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# Design Oriented Structural Modeling for Airplane Conceptual Design Optimization

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## End of Grant Summary

The main goal for research conducted with the support of this grant was to develop design oriented structural optimization methods for the conceptual design of airplanes. Traditionally in conceptual design airframe weight is estimated based on statistical equations developed over years of fitting airplane weight data in data bases of similar existing airplanes. Utilization of such regression equations for the design of new airplanes can be justified only if the new airplanes use structural technology similar to the technology on the airplanes in those weight data bases. If any new structural technology is to be pursued or any new unconventional configurations designed the statistical weight equations cannot be used. In such cases any structural weight estimation must be based on rigorous "physics based" structural analysis and optimization of the airframes under consideration.

The problem is that rigorous structural and loads analysis of complete airframes involve large scale mathematical models requiring substantial computational resources. If optimization of the structure is required, these analyses have to be executed many times repeatedly. Preparation of detailed structural models of complete configurations also requires considerable resources. If accurate structural analysis of airframes is to become part of the conceptual design optimization task, accurate but computationally "cheap" mathematical models have to be developed, and methods for automated generation of these models from geometry information must be created.
Work under this grant progressed to explore airframe design-oriented structural optimization techniques along two lines of research:

1. Methods based on "fast" design oriented finite element technology
2. Methods based on equivalent plate / equivalent shell models of airframes, in which the vehicle is modelled as an assembly of plate and shell components, each simulating a lifting surface or nacelle / fuselage pieces.

Since response to changes in geometry are essential in conceptual design of airplanes, as well as the capability to optimize the shape itself, research supported by this grant sought to develop efficient techniques for parametrization of airplane shape and sensitivity analysis with respect to shape design variables. Towards the end of the grant period a prototype automated structural analysis code designed to work with the NASA Aircraft Synthesis conceptual design code ACSYNT was delivered to NASA Ames. Integration with ACSYNT in the analysis-only mode (no optimization) was demonstrated. Unfortunately, at that point the project ended. No integration of the new structures sizing capability with ACSYNT's loads capabilities were carried out. No further studies of integration of rigorous structural design technology with ACSYNT were pursued.

Work under this grant led to significant contributions in the area of airframe structural modeling for design and airframe structural shape optimization:

1. The equivalent plate method for wing structures was thoroughly studied and improved. Discoveries made by this research work led to improvements and further development of the NASA Langley ELAPS code used for conceptual and preliminary design by many organizations. A technique for integrating panel buckling analysis (and its sensitivity with respect to shape) with equivalent plate wing box models was also successfully developed.

2. New insights and valuable lessons in the area of finite element based structural modeling technology were gained. Analytic Shape sensitivities of finite element results were derived and tested. Development of FE based structural

shape design capability for capturing both local and global buckling failure modes was successful.

3. In general, a thorough overview of the field and of candidate techniques was made possible. Insights from this overview will influence future research and development in this area.

The research conducted with the support of this grant was documented in a number of masters and Ph.D. dissertations, as well as conference and journal papers. The following list represents key publications:

Livne, E., "Equivalent Plate Structural Modeling for Wing Shape Optimization Including Transverse Shear". J. Aircraft, Vol. 32, No. 6, pp. 1278-1288, June 1994.

Livne, E., "Analytic Sensitivities for Shape Optimization in Equivalent Plate Structural Models", J. Aircraft, Vol. 31, No. 4, pp. 961-969, July-August 1995.

Livne, E., and Milosavljevic, R., "Analytic Sensitivity and Approximation of Skin Buckling Constraints in Wing Shape Synthesis", J. Aircraft, Vol. 32, No. 5, pp. 1102-1113, Sept.-Oct. 1995.

Livne, E., and Mineau, D., "Panel Flutter Constraints: Analytic Sensitivities and Approximations Including Planform Shape Design Variables, J. Aircraft, Vol. 34, No. 4, pp. 558-568, July-August 1997.

Livne, E., "Integrated Aeroservoelastic Optimization: Status and Direction", J. Aircraft, Vol. 36, No. 1, pp. 122-145, Jan.-Feb. 1999.

Shin, Y., and Livne, E., "Finite Element Based Analytic Shape Sensitivities of Local and Global Airframe Bucking Constraints", J. Aircraft, to be published 1999.

Harvey, M., "Automated Finite Element Modeling of Wing Structures for Shape Optimization", Master of Science in Aeronautics and Astronautics thesis, University of Washington, Aeronautics and Astronautics, 1993.

Lau, M.Y., "Conceptual Design Oriented Wing Structural Analysis and Optimization", Master of Science in Aeronautics and Astronautics thesis, University of Washington, Aeronautics and Astronautics, 1996.