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UNSTEADY AERODYNAMICS AND AEROELASTIC RESEARCH AT AFWAL

L. J. Huttsell
and
W. A. Sotomayer
Air Force Wright Aeronautical Laboratories
Structures Division (AFWAL/FIBRC)
Wright-Patterson AFB, Ohio

OUTLINE

The presentation (Figure 1) will be broken into two areas: (1) transonic unsteady aerodynamic development of the XTRAN3S code and (2) some other aeroelastic research and development within the Structures Division (Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory). The first area will cover historical development of the XTRAN3S program, the Joint AF/NASA unsteady aerodynamics program to expand and improve this code, and the new efforts for applications and improvements of XTRAN3S. The second area will cover three aeroelastic research and development efforts that may be of interest to this group. These efforts are (1) an Analog and Digital Aeroservoelasticity Method called ADAM, (2) an Automated STRuctural Optimization System called ASTROS, and (3) a new effort for improved flight loads predictions.

- TRANSONIC UNSTEADY AERO DEVELOPMENT - XTRAN3S
  - HISTORICAL DEVELOPMENT
  - JOINT AF/NASA PROGRAM
  - CURRENT RESEARCH AND APPLICATIONS
- AEROELASTIC RESEARCH AND DEVELOPMENT
  - ANALOG AND DIGITAL AEROSERVOELASTICITY METHOD
  - AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM
  - FLIGHT LOADS PREDICTION METHOD

Figure 1

HISTORICAL DEVELOPMENT OF XTRAN3S

Figure 2 gives a roadmap showing the development of the XTRAN3S code. In 1974, Ballhaus and Steger published a report (NASA TM X-73,082) on fully implicit finite difference schemes for 2-D unsteady transonic flows that permitted time step selection based on accuracy rather than stability considerations. This led to the development of the LTRAN2 code which used a conservative, implicit finite-difference algorithm to integrate the non-linear, low-frequency, transonic, small-disturbance equation in time. The XTRAN3S (eXact TRANsonic 3-dimensional aerodynamics with Structural effects) code is an extension of the Ballhaus/Goorjian procedure used in LTRAN2. The XTRAN3S code was developed by Boeing under an AFWAL contract. Both NASA Ames and Langley provided valuable consultation during the contract and worked to extend and improve the code.

In 1985, a joint AFWAL and NASA (Ames and Langley) effort was initiated to extend and improve XTRAN3S and to explore promising long-term computational fluid dynamics (CFD) methods. All agreed to work to achieve a code to satisfy the needs of future Air Force fighters by the 1989 time period. The next few charts will give more details on each participant's efforts on XTRAN3S. Details of current applications and research will also be presented on a later chart.

NASA Langley's efforts on XTRAN3S and their in-house research with Approximate Factorization (AF) algorithms led to the recent development of their transonic small disturbance code called CAP-TSD. There will be several papers presented at this symposium on this code.

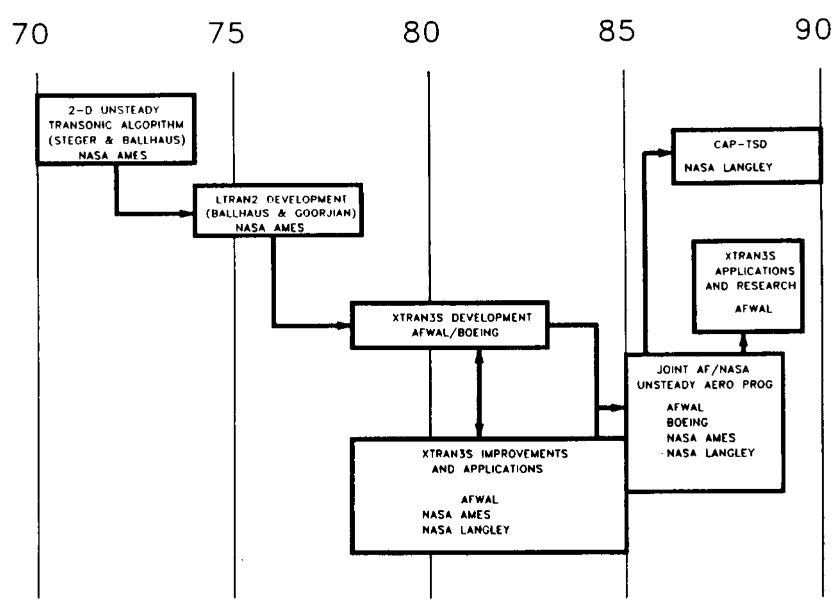

Figure 2

JOINT AFWAL, NASA LANGLEY, NASA AMES EFFORT

AFWAL

The XTRAN3S code has been used at AFWAL for steady and unsteady aerodynamic calculations and for dynamic aeroelastic analysis. Figure 3 lists some of past and on-going efforts with XTRAN3S at AFWAL. In-house unsteady aerodynamic applications have been made for the LANN wing, F-5 wing, and F-5 wing with control surface. Presently, W. Sotomayer is investigating non-reflective far-field boundary conditions for XTRAN3S. Another on-going effort involves aeroelastic calculations for the Cornell 45 degree swept wing which will be discussed in more detail on the next chart.

XTRAN3S Applications and Improvements

AFWAL FDL In-House

- F-5 Wing and Wing-Control Surface
- LANN Wing
- Non-Reflecting Boundary Conditions
- Aeroelastic Calculations for Cornell Wing

Figure 3

AEROELASTIC CALCULATIONS FOR CORNELL WING

Subsonic and supersonic aeroelastic calculations have been conducted by AFWAL for the Cornell 45° Swept Wing shown in Figure 4. A set of dynamically similar models of different mass and stiffness was tested by Cornell Aeronautical Laboratory in 1956, and the non-dimensional flutter trend versus Mach number for various mass ratios are shown in the figure. The results of this in-house effort by Pendleton and French will be presented at the AIAA Aircraft Design Conference in September 1987.

Transonic aeroelastic calculations are underway using the XTRAN3S code. The linear and nonlinear XTRAN3S calculations at M=0.8 agree very well with the doublet lattice predictions and with test data. Additional calculations will be performed in the range of M=.95 to M=1.13 to define the transonic dip and to compare with test data.

CORNELL 45° SWEPT WING FLUTTER TRENDS

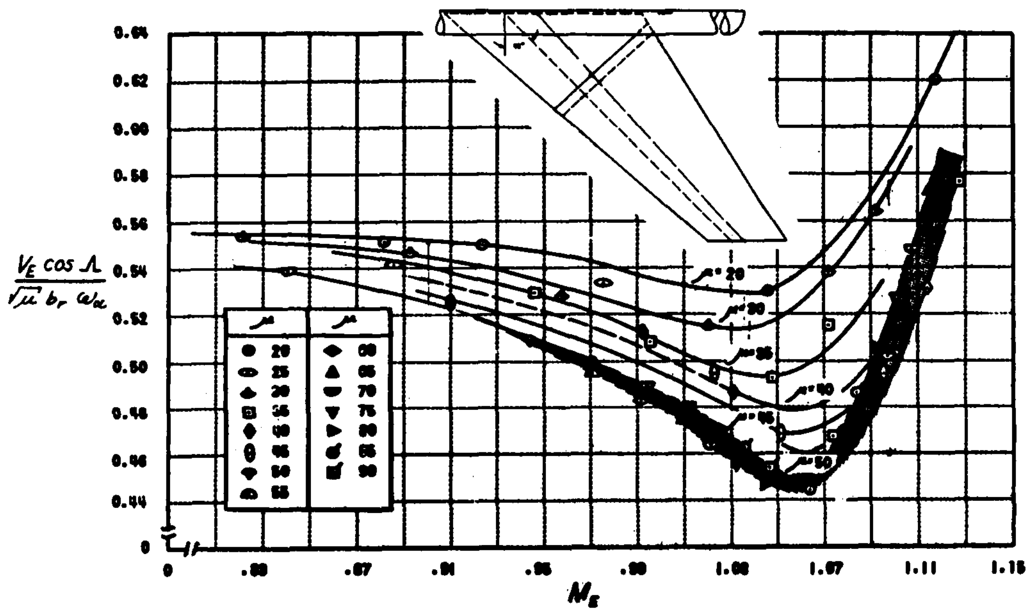

Figure 4

NASA Ames

NASA Ames has been active with the XTRAN3S program since its early development. An outline of their efforts is presented in Figure 5. Their applications include F-5 wing and F-5 wing with tip store, aeroelastic analysis of the B-1 wing, and other analyses for research configurations. Under a NASA Ames contract, Boeing developed the procedure for including inviscid/viscous interaction for three-dimensional transonic flow. NASA Ames developed algorithm improvements and gridding for wing/tip store and a full-volume fuselage capability. Supersonic boundary conditions were recently added to the XTRAN3S code by NASA Ames.

XTRAN3S Applications and Improvements

NASA Ames

- Applications (B-1, F-5, etc.)
- Algorithm Improvements
- Wing/Tip Store Capability
- Full-Volume Fuselage Capability
- Supersonic Capability

Figure 5

NASA Langley

As shown in Figure 6, NASA Langley has also been very active in the application and improvement to the XTRAN3S code. Their applications include the F-5 wing, RAE wing-fuselage, wing/canard, and several research wings. Their improvements include algorithm development, wing/fuselage capability, and wing/tail or canard/wing capability. They have also provided programmer support and managed the Boeing contract for wing/pylon/nacelle capability. Presently they are working on the development and validation of their new code called CAP-TSD (Computational Aeroelasticity Program - Transonic Small Disturbance), utilizing an Approximate Factorization (AF) scheme.

XTRAN3S Applications and Improvements

NASA Langley

- Applications (F-5, RAE Wing-Fuselage, Wing/Canard, etc.)
- Algorithm Improvements
- Wing/Fuselage and Wing/Tail Capability
- Boeing Contract for Wing/Pylon/Nacelle Capability
- Programmer Support

Figure 6

CURRENT RESEARCH AND APPLICATIONS

In June 1986, AFWAL initiated a PRDA (Program Research and Development) for applications and improvements to XTRAN3S. We anticipate three contracts will result from this PRDA (Figure 7). One contract will involve improved unsteady calculations using available experimental pressure data. The second contract will integrate existing capabilities for wing/fuselage, wing/pylon/nacelle, and supersonic analysis into an improved version of XTRAN3S. Applications to a fighter with stores and a transport configuration will be performed to validate this code. The third contract will involve applications of both XTRAN3S and CAP-TSD to a fighter configuration with flight test data.

- UNSTEADY PERTURBATIONS AROUND AN EXPERIMENTAL MEAN
- XTRAN3S INTEGRATION, IMPROVEMENT, AND APPLICATION
    - WING/FUSELAGE
    - WING/PYLON/NACELLE
    - SUPERSONIC
    - A-6 AND TRANSPORT APPLICATION
- XTRAN3S AND CAP-TSD (NASA LANGLEY) APPLICATIONS AND COMPARISON WITH TEST FOR FIGHTER CONFIGURATIONS

Figure 7

AEROSERVOELASTICITY

Structural dynamics, flight controls, and unsteady aerodynamics are independent technologies for the purpose of research, but for modern aircraft design, early simultaneous consideration of these disciplines is necessary to prevent aeroservoelastic problems. Without early interaction between these technologies (Figure 8) in the design process, aircraft with high-gain flight control systems may be driven unstable as a result of the feeding back of structural displacements. Several fighters, bombers, and a target drone have experienced such aeroservoelastic problems. Currently, extensive analyses and tests are required to prevent adverse control system/structural interactions. Aircraft design trends indicate that vehicles of the future will be even more flexible, emphasizing the need for integrated design and analysis procedures to obtain the desired performance.

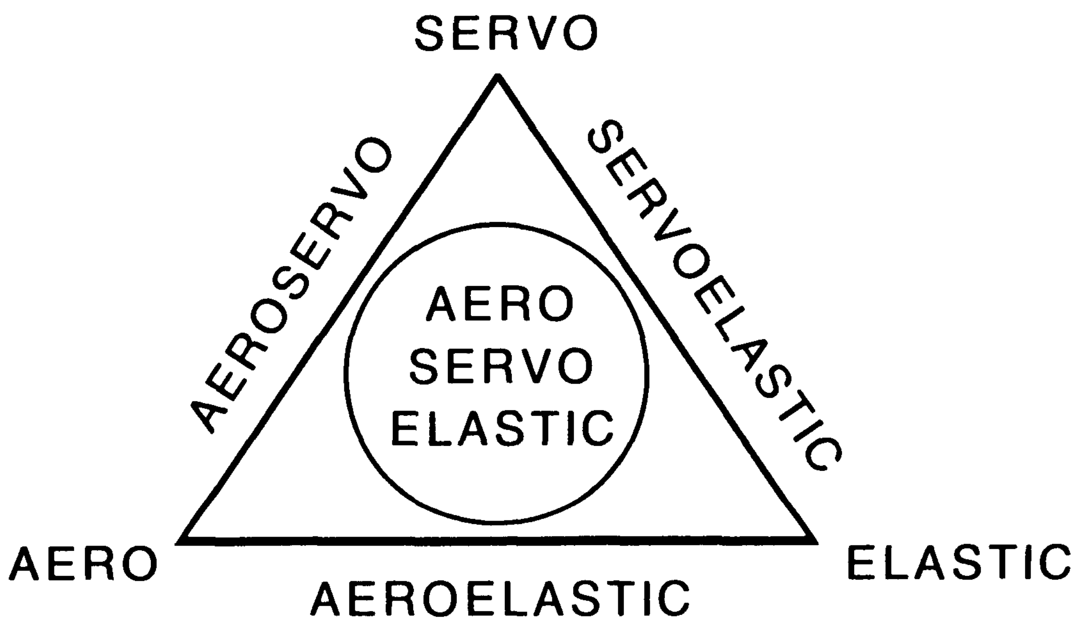

Figure 8

ANALOG AND DIGITAL AEROSERVOELASTIC METHOD (ADAM)

The Flight Dynamics Laboratory is developing techniques to analyze aircraft with either analog or digital flight control systems and is incorporating these into a new in-house analysis computer program called ADAM (Analog and Digital Aeroservoelasticity Method). The objectives of this effort are to improve the in-house capability for performing analyses, to develop the capability to audit ongoing aircraft development programs and to enable the evaluation of proposals of advanced aircraft designs from an aeroservoelastic consideration. A secondary objective is to establish a closer working relationship and to improve communication among structural dynamics, controls, and aerodynamics engineers.

ADAM is capable of analyzing the aeroservoelastic characteristics of complete aircraft in either the longitudinal or lateral/directional modes. The program is currently operational and will be continually improved to add the most desirable features for performing aeroservoelastic analysis. ADAM is now capable of analyzing aircraft stability for analog multi-input/multi-output (MIMO) control systems and for digital systems to a limited extent. The program is being modified to fully account for digital systems. For analyses involving analog control systems, classical root locus criteria are employed. If a digital control system is involved, discretization techniques are used. Figure 9 presents the operational flow diagram for ADAM.

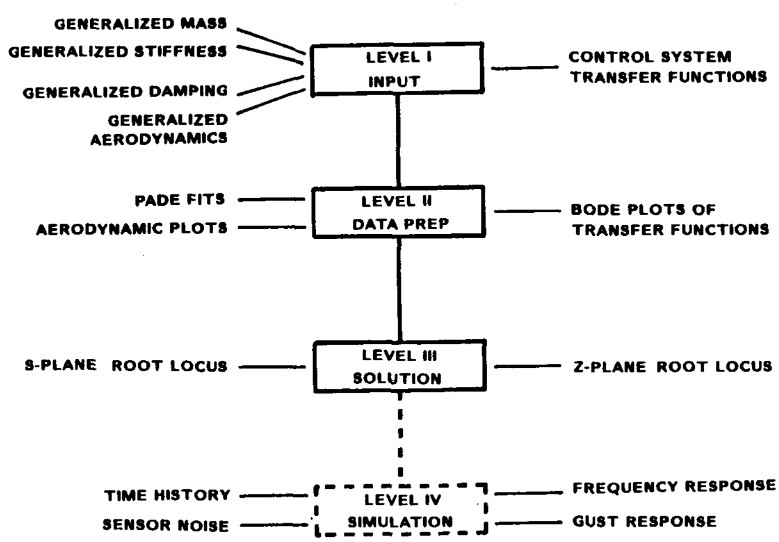

Figure 9

DEVELOPMENT OF AN "AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM' (ASTROS)

The goal of this effort (Figure 10) is to combine modern optimization algorithms and proven multidisciplinary analysis programs with the latest computer software advances. The resulting state-of-the-art structural design tool can help meet performance requirements of future aerospace vehicles with the payoff in least weight and/or cost. A procedure for preliminary structural design or modification of aircraft and spacecraft is being developed.

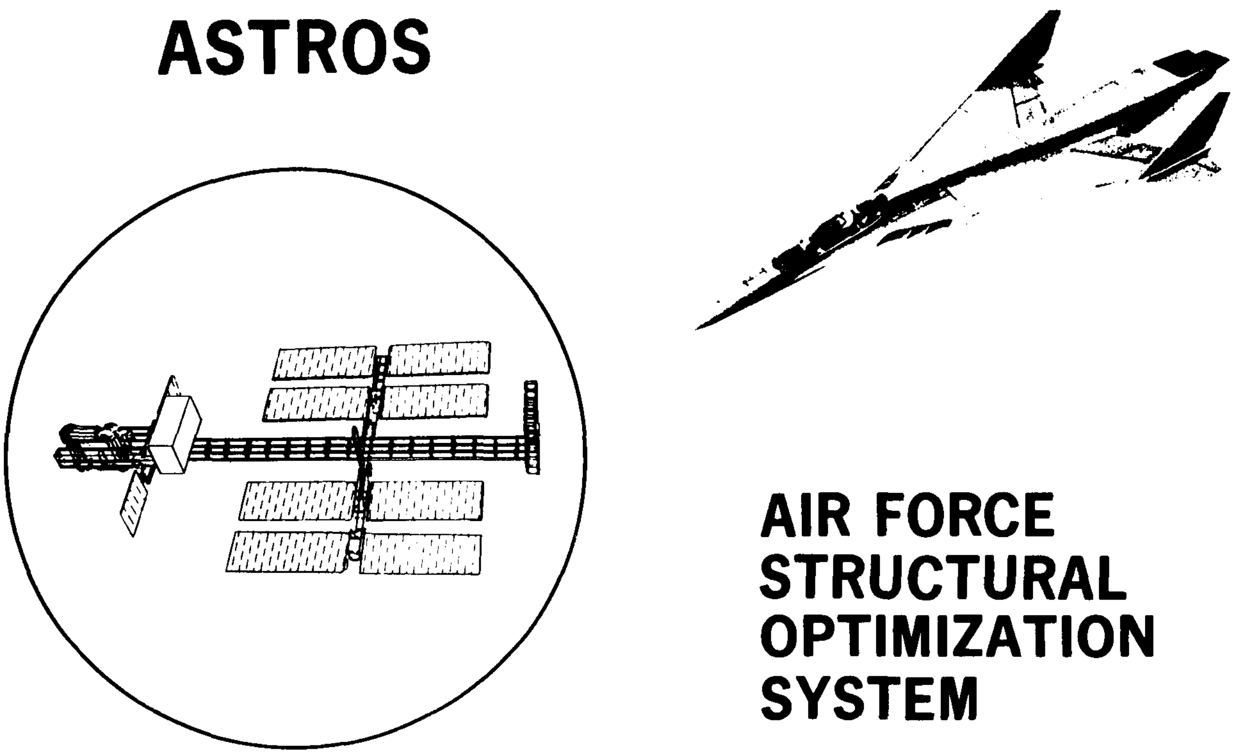

Figure 10

AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM

The computer code for Automated STRuctural Optimization System (ASTROS) has an executive system and an engineering data base management system to support six technical (engineering) modules (Figure 11). The engineering modules include Structures and Dynamics, Air Loads (Subsonic and Supersonic), Aeroelasticity, Sensitivity Analysis, Optimization, and Control Response.

The Structural Analysis is based on the finite element method, incorporating static and thermal loads, buckling analysis, eigenvalue analysis, and dynamic response. The Air Loads module calculates static air loads using Woodward aerodynamics. The Aeroelasticity module calculates the unsteady aerodynamic forces using the subsonic doublet lattice and supersonic potential gradient methods, and calculates flutter speed using the p-k method. In addition to flutter, ASTROS can consider static divergence, control surface effectiveness, and roll effectiveness as design criteria. The goal of the Optimization module is to produce an optimum design starting from an arbitrary initial design, while satisfying all the requirements imposed by the constraints. The Control Response module determines the structural response to control input for the final design.

ASTROS is currently being tested in-house in anticipation of the final code delivery in March 1988. The program is proving useful not only for structural optimization, but also for its capability to do any combination of static or dynamic structural analysis, air loads, or flutter in an analysis mode.

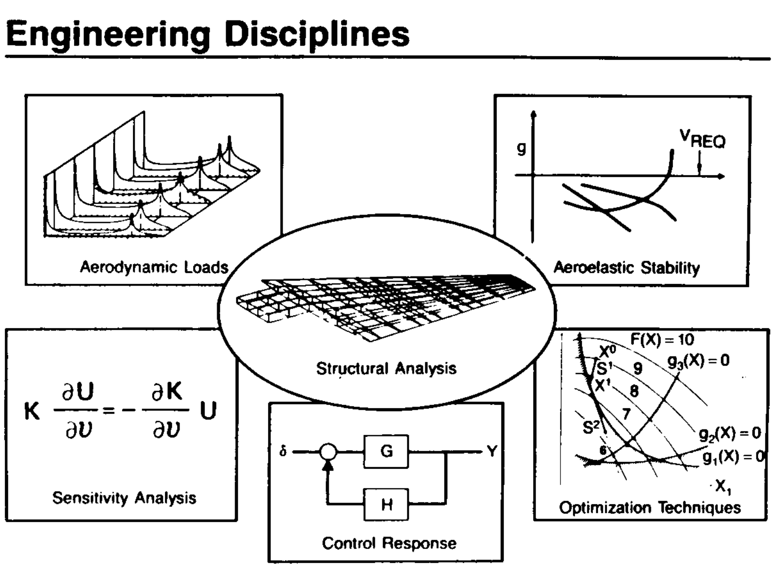

Figure 11

FLIGHT LOADS PREDICTION METHODS FOR FIGHTER AIRCRAFT

The prime motivator that has led to the significant progress in Computational Fluid Dynamics (CFD) for aircraft has been the desire to accurately predict aerodynamic flow field so that aerodynamic performance can be improved and accurate prediction of lift and drag can be obtained. These same advances can improve predictions of structural loads.

The objective of this effort is to apply advanced CFD methods to structural loads calculations (Figure 12). These advanced CFD methods are needed at high angles of attack where separation may occur and in the transonic flight regime where shock waves may significantly affect the loads. The approach is to utilize a proven CFD method coupled with finite element structural analysis software so that loads can be calculated for an elastically deformed structure.

Lockheed-Georgia was the winner of this competitive procurement. The 3-year contract is expected to start in May 1987. The CFD method that Lockheed will use is a full Navier-Stokes flow solver in conjunction with a grid generator that will generate grids about realistic 3-dimensional aircraft. Five (5) months after contract start, Lockheed will deliver an interim version of the software which will calculate the flow field about rigid generic wing/body combination. This will be run on the Cray XMP 12 at Wright Patterson and the Cray XMP 48 at NASA Ames. The AFWAL contact is Mr Elijah Turner, (513) 255-6434 or Autovon 785-6434.

OBJECTIVE: DEVELOP CFD AEROELASTIC LOADS ANALYSIS CODE FOR SEPARATED FLOW

- FULL NAVIER-STOKES
- 2ND-ORDER ACCURATE STEADY/UNSTEADY
- 3-D AIRCRAFT

APPROACH:

- COUPLE EXISTING CFD FLOW SOLVER WITH FINITE ELEMENT STRUCTURAL ANALYSIS SOFTWARE

- VALIDATE CODE

ANTICIPATED COMPLETION: MAY 1990

Figure 12

CONCLUDING REMARKS

An efficient and accurate transonic unsteady aerodynamic method is needed for predicting flight loads, flutter, and aeroservoelastic stability for advanced aircraft. There have been new developments and many improvements to older codes. XTRAN3S which was featured at the last workshop, has been improved and will be a useful code for the near-term. However, to predict th unsteady aerodynamics for high performance maneuvering aircraft, the Euler/Navier-Stokes codes must be extended and improved for complex three-dimensional configurations. The long-term goal is development of Euler/Navier-Stokes unsteady aerodynamic methods for aeroelastic analysis (Figure 13).

- AN EFFICIENT & ACCURATE TRANSONIC UNSTEADY AERO METHOD IS NEEDED FOR ADVANCED AIRCRAFT.
- XTRAN3S WILL CONTINUE TO BE USED IN THE NEAR-TERM.
- AN AIR FORCE LONG-TERM GOAL IS DEVELOPMENT OF EULER/NAVIER-STOKES UNSTEADY AERO METHODS FOR AEROELASTIC ANALYSIS.

Figure 13