Nonlinear Aeroelastic Analysis using ROM/ROM Methodology: Membrane-on-Wedge with Attached Shock

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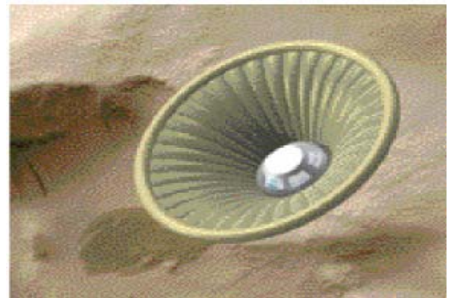
(ABSTRACT)

One of NASA's new space programs is directed towards the unmanned Martian/Titan explorations. The entry vehicle designed to attain the surface of Mars or Titan and return with samples to Earth, might include a flexible, deployable and inflatable decelerator of a clamped ballute type (see figure on right).



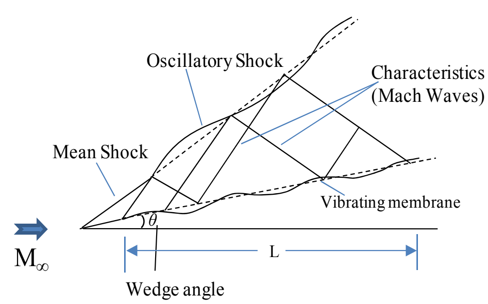
The aeroelastic behavior of the thin structure between the torus top and the bottom of the ballute is of great importance towards the design of ballute. Nonlinear aeroelastic analysis is highly desired because of the expected nonlinear deformations of the membrane-like structure, and the super/hypersonic flow conditions during entry whereby shock waves interact with the structural deformations. The occurrence of aeroelastic instability is therefore of substantial concern. In this present work, a nonlinear structural reduced-order-model (ROM) is closely coupled with the aerodynamic solver to solve the nonlinear aeroelastic problem. The nonlinear static aeroelastic deformed configuration of a mounted membrane-on-ballute is sought first. Thereafter its dynamic instability is investigated at this static deformed position by linking the structural ROM with a CFD-based reduced-order model (ROM), hence called the ROM/ROM simulation.

Implementation of a closely-coupling scheme for the dynamic interaction between nonlinear structures in full-order physical form (e.g. Nastran model) with nonlinear aerodynamics is not a trivial matter. Here, a reduced-order-modeling for nonlinear structures (structural ROM) will render such a close-coupling feasible and solved in a convenient manner. The nonlinear structural ROM is represented in the modal space as below,

$$M_{ij}\,\ddot{q}_j + D_{ij}\,\dot{q}_j + K^{(1)}_{ij}\;q_j + K^{(2)}_{ijl}\,q_j\,q_l + K^{(3)}_{ijlp}\,q_j\,q_l\,q_p = F_i$$

where M_{ij} are the generalized masses, $K^{(1)}_{ij}$, $K^{(2)}_{ijl}$, and $K^{(3)}_{ijlp}$ are stiffness coefficients associated with the linear, quadratic, and cubic terms respectively. The associated modal shapes, i.e., the basis functions are carefully selected by the Nastran-based ELSTEP/FAT procedure. While identifications for the stiffness coefficients $K^{(1)}_{ij}$, $K^{(2)}_{ijl}$, and $K^{(3)}_{ijlp}$ are determined by a series of nonlinear static solutions (e.g, Nastran Solution 106).

For nonlinear aerodynamics, an Euler-based CFD (e.g., CFL3D) ROM procedure is developed using a system identification technique. Specifically, auto-regressive moving average (ARMA) model for generalized aerodynamic force (GAF) outputs is obtained through fitting the training data (multiple system inputs/system outputs) in which the excitation modal inputs employ a staggered sequence of the filtered-impulse-method (FIM) signals.



To demonstrate the ROM/ROM methodology, we first investigate an unsteady membrane-on-wedge 2D model in super/hypersonic flow with attached shock wave (above figure). With this membrane/wedge model, one can fully study the nonlinear shock wave/Mach wave interactions with the nonlinear structures, which is a proper heuristic case in preparation for the eventual aeroelastic analysis on a membrane-on-ballute system.

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