IMPLEMENTATION OF SUPERELEMENT ANALYSIS AT THE PRODUCTION LEVEL

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SUMMARY

In order to increase engineering productivity by more efficient use of computer resources the MSC/NASTRAN superelement capability was tested on an actual production model.

Comparisons made with the single structure approach have shown that the superelement technique is comparable in costs for a single run on large finite element models. This testing program has proven that the superelement method can result in substantial cost benefits for re-design or modification of any separate superelement structure. However, the testing program has also pointed out that it is extremely important for the analyst to understand and control the computer environment in which he works.

INTRODUCTION

At Northrop the responsibility for maintaining and supporting NASTRAN lies with the Advanced Structural Computer Methods (ASCM) group in The Structural Mechanics Reasearch Department.

The responsibilities of this group include the testing of new analytical methods in NASTRAN. If found applicable to production work, ASCM releases these advanced features after training key support personnel.

This paper describes the testing program instituted for a new structural analysis method in NASTRAN, Superelements, and the training of senior technical personnel in its usage.

A major beenfit of this program, a substantial reduction in computer billing due to correctly tuning a new computer, new disk packs and a new version of NASTRAN is discussed.

SELECTION OF ANALYSIS PROCEDURE

MSC/NASTRAN offers three solution techniques for static analysis.

- Single model static analysis
- Substructure analysis
- Superelement analysis

The choice of which method to use depends on many factors, some of which are:

- Computer resources
- Pre and post processors
- Degree of analysis necessary
- Sophistication of user's ability

The last factor, the sophistication of the user, is the most important.

A high degree of user sophistication implies that the user can define and acquire the computer resources necessary to do a job, obtain and maintain the necessary pre and post processors, assist the production groups in using the analysis methods necessary, and have the necessary corporate support.

SINGLE STRUCTURE ANALYSIS

The most straight-forward approach treats the structure as a single finite element model. This often appears to be the quickest and easiest method, especially for a relatively new NASTRAN user. Some indications to the engineer that a more sophisticated method is necessary are:

- Interruption of run due to extremely long computer residency
- Core exceeded during analysis
- High computer billing
- Inability to reanalyze local areas due to high computer costs

It must be emphasized that many of these problems are due to the lack of computer resources perceived by the engineer to be available. These differ greatly at each installation. Before a large project is undertaken the computer system must be audited by the engineer in terms of his present and future needs.

SUBSTRUCTURE ANALYSIS

Substructuring allows the user to divide a large structure into smaller parts. By efficient partitioning, some of the problems associated with the single-shot method can be alleviated.

Efficiency of computer resources is increased, and the total computer billing units required for an analysis using substructuring should be close to that of a single run analysis. (Ref. 1) An advantage to running each substructure separately is that the computer residency time of any single substructure is much less than that of a large single run. This decreases the possibility of a computer failure during execution.

Because re-analysis of any single substructure is effectively reduced to the analysis time required for that single structure, a substantial savings in overall calendar time as well as computer billing time can be made using substructuring.

There are many disadvantages to substructuring however, if not properly used, and the potential user should become acquainted with the experiences of others (Refs. 2 & 3)

SUPERELEMENT ANALYSIS

Superelement or automated multi-level substructuring has incorporated substantial improvements over substructuring.(Ref. 4) Among the most noticeable are:

- NASTRAN direct-access data base and data base management
- Automatic SPC by user request
- Mass-only restarts
- Multiple solutions stored
- Optional continuation after fatal errors
- External superelements
- Excluded superelements
- Stress data recovery at individual superelement level with fixations at boundaries
- Better diagnostics
- Simplification of Job Control Language (IBM)
- "Unlimited" analysis size
- One up-to-date set of finite element models

These features plus the commitment by MSC to further improvements strongly recommend superelements for large production finite element analysis.

SYSTEM APPROACH TO SUPERELEMENT ANALYSIS

Many papers have been written which emphasize that the finite elements to be used must be tested. (Ref. 5, 6, & 7) This approach is absolutely correct. However, experience has shown that it is also extremely important to carefully test a new analysis approach before a commitment is made to use it in production work (Ref. 8). This paper recommends that a systems approach must be taken, where sets and subsets of systems are defined and their relationships to each other tested.

The analysis can be defined as a universal set within which lies the engineers, the computer, computer peripherals, supportive software, and NASTRAN (Fig. 1). Within NASTRAN itself lie other elements such as the particular solution and the finite elements to be used.

To be successful then, all of these elements, sets and subsets must be tested to the satisfaction of the person responsible for the analysis.

Therefore a system approach to the superelement analysis is defined here which includes testing both a small prototype model and a large production prototype model and a user oriented training course.

SUPERELEMENT TRAINING COURSE

Parallel to the superelement testing program a training course has been instituted. It consists of ten senior level engineers from major projects and meets once a week for 2-3 hours. It covers the following:

- Basic Superelement Technique
- Introduction to Computer Systems
- IBM Job Control Language
- Single Level Superelements

It is taught with the belief that all parts of the system must be tried and tested by the user for maximum benefit. Therefore the major learning device is an example problem similar to the small superelement prototype.

NASTRAN PROTOTYPE TESTING

After choosing the correct analytical technique (superelement analysis) a plan of support must be worked out.

This includes:

- Prototype testing

A. Small Prototype Model

A small finite element model should be developed which will test the Direct Matrix Abstraction Program (DMAP) for that version of MSC/NASTRAN to be used during production. (Fig. 2) This model should be simple enough that it can check the DMAP flow economically with the highest priority possible on the computer system. Looping within the DMAP can be followed by creating the same number of superelement in the prototype as in the projected production model. This allows the engineer to make changes to the MSC supplied DMAP before the large model is run. It also allows the engineer to come back later if problems arise during the production run and try to duplicate the production DMAP sequence. The prototype could be expected to grow when realistic features such as MPCs, external superelements, excluded superelements, restart procedures and other real-life features are added down-stream.

The prototype would also have a parallel single structure done which would verify the DMAP flow, validate the elements and the accuracy of stress data recovered.

Hardware compatibility can also be tested as can computer efficiency to guarantee Central Processing Unit (CPU) and Input-Output (I/O) billing units will be kept to a minimum.

B. Large Prototype Model

Although a small model is essential, it is limited to debugging its own DMAP solution flow. The actual production model will be much more complex and might have 100 times as many degrees of freedom in the analysis set. Therefore, in order to fully support a production effort a parallel model should be maintained and run. (Fig. 3 & 4) This also requires a second data base in order to protect the production data base.

B. Large Prototype Model (Continued)

With an on-line production prototype it is now possible to fine tune the analysis techniques as well as test new versions of NASTRAN and new computer systems as they become available.

TESTING PROCEDURE

Realistic evaluation of the substructure and superelement capability in MSC/NASTRAN began in 1977. As each new version of MSC/NASTRAN was released it was tested at Northrop. The first large scale tests using substructures and superelements were made using a finite element model of the T-38 (wing, center and forward fuselages only). A comparison of the program response and system billing for this model was possible using results from previous analyses. At the present identical work is being carried out on the F-18L using MSC/NASTRAN Version 50. (Table 1)

TEST RESULTS

The constantly changing finite element environment at Northrop is shown in figure 5. Both the computer system, the IBM 3033 with 3350 on-line disk packs, and the latest solution DMAP, DMAP1, have performed exceptionally well during testing.

With the advent in January 1979 of a new large processor (IBM 3033) and an on-line NASTRAN data base, single superelements have been modified using IBM-TSO, submitted and results printed within twenty minutes. Only minor changes have been made to DMAP1. These changes give User Warnings for high diagonal ratios, and negatives on the diagonal as well as printing the diagonals. (Table 2)

This testing procedure has proved extremely beneficial, and verified the systems approach, emphasized in this paper. Two analysis methods were compared. Run (I) was a cold start static analysis using the single-shot approach. Run (II) used the superelement technique. As expected, modifications in Run (II) were substantially less expensive than Run (I). (Table 3)

Run (I) was run originally in 1978 as a single large analysis on the IBM 370-168 using Version 42. It was run again in January 1979 as a superelement analysis using Version 42 when the IBM 3033 became available. Run (III) is identical to it but uses Version 50. On the previous system it was felt that computer core was a valuable resource, and therefore Runs (I) and (II) were made using half-track blocking for a 3330 disk pack (full track block on 3350 disk pack was not unacceptable by Version 42) and minimum open core, 450k. As expected I/O operations were very high as was the cost ($1720). By switching to Version 50 (which had been heavily tested using the small prototype), full-track blocking became available as well as the newest superelement features. The core was increased by one-third to 600k and full track blocking instituted. The I/O count dropped substantially as did the cost (to $635). Thus by minor changes using the newest version of NASTRAN the same analysis was made in 37% of the previous cost!

Now, because the superelement technique is being used, modifications can be made to any single superelement, and the effects of these changes on the whole structure seen, for anywhere between $22 (vertical stabilizer) to $223 (Aft half of center fuselage) plus minimal NASTRAN overhead.

As a worst case example, if Run (I) had been made using the single structure approach, then a minor change on the vertical stabilizer would have cost approximately $1700. The same change in Run (III), using the superelement approach would cost approximately $60, 3.5% of the first approach!

CONCLUSIONS

As expected from previous tests using the T-38 NASTRAN model, the superelement method will allow substantial increases in productivity to be realized. In some cases a single superelement (substructure) could be analyzed twenty or more times for the same computer costs necessary using the single structure approach.

Not only will more analysis take place for the same money, but less computer residency time for a structural modification guarantees that more jobs will run to completion before a computer hardware or software failure terminates the jobs, thus requiring another submittal by the engineer.

In general, no matter which analysis method is chosen, it is imperative that the support group has:

- A high level communication channel to data processing
- Influence on computer hardware selection
- Influence on computer peripheral selection
- Input to the definition of the billing algorithm
- Expert comprehension of the computer system
- Comprehensive system data on NASTRAN usage

The MSC/NASTRAN superelement technique, properly used, has at last given the engineer the proper tool for real-world large structure analysis.

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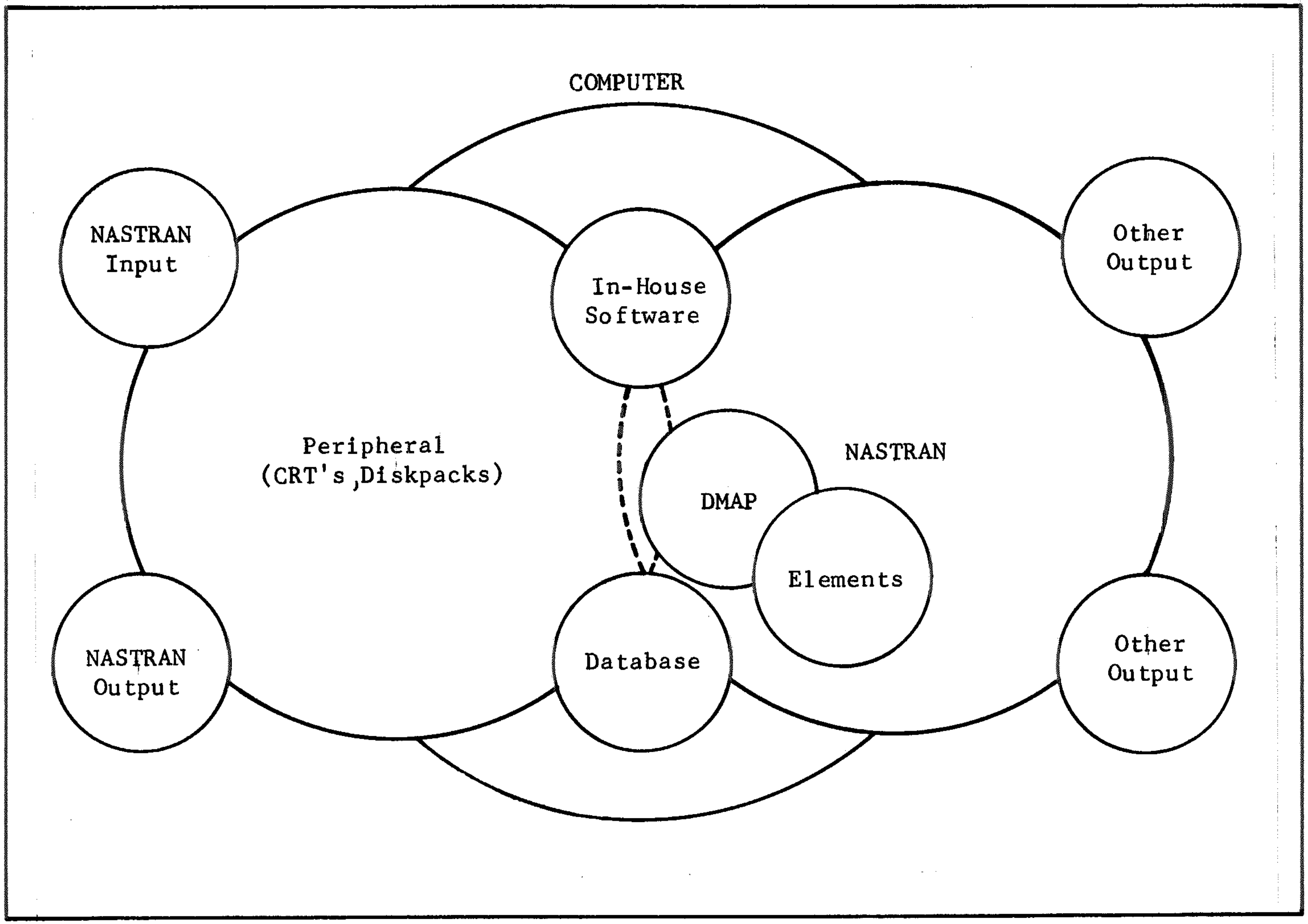

Figure 1. Finite Element Analysis System

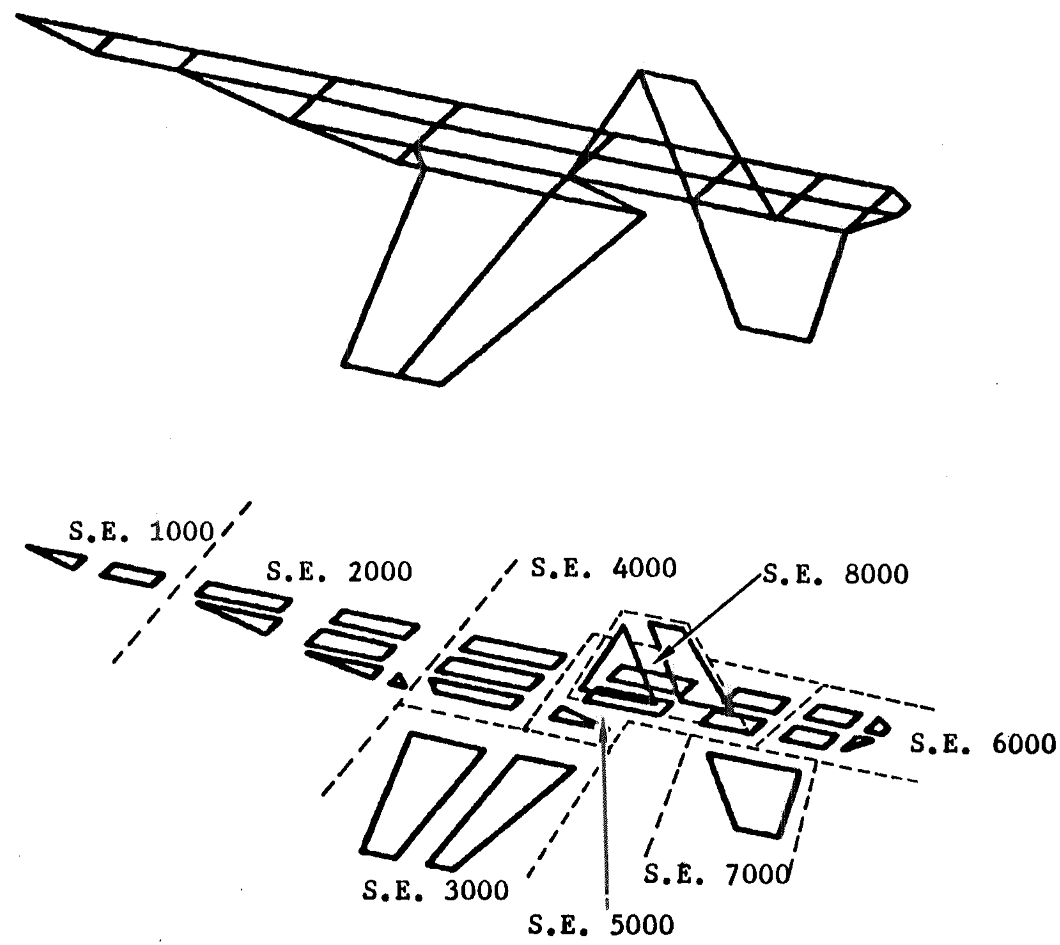

Figure 2. Prototype Finite Element Model

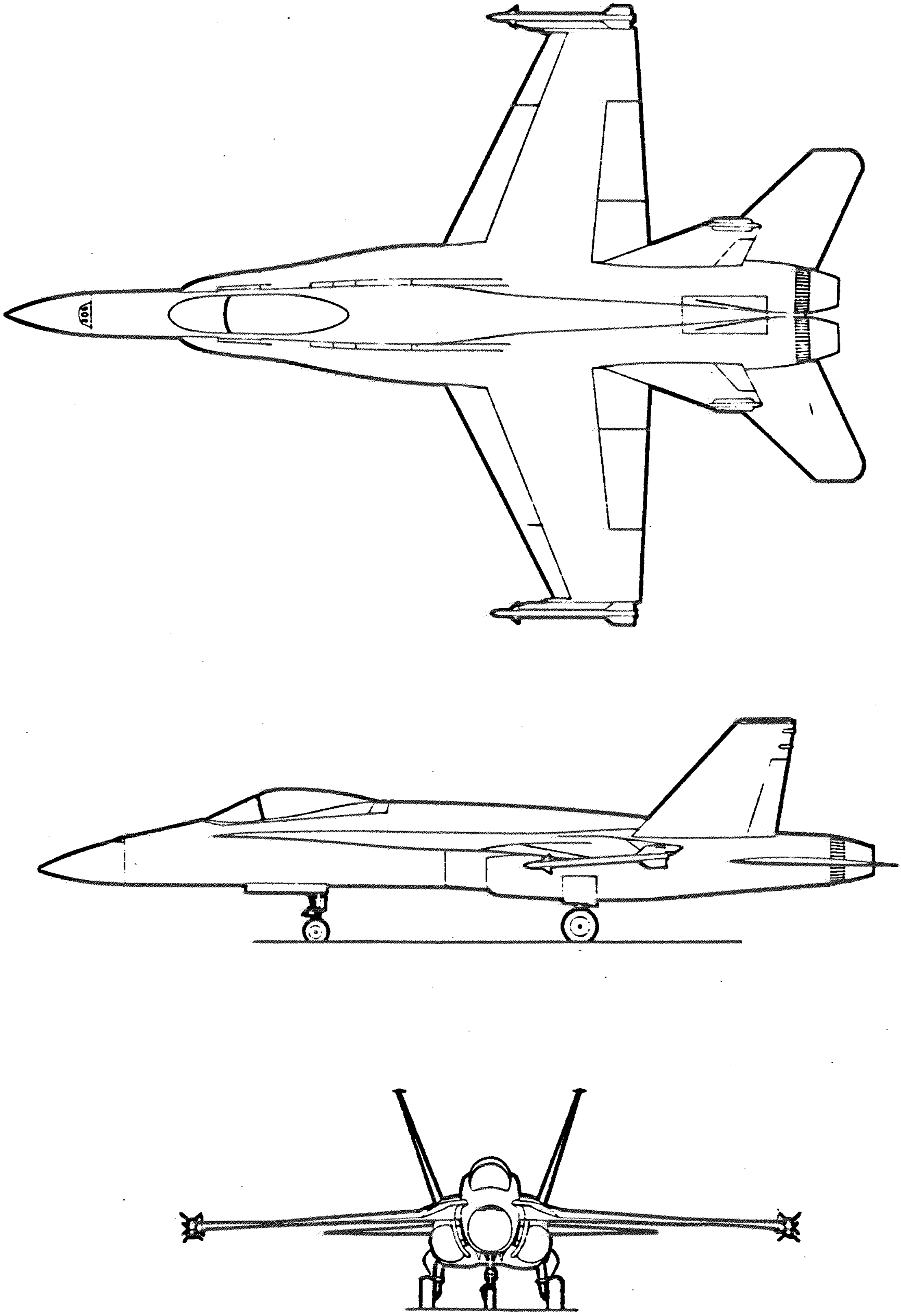

Figure 3. F-18 Production Aircraft

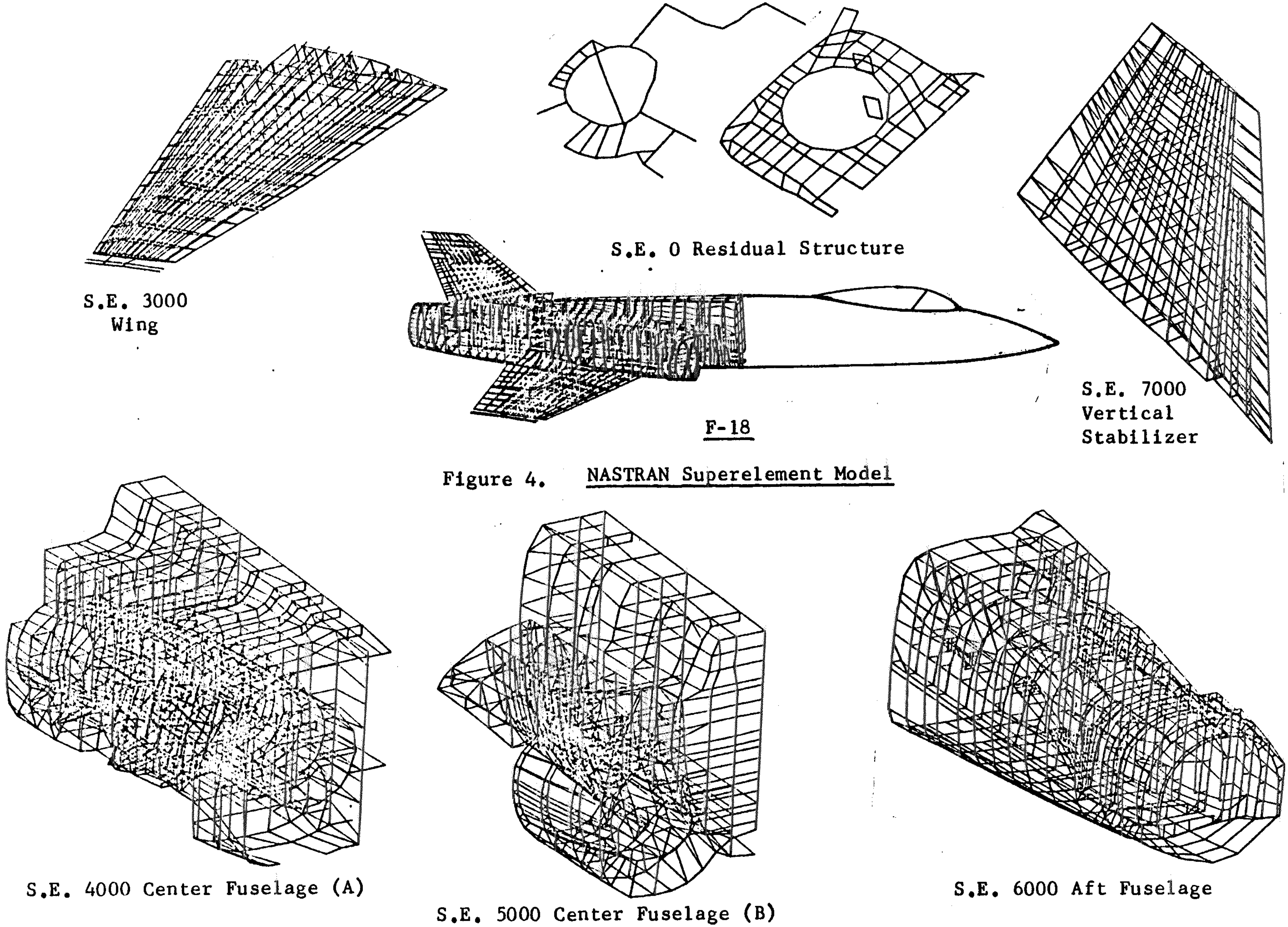

Figure 4. NASTRAN Superelement Model

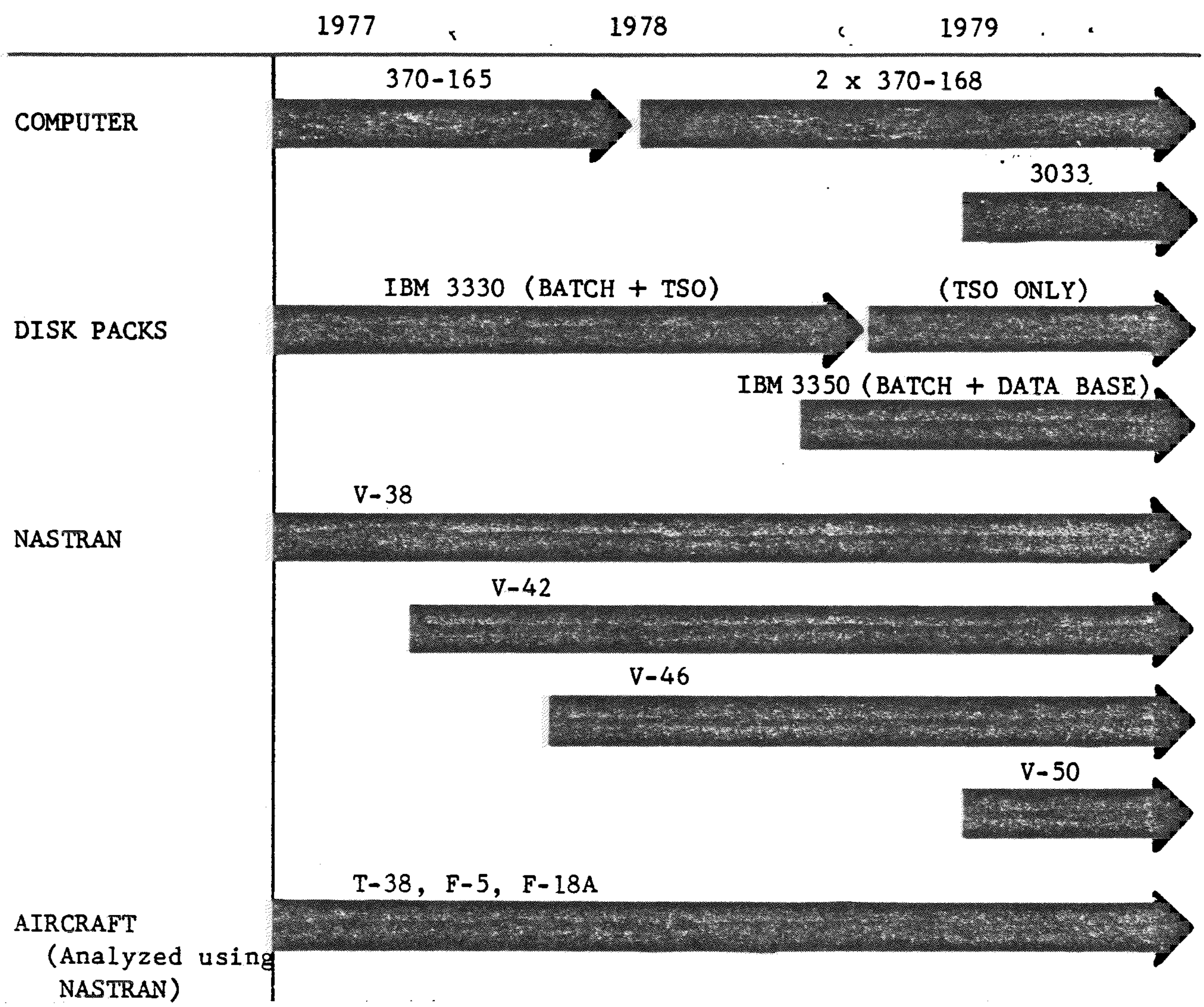

Figure 5. Finite Element Analysis Environment

TABLE 1. NASTRAN TEST SCHEDULE (Static Analysis)

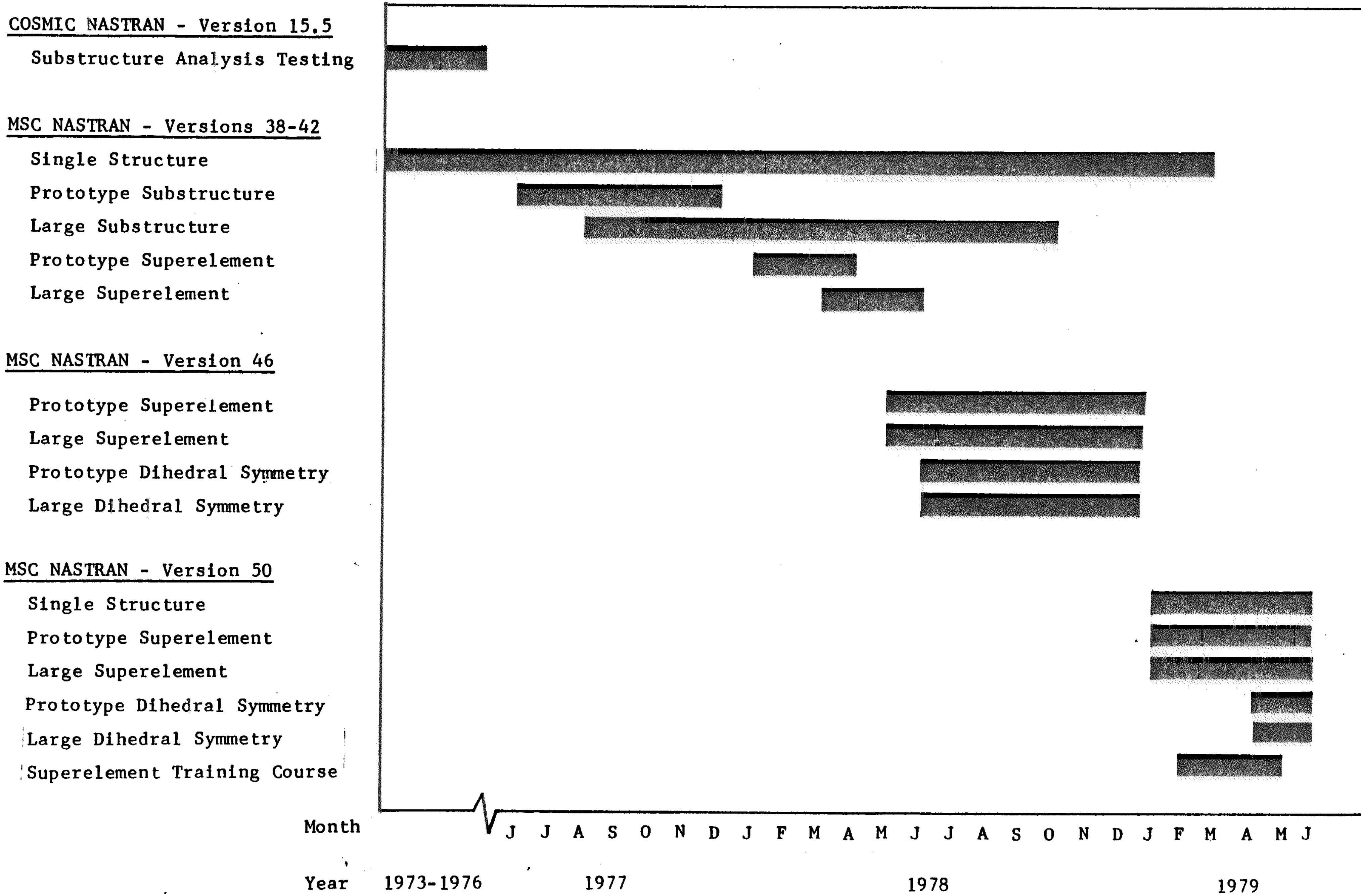

Table 2. Linkage Alter for DMAP1 (MSC Version 50)

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ALTER 321,321
ALTER 326,326
ALTER 314,314
ALTER 365,365
$ NBRCH  =  NUMBER OF SIGN CHANGES
$ IF NEGATIVE TERMS ARE ON THE L-SET DIAG. THEN PRINT IT AND CR
COND NEGDIAG,NP $
ALTER 414
LABEL NEGDIAG $
DIAGONAL KLL/DIAGKLL/ $
DIAGONAL LLL/DIAGLLL/ $
ADD DIAGKLL,DIAGLLL/AMECHS///2  $
MATGPR HGPLS.USET.GSILS,AMECHS//H/L $
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Table 3. Superelement vs. Single Structure

Cost Comparison