The MSC Flight Loads and Dynamics System

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ABSTRACT

The MacNeal-Schwendler Corporation (MSC) developed an aeroelastic analysis and design capability in the late 1970’s and 1980's as part of MSC/NASTRAN. This capability includes flutter analysis, gust analysis and flight loads calculations. The latter is more suited to preliminary and conceptual design. As aerospace companies move to simulate the aeroelastic behavior of the vehicle early in the design cycle, however, there is a need to augment these capabilities to better fit within the current design processes. This augmentation includes new system architecture concepts, enhanced data management and model management and integrated visualization tools that understand aeroelastic models. Finally, new engineering tools need to be implemented that can better model aeroelastic phenomena at an appropriate level of fidelity for use in both vehicle design and production analysis.

This paper will present the critical requirements of the system as understood from numerous discussions with aerodynamicists, loads analysts, dynamicists and aeroelasticians in the aerospace community. Results from this work-in-progress will be presented where appropriate to illustrate the basic architecture, data flow and usage paradigms and their interaction with the aircraft design process.

Introduction

The MacNeal-Schwendler Corporation (MSC) developed an aeroelastic analysis and design capability in the late 1970's and 1980's as part of MSC/NASTRAN. This capability includes flutter analysis, gust analysis and flight loads calculations (Ref. 1). In response to customer feedback, MSC has undertaken a major project to create a Flight Loads and Dynamics System (FLDS) to address the concerns of the customer community and to facilitate the use of MSC/NASTRAN structural model data in the early assimilation of the aeroelastic characteristics into the conceptual, preliminary and detailed design processes.

The Flight Loads and Dynamics System will include a number of general characteristics. In particular, it will include complete pre- and postprocessing support from MSC/PATRAN, including aeroelastic design optimization. This graphical support includes model integrity checking to facilitate the development of aerodynamic and aeroelastic models. To more accurately model the aerodynamic characteristics, the FLDS will incorporate the A502 subsonic and supersonic potential aerodynamics panel code (Ref. 2) which accurately calculates pressure distributions on complex surfaces. An aerodynamic influence coefficient (AIC) matrix calculation is included to approximate the flexibility effects. The geometry of this panel method will be defined in such a way as to allow the incorporation of external aerodynamics, either from wind tunnel or from nonlinear CFD methods. New splining methods to allow the mapping of forces and displacements among the curved surface structural and aerodynamic meshes will be developed.

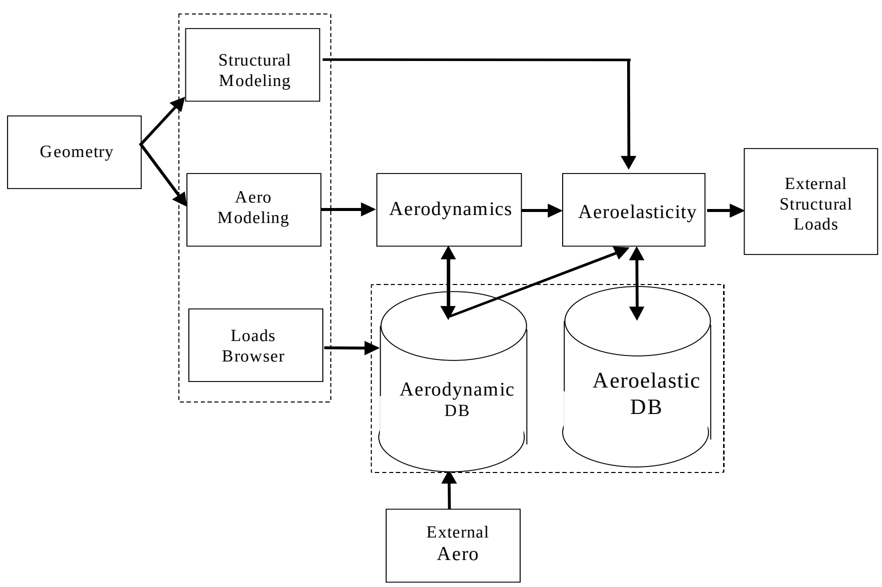
Another arena that is being addressed is the need to more accurately simulate trimmed and abrupt maneuvers in the presence of control systems. The FLDS will address this need in two ways: it will incorporate a Generic Control System (GCS) which allows for rapid generation of reasonable preliminary maneuver loads without the need to fully define a set of flight control laws and it will support a formal interface method to access external control system modeling tools. The GCS uses a minimum control energy heuristic that accounts for control saturation to simulate the control system. Alternatively, for derivative aircraft or for aircraft further along in the design cycle, the flight control system will most likely be known and modeled using tools such as MATLAB or MATRIX_x. To accommodate such control system models, the FLDS will provide a general interface to the external flight control software using a client/server architecture. That interface will allow the simulation of rigid and aeroelastic 6 degree-of-freedom maneuvers using the user-supplied flight control software and 6DOF solver with the structural and aerodynamic data coming from the FLDS.

Another important area is in loads management. Typically, the users need to simulate a number of maneuvers over the flight envelope and look at the resultant loads for the cases (or combinations of cases) that result in peak loads for various components of the aircraft. These loads then become the design loads. The FLDS will facilitate this activity not only by generating the loads, but also by allowing the user to examine the integrated maneuver loads to search for peaks. These points will then be available for full recovery of the distributed loads, stability derivative data and component loads data.

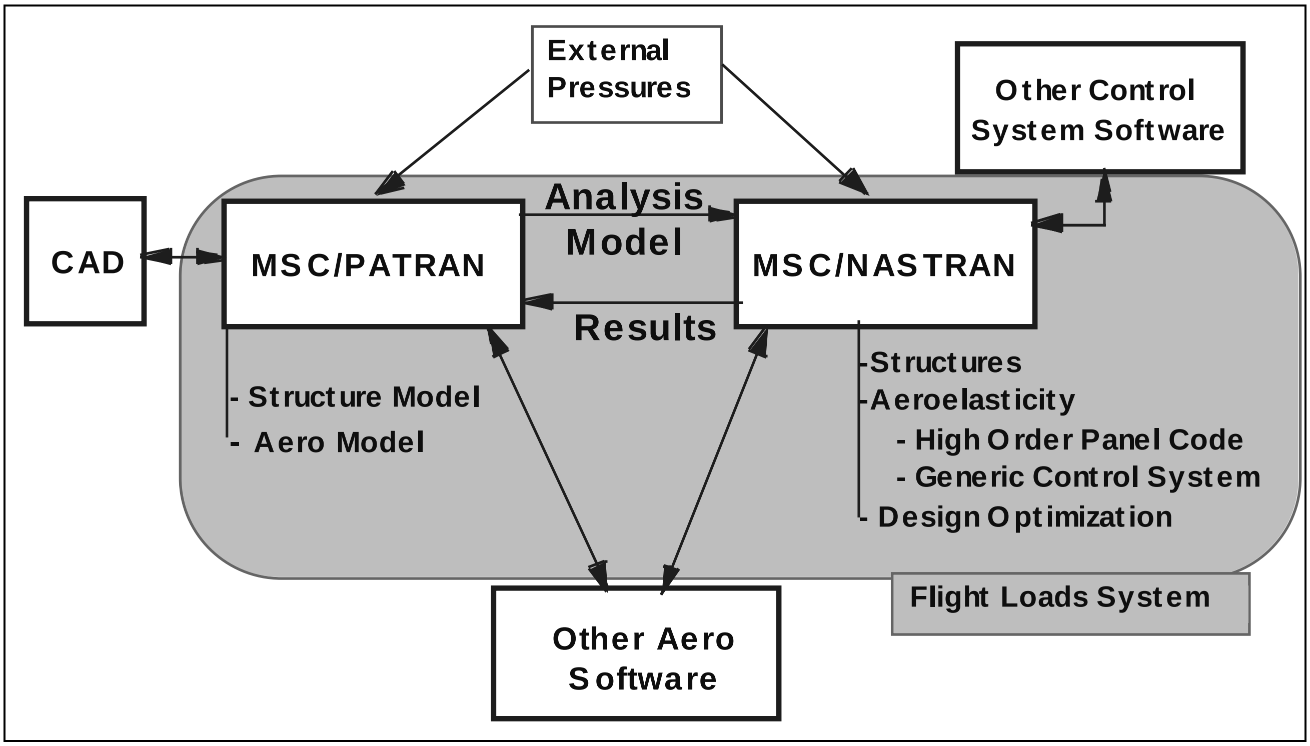
Finally, the system is being designed with a recognition that most companies already have many tools for the creation of aerodynamics and controls models. To make best use of these existing resources, it is important that the FLDS allow the users to incorporate these data into the system. To facilitate this feature, the FLDS development is looking to the STEP standards (AP203 and AP209) to provide a non-proprietary data exchange format that will allow customers to bring their own data into the system and to extract FLDS data for use outside the system.

Architecture

The following chart describes the Flight Loads and Dynamics System architecture, in general.



In basic terms, the FLD System will provide the ability to start with native geometry, (from a number of sources including CAD, STEP AP203/AP209, and IGES); to define an aeroelastic environment with coupled structural and aerodynamic models or to define a rigid aircraft as a point mass coupled to an aerodynamic model. Then, the FLDS will facilitate the definition and evaluation of the appropriate rigid aerodynamic pressure distributions and aeroelastic influence coefficients to generate the external loads on the structure and/or the aerodynamic model. All of these steps will be driven from a graphical system. The following illustration presents the conceptual product integration for this system.



The utility of the existing MSC tools for the modeling and analysis of structures is already known in the community. Therefore, this paper will focus its attention on the aerodynamics, control system, maneuver simulation and loads portions of the FLDS.

Aerodynamic Modeling

Aerodynamic modeling in the FLDS will be supported in MSC/PATRAN. In addition to supporting the new high-order panel method that will be part of MSC/NASTRAN, the modeling of "legacy" MSC/NASTRAN aeroelastic capabilities (e.g., Doublet Lattice, Mach box, etc.) will also be supported. The basic aerodynamic modeling capabilities will include the easy definition of aerodynamic lifting surfaces, bodies, components (collections of surfaces) and control surfaces. It will include detailed model checking to ensure that the geometry satisfies the method-dependent rules and to allow the user to exercise the model and graphically evaluate the results to verify that the model is producing the expected results.

In fact, the FLDS will provide a number of important aerodynamic and aeroelastic model validation features. These include running load plots for components of the rigid aerodynamic model, integrated loads (e.g., rigid coefficients) and graphical views of the aerodynamic database of nonlinear force and pressure data.

Also, graphical tools will facilitate the aeroelastic model development. Splining (coupling the structural model to the aerodynamic model) is one of the most error prone modeling activities in aeroelasticity. The FLDS will include a number of tools to allow the user to graphically define the spline(s) and to evaluate their accuracy for both load transfer and displacement transfer.

Loads Browser

The Loads Browser will be the looking glass into the aerodynamic database. Users will access this tool either from MSC/PATRAN or in a stand-alone manner. The Loads Browser will facilitate the view of the data in both the aerodynamic and aeroelastic databases. These views will include running load plots: bending moment, shear and torque (BMST) on the entire model or on a component basis. It will support the import of external aerodynamic data (from Euler or Navier-Stokes or from wind tunnel) to populate the aerodynamic database and will allow the manipulation of the data to apply corrections to the potential aerodynamics to match test or component integrated load components.

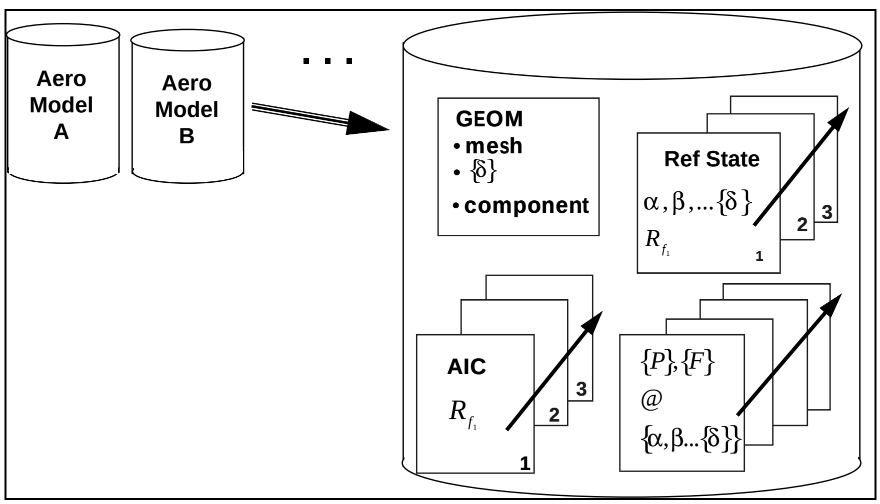
High Order Aerodynamics

The current envisioned environment is one in which the user makes multiple aerodynamic analyses to populate the aerodynamic database for different points within the flight envelope. (This scenario, however, will not be a requirement for those desiring to make a "one shot" run through the system.) The data generated from the aerodynamics analysis will include rigid pressures at configuration points as well as aerodynamic influence coefficients (AIC) that produce a perturbation in pressure due to a perturbation in model geometry. These AIC data are then used to provide a linear approximation to the flexibility effects on aerodynamic pressure distribution.

Aerodynamic Database

The FLDS will allow a nonlinear set of rigid pressure data. Unlike the current capability that presumes that the pressures arise from an AIC operating on a geometric downwash perturbation, hence a linear force-displacement relationship for the aerodynamic parameters (α, β and control surface deflections), the FLDS will provide for a rigid aerodynamic database that supplies rigid pressure fields at known sets of parameters. From these vectors, a piecewise linear interpolation will be used to compute the rigid pressure field at particular other parameter settings (e.g., at trim). Further, the more than one AIC matrix (which is a linearization about a particular point) will be supported for the same model so that the aeroelastic analysis can approximate the elastic effects about points other than the basic onset flow condition.

The aerodynamic database will be used to store baseline plus increment data and will be hierarchical in nature. The following illustrates the aerodynamic database.



As shown above, the aerodynamic database will contain reference states (Mach, angle of attack, side slip angle, pitch rate, roll rate, yaw rate, controls settings) as well their associated aerodynamic influence coefficient matrices. Additional perturbations points will be stored upon user request. This (potentially) nonlinear database will be used to determine pressure distributions at unknown points during analysis.

Aeroelasticity

The aeroelastic features of the FLD System couples the aerodynamic and structural data to perform aeroelastic response analyses. To accommodate the new aerodynamic models, three-dimensional (that is, curved surfaces in three space) splining technology will be available in addition to the current surface and beam splines.

The response analyses will include static aeroelastic response and quasi-static transient maneuver analysis. The maneuvers are quasi-static in that the unsteady nature of the aerodynamics will be ignored while the dynamics of the structural model will be accounted for. As mentioned earlier, these analyses will rely on the nonlinear rigid data and the selected AIC from the aerodynamic database to assemble the applied aerodynamic forces. In the basic, embedded analysis capabilities, the control effectors will be modeled using an improved control system model that allows for blending, scheduling and limiting the control surfaces. In particular, the FLDS will contain an implementation of the Generic Control System (Refs. 3 and 4). This tool is useful for conceptual and preliminary design, while the actual control system software is in development. As the control system design progresses (or when working on derivative aircraft), the FLDS will support the ability to link to an external control system modeled with tools such as MATLAB or MATRIX_X.

Conclusion

In response to customer input, MSC has undertaken a major project to create a Flight Loads and Dynamics System to address the concerns of the customer community and to facilitate the use of MSC/NASTRAN structural model data in the early assimilation of the aeroelastic characteristics into the conceptual, preliminary and detailed design processes.

The Flight Loads and Dynamics System includes complete pre- and postprocessing support from MSC/PATRAN. This graphical support includes model integrity checking to facilitate the development of aerodynamic and aeroelastic models. The FLDS will incorporate a subsonic/supersonic potential aerodynamics panel code, which accurately calculates pressure distributions on complex surfaces. The general geometry of this panel method will be defined in such a way as to allow the incorporation of external aerodynamics, either from wind tunnel or from nonlinear CFD methods. New splining methods to allow the mapping of forces and displacements among the curved surface structural and aerodynamic meshes will be developed.

Another arena that is being addressed is the need to more accurately simulate trimmed and abrupt maneuvers in the presence of control systems. The FLDS will address this need in several ways. It will incorporate a Generic Control System and, for derivative aircraft or for aircraft further along in the design cycle, it will support an interface to external flight control/simulation tools. At this point in the design cycle, the flight control system may be known and modeled using tools such as MATLAB or $MATRIX_x$.

Another important area is in loads management. The FLDS will facilitate this activity not only by generating the loads, but allowing the user to examine the integrated maneuver loads to search for peaks. These points will then be available for full recovery of the distributed loads, stability derivative data and component loads data.

Finally, the system is being designed with a recognition that most companies already have many tools for the creation of aerodynamics and controls models. To make best use of these existing resources, it is important that the FLDS allow the users to incorporate these data into the system. To facilitate this feature, the FLDS development is looking to the STEP standards (AP203 and AP209) to provide a non-proprietary data exchange format that will allow customers to bring their own data into the system.

References

1. Rodden, William P. and Johnson, E.H., *MSC/NASTRAN Aeroelastic Analysis User's Guide, V68*, The MacNeal-Schwendler Corporation, 1994.

2. Epton, Michael A. and Magnus, Alfred E., *PANAIR, A Computer Program for Predicting Subsonic and Supersonic Potential Flows About Arbitrary Configurations Using a High Order Panel Method, Volume I, Theoretical Manual, Version 3.0,* NASA-CR-3251, Revision 1, January, 1992.

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