AERODYNAMICS-STRUCTURES INTERACTION IN AIRFRAME DESIGN

V. B. Venkayya and V. A. Tischler
Air Force Research Laboratory (AFRL)
Wright Laboratory, Wright-Patterson AFB, Ohio

Introduction

Aerodynamics and structures interaction play a critical role in airframe design. It becomes even more significant when viewed in the context of emerging Multidisciplinary Design Optimization (MDO), because the fidelity of the aerodynamic and structures models improves the reliability of the optimal solutions. The primary airframe components affected by the aero-structures interaction are lifting surfaces such as: wings, canards, fins, vertical and horizontal tails, etc.The flexibility effects on the aerodynamic load predictions on modern aircraft can be very significant. They effect both the steady and unsteady aerodynamic behavior as well as the stability aspects. There is a growing interest in both the national laboratories and in industry to develop Aero-Structures Interaction (ASI) tools.

Over the years AFRL has recognized this need and has identified the following topics for research in support of the ASI initiative:

i. Aeroelastic effects in aircraft trim analysis and an estimation of the differences in rigid and flexible stability derivatives.

ii. Procedures for computing the aerodynamic influence coefficients for aeroelastic corrections.

iii. Loads and deformation transformations between the aerodynamics and structures models.

iv. The impact of aeroelastic corrections on the steady and unsteady loads derived from linear aerodynamic theories (panel methods) including first and second order approximations.

v. The status of subsonic, supersonic and transonic aerodynamic predictions.

vi. Wing flexibility effects on non-linear aerodynamic predictions in the context of Euler, Navier Stokes and other Computational Fluid Dynamics (CFD) computations.

vii. Iterative methods for aeroelastic corrections to CFD computations.

viii. The state-space formulation of the equations of motion for aero-servo-elastic analysis and optimization.

In an informal survey of the aerospace industry (both domestic and international) the MacNeal Swendler Corporation (MSC) found a general consensus on the importance of flight loads and aeroelastic analysis in airframe design. In response MSC promised to invest significant resources to develop a comprehensive capability for flight loads and aeroelastic computations. This development is in the context of an upgraded MSC NASTRAN/PATRAN system. The details of their plans will be forthcoming in this aerospace division conference.

The purpose of this paper is to provide a brief review of the ongoing research efforts at AFRL in support of the ASI initiative. This review includes contractual efforts, Small Business Innovative Research (SBIR) Phase I and II programs and in-house research studies. We will touch on a total of six efforts.

1. ASTROS Aerodynamic capabilities.

2. AANDE Program (Lockheed-Martin Contract).

3. Analytical Methods Inc. (AMI) - SBIR Phase II.

4. ZONA Technologies Inc. (ZTI) STTR - Phase II.

5. In-House transonic aero studies.

6. CFD Research Corporation (Contract).

The aero-structure interaction in these programs is through an ASTROS interface, at least as a structures module. Some of these programs go all the way to the ASTROS optimization.

ASTROS Aerodynamic Capabilities[1-5]

The Automated STRuctural Optimization System (ASTROS) (see Fig. 1) has been in use for almost a decade. It was developed by Northrop and Universal Analytics Inc. on contracts from Wright Research and Development Center (WRDC), later Wright Laboratory (WL), and now the Air Force Research Laboratory (AFRL). ASTROS was reasonably well received by the aerospace industry as well as the academic community. Its computer architecture and its organization as a self contained system made it easy to use as a structural optimization system interacting aeroelastically with steady and unsteady aerodynamics. Nevertheless, the aerospace community identified a number of deficiencies in the system, particularly in the area of steady aerodynamics. This prompted initiation of the contract AANDE[6] (Aerodynamic Analysis for the Design Environment) to address some of the deficiencies.The details of the full capabilities of ASTROS are given in Ref. 1-5.

The steady airloads module, which is the subject of a latter discussion in this article, is based on first order panel methods. USSAERO was the primary source of the original steady aeroelastic analysis module. In addition to aeroelastically corrected air pressures associated with aircraft maneuvers, ASTROS computes inertia loads as well and combines them as static airloads for use in static structural analysis. This module also computes steady aero response quantifiers such as control surface and aileron effectiveness, lift, and hinge moment effectiveness parameters.

The unsteady airloads module was primarily designed for flutter velocity computations. The aerodynamic influence coefficients for flutter analysis are generated using the doublet lattice and constant pressure method (CPM). A similar aerodynamic influence coefficient matrix is also generated (although it is not the same) in the steady airloads module for aeroelastic correction of the maneuver loads.

Goals of the AANDE Program (Contractor: Lockheed-Martin Fort Worth Co.)[6]

1. Provide alternative steady aerodynamics to the USSAERO option in ASTROS. The QUADPAN program is the alternative.

2. Provide an asymmetric maneuver loads option in addition to symmetric and antisymmetric maneuvers.

3. Enhance the trim option to full 6 d.o.f. trim and to include multiple control surfaces and nonlinear effects.

4. Improve the spline interface between the aero and structural models.

5. Define the necessary hooks to bring in aerodynamic information from the outside, such as wind tunnel data or from the user's own preferred codes, and complete the design. This includes aeroelastic corrections to the loads as well.

6. Establish procedures to bring in aerodynamic pressures computed by CFD codes (Euler/Navier Stokes) to conduct aeroelastic analysis using ASTROS as a structural analysis module. This procedure implies three basic steps:

a. Compute aerodynamic pressures corresponding to a specified maneuver using a CFD code and transfer the information as structural grid loads to ASTROS.

b. ASTROS makes a static structural analysis for the deformations. These deflections are used to compute the updated angles of attack at the aerodynamic grids.

c. With the updated information the CFD code generates revised pressure information. These steps are repeated until a specified convergence criteria is satisfied.

It should be pointed out however, that it is not certain that this procedure actually converges. Nevertheless, there is a great deal of interest in the procedure or a modification to conduct aero-structure interactions using CFD codes.

The enhancements to ASTROS are classified into two categories:

a. Those integrated into ASTROS.

b. Those that are externally interfaced.

Items 1-4 in the foregoing discussion are integrated enhancements while 5 and 6 are externally interfaced enhancements. See Fig. 2 for a summary of these capabilities.

Analytical Methods Inc (AMI): Phase II Contract[7-9]

AMI, Redmond WA, is conducting this Phase II effort. Its purpose is to interface their proprietary aerodynamic codes MGAERO and VSAERO with ASTROS to provide additional flexibility to capture the aero-structure interaction aspects of **MDO**. MGAERO is an Euler code and its capabilities are outlined first (also see Fig. 3).

MGAERO is a Cartesian Multi-Grid Euler Code coupled with a boundary layer method. Some of the important features of this code are:

- Rotational Compressible Flow
- Steady State (Four Stage Iteration)
- Arbitrary Configurations
- Flow Separation (Within B.L.M. Limits)
- Induced Drag
- Shock Correction
- Viscous Effects on Wings
- Skin Friction Drag

The anticipated mode of coupling for aeroelastic analysis is shown in Fig. 4.

VSAERO is the other AMI proprietary code that will be interfaced with ASTROS for steady/maneuver loads calculations with aeroelastic corrections. VSAERO is similar to QUADPAN in the sense that it is a second order linear panel code. Some of its features are:

- Subsonic, Quasi-Steady Flow
- Integral Panel/Boundary Layer Method
- Complex Geometries - Thick and VORTEX Lattice Surfaces
- Wake Modeling
- Stability and Control

The VSAERO-ASTROS coupling is similar to that with QUADPAN except both VSAERO and MGAERO are external interfaces and not an integral part of ASTROS. Access charges to these programs need to be negotiated with AMI.

STTR - Phase-II Program with Zona Technology Inc (ZTI)[10-12]

The STTR - Phase II program with ZTI has two primary objectives:

1. Integrate four of ZTI's codes into ASTROS for static and dynamic aeroelastic analysis.

2. Develop a state-space model for aeroservoelastic analysis using ZTI's aerodynamics, ASTROS' mass, stiffness and damping information and augmenting these with input/output (actuator/sensor) models.

The four ZTI aerodyanamic codes are ZONA6, ZTAIC, ZONA7, and ZONA7U. Their range of applicability is shown in Fig. 5.

ZTI specially built the unified aerodynamic module, ZAERO, for arbitrary wing-body configurations for all MACH numbers using their four aero programs mentioned earlier. This aero-structrue interaction involved the following three tasks:

- Constructed a Unified Aerodynamic Influence Coefficient (UAIC) matrix for all Mach numbers.

- Developed an Aerodynamic Geometry Module (AGM) for arbitrary wing-body configurations.

- Developed a 3-D spline module for connecting 3-D ZAERO models with FEM models.

Fig. 6 shows the ASTROS/ZAERO program architecture.

The next step is the development of state-space models for aeroservoelastic analysis. For additional details see Ref. 12.

Fig. 7 lists the linear steady aerodynamics codes to be interfaced for ASTROS maneuver loads computations.

Additional Efforts in Support of ASI at AFRL

Due to time limitations we will have an abridged discussion of the ASI initiative at AFRL. Particularly, the discussion of the four items in this section is further shortened, but their details can be obtained from Ref. 14-17.

A recent PhD thesis by Ray Kolonay of our laboratory made a significant contribution to the optimization of an aircraft wing with a transonic flutter constraint along with static strength and minimum size constraints. The structural and optimization interface in this work is ASTROS, while the CAP-TSD (Unsteady Transonic Small Disturbance) program is used for the transonic flutter computations. An approximate procedure for the transonic flutter constraint computations is developed in the thesis. At least two wing configurations were used to test the method developed in this work.

Another notable in-house effort in support of ASI is a paper titled, "Application of the ENS3DAE (Euler/Navier Stokes Aeroelastic) Method". It is a collaborative effort by NASA Langley and WPAFB. ENS3DAE was originally developed by the Lockheed Aeronautical Systems Company (now Lockheed-Martin) under contract from Wright Laboratory. It has been used since 1989 to study a variety of configurations in the CFD environment. For additional details see Ref. 15.

Since 1994 GTRI (under contract from Wright Laboratory) has been conducting CFD-CSD interaction studies. Fig. 8 outlines the procedure adopted in this study. Ref. 16 gives additional details.

In 1996 WL/FIM awarded a contract to the CFD-Research Corporation (CFD-RC) to develop an effective CFD-CSM interface environment for aeroelastic studies. The title of the effort is "Development and Validation of a Parallel Distributed Computing Environment for Aero-Structural-CFD Analysis". The effort will be conducted in three phases. In Phase I CFD-RC defines the computational architecture of the system to be developed. The object is to develop a generic system which can be used to interface a variety of CFD and CSM codes including all the auxiliary tools such as grid generation, aero-structures interpolations etc. In Phase II they will select two or more CFD codes and two CSM codes (MSC-NASTRAN and ASTROS) for demonstration. In Phase III they will validate with analytical and test results available in the literature. For details see Ref. 17.

References

1. Kolonay, R. M., and Venkayya, V. B., "Automated Structural Optimization System (ASTROS)," ASIAC Current Awareness Bulletin, Fall 1991, WL/FIBD/ASIAC, Wright Patterson AFB OH 45433

2. Venkayya, V. B., Tischler, V. A., Kolonay, R. M., and Negaard, G., "An Enhanced MDO Environment for Airframe Structural Optimization," ASIAC Current Awareness Bulletin, Summer 1997, WL/FIBD/ASIAC, Wright Patterson AFB OH 45433

3. ASTROS (Automated STRuctural Optimization System), Information Pamphlet, Available from WL/FIBD, Wright Patterson AFB OH 45433

4. Neill, D. J., and Herendeen, D. L., "ASTROS Enhancements Volume III - ASTROS Theoretical Manual," WL-TR-96-3006, May 1995

5. Neill, D. J., and Herendeen, D. L., "ASTROS Enhancements Volume I - ASTROS User's Manual," WL-TR-96-3004, May 1995

6. Love, M., et.al., "*AANDE* - Aerodynamic ANalysis for the Design Environment," AFRL-TR-98-xxxx, WL/FIBD, Wright Patterson AFB OH 45433

7. Nathman, J. K., and Summa, J. M., "Multidisciplinary Design Optimization," WL-TR-96-3085, 1996

8. Nathman, J. K., and Barton, J. M., "Aeroelastic Calculations with an Euler Code," Analytical Methods, Inc., AIAA Applied Aerodynamics Conference, Georgia Institute of Technology, May 1997

9. Nathman, J. K., "Analysis of Leading-Edge Vortices on Complex Configurations," Analytical Methods, Inc., AIAA 3rd Applied Aerodynamics Conference, 14-16 October 1985, Colorado Springs CO

10. Chen, P. C., Liu, D. D., et.al., "Enhancement of the Aeroservoelastic Capability in ASTROS, " WL-TR-96-3119, September 1996

11. "A Collection of References for Zona Codes - ZONA51/ZONA51U, ZONA1, ZONA6, ZSTORE/ZONAIR," ZONA Technology, Inc., 2651 W. Guadalupe Rd, Suite B-228, Mesa AZ 85202

12. Chen, P. C., Sarhaddi, D., and Liu, D. D., "A Unified Unsteady Aerodynamic Module for Aeroelastic and MDO Applications," Research and Technology Organization, 85th Meeting of the Structures and Materials Panel, 13-17 October 1997.

13. Kolonay, R. M., "Unsteady Aeroelastic Optimization in the Transonic Regime," A Thesis Submitted to the Faculty of Purdue University, December 1996.

14. Schuster, D. M., Beran, P. S., and Huttsell, L. J., "Application of the ENS3DAE Euler/Navier-Stokes Aeroelastic Method," AGARD Structures and Materials Panel, October 1994.

15. Smith, M. J., Hodges, D. H., and Cesnik, C. E. S., "An Evaluation of Computational Algorithms to Interface between CFD and CSD Methodologies," WL-TR-96-3055, WL/FIMC, Wright Patterson AFB OH 45433, November 1995

16. Harrand, V. J., Kingsley, G. M., Siegel, J. M. Jr., et al, "Development and Validation of Parallel Distributed Computing Environment for Aero-Structural-CFD Analysis," Presented at the First Annual Meeting at WL/FIMC, Wright Patterson AFB OH 45433, October 1997

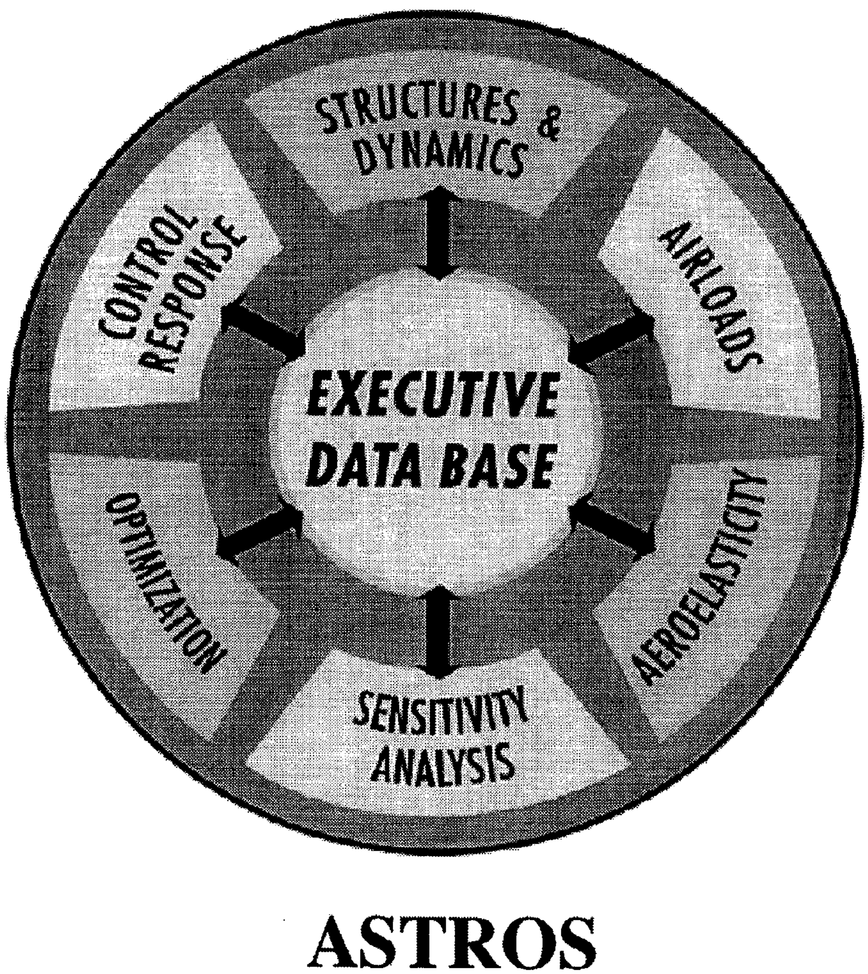

Figure 1. Airframe Integrated Design

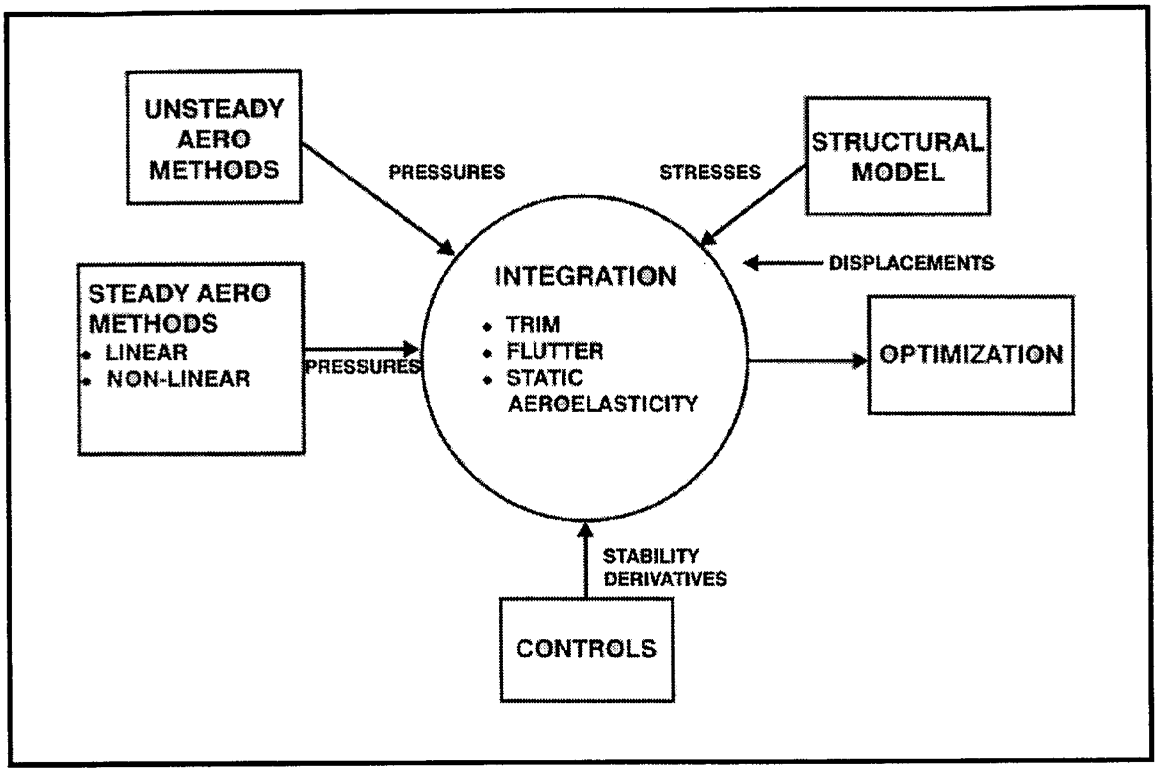

Figure 2. ANNDE Enhancements to ASTROS

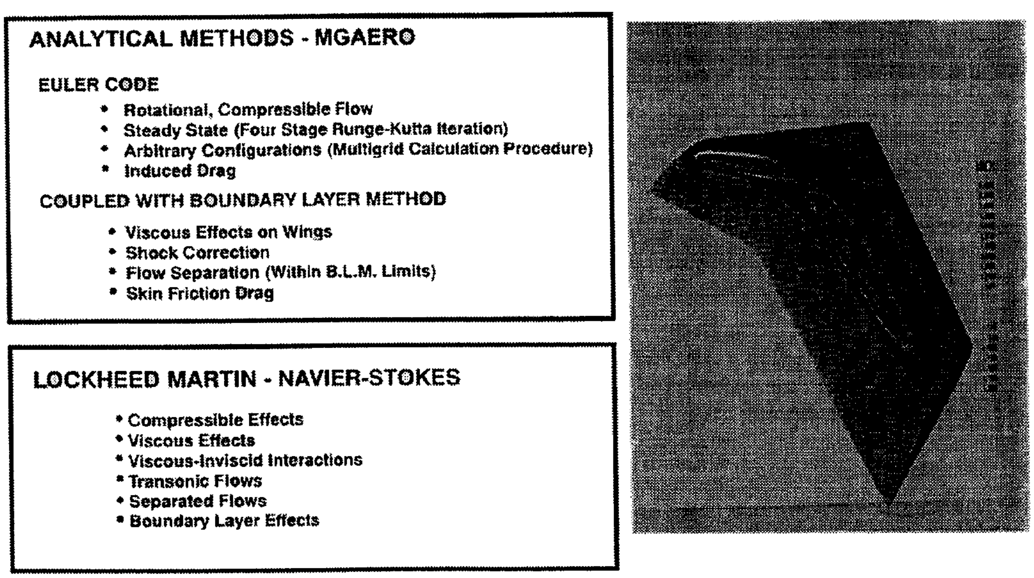

Figure 3. Aero-Structure Interaction-CFD Interface

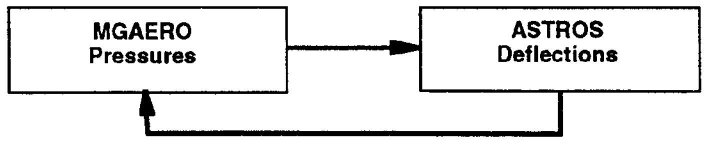

Figure 4. Coupling for Aeroelastic Analysis

Calculates air loads for flutter analysis
- Constant pressure methods
- Doublet Lattice
- Zona Codes

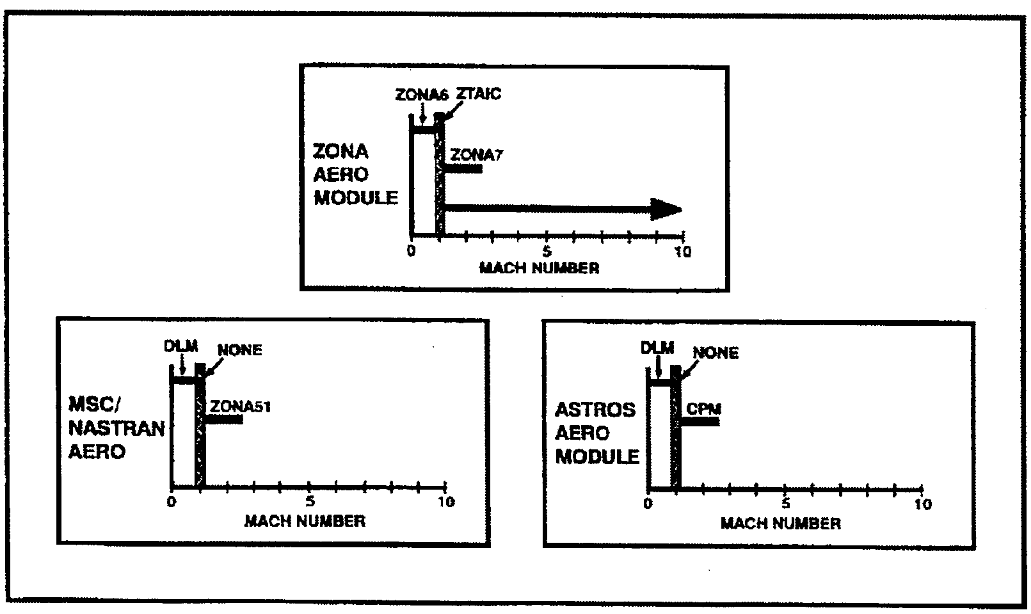

Figure 5. Aeroservoelastic Analysis Through Unsteady Aero Codes Interface

- Database entities generated by *AGM*, *3-D Spline* and *ZAERO* Modules are computed during the ASTROS preface phase and are not recomputed in the analysis/optimization loop.

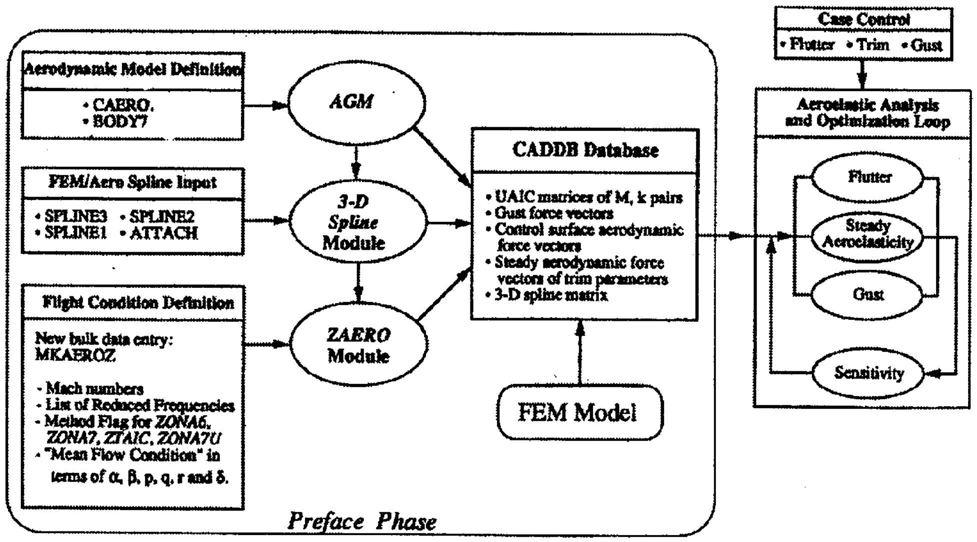

Figure 6. ASTROS/ZAERO Program Architecture

Calculates air loads for sub/supersonic static aeroelastic analysis

- **USSAERO**
- **VSAERO**
- **QUADPAN**
- **PANAIR**
- **VORLAX**

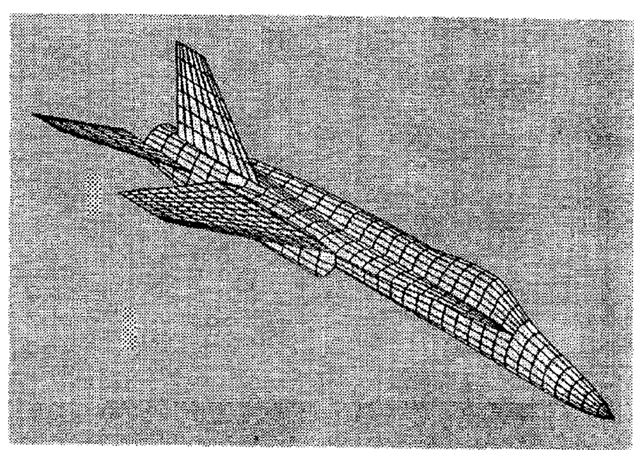

Figure 7. List of Linear Aero Codes Interfaces

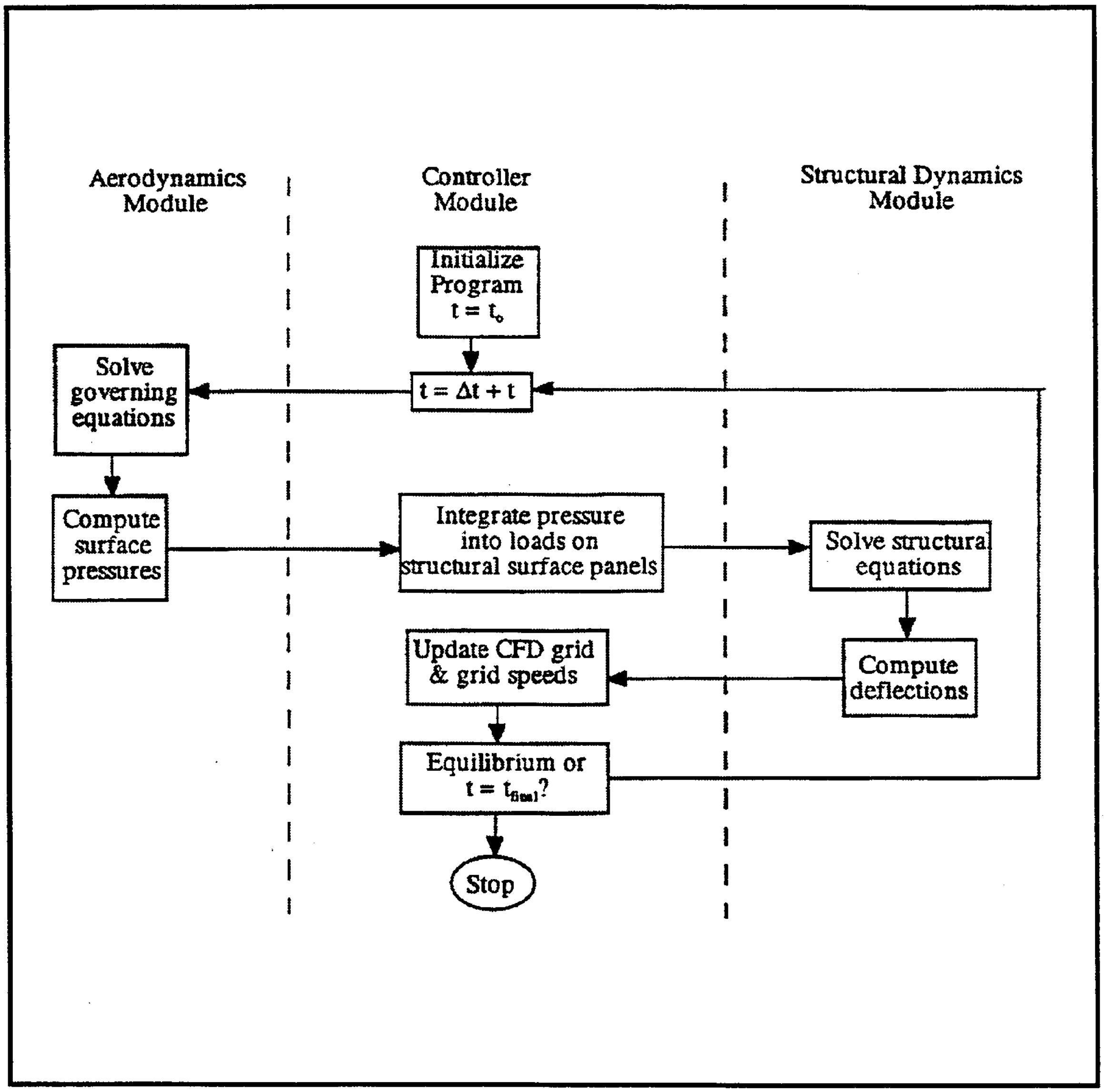

Figure 8. Typical Schematic for a Coupled CFD-CSD Methodology