DYNAMIC AND AEROELASTIC ANALYSES OF TURBOSYSTEMS IN NASTRAN

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SUMMARY

Several new capabilities dealing with the dynamic and aeroelastic analyses of turbosystems have been added as standard features to the April 1986 release of NASTRAN. This paper gives a brief description of these capabilities and outlines their implementation in NASTRAN.

INTRODUCTION

In a series of related efforts over the past few years, NASA's Lewis Research Center (NASA LeRC) has sponsored the development of a number of analytical capabilities addressing the static, dynamic and aeroelastic problems of axial-flow turbosystems (References 1-10). To benefit from the state-of-the-art structural modeling and analyses techniques, these analytical developments were implemented in the general purpose finite element program NASTRAN. The capabilities are based on a unified approach to representing and integrating the structural and aerodynamic aspects of the turbomachinery problems.

The enhancements to NASTRAN developed under the above efforts can be grouped into two phases. The capabilities developed in the first phase (References 1-7) were incorporated into the UNIVAC Level 17.7 version of NASTRAN at NASA LeRC. These capabilities were subsequently expanded in the second phase (References 8-10) and made operational on RPK's CRAY version of the April 1984 release of NASTRAN at NASA LeRC. In order to make all of these enhancements available to the general NASTRAN user community, these capabilities have now been incorporated as standard features into the April 1986 release of NASTRAN.

DESCRIPTION OF THE NEW CAPABILITIES

Some of the new capabilities have been summarized in Reference 11. However, the authors feel it is very helpful and timely for NASTRAN users to have all of the new capabilities described in one paper presented to coincide with their incorporation in the April 1986 release of NASTRAN. Accordingly, the new capabilities are briefly described below. It is noted that all of the capabilities address tuned cyclic structures, that is, structures composed of cyclic sectors identical in mass, stiffness, damping and constraint properties.

1. Static Aerothermoelastic 'Design/Analysis' of Axial-Flow Compressors (References 1-3)

The non-linear interactive influences between the flexible structure of axial-flow compressor rotor or stator stage, and the steady state aerothermodynamics of the internal flow are addressed. The 'design' problem embraces the process of arriving at an 'as manufactured' blade shape to produce a desired design point pressure ratio, given the flow rate and the rotational speed. The subsequent process of analyzing the structural and aerothermodynamic performance at off-design operating points is termed the 'analysis' problem.

The three-dimensional aerothermodynamic theory discussed in Reference 12 is used. The capability also yields a differential stiffness matrix at the end of the iterative non-linear solution process for use in subsequent modal, flutter, dynamic and aerodynamic response analyses.

2. Modal Flutter Analysis of Axial-Flow Turbomachines (References 1-3)

Unstalled flutter boundaries of axial-flow turbomachines (compressors and turbines) can be determined using this capability. The aeroelastic stability of a given operating point of a given stage of the turbomachine is investigated in terms of modal families of several circumferential harmonic indices considered one at a time.

Two-dimensional cascade unsteady aerodynamic theories of Reference 13 (subsonic) and Reference 14 (supersonic) are used.

3. Forced Vibration Analysis of Rotating Cyclic Structures (References 4,5)

Cyclic structures rotating about their axis of symmetry, and subjected to sinusoidal or generally periodic loads moving with the structure are addressed. In addition, the axis of rotation itself is permitted translational oscillations resulting in inertial loads. Coriolis and centripetal acceleration effects are also included.

The problem is treated using the direct approach in NASTRAN.

4. Modal Flutter Analysis of Advanced Turbopropellers (References 6,7)

Unstalled flutter boundaries of multi-bladed advanced turbopropellers can be determined using this capability. Such propellers comprise thin blades of low aspect ratio and varying sweep. The analysis is similar to that for axial-flow turbomachines with the addition that the unsteady aerodynamics have been modified to recognize the blade sweep effects.

5. Modal Forced Vibration Analysis of Aerodynamically Excited Turbosystems (References 8-10)

Vibratory response of turbosystems subjected to aerodynamic excitation is addressed. Turbosystems such as single- and counter-rotating advanced turbopropellers with highly swept blades, and axial-flow compressors and turbines can be analyzed. The dynamic response problem is treated in terms of the normal modal coordinates of these tuned rotating cyclic structures. Both rigid and flexible hubs/disks are considered. Coriolis and centripetal accelerations, as well as differential stiffness effects, are also included.

Generally non-uniform steady inflow fields and uniform flow fields arbitrarily inclined at small angles with respect to the axis of rotation of the turbosystem are considered as the sources of aerodynamic excitation. Subsonic and supersonic relative inflows are addressed, with provision for linearly interpolating transonic airloads.

A stand-alone pre-processor program, independent of NASTRAN, has been additionally developed to compute the applied vibratory airloads on the blades of these turbosystems (Reference 10). This program, called AIRLOADS, is available separately from COSMIC.

NASTRAN IMPLEMENTATION

The incorporation of the new capabilities described above involved extensive changes to NASTRAN. These are outlined below.

1. Additions to the Rigid Format Data Base

The Rigid Format Data Base was expanded by the addition of two new rigid formats (DISP 16 for Static Aerothermoelastic Design/Analysis and AERO 9 for Cyclic Modal Flutter Analysis) and two new DMAP ALTER packages for the Forced Vibration Analysis of Rotating Cyclic Structures. Both of the ALTER packages represent DMAP ALTERs to the DISP 8 rigid format. One of the ALTER packages uses the direct approach and the other uses the modal approach. The latter one also allows for the effects of the generalized aerodynamic matrix due to oscillatory blade motions.

2. Additions to the Source Code

A total of 83 subprograms were added to NASTRAN in order to incorporate the new capabilities. These involve the following important additions.

A. Four new functional modules

ALG	---	Aerodynamic load generator (for use in the new DISP 16 rigid format)
APDB	---	Aerodynamic pool distributor for blades (for use in the new AERO 9 rigid format)
FVRSTR1	---	Forced vibration response analysis of rotating cyclic structures - Phase 1 (for use in the new DMAP ALTER packages)
FVRSTR2	---	Forced vibration response analysis of rotating cyclic structures - Phase 2 (for use in the new DMAP ALTER packages)

B. Two new bulk data cards

STREAML1	---	Defines grid points on a blade streamline from the leading edge to the trailing edge
STREAML2	---	Defines aerodynamic data for a blade streamline

C. Several new bulk data parameters (PARAMs)

3. Modifications to the Source Code

A total of 35 existing subprograms were modified in order to incorporate the new capabilities into NASTRAN.

CONCLUDING REMARKS

A brief description of a number of new capabilities added to the April 1986 release of NASTRAN for the dynamic and aeroelastic analyses of turbosystems has been presented. An outline of their implementation in NASTRAN is also given.

ACKNOWLEDGEMENTS

The authors take this opportunity to rightfully acknowledge the valuable contributions of Mr. A. Michael Gallo, Dr. G. C. C. Smith, Ms. B. J. Dale and Mr. S. C. Skalski, of Bell Aerospace Textron, to the development of the above-mentioned new capabilities in NASTRAN.

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