Common Research Model (CRM) Wingbox Finite Element Models:

Wingbox Models Description:

Several full-scale semi-span wingbox structures were developed based on the CRM outer mold line (OML) loft provided by NASA Langley Research Center and contains combinations of explicitly modeled shell based structures. Some explicit shell-based primary structures also include implicit stiffening elements. The CRM structural baseline FEMs are module-parametric CAE isotropic aluminum based primary and secondary structural models including two or more selectable spanwise zone-tailored main spars and skins, 50+ ribs, stringers, rib caps and stiffeners. FEMs are provided in Nastran BDF and Hypermesh HM format along with original parasolid (X_t) midsurfaces. Several model sets are provided as a starting point for researcher analysis and sizing studies:

1. CRM_V15wingbox (CQUAD FEM with *implicit* stiffeners)
2. CRM_V14wingbox (Coarse and Refined CQUAD FEM with *implicit* stiffeners)
3. CRM_V12wingbox (DOE model with Coarse and Refined CQUAD FEM and *explicit* stiffeners)
4. CRM_MatlabBASELINE (CTRIAR FEM with *implicit* stiffeners)

Shell based parametric wingbox FEMS are termed V12, V14, V15 and MatlabBASELINE. The baseline structural layouts shown below are termed a "conventional" design, reflect standard design handbook layouts.

Modeling Details and Differences:

Models V12 thru 15 are shown in Figure 1 from Left to Right and differ primarily in mesh density and element topology. V12, Figure 2 , contains only explicit shell based geometry (coarse and fine versions available) and run-out stringers whereas V14 and V15 utilized implicit chord-spaced stiffeners throughout (CBARs) to reduce computational expense and eliminate the mid-chord spars in favor of optional chord-spaced shear-webs as shown in Figure 3. Both V12 and V14 have IBD fuselage rib intersections which result in limited CTRI element topologies. V15 is similar to V14 with the exception that some ribs were re-oriented to avoid IBD fuselage rib intersections for a CQUAD-dominant structure which traditionally improves outer fiber principal stresses prediction and can improve future large strain nonlinear solutions. Coarse versions (for V12, V14) were developed to facilitate computationally inexpensive DOE parametric investigations, whereas refined versions (higher mesh density) were constructed for more detailed examination of stress and buckling. The MatlabBaseline FEM, shown in Figure 2, (derived from Virginia Tech-NASA WingOpt) was generated from Matlab discrete code and extensively explored for aeroelasticity optimizations. It is similar in mesh density to the V15 model except it contains CTRIAR shell topology, which facilitated aeroelastic meshing efficiency, and omits outboard fuselage

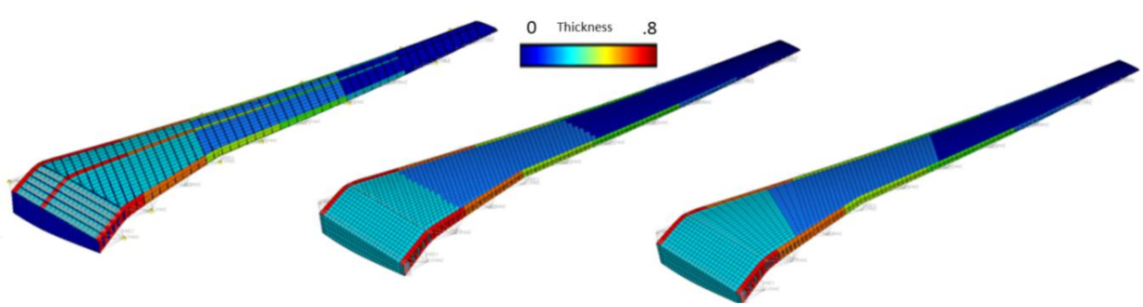

Figure 1: Evolution of CRM wingbox shell based FEMS: V12, V14, V15 (refined models shown)

fairing fixity. Element card property definitions (modulus, thickness, orientations and boundaries) were chosen based on conventional design handbook guidance as a suggested starting point for the researcher to facilitate independent sizing analysis.

Implicit stiffeners were also included in latter FE model versions (V14, V15) to promote computational efficiency and suppress local modes using CBAR elements for rib stiffeners, stringers and spar caps. Also modeled are leading and trailing edge flap masses using simple CONM2 lumped masses connected with RBE3 interpolation elements to spar cap stiffener sections. Models were reviewed for element aspect ratio, elimination of geometric intersections (including revised chord spaced stringers and webs) and fundamental dynamics response stability. The chief benefit of the implicit-hybrid models was to exploit improved element aspect ratios for computational accuracy and eliminate local natural modes during aeroelasticity investigations which are more prevalent in explicit detailed model stiffening elements. An updated version of the wingbox structure is planned to incorporate optimal element aspect ratios, engine masses and nacelles, control surfaces and fuel loads.

Engine masses and nacelle aero loads are not included at this time and may accompany a future flutter deck as a CAERO card in subsequent iterations.

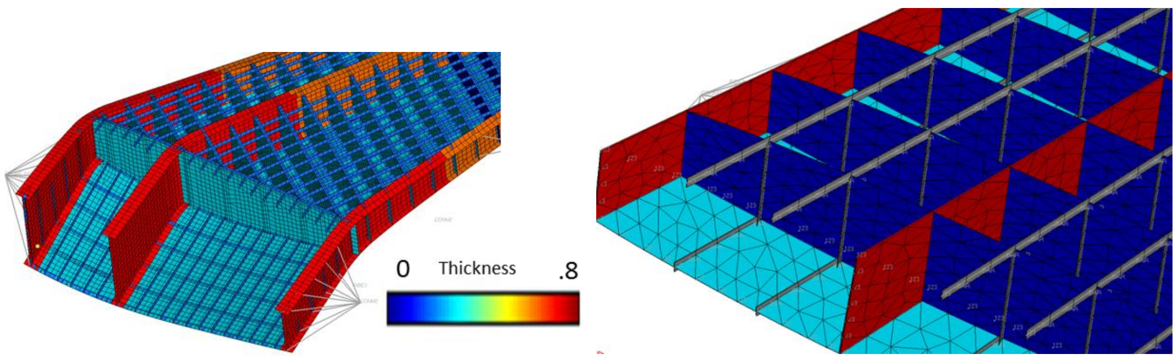

Figure 2: CRM wingbox internal structure, explicit model V12 (left), MatlabBaseline (Right)

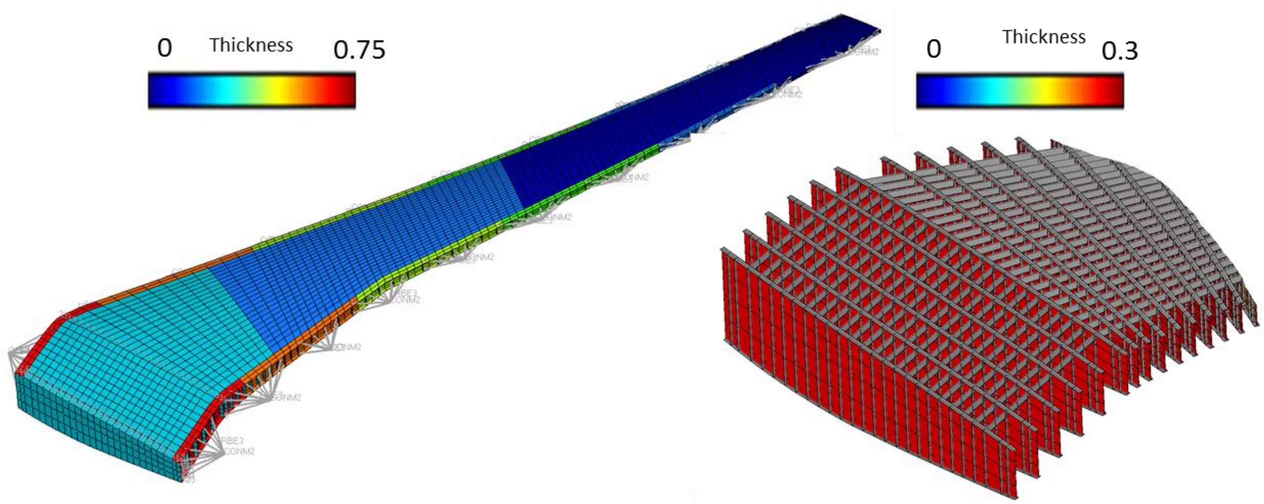

Figure 3: CRM wingbox internal structure with implicit stiffeners and shear webs; V14/15

Wingbox Load Conditions and Constraints:

The mission defined for this transport category vehicle is similar to a Boeing wide/body single-aisle commercial transport aircraft with a 3-5k nm range and gross vehicle weight (GVW) approaching 500,000 lbm.

Component level reinforcement structures (caps, stiffeners etc) include relevant detail for assembly interface features promoting individual component, sub-assembly and installation level stability that follows the spirit of FAR 25 commercial design practices (i.e. M. Niu). Reinforcements were added for basic sizing but do not incorporate system related sizing impacts (fuel/control system penetrations, slosh loading, landing gear provisions) or the resulting internal details (stringer and rib stiffeners/penetrations etc.) at this time. For example, explicit rib caps, rib stiffeners and stringers were added to maintain rib buckling stability under typical compression loads (Brazier loading), min gage damage tolerance and manufacturing constraint (prestresses from processing machining/forming). Stringers were added to increase section properties spanwise for load path continuity, section properties enhancement and panel buckling considerations.

A conservative uniform SLD (spanwise load distribution) of -2.0 to + 3.75g static sizing check (Nastran SOL101, 105) , modal assurance (SOL103,106), and flutter analysis (SOL144,145), Figure 5, were conducted for a GVW of 500 kips at flight conditions Mn .85, FL350 to ensure strength and stability bounds respectively. Basic static sizing checks included simplified FAR25.341 gust (+3.75/-2.0g), FAR25.333 maneuver (2.5g) and AC25.491 taxi bump (-2.0g) as part of a loads review sampling (all cases not presented) shown in Figure 4.

Description	Mach	Alt (ft)	Global Load factor (psi, g..)	Distribution	Source	Comment
Cruise	0.85	35000	1.16	UNIFORM, SLD	CR-2009-215932, FAR25.xxx	Primary Loading location
Wing Loading psid						
<u>Gust (3.75 g)</u>			*(3.75g / 3-4 psid)*	-	*25.341*	
Vertical Up			3.4/3.6 psid	Z dir	CR-2009/25.341	Wing Surfaces
Vertical Down			-3.85 psid	Z dir	CR-2009,25.341	Wing Surfaces
Left Lateral			+/-3.8 psid	side Load(Y dir)	CR-2009	Fuse, VT
Right lateral			2.2 psid	side Load(Y dir)	CR-2009	Fuse, VT
<u>Maneuver Load (2.5G).</u>			*(2.5g)*	-	*25.337*	
Pushover (1g)			-1g	Z dir	25.333	Wing Surfaces
2.5g (STD manuever)			2.5g	Z dir	25.337,25.333	Wing Surfaces
Check Roll - symm			1.67g, 8psid	Z dir	CR-2009, 25.349	Wing Surfaces, Aileron
Roll Manuevers Aileron			tbd	Z dir, y,x	CR-2009,25.331,25.349	Wing Surfaces, Aileron
Dynamic Overswing.			tbd	side Load(Y dir)	CR-2009, 25.177	Fuse, VT-rudder
Rudder Reversal .			tbd	side Load(Y dir)	25.177	Fuse, VT-rudder
<u>Other</u>						
Pressurization . - 2P			18 psid	Cylindrical	25.365	Fuse, Wing Attach pre-strain
Taxi – bump			2.0g	Z dir	25.235/AC25.191-1, FAA ,CR-2009	Fuse, Wing attach
Fwd Crash			9-14g Fwd, 4g lateral	X dir	25.562	Fuse, Wing attach
Landing & Side- Load			10fps, 20 G damped	Vertical, Xwind	25.473,25.479 25.485, 25.487	MLG attach

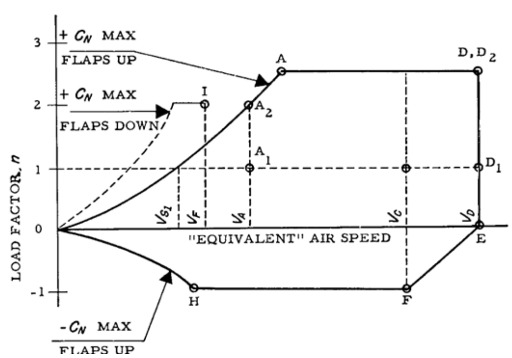

Figure 4: Typical Part 25 Load Cases and standard transport V-N diagram, FAR25.333

Wheel braked roll, spin-up, one-gear landings and crash loads were not considered here to simplify analyses. For increasing aspect ratios, however it is recommended to add hard-landing load (ie. FAR25.479/485) cases to ensure wingtip displacements do not exceed practical limits and cross-controlled side-loaded landings have sufficient ground-tip clearance for selected trim cases unless design provisions are made (i.e. rollers).

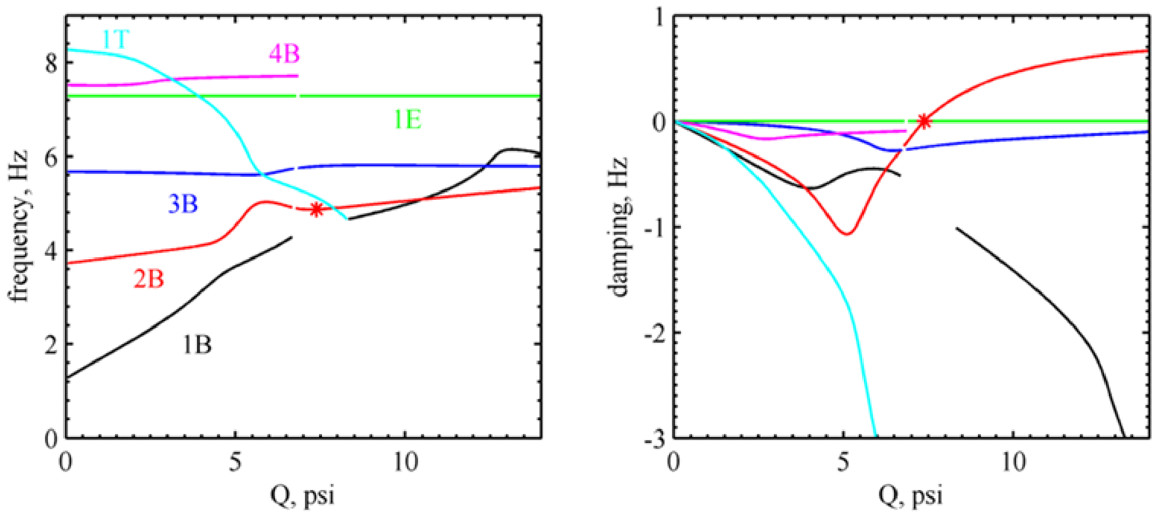

Figure 5: Representative flutter Plot for V15 CRM wing of Aspect Ratio 9 without optional shear webs

Level Fuel weight (static head) was incorporated for static strength examination but is not otherwise included in the model sets due to the dynamic nature of subsequent load cases (slosh, vibration, Breguet trim).

Wingbox boundary constraints are simple cantilever at the root with simulated pressure vessel attach lug fittings at body-fairing intersections in some models. Modeling provisions for the fuselage interface and coupling (CELAS spring elements) are planned for a future release.