N89-24655

IMPROVING TRANSIENT ANALYSIS TECHNOLOGY FOR AIRCRAFT STRUCTURES

R. J. Melosh
Duke University, Durham, NC

Mladen Chargin
NASA Ames Research Center, Moffett Field, CA

1. INTRODUCTION

Aircraft dynamic analyses are demanding of computer simulation capabilities. The modeling complexities of semi-monocoque construction, irregular geometry, high-performance materials, and high-accuracy analysis are present. At issue are the safety of passengers and the integrity of the structure for a wide variety of flight-operating and emergency conditions.

Figure 1 is a sketch of a typical structure. It dipicts one of NASA Ames designs of an oblique wing. The wing chord varies from 18.36 inches at the root to 37.8 inches at its 254.4 inch span. The skins are formed of a 0°/±45°/90° 76%/14%/10% graphite/epoxy composite. The skin varies in thickness from .625 inch at the root to .184 inch at the tip. The skins are supported by 5 vertically stiffened spars and 14 stiffened ribs. All the support structure is designed in aluminum. The wing must be proofed against landing, lift and drag, gust, buffet, vibration, and oscillating aerodynamic loading.

The figures and text that follow examine the technology which supports engineering of aircraft structures using computer simulation. They briefly describe available computer support and recommend improving accuracy and efficiency. Improved accuracy of simulation will lead to more economical structure. Improved efficiency will result in lowering development time and expense.

2. SIMULATION SUPPORT

Figure 2 lists the dynamicists' tasks for computer simulation of transient analysis. Dynamicists define the finite-element representation of their structure and its boundary conditions. They select the procedures to use in integrating the equations of motion over time, and define the models and extent of stress evaluation. They interpret analysis results with respect to the real system, drawing upon their knowledge of the models, algorithms, and the computer configuration which implements the simulation.

Figure 3 identifies the computer capabilities which support implementation of the tasks of Figure 2. Existing finite-element models provide for both Rayleigh-Ritz and heuristic models. Three methods of reducing the vector basis, four classes of numerical quadrature, and at least three processes for evaluating stresses are available. Interpretation software facilitates plotting and tabulating data.

3. ACCURACY ASSESSMENT

Figure 4 is typical of the type of data that would be useful to the dynamicist in assessing analysis accuracy. The continuous folded line on this figure plots the actual spatial discretization error for the first two resonant frequencies. The dashed folded line portrays the error predicted using accuracy qualifying logic.

Figure 5 shows similar data qualifying the prediction of transient response with respect to spatial discretization error. The fact that this error can accumulate during the history emphasizes the need for continuous monitoring of this error source.

Figure 6 notes the principal sources of inaccuracy in each of the simulation tasks. The sources include spatial discretization, time discretization, process, round-off, idealization, and human errors. These sources induce accuracy loss in each task which can accumulate from task to task and obliterate accuracy.

Figure 7 is a bar chart of the comprehensiveness of support of each error source in contemporary simulations. No known production computer code is complete with respect to any source. Most codes provide partial protection against process and roundoff error only. Consequently, we cannot regard transient analysis results as reliable. For some of these sources, new technology is needed to determine accuracy; for others, suggested techniques require evaluation; and for the rest, only implementation in production codes is necessary.

4. ANALYSIS EFFICIENCY

Figure 8 cites the sources of inefficiency in simulation tasks with respect to technology and software. These sources involve use of non-optimum models, inappropriate integration algorithms, and unsuitable space and time grids. Lack of efficiency measures in computer codes inhibits experimental improvement of simulation efficiency in practice.

Figure 9 illustrates the inefficiency of available beam models for predicting modal frequencies. This figure shows the logarithmic relation between the number of modal frequencies and the equivalent number of elements and nodal variables. The first is a measure of the computer resources needed for equation coefficient; the second, those needed for equation integration. The data show that the efficiency of the Bernouilli-Euler beam model is less than 50 percent of that of the ideal model.

Figure 10 focuses on the efficiency of nodal siting for the beam. The abscissa of the graph measures the number of calculations. The ordinate indicates the number of accurate modes. These curves illustrate the existence of a distinct optimum grid for each mode. Analysis using the optimum grid requires only one-third the calculations of the average grid.

Figure 11 gives the conventional wisdom for selecting the time integration process of transient analysis. This table pertains to linear dynamic analyses. Considering the number of calculations, the data indicates that a different algorithm is advisable depending upon whether the frequency content of response is high or low and whether the integration time is brief or extended compared with the period of the fundamental mode. Comparing the best to the worst choice of algorithm we find an advantage of a factor which is a function of the order and band of the integration operator matrix.

Figure 12 provides data for comparing the efficiency of integration algorithms for a highly nonlinear transient analysis of a cylinder. These data indicate that explicit (central differences) and explicit (Newmark Beta) are competitive but modal synthesis is not. Choosing the better algorithm may reduce the number of calculations to 1/100 of those of modal synthesis.

Figure 13 summarizes the potential for improving simulation efficiency by improving both models and algorithms. It indicates the opportunity for reducing the number of calculations by three orders of magnitude.

5. CONCLUSIONS

Now, computer implementation of transient analysis of aircraft structures provides for accurate response predictions. The dynamicist can hope to determine the accuracy of his particular simulation only by "heroic" efforts. Steps he may make to satisfy his desire for efficient analysis are heuristic.

Thus, desirable new technology includes a validated comprehensive set of simulation accuracy and relative efficiency measures. Using these measures to identify research opportunities will lead naturally to better models and data processing algorithms.

The ultimate benefit of accuracy measures will be that dynamicists will have the data they need to more fully understand and interpret the computer's time histories. The ultimate benefit of efficiency measures will be exploitation of the potential to reduce the number of calculations of transient analysis by one to three orders of magnitude. (Fig. 14).

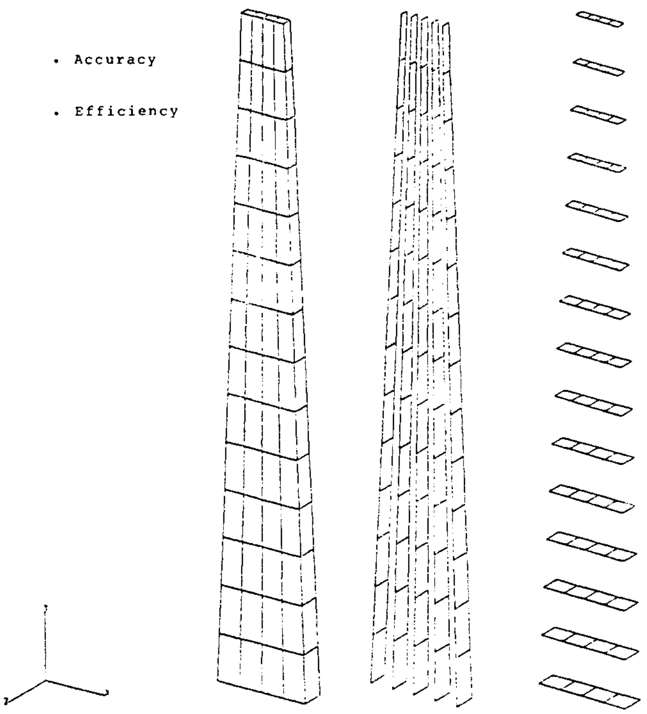

Figure 1. Typical structure: NASA Ames design of oblique wing.

FORM EQUATIONS OF MOTION

- Select element models
- Generate element matrices
- Design, redesign meshes
- Assemble equation coefficients

INTEGRATE EQUATIONS OVER TIME

- Select basic vectors
- Select integration rules
- Reduce equations
- Evolve time histories

EVALUATE RESPONSE DATA

- Find peak displacements
- Evaluate stresses
- Select stress formulas
- Find peak stresses

INTERPRET SIMULATION RESULTS

- Validate models, processes
- Qualify analysis results
- Verify production analysis
- Relate to the Physical system

Figure 2. Tasks of simulation.

FORM EQUATIONS OF MOTION

- Library of element models
- Modeling experience
- Assembly process
- Data generators
- Grid generators and smoothers
- Geometry plotters
- Element model generators

INTEGRATE EQUATIONS OVER TIME

- Modal, Guyan, and Ritz vector technology
- Sparse matrix operations
- Experience in transient analysis
- Duhamel, explicit, implicit, and quasi-static integrators

EVALUATE RESPONSE DATA

- Interpolation logic
- Displacement differentiation, D'Alembert, inertia relief methods
- Peak stress logic

INTERPRET SIMULATION RESULTS

- Element validation tests
- Process validation tests
- Error measures
- Sensitivity analysis
- Tabulations and response plots
- Data retrieval logic

Figure 3. Supporting simulation technology.

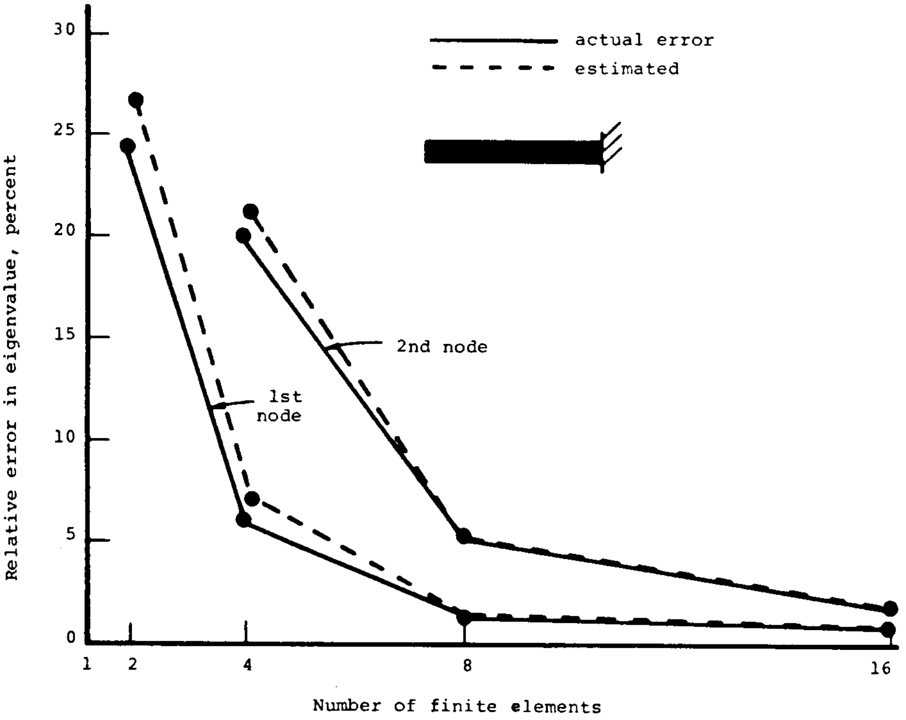

Figure 4. Spatial discretization errors in eigenvalues.

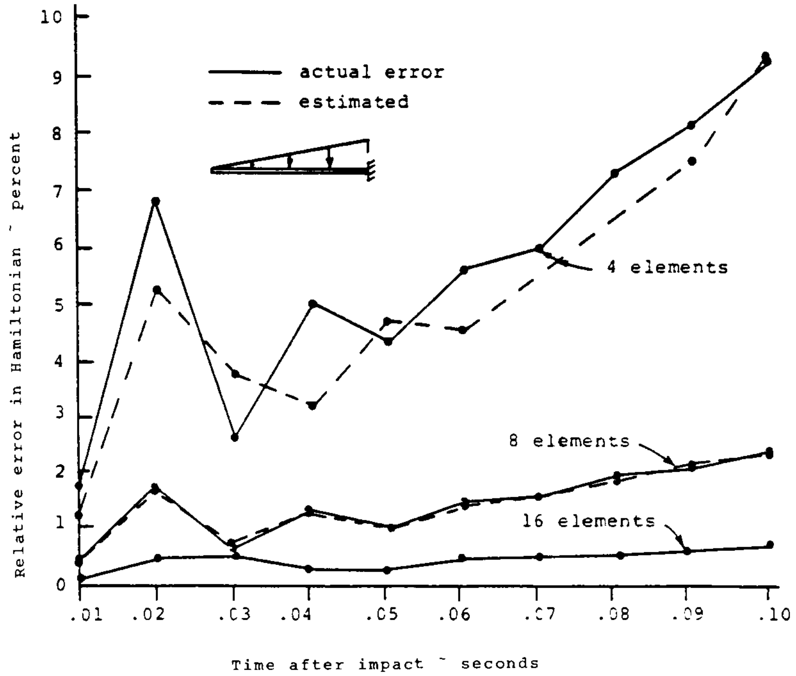

Figure 5. Transient analysis discretization errors.

FORM EQUATIONS OF MOTION

- Human error
- Idealization of geometry, materials, B.C.
- Spatial discretization

INTEGRATE EQUATIONS OVER TIME

- Spatial discretization
- Time discretization
- Integration process
- Round-off

EVALUATE RESPONSE DATA

- Spatial discretization
- Time discretization
- Stress evaluation process
- Round-off

INTERPPET SIMULATION RESULTS

- Human error
- Technology omissions

Figure 6. Sources of inaccuracy in transient analysis.

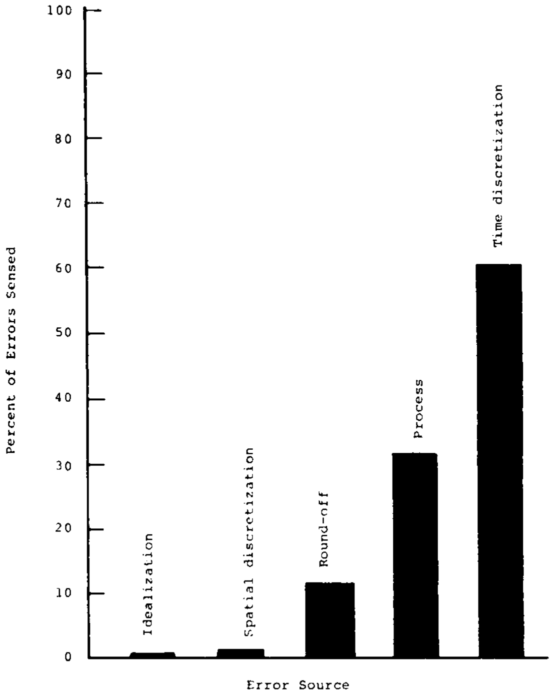

Figure 7. Control of inaccuracies.

FORM EQUATIONS OF MOTION

- Inefficient element models
- Non-optimum grids
- Non-optimum meshes

INTEGRATE EQUATIONS OVER TIME

- Irrelevant generalized coordinates
- Excessive time steps
- Irregular time steps

EVALUATE RESPONSE DATA

- Excessive sampling in time
- Excessive sampling in space

INTERPRET SIMULATION RESULTS

- Inadequate and inefficient documentation
- Insufficient validation
- Inexperienced analysts

Figure 8. Sources of inefficiency.

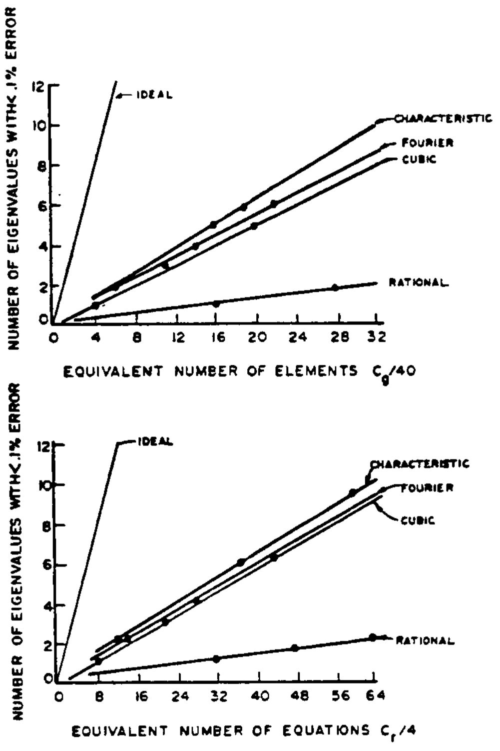

Figure 9. Efficiency of beam element models.

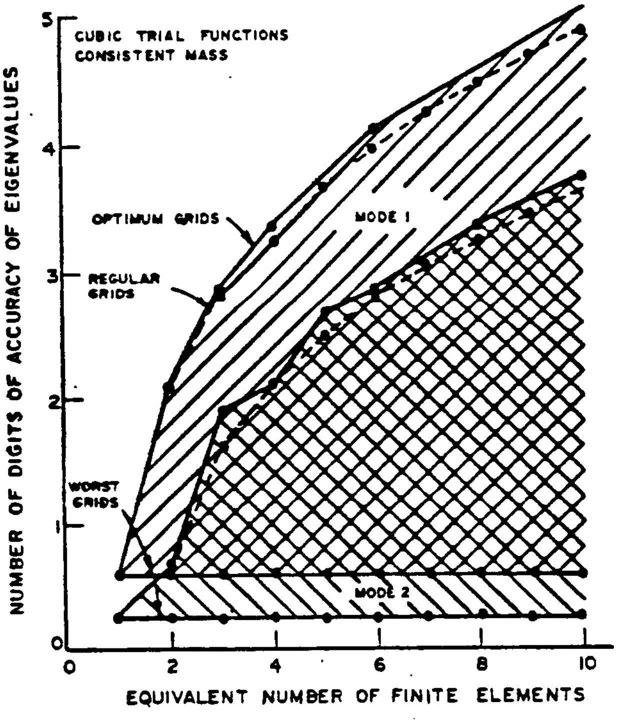

Figure 10. Efficiency of grid designs.

ANALYSIS CLASS(1)	BEST INTEGRATION ALGORITHM	NO. OF CALCS.(2)	BEST/WORST(3)
H.B.	Central or Newmark	Nb^2	N
L.B.	Wilson Ritz	16Nb	b
H.E.	Newmark	$4Nb\frac{t_p}{\Delta t_i}$	N/b
L.E.	Modal Synthesis	$8N\frac{t_p}{\Delta t_i}$	$N\frac{t_p}{\Delta t_i}$

(1)

H = high frequency response important; L = low

B = brief period of integration; E = extensive period

(2)

N = no. of equations of motion

b = semi-band width of integration operator matrix

t_p = period of integration

Δt_i = time step required

(3)

Comparing Central Differences, Newmark Beta, Modal Synthesis, and Wilson's Ritz Vectors methods.

Figure 11. Efficient time integration-linear.

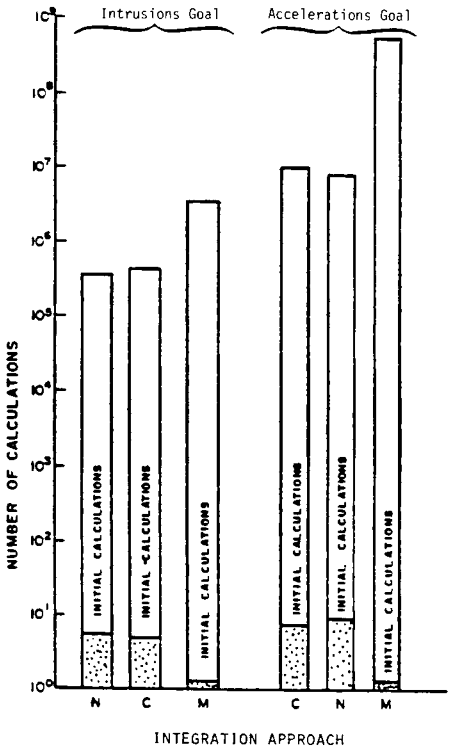

Figure 12. Calculations for nonlinear analysis.

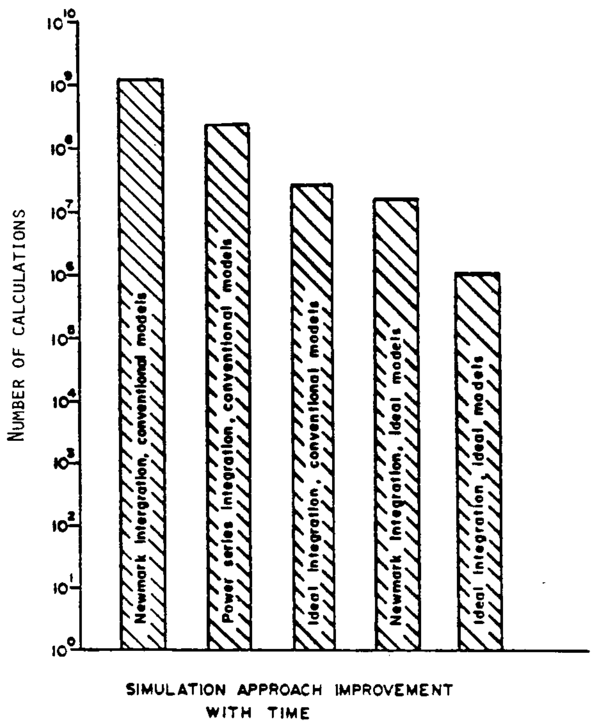

Figure 13. Improvement of simulation efficiency.

STATE-OF-THE-ART

- CAPABILITY FOR ACCURACY EXISTS
- ACCURACY NOT WELL QUANTIFIED
- EFFICIENCY EMPIRICAL

PROSPECTIVE IMPROVEMENTS

- COMPREHENSIVE SET OF ACCURACY SENSORS
- A SET OF EFFICIENCY SENSORS

BENEFITS

- SELF-QUALIFIED TRANSIENT ANALYSIS
- MUCH IMPROVED EFFICIENCY

Figure 14. Conclusions.