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GEOMETRIC VERSUS FINITE ELEMENT MODELING
CURRENT AND FUTURE TRENDS AT NORTHROP

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ABSTRACT

Engineering Automation at Northrop encompasses the various design and analytical phases of air vehicle development. Design systems addresses automation of engineering/tooling design and computer-aided manufacturing processes. The analysis systems automate aeroelastic modeling and postprocessing analysis results. These systems interface with aircraft loft and geometric entities thru localized transfer techniques. However, total integration effort based on a geometric database nucleus with peripheral design, analytical and manufacturing systems is well underway. An outline of the present and future trends is presented to help channel the RPI effort in this direction.

Integrated CAD/CAM/CAE

$\boxed{\text{Topic}}$

Geometric vs Finite Element Modeling

Current and Future Trends at Northrop

Presentation to RPI on May 12, 1987 by :

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NORTHROP
Aircraft Division

Integrated CAD/CAM/CAE

RPI/CAM-I Objective

To develop Functional Requirements for an Integrated Geometric Modeling and Engineering Analysis Subsystem as Part of an Overall PRODUCT MODELING SYSTEM

Presentation Outline

- Brief Overview of Current Capabilities at Northrop
- Recommendations for an INTEGRATED System
- Suggested Phased Implementation Plan

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Abstract

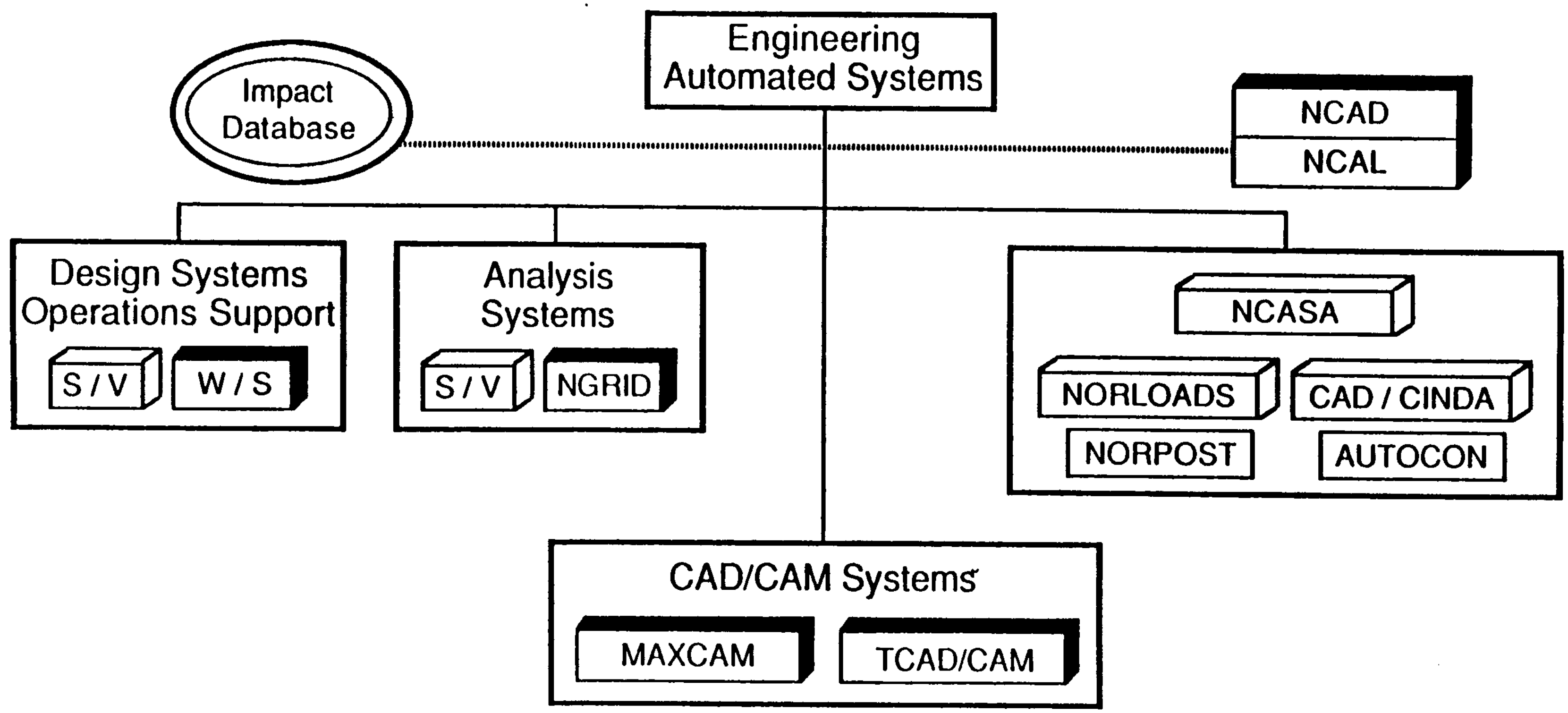
Engineering Automation at Northrop encompasses the various design and analytical phases of air vehicle development.

Design systems address automation of engineering/tooling design and computer-aided manufacturing processes.

Analysis systems automate aerolastic modeling, analysis and postprocessing.

These systems Interface with Aircraft Loft and Geometric Entities thru localized transfer techniiques. However Total Integration effort based on a Geometric Database Nucleus with Design, Analytical and Manufacturing Systems Peripherals is well underway. An outline of the present and future trends is presented to help channel the RPI/CAM-I effort in this direction.

Engineering Automation Projects Requiring Geometric Interface



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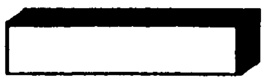
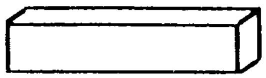


Program Generates and Maintains Geometric Database



Program Interfaces with Geometric Database

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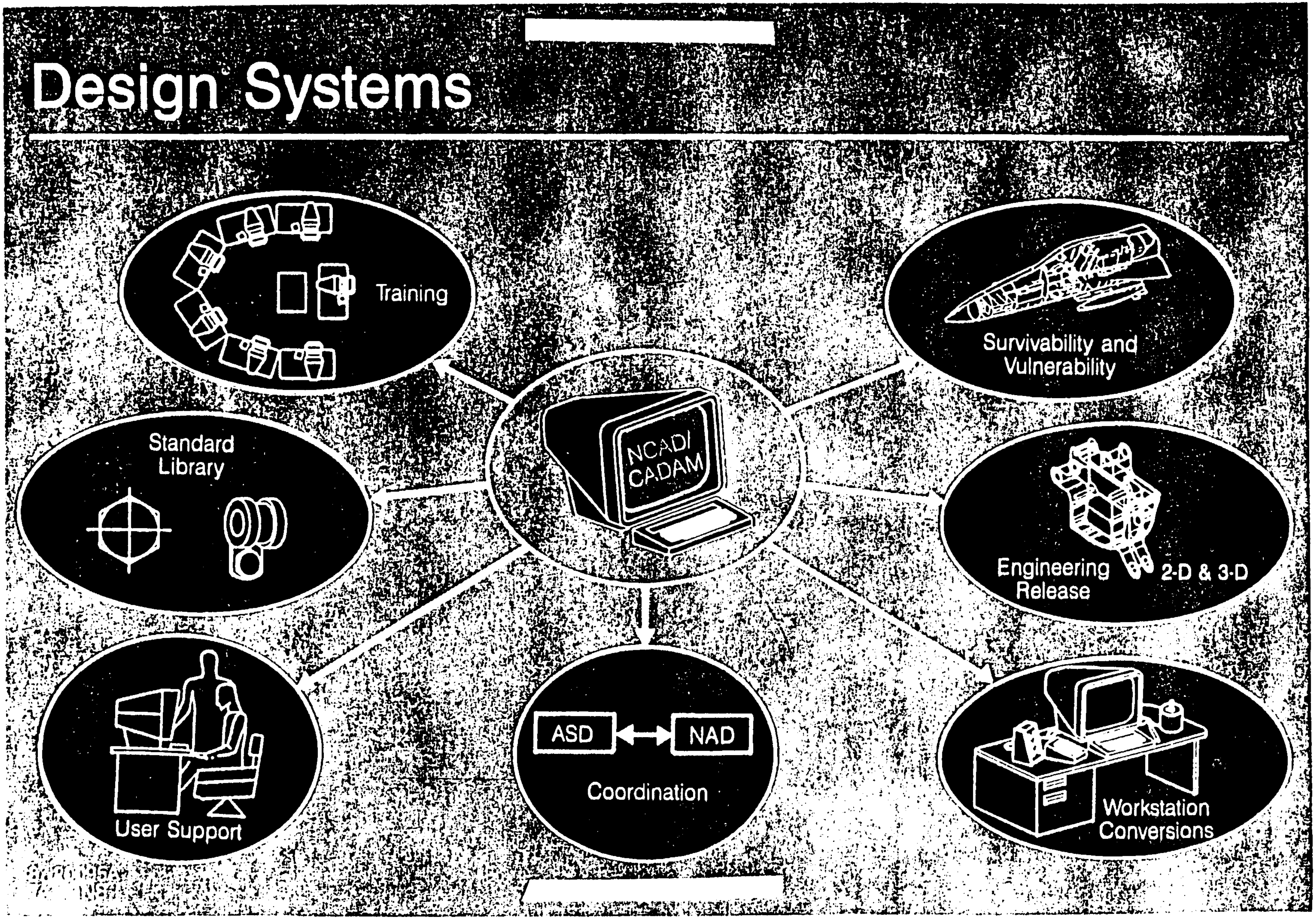
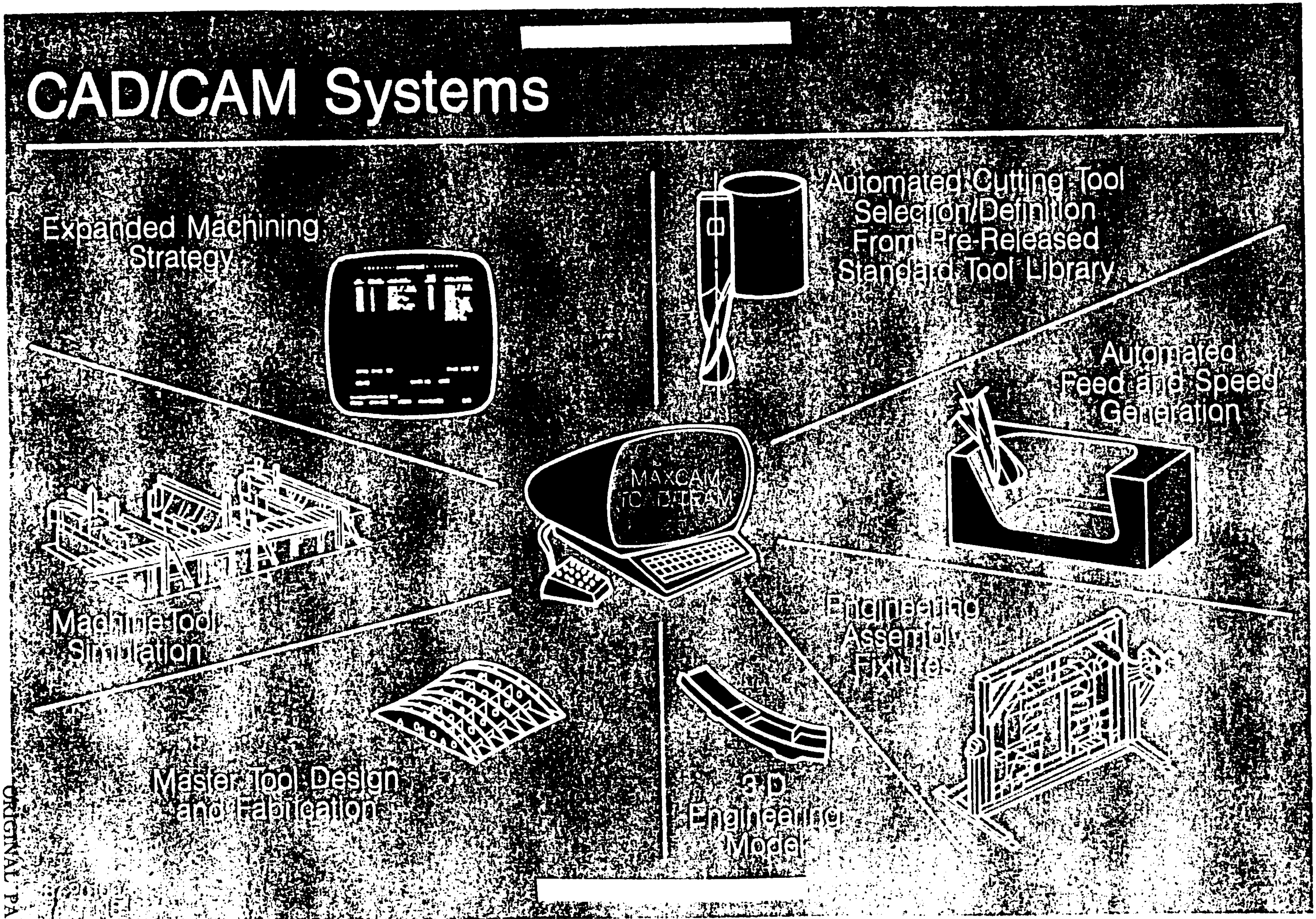
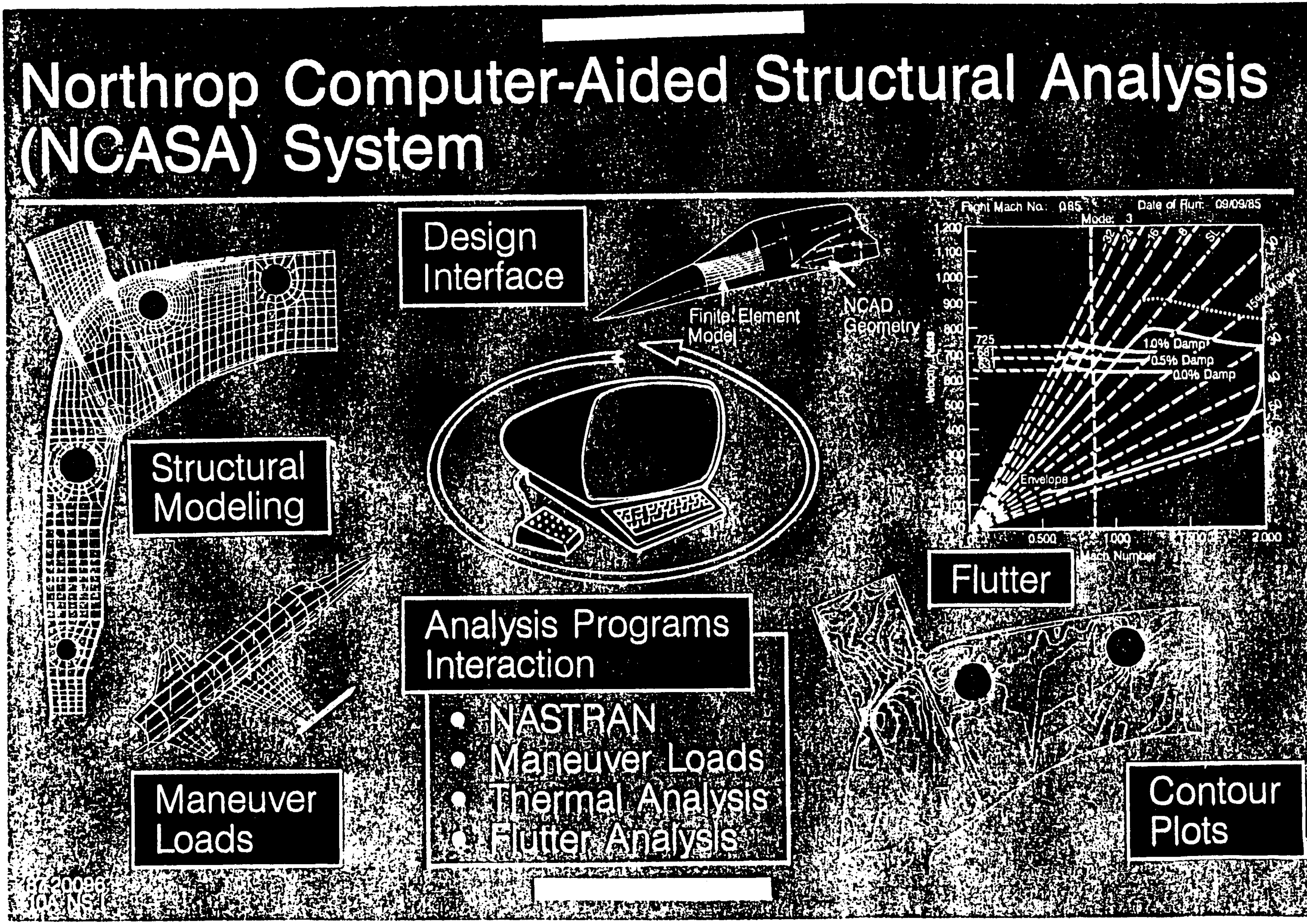

Design Systems
Training
Survivability and
Vulnerability
NCAD/
CADAM
Standard
Library
Engineering
Release
2-D & 3-D
ASD
NAD
Coordination
User Support
Workstation
Conversions


CAD/CAM Systems
Expanded Machining Strategy
Automated Cutting Tool Selection/Definition From Pre-Released Standard Tool Library
Automated Feed and Speed Generation
MAXCAM
Machine Tool Simulation
Engineering Assembly Fixture
Master Tool Design and Fabrication
3-D Engineering Model



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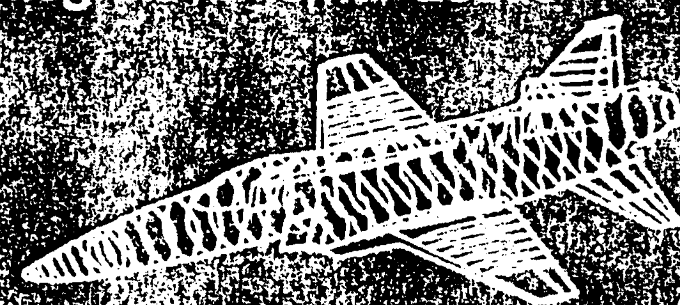
NCASA Overview

Design Interface

- Data Transfer From
  - NCAD/NCAL Loft
  - NCAD 3-D Layouts
  - CADAM Engineering Files
- Interactive Grid Generation

NCASA Modeling

- Generate Airframe Model
- Specify Materials and Properties
- Identify Loads and Constraints
- Integrate External Loads



- Create Freebody Models and Fine Mesh for Local Effects

Batch Program

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NCASA Overview (Cont)

Batch Programs

- NASTRAN: Structural Analyzer
- MLOADS: Maneuver Loads Analyzer
- CINDA: Thermal Analyzer
- F037: In-House Flutter Analyzer

Data Base

Analysis Results

NCASA Postprocessor

- Statics Analysis
  - Deformation, Loads and Reactions
  - Element Stresses and Strains
- Dynamics Analysis
  - Vibration Modes and Frequencies
  - Gust Response and Flutter Summary
- Thermal Analysis
  - Temperatures and Heat Flux
- NORLOADS
  - Aerodynamic Coefficients
  - Panel Loads and Time History

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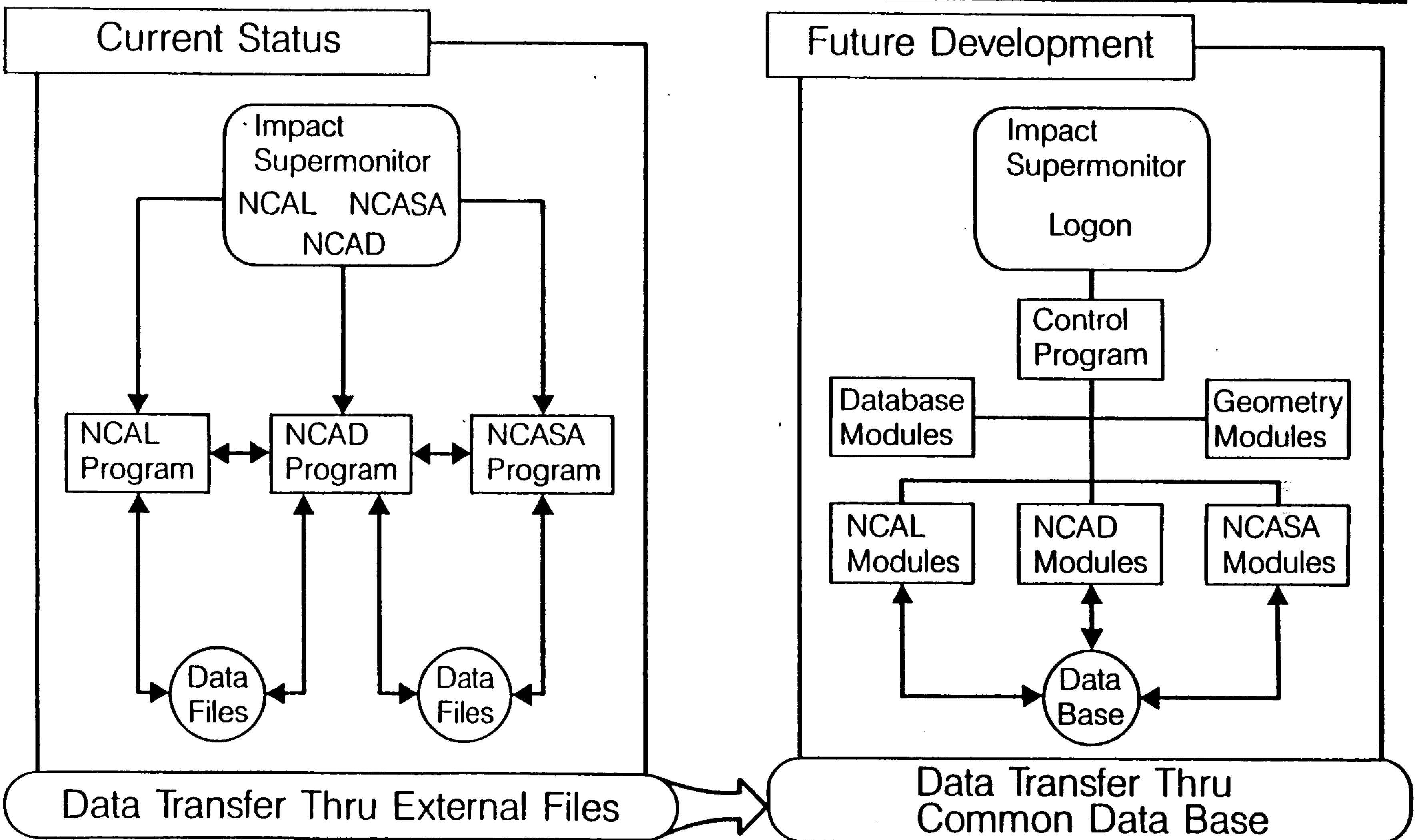
The IMPACT System
Current & Future Trends



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Integrated CAD/CAM/CAE

Essentials

- Nucleus :
  - Physical Data Files
  - Data Manager
- Peripherals :
  - Utility Libraries
    - Data Dictionary
    - Evaluators
    - Math Utilities
  - Interactive Drivers
    - File I/O
    - Model Access
    - Display
    - Plotting
  - Application Modules
    - Configuration
    - Design
    - Structural Analysis
    - Manufacturing
    - Process Planning
    - Release Procedures

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Model Data Manager

Design Criteria

- Unlimited Model Size :
  By Use of Paging and Interactive Swapping between In-Core Memory and Disk Storage
- Data Structure :
  Primitives / Non-Primitives / Attributes
  Three Level Element Data Hierarchy
- Data Access
  Through Data Servers
- Fast Search Data Structure using Correlation Value
- Self Packing Data Structure Scheme
- Dynamic Memory Management
- Ease of Incorporation of New Data Structure
- Ease of Extending Existing Data Structure Characteristics
- Compatible with Evolving Industry Standards, viz., PHIGS, PDES & IGES
- Traceability of Changes
- Portability :
  to IBM Mainframes and Workstations, Vector and Raster Graphics Tubes

Integrated CAD/CAM/CAE

Phased Implementation Guidelines

- Allow Orderly Transition from Present Geometry Systems
- Allow Upward Compatibility of Existing Models
- Implement Evaluator Driven Geometry Utilities
- Specify Milestones with Incremental Benefits

Integrated CAD/CAM/CAE

Conclusions

Design of an INTEGRATED CAD/CAM System Should Not be Limited to

Geometry and Finite Element Modeling Only

But

It Should Also Address Various Engineering Analysis,

Postprocessing and Manufacturing Applications

IDEALIZED FINITE ELEMENT MODELS

Mark S. Shephard
Rensselaer Polytechnic Institute

Concerned with the evolution from the Augmented Model, to the Idealized Model, to the Finite Element Model.

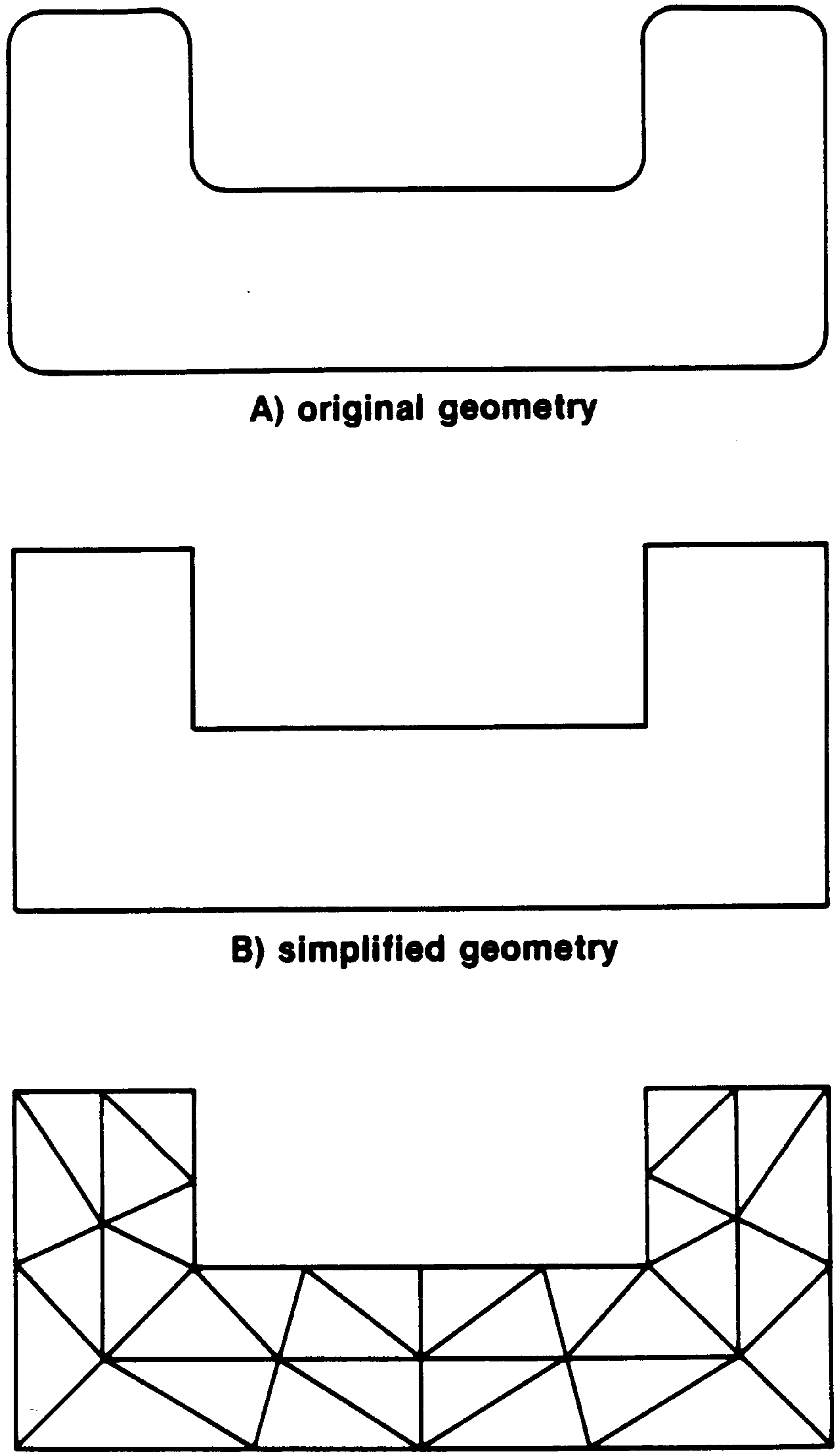
Augmented Model - Original geometric model plus analysis attributes.

Idealized Model - The geometric representation plus analysis attributes that is discretized into the finite element model.

Finite Element Model - The discrete model sent to the finite element analysis program.

Differences Between Augmented Model and Idealized Model

1. Geometric simplification - ignoring specific geometric features such as small holes and fillets.
2. Geometric Enrichment - including geometry in the numerical analysis model not originally represented in the augmented model (air around a model and zero thickness interfaces, etc).
3. Geometric Dimension Reduction - Replacing portions of a model with reduced dimension entities with the eliminated dimensions represented by section properties tied to the reduced dimension elements.



A) original geometry

B) simplified geometry

C) finite element model

FIGURE 3. GEOMETRIC SIMPLIFICATION

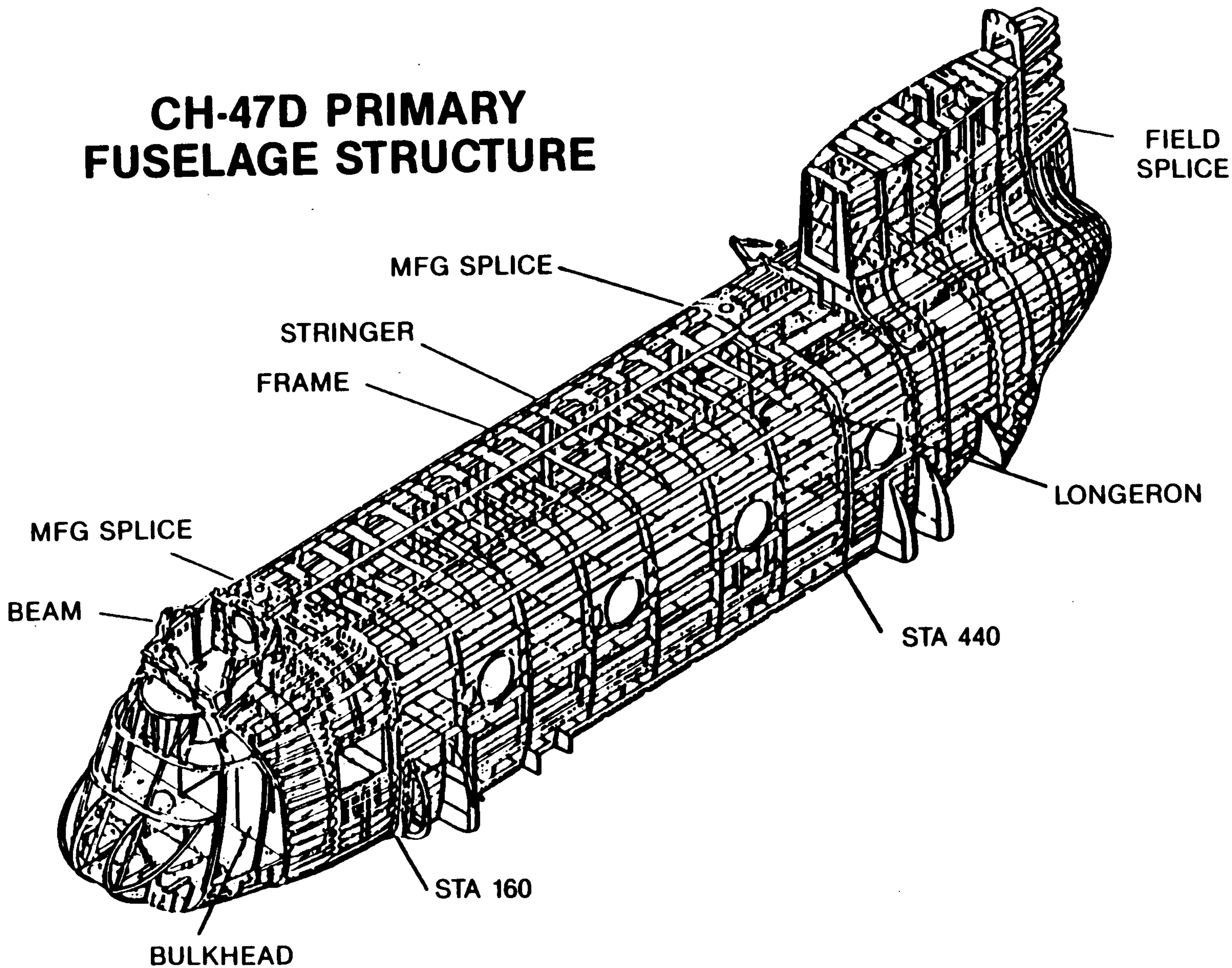


FIGURE 4. GEOMETRIC REPRESENTATION OF HELICOPTER AIRFRAME STRUCTURE

STATIC MODELING
CH-47D NASTRAN STRUCTURAL MODEL

NASTRAN MODEL

1,883 STRUCTURAL NODES
5,758 STRUCTURAL ELEMENTS

NO. OF ELEMENTS	TYPE
398	CBAR — BEAM
76	CELAS2 — SPRING
3,253	CONROD — AXIAL
1,707	CSHEAR — QUADRILATERAL SHEAR
156	CTRMEM — TRIANGULAR MEMBRANE
156	CQUAD1 — QUADRILATERAL SHELL
12	CTRIA1 — TRIANGULAR SHELL

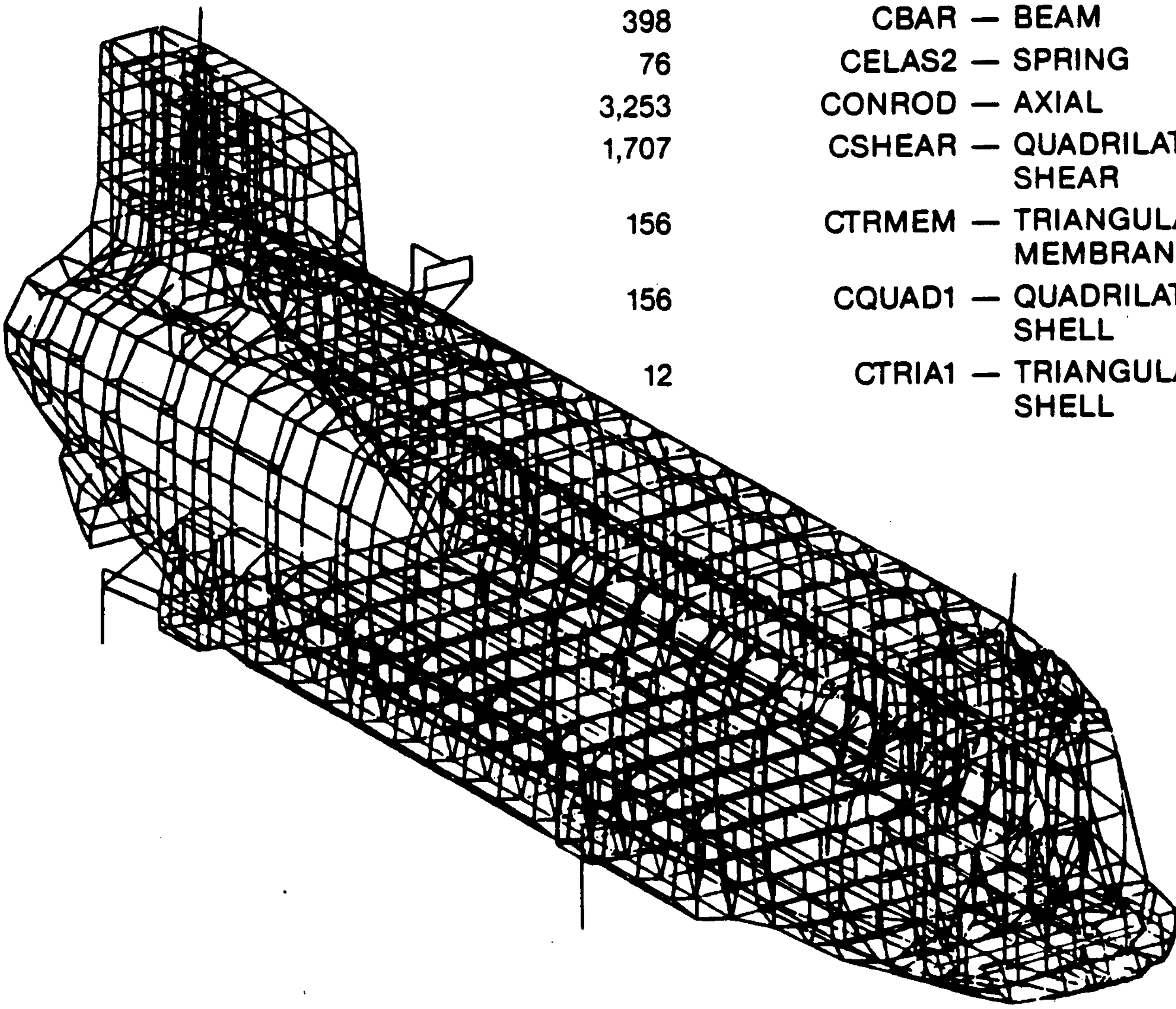
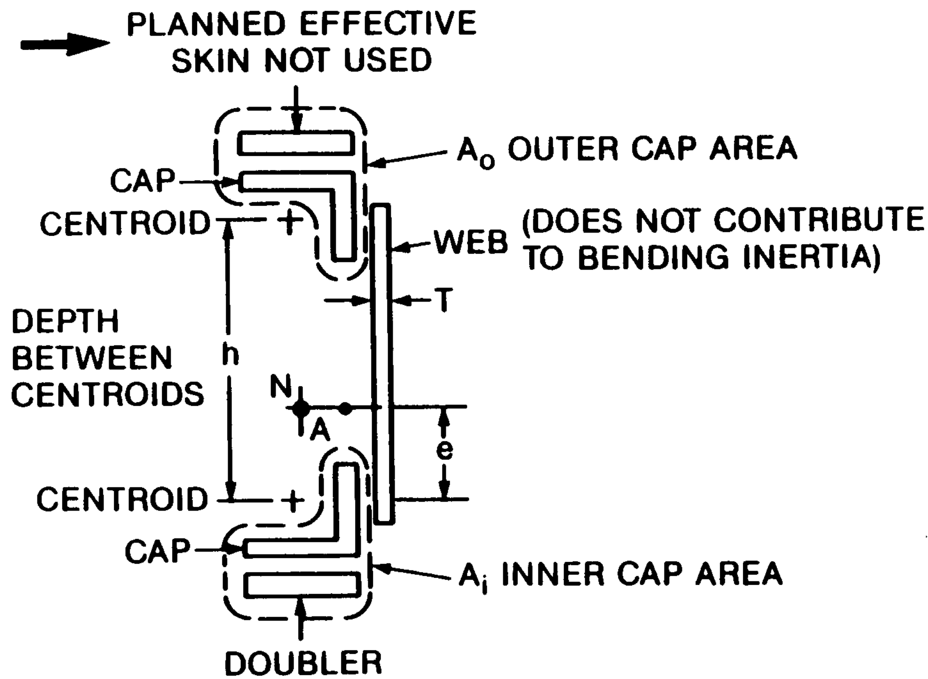


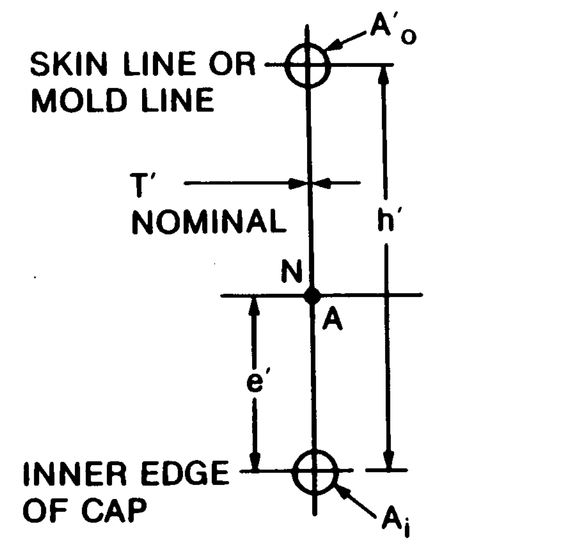
FIGURE 5. FINITE ELEMENT MODEL OF AIRFRAME STRUCTURE

STATIC MODELING GUIDES — FRAMES DETERMINING EQUIVALENT BENDING INERTIA

REAL FRAME CROSS SECTION



NASTRAN FRAME CROSS SECTION MODEL



$$e = \frac{A_o h}{A_o + A_i}, \quad \boxed{I_{N/A} = A_o (h-e)^2 + A_i e^2}$$

$$e' = \frac{A'_o h'}{A'_o + A'_i} \qquad I_{N/A} = A'_o (h'-e')^2 + A'_i e'^2$$

$$\text{LET, } A'_o = \left(\frac{h}{h'}\right)^2 A_o \quad \text{AND } A'_i = \left(\frac{h}{h'}\right)^2 A_i$$

$$e' = \frac{A_o h}{A'_o + A'_i} = \frac{h'}{h} e$$

SAME AS REAL FRAME

$$I_{N/A} = \left(\frac{h}{h'}\right)^2 A_o \left(h' - \frac{h'e}{h}\right)^2 + \left(\frac{h}{h'}\right)^2 A_i \left(\frac{h'}{h}\right)^2 e^2 = \boxed{A_o (h-e)^2 + A_i e^2}$$

FIGURE 6. PROPERTY CALCULATION FOR AN INDIRECT ELEMENT TYPE

COMMON APPROACHES TO DEVELOPING IDEALIZED MODELS

DIRECTLY DEFINE IDEALIZED MODEL

The majority of geometric representations used in finite element modeling are defined solely for that purpose. That is the augmented model and idealized model are the same. This is an inefficient approach and does not make the best use of available technology.

MODIFY AUGMENTED MODEL TO BECOME IDEALIZED MODEL

Carry out modeling operations to alter the augmented model evolving it into the idealized model.

TREAT IDEALIZATION INFORMATION AS NUMERICAL MODELING ATTRIBUTES TIED TO THE AUGMENTED MODEL

Indicate what entities are to be altered and have the appropriate information automatically tied to entities in the augmented model as attribute information. The discretization procedures would then be responsible for insuring that the finite element model reflects the idealizations.

MODIFY AUGMENTED MODEL TO BECOME IDEALIZED MODEL

Advantages -

It is reasonably straight forward to see how this approach would operate. The user would have a first hand understanding of the modifications.

Disadvantages -

The user is required to perform geometric modeling modifications manually. Could not support use of adaptive idealization procedures.

Technical Issues -

Data Structures - should there be two identical structures for the augmented and idealized model?
Recovery - how does one recover portion of a model if the idealization process is changed?

TREAT IDEALIZATION INFORMATION AS

NUMERICAL MODELING ATTRIBUTES

TIED TO THE AUGMENTED MODEL

Advantages -

Would support the evolution to automated, adaptive techniques for developing idealized models thus potentially being more efficient and robust. Would reduce total amount of storage needed making it easy to track the modeling assumptions used.

Disadvantages -

Do not know how to handle such an approach fully enough at this time.

Technical Issues -

Idealization procedures - do not know all the idealization procedures desired well enough to try to define geometric operators to support them.
Data structures - do not fully know how to house all the possible idealization attributes in the augmented model.
Discretization - the discretization process would become more than just mesh generation in this case, must have procedures to account for model differences automatically.

TECHNICAL AREAS IMPORTANT TO

THE AUTOMATION OF

IDEALIZED MODEL GENERATION

Attribute Data Structure of Augmented Model

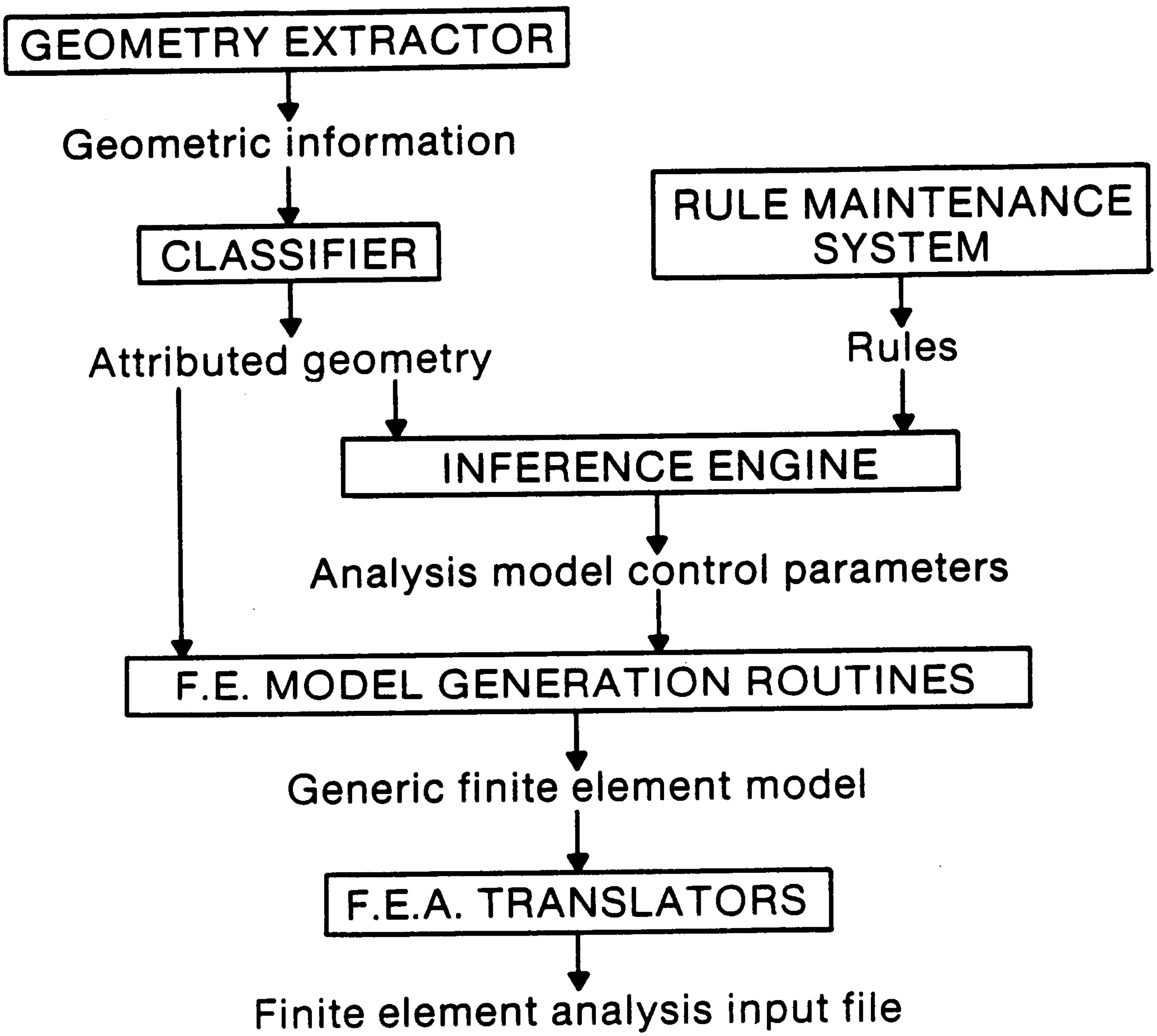
Geometric Operators to Support the Generation of the Idealized Model from the Augmented Model

Feature Recognition Techniques

Knowledge-Based Modeling Procedures

Adaptive Analysis Techniques for Determining Idealizations

A KNOWLEDGE-BASED APPROACH FOR DEVELOPING IDEALIZED MODELS



A COMBINED KNOWLEDGE-BASED AND ADAPTIVE TECHNIQUE FOR ONE FORM OF GEOMETRIC SIMPLIFICATION: IGNORING CIRCULAR HOLES IN 2-D STRESS ANALYSIS

Approach -

1. Determine candidate holes - those that are less that some percent of the net section through object at that location, and not too close to an edge.
2. Analyze object ignoring all candidate holes. This gives basic flow of loads to supports.
3. Apply correction factors to the stress at the locations of the ignored holes based on 'standard analytic' formulae.
4. Include only those holes with estimated values higher than some fraction of the limiting stress.

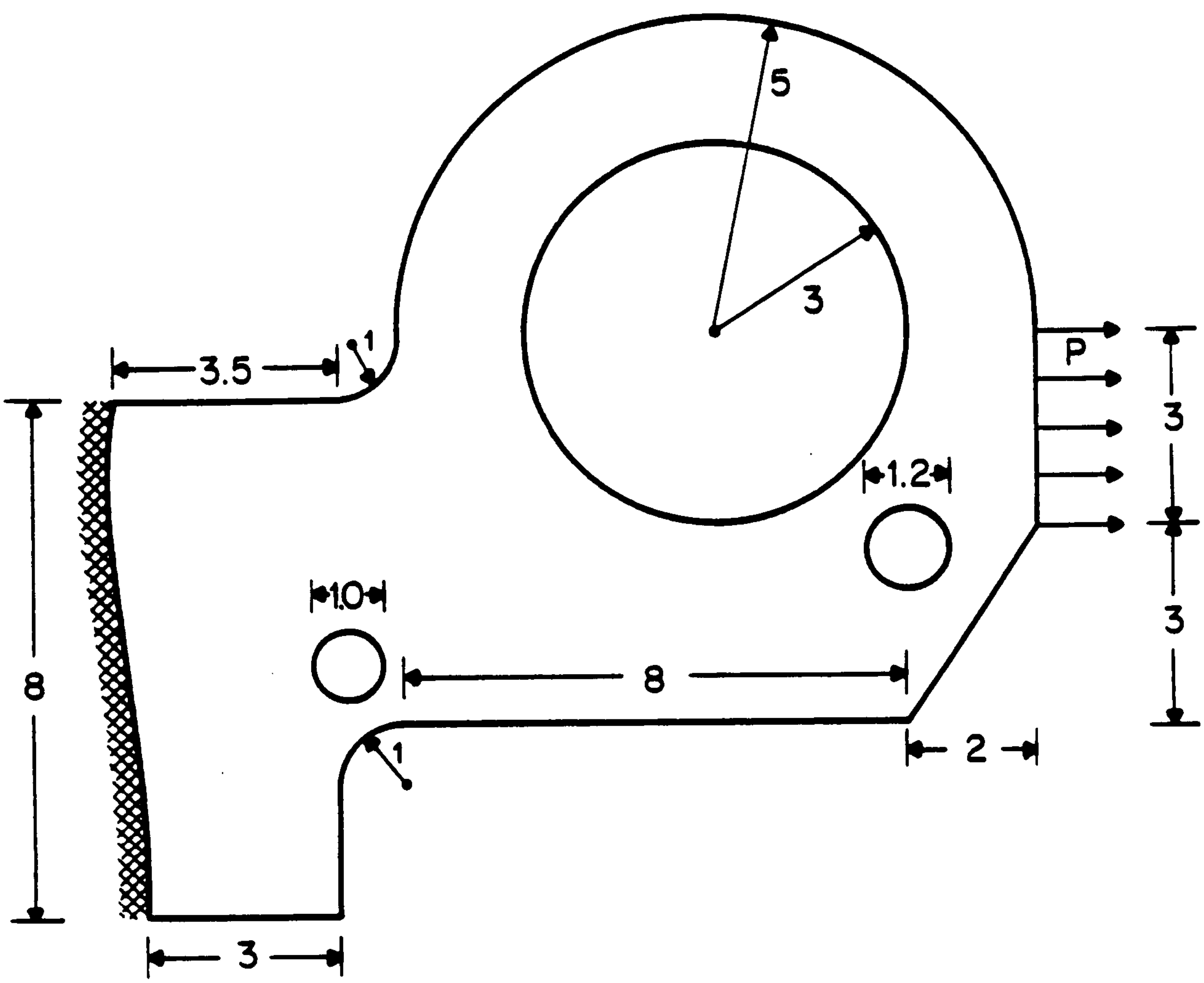


Figure 10. Geometry for cam example.

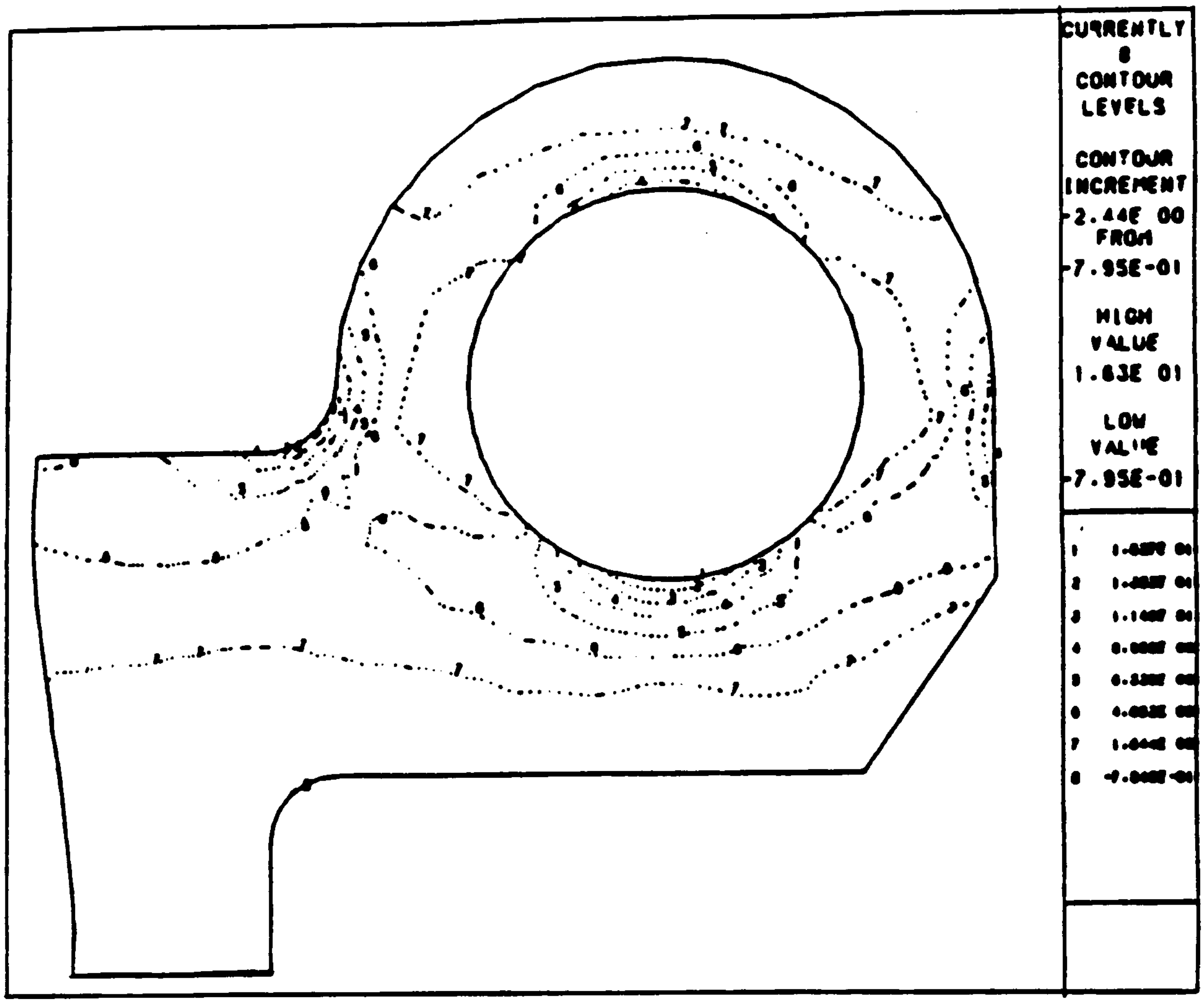


Figure 11. Stress contours with holes ignored.

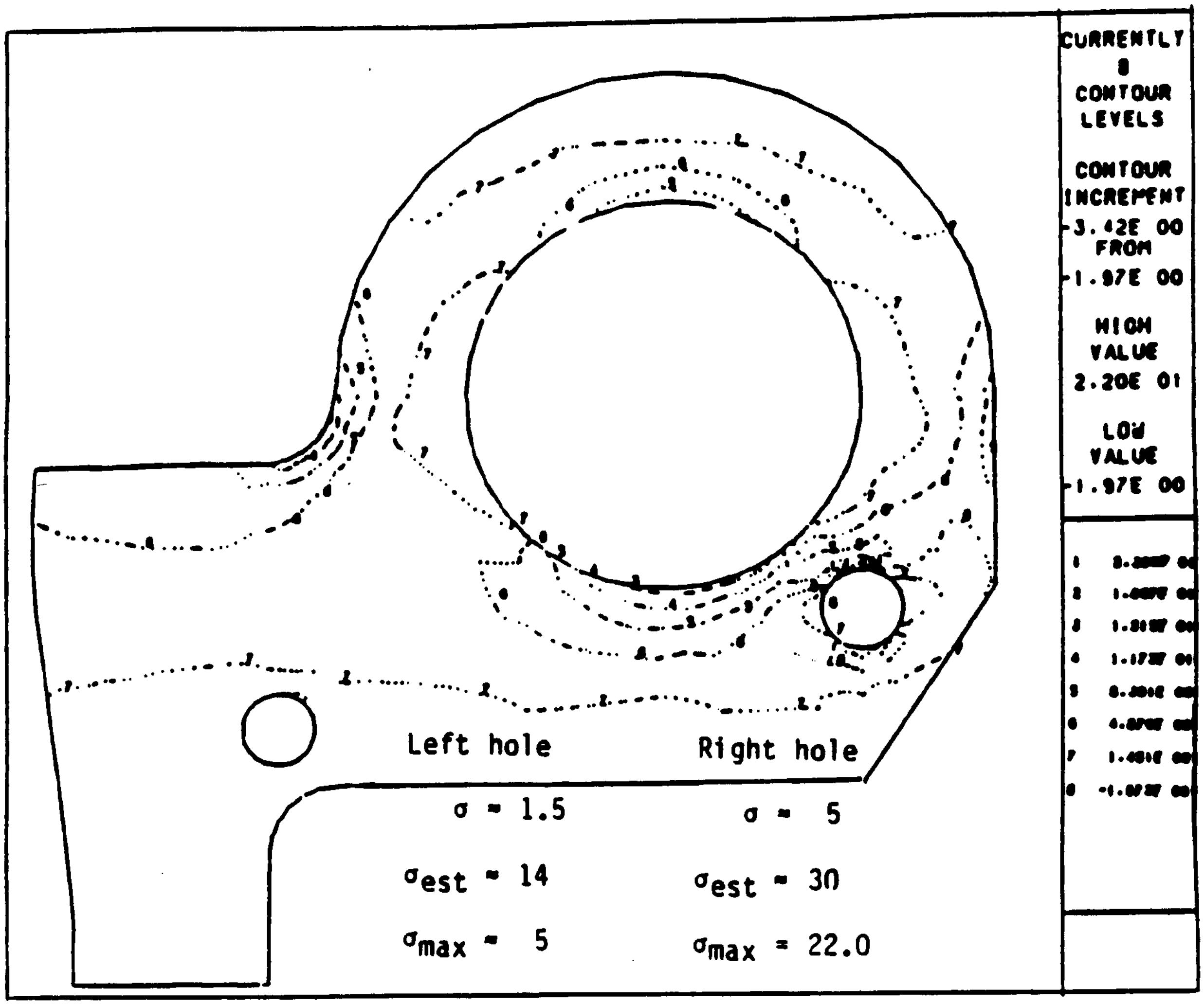


Figure 12. Stress contours with holes included.

BUILDING FINITE ELEMENT APPLICATIONS
USING NON-MANIFOLD BOUNDARY OPERATORS

An Approach to a dynamic interface that is a level above those discussed above. Application programs would employ both the modeling functionalities and data structures of the geometric modeling system without knowing the details of either.

This is consistent with object-based procedures that are becoming popular.

A start to such a capability employing the Radial-Edge non-manifold data structure is proposed by Kevin J. Weiler in his Ph.D. thesis for the process of defining geometric models.

A complete set of Non-Manifold Boundary Operators needed to support this approach.

BUILDING FINITE ELEMENT APPLICATIONS USING NON-MANIFOLD BOUNDARY OPERATORS

Classes of Operators Needed -

Obtaining Objects Based on Type - ability to find objects of given types.

Determining Object Adjacencies - find how an object is related to others of a given type.

Geometric Interrogations - determine a geometric property of an object.

Attribute Interrogations - determine the attributes of an object.

Attribute Assignment - tie attribute to objects.

Geometric Modification - carry out a geometric modeling operation based on a given set of objects.

BUILDING FINITE ELEMENT APPLICATIONS USING NON-MANIFOLD BOUNDARY OPERATORS

Typical Objects -

Topological entities

Geometric entities

Attributes

The topological entities represent the 'glue' needed to hold such a system together, however this can be transparent to the applications built on it.

The approach is in a very early phase of investigation. It is not clear if it will work.