modal Forms

$$[M_{hh}] = [\diagdown m_i \diagdown] + [\phi_{dh}]^T [M^2_{dd}] [\phi_{dh}]$$

$$[B_{hh}] = [\diagdown b_i \diagdown] + [\phi_{dh}]^T [B_{dd}] [\phi_{dh}]$$

$$[K_{hh}]^t = [\diagdown k_i \diagdown] + [\phi_{dh}]^T [K^2_{dd}] [\phi_{dh}]$$

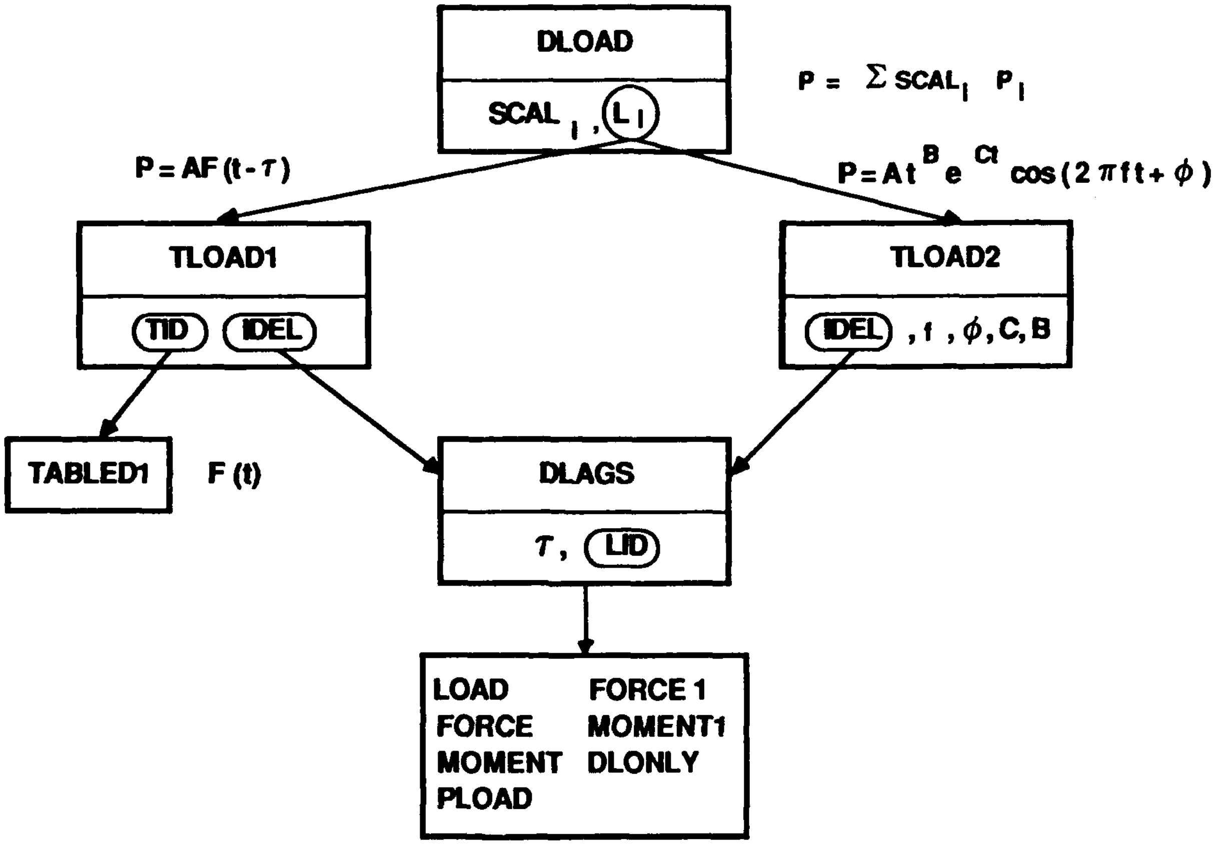
$$[K_{hh}]^f = (1+ig) [\diagdown k_i \diagdown] + [\phi_{dh}]^T [K^2_{dd}] [\phi_{dh}]$$

Where	m_i	are the generalized mass terms
	b_i	are the generalized modal damping terms
	k_i	are the generalized stiffness terms

Dynamic Load Generation
Transient Response

$$P(x, y, z, t) = S(x, y, z)\,F(t)$$

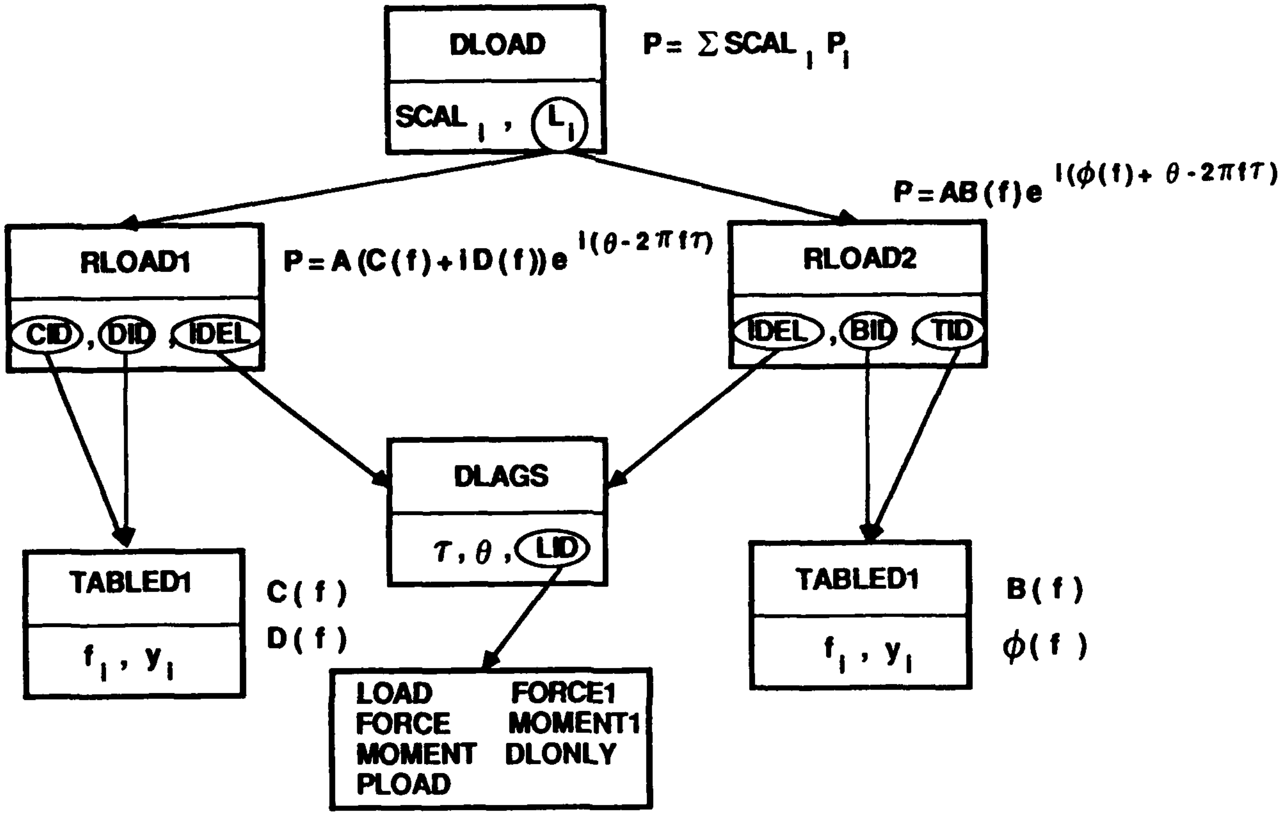
Input Flow



Dynamic Load Generation Frequency Response

$$P(x,y,z,f) = S(x,y,z)\,F(f)$$

Input Flow

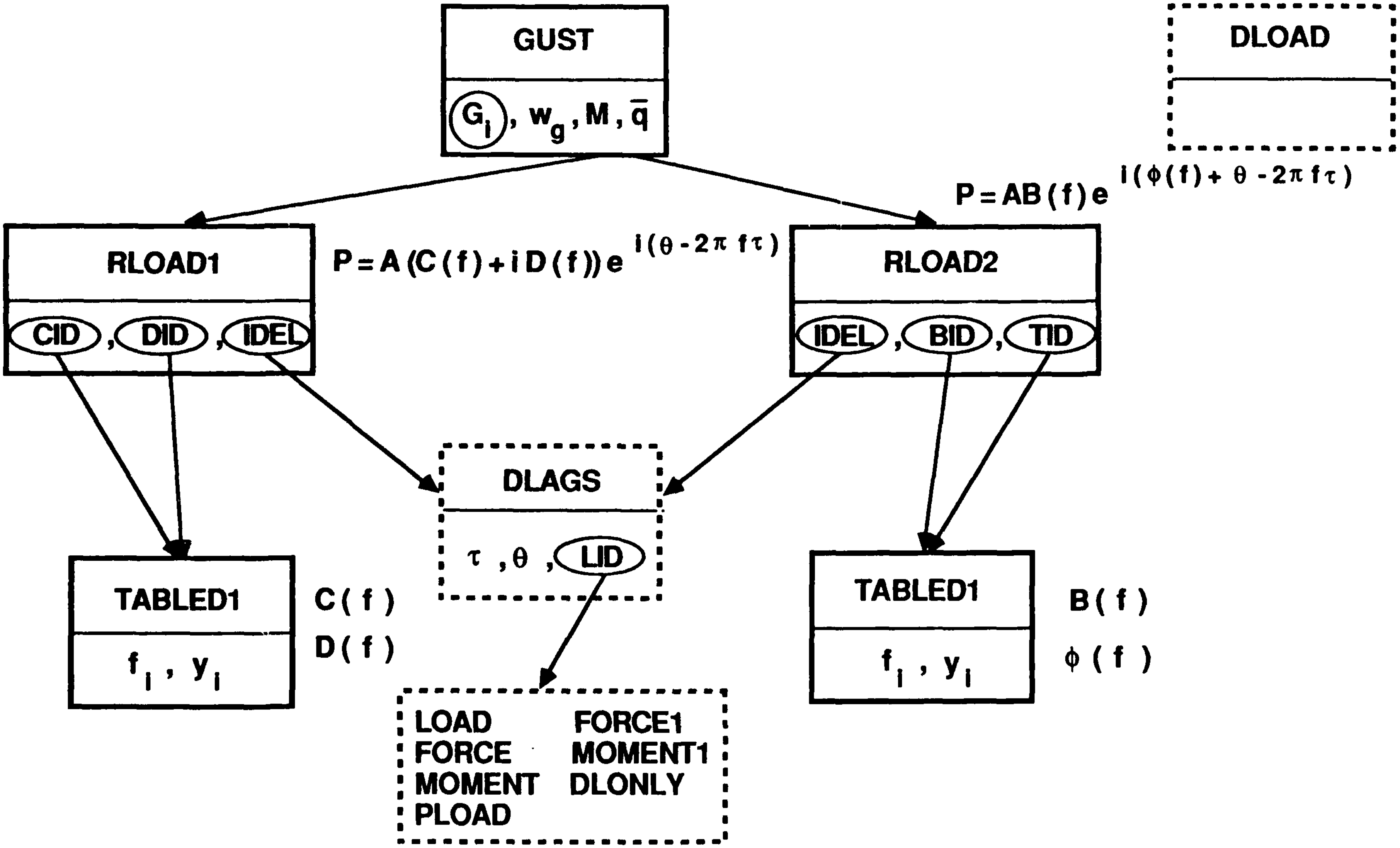


$P = \Sigma\, SCAL_i\, P_i$

$P = A(C(f) + iD(f))e^{i(\theta - 2\pi f \tau)}$

$P = AB(f)e^{i(\phi(f) + \theta - 2\pi f \tau)}$

Dynamic Load Generation - Gust Response



GUST

$\textcircled{G_i}$, w_g, M, $\bar{q}$

DLOAD

RLOAD1

CID, DID, IDEL

$P = A\,(C(f) + i\,D(f))\,e^{i(\theta - 2\pi f\tau)}$

RLOAD2

IDEL, BID, TID

$P = AB(f)\,e^{i(\phi(f) + \theta - 2\pi f\tau)}$

TABLED1

f_i, y_i

$C(f)$

$D(f)$

DLAGS

τ, θ, LID

TABLED1

f_i, y_i

$B(f)$

$\phi(f)$

LOAD
FORCE
MOMENT
PLOAD
FORCE1
MOMENT1
DLONLY

Dynamic Response Solution Techniques

Uncoupled Modal - Equations Can be Solved in Closed Form

Transient Response

$$u_{i,\ n+1} = F\ u_{i,n} + G\ \dot{u}_{i,n} + A\ P_{i,n} + B\ P_{i,n+1}$$

Frequency Response

$$u_i\ (\omega) = \frac{P_i(\omega)}{-m_i\omega^2 + ib_i\omega + k_i}$$

Coupled Modal and Direct Equations Require Additional Complexity

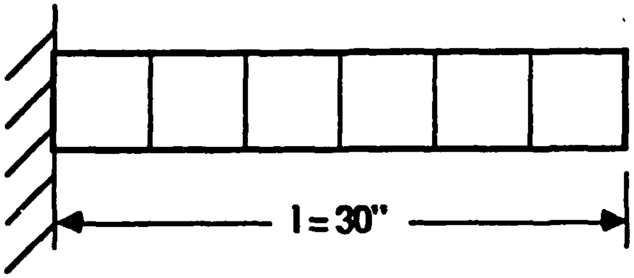
Transient Response Uses Newmark - Beta

$$[A]\ \{u_{n+1}\} = \frac{1}{3}\ \{P_{n+1} + P_n + P_{n-1}\} + [B]\ \{u_n\} + [C]\ \{u_{n-1}\}$$

Frequency Response - Decomposition and FBS of

$$[-\omega^2\ M_{hh} + i\omega B_{hh} + K_{hh}]\ \{u_h\} = \{P_h\}$$

Transient Response with a Feedback System



Mode	Frequency (Hz)
1	4.35
2	26.47
3	72.18
4	137.0
5	275.0

Damping Matrix

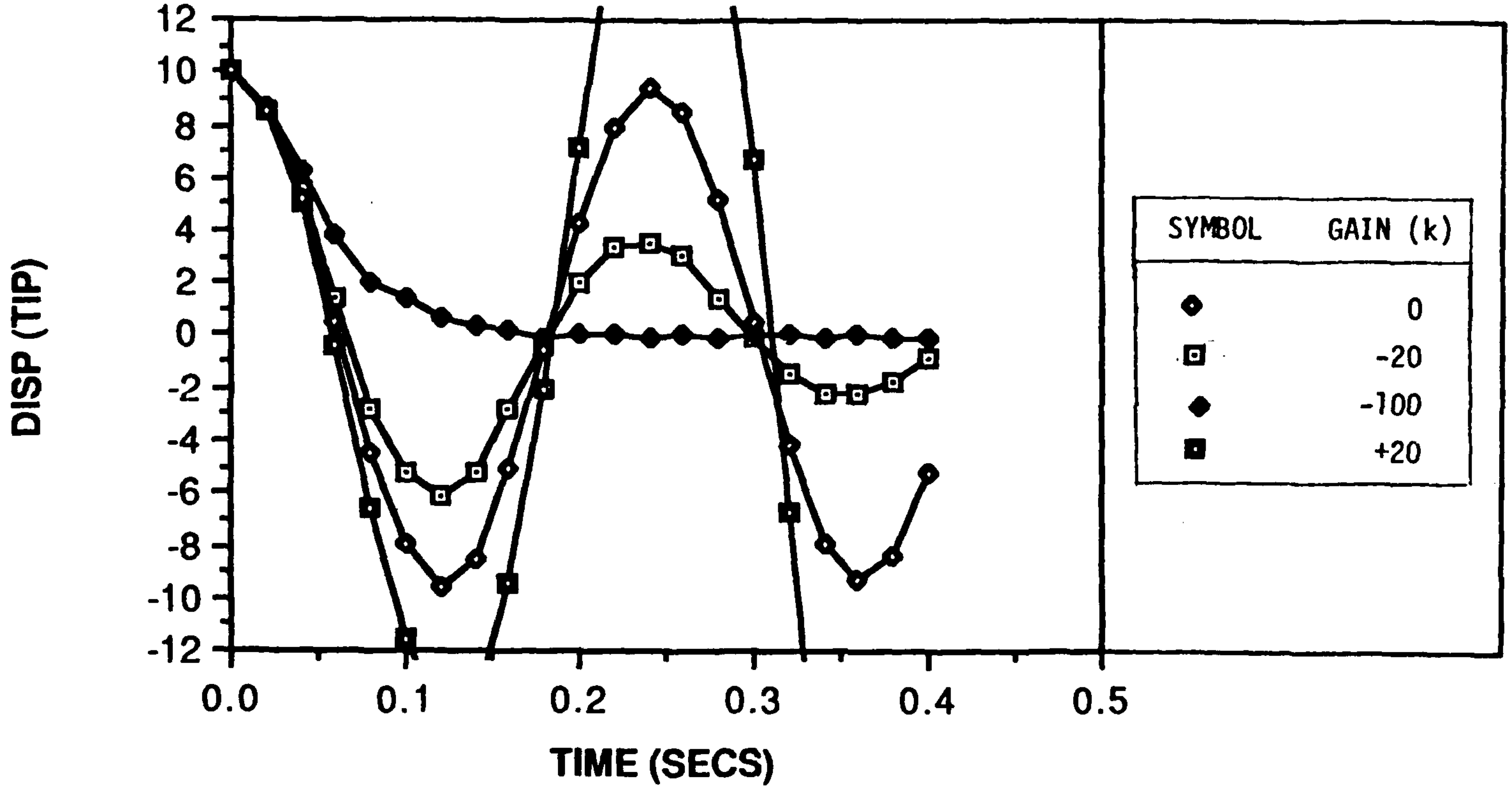
$B_{hh} = 3.18 \cdot 10^{-4} K_{hh}$

10 Inch Tip Deflection
was Imposed at $t = 0$

Feedback System :

$$F_{TIP} = \frac{ks\ W_{TIP}}{s^2 + 100s + 10000}$$

Response as a Function of Gain



Gust Analysis

- Gust Equation :

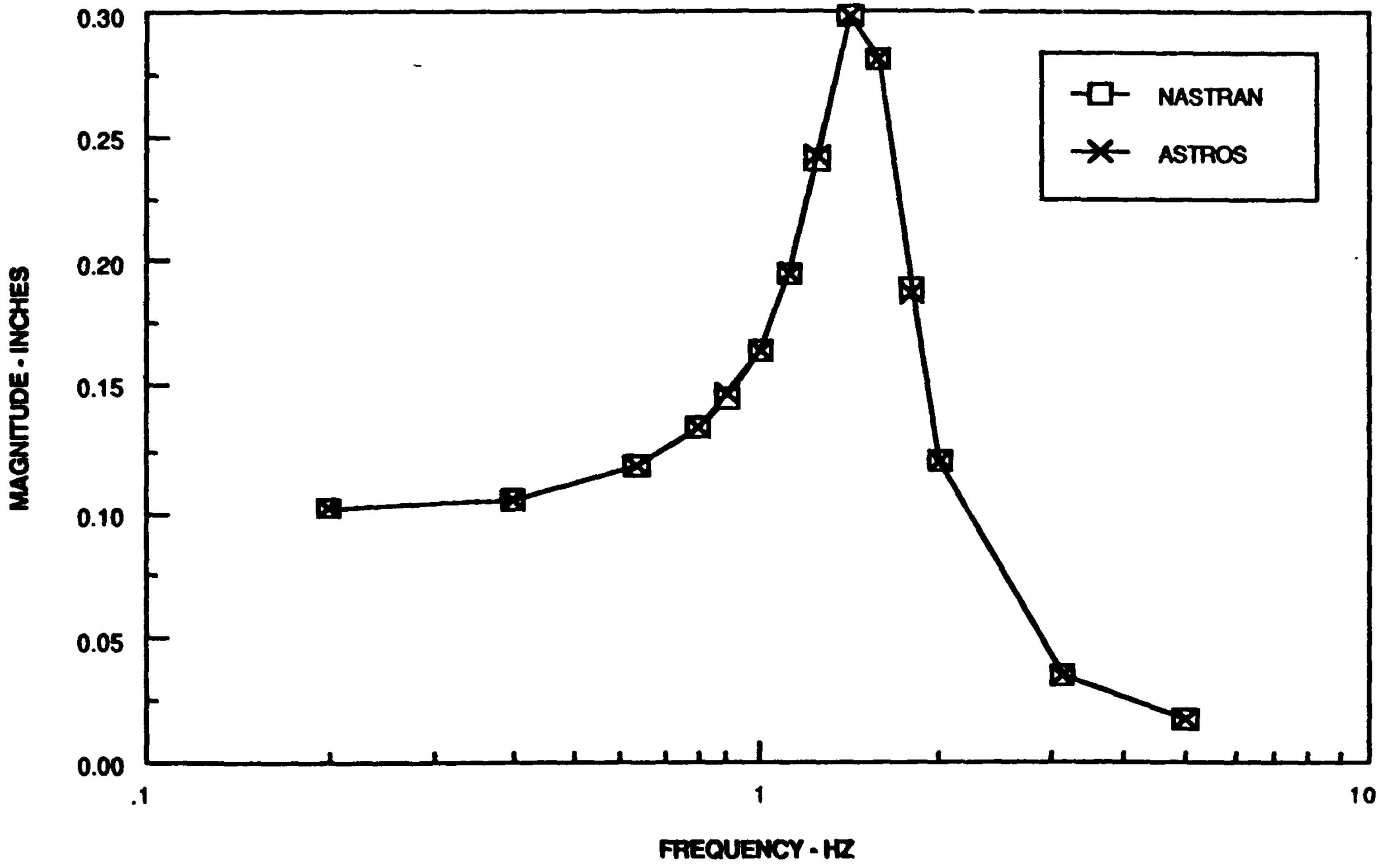
$$\left[-\omega^2 M + i\,\omega\left(B - \frac{\overline{q}\,b}{V}\,Q^{I}(\omega)\right) + K - \overline{q}\,Q^{R}(\omega)\right]u = P(\omega)$$

- Equation is Solved in the Frequency Domain Using the Modal Method

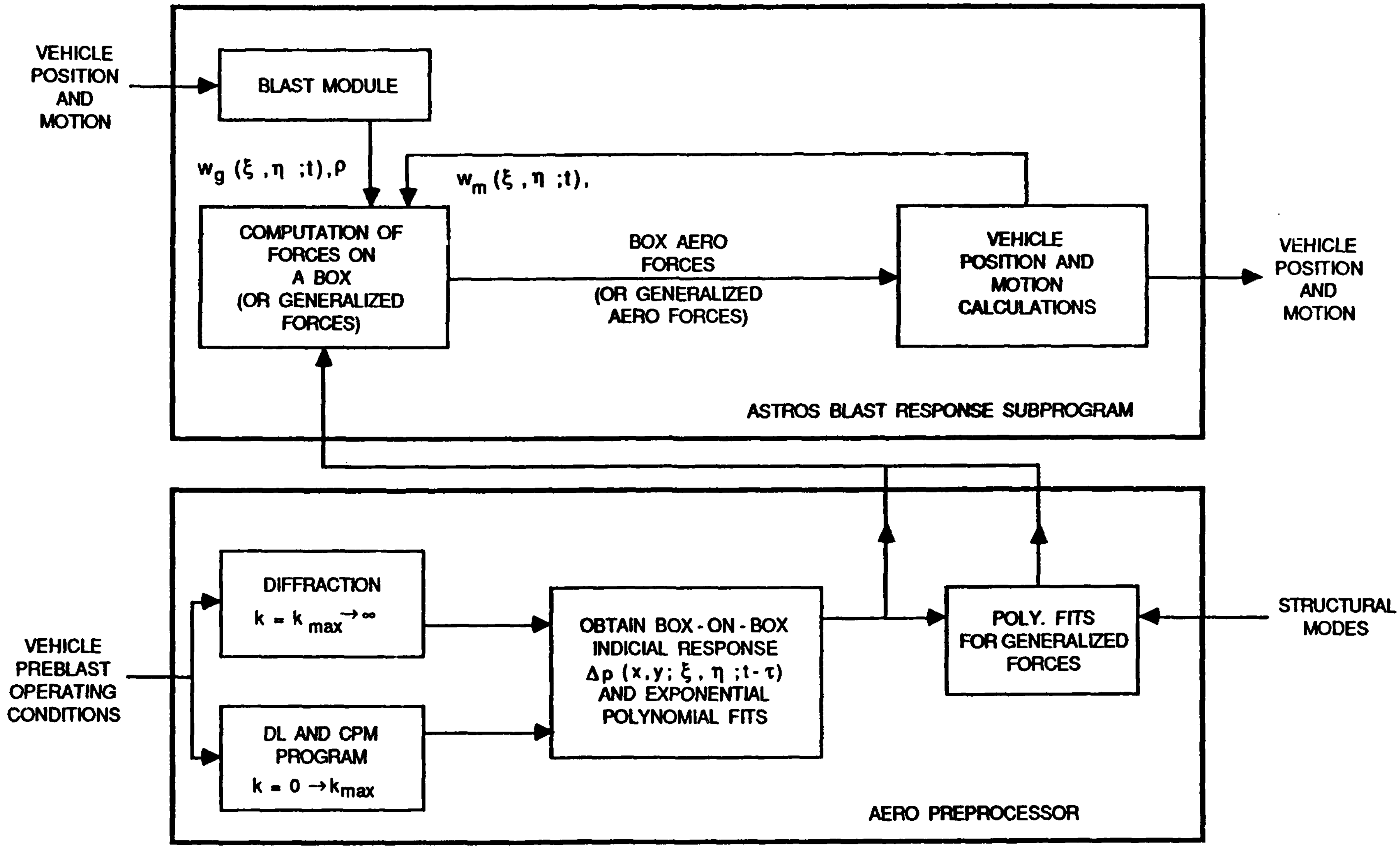
- Gust Loads are a Combination of :
  - Mode Shapes
  - Spline Matrix
  - Frequency Dependent Aerodynamics
  - Aircraft Geometry

- Existing Code was a Major Resource for the New Capability

Gust Response of the Swept Wing



The Nuclear Blast Calculation



VEHICLE POSITION AND MOTION

BLAST MODULE

$w_g(\xi, \eta; t), \rho$

$w_m(\xi, \eta; t),$

COMPUTATION OF FORCES ON A BOX (OR GENERALIZED FORCES)

BOX AERO FORCES (OR GENERALIZED AERO FORCES)

VEHICLE POSITION AND MOTION CALCULATIONS

VEHICLE POSITION AND MOTION

ASTROS BLAST RESPONSE SUBPROGRAM

VEHICLE PREBLAST OPERATING CONDITIONS

DIFFRACTION

$k = k_{max} \to \infty$

DL AND CPM PROGRAM

$k = 0 \to k_{max}$

OBTAIN BOX-ON-BOX INDICIAL RESPONSE $\Delta p(x, y; \xi, \eta; t-\tau)$ AND EXPONENTIAL POLYNOMIAL FITS

POLY. FITS FOR GENERALIZED FORCES

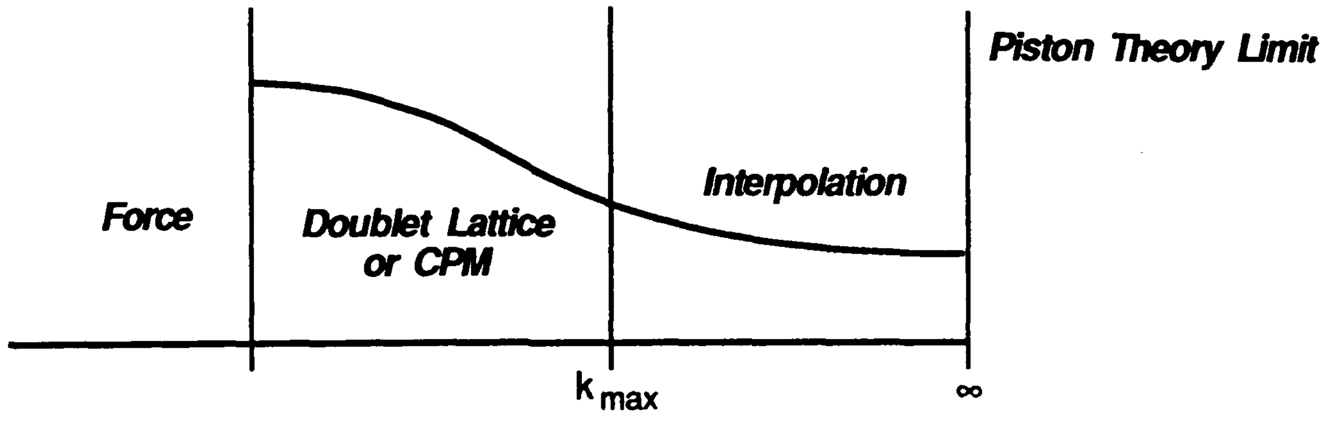
STRUCTURAL MODES

AERO PREPROCESSOR

The Aero Preprocessor For Nuclear Blast Calculation

- The Blast Calculations are Performed in the Time Domain While Unsteady Aerodynamics are Available in the Frequency Domain

- Fourier Transform Techniques are Used to Compute Indicial Time Response From Frequency Dependent Aerodynamics



- Special Treatment is Given to the Early Time Loading of a Box on Itself

The Aero Preprocessor (Concluded)

- **Indicial Function is Fit By Decaying Exponentials**

$$F\ (t) = a_o + \sum_n a_n \exp(\beta_n t)$$

β_n Values are User Input

Fit is Performed at User Input Times t_m

- **Matrix Notation For Load at Time t Due to Disturbance at Time t' is**

$$[F(t,t')] = [MATSS] + \sum_{n=1}^{N} [MATTR]_n \exp(-\beta_n(t-t'))$$

- **Matrices are Converted to Generalized Form For the Response Calculation**

The Blast Response Calculation

- **A Trim Analysis is Performed to Obtain Initial Conditions**
  - Similar to Static Aeroelastic Trim Analysis
  - Modal Coordinates are Used

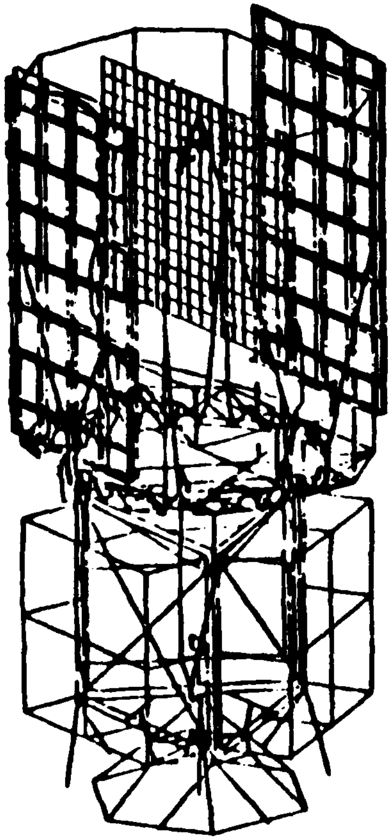
- **Transient Response Performed Using Newmark - Beta**
- **Gravity and Inertia Forces Included in the Calculation**
- **Aerodynamic Forces Combine Effects From**

  Blast Wave
  Vehicle Translation
  Vehicle Rotation
  Vehicle Deformations

- **Matrix Equation For Aerodynamic Forces Computed Recursively**

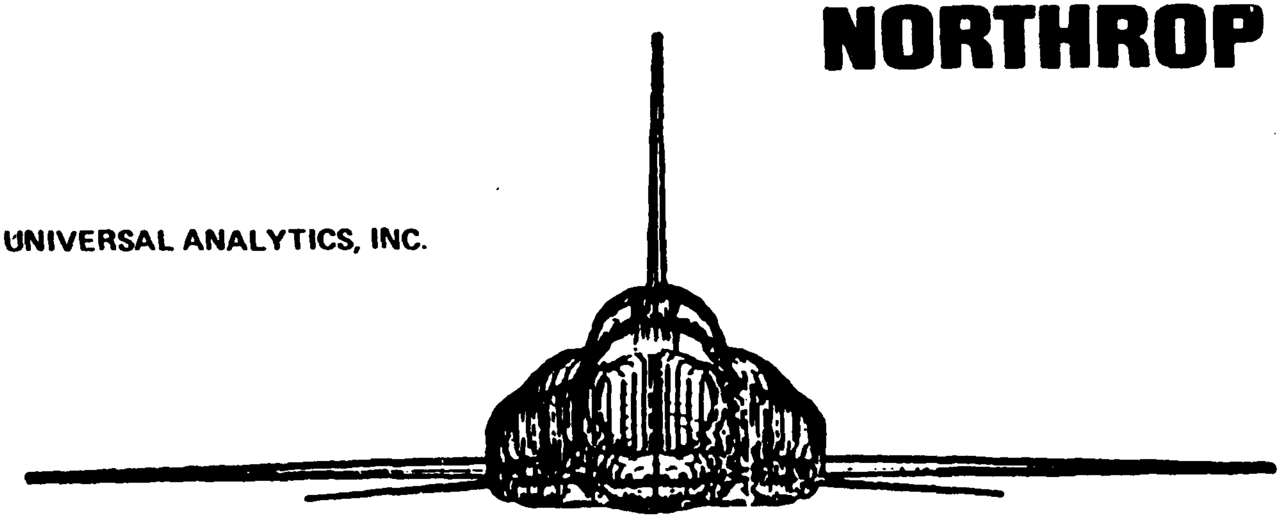
ASTROS User Training Workshop

20–24 June 1988



NORTHROP

UNIVERSAL ANALYTICS, INC.



User Interface

User's Interface to ASTROS

- Overview
- Solution Control
- Bulk Data
- Output
- Executive Control Sequence (MAPOL)
- Advanced Topics

ASTROS System Organization

- ASTROS System Consists of Two Stand Alone Executables
  - System Generation Program
  - ASTROS Procedure
- SYSGEN Generates Data Needed to Form and Run ASTROS
  - Creates a Link Between Modules and Executive
  - Forms System Data Base
  - Intended to be Run Only Once at Installation
- ASTROS Procedure
  - Executive System
  - Engineering Software

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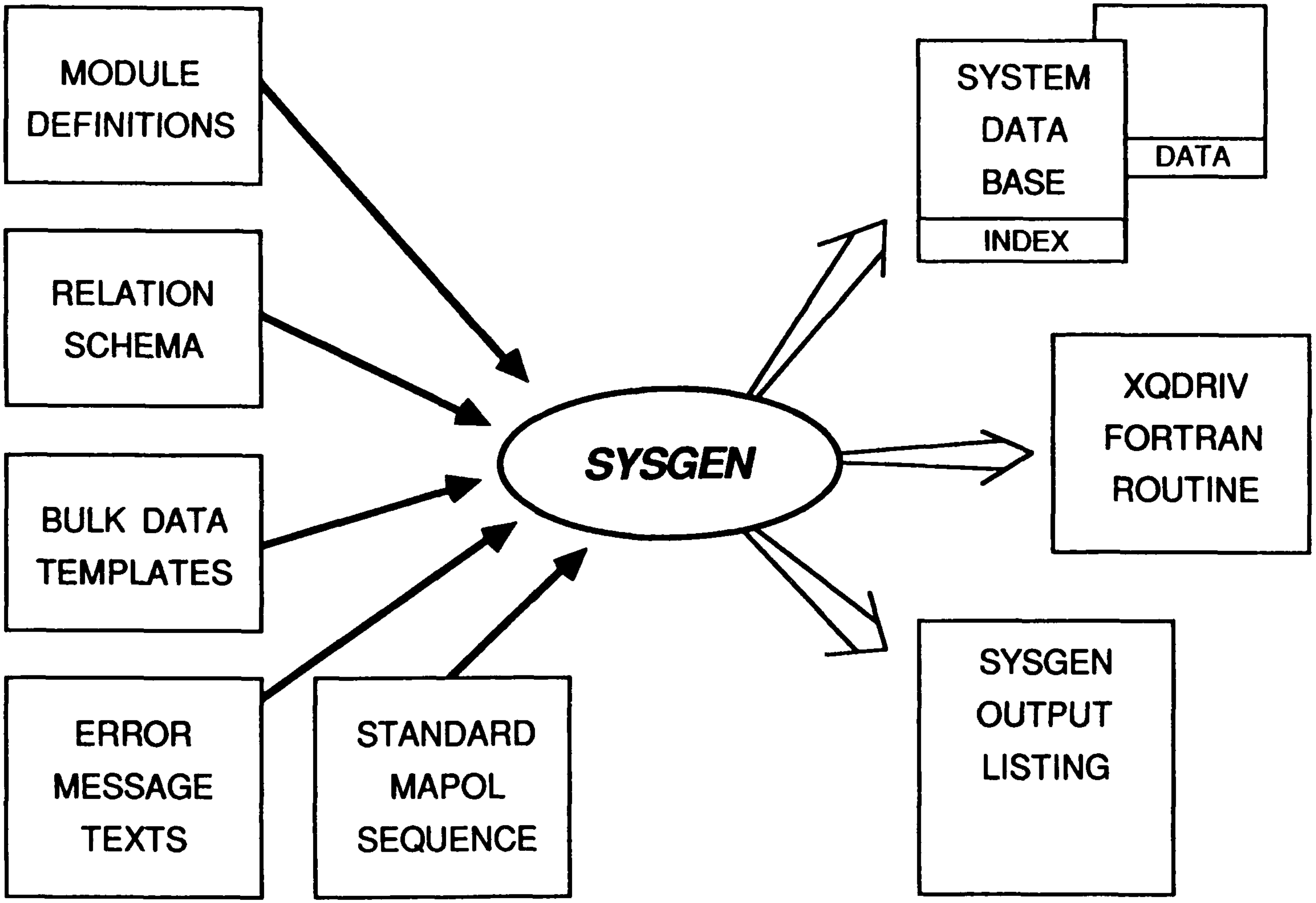
ASTROS System Generation Program, SYSGEN



MODULE DEFINITIONS

RELATION SCHEMA

BULK DATA TEMPLATES

ERROR MESSAGE TEXTS

STANDARD MAPOL SEQUENCE

SYSGEN

SYSTEM DATA BASE

DATA

INDEX

XQDRIV FORTRAN ROUTINE

SYSGEN OUTPUT LISTING

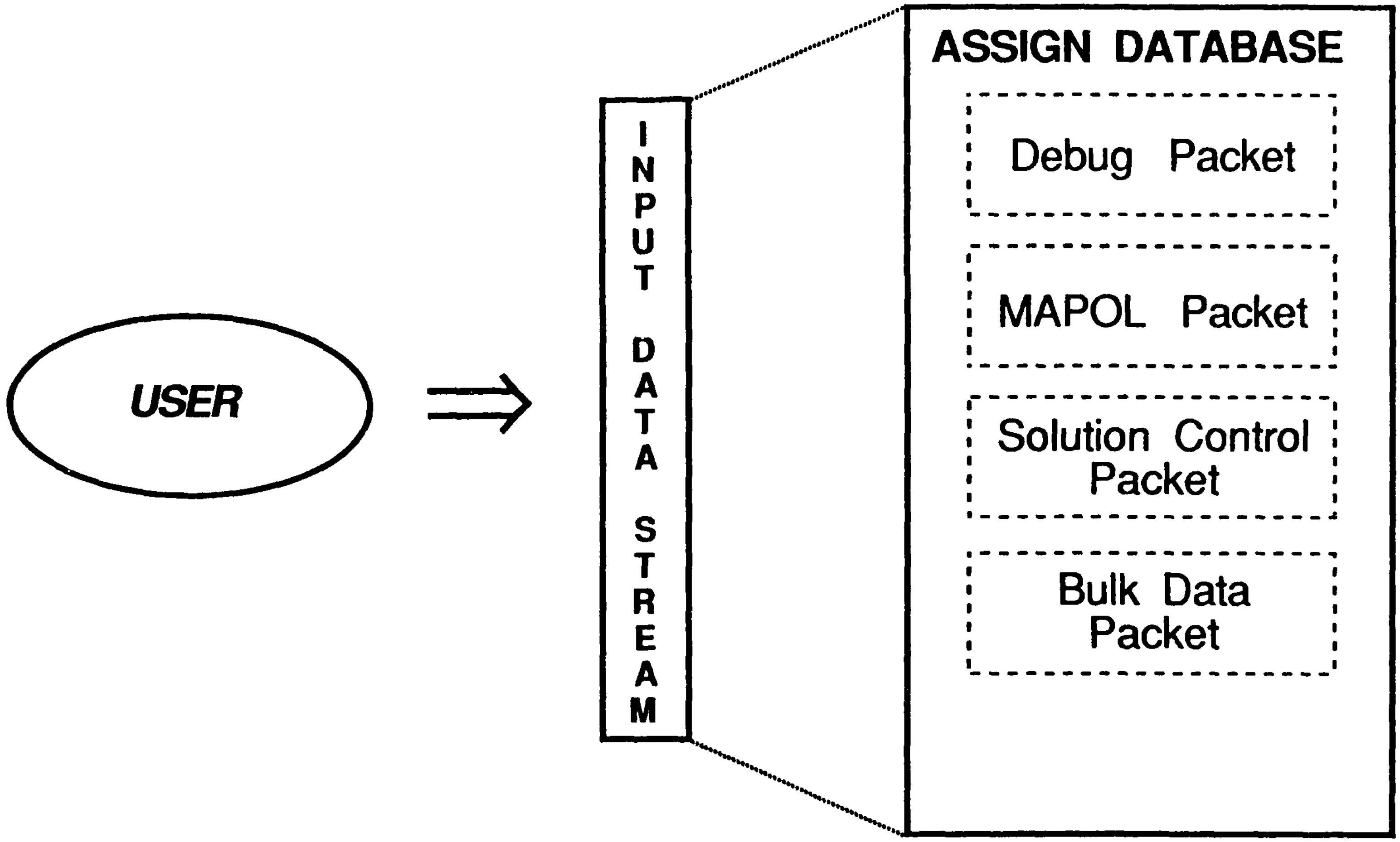
SYSGEN Output As User Documentation

- Lists Argument Types For All MAPOL Modules
- Lists Relational Schemata For " HIDDEN " Relations
- Lists the Complete Set of Bulk Data Templates
- Lists Error Message Texts and Indicates with Which " Module " They are Associated
- Provides Current Listing of the Standard MAPOL Sequence

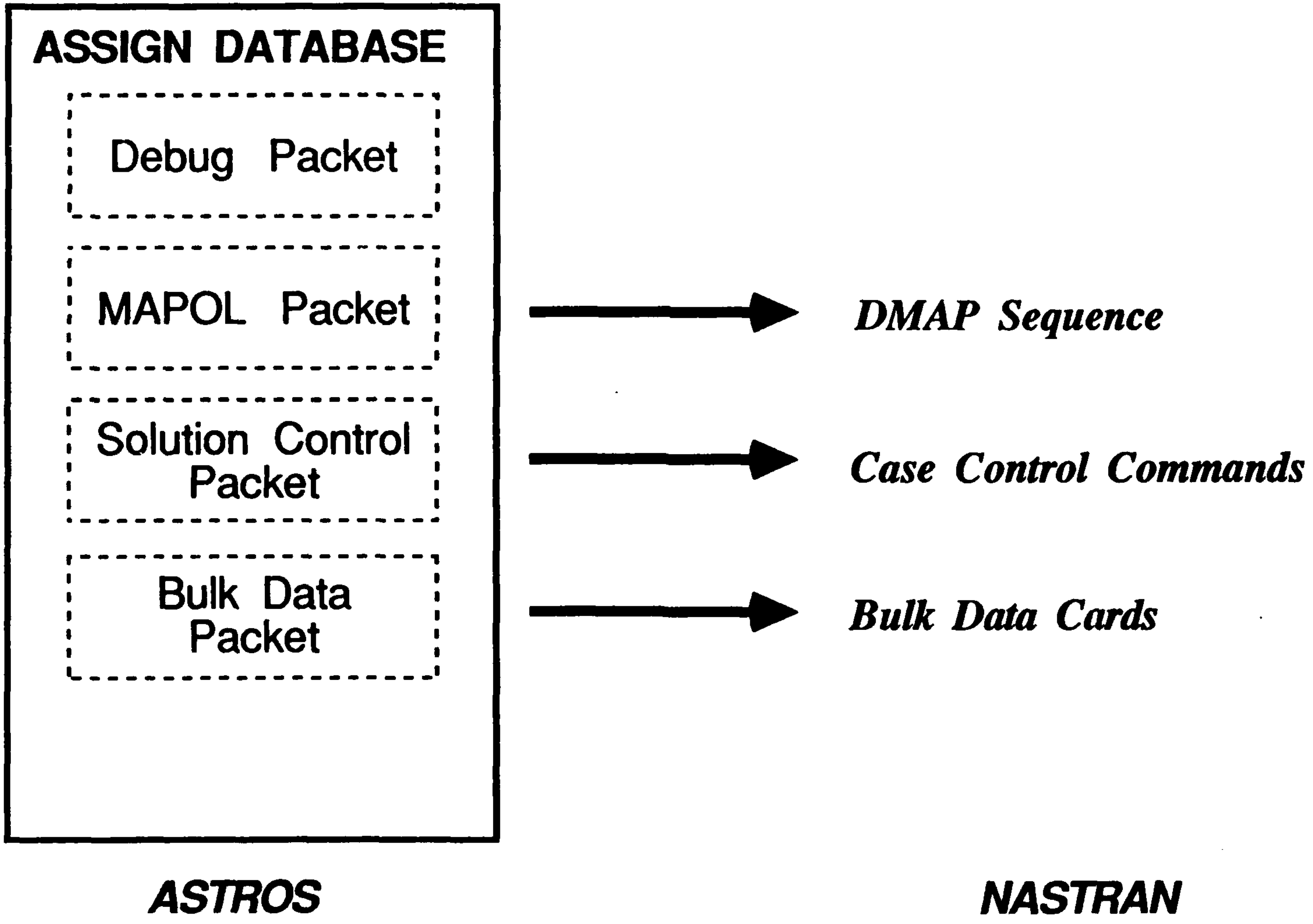
SYSGEN Output As User Documentation (Continued)

- Represents Actual Data Defining the ASTROS System
- Is More Accurate and Current Than Other Documentation
- Has More Concise Format for the Experienced User
- Can Be Made Available " On - Line "

ASTROS User Interface



Similarities Between ASTROS Input and NASTRAN Input



ASSIGN DATABASE

Debug Packet

MAPOL Packet → *DMAP Sequence*

Solution Control Packet → *Case Control Commands*

Bulk Data Packet → *Bulk Data Cards*

ASTROS

NASTRAN

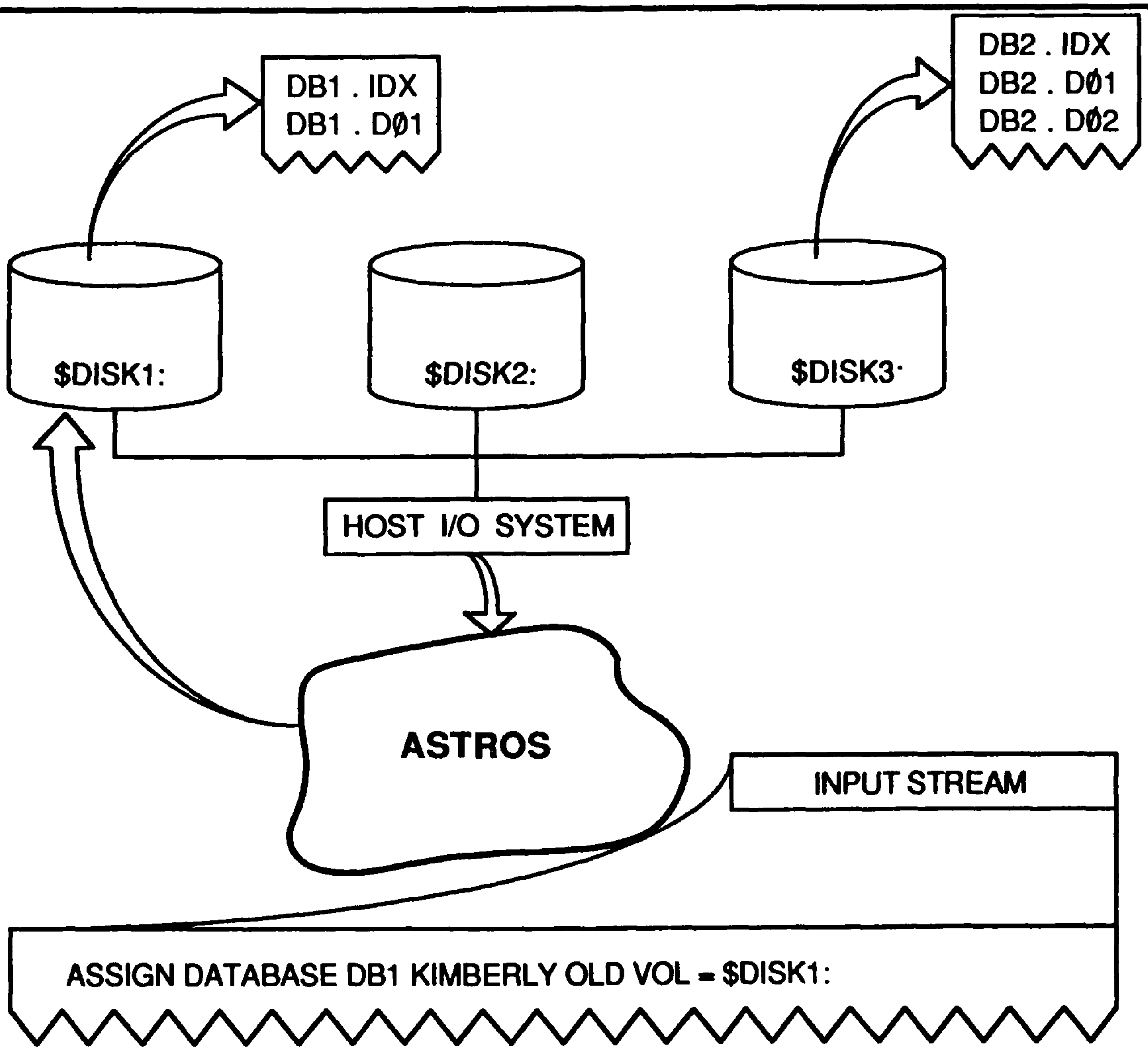
The ASSIGN DATABASE Directive

ASSIGN DATABASE <dbname> <password> <status> {params}

• dbname	is a name identifying the run time data base files (maximum of 8 characters)
• password	is a user assigned password for the data base files (maximum of 8 characters)
• status	is the status of the data base files. Must be either OLD, NEW or TEMP
• params	are optional (installation dependent) parameters e. g., DBLKSIZE = n, IBLKSIZE = n, etc.

- MUST Be the First Item in the Input Stream

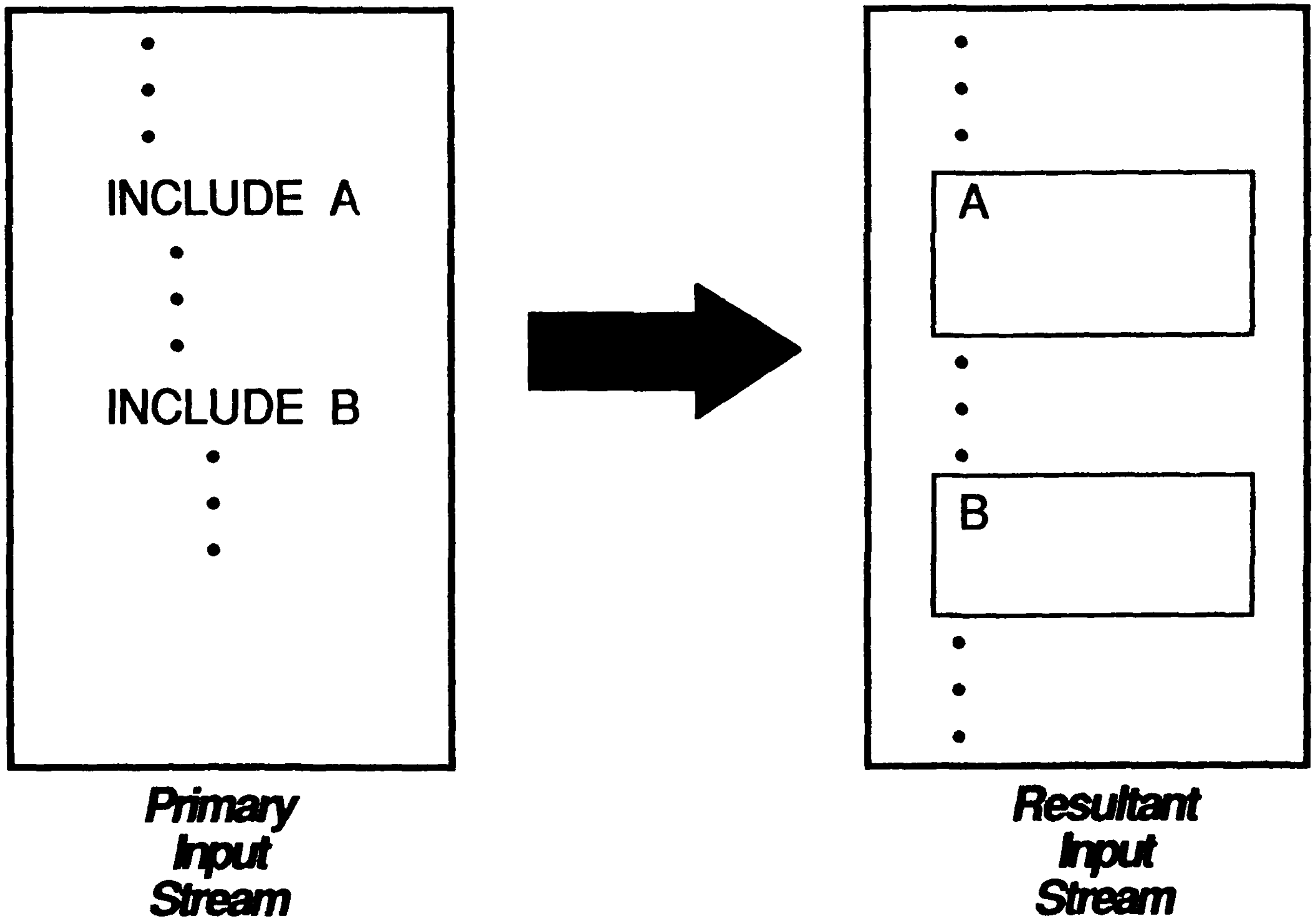
The Function of ASSIGN DATABASE Directive



The INCLUDE Directive

INCLUDE < filename >

- filename is a Host Dependent Name Used in a FORTRAN Open Statement



•
•
•
INCLUDE A
•
•
•
INCLUDE B
•
•
•

Primary Input Stream

•
•
•
A
•
•
•
B
•
•
•

Resultant Input Stream

DEBUG Packet

- **Represents a Legitimization of a Development Feature**
- **Provides Keyword Based Requests for Specific Executive, Data Base and Engineering Debug Output :**

```
DEBUG
Key 1, Key 2 . . .
Key 3, . . .
```

- **Keywords :**

Executive	**Data Base**	**Engineering**
MSTACK	TRACE	MPYAD = n
MEXEC	EVENT	
MOBJ	BUFFER	
MTRACE	IOSTAT = { FULL, SUM }	
MATRIX	MEMORY	
	ENTITY = name	
	CALLSTAT	
	NOCOREDIR	

Solution Control Packet

- Analogous to CASE CONTROL in NASTRAN
- Selects Optimization/Analysis Tasks To Be Performed
- Selects Engineering Data for Each Task
- Selects Output Quantities

Solution Control Hierarchy

Type of Boundary Condition

Analyze Optimize

Boundary Condition

Spc
Mpc
Reduce
Support
Method
Dynred
Inertia
Tfl
K2pp
M2pp
B2pp
Damping
Eset

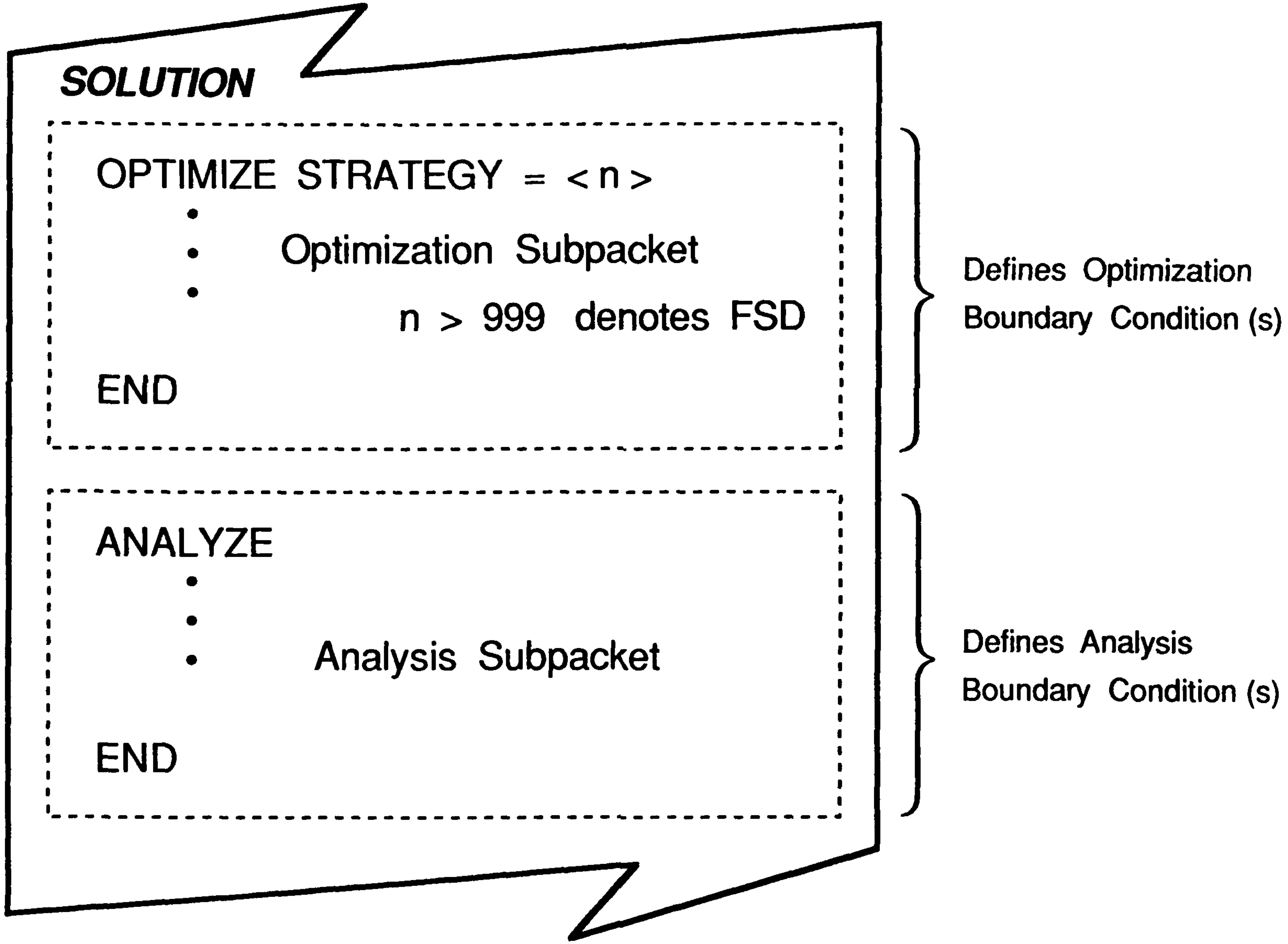
Discipline (Options)

Statics
Modes
Saero
Flutter
Transient
Frequency
Blast

Solution Control Contrasts Between NASTRAN and ASTROS

- Multidisciplinary Executions are Supported by ASTROS
- Boundary Conditions are More Explicitly Defined in ASTROS
- ASTROS Solution Control Enables Optimization Cases and Analysis Cases to be Independently Selected

Solution Control Boundary Condition Type



SOLUTION

OPTIMIZE STRATEGY = < n >

•

• Optimization Subpacket

•

n > 999 denotes FSD

END

Defines Optimization Boundary Condition (s)

ANALYZE

•

•

• Analysis Subpacket

END

Defines Analysis Boundary Condition (s)

Solution Control Boundary Condition Definition

BOUNDARY < option > , {< option > , ... }

- **Matrix Reductions**

SPC = < n >
MPC = < n >
REDUCE = < n >   DYNRED = < n >   INERTIA = < n >
SUPPORT = < n >

- **Eigen Analysis Method**

METHOD = < n >

- **Dynamic Matrix Assembly**

DAMPING = < n >   K2PP = < name >
TFL = < n >   B2PP = < name >
ESET = < n >   M2PP = < name >

STATICS Discipline Options

STATICS (MECHANICAL = < n >, GRAVITY = < n >, THERMAL = < n >,
DCONSTRAINT = < n >)

- MECHANICAL Selects Mechanical Loads

  FORCE, MOMENT, PLOAD,
  FORCE1, MOMENT1, LOAD

- GRAVITY Selects Gravity Loads

  GRAV

- THERMAL Selects Temperature Distribution for Thermal Loads

  TEMP, TEMPD

- Each Set of Options Defines a Single Load Case as a Superposition of All Load Types

STATICS Discipline Options (Continued)

STATICS (MECHANICAL = < n >, GRAVITY = < n >, THERMAL = < n >, DCONSTRAINT = < n >)

- DCONTRAINT Selects Displacement Constraints To Be Applied to the Load Condition

  DCONDSP

- Note that Stress and/or Strain Constraints are Applied Through Bulk Data Entry DCONSTR Which is Not Selected By Solution Control
- No STATICS Options are Required But at Least One of MECH, GRAV or THERM Must Be Present

MODES Discipline Options

MODES (DCONSTRAINT = < n >)

- DCONSTRAINT Optionally Selects Modal Frequency Constraints To Be Applied to the Normal Modes

  DCONFRQ

- Note that Only One Modal Analysis May Be Performed in a Boundary Condition Using the BOUNDARY METHOD = < n > to Obtain Extraction Data

SAERO Discipline Options

SAERO (TRIM = < n >, DCONSTRAINT = < n >)

- TRIM Provides the Required Flight Configuration Information as Specified by the TRIM Bulk Data Entry
- DCONSTRAINT Optionally Selects Displacement, Aileron Effectiveness and/or Lift Effectiveness Constraints, DCONDSP, DCONALE and DCONCLA, Respectively
- Just as for STATICS, Stress and/or Strain Constraints May Be Applied Using the DCONSTR Bulk Data Entry
- SAERO Requires BOUNDARY SUPPORT = < n > to Define the Rigid Body Degrees of Freedom Appropriate to the TRIM
- SAERO Discipline Precludes the Use of Dynamic Reduction

FLUTTER Discipline Options

FLUTTER (FLCOND = < n >, DCONSTRAINT = < n >)

- FLCOND Provides the Required Flutter Parameters as Specified by the FLUTTER Bulk Data Entry
- DCONSTRAINT Optionally Selects Flutter Constraints Specified by DCONFLT Bulk Data Entries
- Flutter Analysis Requires That the Eigenvalue Extraction Method Be Specified in the Boundary Definition

TRANSIENT Discipline Options

TRANSIENT $\left\{\begin{array}{c}\textbf{MODAL}\\ \underline{\textbf{DIRECT}}\end{array}\right\}$ **(DLOAD = < n >, TSTEP = < n >, FFT = < n >,**
IC = < n >, GUST = < n >)

- DLOAD Specifies the Spatial and Temporal Load Components
- TSTEP Specifies the Time Steps for Response Calculations
- IC Provides Optional Initial Conditions for Direct Transient Analysis
- FFT Allows Specification for Fast Fourier Transform Methods
- GUST, Which Must Use FFT, Provides for Discrete Gust Loads But Is Not Functional

FREQUENCY Discipline Options

$$\textbf{FREQUENCY} \left\{ \begin{matrix} \textbf{MODAL} \\ \underline{\textbf{DIRECT}} \end{matrix} \right\} \quad \textbf{(DLOAD} = \textbf{<n>}, \ \textbf{FSTEP} = \textbf{<n>}, \ \textbf{GUST} = \textbf{<n>)}$$

- DLOAD Specifies the Spatial and Frequency Dependent Load Components
    - Note That DLOAD is Required by Solution Control Even Though It is Ignored for the GUST Option
- FSTEP Specifies the Frequency Steps for Response Calculations
- GUST Optionally Specifies the Gust Parameters for Harmonic Gust Response
- MODAL Analyses Require BOUNDARY METHOD = < n > to Perform Real Eigenanalysis

BLAST Discipline Options

BLAST $\left\{\begin{array}{c}\underline{\textbf{MODAL}}\\ \textbf{DIRECT}\end{array}\right\}$ **(BLCOND = < n >, TSTEP = < n >)**

- BLCOND Selects the Required Nuclear Blast Parameters from the BLAST Bulk Data Entry
- TSTEP Specifies Time Steps for the Transient Response Analysis
- MODAL Analyses is the Default (Unlike Other Dynamic Response Disciplines) and the DIRECT Analysis is Not Functional
- MODAL Analyses Require BOUNDARY METHOD = < n > for Real Eigenanalysis

Combining Disciplines In A Single Boundary Condition

	STATICS	MODES	SAERO	FLUTTER	TRANSIENT	FREQUENCY	BLAST
STATICS	OK						
MODES	OK	X					
SAERO	X	X	R				
FLUTTER	OK	OK	X	OK			
TRANSIENT	OK	OK	X	OK	X		
FREQUENCY	OK	OK	X	OK	OK	X	
BLAST	OK	OK	X	OK	OK	OK	X

X - Precluded R - Allowed With Restrictions

Multidisciplinary Restrictions In ASTROS

- **Aeroelastic Correction for SAERO Discipline Precludes Any Other Discipline in the Same Boundary Condition**
- **Aeroelastic Correction Must Be Unique in a Boundary Condition so Multiple SAERO Disciplines Restricted to:**
  - Symmetric Analyses Only
  - Same Mach Number
  - Same Dynamic Pressure
- **Only One Modal Analysis Allowed in a Boundary Condition**
- **TRANSIENT, FREQUENCY and BLAST are Limited to One Analysis Each Per Boundary Condition**

Solution Control Output Requests

$\left\langle \begin{array}{c}\text{PRINT}\\ \text{PUNCH}\end{array} \right\rangle$ {(< form >)} < option > {(form)}, < subcase >, ...

- **Select Particular Response Quantities for Particular " Subcases " To Be :**
  - PRINTed to the User Output File
  - PUNCHed to the User Punch File
- **Once Selected, an Output Request Remains in Force at or Below that Level in the Hierarchy Until Overridden**

Solution Control Output Requests FORM Options

$$< \begin{matrix}\text{PRINT}\\ \text{PUNCH}\end{matrix} > \left\{\left(\frac{\text{RECTANGULAR}}{\text{POLAR}}\right)\right\} < \text{OPTION} > \left\{\left(\frac{\text{RECTANGULAR}}{\text{POLAR}}\right)\right\} \ldots.$$

- PRINT or PUNCH Form Provides a Default for the Entire Output Request
- < option > Form Overrides the PRINT / PUNCH Default Form
- RECTANGULAR Selects Real / Imaginary Parts of Complex Quantities
- POLAR Selects Magnitude / Phase of Complex Quantities
- < form > is Ignored for Real Quantities

Solution Control Output Requests: Response Quantity Options

OPTION	STAT	MODE	SAERO	FLUT	TRANS	FREQ	BLAS
PRESSURE = <n>	---	---	X	---	---	---	---
VELOCITY = <n>	---	---	---	---	X	X	X
DISPLACEMENT = <n>	X	X	X	X^1	X	X	X
ENERGY = <n>	X	X	X	---	X	---	X
FORCE = <n>	X	X	X	---	X	---	X
GPFORCE = <n>	X	---	X	---	---	---	---
LOAD = <n>	X	---	X	---	X	X	X
SPCFORCE = <n>	X	---	X	---	---	---	---
STRESS = <n>	X	X	X	---	X	---	X
ACCELERATION = <n>	X^2	---	X^2	---	X	X	X
STRAIN = <n>	X	X	X	---	X	---	X
ROOT = <n>	---	X^3	---	X^3	---	---	---
TRIM	---	---	X	---	---	---	X

1. Flutter displacements (mode shapes) are only available for analysis and then only if a flutter crossing is found.
2. The accelerations are available for STATICS with inertia relief and all SAERO Analyses.
3. ROOTS will print real eigenvalue extraction summary data for MODES and complex eigenvalues for FLUTTER.

Solution Control Output Requests: Response Quantity Options (Cont'd)

- **Most Options Have a Subset Selection**

  Option = < n >

  $$n = \left\{ \begin{array}{l} \text{ALL} \\ \text{NONE} \\ \text{Integer Set ID} \end{array} \right\}$$

- **Integer Set Identification Selects Bulk Data Entries**

  GRIDLIST

  ELEMLIST

- **TRIM is a Toggle with No Subset Selection**
- **ROOTS Subset Selection is Not Functional**

  Integer Set ID ⇔ ALL

Solution Control Output Requests: Response Quality Options (Concl'd)

- DESIGN - a Toggle to Select Print of Global and Active Local Design Variables at Each Design Iteration
- DCONSTRAINT - a Toggle to Select Print of Active Constraint Values at Each Design Iteration
- Only Valid for OPTIMIZE Boundary Conditions
- Discipline Independent

Solution Control Output Requests: Subcase Options

- For All Disciplines Except STATICS and SAERO, More Than One "Subcase" is Generated By the Discipline Option
- ASTROS <u>Requires</u> Specific Declaration of Subcases to Which Output Requests Apply
- Absence of a Subcase Selection Implies That the Print Request Applies to <u>NO</u> Subcases

Solution Control Output Requests: Subcase Options (Concl'd)

- **Mode = <n> Selects Which Eigenvectors Are to Be Used to Satisfy Print Requests for MODES Discipline**

  <n> Refers to the MODELIST Bulk Data Entry

- **TIME = <n> Selects Time Steps for TRANSIENT and BLAST Disciplines**

  <n> Refers to the TIMELIST Bulk Data Entry

- **FREQ = <n> Selects Frequency Steps for FREQUENCY Discipline**

  <n> Refers to the FREQLIST Bulk Data Entry

Solution Control Output Requests: Common Pitfall

```
SOLUTION
ANALYZE
       BOUNDARY SPC = 10 , METHOD = 100

              PRINT    DISP = ALL
              STATICS  (MECH = 10)
              PRINT    MODE = 5, DISP = 5
              MODES
END
```

- A Discipline Command is Not Terminated Until Another Discipline is Encountered

- This Example Results in DISP = 5 for Both STATICS and MODES

Solution Control Output Selection: Output Labeling

TITLE	-	A title header that will appear as the first line on each page of output.
SUBTITLE	-	A secondary header that will appear on the second line of each page of output.
LABEL	-	A tertiary header that is typically used to identify subcase (discipline level) output.

- Similar to Their NASTRAN Counterparts
- A Confusion Can Arise When Discipline Independent Data are Labeled with the LABEL of the 1st Discipline

Solution Control Example

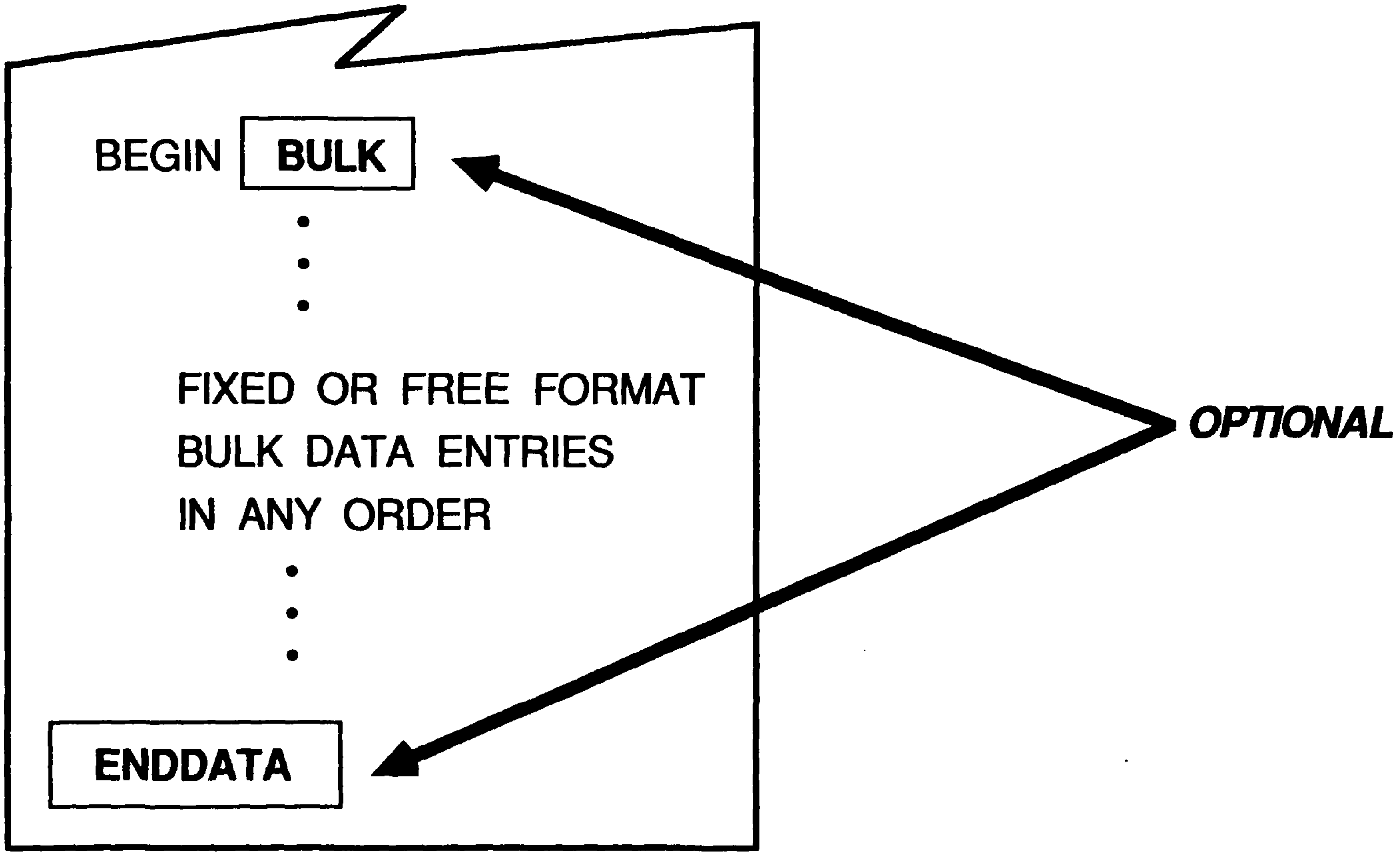
```
SOLUTION
TITLE = SWEPT WING MULTIDISCIPLINARY OPTIMIZATION
OPTIMIZE STRATEGY = 57
     PRINT DCONSTRAINT,  ROOT = ALL,  DISP = 5
     BOUNDARY        MPC = 1000, REDUCE = 1002, METHOD = 1003
          FLUTTER    ( FLCOND = 100, DCONSTRAINT = 101 )
          MODES      ( DCONSTRAINT = 200 )
          STATICS    ( MECHANICAL = 300, DCONSTRAINT = 301 )
     BOUNDARY        MPC = 2000,  SPC = 2001, REDUCE = 2002, SUPPORT = 2003
          SAERO      ( TRIM = 400, DCONSTRAINT = 401)
END
ANALYZE
     BOUNDARY        MPC = 1000, SPC = 1001, REDUCE = 1002, METHOD = 1003,
                     M2PP = MTRANS, B2PP = BTRANS, K2PP = KTRANS, ESET = 1004

          TRANSIENT MODAL (DLOAD = 500, TSTEP = 501)
          PRINT DISPLACEMENT = ALL, TIME 10, STRAIN = 12
END
```

Bulk Data Packet

- Analogous to BULK DATA Deck in NASTRAN
- Defines Structural and Aerodynamic Model Geometry
- Defines the Design Variables and Constraints
- Defines the Pool of Discipline Dependent Data for Each Analysis for Selection By Solution Control

Bulk Data Packet



BEGIN **BULK**

•
•
•

FIXED OR FREE FORMAT
BULK DATA ENTRIES
IN ANY ORDER

•
•
•

ENDDATA

OPTIONAL

Bulk Data Entry Formats

- ***Small Field Entry with a Large Field Continuation***

<table>
<tr><th>mnemonic</th><th>data</th><th>data</th><th>data</th><th>data</th><th>data</th><th>data</th><th>data</th><th>data</th><th>mnemonic</th></tr>
<tr><td>NAME</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>ABC</td></tr>
<tr><td>* BC</td><td colspan="2">← 16 →</td><td colspan="2">← 16 →</td><td colspan="2">← 16 →</td><td colspan="2">← 16 →</td><td></td></tr>
</table>

- ***Large Field Entry with a Small Field Continuation***

<table>
<tr><th>mnemonic</th><th colspan="2">data</th><th colspan="2">data</th><th colspan="2">data</th><th colspan="2">data</th><th>mnemonic</th></tr>
<tr><td>NAME *</td><td colspan="2">← 16 →</td><td colspan="2">← 16 →</td><td colspan="2">← 16 →</td><td colspan="2">← 16 →</td><td>ABC</td></tr>
<tr><td>* BC</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td>DEF</td></tr>
<tr><td>+ EF</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td>← 8 →</td><td></td></tr>
</table>

Bulk Data Entries: Fixed And Free Formats

- Each Line Must Be All Fixed or All Free Format
- Fixed Format Requires Data to Reside Within the Proper Field
- Free Format is Denoted By a Comma in the First 10 Columns; Each Field is Separated By a Comma
- Each Free Format Field Must Reside At or To the Left of Its Fixed Format Position
- Free Format Continuations May Reside on the Same Physical Line

```
MKAERO1, , 0.3, 0.5, , , , , ABC , +BC, 0.01, 0.05, 0.1, 0.2
MKAERO1, , 0.3, 0.5, , , , , 0.01, 0.05, 0.1, 0.2
```

Bulk Data Entries: Data Fields

- Integer Data May Be Composed of Any of the Decimal Digits and an Optional Leading Plus (+) or Minus (-) Sign

  450
  \- 37
  \+ 45

- Real Data Must Contain a Decimal Point But May Be Formed in Several Ways :

  3.1
  0.0E0
  \- 0.31E+1

- Character Data May Contain Any Combination of Alphanumeric Data

- Blank Fields are Automatically Replaced with 0 , 0.0 or "   " Depending on the Field Type

ASTROS/NASTRAN Bulk Data Format Differences

- ASTROS Continuation Lines Must Follow the Parent Entry
- ASTROS Continuation Mnemonics Need Not Be Unique
- ASTROS Free Format Does Not Allow a Blank as the Field Separator
- Real Data Containing More Characters Than the Field Size Will Not Be Rounded
- Imbedded Blanks are Not Allowed in Real or Integer Data Fields

Bulk Data Entry Differences Between ASTROS And NASTRAN

- **ASTROS Has 132 Bulk Data Entries Defined**
- **50 are Unchanged Relative to NASTRAN**
    - Static Loads
    - Boundary Condition Specification
    - Geometry
    - Material Properties
    - Unsteady Aerodynamic Model Geometry
- **41 are New for ASTROS**
    - Design Variables
    - Design Variable Linking
    - Design Constraints
    - Steady Aerodynamics Model Geometry
    - Discipline Data for New Disciplines
- **Remainder are Changed to Some Degree**

ASTROS Modifications To Existing NASTRAN Cards

- **Changes to Dynamic Loads Specification**
  - GUST
  - RLOAD1
  - RLOAD2
  - TLOAD1
  - TLOAD2
- **Multidisciplinary Analysis Changes**
  - ASET
  - ASET1
  - OMIT
  - OMIT1
  - EPOINT
  - SUPORT
  - AERO
  - MKAERO1
  - MKAERO2
  - FLUTTER
  - TRIM
- **Changes to Connectivity and Property Entries for Shape Function Design Variable Linking**
- **Other Changes**
  - DMI
  - DMIG
  - TABDMP1
  - TABLED1

Multidisciplinary Analysis Changes

Guyan Reduction, Extra Points and Support Points are All Boundary Condition Dependent

1	2	3	4	5	6	7	8	9	10
ASET	SETID	ID	C	ID	C	ID	C		
ASET	16	2	23	3516					

1	2	3	4	5	6	7	8	9	10
EPOINT	SETID	ID	ID	ID	ID	ID	ID	ID	CONT
EPOINT	1000	3	18	1	4	16	2		

CONT	ID	ID	ID	- etc -					

1	2	3	4	5	6	7	8	9	10
SUPORT	SETID	ID	C	ID	C	ID	C		
SUPORT	1000	16	215						

Multidisciplinary Analysis Changes (Continued)

Subcase Dependencies Moved to FLUTTER, $MKAERO_i$ Entries and Removed From AERO Entry

1	2	3	4	5	6	7	8	9	10
FLUTTER	SID	METHOD	DENS	MACH	VEL	MLIST	EPS		CONT
FLUTTER	19	PK	119	219	319	10	1. -4		ABC

CONT	SYMXZ	SYMXY							
+BC	1	0							

1	2	3	4	5	6	7	8	9	10
MKAERO1	SYMXZ	SYMXY	m_1	m_2	m_3	m_4	m_5	m_6	CONT
MKAERO1	1	0	0.1	0.7					+ABC

CONT	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	
+ABC	.3	.6							

1	2	3	4	5	6	7	8	9	10
AERO	ACSID	REFC	RHOREF						
AERO	100	300.0	1.1E-7						

Multidisciplinary Analysis Changes (Concluded)

Subcase Dependencies Moved to TRIM Entry and a Subcase Independent AEROS Entry Created

1	2	3	4	5	6	7	8	9	10
TRIM	TID	MACH	QDP	SYMXZ	TRMTYP	NZ	QRATE	VO	
TRIM	1	.9	100.	1	1	1.0	0.0	0.0	

1	2	3	4	5	6	7	8	9	10
AEROS	ACSID	RCSID	REFC	REFB	REFS	GREF	REFD	REFL	
AEROS	10	20	10.	100.	1000.	1			

Shape Function Design Variable Linking Changes

- *Added Local Variable Gauge Constraint and Other Linking Data*
- *For Analysis or Optimization with Physical Linking, no Changes are Needed Relative to NASTRAN*

1	2	3	4	5	6	7	8	9	10
CBAR	EID	PID	GA	GB	X1 , GO	X2	X3	TMAX	CONT
CBAR	2	39	7	3	13				123
CONT	PA	PB	W1A	W2A	W3A	W1B	W2B	W3B	
+23		513							

1	2	3	4	5	6	7	8	9	10
PBAR	PID	MID	A	I1	I2	J	NSM	TMIN	CONT
PBAR	39	6	2.9		5.97				123
CONT	C1	C2	D1	D2	E1	E2	F1	F2	CONT
+23			2.0	4.0					
CONT	K1	K2	I12	R12	R22	ALPHA			

Direct Matrix Input - DMI and DMIG

ASTROS Data Base Requires Different Form for These Two Bulk Data Entries

1	2	3	4	5	6	7	8	9	10
DMI	NAME	PREC	FORM	M	N				CONT
DMI	TEST	RDP	REC	3	4				ABC
CONT	C1	R1	A(R1,C1)	C2	R2	A(R1,C2)	A(R1+1,C2)	C3	CONT
+BC	1	2	2.0	2	1	3.0	4.0	4	DEF
CONT	R1	A(R1,C3)	C4	R2	A(R2,C4)				
+EF	1	5.0	4	3	6.5				

1	2	3	4	5	6	7	8	9	10
DMIG	NAME	PREC	FORM						CONT
DMIG	TEST	RDP	REC						ABC
CONT	GCOL	CCOL	GROW	CROW	X_{ij}	Y_{ij}			CONT
+BC	1001	4	2001	2	1.25+5				DEF
CONT	GCOL	CCOL	GROW	CROW	X_{ij}	Y_{ij}			CONT
+EF	1001	4	3001	3	2.67+4	etc			

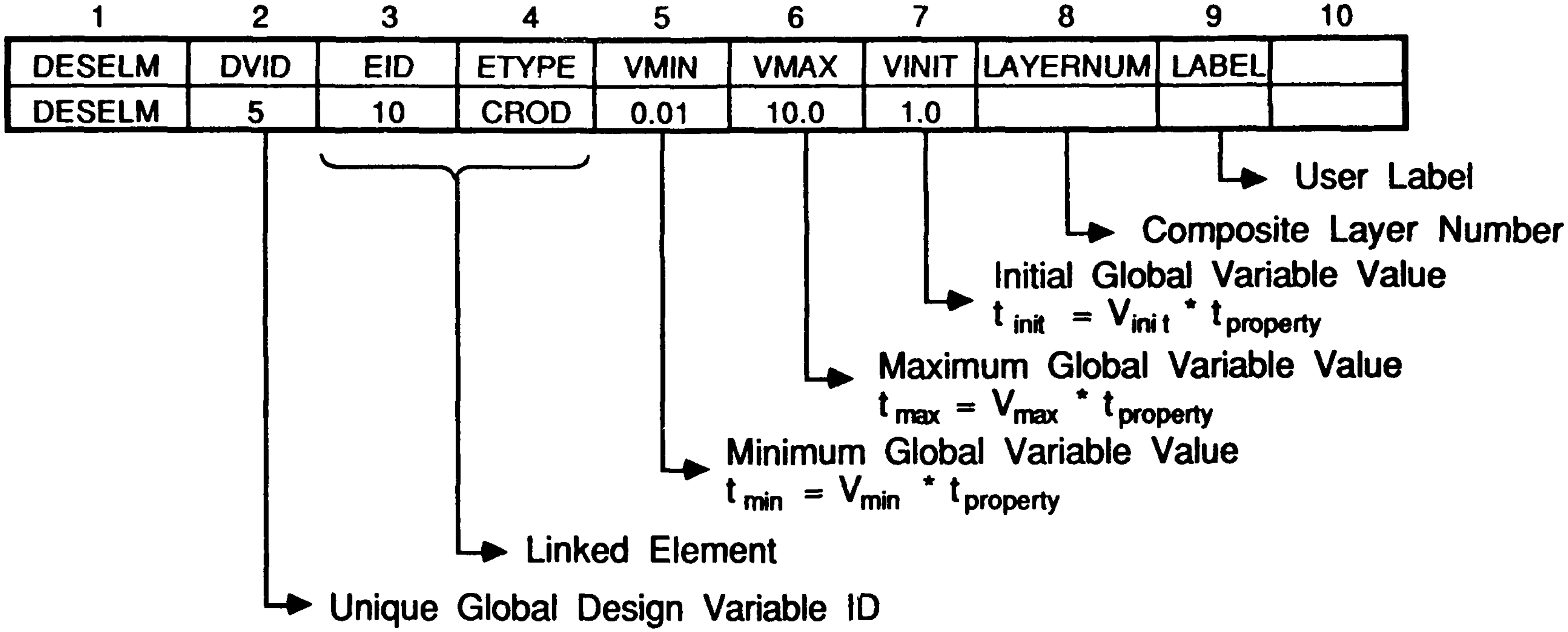
The Design Variable in ASTROS

$$\{t\} = [P]\{v\}$$

t - Element Properties (Local Design Variable)
v - Global Design Variable
P - Linking Matrix

There are Three Options for Specifying the Link Between Element Properties and Global Design Variables

Unique Physical Design Variable Linking



1	2	3	4	5	6	7	8	9	10
DESELM	DVID	EID	ETYPE	VMIN	VMAX	VINIT	LAYERNUM	LABEL	
DESELM	5	10	CROD	0.01	10.0	1.0			

User Label

Composite Layer Number

Initial Global Variable Value
$t_{init} = V_{init} * t_{property}$

Maximum Global Variable Value
$t_{max} = V_{max} * t_{property}$

Minimum Global Variable Value
$t_{min} = V_{min} * t_{property}$

Linked Element

Unique Global Design Variable ID

ONE ELEMENT/LAYER FOR EACH GLOBAL VARIABLE

Linked Physical Design Variable Linking

1	2	3	4	5	6	7	8	9	10
DESVAR	DVID	VMIN	VMAX	VINIT	LAYERNUM	LABEL			
DESVAR	6	0.01	2.0	1.0	13	INBDTOP			

⇕

1	2	3	4	5	6	7	8	9	10
PLIST	DVID	PTYPE	PID1	PID2	PID3	PID4	PID5	PID6	CONT
PLIST	6	PCOMP	12	14	22				

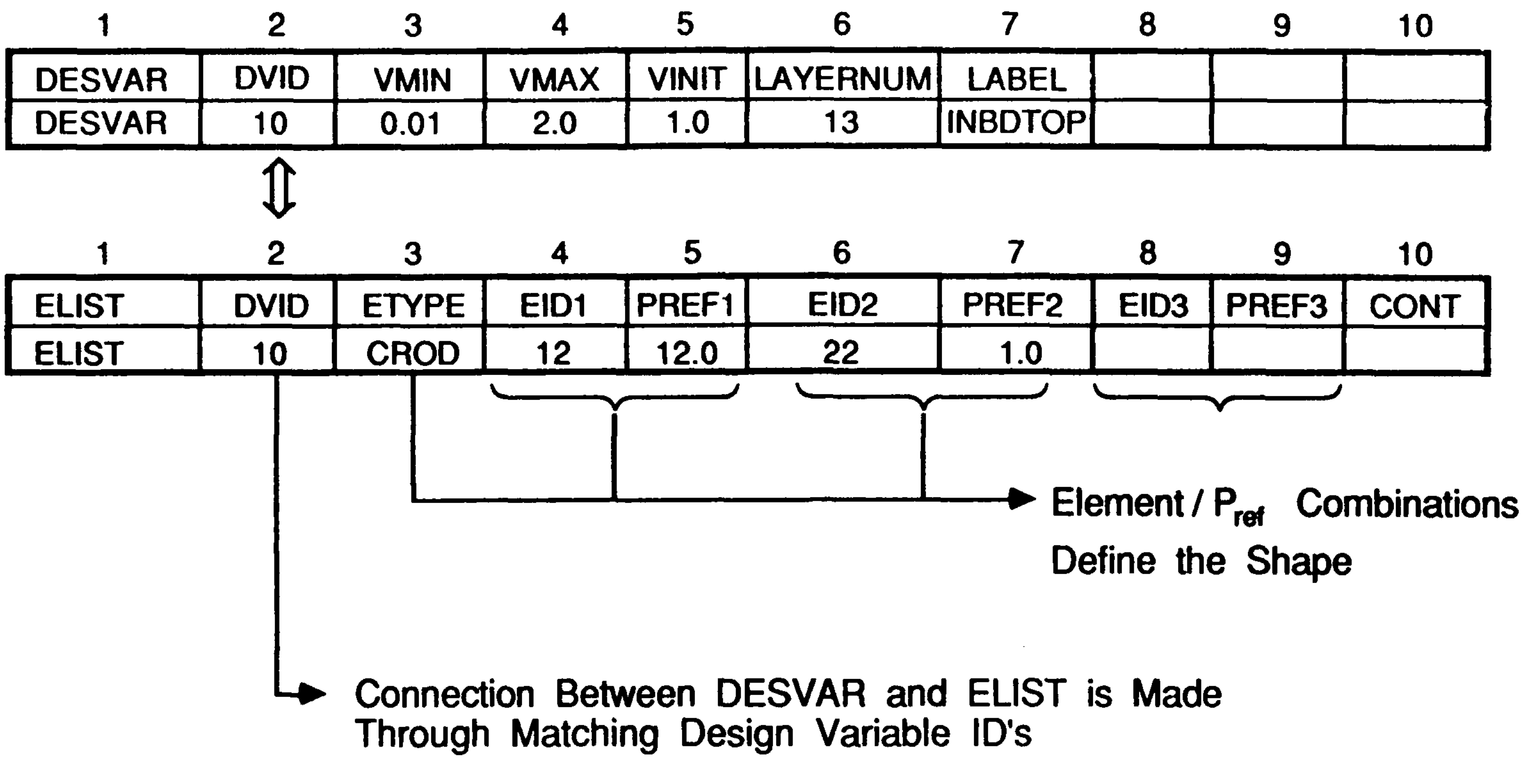
Each Property ID Links
One Local Variable for Each
Connected Element

Property Type
More than One PLIST May Be Used to
Link Different Element Types

Connection Between DESVAR and PLIST is Made
Through Matching Design Variable ID's

ONE GLOBAL VARIABLE FOR EACH LINKED ELEMENT/LAYER

Shape Function Design Variable Linking



1	2	3	4	5	6	7	8	9	10
DESVAR	DVID	VMIN	VMAX	VINIT	LAYERNUM	LABEL			
DESVAR	10	0.01	2.0	1.0	13	INBDTOP			

⇕

1	2	3	4	5	6	7	8	9	10
ELIST	DVID	ETYPE	EID1	PREF1	EID2	PREF2	EID3	PREF3	CONT
ELIST	10	CROD	12	12.0	22	1.0			

Element / P_{ref} Combinations Define the Shape

Connection Between DESVAR and ELIST is Made Through Matching Design Variable ID's

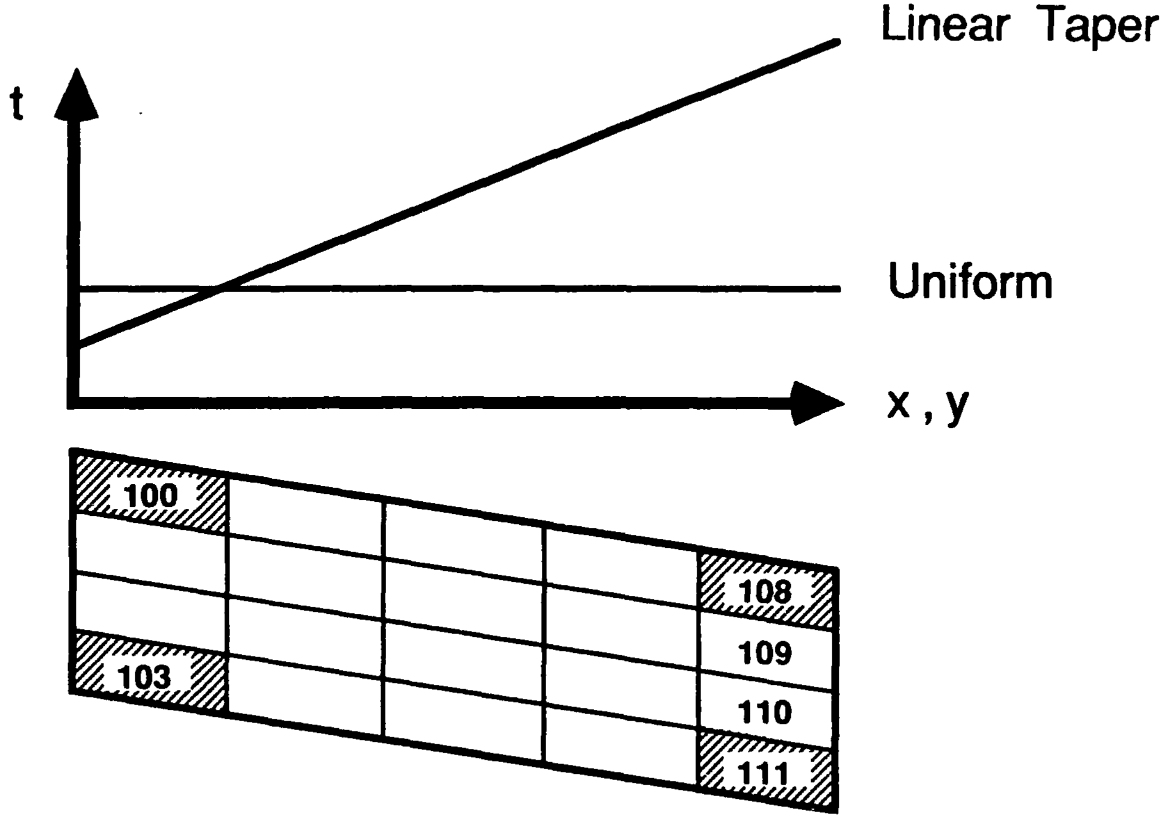
MULTIPLE ELEMENTS FOR EACH GLOBAL VARIABLE AND/OR MULTIPLE VARIABLES FOR EACH ELEMENT/LAYER

Minimum Gauge Constraints With Shape Function Linking

- Generality of Shapes Precludes the Use of Side Constraints
- Gauge Constraints are Instead Imposed as True Constraints
- The Potentially Large Number of " Active " Gauge Constraints Requires the User to Define a Subset of Elements to Control the Local Variables
- The DCONTHK Bulk Data Entry Has Been Defined for this Purpose

The DCONTHK Entry

1	2	3	4	5	6	7	8	9	10
DCONTHK	ETYPE	EID	EID	EID	EID	EID	EID	EID	CONT
DCONTHK	QDMEM1	100	103	108	111				



Design Variable Linking

- Design Variable Identification Numbers Must Be Unique Between DESVAR and DESELM Entries
- A Local Property May Only Be Linked to a Single Physical Global Design Variable
- All Designed Layers of a Composite Element Must Be Linked Using Either Physical or Shape Function Linking
- Initial Local Variable Values and Gauge Constraints are Determined from Both the Initial Property Value and Design Variable Values
- Shape Function Linking Enforces an Initially Uniform Local Property Distribution

Limitations In Design Variable Linking

- Physical Linking Should Be Allowed Through an Element List
- The Same Shape Linked to Multiple Design Variables Requires Duplicate ELIST Entries
- A Designed Composite Element is Restricted to a Single Minimum Gauge for All Layers
- Two Layers of a Composite Element Cannot Be Linked to the Same Design Variable

Design Constraints In ASTROS

	STATICS	MODES	SAERO	FLUTTER
STRESS/STRAIN	X	---	X[1]	---
DISPLACEMENT	X	---	X[1]	---
FREQUENCY	---	X	---	---
FLUTTER	---	---	---	X
AILERON EFFECTIVENESS	---	---	X[2]	---
LIFT EFFECTIVENESS	---	---	X[1]	---

1. **Symmetric Analyses Only**
2. **Antisymmetric Analyses Only**

Stress/Strain Constraint Specification

- **Constraints are Applied to Materials Via Bulk Data Entries**
- **ASTROS Automatically Generates the Proper Constraint (s) for Each Element for Each Static and Symmetric Steady Aeroelastic Analysis**

1	2	3	4	5	6	7	8	9	10
DCONSTR	MID	CRIT	MID	CRIT	MID	CRIT	MID	CRIT	
DCONSTR	1	VMISES	10	VMISES					

- **Criteria are:**

VMISES	for von Mises Stress Criterion
TSAIWU	for Tsai - Wu Strength Ratio
STRAIN	for Principal Strain Constraint

DCONSTR And The MAT1 Material Property

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RHO	A	TREF	GE	CONT
MAT1	17	3.+7		0.33	4.28	6.5-6	5.37-6	0.23	ABC

CONT	ST	SC	SS						
+BC	20.+4	15.+4	12.+4						

- **Only VMISES and STRAIN Constraints May Be Applied**
- **For von Mises**

  ST - Tension Stress Allowable
  SC - Compression Stress Allowable
  SS - Shear Stress Allowable

- **For Principal Strain**

  ST - Tension Strain Allowable in Microunits/Unit
  SC - Compression Strain Allowable in Microunits/Unit
  SS - Not Used

DCONSTR And The MAT2 Material Property

1	2	3	4	5	6	7	8	9	10
MAT2	MID	G11	G12	G13	G22	G23	G33	RHO	CONT
MAT2	13	6.2+3			6.2+3		5.1+3	0.056	ABC

CONT	A1	A2	A12	TO	GE	ST	SC	SS	
+BC	6.5-6	6.5-6		-500.0	0.002	20.+5	15.+5	10.+5	

- **Only VMISES and STRAIN Constraints May Be Applied**
- **For von Mises**

ST - Tension Stress Allowable
SC - Compression Stress Allowable
SS - Shear Stress Allowable

- **For Principal Strain**

ST - Tension Strain Allowable in Microunits/Unit
SC - Compression Strain Allowable in Microunits/Unit
SS - Not Used

DCONSTR And The MAT8 Material Property

1	2	3	4	5	6	7	8	9	10
MAT8	MID	E1	E2	NU12	G12	G1.Z	G2.Z	RHO	CONT
MAT8	171	30.+6	1.+6	0.3	2.+6	3.+6	1.5+6	0.056	+ABC

CONT	A1	A2	TREF	Xt	Xc	Yt	Yc	SS	CONT
+BC	28.-6	1.5-6	155.0	1.+4	1.5+4	2.+2	8.+2	1.+3	+DEF

CONT	Ge	F12							
+DEF	1.-4			-					

- **Only TSAIWU and STRAIN Constraints May Be Applied**
- **For Tsai - Wu**

  X_t, X_c - Tension and Compression Fiber Stress Allowable
  Y_t, Y_c - Tension and Compression Transverse Stress Allowable
  SS - Shear Stress Allowable
  F12 - Tensor Interaction Strength

- **For Principal Strain**

  X_t, X_c - Tension and Compression Strain Allowables in Microunits/Unit
  Y_t, Y_c, SS, F12 - Not Used

Additional Stress/Strain Constraint Information

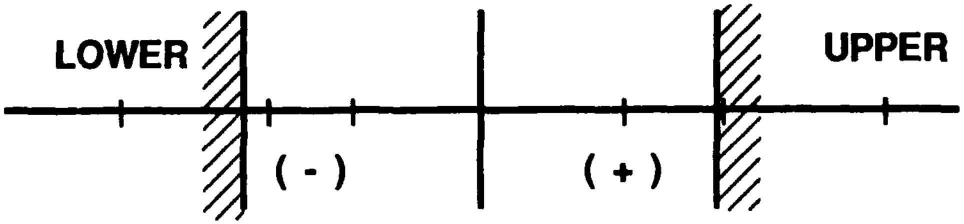
- The Isoparametric Hexahedron Elements (IHEX1 , IHEX2 , and IHEX3) Cannot Be Constrained
- The Principal Strain Constraint for the BAR Element is Not Available
- The Scalar Spring " Stress " Value May Only Be Constrained Through a Displacement Constraint
- An Element Need Not Be Designed to Be Constrained

Displacement Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONDSP	CTSET	DCID	CTYPE	DALL	LABEL	G	C	A	CONT
DCONDSP	1	10	LOWER	-2.3	TIP	32	3	2.0	ABC

CONT		G	C	A	G	C	A		etc
+BC		7	3	-4.0					

- DCID is a Constraint ID That Must Be Unique Within Each Constraint Set
- All Displacement Components From a Unique Combination of CTSET / DCID Will Be Summed in the Constraint
- CTYPE May Be UPPER or LOWER



Frequency Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCON FRQ	SID	MODE	CTYPE	FRQALL					
DCONFRQ	3	1	LOWER	6.0					

- **MODE Refers to Mode Number as Determined By the Eigenanalysis**
- **More Than One Constraint Can Be Applied to the Same Mode**
- **Cannot Use Multiple Constraints to Exclude a Frequency From a Region**

Flutter Constraint Form

$$g = \frac{\gamma - \gamma_{REQ}}{GFACT} \leq 0.0$$

Where

γ - Extracted Damping Value

$$= \frac{Re(p)}{k} \quad \text{For Oscillatory Roots}$$

$$= \frac{p}{\ell n 2} \quad \text{For Real Roots}$$

γ_{REQ} - Required Damping Value Which Can Be a Function of Velocity

GFACT - Normalization Factor

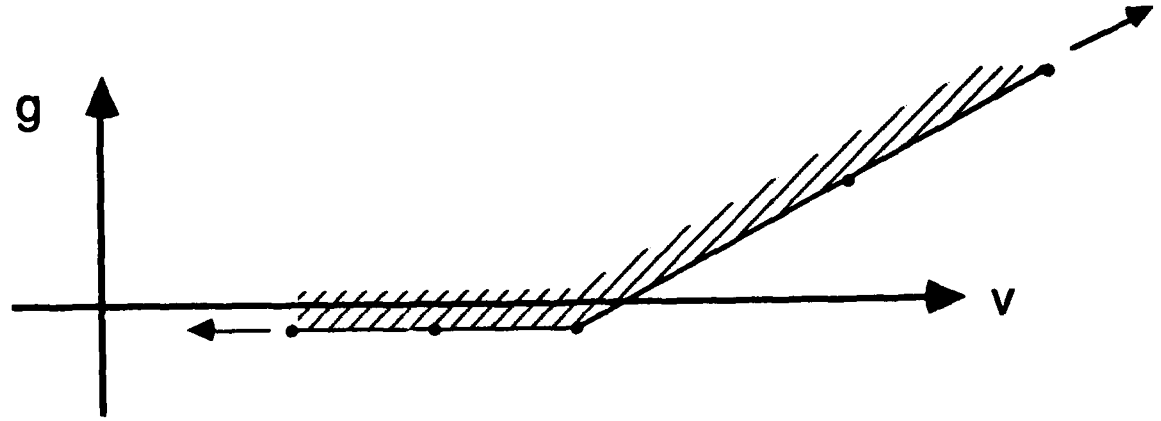
NOTE : IT IS NOT NECESSARY TO KNOW THE FLUTTER SPEED

Flutter Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONFLT	SID	GFACT	V1	GAM1	V2	GAM2	V3	GAM3	CONT
DCONFLT	2		100.0	-.01	1000.0	0.0	1500.0	0.0	+ABC

CONT	V4	GAM4	V5	- etc -					
+BC									

- GFACT is a Normalization Parameter to Make Different Constraint Types Have Similar Magnitudes; Default = 0.10
- V_i , GAM_i Specify the Constraint Boundary on a V - g Diagram



Aileron Effectiveness Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONALE	SID	CTYPE	AEREQ						
DCONALE	25	LOWER	0.4						

- May Only Be Applied to Antisymmetric Analyses
- CTYPE May Be UPPER or LOWER
- Required Effectiveness May Be Positive or Negative so That a Reversed Aileron Condition May Be Imposed

Lift Effectiveness Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONCLA	SID	CTYPE	CLAREQ						
DCONCLA	25	UPPER	0.8						

- **May Only Be Applied to Symmetric Analyses of One or Two Degree of Freedom Trim**
- **CTYPE May Be UPPER or LOWER**
- **For Completeness, CLAREQ May Be Either Positive or Negative**

Unsteady Aerodynamic Parameters

1	2	3	4	5	6	7	8	9	10
AERO	ACSID	REFC	RHOREF						
AERO	100	300.0	1.1E-7						

Reference Density

Reference Chord Length

Coordinate System ID

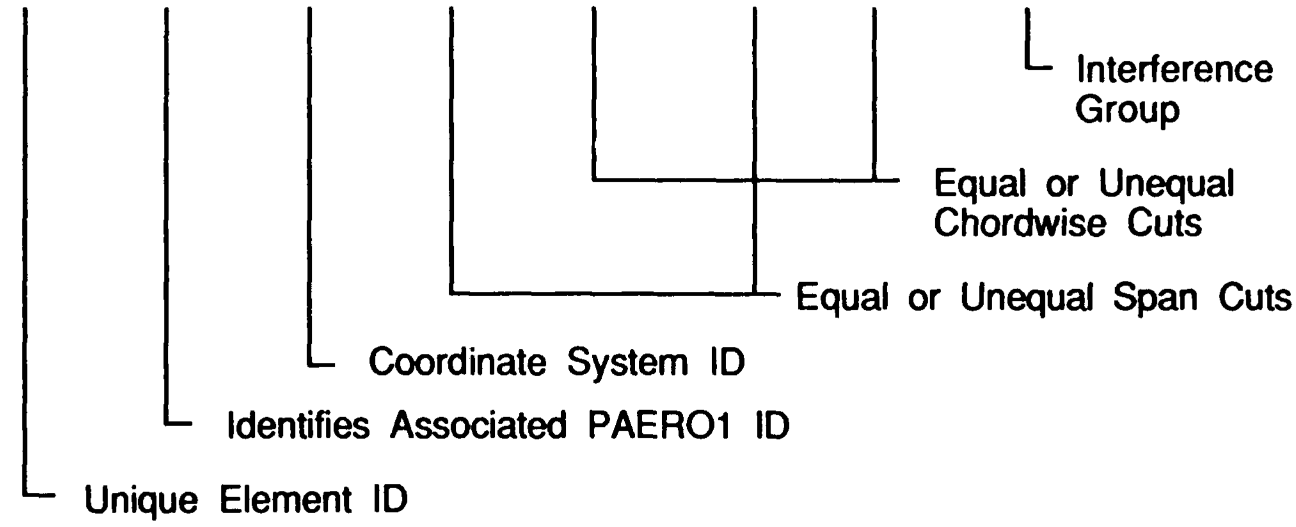
NASTRAN Has Added Fields

Velocity Field is Redundant

Symmetry Fields Limit Multidisciplinary Capability

Unsteady Aerodynamic Lifting Surfaces

1	2	3	4	5	6	7	8	9	10
CAERO1	EID	PID	CP	NSPAN	NCHORD	LSPAN	LCHORD	IGID	CONT
CAERO1	1000	1		3			2	1	ABC

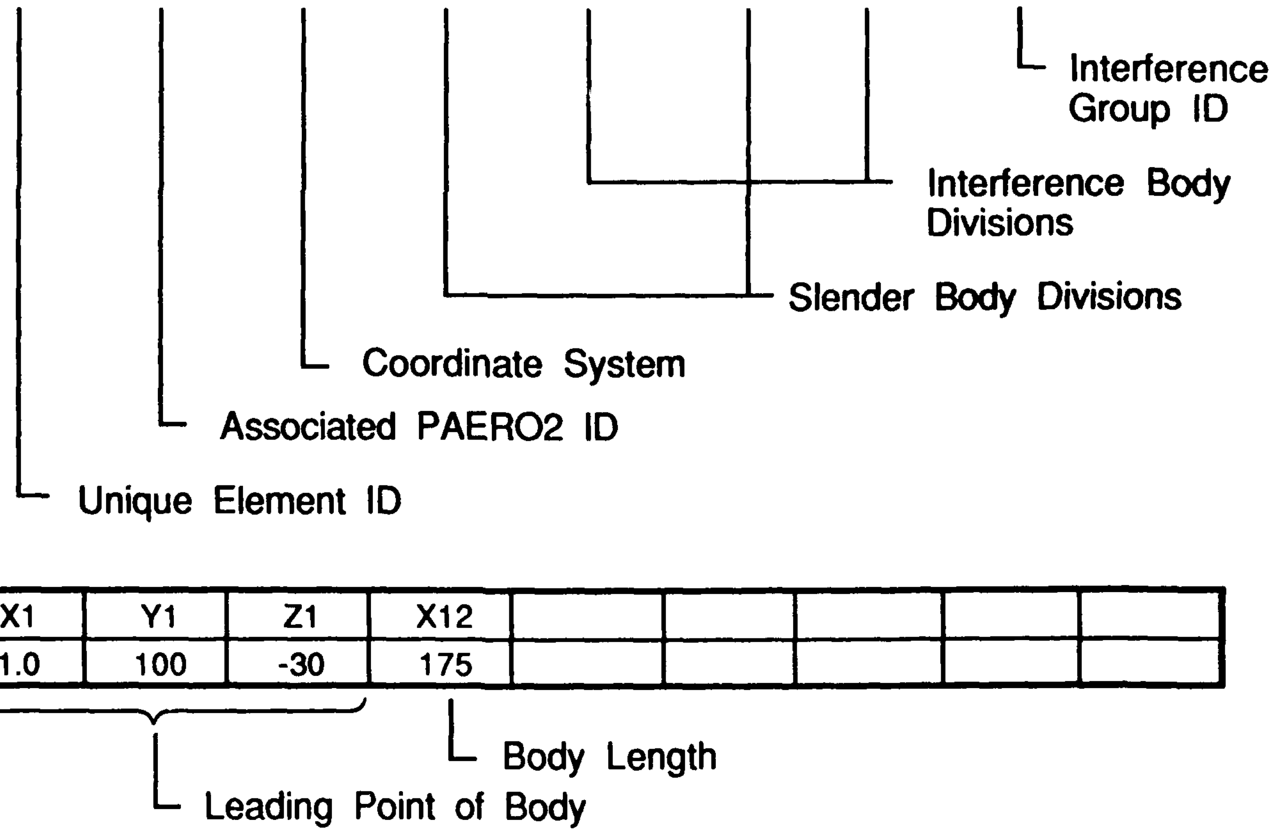

Interference Group
Equal or Unequal Chordwise Cuts
Equal or Unequal Span Cuts
Coordinate System ID
Identifies Associated PAERO1 ID
Unique Element ID

+BC	X1	Y1	Z1	X12	X4	Y4	Z4	X43	
+BC	0.0								

Panel Boundaries - Edges are Parallel to the Flow

Unsteady Aerodynamic Body Connection

1	2	3	4	5	6	7	8	9	10
CAERO2	EID	PID	CP	NSB	NINT	LSB	LINT	IGID	CONT
CAERO2	1500	2	100		4	99		1	abc



Interference Group ID

Interference Body Divisions

Slender Body Divisions

Coordinate System

Associated PAERO2 ID

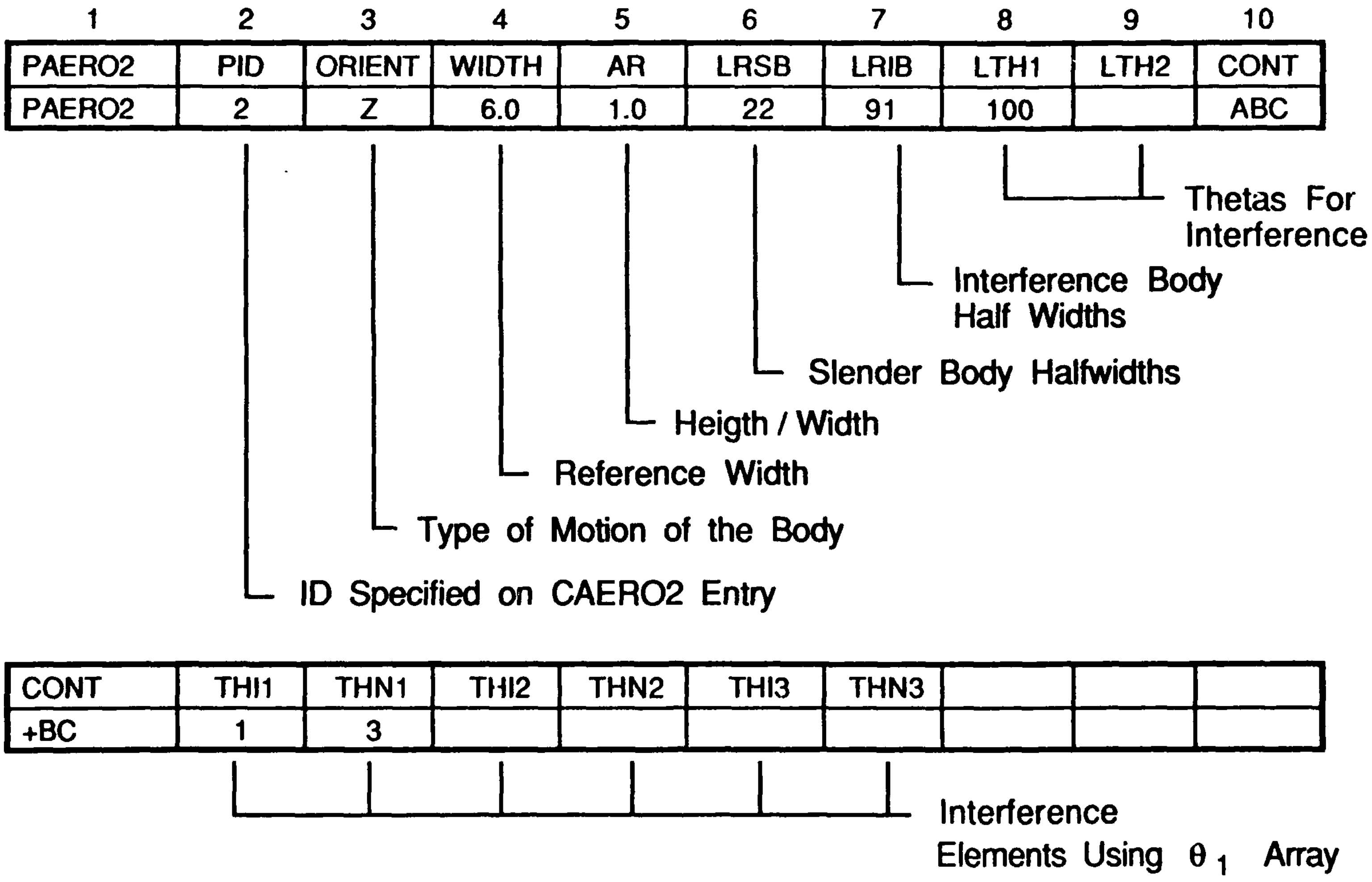
Unique Element ID

CONT	X1	Y1	Z1	X12					
+bc	-1.0	100	-30	175					

Body Length

Leading Point of Body

Unsteady Aerodynamic Body Properties



1	2	3	4	5	6	7	8	9	10
PAERO2	PID	ORIENT	WIDTH	AR	LRSB	LRIB	LTH1	LTH2	CONT
PAERO2	2	Z	6.0	1.0	22	91	100		ABC

Thetas For Interference

Interference Body Half Widths

Slender Body Halfwidths

Heigth / Width

Reference Width

Type of Motion of the Body

ID Specified on CAERO2 Entry

CONT	THI1	THN1	THI2	THN2	THI3	THN3			
+BC	1	3							

Interference Elements Using θ_1 Array

Flutter Analysis Conditions

1	2	3	4	5	6	7	8	9	10
FLUTTER	SID	METHOD	DENS	MACH	VEL	MLIST	EPS		CONT
FLUTTER	19	PK	119	219	319	10	1.-4		ABC

List of Modes To Be Deleted From Analysis

ID of Entry Defining Velocities

ID of Entry Defining Mach Numbers

ID of Entry Defining Density Ratios

Flutter ID Specified in Solution Control

CONT	SYMXZ	SYMXY							
+BC	1	0							

Symmetry Flags

Multidisciplinary Analysis Requires Symmetry Condition as Part of the Specification

Bulk Data Entries For Steady Aerodynamics

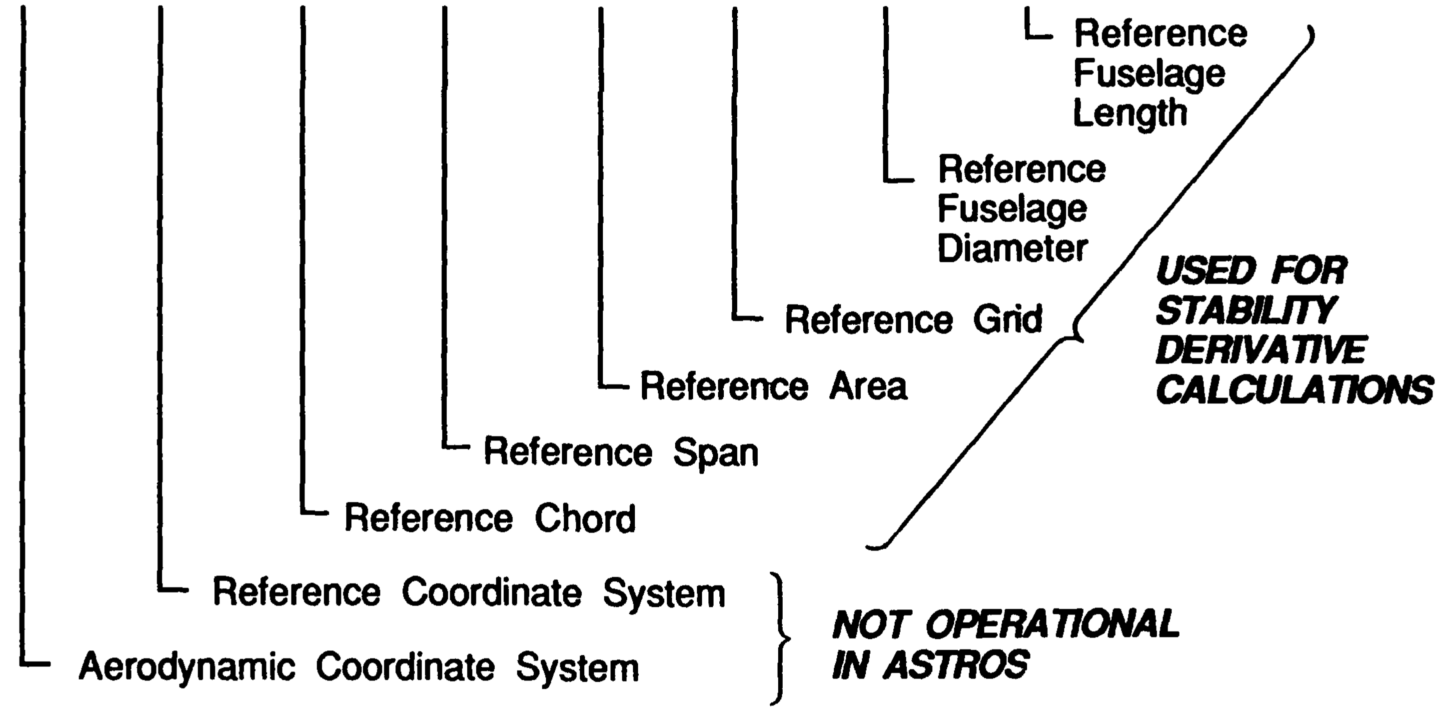
FUNCTION			
CONFIGURATION	**PANELING**	**REFERENCE DATA**	**TRIM**
AIRFOIL	CAERO6	AEROS	TRIM
BODY	PAERO6		
AXSTA	AESURF		
AEFACT	AEFACT		

Configuration Data Provide Detailed Definition of the Aerodynamic Outline

Paneling Data Define the Mathematical Representation in USSAERO

Steady Aerodynamic Parameters

1	2	3	4	5	6	7	8	9	10
AEROS	ACSID	RCSID	REFC	REFB	REFS	GREF	REFD	REFL	
AEROS	10	20	10.	100.	1000.	1			



Reference Fuselage Length

Reference Fuselage Diameter

Reference Grid

Reference Area

Reference Span

Reference Chord

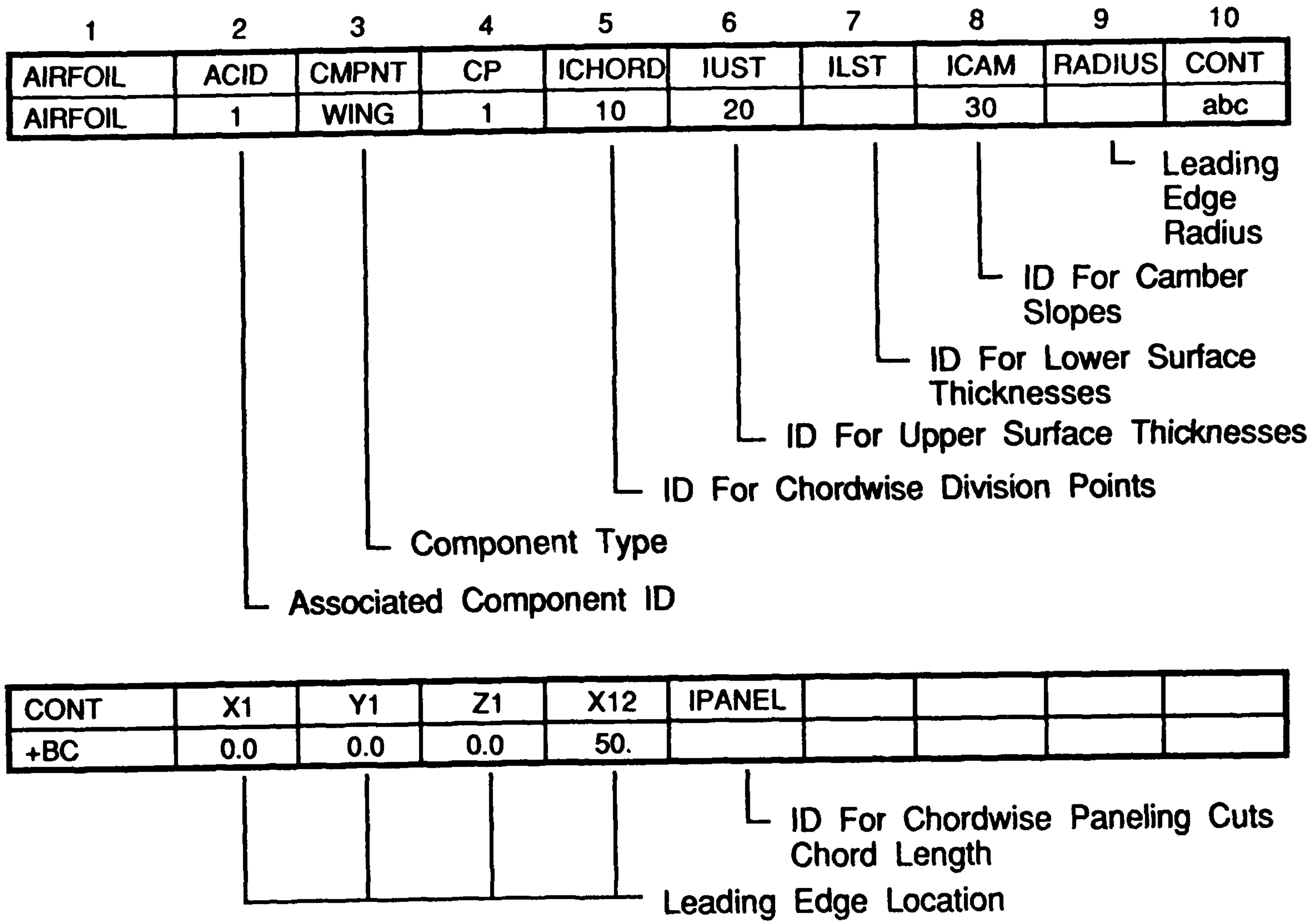
USED FOR STABILITY DERIVATIVE CALCULATIONS

Reference Coordinate System

Aerodynamic Coordinate System

NOT OPERATIONAL IN ASTROS

Airfoil Properties



1	2	3	4	5	6	7	8	9	10
AIRFOIL	ACID	CMPNT	CP	ICHORD	IUST	ILST	ICAM	RADIUS	CONT
AIRFOIL	1	WING	1	10	20		30		abc

Leading Edge Radius

ID For Camber Slopes

ID For Lower Surface Thicknesses

ID For Upper Surface Thicknesses

ID For Chordwise Division Points

Component Type

Associated Component ID

CONT	X1	Y1	Z1	X12	IPANEL				
+BC	0.0	0.0	0.0	50.					

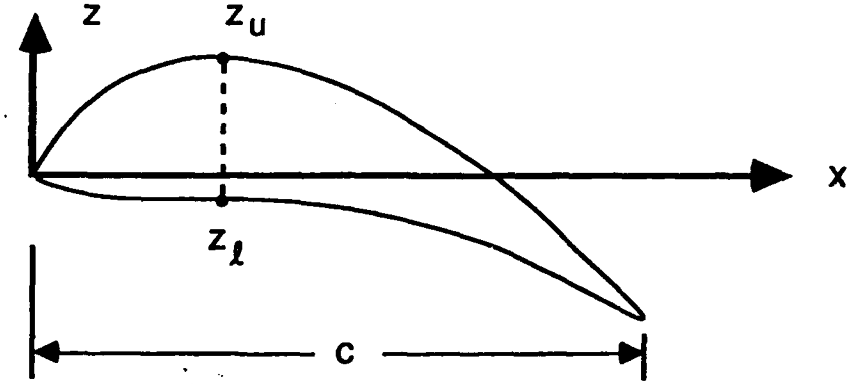
ID For Chordwise Paneling Cuts

Chord Length

Leading Edge Location

Airfoil Properties (Concluded)

- Chordwise Divisions are Given in Percent Chord
- Thickness / Camber Data are Defined as



Upper + Lower	*Upper + Camber*
Upper = $100\, z_u / c$	Upper = $100\,(z_u - z_\ell)/c$
Lower = $-100\, z_\ell / c$	Camber = $50\,(z_u + z_\ell)/c$

Steady Aerodynamic Lifting Surface

1	2	3	4	5	6	7	8	9	10
CAERO6	ACID	CMPNT	CP	IGRP	LCHORD	LSPAN			
CAERO6	1	WING		1	20	30			

ID of Spanwise Panel Cuts

ID of Chordwise Panel Cut

Group Number

Reference Chord

Reference Coordinate System

Chordwise Cuts are in Percent Chord

Spanwise Cuts are in Physical Coordinates

Body Properties

1	2	3	4	5	6	7	8	9	10
BODY	BCID	CMPNT	CP	NRAD	XLOC	YLOC	ZLOC		
BODY	10	FUSEL	0	3					

Leading Point of POD

Number of Equal Radial Cuts

Component Type

Component ID

Station Properties

AXSTA	BCID	XSTA	CBOD	ABOD	LYRAD	LZRAD			
AXSTA	10	10.0	0.5		10	20			

ID For Z ORDINATES

ID For Y Ordinates

Body Area

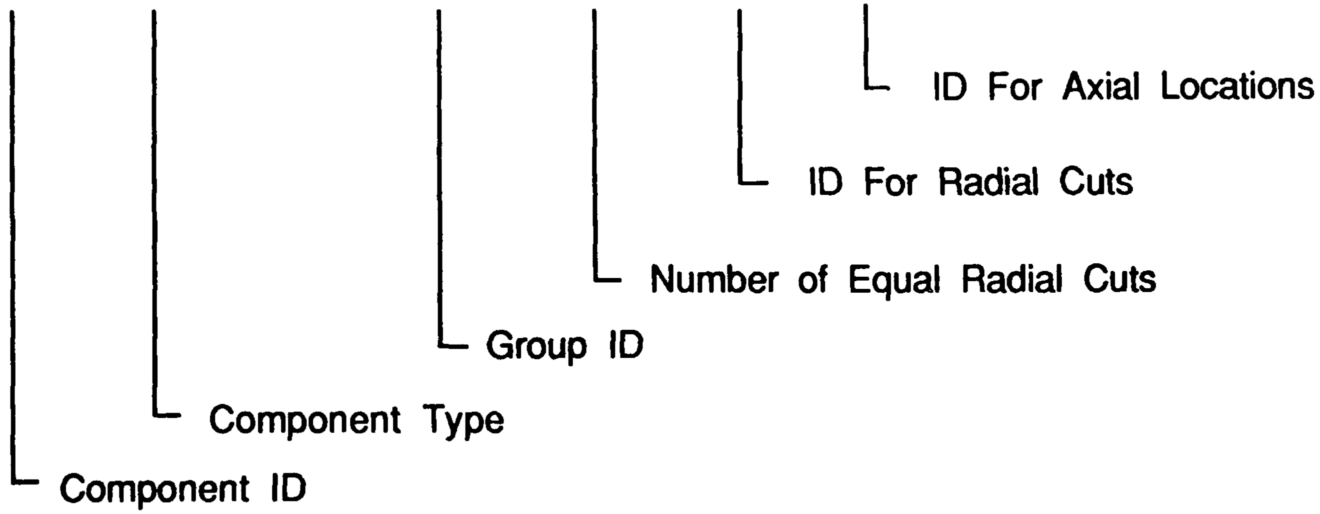
Body Camber Value

Station Location

Component ID

Steady Aerodynamic Body Surface

1	2	3	4	5	6	7	8	9	10
PAERO6	BCID	CMPNT	CP	IGRP	NRAD	LRAD	LAXIAL		
PAERO6	10	FUSEL	0	3	4				



NRAD and LRAD Cannot Both Be Non - Zero

If NRAD and LRAD are Blank, BODY or AXSTA Data are Used

If LAXIAL is Blank, AXSTA Data are Used

Limits on Configuration Data in USSAERO

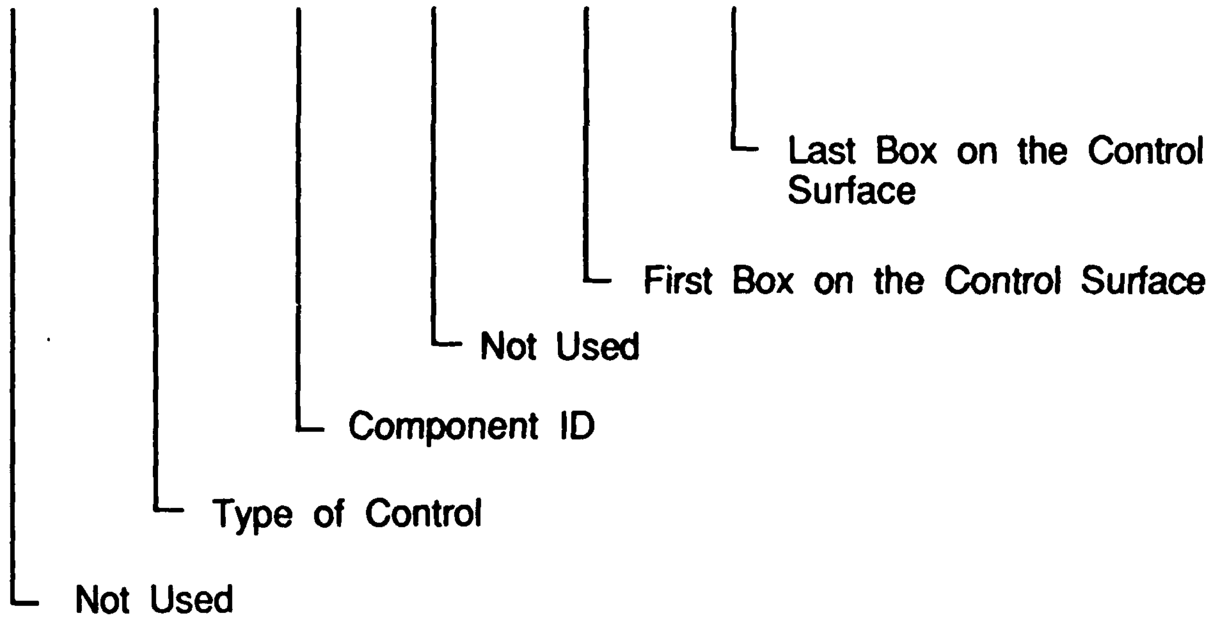
PARAMETER	LIMIT	BULK DATA ENTRY	DATA FIELD	QUANTITY
NWAF	$2 \leq NWAF \leq 20$	AIRFOIL	N/A	Airfoils on the wing
NFIN & NCAN	NFIN = 2 NCAN = 2	AIRFOIL	N/A	Airfoils on canards and fins
NF	$0 \leq NF \leq 6$	CAERO6	N/A	Fins in a given group
NCAN	$0 \leq NCAN \leq 6$	CAERO6	N/A	Canards in a given group
NFUS	$NFUS \leq 6$	BODY	N/A	Fuselage segments
NP	$0 \leq NP \leq 9$	BODY	N/A	Pods
NWAFOR	$3 \leq NWAFOR \leq 30$	AIRFOIL	ICHORD	Chordwise division points to define a wing airfoil
NFINOR & NCANOR	$3 \leq NFINOR \leq 10$ $3 \leq NCANOR \leq 10$	AIRFOIL	ICHORD	Chordwise division points to define a fin or canard airfoil
NFORX	$2 \leq NFORX \leq 30$	AXSTA	N/A	Axial stations per fuselage segment
NRADX	$3 \leq NRADX \leq 20$	AXSTA/ BODY	LYRAD/ NRAD	Radial cuts for a given axial station for half the fuselage
NPODOR	$2 \leq NPODOR \leq 30$	AXSTA	N/A	Axial stations per pod
NTS	$3 \leq NTS \leq 21$	AXSTA/ BODY	N/A	Radial cuts for a given axial station for a complete pod

Limits on Paneling Data in USSAERO

PARAMETER	LIMIT	BULK DATA ENTRY	DATA FIELD	QUANTITY
NBOX	$NBOX \leq 600$	N/A		Total number of boxes in the model
KWAF	$2 \leq KWAF \leq 20$	CAERO6	LSPAN	Spanwise division to define wing panel edges
KWAFOR	$3 \leq KWAFOR \leq 30$	CAERO6	LCHORD	Chordwise divisions to define wing panel edges
KFORX	$2 \leq KFORX \leq 30$	PAERO6	LAXIAL	Axial panel edges for a fuselage segment
KRADX	$3 \leq KRADX \leq 20$	PAERO6	LRAD	Radial panel edges for a fuselage segment
KF & KCAN	$2 \leq KF \leq 20$ $2 \leq KCAN \leq 20$	CAERO6	LSPAN	Spanwise divisions to define fin (canard) panel edges
KFINOR & KCANOR	$3 \leq KFINOR \leq 30$ $3 \leq KCANOR \leq 30$	CAERO6	LCHORD	Chordwise divisions to define fin (canard) panel edges
KPOD	$3 \leq KPOD \leq 30$	PAERO6	LAXIAL	Axial panel edges for a pod
KTRAD	$3 \leq KTRAD \leq 21$	PAERO6	LRAD	Radial panel edges per pod

Control Surface Definition

1	2	3	4	5	6	7	8	9	10
AESURF	SETID	LABEL	ACID1	CID1	FBOXID1	LBOXID1			
AESURF	600	ELEV	6000	1	6010	6030			



Last Box on the Control Surface

First Box on the Control Surface

Not Used

Component ID

Type of Control

Not Used

Flight Condition Parameters

1	2	3	4	5	6	7	8	9	10
TRIM	TID	MACH	QDP	SYMXZ	TRMTYP	NZ	QRATE	VO	
TRIM	1	.9	100.	1	1	1.0	0.0	0.0	

Velocity

Pitch Rate

Load Factor

Trim Type
- 0 No Trim
- 1 Lift
- 2 Lift + Pitching

Symmetry
- 1 Symmetric
- -1 Antisymmetric

Dynamic Pressure

Mach Number

TRIM ID From Solution Control

Rigid Load Transfer

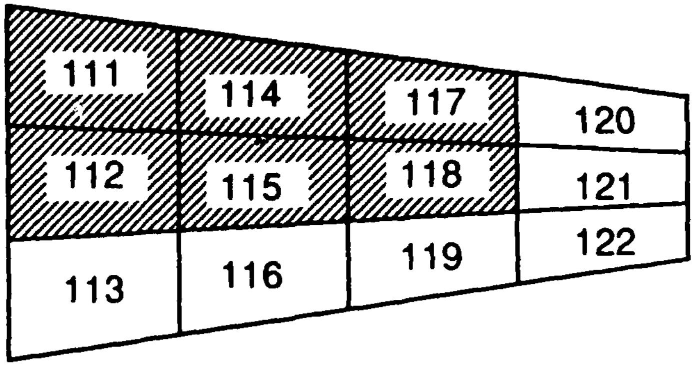
1	2	3	4	5	6	7	8	9	10
ATTACH	EID	MACROID	BOX1	BOX2	RGRID				
ATTACH	100	111	111	118	1				

Grid Point of Transfer

Last Box For Transfer

First Box For Transfer

ID of Aerodynamic Component



Sample Data Affects the Shaded Boxes

The ASTROS Input File Processor (IFP)

- An Application Module that Interprets the Bulk Data Entries Based on the Templates
- Performs Intra - Entry Error Checks as Directed on the Templates
- On Restart, Appends Additional Entries Onto Existing Data
- Must Be Called By the Executive for Every Execution

The ASTROS Bulk Data Template

*** GRID BULK DATA ENTRY TEMPLATE ***

```
GRID     |ID       |CP       |X1       |X2       |X3       |CD       |PS       |         |         |
CHAR     |INT      |INT      |REAL     |REAL     |REAL     |INT      |INT      |         |         |
DEFAULT
CHECKS    GT 0      GE 0                                   GE 0      COMP
          1         2         3         4         5         6         -7
GRID      GRIDID    CP        X         Y         Z         CD        PERMSPC             38        $
```

*** EIGR BULK DATA ENTRY TEMPLATE ***

```
EIGR     |SETID    |METHOD   |F1       |F2       |NE       |ND       |         |E        |CONT     |
CHAR     |INT      |CHAR     |REAL     |REAL     |INT      |INT      |         |REAL     |CHAR     |
DEFAULT                                                                         1.E-10
CHECKS    GT 0      RMETH     GE 0.     GEP       GE 0      GE 0                EIGE
          1         2         4         5         6         7                   8
EIGR      SETID     METHOD    MINFREQ   MAXFREQ   ROOTEST1  ROOTDES1            ORTHPARM31
+EIGR    |NORM     |G        |C        |                                                            |
CHAR     |CHAR     |INT      |INT      |                                                            |
DEFAULT   MAX
CHECKS    NORM      EIGG      EIGC
          9         11        -12
          NORM      GRID1     COMPNTS1                                                             $
```

User Output From ASTROS

- System Controlled Output
- Solution Controlled Output
- Executive Controlled Output

System Controlled Output From ASTROS

- Title Page and Page Headers
- Default Output From Engineering Modules
- System and User Error Messages

ASTROS System Headers

```
                         ::::::::::::::::::::::::::::::::::::::::::::::::::
                         ::                                              ::
                         ::  AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM    ::
                         ::                                              ::
                         ::  *****  *****  *****  *****  *****  *****    ::
                         ::  *   *  *        *    *   *  *   *  *        ::
                         ::  *****  *****    *    *****  *   *  *****    ::
                         ::  *   *      *    *    * *    *   *      *    ::
                         ::  *   *  *****    *    *   *  *****  *****    ::
                         ::                                              ::
                         ::   INITIAL PRODUCTION RELEASE - VERSION 2     ::
                         ::                                              ::
                         ::            DEC VAX/VMS SERIES                ::
                         ::              JUNE 1, 1988                    ::
                         ::                                              ::
                         ::::::::::::::::::::::::::::::::::::::::::::::::::
ASSIGN DATABASE FSW3 SHAZAM NEW DELETE
```

TITLE	ASTROS VERSION X DATE PAGE #
SUBTITLE	ASTROS ITERATION X
LABEL	RESPONSE QUANTITY LABELING

ASTROS Default Output From Engineering Modules

- Very Limited Amount to Reduce Magnitude of Output
- BDCASE / ABOUND Boundary Condition Summaries
- Active Constraint Summary
- Approximate Optimization Summary
- Final Design Data
- Termination States and Timing Summary

Boundary Condition Default Output

```
 MODIFIED ACOSS II MODEL                                              ASTROS VERSION 2
 NATURAL FREQUENCY DESIGN, FIRST 2 MODES                              ASTROS ITERATION 1

     B O U N D A R Y   C O N D I T I O N   S U M M A R Y   F O R   B O U N D A R Y   C O N D I T I O N 1


****        STATICS/NORMAL MODES          *******                      DYNAMIC RESPONSE                       ****
***                                        *****                 MODAL            *****       DIRECT           ***
** STATICS MASS MODES          SAERO        *** FLUTTER    TRANS     FREQ   BLAST  ***  TRANS     FREQ    BLAST **
*    NO     YES  YES            NO           *    NO        NO        NO     NO     *    NO        NO      NO    *
```

```
ABOUND SUMMARY FOR BOUNDARY CONDITION    1 :

       ABC       NAU     NADSC      NADC       AFC       AAC       NAE      NMPC      NSPC     NOMIT     NRSET    NLOADS
        1         0         0         2         0         0         0         0       108        36         0         0
```

Active Constraint Summary

```
MODIFIED ACOSS II MODEL                                                     ASTROS VERSION 2
NATURAL FREQUENCY DESIGN, FIRST 2 MODES                                     ASTROS ITERATION 9

                     S U M M A R Y   O F   A C T I V E   C O N S T R A I N T S
                                  2 CONSTRAINTS RETAINED OF 2 APPLIED

                  THE APPROXIMATE OPTIMIZATION PROBLEM WAS CONVERGED WITH
                  FEASIBLE CONSTRAINT CRITERIA (CTLMIN)...:    5.00000E-04 AND
                  ACTIVE CONSTRAINT CRITERIA   (CTL)......:   -5.00000E-04

                  CURRENT MAXIMUM CONSTRAINT VALUE...:    6.48499E-04

                  TO TERMINATE                    ...:    -1.50000E-03 <    6.48499E-04 <=    1.00000E-03

                  *** ASTROS OPTIMIZATION HAS CONVERGED ***

     COUNT   CONSTRAINT VALUE     CONSTRAINT TYPE     TYPE COUNT  BOUNDARY ID  SUBCASE  ELEMENT TYPE   EID

       1       -1.45733E-04     LOWER BOUND FREQUENCY      1           1          2                     0
       2        6.48499E-04     LOWER BOUND FREQUENCY.     2           1          1                     0
```

Approximate Optimization Summary

```
****          ASTROS APPROXIMATE OPTIMIZATION                    ****
***                SUMMARY - ITERATION  1                         ***
**            METHOD = MATH PROGRAMMING                            **
*   CURRENT      PREVIOUS     OBJECTIVE     PERCENT  CONVERGENCE    *
*  OBJECTIVE    OBJECTIVE       CHANGE       CHANGE      FLAG       *
*  3.98656E+01  4.83053E+01  -8.43971E+00  -17.472  NOT CONVERGED  *
```

Final Design Information: Iteration History

```
MODIFIED ACOSS II MODEL                                                      ASTROS VERSION 2
NATURAL FREQUENCY DESIGN, FIRST 2 MODES                                      ASTROS ITERATION 9

                          A S T R O S   D E S I G N   I T E R A T I O N   H I S T O R Y

 ITERATION  OBJECTIVE      NUMBER    NUMBER     NUMBER       NUMBER       NUMBER     NUMBER NUMBER  APPROXIMATE
            FUNCTION      FUNCTION  GRADIENT   RETAINED      ACTIVE      VIOLATED    LOWER  UPPER     PROBLEM
  NUMBER     VALUE          EVAL      EVAL    CONSTRAINTS  CONSTRAINTS  CONSTRAINTS  BOUNDS BOUNDS  CONVERGENCE


    1      4.83053E+01       0         0          0            0            0          0      0   NOT CONVERGED
    2      3.98656E+01      38         8          2            0            0         12     45   NOT CONVERGED
    3      3.13249E+01      69         7          2            1            0          0     22   NOT CONVERGED
    4      2.83210E+01     152        20          2            2            0          0     24   NOT CONVERGED
    5      2.74327E+01      96        17          2            2            1          0     21   NOT CONVERGED
    6      2.65418E+01      82        20          2            2            0          0      7   NOT CONVERGED
    7      2.66694E+01      24         6          2            2            0          0      0   CONVERGED
    8      2.65104E+01      37         8          2            2            0          0      0   NOT CONVERGED
    9      2.64772E+01      21         4          2            2            0          0      0   CONVERGED

  THE FINAL OBJECTIVE FUNCTION VALUE IS:
                               FIXED =      2.90300E+01
                          + DESIGNED =      2.64772E+01
                                          -------------
                               TOTAL =      5.55072E+01
```

Final Design Information: Design Variables

```
                  A S T R O S   D E S I G N   V A R I A B L E   V A L U E S


 DESIGN      DESIGN          MINIMUM        MAXIMUM       OBJECTIVE      LINKING        USER
VARIABLE    VARIABLE
   ID        VALUE            VALUE          VALUE       SENSITIVITY     OPTION        LABEL

    1      6.99495E-02    1.00000E-02    1.00000E+03    3.25982D-01  UNIQUE PHYSICAL
    2      7.01583E-02    1.00000E-02    1.00000E+03    3.25982D-01  UNIQUE PHYSICAL
    3      1.86396E+00    1.00000E-02    1.00000E+03    5.59054D-01  UNIQUE PHYSICAL
    4      1.12259E+00    1.00000E-02    1.00000E+03    2.23622D-01  UNIQUE PHYSICAL
    5      4.33342E-02    1.00000E-02    1.00000E+03    6.02120D-01  UNIQUE PHYSICAL
    6      1.08177E+00    1.00000E-02    1.00000E+03    2.23622D-01  UNIQUE PHYSICAL
    7      4.33342E-02    1.00000E-02    1.00000E+03    6.02120D-01  UNIQUE PHYSICAL
    8      5.48568E-02    1.00000E-02    1.00000E+03    4.47243D-01  UNIQUE PHYSICAL
    9      1.80389E+00    1.00000E-02    1.00000E+03    5.59054D-01  UNIQUE PHYSICAL
   10      6.99411E-02    1.00000E-02    1.00000E+03    3.25982D-01  UNIQUE PHYSICAL
   11      7.01594E-02    1.00000E-02    1.00000E+03    3.25982D-01  UNIQUE PHYSICAL
```

```
   S U M M A R Y   O F   L O C A L   D E S I G N   V A R I A B L E S  --  F I N A L   R E S U L T S
                                 R O D   E L E M E N T S
              EID       LINKING OPTION       AREA          MINIMUM     MAXIMUM
                1    UNIQUE PHYSICAL    6.99494660E-01    1.000E-01   1.000E+04
                2    UNIQUE PHYSICAL    7.01583207E-01    1.000E-01   1.000E+04
                3    UNIQUE PHYSICAL    1.86395588E+01    1.000E-01   1.000E+04
                4    UNIQUE PHYSICAL    1.12259197E+01    1.000E-01   1.000E+04
                5    UNIQUE PHYSICAL    4.33341980E-01    1.000E-01   1.000E+04
                6    UNIQUE PHYSICAL    1.08177452E+01    1.000E-01   1.000E+04
                7    UNIQUE PHYSICAL    4.33341980E-01    1.000E-01   1.000E+04
                8    UNIQUE PHYSICAL    5.48567891E-01    1.000E-01   1.000E+04
                9    UNIQUE PHYSICAL    1.80388851E+01    1.000E-01   1.000E+04
               10    UNIQUE PHYSICAL    6.99411273E-01    1.000E-01   1.000E+04
```

Order Of Output For Selected Quantities

- **Discipline Quantities are Ordered for Each Boundary Condition**

  (1) Trim Parameters
  (2) Flutter Analysis Results
  (3) Applied Loads
  (4) Displacements, Velocities and/or Accelerations
  (5) Element Response Quantities Alphabetic By Element Type for:

    (a) STRESS
    (b) STRAIN
    (c) FORCE
    (d) STRAIN ENERGY

- **Design Quantities Follow All Boundary Condition Output**
- **Within Each Quantity, The Disciplines are Treated:**

  (1) STATICS
  (2) MODES
  (3) SAERO
  (4) FLUTTER
  (5) TRANSIENT
  (6) FREQUENCY
  (7) BLAST

OFP Example - Stability Derivatives

```
SIMPLIFIED WING STRUCTURE DESIGN                                          ASTROS VERSION 1.00   10/14/87
STRESS, DISP, LIFT AND AILERON EFFECTIVENESS CONSTRAINTS                  ASTROS ITERATION 1
UNCONSTRAINED STABILITY DERIVATIVES

                                  NONDIMENSIONAL LONGITUDINAL STABILITY DERIVATIVES

                           MACH =  8.0000E-01   QDP =  6.5000E+00   REFERENCE GRID =        20

                           REFERENCE AREA =  2.4000E+03     REFERENCE CHORD =  2.0000E+01

       PARAMETER                         LIFT                                      PITCHING MOMENT
                            RIGID       RIGID       FLEXIBLE           RIGID       RIGID       FLEXIBLE
                           (DIRECT)    (SPLINED)                      (DIRECT)    (SPLINED)
                           ------------------------------------       ------------------------------------

   THICKNESS AND CAMBER     0.0099      0.0099      0.0174             0.0057      0.0057      0.0093

   ALPHA(DEGS)              0.1173      0.1173      0.1864            -0.0062     -0.0062      0.0268

   ALPHA(RADS)              6.7225      6.7224     10.6785            -0.3551     -0.3551      1.5348

   ELEVATOR(DEGS)           0.0118      0.0118      0.0081            -0.0431     -0.0431     -0.0458

   ELEVATOR(RADS)           0.6779      0.6779      0.4646            -2.4701     -2.4701     -2.6218

   PITCH RATE(DEGS/SEC)     0.0923      0.0923      0.0830            -0.2033     -0.2033     -0.2109

   PITCH RATE(RADS/SEC)     5.2904      5.2904      4.7549           -11.6503    -11.6503    -12.0849

     TRIM RESULTS
     ------------

      ALPHA =      1.3313E+00 (DEGS)          ELEVATOR =      -1.3371E+00 (DEGS)
```

OFP Example - Stress Output

```
5X50 LONG, NARROW ORTHOTROPIC PLATE, W/QUAD4'S                                    ASTROS VERSION  1.00 10/ 6/87
QAJOB-D10410
SINE LOAD                                                                   STATICS ANALYSIS: BOUNDARY 1, SUBCASE 1
                 S T R E S S E S   I N   Q U A D R I L A T E R A L   P L A T E S   ( Q U A D 4 )
  ELEMENT  LAYER      FIBER            STRESSES IN ELEMENT COORD SYSTEM           PRINCIPAL STRESSES (ZERO SHEAR)
     ID     NO.      DISTANCE       NORMAL-X       NORMAL-Y       SHEAR-XY       ANGLE         MAJOR          MINOR
      1      0     5.00000E-01   1.90822E+01    2.07259E+01   -3.37227E-01    -78.8454    2.07924E+01    1.90157E+01
                  -5.00000E-01  -1.90822E+01   -2.07259E+01    3.37227E-01     11.1546   -1.90157E+01   -2.07924E+01
      2      0     5.00000E-01   1.72141E+01    1.86962E+01   -9.76428E-01    -63.5978    1.91809E+01    1.67294E+01
                  -5.00000E-01  -1.72141E+01   -1.86962E+01    9.76428E-01     26.4022   -1.67294E+01   -1.91809E+01
      3      0     5.00000E-01   1.36604E+01    1.48375E+01   -1.52206E+00    -55.5697    1.58808E+01    1.26171E+01
                  -5.00000E-01  -1.36604E+01   -1.48375E+01    1.52206E+00     34.4303   -1.26171E+01   -1.58808E+01
      4      0     5.00000E-01   8.77119E+00    9.52648E+00   -1.91758E+00    -50.5705    1.11032E+01    7.19443E+00
                  -5.00000E-01  -8.77119E+00   -9.52648E+00    1.91758E+00     39.4295   -7.19443E+00   -1.11032E+01
      5      0     5.00000E-01   3.02235E+00    3.28265E+00   -2.12568E+00    -46.7519    5.28217E+00    1.02284E+00
                  -5.00000E-01  -3.02235E+00   -3.28265E+00    2.12568E+00     43.2481   -1.02284E+00   -5.28217E+00
      7      0     5.00000E-01   1.58623E+01    1.30028E+01   -8.27571E-01    -15.0318    1.60845E+01    1.27806E+01
                  -5.00000E-01  -1.58623E+01   -1.30028E+01    8.27571E-01     74.9682   -1.27806E+01   -1.60845E+01
      8      0     5.00000E-01   1.43088E+01    1.17305E+01   -2.39648E+00    -30.8613    1.57409E+01    1.02985E+01
                  -5.00000E-01  -1.43088E+01   -1.17305E+01    2.39648E+00     59.1387   -1.02985E+01   -1.57409E+01
      9      0     5.00000E-01   1.13556E+01    9.30926E+00   -3.73425E+00    -37.3385    1.42043E+01    6.46056E+00
                  -5.00000E-01  -1.13556E+01   -9.30926E+00    3.73425E+00     52.6615   -6.46056E+00   -1.42043E+01
     10      0     5.00000E-01   7.29094E+00    5.97671E+00   -4.70479E+00    -41.0245    1.13843E+01    1.88338E+00
                  -5.00000E-01  -7.29094E+00   -5.97671E+00    4.70479E+00     48.9755   -1.88338E+00   -1.13843E+01
```

System And User Error Messages

- Application Modules and Some Executive Routines Use Common Error Message Utility
    - Data Base
    - MAPOL Compiler
    - Solution Control
    - Some Large Matrix Utilities
- 4 Levels of " Standard " Error Message
    1. (1) System Fatal
    2. (2) User Information
    3. (3) User Warning
    4. (4) User Fatal

Determining The Source Of An Error

- **Message Text is Verbose**
- **Message Number is Included in Standard Message**

```
*** USER WARNING MESSAGE ***        NUMBER 1.17.3
INVALID DATA IN FIELD " DVID ."
DESELM  DVID    EID     ETYPE   VMIN    VMAX    VINIT   LAYRNUM LABEL
DESELM  -11     1       CROD    0.01            1.0
```

- **Data Base Errors Give Associated Entity and Attempted Action**

```
***DATABASE FATAL ERROR REPOS 05 ENCOUNTERED
***INTERFACE ROUTINE IS REPOS
***CURRENT ENTITY NAME IS PROJINDX

***THE REQUEST ATTRIBUTE VALUE IN A RELATIONAL POSITION CALL DOES NOT EXIST IN THE RELATION
***DUMP OF DATA BASE TABLES AT TIME OF ERROR
***DUMP OF MEMORY MANAGER BLOCKS

POINTER  NAME  GROUP   PREV     NEXT    ASIZE    USIZE   FIRSTWRD
-------  ----  -----  ------   ------   ------   -----   --------
      0  ***FREE****      -1   769850   769844
 769850  RELINDEX          0   770368      512   DBBLK
 770368  PGMTST       769850   770886      512   DBBLK
 770886  RELSCHEM     770368   772940     2048   DBBLK
```

Executive Controlled Output

- **Optional Print Arguments on Application Modules**
  - Input Processor, IFP
  - Aerodynamics Processors, PFAERO and AMP
  - Flutter Analysis Module, FLUTTRAN
  - Stress Constraint Evaluation Module, SCEVAL
  - Design Module, DESIGN
- **Executive Print Utilities**
  - Structural Set Definition Print Utility
  - Structural Matrix Print Utility
  - General Matrix Print Utility
  - General Relational Print Utility
  - General Unstructured Entity Print Utility

Optional Print Arguments For IFP

CALL IFP (GSIZE, Sort, Echo)

Sort

= 0	Any Echo is Sorted (Default)
> 0	Any Echo is Unsorted

Echo

= 0	Echo to Output File (Default)
= 1	No Echo
= 2	Echo Only to Punch File
> 2	Echo to Both Output and Punch Files

Optional Print Argument For DESIGN

CALL DESIGN (CONVERGE, MOVLIM, CNVRGLIM, CTL, CTLMIN, OPSTRAT, NUMOPTBC, [AMAT] , print) ;

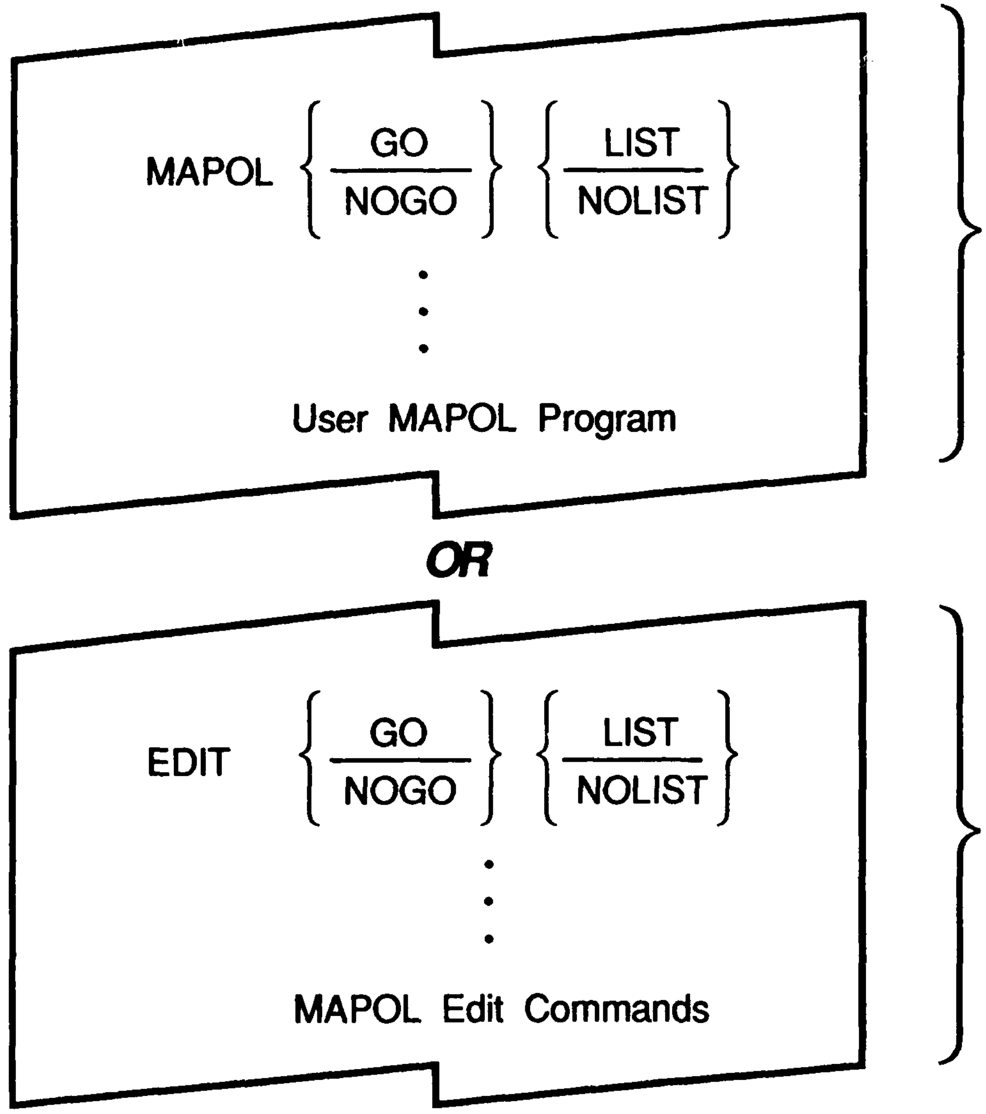
PRINT	**ACTION**
0	*No output is generated*
1	Initial design information and final results
2	The above and function values at each iteration
3	The above and internal MicroDOT parameters
	⋮

- Only Internal Labeling is Used
- Order of Constraints May Not Match Other ASTROS Output
- Internal Scaling Further Modifies the Output

ASTROS Executive System

- Execution is Directed by the High Level Language MAPOL
  - Similar Role to that Played by DMAP in NASTRAN
  - Has Syntax Similar to a Scientific Programming Language
- A Single Standard Sequence is Defined During System Generation
- The Standard Sequence can be Edited or Replaced at Execution Based on Directives in the Input Stream

The MAPOL Packet



MAPOL $\left\{\frac{\text{GO}}{\text{NOGO}}\right\} \left\{\frac{\text{LIST}}{\text{NOLIST}}\right\}$

⋮

User MAPOL Program

User Written Standalone MAPOL Program

OR

EDIT $\left\{\frac{\text{GO}}{\text{NOGO}}\right\} \left\{\frac{\text{LIST}}{\text{NOLIST}}\right\}$

⋮

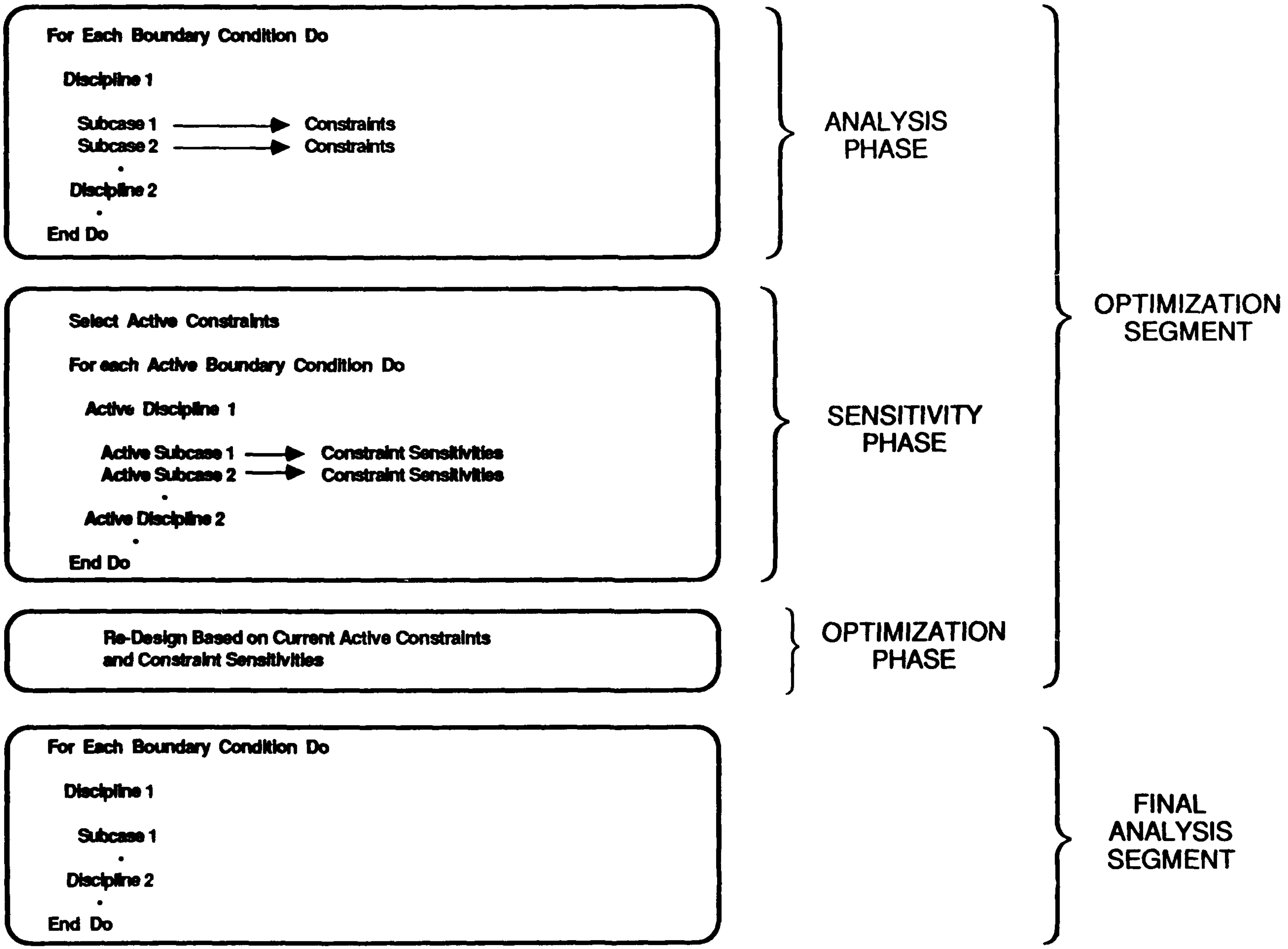
MAPOL Edit Commands

Edit Commands and/or MAPOL Code to Modify the Standard Sequence

The Standard MAPOL Sequence

- 1500 Line MAPOL Program
- Supports All the Features in ASTROS
- Carefully Documented
    - Highly Structured
    - In - Line Comments
    - Detailed Documentation in Appendix C of the User's Manual

Structure Of The Standard MAPOL Sequence



For Each Boundary Condition Do
Discipline 1
Subcase 1 → Constraints
Subcase 2 → Constraints
•
Discipline 2
•
End Do

ANALYSIS PHASE

Select Active Constraints
For each Active Boundary Condition Do
Active Discipline 1
Active Subcase 1 → Constraint Sensitivities
Active Subcase 2 → Constraint Sensitivities
•
Active Discipline 2
•
End Do

SENSITIVITY PHASE

Re-Design Based on Current Active Constraints
and Constraint Sensitivities

OPTIMIZATION PHASE

OPTIMIZATION SEGMENT

For Each Boundary Condition Do
Discipline 1
Subcase 1
•
Discipline 2
•
End Do

FINAL ANALYSIS SEGMENT

Features Of The MAPOL Language

- **Data Type Declarations**

  INTEGER
  REAL
  COMPLEX
  LOGICAL
  LABEL

  MATRIX , IMATRIX
  RELATION
  UNSTRUCT , IUNSTRUCT

- **Arithmetic Expressions, Logical Expressions, Relational Expressions**

  + , - , * , / , **
  NOT , AND , OR , XOR
  = , <> , > , >= , < , <=

- **Control STATEMENTS**

  GOTO
  FOR . . . . DO
  WHILE . . . DO
  IF . . . THEN . . . ELSE

Features Of The MAPOL Language (Concluded)

- **In - Line Procedures and Functions Analogous to FORTRAN Subroutines and Functions**

- **Intrinsic Functions**
  - Mathematical

    SIN , COS , LN , MAX . . . .
  - Relational

    RELUSE , RELADD , RELEND . . . .
  - General

    EXIT

    TRNSPOSE

User Supplied MAPOL Program Example

```
MAPOL NOLIST
$                                                                       $
$         SPECIAL MAPOL SEQUENCE FOR GENERALIZED AERO DATA              $
$                                                                       $
INTEGER  GSIZE,       NUMOPTBC,      NBNDCOND,       OPSTRAT,   MINDEX,
         NAERO;
MATRIX   [AICMAT(2)], [AAICMAT(2)],  [AIRFRC(2)],    [GTKG],    [GSTKG],
         [UGTKG],     [AJJTL],       [D1JK],         [D2JK],    [SKJ],
         [FORC],      [PHIKH],       [QHHL],         [DELCP],   [AJJDC],
         [QKKL],      [QKJL],        [QJJL];
$                                                                       $
$                BEGIN MAPOL SOLUTION SEQUENCE                          $
$                                                                       $
CALL SOLUTION( NUMOPTBC , NBNDCOND,  OPSTRAT );
CALL IFP ( GSIZE, 1 );
$                                                                       $
$         PRINT OUT THE DIRECT MATRIX INPUT PHIKH                       $
$                                                                       $
CALL UTMPRT ( , [PHIKH] );
$                                                                       $
$             GENERATE THE AIC MATRIX AND THE                           $
$             SPLINE TRANSFORMATION MATRICES                            $
$                                                                       $
CALL PFAERO ( GSIZE, [AICMAT(MINDEX)], [AAICMAT(MINDEX)],
              [AIRFRC(MINDEX)], MINDEX, NAERO, [GTKG],
              [GSTKG], [UGTKG], [AJJTL], [D1JK], [D2JK], [SKJ], [AJJDC] );
CALL AMP    ( [AJJTL], [D1JK], [D2JK], [SKJ], [QKKL], [QKJL], [QJJL] );
$                                                                       $
$             COMPUTE THE GENERALIZED AERO FROM DMI AND AICS            $
$                                                                       $
[FORC]    := [QKKL] * [PHIKH];
[QHHL]    := TRANS ( [PHIKH] ) * [FORC];
[DELCP]   := [AJJDC] * [PHIKH];
CALL UTMPRT ( , [FORC], [DELCP], [QHHL]);
END;
```

Modifying The Standard MAPOL Sequence

- **3 Commands are Available**

```
INSERT    a
DELETE    a {, b}
REPLACE   a {, b}
```

- **Line Numbers a and b Refer to Those in the SYSGEN Output Listing of the Standard Sequence**
- **No Abbreviations are Allowed in Edit Command Names**
- **Editing Must Be Done in Increasing Line Number Order**

ASTROS Executive Sequence - User Interface

- **Typical Changes to the Standard Sequence**
  - Splitting Execution Into Separate Initialization/Looping Phases ("Restart")
  - Modification of Optimization Parameters
    - *Maximum Number of Iterations*
    - Move Limits
    - Convergence Criteria
    - Constraint Deletion Parameters
  - Modification of Print Levels in Engineering Modules
- **Typical Replacements to Standard Sequence Involve :**
  - Restart to Compute and Print Additional Data
  - Special Purpose Analyses

ASTROS User Training Workshop

20-24 June 1988

The ASTROS Executive System and Database Manager

David L. Herendeen

Universal Analytics, Inc.

Outline of Presentation

- Background
- Design Goals
- Views of the ASTROS System
- The System Design
    - The CADDB Database
    - The ASTROS "Machine"
    - The Execution Subsystem
- Conclusions

ASTROS SOFTWARE DESIGN

BACKGROUND - LESSONS FROM OTHER SOFTWARE SYSTEMS

- NASTRAN
- IPAD
- SECOND GENERATION HELICOPTER ANALYSIS

UNIVERSAL ANALYTICS, INC.

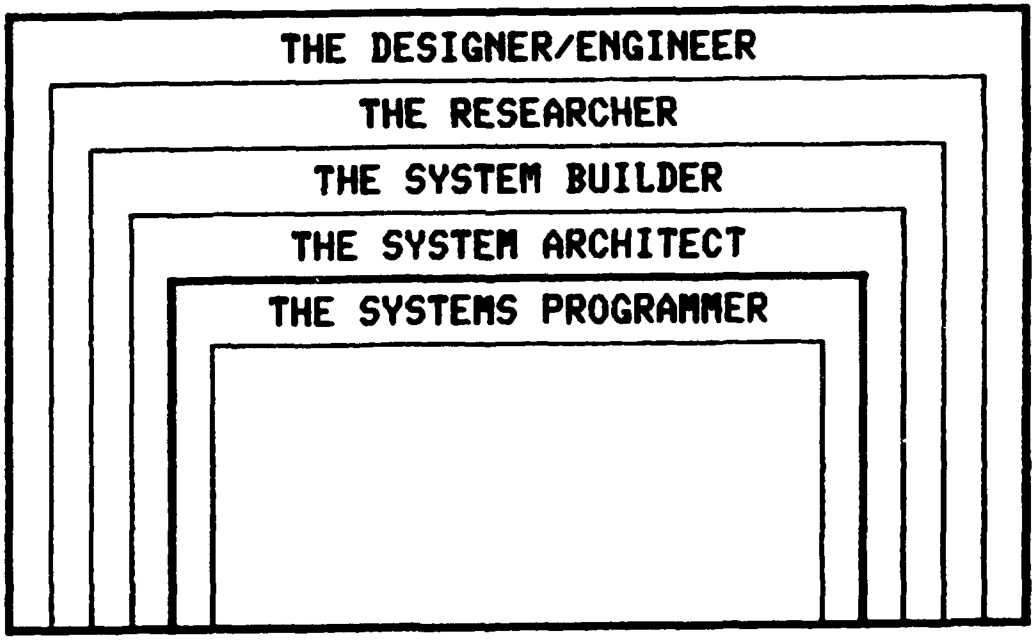
ASTROS SOFTWARE DESIGN

ASTROS DESIGN GOALS

- CORRECTNESS AND RELIABILITY
- COST-EFFECTIVE MAINTENANCE/ENHANCEMENT
- EFFICIENT COMPUTER RESOURCE UTILIZATION
- SIMPLIFIED USER INTERFACE
- PORTABILITY TO NEW COMPUTERS
- COMPREHENSIVE AND USABLE DOCUMENTATION

ASTROS SOFTWARE DESIGN

VIEWS OF THE ASTROS SYSTEM



THE DESIGNER/ENGINEER

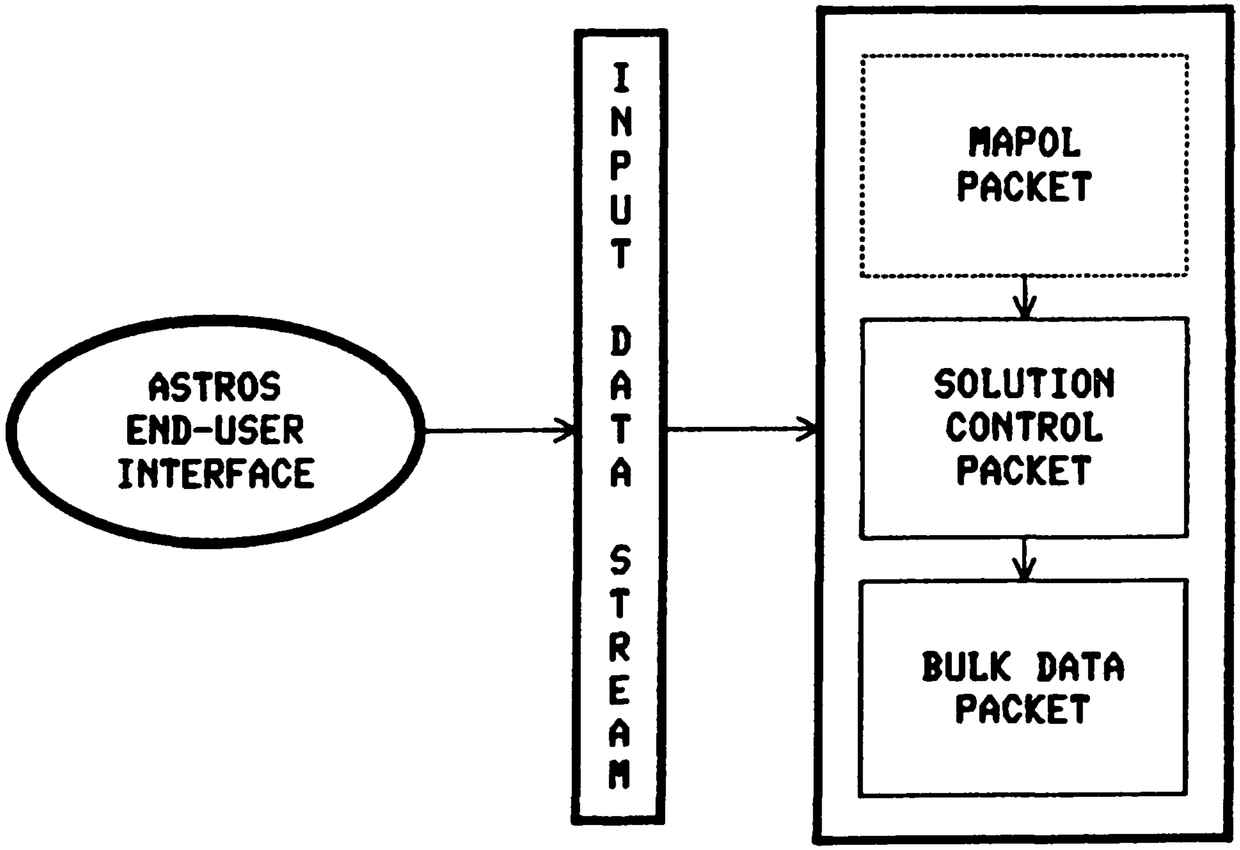
THE RESEARCHER

THE SYSTEM BUILDER

THE SYSTEM ARCHITECT

THE SYSTEMS PROGRAMMER

ASTROS SOFTWARE DESIGN



ASTROS
END-USER
INTERFACE

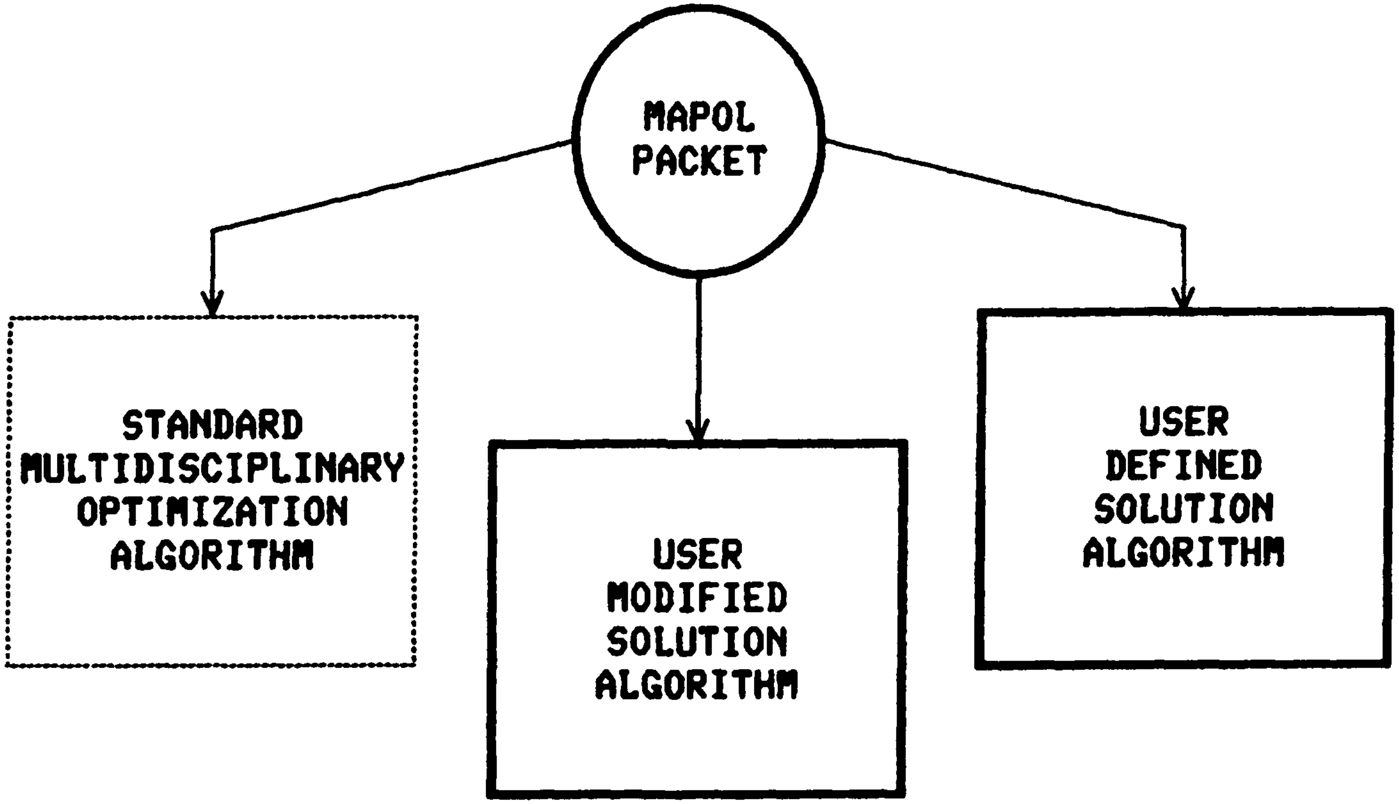
INPUT DATA STREAM

MAPOL
PACKET

SOLUTION
CONTROL
PACKET

BULK DATA
PACKET

ASTROS SOFTWARE DESIGN



MAPOL
PACKET

STANDARD
MULTIDISCIPLINARY
OPTIMIZATION
ALGORITHM

USER
MODIFIED
SOLUTION
ALGORITHM

USER
DEFINED
SOLUTION
ALGORITHM

ASTROS SOFTWARE DESIGN

MAPOL CODE SEGMENT FROM STANDARD SOLUTION ALGORITHM

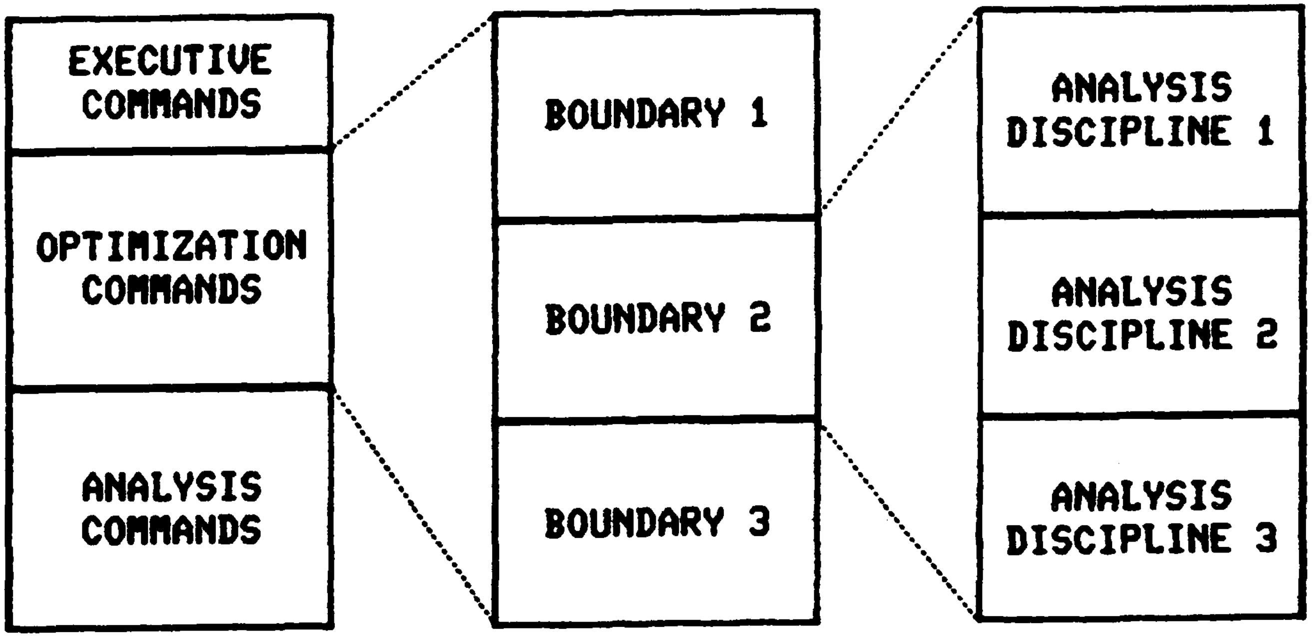
```
$***********************************************************

     ELIMINATE RIGID-BODY SUPPORTS

***********************************************************$
     IF SUPPORT<>0 THEN
        CALL PARTN( [KAA],[KLR],, [KLL],[PALR] );
        IF MASS<>0 CALL PARTN( [MAA],[MLR],,[MLL],[PALR] );
        IF LOAD<>0 CALL ROWPART( [SLA],[SLL],[SLR],[PALR] );
     ELSE
        [KLL] := [KAA];
        IF MASS<>0 [MLL] := [MAA];
        IF LOAD<>0 [SLL] := [SLA];
     ENDIF;
```

ASTROS SOFTWARE DESIGN

STRUCTURE OF SOLUTION CONTROL



EXECUTIVE COMMANDS

OPTIMIZATION COMMANDS

ANALYSIS COMMANDS

BOUNDARY 1

BOUNDARY 2

BOUNDARY 3

ANALYSIS DISCIPLINE 1

ANALYSIS DISCIPLINE 2

ANALYSIS DISCIPLINE 3

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ASTROS SOFTWARE DESIGN

SAMPLE SOLUTION CONTROL SEGMENT

```
TITLE = OPTIMIZATION AND ANALYSIS OF STRUCTURE
ASSIGN DATABASE NAME=MYDATA,PASS=DLH,NEW,M.D. DATA
ASSIGN FORM(1) M.D. DATA FOR FILE 1
ASSIGN BINA(2) M.D. DATA FOR FILE 2
OPTIMIZE STRATEGY=999
SUBT = OPTIMIZATION PHASE
  BOUNDARY SPC=10
    STATICS
      LOAD  MECH=10,THERMAL=20
        LABEL = FIRST B.C. STATIC LOAD = 10
        PRINT  DISP=10,STRESS=20
      LOAD  MECH=10,GRAV=99
        LABEL = FIRST B.C. STATIC LOAD = 20
        PRINT DISP=20
        WRITE FORM(1)  DISP=50,STRESS=90
  BOUNDARY MPC=51,SPC=52,REDUCE=53,SUPPORT=54
    STATICS
      LOAD  MECH=40,ENFORCED=77
        LABEL = SECOND B.C. STATIC LOAD = 10
      LOAD  MECH=40
        LABEL = SECOND B.C. STATIC LOAD = 40
END
```

THE ASTROS

COMPUTER AUTOMATED DESIGN DATA BASE

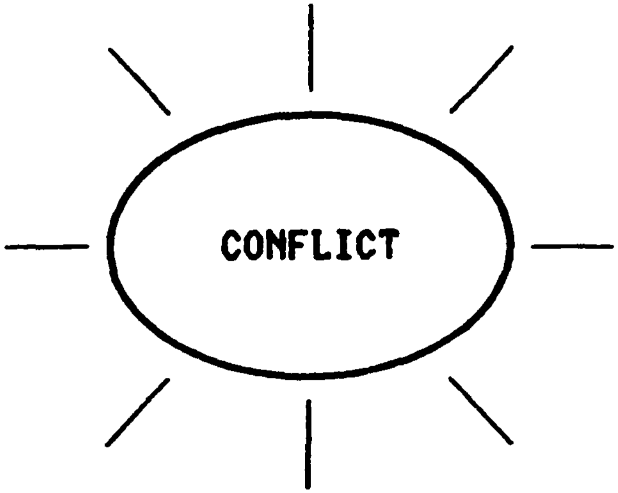
CADDB

ASTROS SOFTWARE DESIGN

DATA HANDLING REQUIREMENTS

- FAST ACCESS TO AND MODIFICATION OF SPECIFIC DATA ITEMS WITHIN LARGE TABLES OF RELATED INFORMATION WITH A WELL-DEFINED STRUCTURE.
- EFFICIENT STORAGE AND MANIPULATION OF LARGE (NOT NECESSARILY) SPARSE MATRICES USED IN MATHEMATICAL COMPUTATIONS.
- LARGE HETEROGENEOUS COLLECTIONS OF VARIABLE LENGTH LOOSELY STRUCTURED DATA.

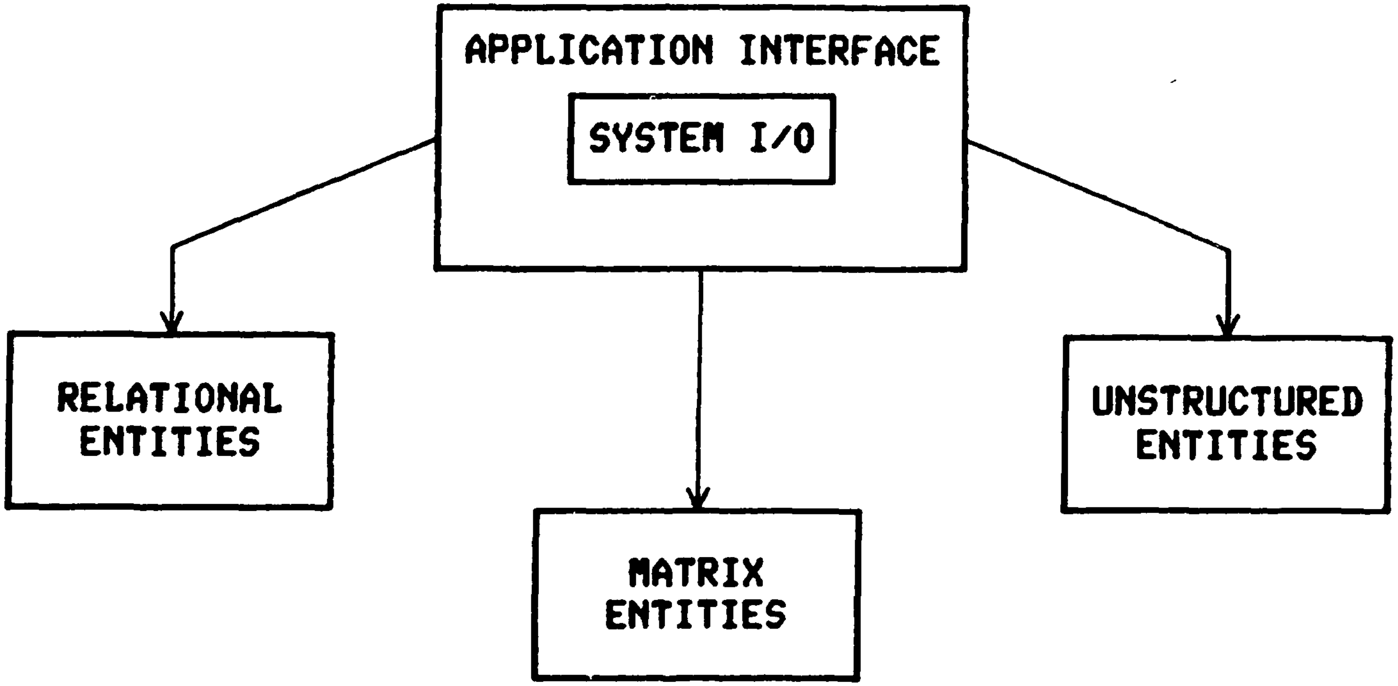
ASTROS SOFTWARE DESIGN



THERE IS NO AVAILABLE DATA BASE THAT SATISFIES THESE REQUIREMENTS WITH A MODICUM OF EFFICIENCY!

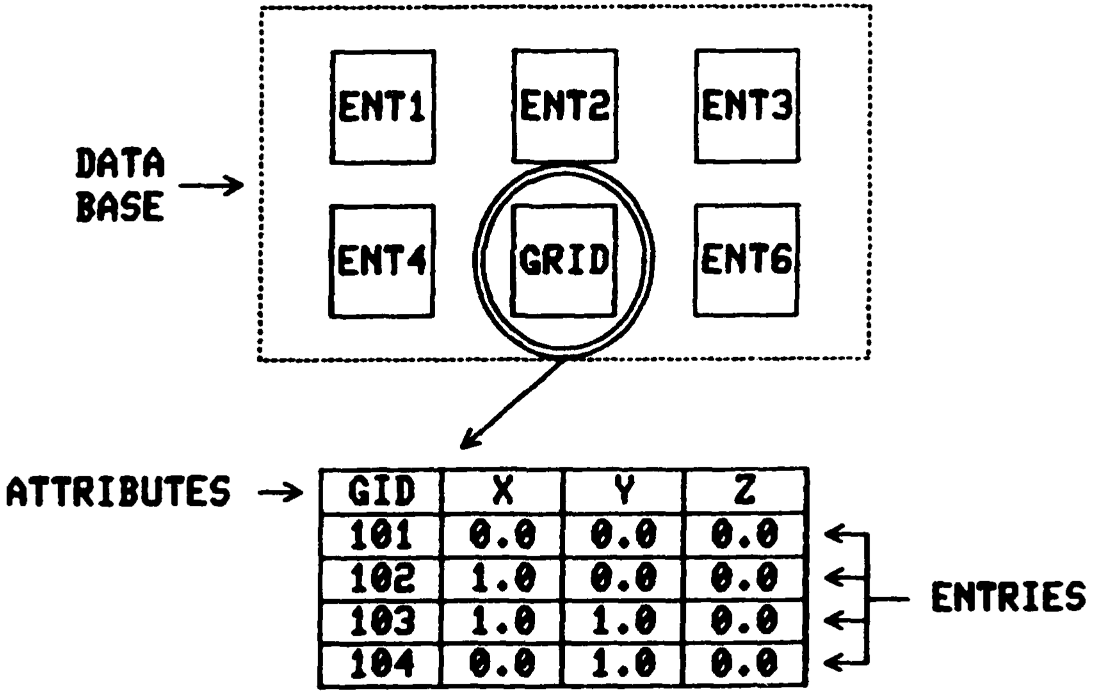
ASTROS SOFTWARE DESIGN

THE CADDB DATA STRUCTURES



ASTROS SOFTWARE DESIGN

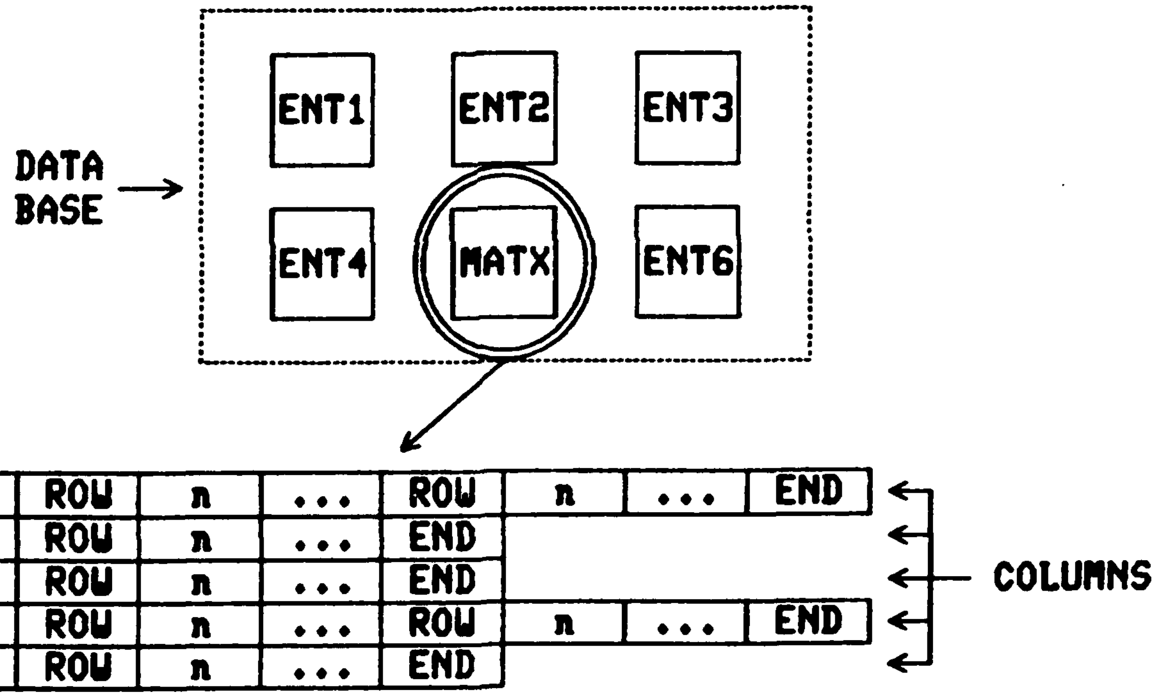
CADDB - RELATIONAL ENTITIES



GID	X	Y	Z
101	0.0	0.0	0.0
102	1.0	0.0	0.0
103	1.0	1.0	0.0
104	0.0	1.0	0.0

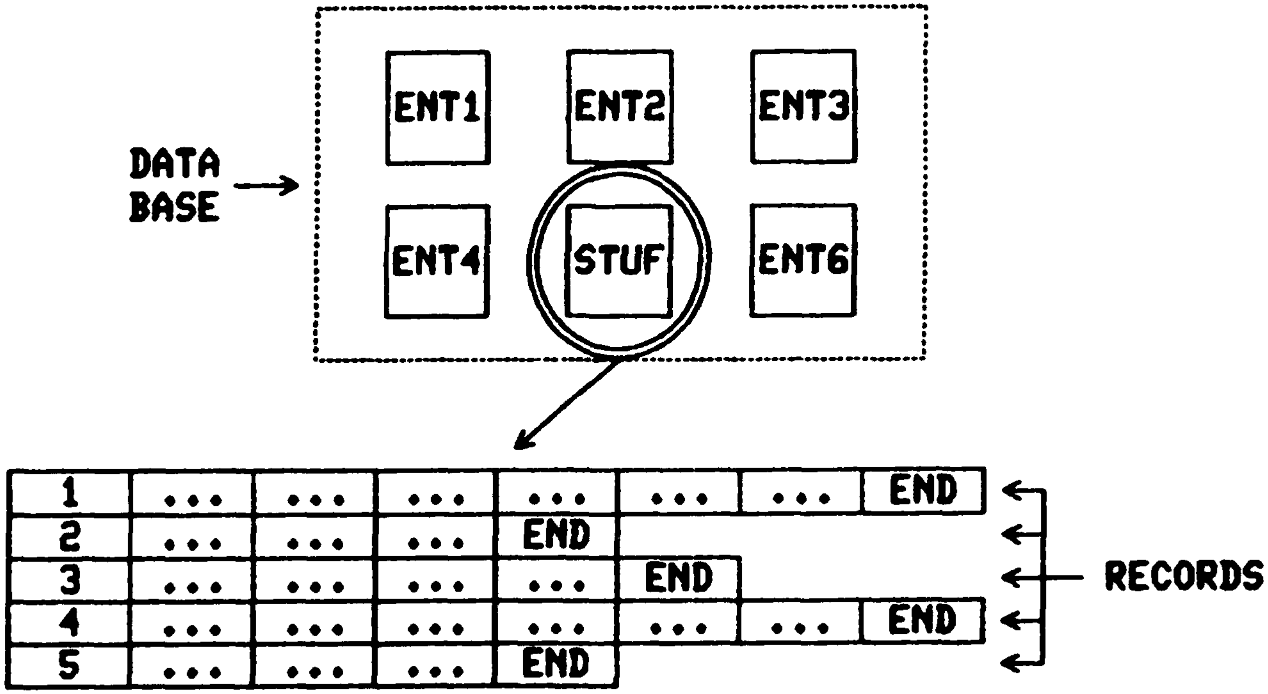
ASTROS SOFTWARE DESIGN

CADDB - MATRIX ENTITIES



ASTROS SOFTWARE DESIGN

CADDB - UNSTRUCTURED ENTITIES



ASTROS SOFTWARE DESIGN

WHY DYNAMIC MEMORY MANAGEMENT?

- OPEN-ENDED PROBLEM SOLVING CAPABILITY
- REUSABILITY OF MEMORY
- FLEXIBLE DATA BASE OPERATION
- BETTER SOFTWARE ENGINEERING

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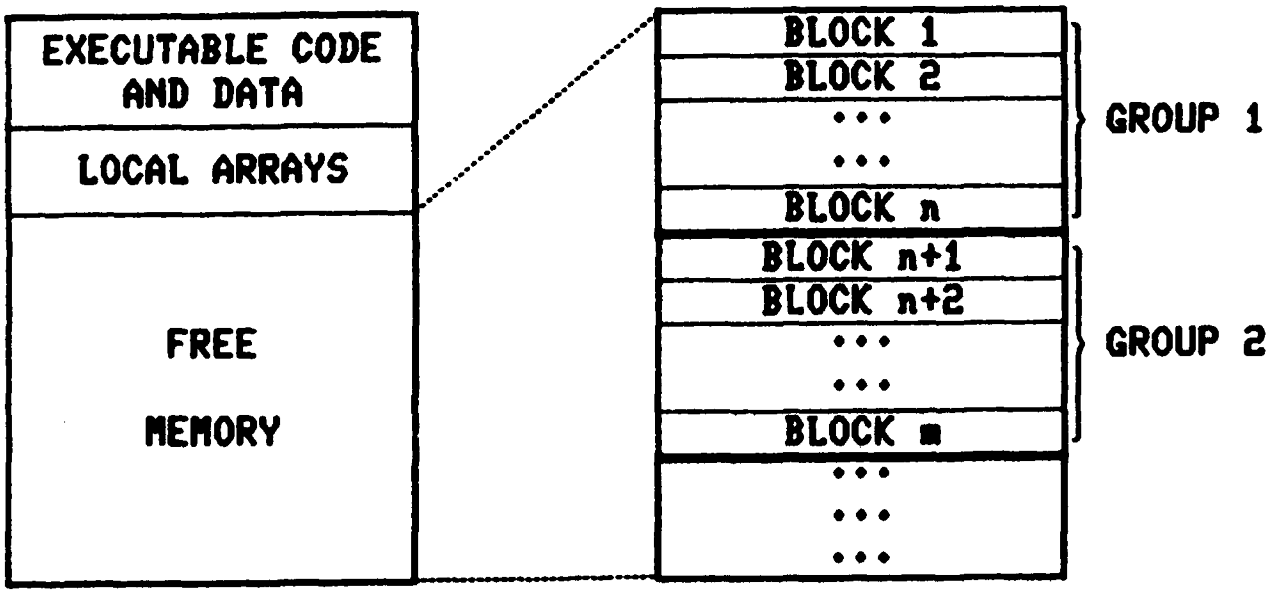
ASTROS SOFTWARE DESIGN

DYNAMIC MEMORY MANAGEMENT



ALLOCATED REGION SIZE

ASTROS SOFTWARE DESIGN

THE DYNAMIC MEMORY MANAGER - SUBROUTINES

SUBROUTINE	FUNCTION
MMINIT	INITIALIZES THE DYNAMIC MEMORY MANAGER. USED ONLY BY THE EXECUTIVE SYSTEM.
MMBASE MMBASC	USED BY EACH MODULE TO DEFINE THE LOCATION OF THE MEMORY BASE ADDRESS.
MMGETB	GETS A BLOCK OF MEMORY OF THE SPECIFIED TYPE AND LENGTH.
MMSTAT	RETURNS THE MAXIMUM CONTIGUOUS MEMORY THAT IS AVAILABLE TO THE MODULE.
MMFREE MMFREG	FREES ALLOCATED MEMORY BY INDIVIDUAL BLOCKS OR BY GROUPS OF BLOCKS.
MMSQUZ	COMPRESSES MEMORY I/O AREAS

ASTROS SOFTWARE DESIGN

CADDB - GENERAL DATA BASE UTILITIES

SUBROUTINE	FUNCTION
DBCREA	CREATES A DATA BASE ENTITY.
DBOPEN	OPENS A DATA BASE ENTITY PRIOR TO I/O.
DBRENA	RENAMES A DATA BASE ENTITY.
DBSWCH	INTERCHANGES THE NAMES OF TWO ENTITIES.
DBDEST	DESTROYS, OR REMOVES, AN ENTITY AND ALL OF ITS DATA FROM THE DATA BASE.
DBFLSH	REMOVES THE DATA CONTENTS OF AN ENTITY.
DBCLOS	TERMINATES I/O FOR AN ENTITY.

ASTROS SOFTWARE DESIGN

CADDB - RELATIONAL UTILITIES

SUBROUTINE	FUNCTION
RESCHM	DEFINES THE SCHEMA OF A RELATION.
REPROJ	DEFINES THE PROJECTION OF THE RELATION PRIOR TO I/O ACTIVITY.
REQURY	QUERIES THE SCHEMA OF A RELATION.
REGET REGETM	GETS, OR FETCHES, A QUALIFIED ENTRY FROM A RELATION.
REUPD REUPDM	UPDATES THE CURRENT ENTRY OF A RELATION.
READD READDM	ADDS A NEW ENTRY TO A RELATION.

CADDB - RELATIONAL UTILITIES (CONT'D)

SUBROUTINE	FUNCTION
REPOS	POSITIONS THE RELATION TO AN ENTRY.
RECOND RESETC	DEFINES CONSTRAINTS OR "WHERE" CONDITIONS FOR THE RELATION.
REGB REGBM	GETS, OR FETCHES, ALL OF THE QUALIFIED ENTRIES FROM A RELATION.
REAB REABM	ADDS A GROUP OF ENTRIES TO A RELATION.
RESORT	SORTS THE ENTRIES OF A RELATION.

ASTROS SOFTWARE DESIGN

CADDB - MATRIX UTILITIES

SUBROUTINE	FUNCTION
MXINIT	INITIALIZES A MATRIX ENTITY FOR I/O.
MXPOS MXRPOS MXNPOS	POSITIONS TO A SPECIFIED MATRIX COLUMN.
MXSTAT	GETS MATRIX COLUMN INFORMATION.
MXPAK	PACKS A COLUMN OF A MATRIX.
MXUNP	UNPACKS A COLUMN OF A MATRIX.
MXPKTI MXPKT MXPKTM MXPKTF	PACKS A COLUMN OF A MATRIX EITHER TERM-BY-TERM OR BY PARTIAL COLUMN.
MXUPTI MXUPT MXUPTM MXUPTF	UNPACKS A COLUMN OF A MATRIX EITHER TERM-BY-TERM OR BY PARTIAL COLUMN.

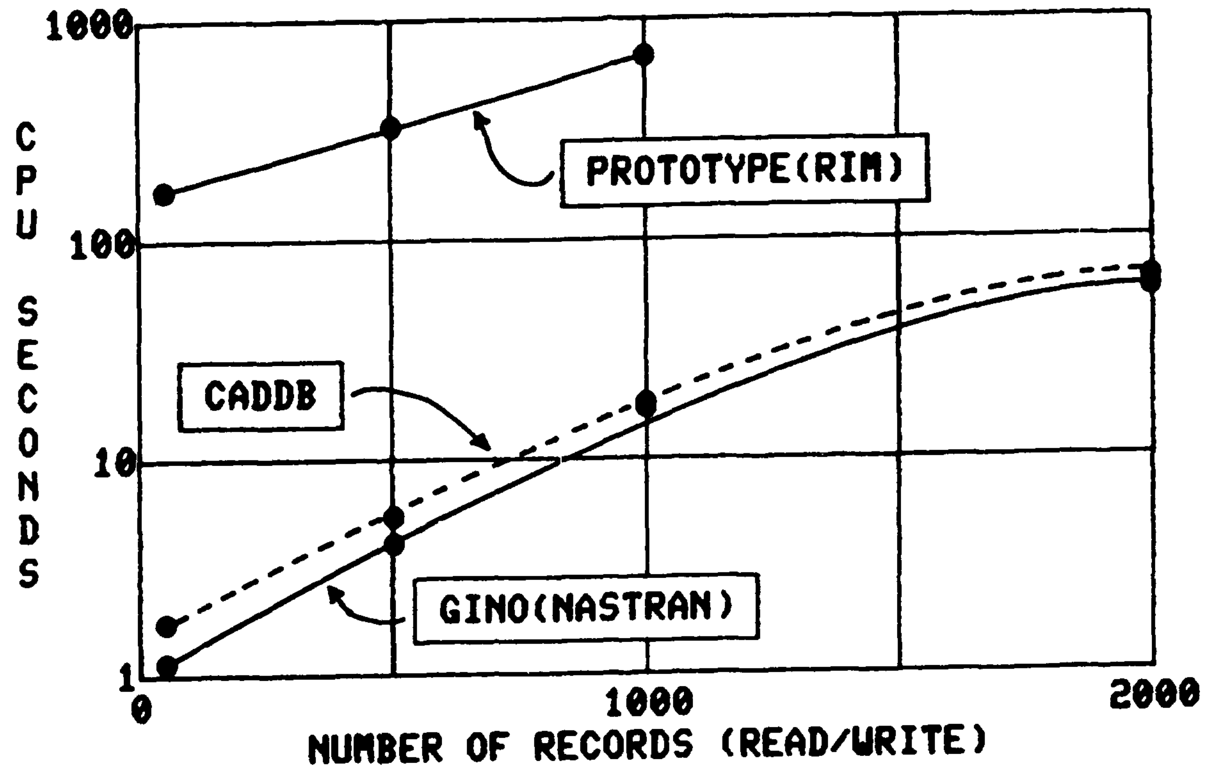
ASTROS SOFTWARE DESIGN

CADDB - UNSTRUCTURED ENTITIES

SUBROUTINE	FUNCTION
UNPOS UNRPOS	POSITIONS TO A GIVEN UNSTRUCTURED RECORD.
UNSTAT	RETURNS THE LENGTH OF A RECORD.
UNGET	GETS, OR FETCHES, AND ENTIRE RECORD.
UNGETP	GETS, OR FETCHES, A PARTIAL RECORD.
UNPUT	ADDS A NEW RECORD TO THE UNSTRUCTURED ENTITY.
UNPUTP	ADDS A PARTIAL RECORD TO THE ENTITY.

ASTROS SOFTWARE DESIGN

CADDB PERFORMANCE - UNSTRUCTURED ENTITIES



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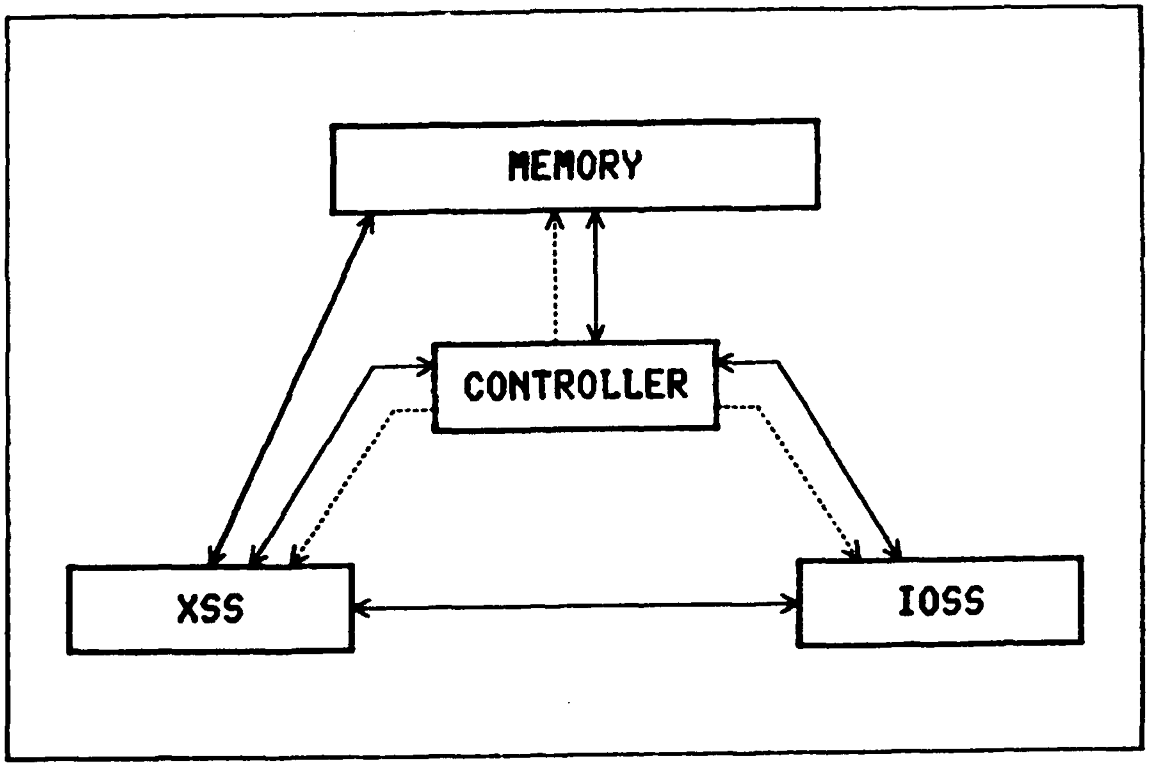
THE ARCHITECTURE

OF THE

ASTROS EXECUTIVE SYSTEM

ASTROS SOFTWARE DESIGN

THE ASTROS "MACHINE"



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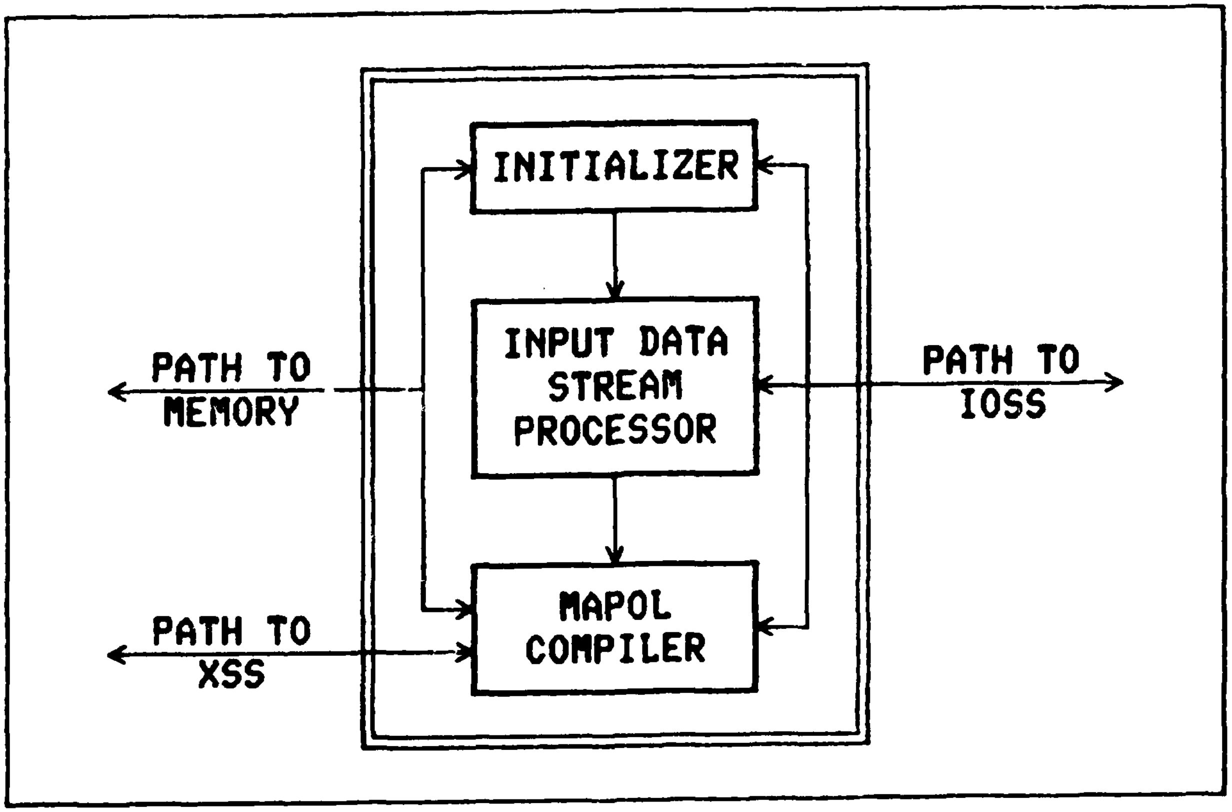
ASTROS SOFTWARE DESIGN

THE CONTROLLER



ASTROS SOFTWARE DESIGN

THE MAPOL LANGUAGE

- HIGH-ORDER, PROBLEM ORIENTED
- FLEXIBLE SYSTEM CONTROL MECHANISM
- ALGORITHM/CONCEPT DEVELOPMENT
- USER CODE INTERFACE

THE MAPOL LANGUAGE - SIMPLE DATA TYPES

```
INTEGER A,B,C;
REAL D,E,F;
COMPLEX I;
LOGICAL K,L,M;
LABEL LAB1,LAB2;
```

ALL EXCEPT LABEL MAY BE ARRAYS:

```
INTEGER A(10),B(5);
COMPLEX D(11);
LOGICAL I(5,5);
```

THE IMPLEMENTATION LIMIT IS TWO SUBSCRIPTS

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - COMPLEX DATA TYPES

```
MATRIX [A],[B],[C];

MATRIX [X(10)],[Y(3)];

RELATION R USING I,J,K;
```

RELATIONAL ATTRIBUTES MUST BE DECLARED

MATRICES MAY HAVE A SINGLE SUBSCRIPT

ASTROS SOFTWARE DESIGN

SAMPLE MAPOL GRAMMAR - OPERATOR PRECEDENCE RELATIONS

```
<SASSIGN>   ::=  <SVAR>   :=  <SEXPR>
<SEXPR>     ::=  <SEXPR>  +   <STERM>
<SEXPR>     ::=  <SEXPR>  -   <STERM>
<SEXPR>     ::=  +  <STERM>
<SEXPR>     ::=  -  <STERM>
<SEXPR>     ::=  <STERM>
<STERM>     ::=  <STERM>  *   <SFACTOR>
<STERM>     ::=  <STERM>  /   <SFACTOR>
<STERM>     ::=  <SFACTOR>
<SFACTOR>   ::=  <SPRIM>  **   <SFACTOR>
<SFACTOR>   ::=  <SPRIM>
<SPRIM>     ::=  <SVAR>
<SPRIM>     ::=  CONST
<SPRIM>     ::=  (  <SEXPR>   )
```

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - LOOPING CONSTRUCTS

```
WHILE X<3 DO
...
...
...
ENDDO;
```

```
FOR I=1 TO 17 DO
...
...
...
ENDDO;
```

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - OPERATIONS

ARITHMETIC	LOGICAL	RELATIONAL	MATRIX
**	.AND.	=	*
*	.OR.	>	+
/	.XOR.	<	-
+	.NOT.	>=	()[]
-		<=	
		<>	

OPERATORS ARE POLYMORPHIC

ARITHMETIC DONE IN "HIGHEST" TYPE

ASSIGNMENT DETERMINES FINAL TYPE

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - INLINE PROCEDURES

```
PROC USQRT(A,SQRTA);
REAL A,SQRTA,EPS,DELTA,AOLD;
     EPS := 0.001;
     SQRTA := 1.0;
     DELTA := 1.0;
     WHILE ABS(DELTA)>EPS DO
         AOLD := SQRTA;
         SQRTA := AOLD - ((AOLD*AOLD-A)/(2.0*AOLD));
         DELTA := SQRTA - AOLD;
     ENDDO;
ENDP;
```

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - MATRIX OPERATIONS

SAMPLE PROBLEM

FOR USER-INPUT MATRICES A,B AND C AND REAL PARAMETERS ALPHA AND BETA, WE WISH TO COMPUTE THE MATRIX X DEFINED BY:

$[X] = [A][B] + [C]$ IF ALPHA < 0

$[X] = [\ \mathrm{BETA}[A] + [B]\ ]^T$ IF ALPHA $= 0$

$[X] = [A][C]^{-1}[B]$ IF ALPHA > 0

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - MATRIX OPERATIONS

```
MATRIX [X],[A],[B],[C];
REAL ALPHA,BETA;
    IF ALPHA<0 THEN
        [X] := [A] * [B] + [C];
    ELSE
        IF ALPHA=0 THEN
            [X] := TRANS( BETA[A] + [B] );
        ELSE
            [X] := [A] * INV([C]) * [B];
        ENDIF;
    ENDIF;
END;
```

ASTROS SOFTWARE DESIGN

THE MAPOL COMPILER - PEEPHOLE OPTIMIZATION

THE MAPOL CODE: `A:=B*C+D;`

YIELDS THE EXECUTABLE:

```
PUSHM A
PUSHM B
PUSHM C
MAT*
PUSHM D
MAT+
SWITCH
```

BUT, IF A,B,C, AND D
ARE MATRICES...

```
PUSHM A
PUSHM B
PUSHM C
PUSHM D
PUSHI 4
CALL 'MPYAD'
SWITCH
```

ASTROS SOFTWARE DESIGN

DATA BASE OPERATIONS

DATA BASE	DBOPEN	DBCLOS		
RELATIONS	DBMAKE	DBUSE	DBEND	
ENTRIES	DBGET	DBPUT	DBADD	DBDEL
QUALIFICATION	DBCOND			

THESE MAPOL UTILITIES ARE NOT 1-1 WITH APPLICATION ROUTINES

MAPOL LANGUAGE - DATABASE OPERATIONS

SAMPLE PROBLEM

THERE IS A RELATION CALLED 'GRID' THAT EXISTS ON THE ASTROS DATA BASE. THE ATTRIBUTES OF 'GRID' ARE:

GID - ID OF THE GRID POINT (INTEGER)
X - THE X COORDINATE OF THE GRID (REAL)
Y - THE Y COORDINATE OF THE GRID (REAL)
Z - THE Z COORDINATE OF THE GRID (REAL)

WE WISH TO COMPUTE THE DISTANCE FROM THE FIRST GRID POINT TO EACH OF THE OTHERS.

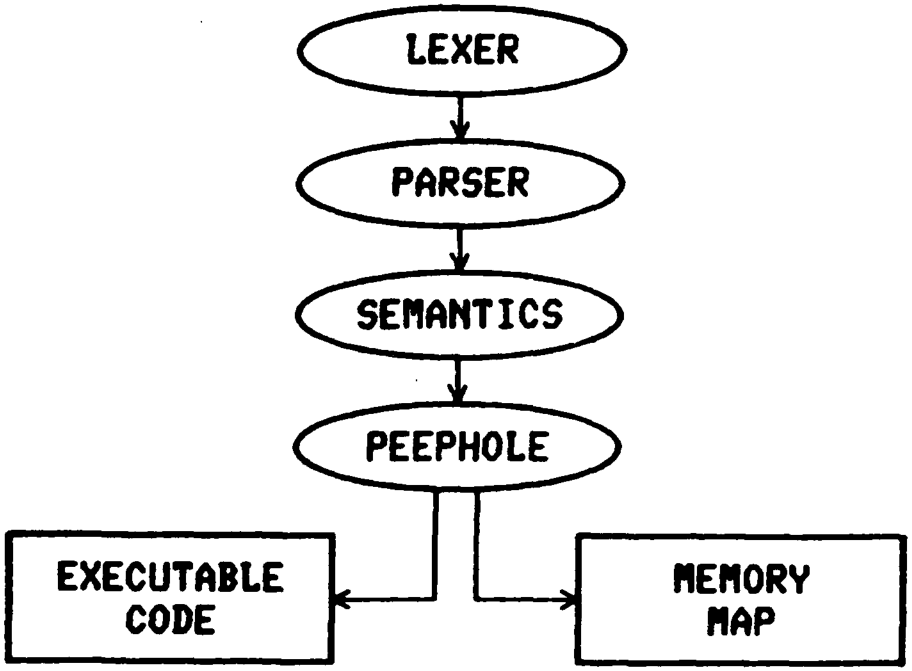
ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - DATABASE OPERATIONS

```
REAL DEL(100),X1,X2,X3;
INTEGER I,L;
RELATION GRID USING GID,X,Y,Z;
     CALL DBUSE( GRID , L );
     CALL DBGET( GRID );
     X1 := GRID.X;
     X2 := GRID.Y;
     X3 := GRID.Z;
     FOR I = 2 TO L DO
          CALL DBGET( GRID );
          DEL(I) := SQRT( (X1-GRID.X)**2 + (X2-GRID.Y)**2 +
                    (X3-GRID.Z)**2 );
     ENDDO;
     CALL DBEND( GRID );
END;
```

ASTROS SOFTWARE DESIGN

THE MAPOL COMPILER



LEXER

PARSER

SEMANTICS

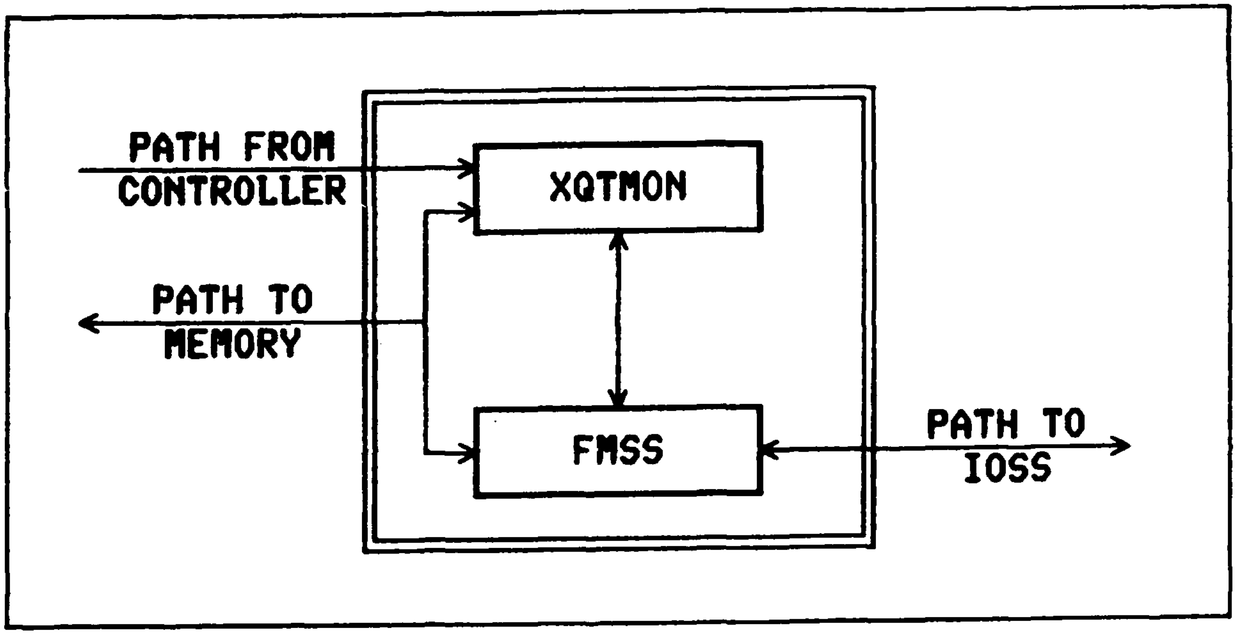
PEEPHOLE

EXECUTABLE CODE

MEMORY MAP

ASTROS SOFTWARE DESIGN

THE EXECUTION SUBSYSTEM (XSS)



PATH FROM CONTROLLER

XQTMON

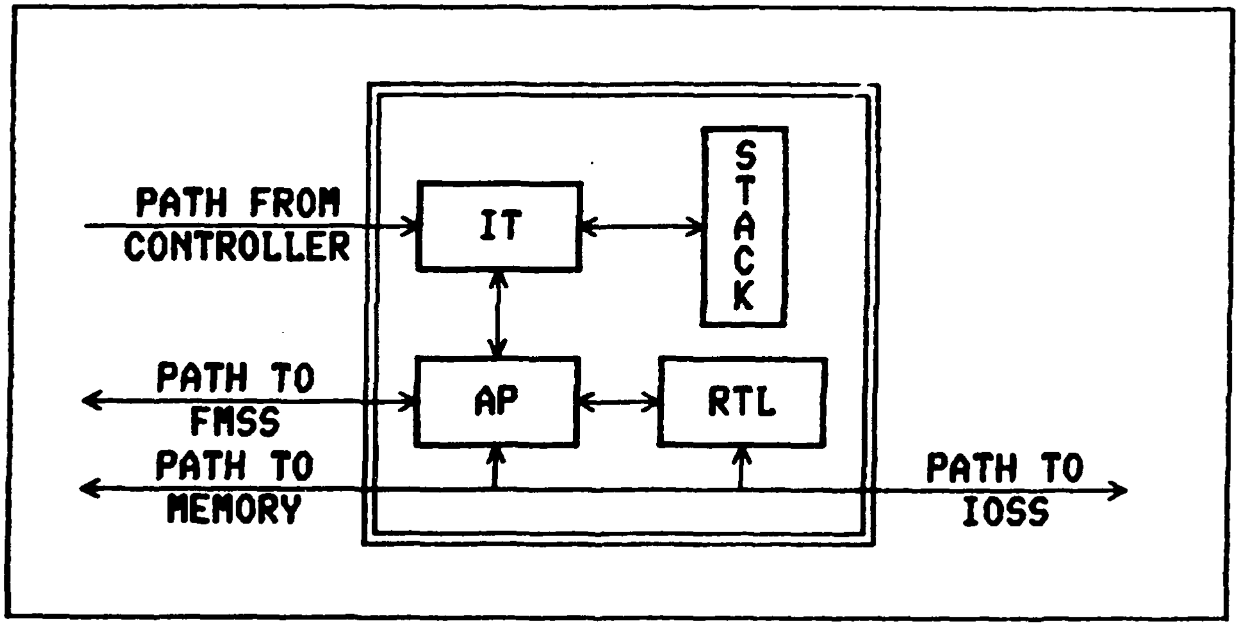
PATH TO MEMORY

FMSS

PATH TO IOSS

ASTROS SOFTWARE DESIGN

THE EXECUTION MONITOR (XQTMON)



ASTROS SOFTWARE DESIGN

THE RUN-TIME ENVIRONMENT

- STACK MODEL OF EXECUTION
- ONE-ADDRESS CODE
- HIGH-ORDER "MEMORY"

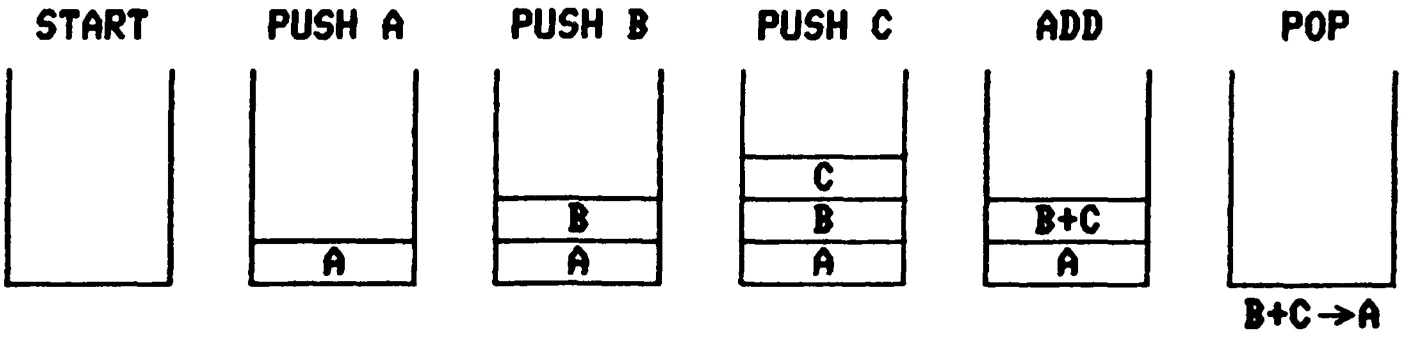
ASTROS SOFTWARE DESIGN

THE STACK MODEL OF EXECUTION

SOURCE STATEMENT: A := B + C;

EXECUTABLE CODE:
```
PUSH A
PUSH B
PUSH C
ADD
POP
```

THE INSTRUCTION STACK



ASTROS SOFTWARE DESIGN

THE INSTRUCTION TRANSLATOR

- FETCHS EXECUTABLE INSTRUCTIONS
- TRANSLATES INSTRUCTIONS
- LOADS OPERANDS INTO STACK
- BRANCHES TO AP, RTL, OR FMSS

ASTROS SOFTWARE DESIGN

THE ASTROS "MACHINE" INSTRUCTION SET

STACK
- PUSH
- PUSHI
- PUSHR
- POP

LINKAGE
- GOSUBX
- GOSUBU
- GOMOD

BRANCHING
- JMP
- JLT
- JGT
- JLE
- JGE
- JNE

OTHER
- REF
- NOP
- HALT
- ATTR

OPERATORS
- NEG
- ADD
- SUB
- MUL
- DIV
- EXP

PROCS
- LPARM
- RETURN

LOOPING
- INCRE
- LOOPE

ASTROS SOFTWARE DESIGN

THE ARITHMETIC PROCESSOR (AP)

- STANDARD MATHEMATICAL OPERATIONS
  - ADDITION
  - SUBTRACTION
  - MULTIPLICATION
  - DIVISION
  - EXPONENTIATION
- LOGICAL OPERATIONS
  - CONJUNCTION
  - DISJUNCTION
  - NEGATION
  - EQUIVALENCE

ASTROS SOFTWARE DESIGN

THE RUN-TIME LIBRARY (RTL)

- MATHEMATICAL FUNCTIONS
- MATRIX OPERATIONS
- DATA BASE OPERATIONS

ASTROS SOFTWARE DESIGN

THE RUN-TIME LIBRARY

TRIG
- SIN
- COS
- TAN
- ASIN
- ACOS
- ATAN
- SINH
- COSH
- TANH

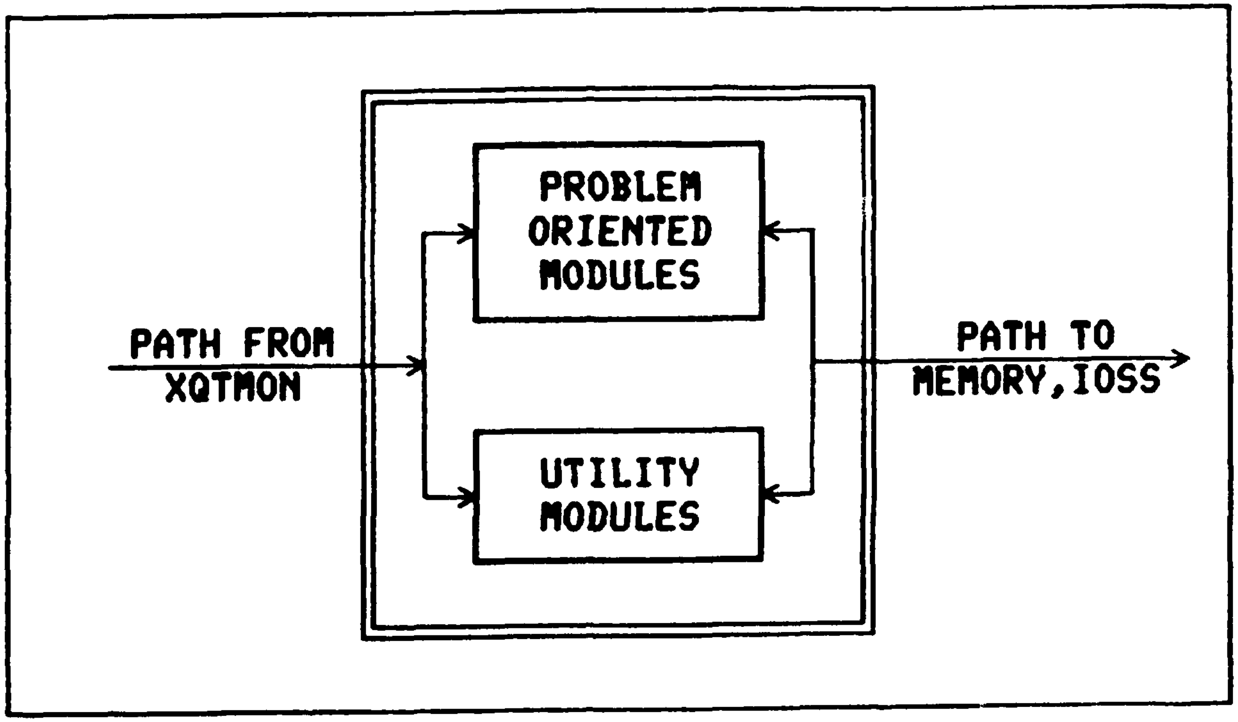
MATRIX
- INV
- TRANS
- DET
- DIAG
- IDENT
- LEN

LOGICAL
- AND
- OR
- XOR
- NOT

MATH
- EXP
- LN
- LOG
- SQRT
- ABS
- RE
- IM
- CONJ
- MAX
- MIN

ASTROS SOFTWARE DESIGN

THE FUNCTIONAL MODULE SUBSYSTEM (FMSS)



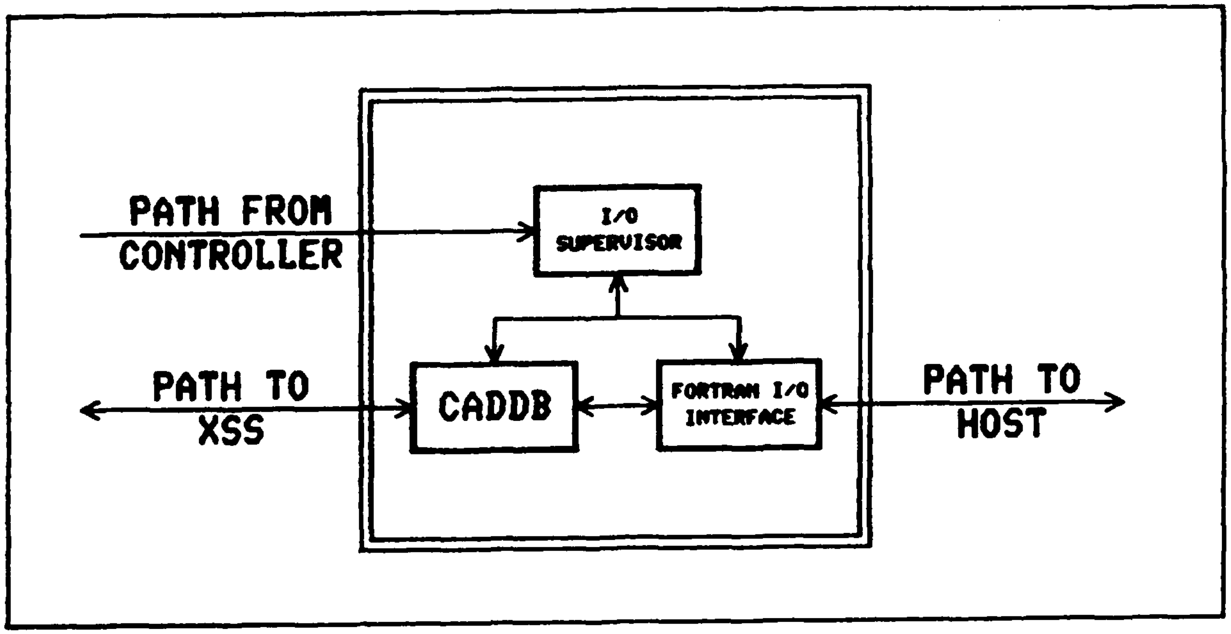
ASTROS SOFTWARE DESIGN

MATRIX UTILITY MODULES

PROCEDURE	BASIC OPERATION
ADD	$[A] = a[A] + b[B]$
DECOMP	$[A] \rightarrow [L][U]$
FBS	$[X] = ([L][U])^{-1}[B]$
MERGE	$[A] \rightarrow \left[\begin{array}{c:c} A11 & A12 \\ \hdashline A21 & A22 \end{array}\right]$
MPYAD	$[X] = [A][B] + [C]$
PARTN	$[A] \rightarrow \left[\begin{array}{c:c} A11 & A12 \\ \hdashline A21 & A22 \end{array}\right]$
SOLVE	$[X] = [A]^{-1}[B]$
TRANS	$[X] = [A]^{T}$

ASTROS SOFTWARE DESIGN

THE INPUT/OUTPUT SUBSYSTEM (IOSS)



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MEETING THE DESIGN GOALS - CONCLUSION

- CORRECTNESS AND RELIABILITY
- COST-EFFECTIVE MAINTENANCE/ENHANCEMENT
- EFFICIENT COMPUTER RESOURCE UTILIZATION
- SIMPLIFIED USER INTERFACE
- PORTABILITY TO NEW COMPUTERS
- PROTOTYPES HAVE PROVEN CONCEPT

ASTROS User Training Workshop

20-24 June 1988

ICE - The Interactive CADDB Environment

David L. Herendeen

Universal Analytics, Inc.

ICE: What and Why

- ICE is an Interactive Interface for ASTROS
- ICE is an SQL-Compatible Database Management System
- ICE has been Extended for Scientific Data Requirements
- ICE can Assist in Reviewing ASTROS Results because:
    - They May Be Voluminous
    - They are Often Complex
    - They May Be Needed for Other Analyses

Classification of ICE Commands

- CQL Command Editing
- Data Retrieval - Relations
- Creating Views of Entities
- Selective Modification of Data
- Environment Commands
- Security Commands
- Entity Creation
- Data Retrieval - Matrices
- Inserting Data into Entities
- Removing Entities and Data
- Report Generation Commands
- Utility Commands

CQL Command Editing

- **LIST** [line_1 [**TO** line_n]];
- **DELETE** [line_1 [**TO** line_n]];
- **ENTER** "new_line";
- **CHANGE** "string_1" "string_2";
- **RUN;**

Creating Database Entities

- **DESCRIBE** [entity_name];
- **CREATE RELATION** relation_name
  { (<schema_list>) |
  LIKE old_rel_name };
- **CREATE MATRIX** matrix_name
  { (<matrix_attributes>) |
  LIKE old_mat_name };

The DESCRIBE Command

```
ICE> DESCRIBE;
.... ENTITY NAME  TYPE  SIZE
.... -----------  ----  ----
.... GRID         REL     10
.... QUAD4        REL      4
.... PSHELL       REL      3
.... Q4STR001     REL      4
.... Q4STR002     REL      4
.... KGG          MAT      5
.... UNKNOWN      UN       1
```

The DESCRIBE Command

```
ICE> DESCRIBE PSHELL;
.... RELATION  PSHELL SCHEMA IS:
.... ATTRIBUTE  TYPE    LEN
.... ---------  ----   -----
.... PID        INT       1
.... MID        INT       1
.... T          RSP       1
.... CURRENT CONTENTS  3 ENTRIES
```

```
ICE> DESCRIBE KGG;
.... REAL, DOUBLE PRECISION, SYMMETRIC MATRIX KGG
....   5 ROWS,    5 COLUMNS,    DENSITY = 52.0%
```

```
ICE> DESCRIBE UNKNOWN;
.... UNSTRUCTURED ENTITY UNKNOWN
....    8 RECORDS, LONGEST RECORD IS 2044
```

The CREATE RELATION Command

```
ICE> CREATE RELATION GRIDX
  2>    ( GID INT KEY,
  3>      CID INT,
  4>      X   RSP,
  5>      Y   RSP,
  6>      Z   RSP );
```

attribute_type	*DESCRIPTION*	*attribute_length*	CAN BE KEY?
INT	Integer value	Not Used	YES
AINT	Array of Integer Values	Number of Elements in Array	NO
RSP	Real Single Precision Values	Not Used	NO
ARSP	Array of Real Single Precision Values	Number of Element in Array	NO
RDP	Real Double Precision Values	Not Used	NO
ARDP	Array of Real Double Precision Values	Number of Elelement in Array	NO
STR	Character String	Number of Characters in String	YES

The CREATE MATRIX Command

```
ICE> CREATE MATRIX NEWKGG
  2>   ( TYPE RDP,
  3>     FORM SYMMETRIC,
  4>     ROWS 5 );
```

ATTRIBUTE	KEYWORD	DESCRIPTION
data type	**RSP**	Real Single Precision Terms
	RDP	Real Double Precision Terms
	CSP	Complex Single Precision Values
	CDP	Complex Double Precision Values
shape	**RECTANGULAR**	Rectangular; n x m
	SYMMETRIC	Symmetric, $A_{ij} = A_{ji}$
	DIAGONAL	Diagonal, $A_{ij} \equiv 0 \ \forall i \neq j$
	IDENTITY	Identity; $A_{ii} \equiv 1.0, A_{ij} \equiv 0 \ \forall i \neq j$

Retrieving Data from Relations

- **SELECT** <select_list> <FROM_part>
  [<WHERE_part>][<GROUP_part>]
  [<SORT_part>];
- <WHERE_part> → **WHERE** <search_condition>
- <GROUP_part> → **GROUP BY** <attribute_list>
- <SORT_part> → **SORT BY** <sort_list>

SELECTing Data from Relations

```
ICE> SELECT EID,PID,G1,G2,G3,G4 FROM QUAD4;

  EID    PID     G1     G2     G3     G4
-----  -----  -----  -----  -----  -----
    1      1      1      2      7      6
    2      2      2      3      8      7
    3      1      3      4      9      8
    4      2      4      5     10      9
```

```
ICE> SELECT G4,G1 FROM QUAD4;

   G4     G1
-----  -----
    6      1
    7      2
    8      3
    9      4
```

SELECTing Data from Relations

```
ICE> SELECT DISTINCT PID FROM QUAD4;

  PID
-----
    1
    2
```

```
ICE> SELECT EID,PID,GRIDS FROM QUAD4;

  EID    PID                  GRIDS(4)
-----  -----  --------------------------
    1      1      1      2      7      6
    2      2      2      3      8      7
    3      1      3      4      9      8
    4      2      4      5     10      9
```

Qualifying the SELECTion

```
ICE> SELECT * FROM GRID WHERE X > 3.0;

  GID    CID            X            Y            Z
-----  -----  -----------  -----------  -----------
    5      0  4.00000E+00  1.00000E+00  0.00000E+00
   10      0  4.00000E+00  0.00000E+00  0.00000E+00
```

```
ICE> SELECT GID FROM GRID WHERE X > 2.0 AND Y = 0.0;

  GID
-----
    9
   10
```

Qualifying the SELECTion

```
ICE> SELECT GID,X FROM GRID
  2>     WHERE ( X > 2.0 AND Y = 0.0 )
  3>     OR      GID = 1;

  GID             X
-----  ------------
    1   0.00000E+00
    9   3.00000E+00
   10   4.00000E+00
```

SELECTing from a Set

```
ICE> SELECT GID,X,Y,Z FROM GRID WHERE X IN (3.0,4.0);

  GID            X             Y             Z
-----  ------------  ------------  ------------
    4   3.00000E+00   1.00000E+00   0.00000E+00
    5   4.00000E+00   1.00000E+00   0.00000E+00
    9   3.00000E+00   0.00000E+00   0.00000E+00
   10   4.00000E+00   0.00000E+00   0.00000E+00
```

Using Arithmetic Expressions

```
ICE> SELECT GID,SQRT(X**2+Y**2+Z**2) FROM GRID
  2>      WHERE Y = 1.0;

  GID  SQRT(X**2+Y**2+Z**2)
-----  --------------------
    1           1.00000E+00
    2           1.41421E+00
    3           2.23607E+00
    4           3.16228E+00
    5           4.12311E+00
```

```
ICE> SELECT EID,SIGY FROM Q4STR001 WHERE
  2>      SIGY >= 2.0*SIGX;

  EID         SIGY
-----  -----------
    1  2.00000E+06
    2  1.00000E+07
```

Using Arithmetic Expressions

FUNCTION	PURPOSE	ATTRIBUTE RESTRICTIONS
ABS(x)	Absolute value	RSP, RDP or INT x
ACOS(x)	Inverse trigonometric cosine	RSP or RDP x
ASIN(x)	Inverse trigonometric sine	RSP or RDP x
ATAN(x)	Inverse trigonometric tangent	RSP or RDP x
COS(X)	Trigonometric sine	RSP, RDP or int x
COSH(x)	Hyperbolic cosine	RSP, RDP or INT x
DBLE(x)	Convert to RDP	RSP or INT x
EXP(x)	Exponential function e^x	RSP or RDP x
FLOAT(i)	Convert to RSP	INT i
INT(x)	Convert to INT	RSP or RDP x
LN(x)	Natural (base e) logarithm	RSP, RDP or INT x
LOG(x)	Common (base 10) logarithm	RSP, RDP or INT x
SIN(x)	Trigonomtric sine	RSP, RDP or INT x
SINH(x)	Hyperbolic sine	RSP, RDP or INT x
SQRT(x)	Square root	RSP, RDP, or INT x
TAN(x)	Trigonometric tangent	RSP, RDP, or INT x
TANH(x)	Hyperbolic tangent	RSP, RDP or INT x

Grouping the Results

```
ICE> SELECT PID FROM QUAD4
  2>     GROUP BY PID;

  PID
-----
    1
    2
```

```
ICE> SELECT QUAD4.PID,MAX(Q4STR001.SIGX)
  2>     FROM QUAD4,Q4STR001
  3>     WHERE QUAD4.EID = Q4STR001.EID
  4>     GROUP BY QUAD4.PID;

  PID     MAX(SIGX)
-----  ------------
    1   2.00000E+06
    2   3.00000E+06
```

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Sorting the Results

```
ICE> SELECT * FROM Q4STR001
  2>     SORT BY SIGX,SIGY;

  EID          SIGX          SIGY         TAUXY
-----  ------------  ------------  ------------
    1   1.00000E+06   2.00000E+06   4.00000E+04
    4   2.00000E+06   1.00000E+06   5.00000E+04
    3   2.00000E+06   3.00000E+06   4.00000E+04
    2   3.00000E+06   1.00000E+07   6.00000E+03
```

```
ICE> SELECT QUAD4.PID,MAX(Q4STR001.SIGX)
  2>     FROM QUAD4,Q4STR001
  3>     WHERE QUAD4.EID=Q4STR001.EID
  4>     GROUP BY QUAD4.PID
  5>     SORT BY 2 DESC;

  PID     MAX(SIGX)
-----  ------------
    2   3.00000E+06
    1   2.00000E+06
```

The SUBQUERY

```
ICE> SELECT PID FROM QUAD4 WHERE EID=4;

  PID
-----
    2

ICE> SELECT T FROM PSHELL WHERE PID=2;

           T
------------
 5.00000E-01
```

```
ICE> SELECT T FROM PSHELL WHERE
  2>     PID = ( SELECT PID FROM QUAD4 WHERE
  3>                EID=4 );

           T
------------
 5.00000E-01
```

The SUBQUERY

```
ICE> SELECT EID,TAUXY FROM Q4STR001 WHERE
  2>      TAUXY > ALL ( SELECT TAUXY FROM Q4STR002 );

  EID         TAUXY
-----  ------------
    1   4.00000E+04
    3   4.00000E+04
    4   5.00000E+04
```

```
ICE> SELECT EID FROM QUAD4
  2>  WHERE PID IN ( SELECT PID FROM PSHELL
  3>                 WHERE T = 0.5 )
  4>  AND EID IN ( SELECT EID FROM Q4STR001
  5>                 WHERE SIGX > 2.0E+6 );

  EID
-----
    2
```

The SUBQUERY

```
ICE> SELECT GID,X FROM GRID
  2>   WHERE GID IN ( SELECT G1 FROM QUAD4 WHERE
  3>                    PID IN ( SELECT PID FROM PSHELL WHERE
  4>                                T = 0.01 ));

  GID              X
-----  ------------
    1   0.00000E+00
    3   2.00000E+00
```

The Group Operators

```
ICE>  SELECT AVG(X) FROM GRID WHERE Y = 1.0;

       AVG(X)
------------
 2.00000E+00
```

GROUP OPERATOR	DESCRIPTION
AVG	Computes the average value of the specified attribute expression for all entries which satisfy the selection criteria.
SUM	Computes the algebraic sum of the attribute expression values.
MIN	Finds the minimum of the qualified attribute selection.
MAX	Finds the maximum of the qualified attrribute selection.
COUNT	Counts the number of entries which satisfy the given selection criteria.

The Group OperatorsI

```
CE> SELECT MAX(SIGX),MIN(SIGY)
  2>      FROM Q4STR001;

   MAX(SIGX)     MIN(SIGY)
------------  ------------
 3.00000E+06   1.00000E+06
```

```
ICE> SELECT GID FROM GRID
  2>      WHERE X = ( SELECT MAX(X) FROM GRID );

  GID
-----
    5
   10
```

The Group Operators

```
ICE> SELECT PID,MAX(G3) FROM QUAD4
  2>      GROUP BY PID;

  PID  MAX(G3)
-----  -------
    1        9
    2       10
```

```
ICE> SELECT COUNT(*) FROM QUAD4
  2       WHERE PID = 2;
COUNT(*)
--------
       2
```

The JOIN Operation

```
ICE> SELECT EID,QUAD4.PID,MID FROM
  2>      QUAD4,PSHELL
  3>         WHERE EID = 1
  4>         AND   QUAD4.PID = PSHELL.PID

  EID    PID    MID
-----  -----  -----
    1      1    101
```

```
ICE> SELECT EID,QUAD4.PID,MID FROM
  2>      QUAD4,PSHELL WHERE
  3>         QUAD4.PID = PSHELL.PID;

  EID    PID    MID
-----  -----  -----
    1      1    101
    2      2    201
    3      1    101
    4      2    201
```

Relational Algebra

- **SELECT INTERSECTION OF** rel_name_1
  AND rel_name_2
  [AS rel_name_3 **];**

- **SELECT UNION OF** rel_name_1
  AND rel_name_2
  [AS rel_name_3 **];**

- **SELECT DIFFERENCE OF** rel_name_1
  AND rel_name_2
  [AS rel_name_3 **];**

Retrieving Data from Matrices

- SELECT COLUMNS

```
    [ ( { FULL | STRING | BAND } ) ]
    column_list
    FROM matrix_name
    [ <WHERE_part> ];
```

The SELECT COLUMNS Command

```
ICE> SELECT COLUMNS(FULL) * FROM KGG;

MATRIX KGG, REAL DOUBLE PRECISION, 5 ROWS, 5 COLUMNS
-----------------------------------------------------------
COLUMN 1
1.00000   2.00000   0.00000   0.00000   0.00000
-----------------------------------------------------------
COLUMN 2
2.00000   3.00000   4.00000   0.00000   0.00000
-----------------------------------------------------------
COLUMN 3
0.00000   4.00000   5.00000   6.00000   0.00000
-----------------------------------------------------------
COLUMN 4
0.00000   0.00000   6.00000   7.00000   8.00000
-----------------------------------------------------------
COLUMN 5
0.00000   0.00000   0.00000   8.00000   9.00000
```

The SELECT COLUMNS Command

```
ICE> SELECT COLUMNS(STRING) 1,2 FROM KGG;

MATRIX KGG, REAL DOUBLE PRECISION, 5 ROWS, 5 COLUMNS
----------------------------------------------------------
COLUMN 1, STRING 1 - BEGINS AT ROW 1
1.00000   2.00000
----------------------------------------------------------
COLUMN 2, STRING 1 - BEGINS AT ROW 1
2.00000   3.00000   4.00000
```

```
ICE> SELECT COLUMNS * FROM KGG WHERE ROWS IN (2);

MATRIX KGG, REAL DOUBLE PRECISION, 5 ROWS, 5 COLUMNS
----------------------------------------------------------
ROW 2, COLUMN 1
2.00000   3.00000   4.00000   0.00000   0.00000
```

Creating Views of Entities

- **CREATE VIEW** relation_name
  [<attribute_name_list>]
  AS <select_part>;
- **EXTRACT MATRIX** matrix_name
  <matrix_select_part>;

The CREATE VIEW and EXTRACT MATRIX Commands

```
ICE> CREATE VIEW SIGYQ41 AS
  2>      SELECT SIGY FROM Q4STR001;
```

```
ICE> EXTRACT MATRIX KNN AS
  2>      SELECT COLUMNS 1,3,5 FROM KGG
  3>         WHERE ROW IN (1,3,5);

ICE> ... MATRIX KNN EXTRACTED
```

Inserting Data into Entities

- **INSERT INTO** relation_name <value_part>;
- <value_part> → **VALUES** (value_list)
- **INSERT INTO MATRIX** matrix_name
  <new_value_list>;
- <new_value_term> → **VALUES AT** row_id
  (string_list)

The INSERT Commands

```
ICE> INSERT INTO GRID VALUES (11,0,5.0,0.0,0.0);
....  1 ENTRY INSERTED
```

```
ICE> CREATE RELATION GRIDY1
  2> ( GID INT KEY, CID INT,
  3>   X RSP,Y RSP,Z RSP );
....  RELATION GRIDY1 CREATED
ICE> INSERT INTO GRIDY1
  2>    ( SELECT * FROM GRID
  3>          WHERE Y=1.0);
....  5 ENTRIES INSERTED
```

```
ICE> INSERT INTO MATRIX KGG
  2>    VALUES AT 2 (25.0)
  3>    VALUES AT 5 (30.0,40.0);
....  COLUMN ADDED TO KGG
```

Selective Modification of Data

- **UPDATE** relation_name **SET** new_value_list
  [<WHERE_part>];
- **UPDATE MATRIX** matrix_name **SET** column_list
  TO <value_list>;
- <value_term> → **VALUES AT** row_id (value_list)
- **ALTER** relation_name **ADD** (<new_schema_list>);

The UPDATE Commands

```
ICE> UPDATE QUAD4 SET PID=1 WHERE EID=2;
....  1 ENTRY UPDATED
ICE> SELECT * FROM QUAD4 WHERE EID=2;
  EID    PID     G1     G2     G3     G4
-----  -----  -----  -----  -----  -----
    2      1      2      3      8      7
```

```
ICE> UPDATE PSHELL SET MID=501,T=0.25 WHERE PID=1;
....  1 ENTRY UPDATED
ICE> SELECT * FROM PSHELL;

  PID    MID            T
-----  -----  -----------
    1    501  2.50000E-01
    2    201  5.00000E-01
    3    301  3.00000E-01
```

The UPDATE Commands

```
ICE> UPDATE GRID SET Y=2.0 WHERE X=2.0 AND Y=1.0;
```

```
ICE> UPDATE QUAD4 SET PID=3
  2>      WHERE EID IN
  3>      ( SELECT EID FROM Q4STR001
  4>           WHERE SIGY > 2.0E+6 );

....  2 ENTRIES UPDATED
ICE> SELECT EID,PID FROM QUAD4 WHERE PID=3;

  EID    PID
-----  -----
    2      3
    3      3
```

The UPDATE Commands

```
ICE> SELECT COLUMNS(STRING) 3 FROM KGG;
MATRIX KGG, REAL DOUBLE PRECISION  5 ROWS, 5 COLUMNS
----------------------------------------------------------
COLUMN 1, STRING 1 - BEGINS IN ROW 2
 4.00000E+00   5.00000E+00   6.00000E+00

ICE> UPDATE MATRIX KGG SET 3 TO
  2      VALUES AT ROW 3 (20.0);

....  1 COLUMN UPDATED

ICE> SELECT COLUMNS(STRING) 3 FROM KGG;
MATRIX KGG, REAL DOUBLE PRECISION  5 ROWS, 5 COLUMNS
----------------------------------------------------------
COLUMN 1, STRING 1 - BEGINS IN ROW 2
 4.00000E+00   2.00000E+01   6.00000E+00
```

```
ICE> UPDATE MATRIX KGG SET 5 TO
  1>      VALUES AT 1 (5.0);
ERR> CANNOT UPDATE MATRIX KGG AT COLUMN 5 ROW 1
```

The ALTER Command

```
ICE> ALTER GRID ADD ( DIST,RSP );
.... ATTRIBUTE DIST ADDED TO GRID
ICE> DESCRIBE GRID;

.... ATTRIBUTE  TYPE   LEN
.... ---------  ----  -----
....       GID   INT     1
....       CID   INT     1
....         X   RSP     1
....         Y   RSP     1
....         Z   RSP     1
....      DIST   RSP     1
```

Removing Data from CADDB

- **PURGE { RELATION | MATRIX | UNSTRUCTURED }** entity_name;
- **DELETE FROM RELATION** relation_name [<WHERE_part>];
- **DELETE FROM MATRIX** matrix_name (column_list);

The DELETE Commands

```
ICE> DELETE FROM RELATION GRID
  2>       WHERE Y = 0.0;
```

```
ICE> DELETE FROM RELATION PSHELL
  2>      WHERE PID = ( SELECT PID FROM QUAD4
  3>                       WHERE EID = 2 );

ICE> SELECT * FROM PSHELL;
  PID    MID             T
-----  -----  ------------
    1    101   1.00000E-01
    3    301   3.00000E-01
```

The DELETE Commands

```
ICE> DELETE FROM MATRIX KGG (1,3,5);

....  3 COLUMNS DELETED FROM KGG

ICE> SELECT COLUMNS(FULL) * FROM KGG;
MATRIX KGG, REAL DOUBLE PRECISION  5 ROWS,  2 COLUMNS
-----------------------------------------------------------
COLUMN 1, ROW 1
 2.00000E+00   3.00000E+00   4.00000E+00
-----------------------------------------------------------
COLUMN 2, ROW 3
 6.00000E+00   7.00000E+00   8.00000E+00
```

File Environment Commands

- SET{ SCRIPT | ARCHIVE |
  REPORT | INTERFACE } TO "file_name";
- SCRIPT OFF;
- SCRIPT ON [REPLAY];
- { ARCHIVE | REPORT | INTERFACE }
  { ON | OFF };
- INTERFACE FORMAT "format_specifier";

The SCRIPT FILE

```
...
...     CQL Command Sequence 1
...
SCRIPT OFF;
...
...     CQL Command Sequence 2
...
SCRIPT OFF;
```

The SCRIPT FILE

```
ICE> SET SCRIPT TO "MYCOM.DAT";
ICE> ...
ICE> ...              Command Sequence 1 is Executed
ICE> ...
ICE> Commands are Entered by the User at the Terminal
ICE> SCRIPT ON;
ICE> ...
ICE> ...              Command Sequence 2 is Executed
ICE> ...
ICE> Commands are Entered by the User at the Terminal
ICE> SCRIPT ON;
ICE> ...ERROR - SCRIPT FILE EXHAUSTED
ICE> SCRIPT ON REPLAY;
ICE> ...
ICE> ...              Command Sequence 1 is Replayed
ICE> ...
ICE> Commands are Entered by the User at the Terminal
```

Report Generation – 1

- **SET** < page_option_list >
- < page_option_term > → { **LINEWIDTH** n |
  PAGELENGTH n |
  INTWIDTH n |
  FLOATWIDTH n }

Report Generation — 2

- SET UNDERLINE "underline_character";
- SET { HEADER | FOOTER } "title_line"
  [<justification>]
  [DATE] [PAGE];
- SET BREAK ON attribute_name
  [SKIP n] [PAGE];

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Report Generation – 3

- **SET COLUMN** attribute_name <column_options>;
- <column_options> → [<heading_info>]
  [<format_info>]
  [<justification >]
  [**TEMP**] [**CLEAR**]
- <heading_info> → **LABEL** { "string" |
  "multi_line_title" };

Report Generation – 4

```
●  <justification> --> { LEFT |
                          RIGHT |
                          CENTER };

●  <format_info> --> FORMAT
                      "{ Iw | Fw.d |
                         Ew.d | Dw.d |
                         Aw | Gw.d }";
```

The SET COLUMN Command

```
ICE> SET COLUMN EID HEADING "ELEMENT/ID NUMBER"
ICE> SET COLUMN PID HEADING "PSHELL ID"
ICE> SELECT * FROM QUAD4;

  ELEMENT
ID NUMBER  PSHELL ID     G1     G2     G3     G4
---------  ---------  -----  -----  -----  -----
        1          1      1      2      7      6
        2          2      2      3      8      7
        3          1      3      4      9      8
        4          2      4      5     10      9
```

The SET COLUMN Command

```
ICE> SET COLUMN GID LABEL "GRID ID";
ICE> SET COLUMN X FORMAT "F9.5";
ICE> SET COLUMN Y FORMAT "F9.5";
ICE> SET UNDERLINE "=";
ICE> SELECT * FROM GRID WHERE X=4.0;

GRID ID   CID         X         Y            Z
======= ===== ========= ========= ============
      5     0   4.00000   1.00000  0.00000E+00
     10     0   4.00000 0.0        0.00000E+00
```

Page Headers, Footers and Breaks

```
ICE> SET HEADER "GRID POINTS ALONG STATION X=4.0" PAGE;
ICE> SET FOOTER "ASTROS DESIGN SAMPLE" CENTER;
ICE> SELECT * FROM GRID WHERE X=4.0;

          GRID POINTS ALONG STATION X=4.0       PAGE   1

 GRID
   ID    CID          X          Y             Z
-----  -----  ---------  ---------  ------------
    5      0    4.00000    1.00000   0.00000E+00
   10      0    4.00000  0.0         0.00000E+00

            ASTROS DESIGN SAMPLE                29-Feb-88
```

Page Headers, Footers and Breaks

```
ICE> SET BREAK ON PID SKIP 1;
ICE> SELECT * FROM QUAD4 GROUP BY PID;

  EID    PID     G1     G2     G3     G4
-----  -----  -----  -----  -----  -----
    1      1      1      2      7      6
    3      1      3      4      9      8

    2      2      2      3      8      7
    4      2      4      5     10      9
```

CADDB Security

- **SET PASSWORDS** <password_list>
- <password_term> → { **READ**=pass |
  WRITE=pass |
  MODIFY=pass |
  DELETE=pass }
- **USE PASSWORDS** <password_list>

Utility Functions

- **SET TOLERANCE** value [**PERCENT**];
- **HELP** [command_name [command_part]];
- **SHOW** [<variable_class_list>];
- <variable_class> → { **FILES** | **COLUMN**
  | **PAGE** }

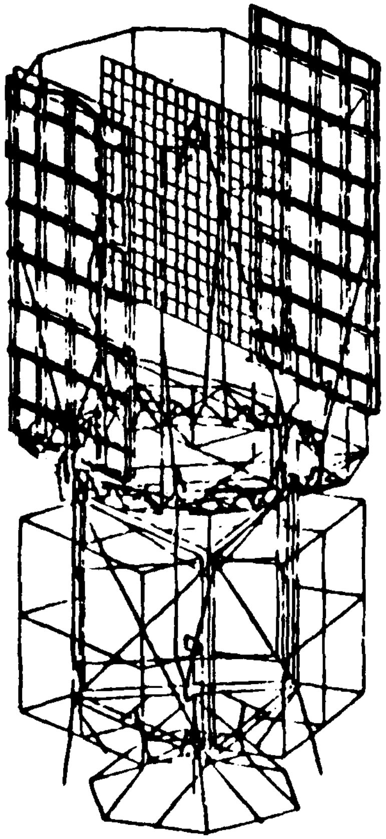
Conclusions

- ICE has Great Potential for Improving the Design Process
- ICE Allows Nearly Unlimited Querying of ASTROS Data
- ICE Can be Used in Conjunction with Other Programs
- ICE Can Increase the Understanding of Design Results

AF WRIGHT AERONAUTICAL LABORATORIES

AUTOMATED STRENGTH-AEROELASTIC DESIGN OF AEROSPACE STRUCTURES

NORTHROP



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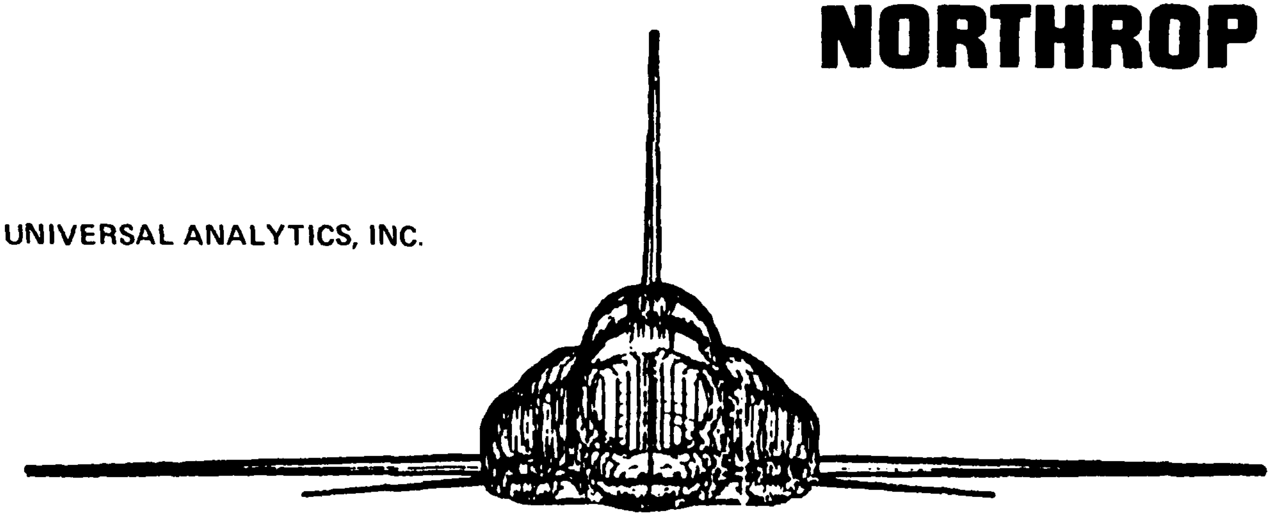
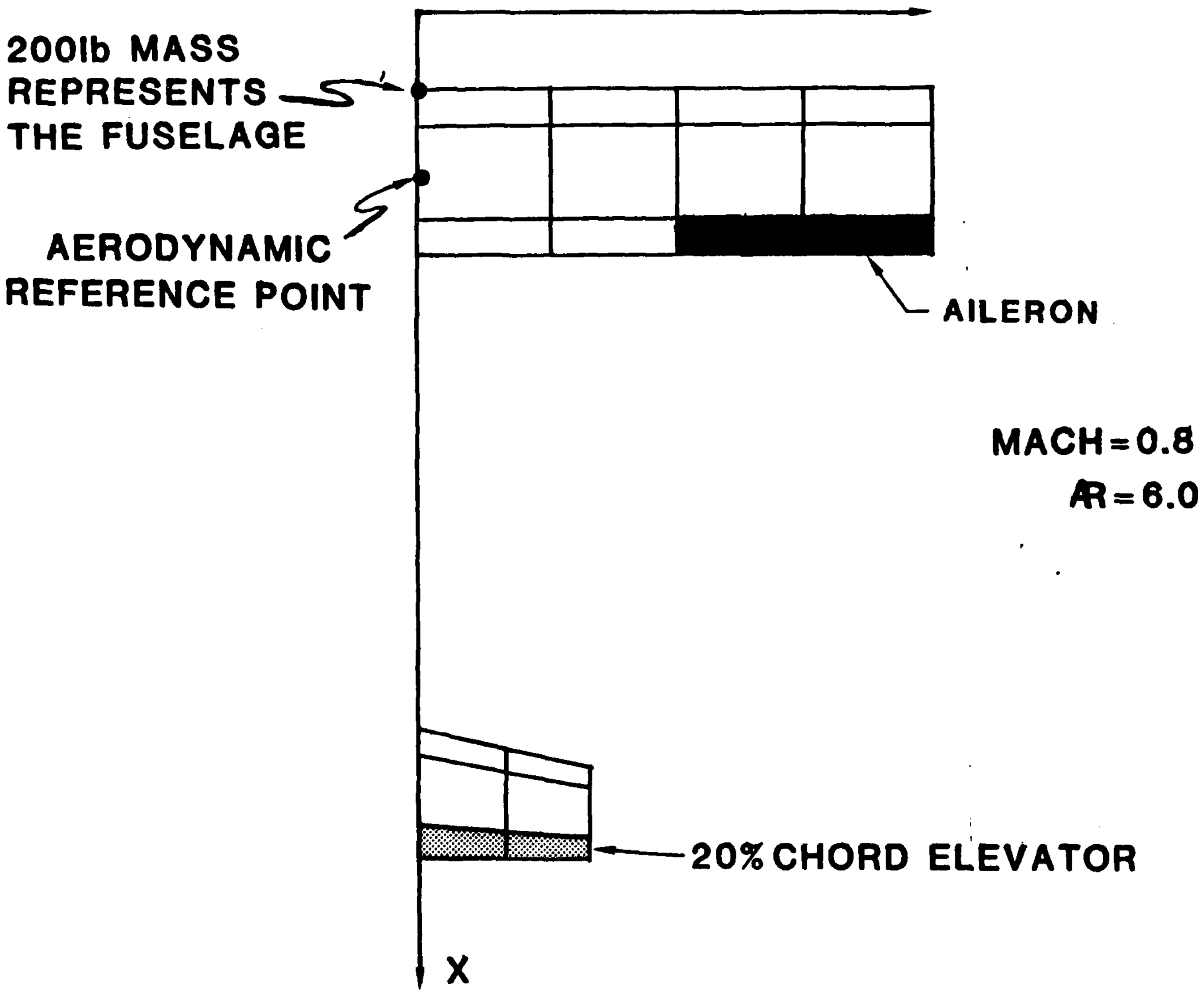
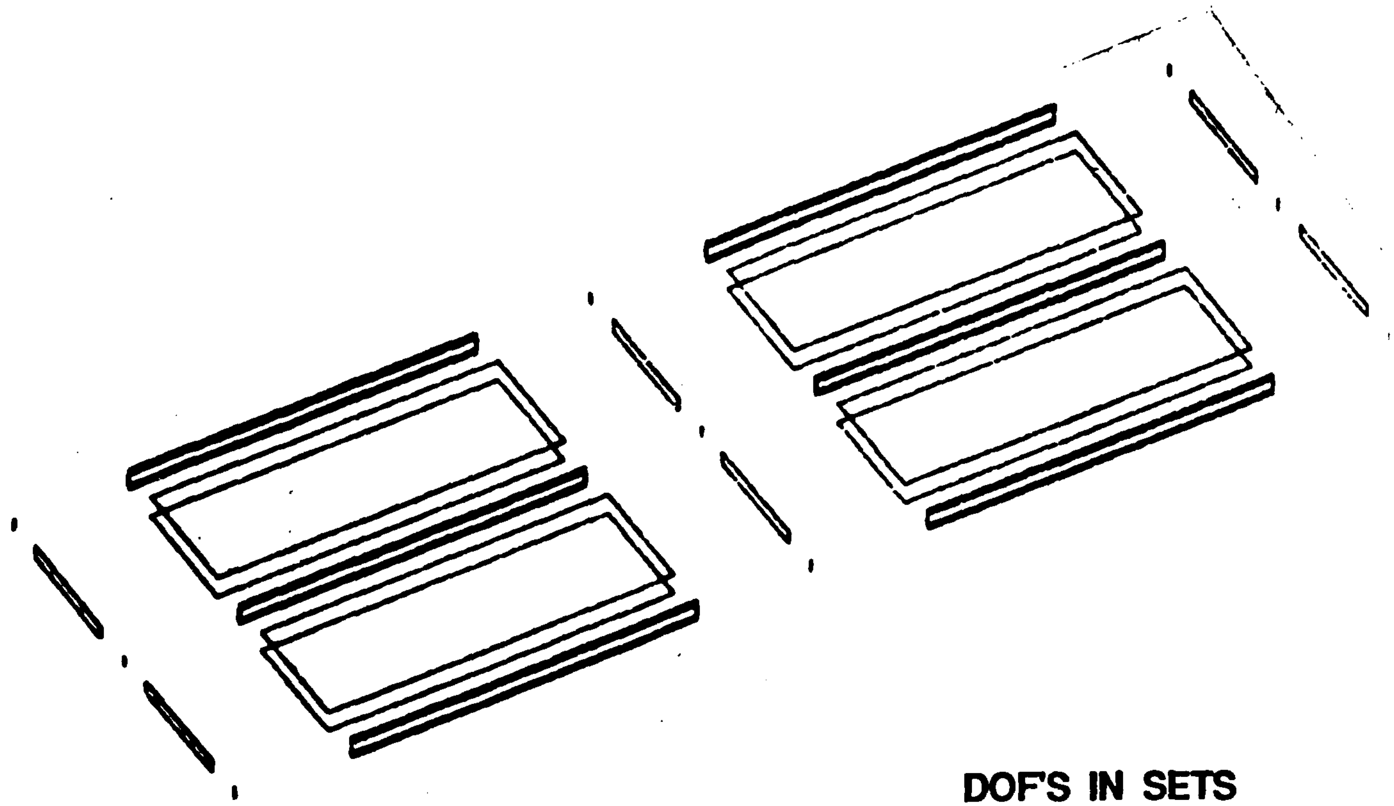


Applications

AERODYNAMIC MODEL FOR RECTANGULAR WING



Rectangular Wing Box Model



	ELEMENTS
ROD	9
SHEAR	12
QUAD MEMBRANE	6
CONM2	1
TOTAL	28

DOF'S IN SETS

	SYMMETRIC	ANTI SYMMETRIC
MPC	4	6
SPC	64	71
SOLUTION	44	36
REFERENCE	2	1
TOTAL	114	114

10-13-87-05-EJ

Aeroelastic Design Conditions For The Rectangular Wing

Constraint	Case			
	A	B	C	D
Maximum Tip Rotation (Degs)	1.0	1.0	---	1.0
Maximum Lift Effectiveness	---	1.60	---	1.6
Minimum Aileron Effectiveness	---	---	0.30	0.30

Stress Constraints were Applied Cases A, B and D :

$\sigma_T \leq 20$ ksi

$\sigma_U \leq 15$ ksi

$T_{xy} \leq 12$ ksi

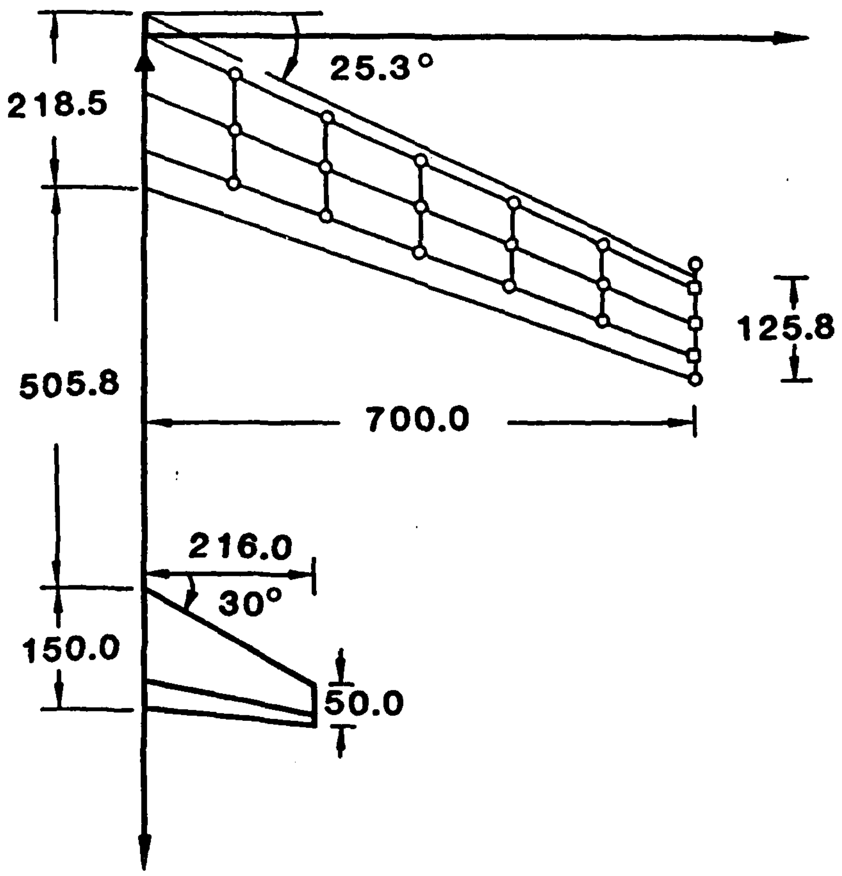
10-15-87-01-EJ

Design Results for the Rectangular Wing

Parameter	Case			
	A	B	C	D
Inboard Thickness	0.135	0.174	0.106	0.174
Outboard Thickness	0.082	0.058	0.082	0.058
Weight	26.00	27.68	22.57	27.68
Tip Rotation	1.00	1.00	1.78	1.00
Lift Effectiveness	1.843	1.60	2.22	1.60
Aileron Effectiveness	0.312	0.308	0.300	0.308
Trimmed Angle of Attack	1.05	1.26	0.83	1.26
Trimmed Elevator Setting	-1.26	-1.56	-0.99	-1.56

10-15-87-01-EJ

Swept Wing Example
Model Geometry



Design Requirements for the Swept Wing

- Boundary Condition 1 - Cantilevered at Root
  - Flutter Speed > 530 KEAS, M = 0.8, Sea Level
  - First Modal Frequency ≥ 1.5 Hz
- Boundary Condition 2 - Unrestrained
  - Trimmed Symmetric 4g Pullup, M = 1.25, 25000 Ft
  - Stress Limits in Cover Skins

$\sigma_t \leq 60$ Ksi

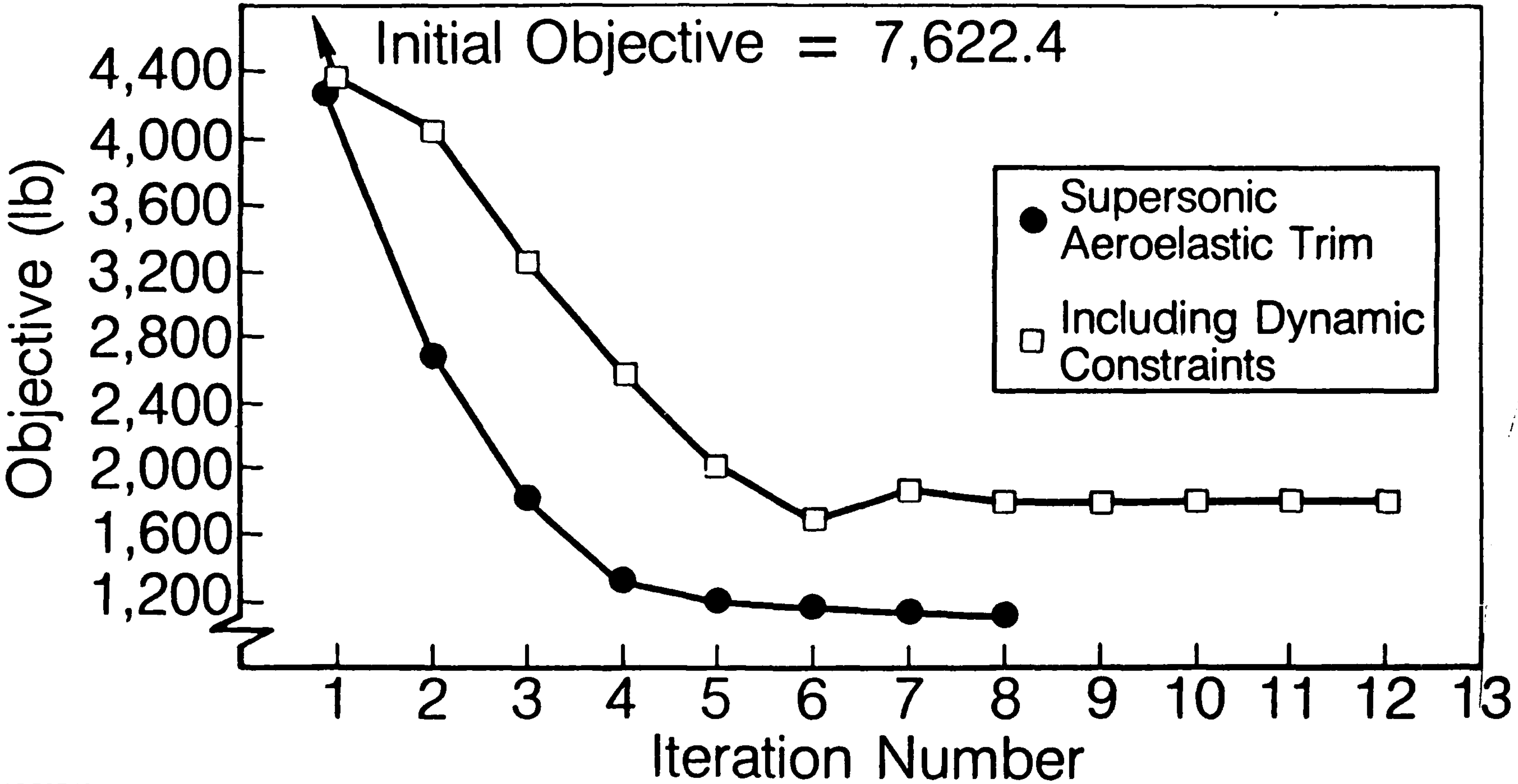
$\sigma_c \leq 50$ Ksi

$\tau_{xy} \leq 30$ Ksi

- 13 Design Variables

60 Constraints

Swept Wing Example — Iteration History



87-50540
3Q NS

Intermediate Complexity Wing Model Geometry

No. of Nodes

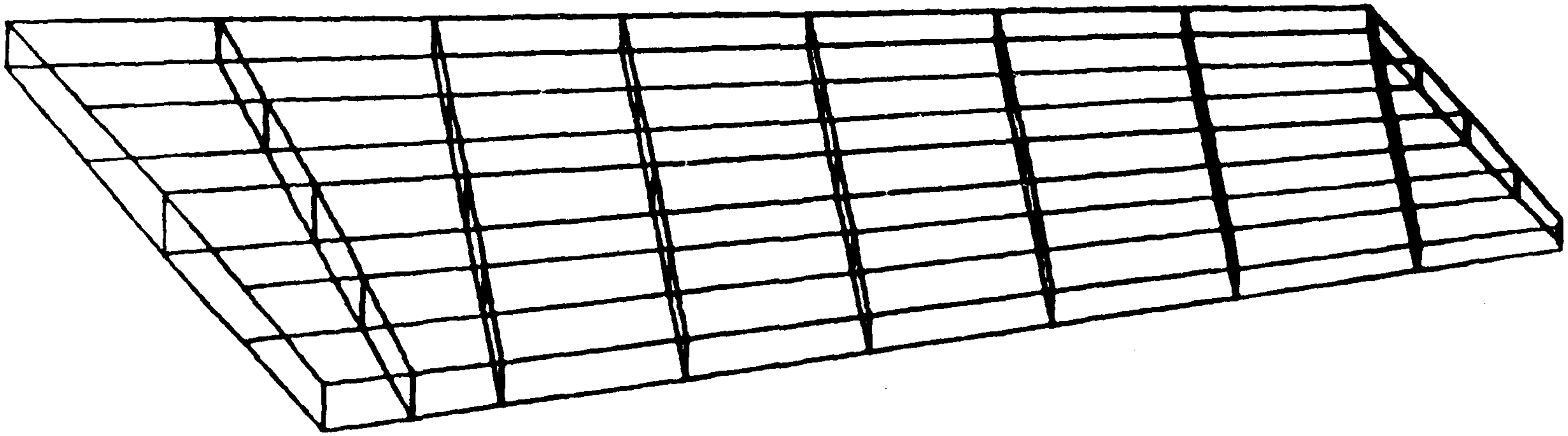
88

No. of Elements

39	Rods
55	Shear Panels
62	Quadrilateral Membrane
2	Triangular Membrane
158	Total

No. of DOF's

294	Constrained
234	Unconstrained
528	Total



Design Requirements For Intermediate Complexity Wing

- Displacement Constraints
    - All out of plane tip displacements are limited to ± 10 inches

- Isotropic Material

$E = 10.5 \times 10^6$ psi

$\nu = 0.30$

$\rho = 0.10$ lb/in^3

$t_{min} = 0.04$ in

$\sigma_T \leq 45$ ksi

$\sigma_C \leq 55$ ksi

$\tau_{xy} \leq 45$ ksi

- Orthotropic Material

$E_1 = 19.9 \times 10^6$ psi

$E_2 = 1.5 \times 10^6$ psi

$\nu_{12} = 0.32$

$G_{12} = 0.85 \times 10^6$ psi

$\rho = 0.055$ lb/in^3

$t_{min} = 0.04$ in

$\varepsilon_T \leq 4500\ \mu$

$\varepsilon_C \leq 3200\ \mu$

Design Cases For Intermediate Complexity Wing

- Problem 1

  Strength Constraints Under Two Static Loads

  20 Displacement Constraints
  316 Von Mises Stress Constraints

  Isotropic Material Properties

  Upper/Lower Surfaces Linked - 57 Design Variables

- Problem 2

  Strength Constraints Under Two Static Loads

  20 Displacement Constraints
  110 Von Mises Stress Constraints
  256 Principal Strain Constraints

  Orthotropic Material Properites

  Upper/Lower Surfaces Linked For Each Ply Orientation

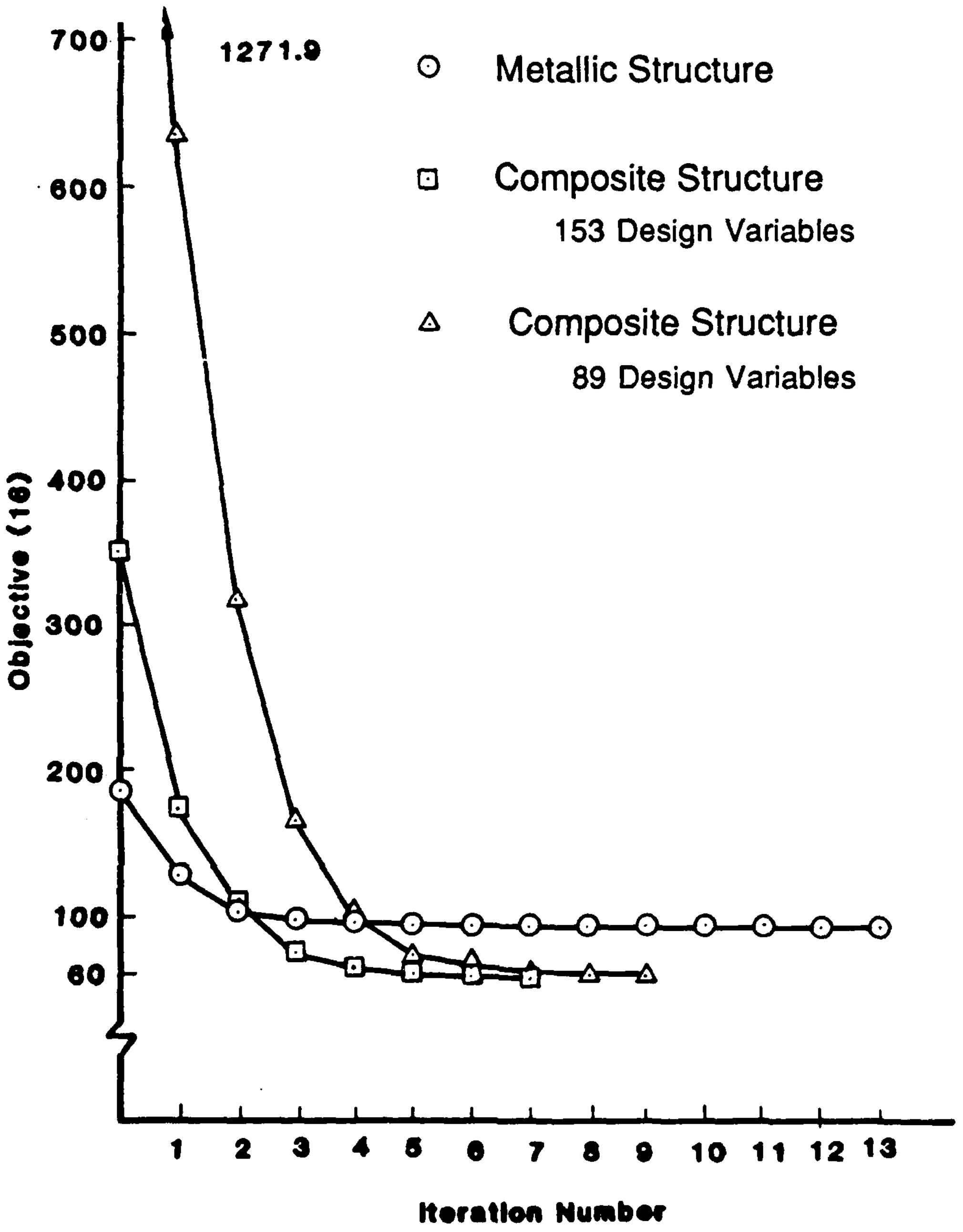
  153 Design Variables

- Problem 3 - Same as Problem 2 Except:

  Upper/Lower Surfaces Linked For Each Bay For Each Ply

  89 Design Variables

Intermediate Complexity Wing Iteration Histories



Design Requirements for the Intermediate Complexity Wing

- **Flutter Constraints**

  $V_f \leq$ 925 knots
  ρ = .0023769 slugs/ft^3
  M = 0.80

- **Isotropic Material in Substructure**

  E = 10.5 x 10^6 psi
  ν = 0.30

  ρ = 0.10 lb/in^3
  t_{min} = 0.04 in

  $\sigma_T \leq$ 45 ksi
  $\sigma_C \leq$ 55 ksi
  $\tau_{xy} \leq$ 45 ksi

- **Orthotropic Material in Skins**

  E_1 = 18.5 10^6 psi
  E_2 = 1.6 x 10^6 psi

  ν_{12} = 0.25
  G_{12} = 0.65 x 10^6 psi

  ρ = 0.055 lb/in^3
  t_{min} = 0.00525 in

  $X_T = X_C = Y_T = Y_C$ = 1.15 x 10^5 psi
  $S \leq$ 1.0 x 10^{15}

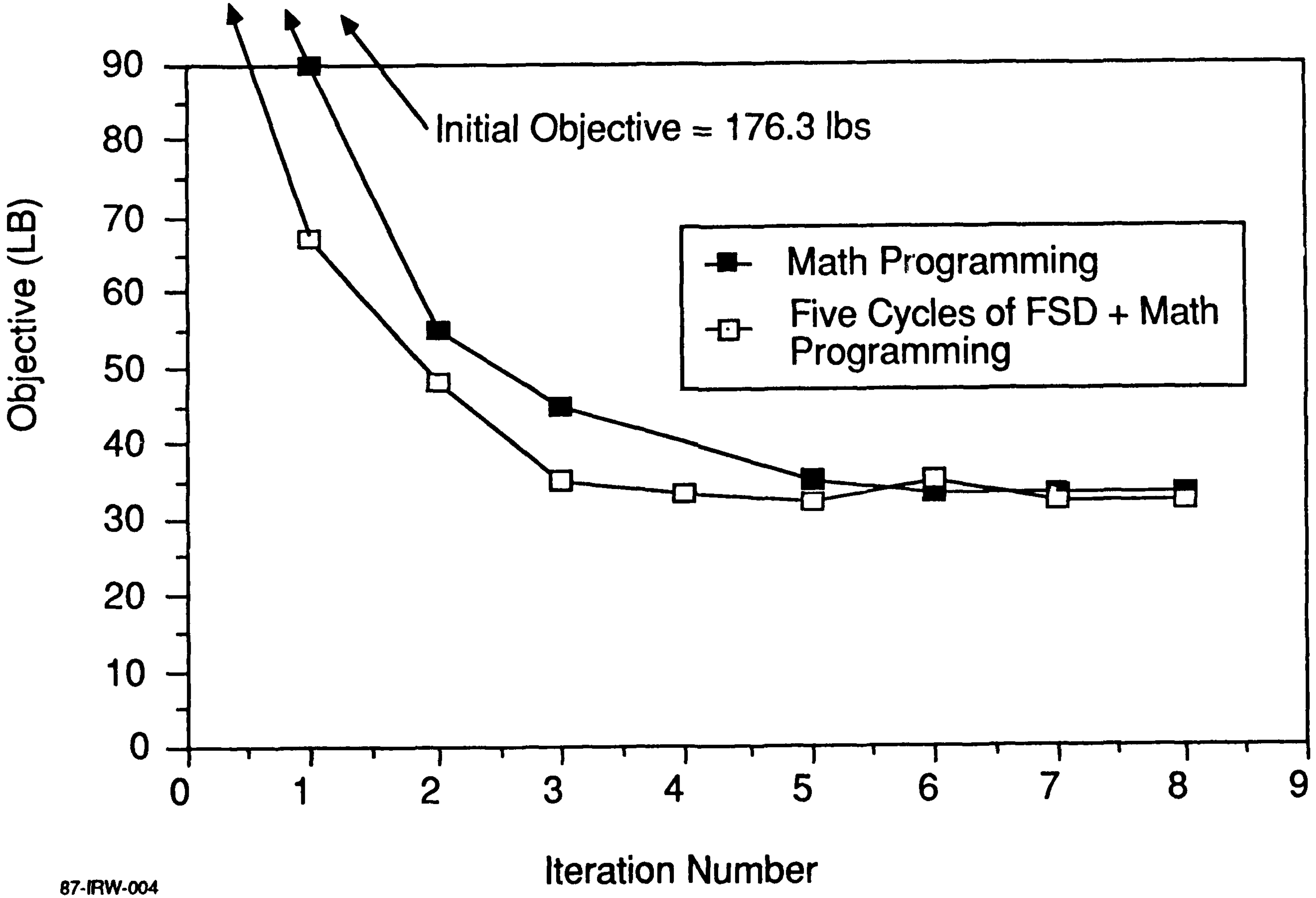
Design Cases For Intermediate Complexity Wing

- Problem 1
  - Strength Contraints Under Two Static Loads
    - 110 Von Mises Stress Constraints
    - 256 TSAI WU Constraints
  - Upper/Lower Surfaces Linked For Each Ply Orientation
    - 153 Design Variables

- Problem 2 - Same as Problem 1 Except:
  - Flutter Constraint is Imposed

- Problem 3 - Same as Problem 2 Except:
  - Shape Functions Are Used
    - 22 Design Variables
    - Ribs and Posts not Designed
- Problem 4 - Same as Problem 3 Except:
  - Flutter Contraint is Imposed

ICW Strength and Flutter Design - Iteration Histories

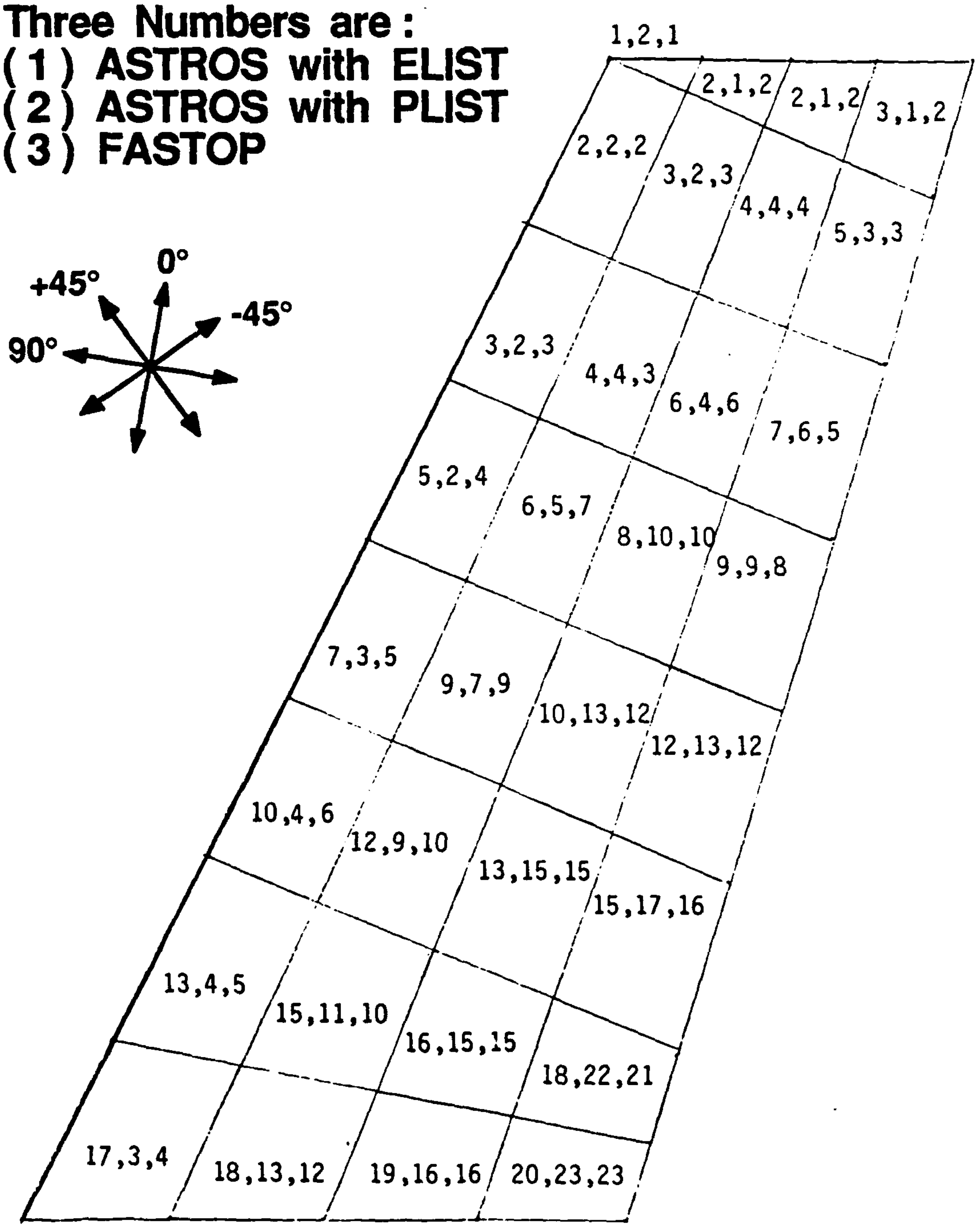


87-IRW-004

ICW Strength Design

Ply Counts for the 0° Laminate

Three Numbers are:
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



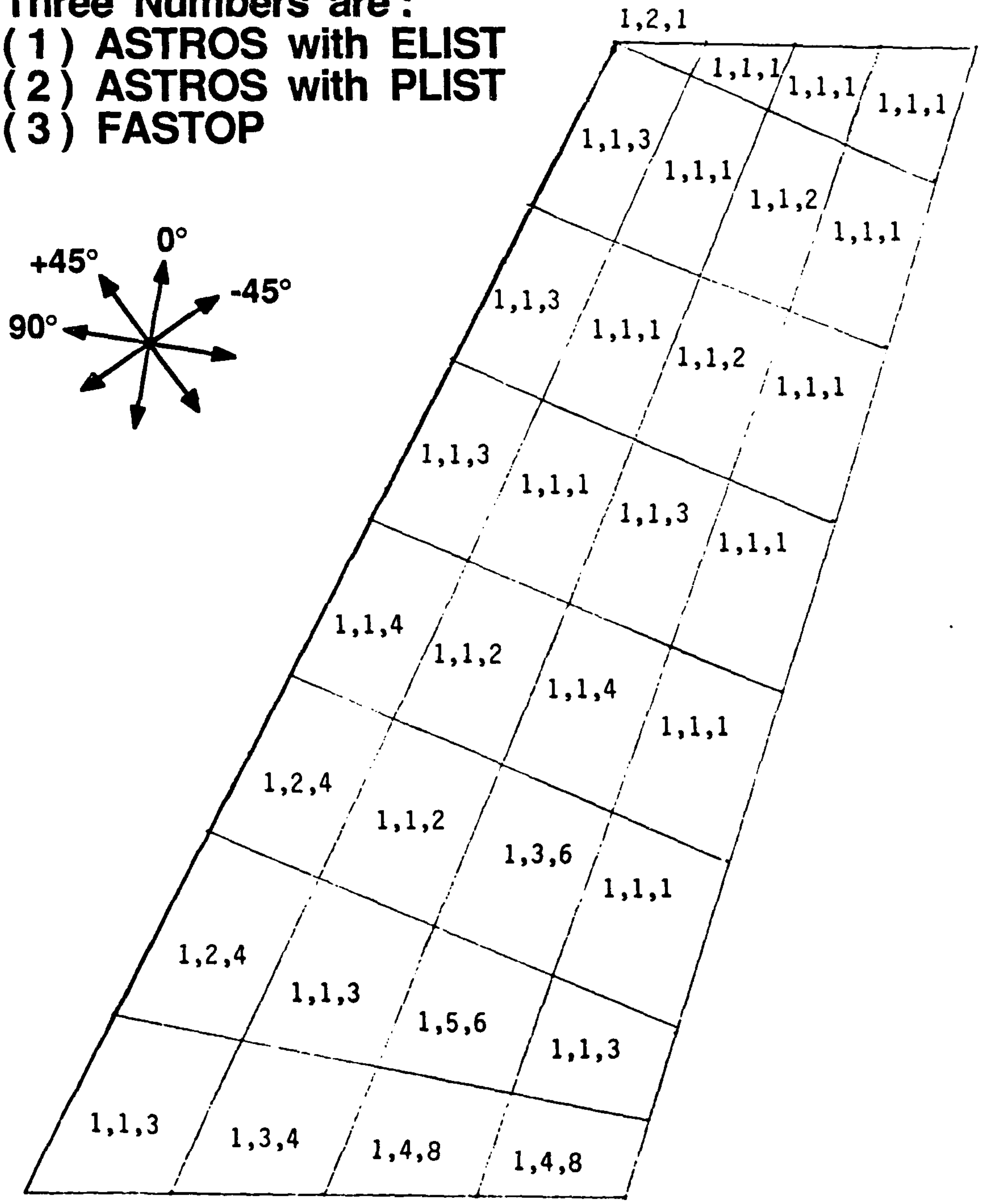
10-15-87-12-EJ

ICW Strength Design

Ply Counts for the +45° Laminate

Three Numbers are:

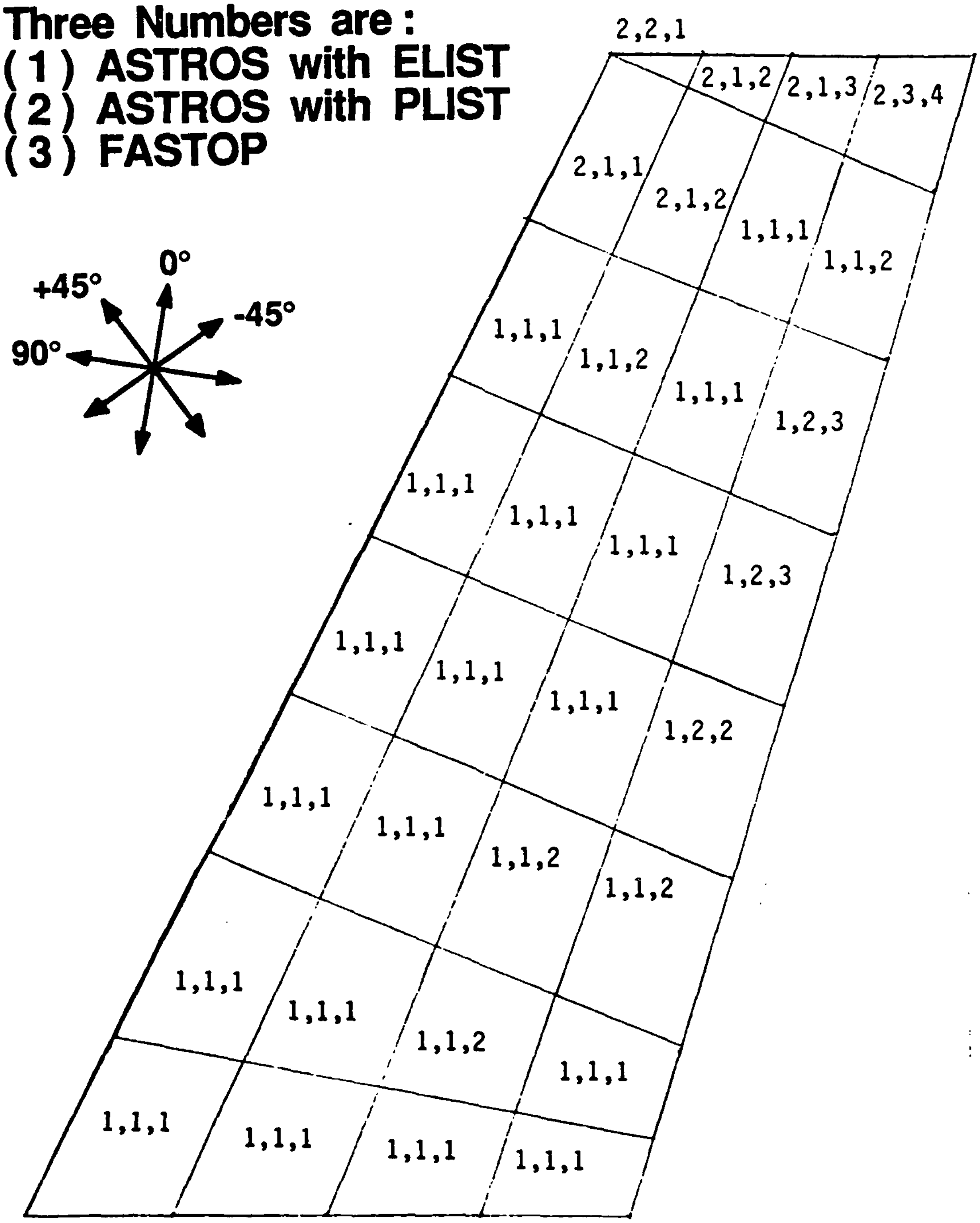
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



ICW Strength Design

Ply Counts for the -45° Laminate

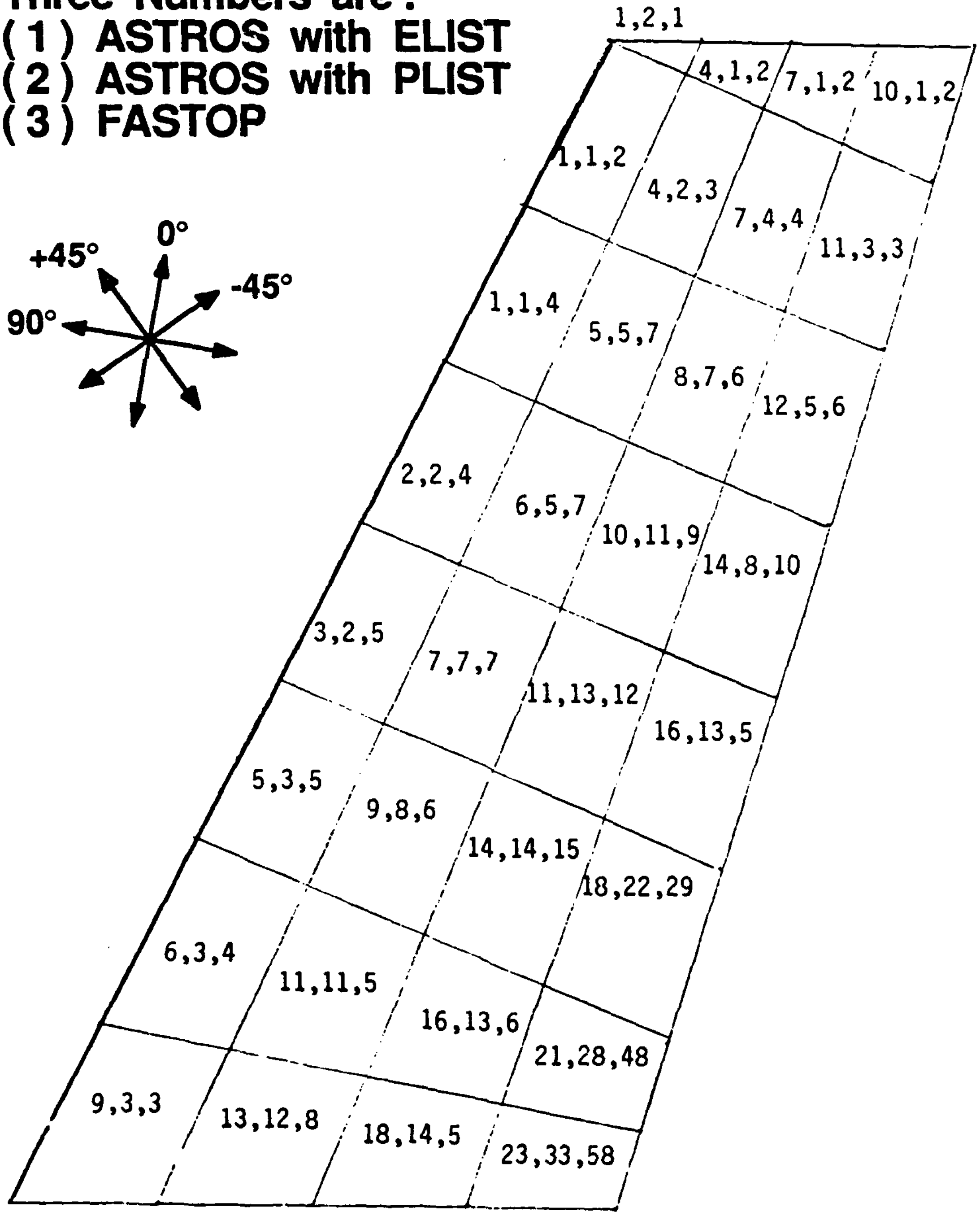
Three Numbers are:
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



ICW Strength & Flutter Design

Ply Counts for the 0° Laminate

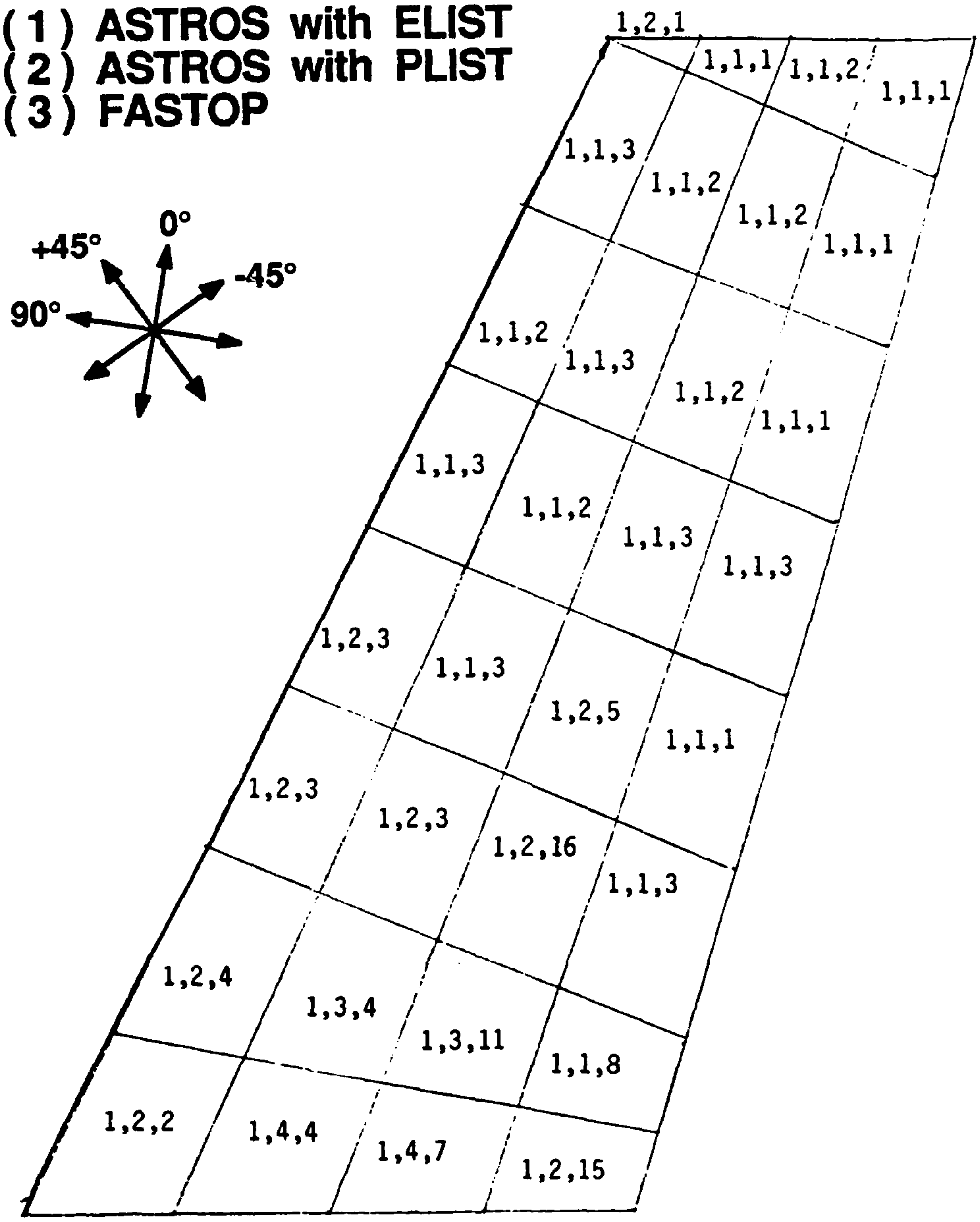
Three Numbers are:
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



ICW Strength & Flutter Design

Ply Counts for the +45° Laminate

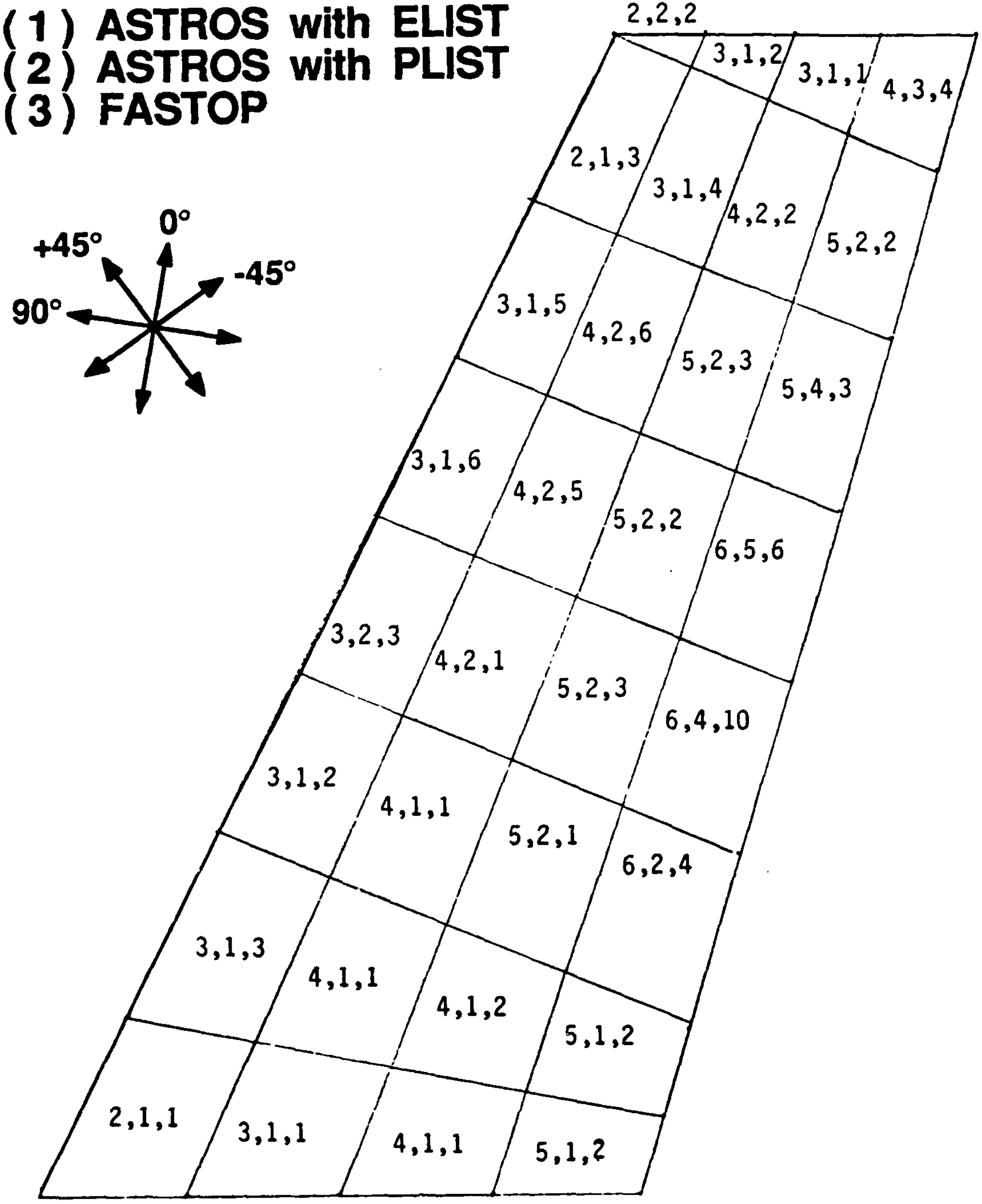
Three Numbers are :
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



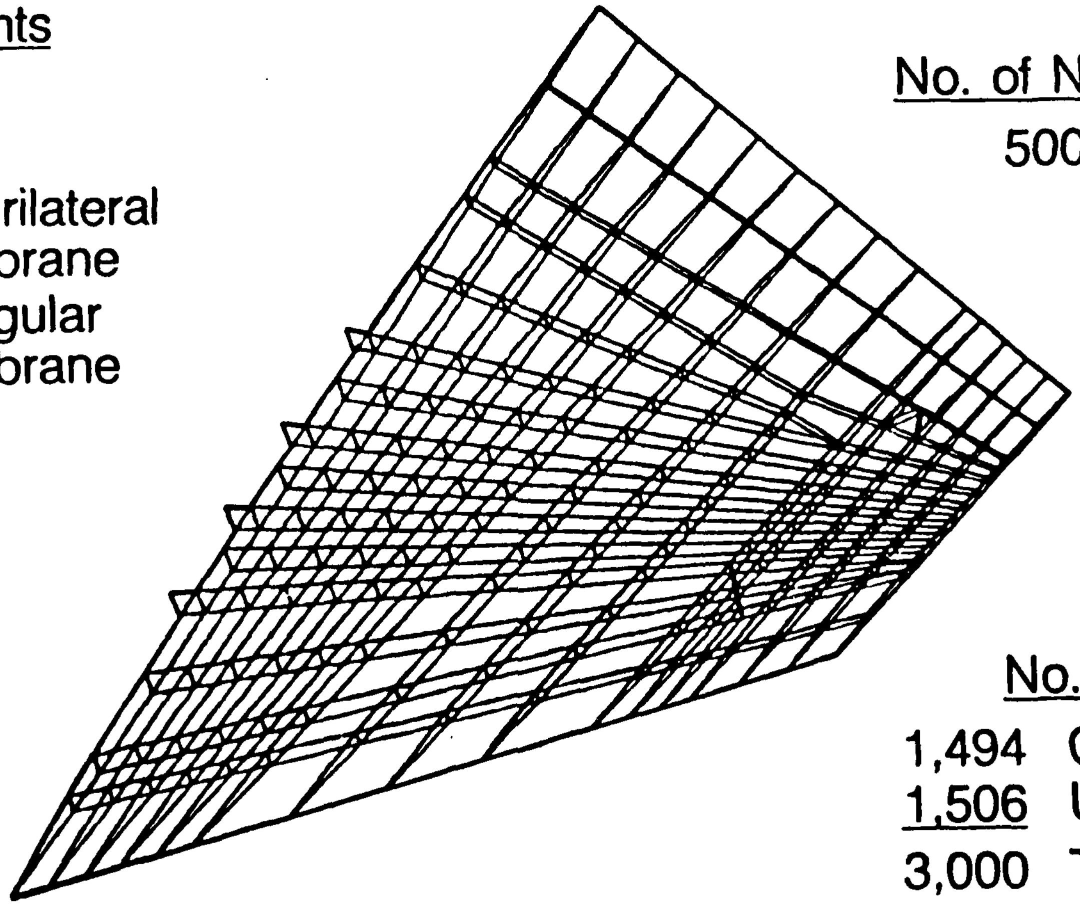
ICW Strength & Flutter Design

Ply Counts for the -45° Laminate

Three Numbers are :
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



Structural Model of the N372-4 Fighter Wing



No. of Elements	
8	Bars
468	Rods
1,570	Quadrilateral Membrane
67	Triangular Membrane
2,113	Total

No. of Nodes

500

No. of DOFs	
1,494	Constrained
1,506	Unconstrained
3,000	Total

87-50539
3Q NS

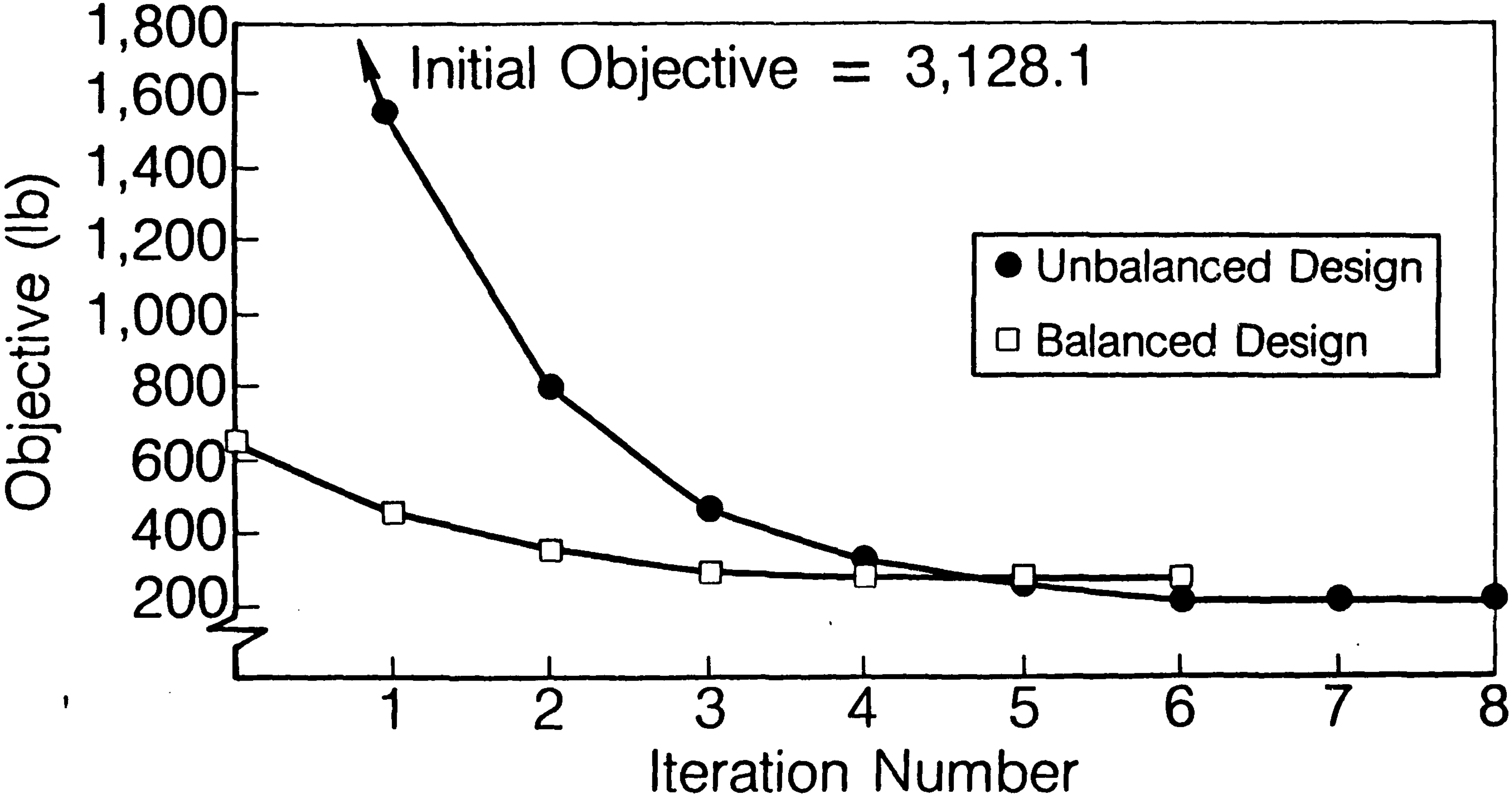
Design Requirements for the N372-4 Fighter Wing

- Single Boundary Condition - Cantilevered at Root
  - Static Load Equivalent to Rigid Air Load During a Symmetric 13.5 g Pullup, M = 2.5, 50000 Ft
  - Limits on Principal Strain of Torque Box Cover Skins

$$\varepsilon_1 \, , \, \varepsilon_2 \leq 0.0050$$

- Two Design Models
  - Unbalanced Laminate with 40 Design Variables
  - Balanced Laminate with 30 Design Variables
- 612 Strain Constraints

N372-4 Example — Iteration History



87-50541
3Q NS

ASTROS User Training Workshop

Problem Set Definitions

Problem Set #1: Space Truss
1–1: Modal Analysis using Guyan and Generalized Dynamic Reduction
1–2: Optimization for first two Natural Frequencies

Problem Set #2: Rectangular Wing
2–1: Static Analysis for Tip Load
2–2: Optimization for Stress constraints
2–3: Optimization for Stress constraints with Shape Functions
2–4: Static Analysis with Inertia Relief
2–5: Aeroelastic Trim for Wing in Straight, Level Flight
2–6: Aeroelastic Trim for Wing-Tail combination in Pull-up maneuver
2–7: Aeroelastic Analysis for Roll maneuver
2–8: Optimization for Stress and Tip Twist
2–9: Optimization for Stress, Tip Twist, and Lift Effectiveness
2–10: Optimization for Stress, Tip Twist, Lift and Aileron Effectiveness

Problem Set #3: Cantilvered Plate
3–1: Static and Modal Analyses
3–2: Transient Analysis
3–3: Subsonic and Supersonic Flutter Analysis

Problem Set #4: Swept Wing
4–1: Static Analysis for Gravity Load
4–2: Modal Analysis
4–3: Optimization for Stress and Frequency constraints
4–4: Subsonic Flutter Analysis
4–5: Supersonic Air Loads

Problem Set #5: Plane Frame
5–1: Optimization of 40 member Plane Frame for Stress and Displacement Constraints

Workshop Requirement is to complete 10 of the above 21 problems,
including at least one from each problem set.

ASTROS User Training Workshop
Problem Set #1: ACOSS Space Truss

The Active Control Of Space Structures (ACOSS) model II was developed by the Charles Stark Draper Laboratory. The structure consists of two subsystems: (1) the optical support structure and (2) the equipment section. The two are connected by springs at three points to allow vibration isolation (Figure 1–1). For this problem set disregard the equipment section at the base and consider the optical support structure fixed at the three connection points. The finite element model for this modified ACOSS II (Figure 1–2) has 33 nodes (90 degrees of freedom), 18 concentrated masses, and 113 rod elements made of graphite epoxy given (Table 1–1) with initial areas of 10.0 in^2 for the truss members. The grid points, masses, and element connectivities are given in attachment 1.

For this initial design the first three frequencies of the modified ACOSS II truss are: 1.21, 2.71, and 4.21 hz.

1–1) Verify the first three frequencies. Compare Guyan Reduction (omit degrees of freedom for nodes without concentrated masses) to Generalized Dynamic Reduction for reducing the size of the problem before applying Givens method.

1–2) Design the truss for minimum weight while raising the fundamental frequency to 2 hz and maintaining at least a 1 hz separation of the fundamental mode from the remaining modes. Use a minimum gage size of 0.01 in^2 for the truss elements. What are the first three frequencies and weight for the final design?

Young's Modulus	18.5 x 10^6 psi
Weight Density	0.055 lb/in^3

Table 1–1: Material Properties for Epoxy

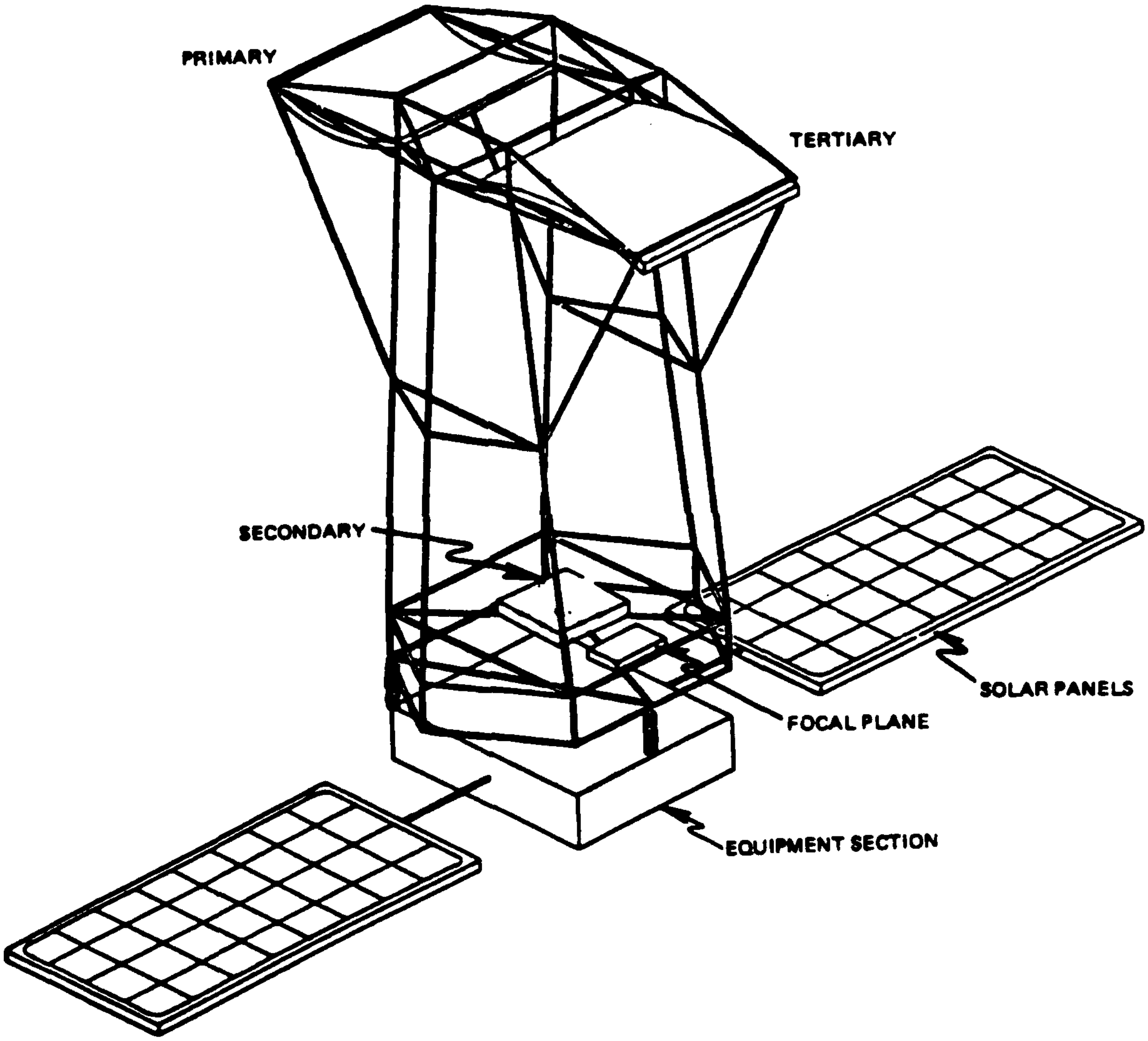


Figure 1–1: ACOSS Model II

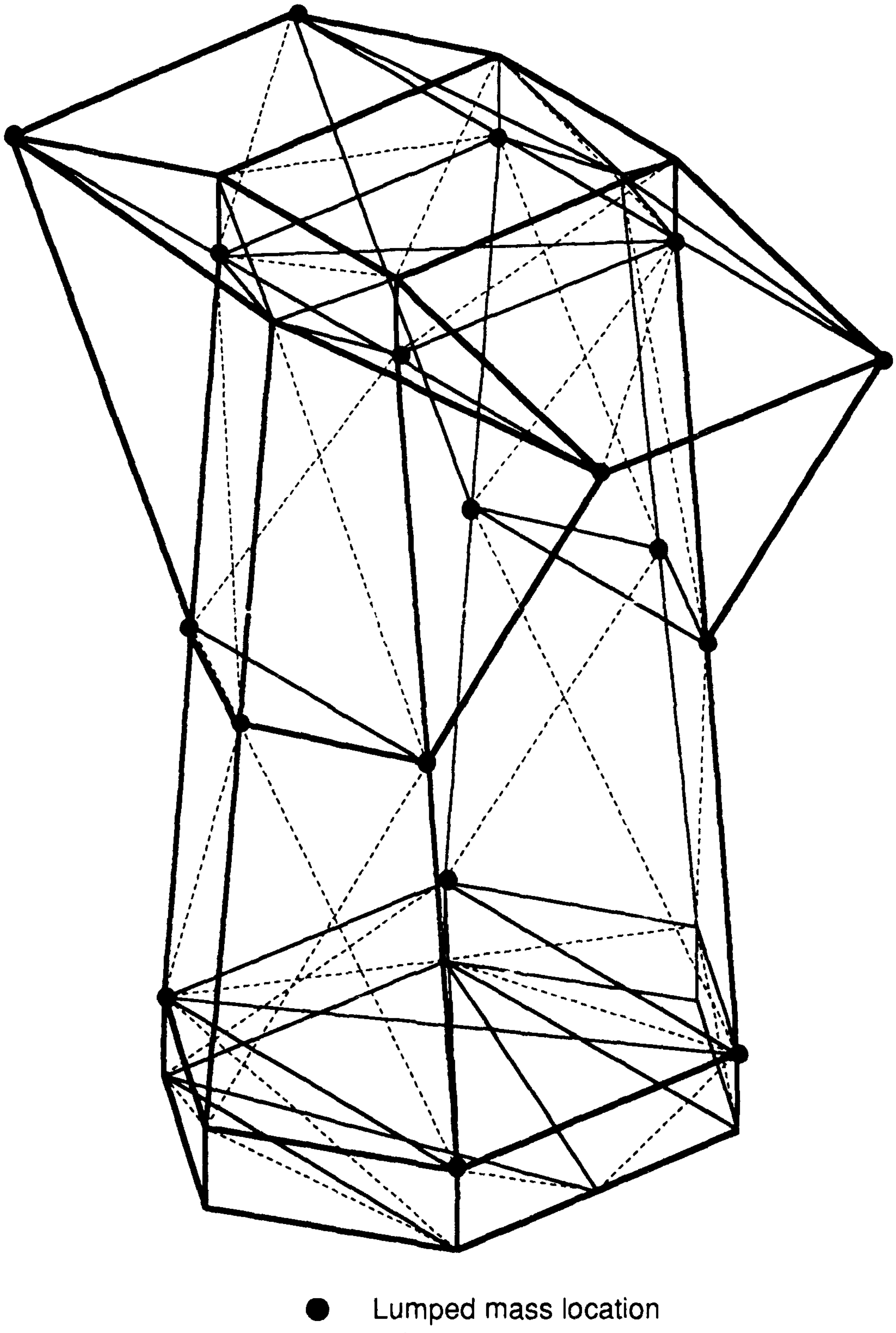


Figure 1–2: Finite Element Model for Modified ACOSS II

ASTROS User Training Workshop
Problem Set #2: Rectangular Wing

Structural Wing Box Model

A simple three-spar rectangular wing box is shown in Figure 2–1. The semi-span is 60" and the chord of the structural box (distance from front to rear spar) is 20". A 200 *lb* concentrated mass with a moment of inertia about the span axis of 22,500 $lb\text{-}in^2$ at the root of the front spar represents the fuselage mass. The wing is made of aluminum (material properties given in Table 2–1). The structural box is modeled using quadrilateral membrane elements for the cover skins, shear panels for the spars and ribs, and rod elements for the vertical posts (cross-sectional properties given in Table 2–2).

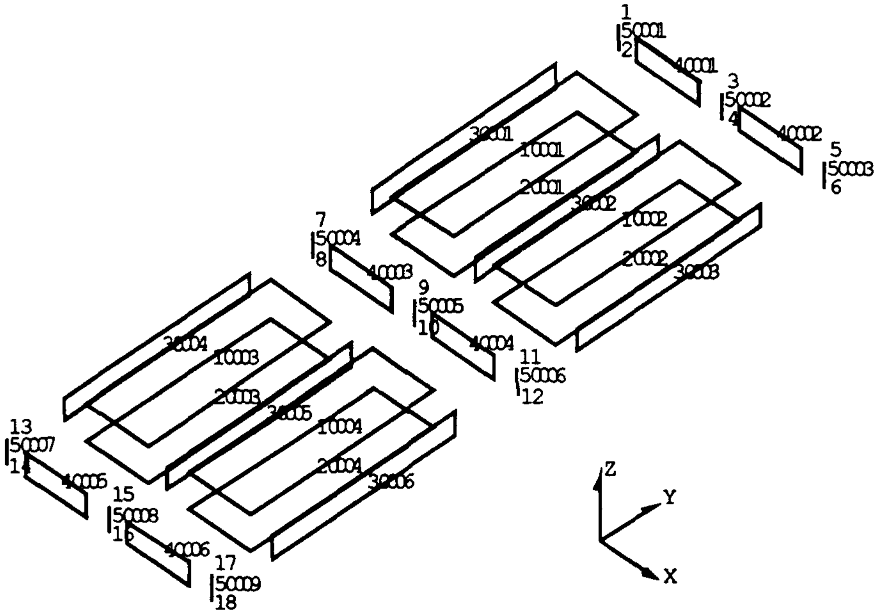


Figure 2–1: Rectangular Wing Structural Box

Young's Modulus	10.0 x 10^6 psi
Poisson's Ratio	0.3
Weight Density	0.1 lb/in^3
Tensile Strength	20.0 ksi
Compressive Strength	15.0 ksi
Shear Strength	12.0 ksi

Table 2–1: Material Properties for Aluminum

Membrane Thicknesses	0.20 in
Shear Thicknesses	0.05 in
Rod Areas	0.01 in^2

Table 2–2: Cross-Sectional Properties

2–1) Perform a static analysis of the wing when it is subjected to 100 *lb* load applied vertically at each of the six grid points at the wing tip. Consider the wing cantilevered at the root. Find the displacements of each grid point and the stresses in the cover skins.

Design Model

Use design variable linking to define four design variables that control the thicknesses of the eight cover skin membrane elements. Each design variable controls a group of two membrane elements, one fore and one aft, so the design variables control the (1) outboard upper skin, (2) outboard lower skin, (3) inboard upper skin, and (4) inboard lower skin. The spars, ribs, and posts remain fixed (are not designed).

2–2) Optimize the structural weight of the cover skins subject to stress constraints (Table 2–1) on the cover skins only . Find the optimum weight and design variable values for the boundary conidtion and static mechanical load given in problem 2–1.

2–3) Repeat problem 2–2 using shape function design variable linking. Use a constant thickness (initially 0.1") and a spanwise linear shape (initially 0.075" inboard and 0.025" outboard) for each of the upper and lower skins (4 design variables).

2–4) Perform a static analysis of the wing with inertia relief for the static load given in problem 2–1. Use multipoint constraints to rigidly connect the six grid points at the wing root to the root of the center spar midway between the top and bottom skins. The fuselage mass is associated with this "aerodynamic reference point" with an offset to locate it at the mid-surface of the front spar. Support the aerodynamic reference point in vertical translation (plunge) and find the displacements and accelerations.

Steady Aerodynamic Panel Model—Wing

The aerodynamic planform (Figure 2–2) for the wing has a 30" chord and 60" semi-span. The structural box's front and rear spar are located at the 13.33% and 80% chord locations, respectively. The aerodynamic box pattern shown in Figure 2–2 has four chordwise cuts at 0%, 20%, 80%, and 100% of the chord and five equal spanwise cuts. The airfoil shape given in Table 2–3 is for a symmetric airfloil (no camber) with a leading edge radius of 1.667%g. An aileron is defined by the two outboard trailing edge boxes of the wing.

2–5) Find the trimmed angle of attack, displacements, and accelerations for symmetric level flight (**1g** load factor) at Mach 0.8 and a dynamic pressure of 6.5 *psi*. Use the wing only and spline the aerodynamic boxes to the upper sufurface structural grid points. Compare the lift coefficient to the theoretical value for a thin airfoil wing.

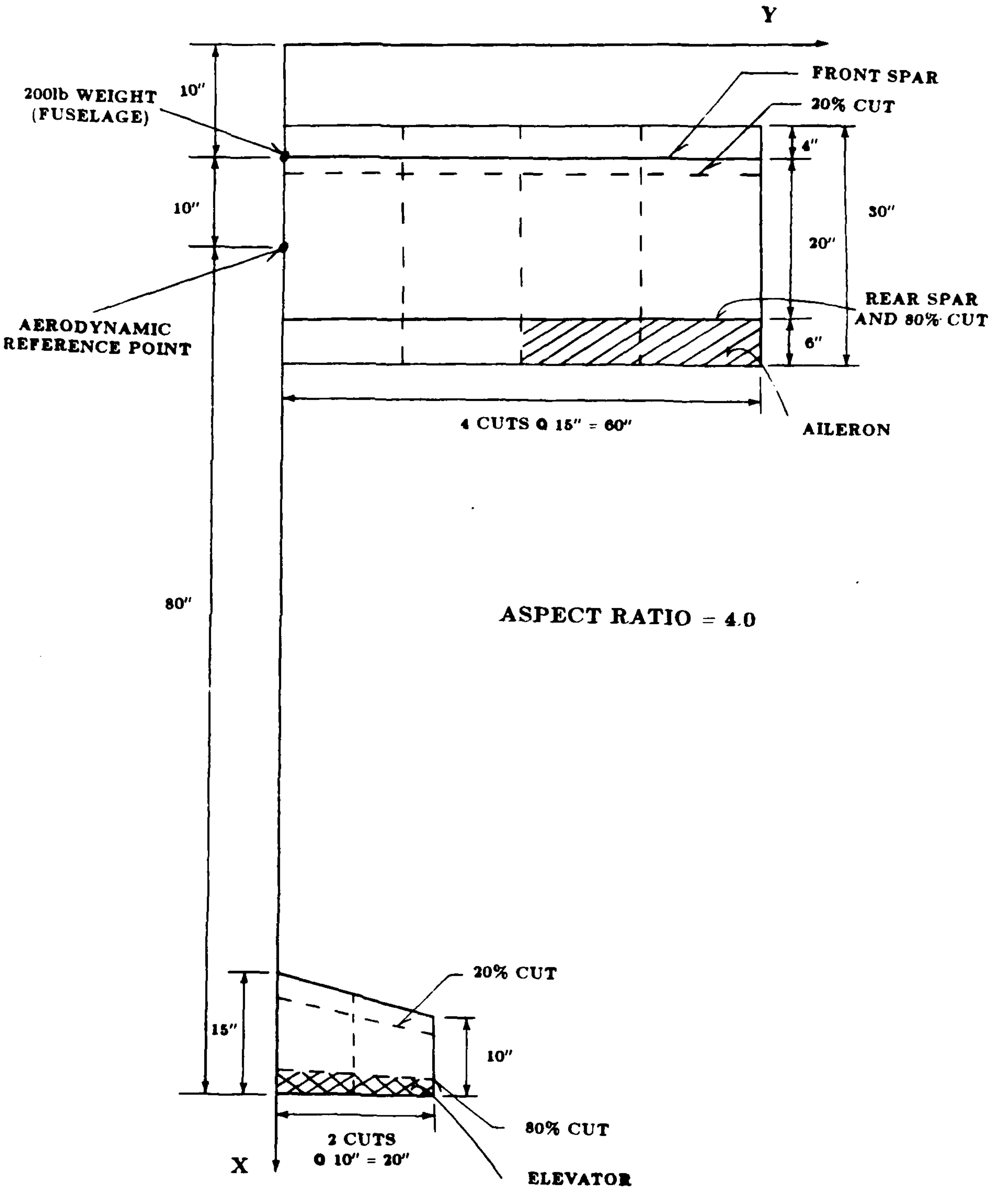


Figure 2–2: Aerodynamic Planform for Rectangular Wing

Chord station	Half thickness
0.	0.
10.	1.667
25.	1.667
50.	1.667
80.	1.667
100.	0.

Table 2–3: Airfoil Shape (all units in % chord)

Steady Aerodynamic Panel Model—Tail

The trailing edge of the elevator in figure 1 is 80" from the aerodynamic reference point (center spar). It's root chord is 15", its tip chord is 10", and its semi-span is 20". The aerodynamic box pattern for the horizontal tail shown in Figure 2–2 (3 equal spanwise cuts, and 4 chordwise cuts at 0%, 20%, 80%, and 100% of the chord). The thickness distribution is the same as for the wing as given in Table 2 with a leading edge radius of 1% An elevator is defined by the two trailing edge boxes on the tail.

2–6) For the wing-tail combination find the trimmed angle of attack, elevator deflection, and tip displacement for a symmetric **8g** pull-up maneuver defined by the flight condition in Table 2–4. Trim the aircraft for lift and pitching moment. Support the structural model for pitch and plunge rigid body modes.

Mach number	0.8
Dynamic Pressure	6.5 psi
Pitch Rate	15.7 deg/sec
Velocity	487.4 knots

Table 2–4: Flight Condition

2–7) Find the rigid and flexible stability derivatives for an anti-symmetric roll maneuver using the flight condition in Table 2–4.

For the following problems optimize the structure using the design variables for problem 2–2. For the final design in problems 2–8 through 2–10 find the values of constraints not imposed during that optimization. Which constraint(s) are critical in driving the design?

2–8) Optimize the structure for the symmetric 8g pull-up of problem 2–6. Impose stress constraints (Table 2–1) on the skins and a maximum tip rotation of 1 degree. Subtract the rotation of the support point from the relative rotation of the tip to calculate the pure elastic twist of the tip.

2–9) Repeat problem 2–8 with the addition of maximum lift effectiveness of 1.60.

2–10) Repeat problem 2–9 with the addition of a minimum aileron effectiveness of 0.30 for the anti-symmetric roll maneuver of problem 2–7.

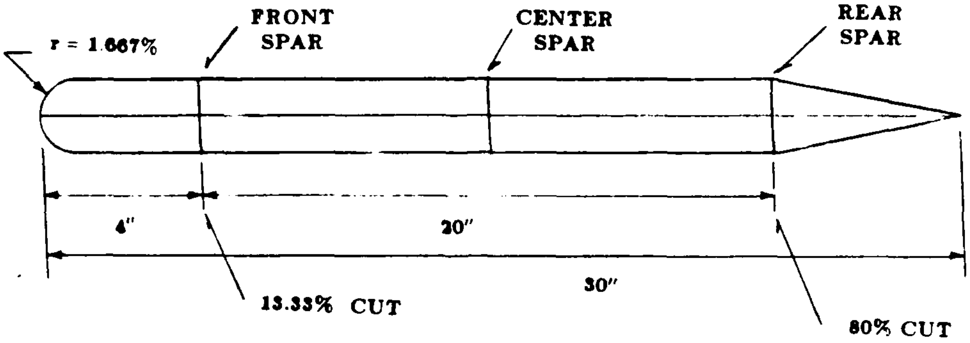


Figure 2–3: Wing Airfoil Section

ASTROS User Training Workshop
Problem Set #3: Cantilevered Plate

Structural Plate Model

The cantilevered aluminum plate in Figure 3–1 is a parallelogram (constant chord, no taper) swept 15° with a uniform thickness of 0.041". The tip is 5.52" from the cantilevered root and the unswept width (chord) is 2". The material properties are given in Table 3–1. The finite element model consists of a course 3x5 mesh.

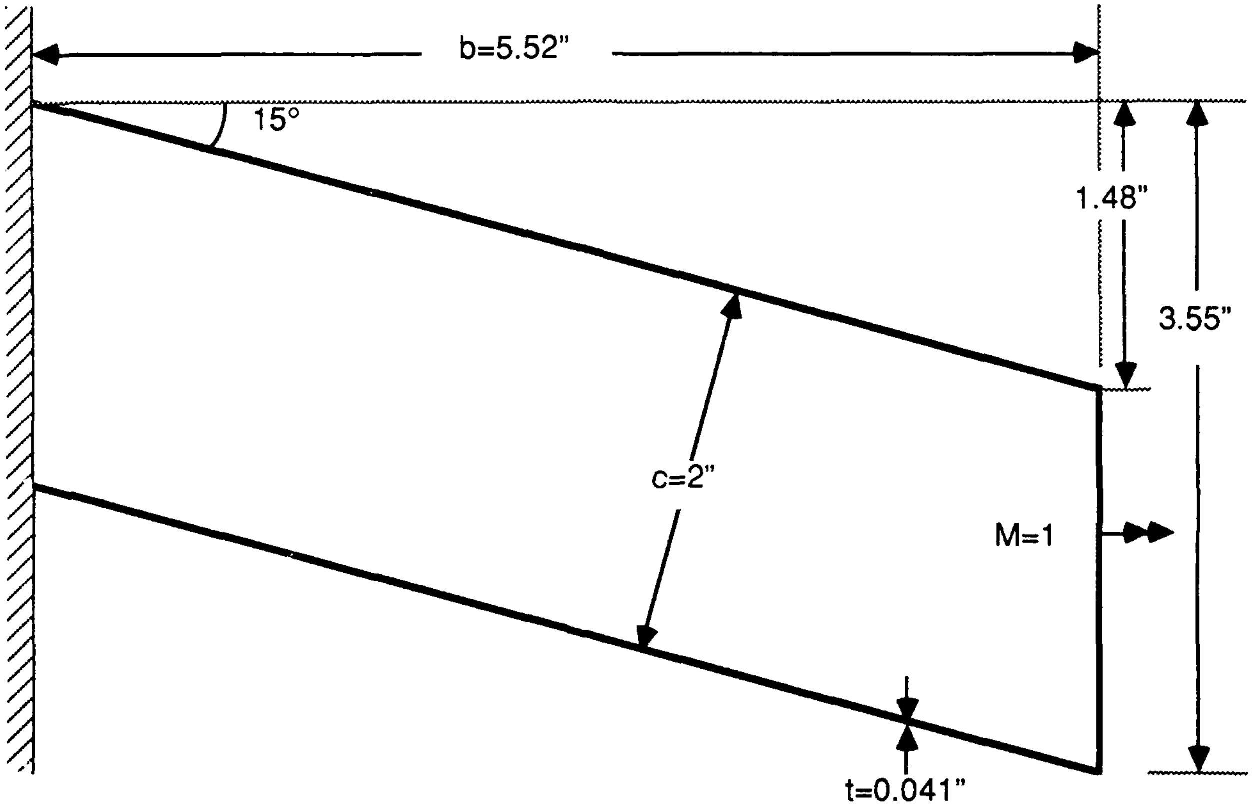


Figure 3–1: Cantilivered Plate

Young's Modulus	10.0 x 10^6 psi
Poisson's Ratio	0.33
Mass Density	2.59 x 10^{-4} lb-sec^2/in^4

Table 1—Material Properties for Magnesium

3–1) Perform a static analysis to determine the displacements for a unit moment applied at the one-third chord location of the tip. Next find the first three natural modes.

3–2) Determine the transient response in the time domain for the time-dependent load given in Figure 3–2 applied at the two free corners of the plate in the transverse direction.

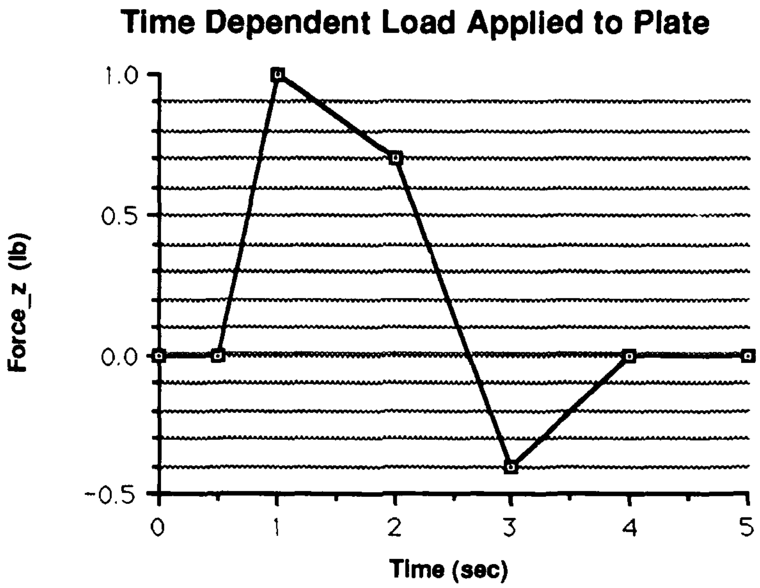


Figure 3–2: Time Dependent Load for Cantilvered Plate

Unsteady Aerodynamic Model

An unsteady aerodyanmic model consists of 5 spanwise and 10 chordwise aerodynamic boxes, equally distributed over the planform defined by Figure 3–1.

3–3) Determine the flutter speed for the subsonic and supersonic flight conditions defined in Table 3–2.

Mach number	0.45	3.0
Air Density Ratio	0.9676	0.3913
Reference Density	11.46×10^{-6} lb-sec^2/in^4	11.46×10^{-6} lb-sec^2/in^4

Table 3–2—Flight Condition

ASTROS User Training Workshop

Problem Set #4: Swept Wing

Structural Wing Box Model

The planform for a swept wing in Figure 4–1 shows the top skin of a structural model. The structural model divides the structural box into six equally spaced spanwise bays and two equal chordwise segments. The skins on both the upper and lower surface are modeled as isoparametric quadrilateral membrane elements. The ribs and spars are modeled using shear panels with rod elements for the spar caps. Rod elements are also used as posts connecting all upper and lower surface nodes. This results in 57 rod elements, 24 quadrilateral membrane elements, and 32 shear panels. The material properties are given in Table 4–1, cross-sectional properties in Table 4–2. The six nodes at the wing root are fixed (cantilvered).

4–1) Perform a statics analysis for a **4g** vertical gravity load and find the displacements and stresses.

4–2) Perform a modal analysis to determine the first five normal modes of the structure..

Design Model

The design model consists the sizes of the skins, spar webs, spar caps, and wing ribs. Use design variable linking to couple elements in each of three spanwise segments of the structure (12 design variables).

4–3) Optimize the structural box (excluding posts) subject to stress constraints on the wing skins (24 constraints) for the 4g gravity load and a 1.5 *hz* lower bound frequency constraint on the first bending mode.

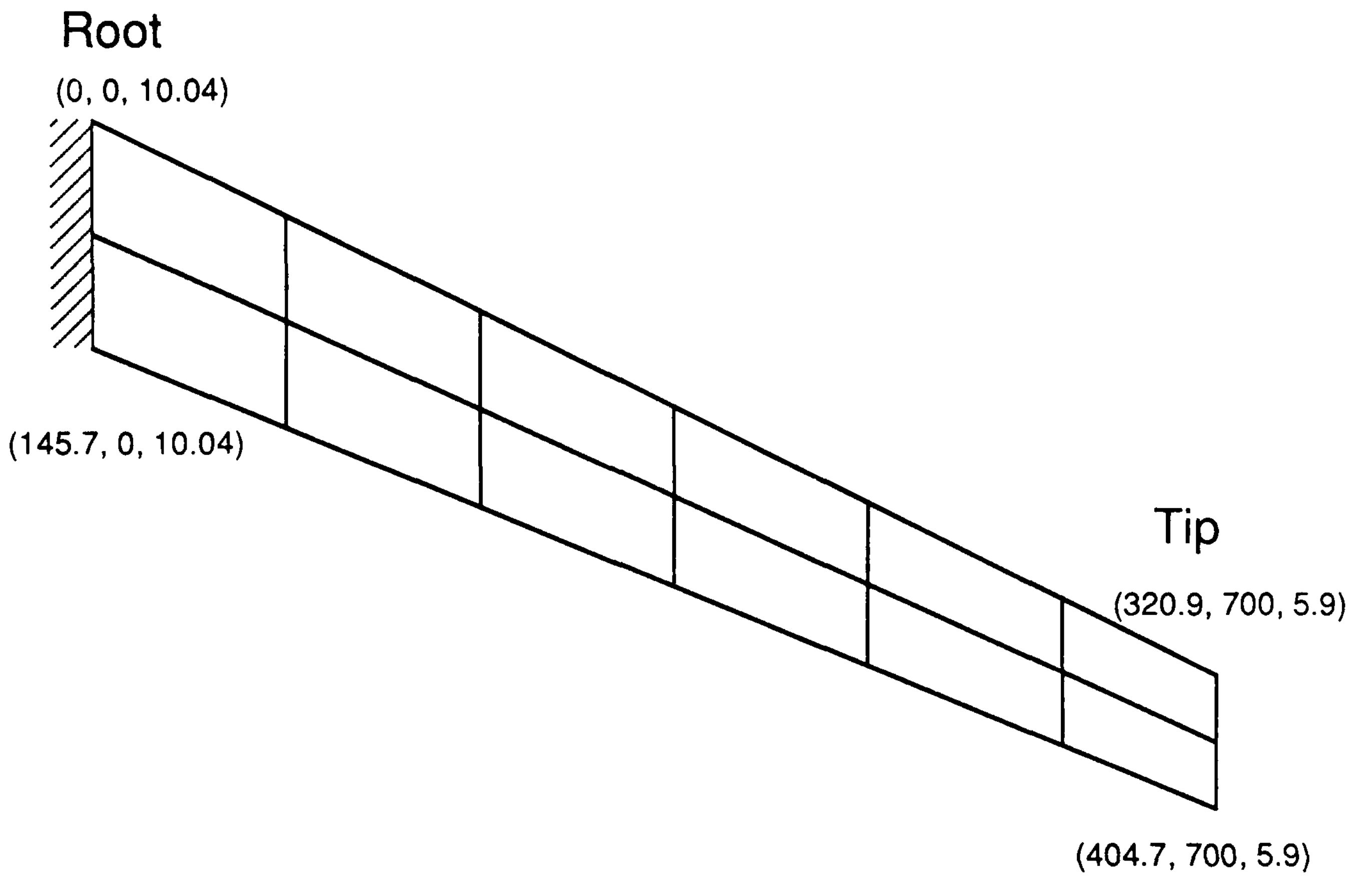


Figure 4–1—Top Surface for Swept Wing

Young's Modulus	10.0×10^6 psi
Poisson's Ratio	0.3
Weight Density	0.1 lb/in^3
Tensile Strength	60.0 ksi
Compressive Strength	50.0 ksi
Shear Strength	30.0 ksi

Table 4–1: Material Properties for Aluminum

Skin Thicknesses	0.16 in
Rib Shear Thicknesses	0.16 in
Spar Shear Thicknesses	0.32 in
Post Rod Areas	0.3 in^2
Spar Cap Rod Areas	2.0 in^2

Table 4–2: Cross-Sectional Properties

Aerodynamic Models

The planform for aerodynamic and structural models are shown together in Figure 4–2. Both the steady and unsteady aerodynamic models represent the wing as a flat plate with 50 boxes per surface. The unsteady model has ten equally spaced spanwise boxes and five chordwise boxes, while the steady model has its chordwise boxes spaced in a cosine distribution (x_i = C[1-cos(ip/5)]/2). The steady model has a horizontal stabilizer to enable trim for both lift and pitching moment. Like the wing, the tail is represented as a flat plate with ten equally spaced spanwise boxes and five chordwise boxes distributed using a cosine distribution. The last two boxes in each chordwise strip are used to represent an elevator. No structure is associated with this tail panel. Both aerodynamic wing models transfer the forces to the structural nodes on the upper surface of the structural box with a linear surface spline. The tail forces for the steady aerodynamic model are rigidly transferred to the center root of the structural box.

4–4) For flight condition 1 in Table 4–3 (Mach 0.8 at sea level) and the strucutral design point given in Table 4–2 determine whether the wing flutters.

4–5) For flight condition 2 in Table 4–3 (Mach 1.25 at 25,000 feet), find the trimmed angle of attack and elevator deflection for a symmetric **4g** pull-up maneuver.

Flight Condition	1 (unsteady)	2 (steady)
Mach number	0.8	1.25
Load Factor	1.0g	4.0g
Elevation	0. ft	25.0 x 10^3 ft
Air Density Ratio	1.0	0.4486
Dynamic Pressure		5.959 psi
Velocity	530.0 knots	752.6 knots
Pitch Rate		4.354°/sec

Table 4–3: Flight Conditions

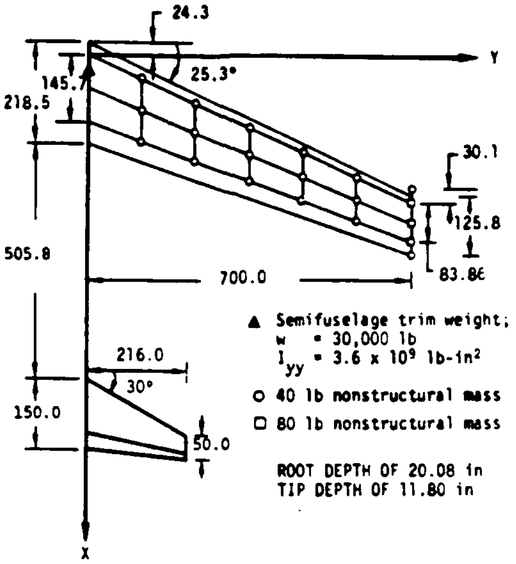


Figure 4–2: Model Geometry for Swept Wing

ASTROS User Training Workshop
Problem Set #5: Forty Member Plane Frame Optimization

The forty member plane frame shown in Figure 5–1 is subjected to the three independent loading conditions described below:

Loading condition 1:

Distributed vertical load (y direction) of 2.4 kips/ft on the intermediate levels and 1.4 kips/ft at the top level. These distributed loads are approximated by nodal forces (25% of the distributed loads at the end points and 50% at the mid span).

Loading condition 2:

Horizontal forces from the left as shown in figure 5-1 (solid arrows) plus 75% of loading condition 1.

Loading condition 3:

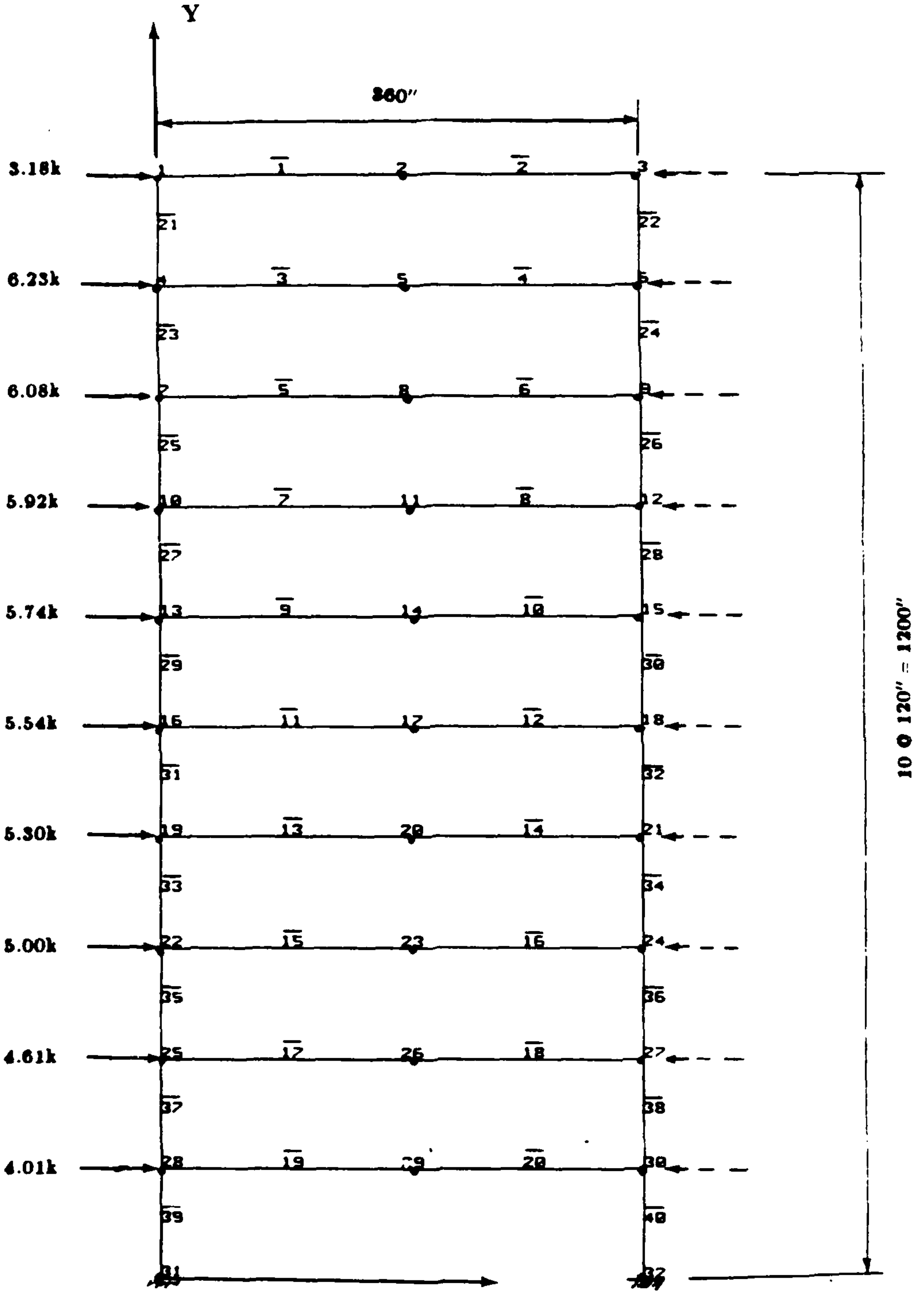
Horizontal forces from the left as shown in figure 5-1 (dashed arrows) plus 75% of loading condition 1.

Using design variable linking define 20 design variables in which the two horizontal beams at each level are grouped into one variable and similarly the the two vertical members at each level are grouped into one variable. The material properties and the intial design variables are given in Table 5–1.

Design Problem: Optimize the structure for minimum weight subjected to horizontal displacement constraints of +2" and -2 inches at the top level of the structure. The relation between the cross-sectional areas and the moment of inertia are given by $I = 4.62\ A^2$. Initial cross-sectional areas for all bars are 30 in^2. Due to symmetry of the frame there are only two independent loading conditions in view of the design variable linking.

Young's Modulus	29.0×10^6 psi
Poisson's Ratio	0.3
Weight Density	0.283 lb/in^3

Table 5–1: Material Properties for Steel



Element denoted by $\bar{i}$
Node denotee by i

Figure 5-1: Forty Member Plane Frame

Space Truss Finite Element Bulk Data

```
$
$ Modified ACOSS II Finite Element Bulk Data
$
$ Coordinates
$
SPC1, 18, 123, 3, 4, 6
GRDSET,,,,,,,456
GRID           1        -275.591   0.000   0.000
GRID           2        -157.480 196.850   0.000
GRID           3        -157.480-196.850   0.000
GRID           4           0.000 196.850   0.000
GRID           5         157.480 196.850   0.000
GRID           6         157.480-196.850   0.000
GRID           7         275.591   0.000   0.000
GRID           8        -275.591   0.000  78.740
GRID           9        -157.480 196.850  78.740
GRID          10        -157.480-196.850  78.740
GRID          11         157.480 196.850  78.740
GRID          12         157.480-196.850  78.740
GRID          13         275.591   0.000  78.740
GRID          14        -236.220   0.000 472.441
GRID          15        -157.480 157.480 472.441
GRID          16        -157.480-157.480 472.441
GRID          17         157.480 157.480 472.441
GRID          18         157.480-157.480 472.441
GRID          19         236.220   0.000 472.441
GRID          20        -196.850   0.000 866.142
GRID          21        -157.480 118.110 866.142
GRID          22        -157.480-118.110 866.142
GRID          23         157.480 118.110 866.142
GRID          24         157.480-118.110 866.142
GRID          25         196.850   0.000 866.142
GRID          26        -157.480 393.701 866.142
GRID          27         157.480 393.701 866.142
GRID          28        -157.480-393.701 866.142
GRID          29         157.480-393.701 866.142
GRID          30        -157.480 118.110 944.882
GRID          31        -157.480-118.110 944.882
GRID          32         157.480 118.110 944.882
GRID          33         157.480-118.110 944.882
$
$ Elements.
$
CROD           1   10001       1       2
CROD           2   10001       1       3
CROD           3   10001       2       3
CROD           4   10001       2       4
CROD           5   10001       3       4
CROD           6   10001       4       5
CROD           7   10001       4       6
CROD           8   10001       3       6
CROD           9   10001       5       6
CROD          10   10001       5       7
CROD          11   10001       6       7
CROD          12   10001       1       8
```

```
CROD        13   10001        2        9
CROD        14   10001        3       10
CROD        15   10001        5       11
CROD        16   10001        6       12
CROD        17   10001        7       13
CROD        18   10001        3        8
CROD        19   10001        2        8
CROD        20   10001        3        9
CROD        21   10001        4        9
CROD        22   10001        4       11
CROD        23   10001        5       12
CROD        24   10001        5       13
CROD        25   10001        6       13
CROD        26   10001        3       12
CROD        27   10001        6       10
CROD        28   10001        8        9
CROD        29   10001        8       10
CROD        30   10001        9       10
CROD        31   10001        9       12
CROD        32   10001       10       11
CROD        33   10001        9       11
CROD        34   10001       10       12
CROD        35   10001       11       12
CROD        36   10001       11       13
CROD        37   10001       12       13
CROD        38   10001       14       15
CROD        39   10001       14       16
CROD        40   10001       15       16
CROD        41   10001       17       18
CROD        42   10001       17       19
CROD        43   10001       18       19
CROD        44   10001        8       14
CROD        45   10001       10       14
CROD        46   10001       10       16
CROD        47   10001        9       16
CROD        48   10001        9       15
CROD        49   10001       11       17
CROD        50   10001        8       15
CROD        51   10001       11       18
CROD        52   10001       12       18
CROD        53   10001       12       19
CROD        54   10001       13       19
CROD        55   10001       13       17
CROD        56   10001       14       20
CROD        57   10001       14       22
CROD        58   10001       16       22
CROD        59   10001       16       21
CROD        60   10001       15       21
CROD        61   10001       15       20
CROD        62   10001       17       23
CROD        63   10001       18       23
CROD        64   10001       18       24
CROD        65   10001       19       24
CROD        66   10001       19       25
CROD        67   10001       17       25
CROD        68   10001       15       26
CROD        69   10001       16       28
CROD        70   10001       17       27
```

```
CROD            71    10001         18        29
CROD            72    10001         20        21
CROD            73    10001         20        22
CROD            74    10001         21        22
CROD            75    10001         23        24
CROD            76    10001         23        25
CROD            77    10001         24        25
CROD            78    10001         21        23
CROD            79    10001         21        24
CROD            80    10001         22        24
CROD            81    10001         21        30
CROD            82    10001         22        31
CROD            83    10001         24        33
CROD            84    10001         23        32
CROD            85    10001         23        30
CROD            86    10001         21        31
CROD            87    10001         22        33
CROD            88    10001         24        32
CROD            89    10001         30        31
CROD            90    10001         31        33
CROD            91    10001         32        33
CROD            92    10001         30        32
CROD            93    10001         31        32
CROD            94    10001         20        26
CROD            95    10001         21        26
CROD            96    10001         21        27
CROD            97    10001         23        27
CROD            98    10001         25        27
CROD            99    10001         26        27
CROD           100    10001         20        28
CROD           101    10001         22        28
CROD           102    10001         24        28
CROD           103    10001         24        29
CROD           104    10001         25        29
CROD           105    10001         28        29
CROD           106    10001         26        30
CROD           107    10001         27        32
CROD           108    10001         28        31
CROD           109    10001         29        33
CROD           110    10001         20        31
CROD           111    10001         20        30
CROD           112    10001         25        33
CROD           113    10001         25        32
$
$ Properties and materials.
$
PROD       10001       1    10.0
MAT1           1 1.85E+7 9.25E+6 0.00000 .000142 0.00000 0.00000 0.00000+MT
+MT    1 3.00E+4 3.00E+4
$
$ Non-structural masses.
$
CONM2,  9,  9, , 2.855
CONM2, 10, 10, , 2.855
CONM2, 11, 11, , 2.855
CONM2, 12, 12, , 2.855
CONM2, 14, 14, , 0.046
CONM2, 15, 15, , 0.097
```

```
CONM2, 16, 16, , 0.097
CONM2, 17, 17, , 0.097
CONM2, 18, 18, , 0.097
CONM2, 19, 19, , 0.046
CONM2, 21, 21, , 2.141
CONM2, 22, 22, , 2.141
CONM2, 23, 23, , 2.141
CONM2, 24, 24, , 2.141
CONM2, 26, 26, , 2.855
CONM2, 27, 27, , 2.855
CONM2, 28, 28, , 1.428
CONM2, 29, 29, , 1.428
```

Attachment 2
Rectangular Wing Finite Element Bulk Data

```
$
$ Coordinates for Rectangular Wing Box (inches)
$
GRDSET                                                        456
GRID           1         10.0    60.0      0.50
GRID           2         10.0    60.0     -0.50
GRID           3         20.0    60.0      0.50
GRID           4         20.0    60.0     -0.50
GRID           5         30.0    60.0      0.50
GRID           6         30.0    60.0     -0.50
GRID           7         10.0    30.0      0.50
GRID           8         10.0    30.0     -0.50
GRID           9         20.0    30.0      0.50
GRID          10         20.0    30.0     -0.50
GRID          11         30.0    30.0      0.50
GRID          12         30.0    30.0     -0.50
GRID          13         10.0    0.0       0.50
GRID          14         10.0    0.0      -0.50
GRID          15         20.0    0.0       0.50
GRID          16         20.0    0.0      -0.50
GRID          17         30.0    0.0       0.50
GRID          18         30.0    0.0      -0.50
$ Aerodynamic Reference Point
GRID          20         20.0    0.0      0.0                     126
$
$ Rigid Connection to Fuselage
$
$ Root connection chordwise
MPC, 100, 13, 1, -1.0, 20, 1, 1.0, , , 20, 5,  0.5
MPC, 100, 14, 1, -1.0, 20, 1, 1.0, , , 20, 5, -0.5
MPC, 100, 15, 1, -1.0, 20, 1, 1.0, , , 20, 5,  0.5
MPC, 100, 16, 1, -1.0, 20, 1, 1.0, , , 20, 5, -0.5
MPC, 100, 17, 1, -1.0, 20, 1, 1.0, , , 20, 5,  0.5
MPC, 100, 18, 1, -1.0, 20, 1, 1.0, , , 20, 5, -0.5
$ Root connection spanwise
MPC, 100, 13, 2, -1.0, 20, 2, 1.0, , , 20, 4, -0.5
MPC, 100, 14, 2, -1.0, 20, 2, 1.0, , , 20, 4,  0.5
MPC, 100, 15, 2, -1.0, 20, 2, 1.0, , , 20, 4, -0.5
MPC, 100, 16, 2, -1.0, 20, 2, 1.0, , , 20, 4,  0.5
MPC, 100, 17, 2, -1.0, 20, 2, 1.0, , , 20, 4, -0.5
MPC, 100, 18, 2, -1.0, 20, 2, 1.0, , , 20, 4,  0.5
$ Root connection veritically
MPC, 100, 13, 3, -1.0, 20, 3, 1.0, , , 20, 5, 10.0
MPC, 100, 14, 3, -1.0, 20, 3, 1.0, , , 20, 5, 10.0
MPC, 100, 15, 3, -1.0, 20, 3, 1.0
MPC, 100, 16, 3, -1.0, 20, 3, 1.0
MPC, 100, 17, 3, -1.0, 20, 3, 1.0, , , 20, 5, -10.0
MPC, 100, 18, 3, -1.0, 20, 3, 1.0, , , 20, 5, -10.0
$
$ Top Skins
$
CQDMEM1     10001    10001        1       3       9       7  0.0
CQDMEM1     10002    10001        3       5      11       9  0.0
CQDMEM1     10003    10002        7       9      15      13  0.0
CQDMEM1     10004    10002        9      11      17      15  0.0
```

```
PQDMEM1    10001       2  0.2000
PQDMEM1    10002       2  0.2000
$
$ Bottom Skins
$
CQDMEM1    20001   20001       2       4      10       8 0.0
CQDMEM1    20002   20001       4       6      12      10 0.0
CQDMEM1    20003   20002       8      10      16      14 0.0
CQDMEM1    20004   20002      10      12      18      16 0.0
PQDMEM1    20001       2  0.2000
PQDMEM1    20002       2  0.2000
$
$ Spars
$
CSHEAR     30001   30001       1       2       8       7
CSHEAR     30002   30001       3       4      10       9
CSHEAR     30003   30001       5       6      12      11
CSHEAR     30004   30001       7       8      14      13
CSHEAR     30005   30001       9      10      16      15
CSHEAR     30006   30001      11      12      18      17
PSHEAR     30001       1  0.0500  0.0
$
$ Ribs
$
CSHEAR     40001   40001       1       3       4       2
CSHEAR     40002   40001       3       5       6       4
CSHEAR     40003   40001       7       9      10       8
CSHEAR     40004   40001       9      11      12      10
CSHEAR     40005   40001      13      15      16      14
CSHEAR     40006   40001      15      17      18      16
PSHEAR     40001       1  0.0500  0.0
$
$ Posts
$
CROD       50001   50001       1       2
CROD       50002   50001       3       4
CROD       50003   50001       5       6
CROD       50004   50001       7       8
CROD       50005   50001       9      10
CROD       50006   50001      11      12
CROD       50007   50001      13      14
CROD       50008   50001      15      16
CROD       50009   50001      17      18
PROD       50001       1    0.01    0.00   0.000   0.000
$
$ Materials
$
MAT1           1 10.0E+6         0.30    0.10
+MT1
+MT1     20.0E+3 15.0E+3 12.0E+3
MAT1           2 10.0E+6         0.30    0.10
+MT2
+MT2     20.0E+3 15.0E+3 12.0E+3
$
$ Fuselage Mass
$
CONM2, 1, 20, , 200.0, -10.0, 0.0, 0.0, , +CONM
+CONM, , , 22500., , , 22500.
```

```
$
$ Weight to Mass Conversion (for densities and lumped masses)
$
CONVERT, MASS, 0.00259
```

Attachment 3
Cantilevered Plate Finite Element Bulk Data

```
$
$     15 DEGREE SWEPT, UNTAPERED WING. (SEE NACA RM L55E11 FOR A
$     DESCRIPTION OF THE MODEL)  THE STRUCTURE IS MODELLED USING
$     15 CQUAD4 ELEMENTS IN A 3 X 15 ELEMENT GRID.  24 GRID POINTS
$     ARE REQUIRED TO DEFINE THE CORNERS OF THE BENDING ELEMENTS.
$
$     M=.45  EXPERIMENTAL RESULTS:     FLUTTER VEL = 495 FPS (5940
IN/SEC)
$                                      FLUTTER FREQ = 120 HZ
$
GRID           1          0.000   0.000   0.000          123456
GRID           2          0.690   0.000   0.000          123456
GRID           3          1.380   0.000   0.000          123456
GRID           4          2.070   0.000   0.000          123456
$
GRID           5          0.296   1.104   0.000
GRID           6          0.986   1.104   0.000
GRID           7          1.676   1.104   0.000
GRID           8          2.366   1.104   0.000
$
GRID           9          0.592   2.208   0.000
GRID          10          1.282   2.208   0.000
GRID          11          1.972   2.208   0.000
GRID          12          2.662   2.208   0.000
$
GRID          13          0.888   3.312   0.000
GRID          14          1.578   3.312   0.000
GRID          15          2.268   3.312   0.000
GRID          16          2.958   3.312   0.000
$
GRID          17          1.184   4.416   0.000
GRID          18          1.874   4.416   0.000
GRID          19          2.564   4.416   0.000
GRID          20          3.254   4.416   0.000
$
GRID          21          1.480   5.520   0.000
GRID          22          2.170   5.520   0.000
GRID          23          2.860   5.520   0.000
GRID          24          3.550   5.520   0.000
$
CQUAD4       101     100       1       2       6       5
CQUAD4       102     100       2       3       7       6
CQUAD4       103     100       3       4       8       7
CQUAD4       104     100       5       6      10       9
CQUAD4       105     100       6       7      11      10
CQUAD4       106     100       7       8      12      11
CQUAD4       107     100       9      10      14      13
CQUAD4       108     100      10      11      15      14
CQUAD4       109     100      11      12      16      15
CQUAD4       110     100      13      14      18      17
CQUAD4       111     100      14      15      19      18
CQUAD4       112     100      15      16      20      19
CQUAD4       113     100      17      18      22      21
CQUAD4       114     100      18      19      23      22
CQUAD4       115     100      19      20      24      23
```

Attachment 4
Swept Wing Finite Element Bulk Data

```
$
$        SWEPT WING MODEL FROM
$        "A ROOT LOCUS BASED FLUTTER SYNTHESIS PROCEDURE" BY
$        P. HAJELA   STANFORD U.
$        WITH A FLUTTER CONSTRAINT AT SEA LEVEL FOR M=0.80
$        STRESS CONSTRAINTS UNDER A 4 G STATIC AIR LOAD AT
$        25000 FT. (M = 1.25) AND A 1.5 HZ LOW. BOUND FREQ. CONSTRNT.
$
GRID           1             0.0     0.0  10.039
GRID           2             0.0     0.0 -10.039
GRID           3         72.8345     0.0  10.039
GRID           4         72.8345     0.0 -10.039
GRID           5        145.6690     0.0  10.039
GRID           6        145.6690     0.0 -10.039
GRID           7         53.4758 116.667  9.3502
GRID           8         53.4758 116.667 -9.3502
GRID           9        121.1590 116.667  9.3502
GRID          10        121.1590 116.667 -9.3502
GRID          11        188.8430 116.667  9.3502
GRID          12        188.8430 116.667 -9.3502
GRID          13        106.9520 233.333  8.6613
GRID          14        106.9520 233.333 -8.6613
GRID          15        169.4840 233.333  8.6613
GRID          16        169.4840 233.333 -8.6613
GRID          17        232.0170 233.333  8.6613
GRID          18        232.0170 233.333 -8.6613
GRID          19        160.4280 350.0    7.9724
GRID          20        160.4280 350.0   -7.9724
GRID          21        217.8090 350.0    7.9724
GRID          22        217.8090 350.0   -7.9724
GRID          23        275.1910 350.0    7.9724
GRID          24        275.1910 350.0   -7.9724
GRID          25        213.9030 466.667  7.2834
GRID          26        213.9030 466.667 -7.2834
GRID          27        266.1340 466.667  7.2834
GRID          28        266.1340 466.667 -7.2834
GRID          29        318.3650 466.667  7.2834
GRID          30        318.3650 466.667 -7.2834
GRID          31        267.3780 583.333  6.5945
GRID          32        267.3780 583.333 -6.5945
GRID          33        314.4590 583.333  6.5945
GRID          34        314.4590 583.333 -6.5945
GRID          35        361.5390 583.333  6.5945
GRID          36        361.5390 583.333 -6.5945
GRID          37        320.8550 700.0    5.9055
GRID          38        320.8550 700.0   -5.9055
GRID          39        362.7840 700.0    5.9055
GRID          40        362.7840 700.0   -5.9055
GRID          41        404.7130 700.0    5.9055
GRID          42        404.7130 700.0   -5.9055
GRID          43        290.7840 700.0       0.0
GRID          44        434.7830 700.0       0.0
GRID          45         72.8345 0.0         0.0
$
```

```
$       BOUNDARY CONDITION 1
$
MPC,    101,     43,    1,    -4.0,   37,    1,   1.0, , MPC4311
+PC4311,  ,      38,    1,     1.0,   39,    1,   1.0, , MPC4312
+PC4312,  ,      40,    1,     1.0
MPC,    101,     44,    1,    -4.0,   39,    1,   1.0, , MPC4411
+PC4411,  ,      40,    1,     1.0,   41,    1,   1.0, , MPC4412
+PC4412,  ,      42,    1,     1.0
MPC,    101,     43,    2,    -4.0,   37,    2,   1.0, , MPC4321
+PC4321,  ,      38,    2,     1.0,   39,    2,   1.0, , MPC4322
+PC4322,  ,      40,    2,     1.0
MPC,    101,     44,    2,    -4.0,   39,    2,   1.0, , MPC4421
+PC4421,  ,      40,    2,     1.0,   41,    2,   1.0, , MPC4422
+PC4422,  ,      42,    2,     1.0
MPC,    101,     43,    3,       -1.0,   37,    3, 0.85859, , MPC4331
+PC4331,  ,      38,    3,    0.85859,   39,    3,-0.35859, , MPC4332
+PC4332,  ,      40,    3,   -0.35859
MPC,    101,     44,    3,       -1.0,   39,    3,-0.35859, , MPC4431
+PC4431,  ,      40,    3,   -0.35859,   41,    3, 0.85859, , MPC4432
+PC4432,  ,      42,    3,    0.85859
SPC1,       10,  123456,     1,    THRU,    6,    45
SPC1,       10,     456,     7,    THRU,   44
ASET1,  100,  3,  7,  9, 11, 13, 15, 17, ASETA
+SETA,   19, 21, 23, 25, 27, 29, 31, 33, ASETB
+SETB,   35, 37, 39, 41
$
$        BOUNDARY CONDITION 2
$
MPCADD,   2101,    101,   201
MPC,    201,     3,   1,      1.0,  45,   5,  -10.04
MPC,    201,     3,   3,      1.0,  45,   3,  -1.0
MPC,    201,     4,   1,      1.0,  45,   5,  10.04
MPC,    201,     4,   3,      1.0,  45,   3,  -1.0
SPC1,  110,     1246,      45
SPC1,  110,  2456,        1,     THRU,       6
SPC1,  110,   456,        7,     THRU,      44
ASET1,  1100,  3,  7,  9, 11, 13, 15, 17, ASETA
+SETA,   19, 21, 23, 25, 27, 29, 31, 33, ASETB
+SETB,   35, 37, 39, 41, 45, 1, 5
ASET1, 1100, 5, 45
SUPORT,  1,      45,    35
$
$       UPPER AND LOWER SKINS 100 - UPPER, 200 - LOWER
$
CQDMEM1       101    1004      1       7       9       3
CQDMEM1       201    1004      2       8      10       4
CQDMEM1       102    1004      3       9      11       5
CQDMEM1       202    1004      4      10      12       6
CQDMEM1       103    1004      7      13      15       9
CQDMEM1       203    1004      8      14      16      10
CQDMEM1       104    1004      9      15      17      11
CQDMEM1       204    1004     10      16      18      12
CQDMEM1       105    1005     13      19      21      15
CQDMEM1       205    1005     14      20      22      16
CQDMEM1       106    1005     15      21      23      17
CQDMEM1       206    1005     16      22      24      18
CQDMEM1       107    1005     19      25      27      21
CQDMEM1       207    1005     20      26      28      22
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CQDMEM1      108    1005     21     27     29     23
CQDMEM1      208    1005     22     28     30     24
CQDMEM1      109    1006     25     31     33     27
CQDMEM1      209    1006     26     32     34     28
CQDMEM1      110    1006     27     33     35     29
CQDMEM1      210    1006     28     34     36     30
CQDMEM1      111    1006     31     37     39     33
CQDMEM1      211    1006     32     38     40     34
CQDMEM1      112    1006     33     39     41     35
CQDMEM1      212    1006     34     40     42     36
$
$       MODEL SUB STRUCTURE
$       SHEAR PANELS:  300 - LE,   350 - MID, 400 - TE, 500 - CHORDWISE
$       AXIAL RODS:  600 - INBOARD  2 BAYS
$                    700 - MID SPAN 2 BAYS
$                    800 - OUTBOARD 2 BAYS
$
CSHEAR       301    2007      1      2      8      7
CSHEAR       351    2007      3      4     10      9
CSHEAR       401    2007      5      6     12     11
CSHEAR       302    2007      7      8     14     13
CSHEAR       352    2007      9     10     16     15
CSHEAR       402    2007     11     12     18     17
CSHEAR       303    2008     13     14     20     19
CSHEAR       353    2008     15     16     22     21
CSHEAR       403    2008     17     18     24     23
CSHEAR       304    2008     19     20     26     25
CSHEAR       354    2008     21     22     28     27
CSHEAR       404    2008     23     24     30     29
CSHEAR       305    2009     25     26     32     31
CSHEAR       355    2009     27     28     34     33
CSHEAR       405    2009     29     30     36     35
CSHEAR       306    2009     31     32     38     37
CSHEAR       356    2009     33     34     40     39
CSHEAR       406    2009     35     36     42     41
CSHEAR       501    2010      7      8     10      9
CSHEAR       502    2010      9     10     12     11
CSHEAR       503    2010     13     14     16     15
CSHEAR       504    2010     15     16     18     17
CSHEAR       505    2011     19     20     22     21
CSHEAR       506    2011     21     22     24     23
CSHEAR       507    2011     25     26     28     27
CSHEAR       508    2011     27     28     30     29
CSHEAR       509    2012     31     32     34     33
CSHEAR       510    2012     33     34     36     35
CSHEAR       511    2012     37     38     40     39
CSHEAR       512    2012     39     40     42     41
CSHEAR       513    2010      1      2      4      3
CSHEAR       514    2010      3      4      6      5
$
CONROD      1201       1      2     90    0.3
CONROD      1202       3      4     90    0.3
CONROD      1203       5      6     90    0.3
CONROD      1301       7      8     90    0.3
CONROD      1302      13     14     90    0.3
CONROD      1303      19     20     90    0.3
CONROD      1304      25     26     90    0.3
CONROD      1305      31     32     90    0.3
```

```
CONROD     1306     37     38     90     0.3
CONROD     1401      9     10     90     0.3
CONROD     1402     15     16     90     0.3
CONROD     1403     21     22     90     0.3
CONROD     1404     27     28     90     0.3
CONROD     1405     33     34     90     0.3
CONROD     1406     39     40     90     0.3
CONROD     1501     11     12     90     0.3
CONROD     1502     17     18     90     0.3
CONROD     1503     23     24     90     0.3
CONROD     1504     29     30     90     0.3
CONROD     1505     35     36     90     0.3
CONROD     1506     41     42     90     0.3
CROD        601   6001      1      7
CROD        602   6001      2      8
CROD        603   6001      3      9
CROD        604   6001      4     10
CROD        605   6001      5     11
CROD        606   6001      6     12
CROD        607   6001      7     13
CROD        608   6001      8     14
CROD        609   6001      9     15
CROD        610   6001     10     16
CROD        611   6001     11     17
CROD        612   6001     12     18
CROD        701   7002     13     19
CROD        702   7002     14     20
CROD        703   7002     15     21
CROD        704   7002     16     22
CROD        705   7002     17     23
CROD        706   7002     18     24
CROD        707   7002     19     25
CROD        708   7002     20     26
CROD        709   7002     21     27
CROD        710   7002     22     28
CROD        711   7002     23     29
CROD        712   7002     24     30
CROD        801   8003     25     31
CROD        802   8003     26     32
CROD        803   8003     27     33
CROD        804   8003     28     34
CROD        805   8003     29     35
CROD        806   8003     30     36
CROD        807   8003     31     37
CROD        808   8003     32     38
CROD        809   8003     33     39
CROD        810   8003     34     40
CROD        811   8003     35     41
CROD        812   8003     36     42
$
CONM2     50001      7          20.0
CONM2     50002      8          20.0
CONM2     50003      9          20.0
CONM2     50004     10          20.0
CONM2     50005     11          20.0
CONM2     50006     12          20.0
CONM2     50007     13          20.0
CONM2     50008     14          20.0
```

```
CONM2      50009      15            20.0
CONM2      50010      16            20.0
CONM2      50011      17            20.0
CONM2      50012      18            20.0
CONM2      50013      19            20.0
CONM2      50014      20            20.0
CONM2      50015      21            20.0
CONM2      50016      22            20.0
CONM2      50017      23            20.0
CONM2      50018      24            20.0
CONM2      50019      25            20.0
CONM2      50020      26            20.0
CONM2      50021      27            20.0
CONM2      50022      28            20.0
CONM2      50023      29            20.0
CONM2      50024      30            20.0
CONM2      50025      31            20.0
CONM2      50026      32            20.0
CONM2      50027      33            20.0
CONM2      50028      34            20.0
CONM2      50029      35            20.0
CONM2      50030      36            20.0
CONM2      50031      37            40.0
CONM2      50032      38            40.0
CONM2      50033      39            40.0
CONM2      50034      40            40.0
CONM2      50035      41            40.0
CONM2      50036      42            40.0
CONM2      50037      43            40.0
CONM2      50038      44            40.0
$
$      TRIM WEIGHT AT ROOT 1/4 CHORD INCLUDING ROTATIONAL INERTIA
$
CONM2,     51001,     45, , 30000.0, -36.0, , , , +CM01
+CM01,          ,       , 3.6E9
$
PQDMEM1,  1004,   91,    0.04
PQDMEM1,  1005,   91,    0.04
PQDMEM1,  1006,   91,    0.04
$
PSHEAR,   2007,   90,    0.04
PSHEAR,   2008,   90,    0.04
PSHEAR,   2009,   90,    0.04
PSHEAR,   2010,   90,    0.04
PSHEAR,   2011,   90,    0.04
PSHEAR,   2012,   90,    0.04
$
PROD,     6001,   90,    1.0
PROD,     7002,   90,    1.0
PROD,     8003,   90,    1.0
$
$ Material properties
$
MAT1,       90,     10.E6,   ,   0.3,    0.1
MAT1,       91,     10.E6,   ,   0.3,    0.1, , , , ABC
+BC,   60000.0,   50000.0, 30000.0
$
CONVERT,  MASS,  2.588E-3
```

Attachment 5
Plane Frame Finite Element Bulk Data

```
GRDSET, , , , , , , 345
GRID, 1, ,   0.,1200., 0.
GRID, 2, , 180.,1200., 0.
GRID, 3, , 360.,1200., 0.
GRID, 4, ,   0.,1080., 0.
GRID, 5, , 180.,1080., 0.
GRID, 6, , 360.,1080., 0.
GRID, 7, ,   0.,960., 0.
GRID, 8, , 180.,960., 0.
GRID, 9, , 360.,960., 0.
GRID,10, ,   0.,840., 0.
GRID,11, , 180.,840., 0.
GRID,12, , 360.,840., 0.
GRID,13, ,   0.,720., 0.
GRID,14, , 180.,720., 0.
GRID,15, , 360.,720., 0.
GRID,16, ,   0.,600., 0.
GRID,17, , 180.,600., 0.
GRID,18, , 360.,600., 0.
GRID,19, ,   0.,480., 0.
GRID,20, , 180.,480., 0.
GRID,21, , 360.,480., 0.
GRID,22, ,   0.,360., 0.
GRID,23, , 180.,360., 0.
GRID,24, , 360.,360., 0.
GRID,25, ,   0.,240., 0.
GRID,26, , 180.,240., 0.
GRID,27, , 360.,240., 0.
GRID,28, ,   0.,120., 0.
GRID,29, , 180.,120., 0.
GRID,30, , 360.,120., 0.
GRID,31, ,   0.,  0., 0.
GRID,32, , 360.,  0., 0.
BAROR, , , , , 0., 0., 1.
CBAR, 1, 1, 1, 2, , , ,1000.
CBAR, 2, 1, 2, 3, , , ,1000.
CBAR, 3, 1, 4, 5, , , ,1000.
CBAR, 4, 1, 5, 6, , , ,1000.
CBAR, 5, 1, 7, 8, , , ,1000.
CBAR, 6, 1, 8, 9, , , ,1000.
CBAR, 7, 1, 10, 11, , , ,1000.
CBAR, 8, 1, 11, 12, , , ,1000.
CBAR, 9, 1, 13, 14, , , ,1000.
CBAR,10, 1, 14, 15, , , ,1000.
CBAR,11, 1, 16, 17, , , ,1000.
CBAR,12, 1, 17, 18, , , ,1000.
CBAR,13, 1, 19, 20, , , ,1000.
CBAR,14, 1, 20, 21, , , ,1000.
CBAR,15, 1, 22, 23, , , ,1000.
CBAR,16, 1, 23, 24, , , ,1000.
CBAR,17, 1, 25, 26, , , ,1000.
CBAR,18, 1, 26, 27, , , ,1000.
CBAR,19, 1, 28, 29, , , ,1000.
CBAR,20, 1, 29, 30, , , ,1000.
CBAR,21, 1, 1,  4, , , ,1000.
```

```
CBAR,22, 1, 3,  6, , , ,1000.
CBAR,23, 1, 4,  7, , , ,1000.
CBAR,24, 1, 6,  9, , , ,1000.
CBAR,25, 1, 7, 10, , , ,1000.
CBAR,26, 1, 9, 12, , , ,1000.
CBAR,27, 1, 10, 13, , , ,1000.
CBAR,28, 1, 12, 15, , , ,1000.
CBAR,29, 1, 13, 16, , , ,1000.
CBAR,30, 1, 15, 18, , , ,1000.
CBAR,31, 1, 16, 19, , , ,1000.
CBAR,32, 1, 18, 21, , , ,1000.
CBAR,33, 1, 19, 22, , , ,1000.
CBAR,34, 1, 21, 24, , , ,1000.
CBAR,35, 1, 22, 25, , , ,1000.
CBAR,36, 1, 24, 27, , , ,1000.
CBAR,37, 1, 25, 28, , , ,1000.
CBAR,38, 1, 27, 30, , , ,1000.
CBAR,39, 1, 28, 31, , , ,1000.
CBAR,40, 1, 30, 32, , , ,1000.
FORCE, 1, 1, , 1000.,  0.,  -6., 0.
FORCE, 1, 2, , 1000.,  0., -24., 0.
FORCE, 1, 3, , 1000.,  0.,  -6., 0.
FORCE, 1, 4, , 1000.,  0., -12., 0.
FORCE, 1, 5, , 1000.,  0., -48., 0.
FORCE, 1, 6, , 1000.,  0., -12., 0.
FORCE, 1, 7, , 1000.,  0., -12., 0.
FORCE, 1, 8, , 1000.,  0., -48., 0.
FORCE, 1, 9, , 1000.,  0., -12., 0.
FORCE, 1,10, , 1000.,  0., -12., 0.
FORCE, 1,11, , 1000.,  0., -48., 0.
FORCE, 1,12, , 1000.,  0., -12., 0.
FORCE, 1,13, , 1000.,  0., -12., 0.
FORCE, 1,14, , 1000.,  0., -48., 0.
FORCE, 1,15, , 1000.,  0., -12., 0.
FORCE, 1,16, , 1000.,  0., -12., 0.
FORCE, 1,17, , 1000.,  0., -48., 0.
FORCE, 1,18, , 1000.,  0., -12., 0.
FORCE, 1,19, , 1000.,  0., -12., 0.
FORCE, 1,20, , 1000.,  0., -48., 0.
FORCE, 1,21, , 1000.,  0., -12., 0.
FORCE, 1,22, , 1000.,  0., -12., 0.
FORCE, 1,23, , 1000.,  0., -48., 0.
FORCE, 1,24, , 1000.,  0., -12., 0.
FORCE, 1,25, , 1000.,  0., -12., 0.
FORCE, 1,26, , 1000.,  0., -48., 0.
FORCE, 1,27, , 1000.,  0., -12., 0.
FORCE, 1,28, , 1000.,  0., -12., 0.
FORCE, 1,29, , 1000.,  0., -48., 0.
FORCE, 1,30, , 1000.,  0., -12., 0.
FORCE, 2, 1, , 1000.,  0., -4.5, 0.
FORCE, 2, 2, , 1000.,  0., -18., 0.
FORCE, 2, 3, , 1000.,  0., -4.5, 0.
FORCE, 2, 4, , 1000.,  0.,  -9., 0.
FORCE, 2, 5, , 1000.,  0., -36., 0.
FORCE, 2, 6, , 1000.,  0.,  -9., 0.
FORCE, 2, 7, , 1000.,  0.,  -9., 0.
FORCE, 2, 8, , 1000.,  0., -36., 0.
FORCE, 2, 9, , 1000.,  0.,  -9., 0.
```

```
FORCE, 2,10, , 1000.,  0.,  -9., 0.
FORCE, 2,11, , 1000.,  0., -36., 0.
FORCE, 2,12, , 1000.,  0.,  -9., 0.
FORCE, 2,13, , 1000.,  0.,  -9., 0.
FORCE, 2,14, , 1000.,  0., -36., 0.
FORCE, 2,15, , 1000.,  0.,  -9., 0.
FORCE, 2,16, , 1000.,  0.,  -9., 0.
FORCE, 2,17, , 1000.,  0., -36., 0.
FORCE, 2,18, , 1000.,  0.,  -9., 0.
FORCE, 2,19, , 1000.,  0.,  -9., 0.
FORCE, 2,20, , 1000.,  0., -36., 0.
FORCE, 2,21, , 1000.,  0.,  -9., 0.
FORCE, 2,22, , 1000.,  0.,  -9., 0.
FORCE, 2,23, , 1000.,  0., -36., 0.
FORCE, 2,24, , 1000.,  0.,  -9., 0.
FORCE, 2,25, , 1000.,  0.,  -9., 0.
FORCE, 2,26, , 1000.,  0., -36., 0.
FORCE, 2,27, , 1000.,  0.,  -9., 0.
FORCE, 2,28, , 1000.,  0.,  -9., 0.
FORCE, 2,29, , 1000.,  0., -36., 0.
FORCE, 2,30, , 1000.,  0.,  -9., 0.
FORCE, 2, 1, , 1000.,  3.18, 0., 0.
FORCE, 2, 4, , 1000.,  6.23, 0., 0.
FORCE, 2, 7, , 1000.,  6.08, 0., 0.
FORCE, 2,10, , 1000.,  5.92, 0., 0.
FORCE, 2,13, , 1000.,  5.74, 0., 0.
FORCE, 2,16, , 1000.,  5.54, 0., 0.
FORCE, 2,19, , 1000.,  5.30, 0., 0.
FORCE, 2,22, , 1000.,  5.00, 0., 0.
FORCE, 2,25, , 1000.,  4.61, 0., 0.
FORCE, 2,28, , 1000.,  4.00, 0., 0.
FORCE, 3, 1, , 1000.,  0., -4.5, 0.
FORCE, 3, 2, , 1000.,  0., -18., 0.
FORCE, 3, 3, , 1000.,  0., -4.5, 0.
FORCE, 3, 4, , 1000.,  0.,  -9., 0.
FORCE, 3, 5, , 1000.,  0., -36., 0.
FORCE, 3, 6, , 1000.,  0.,  -9., 0.
FORCE, 3, 7, , 1000.,  0.,  -9., 0.
FORCE, 3, 8, , 1000.,  0., -36., 0.
FORCE, 3, 9, , 1000.,  0.,  -9., 0.
FORCE, 3,10, , 1000.,  0.,  -9., 0.
FORCE, 3,11, , 1000.,  0., -36., 0.
FORCE, 3,12, , 1000.,  0.,  -9., 0.
FORCE, 3,13, , 1000.,  0.,  -9., 0.
FORCE, 3,14, , 1000.,  0., -36., 0.
FORCE, 3,15, , 1000.,  0.,  -9., 0.
FORCE, 3,16, , 1000.,  0.,  -9., 0.
FORCE, 3,17, , 1000.,  0., -36., 0.
FORCE, 3,18, , 1000.,  0.,  -9., 0.
FORCE, 3,19, , 1000.,  0.,  -9., 0.
FORCE, 3,20, , 1000.,  0., -36., 0.
FORCE, 3,21, , 1000.,  0.,  -9., 0.
FORCE, 3,22, , 1000.,  0.,  -9., 0.
FORCE, 3,23, , 1000.,  0., -36., 0.
FORCE, 3,24, , 1000.,  0.,  -9., 0.
FORCE, 3,25, , 1000.,  0.,  -9., 0.
FORCE, 3,26, , 1000.,  0., -36., 0.
FORCE, 3,27, , 1000.,  0.,  -9., 0.
```

```
FORCE, 3,28, , 1000.,  0.,  -9., 0.
FORCE, 3,29, , 1000.,  0., -36., 0.
FORCE, 3,30, , 1000.,  0.,  -9., 0.
FORCE, 3, 3, , 1000., -3.18, 0., 0.
FORCE, 3, 6, , 1000., -6.23, 0., 0.
FORCE, 3, 9, , 1000., -6.08, 0., 0.
FORCE, 3,12, , 1000., -5.92, 0., 0.
FORCE, 3,15, , 1000., -5.74, 0., 0.
FORCE, 3,18, , 1000., -5.54, 0., 0.
FORCE, 3,21, , 1000., -5.30, 0., 0.
FORCE, 3,24, , 1000., -5.00, 0., 0.
FORCE, 3,27, , 1000., -4.61, 0., 0.
FORCE, 3,30, , 1000., -4.00, 0., 0.
SPC1, 6, 126, 31, 32
MAT1, 1, 29.+6, , 0.3, 0.283, , , , +MAT1
+MAT1, 24.+3, 24.+3, 24.+9
```

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