



2018 Transport Canada Delegates Conference Presentation

Conair “Special Mission” Airtanker STC
Modifications...
(mostly) from a Structures Perspective.

Presentation Overview

- Conair's Airtanker History & Background
- Airtanker Design (Criteria & Trade-offs)
- Some Regulatory Considerations (SCA)
- Flight Envelopes & External Loads
- Static Structural Analysis
- Fatigue & Damage Tolerance

Conair's Airtanker History



Conair's Airtanker History

- Airtanker Development History
 - List of Airtankers developed by Conair to-date:
- S-2 Tracker/Firecat (1977)
 - 26,000 lb MTOW
 - 870 USG Payload
- DC-6 (1983)
 - 97,290 lb MTOW
 - 2,780 USG Payload



Conair's Airtanker History

- Turbo Firecat (1990)
 - 27,500 lb MTOW
 - 870 USG Payload
- F27 (1986)
 - 45,000 lb MTOW
 - 1,680 USG Payload



Conair's Airtanker History

- L188 (1998 & 2011)
 - 116,000 MTOW
 - 3,000/3,300 USG Payload
- CV580 (2001)
 - 58,150 lb MTOW
 - 2,100 USG Payload



Conair's Airtanker History

- Q400 (2005)
 - 68,200 lb MTOW
 - 2,450 USG Payload
- RJ85 (2014)
 - 97,000 lb MTOW
 - 3,100 USG Payload



Airtanker Design Background

- What is an “Airtanker”?

The terms Airtanker or air tanker generally refer to fixed-wing aircraft used in aerial firefighting, which are fitted with tanks that are filled on the ground using long-term retardant at an air tanker base.

- What is the Airtanker’s “special mission”?

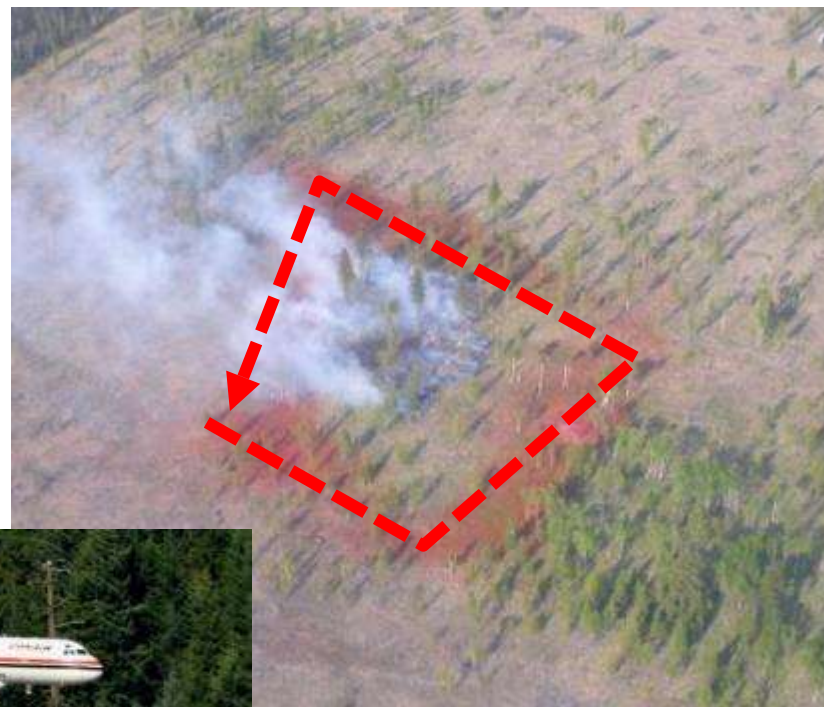
Aerial firefighting is the use of aircraft and other aerial resources to perform the task of aerial dispersion of liquids in the fire prevention and suppression role.

- Most Common Misconception: Airtankers do not directly put out fires

...so, what do they do?

Design Background...2

“Initial Attack”



Design Background...3

“Support Actions”



Design Background...4



Design Background...5

“Bird-dog” Aircraft

Aerostar



Twin Commander



Caravan



525 CitationJet



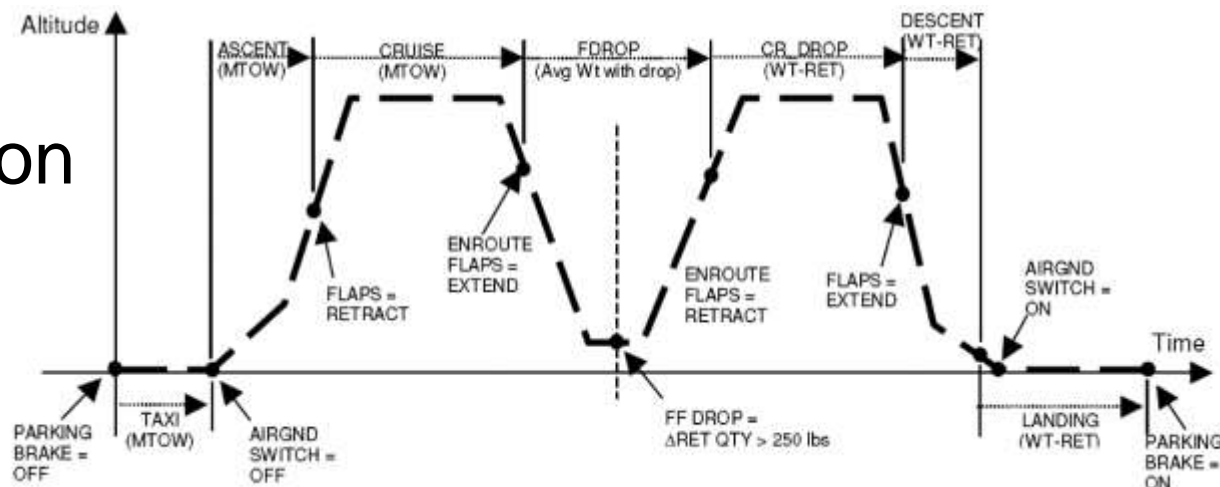
Airtanker Design Criteria & Trade-offs

- Choosing a candidate aircraft.
 - Range & Payload capacity
 - Low speed “drop” performance
 - “Robust” airframe structure
 - Pressurization requirements
- Tank design considerations.
 - Internal vs External Tank trade-offs (ie. ground clearance, landing gear location)
 - Tank location, CG & sloshing effects
 - Airframe weight reductions
 - Tank to airframe connections (stiffness/coupling)
 - Fuselage holes & penetrations

Range & Payload Capacity

- Typical Airtanker Mission
 - ~200 Nm, 45-60 min total flight time.
 - 5-10 min performing low level “firefighting” ops.
 - 5,000-10,000 ft cruise to/from drop site.
 - Full payload take-off, zero payload landing.

Airtanker Mission



Typical Airtanker Mission Range

- Example Flt: T160, 20 Aug 2015, 00:53-01:37 UTC
- Total Time/Dist: 45 min, 175 Nm
- Transit Time/Dist: 20 min out, 88 Nm out
19 min rtn, 83 Nm rtn
- FF Time/Dist: 6 min, 7 Nm

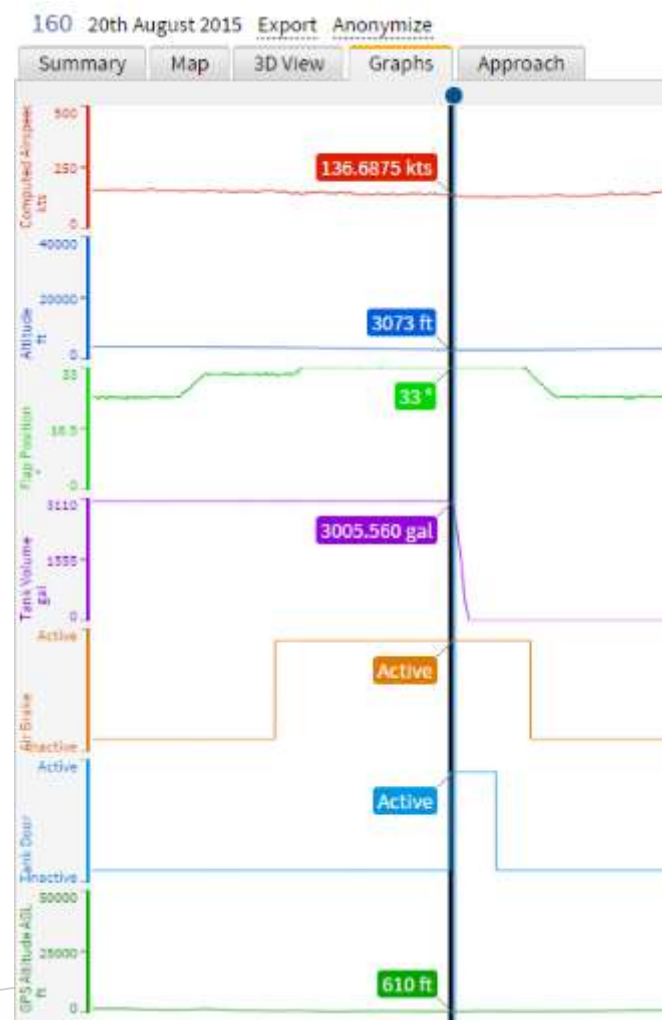
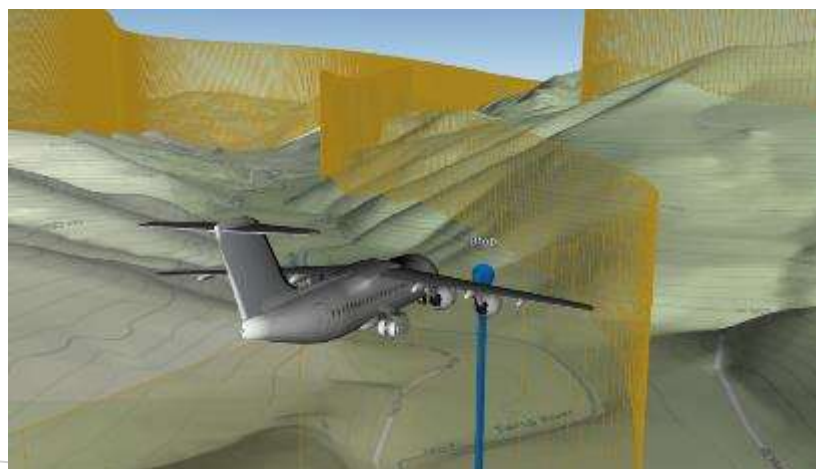


Typical Airtanker Payload Capacity

- USFS Airtanker Categories, by Payload capacities:
 - VLAT: more than 10,000 USG Payload
(DC10, 747 Supertanker)
 - Type 1: 3,000 to 9,999 USG Payload
(P-3, L188, DC-4/6/7, BAE 146, RJ85, MD87, C-130Q & MAFFS, Martin Mars, Be-200)
 - Type 2: 1,800 to 2,999 USG Payload
(P2V, CV580, Q400, AN-32P)
 - Type 3: 800 to 1,799 USG Payload
(CL-215/415, Firecat/TFC, S-2T Tracker, including SEATs ie. AT802)
 - Type 4: less than 800 USG Payload
(small Single Engine Airtankers (SEATs))

Low-Speed “Drop” Performance

- The optimal Airtanker “drop” configuration is:
 - Flat or downhill run.
 - Airspeed: 120-125 kts IAS.
 - Altitude: 100-150 ft AGL.
 - Full flaps deployed, maximize speed margins to stall.



“Robust” Airframe Structure

- Generally, “STOL” & Regional Aircraft (ie. 146/RJ85, Q400) have less optimized, stronger wings & centre fuselage airframe structures =>
 1. Static Margins to manage increased Flaps-Down maneuver & gust Limit Loads.
 2. Designed for more severe Fatigue Spectra Loads & Take-off/Landing cycles.

Pressurization Requirements

- Allows for higher altitude, longer range transits & cruise to fires.
- Improves pilot comfort, reduces pilot fatigue.
- Potential fatigue issues with large fuselage cutouts for doors or vents.

Internal vs External Tank

Trade-offs

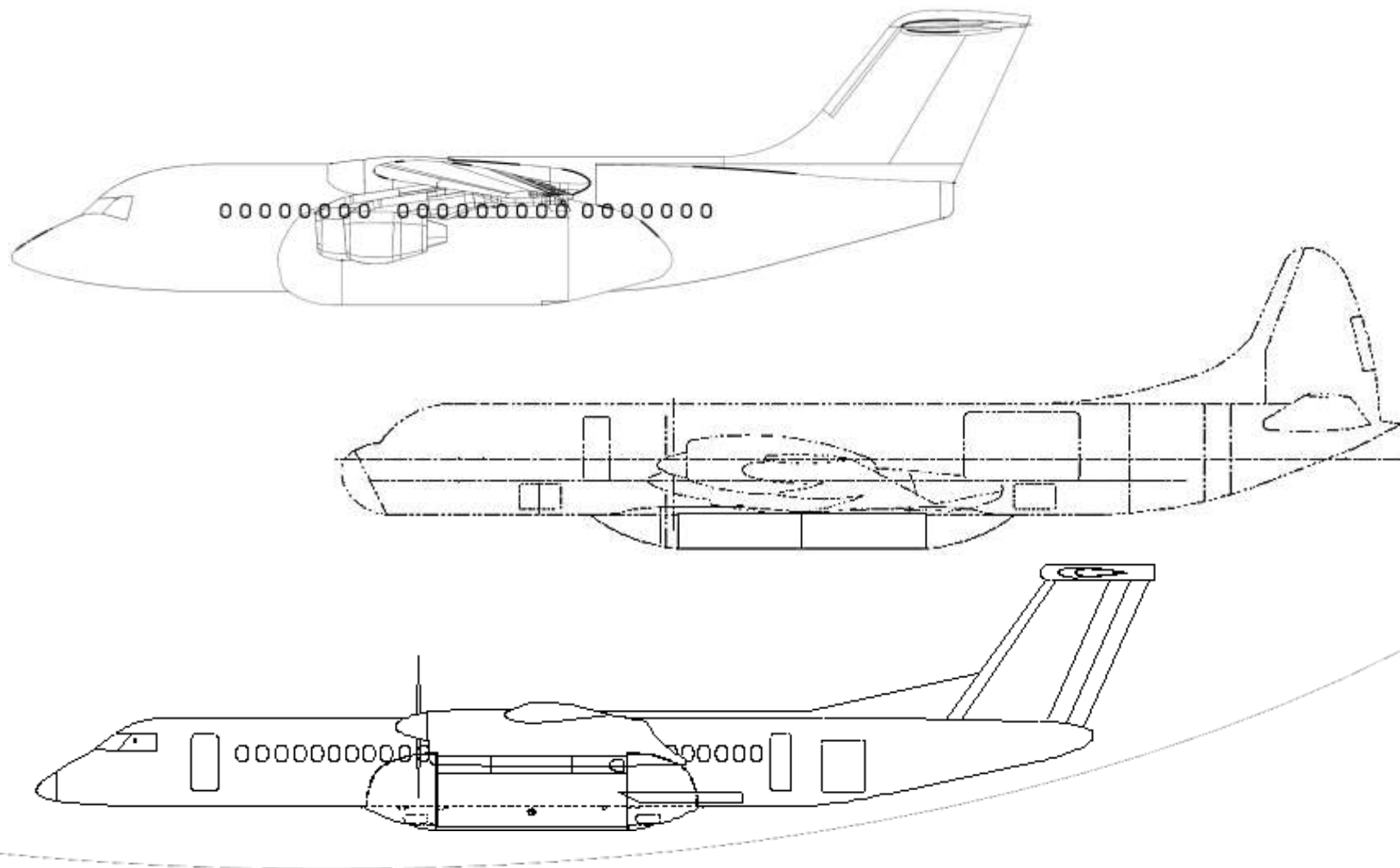
Trade-off Criteria	Internal Tank	External Tank
Tank Weight	Lighter	Heavier
Tank Geometry	Simpler cylindrical or box structure	More complex, conformal structure
Tank Loads	Fluid inertia only	Aerodynamic & inertia
Tank Fairings	Small, or not req'd	Large External
Fuselage Geometry "Obstacles"	Flt Ctls, Hydraulics, Keel & Wingbox structs	Main Landing Gear
Ground Clearance	No issue	Possible issue
Emergency Landing/ Crashworthiness	9G Fwd tank restraint req'd for flight crew.	No internal hazard for flight crew.

Internal vs External Tank

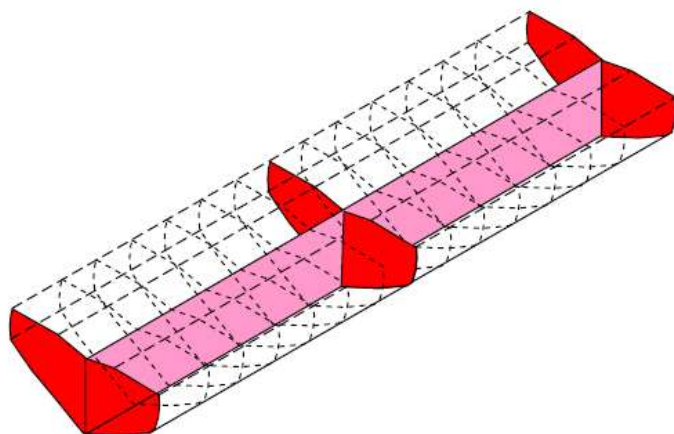
Trade-offs... cont'd

Trade-off Criteria	Internal Tank	External Tank
Venting/Pressurization	From Cabin air? Or pressure-assisted?	External venting only
Doors/Flow Rates	Smaller	Larger
Flow Rates	Worse flow	Better flow
Maintenance	Difficult to remove? Internal tank leakage?	Easily removable? No internal leakage

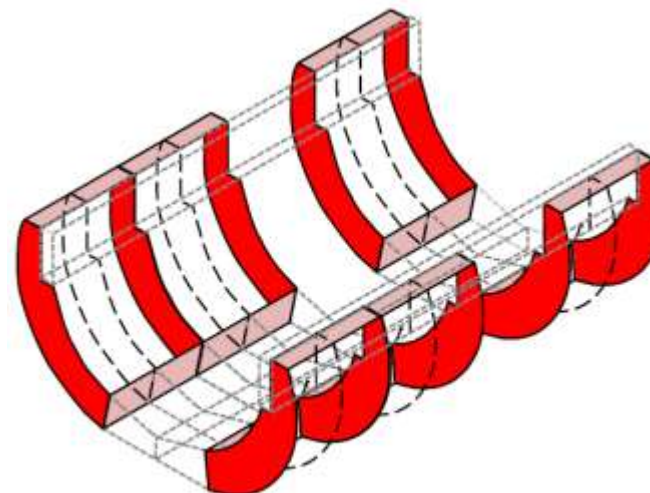
Tank Location & CG



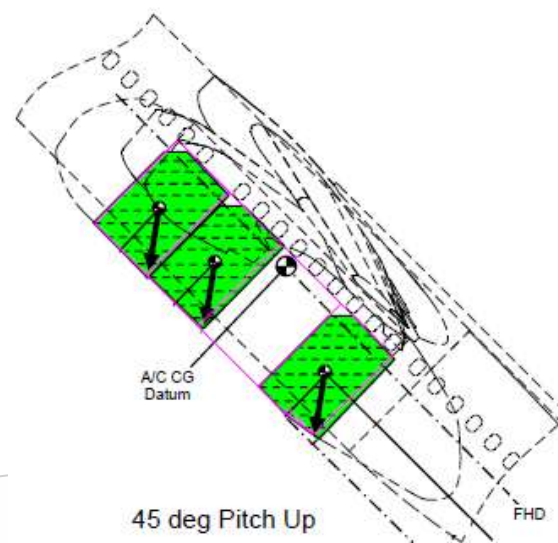
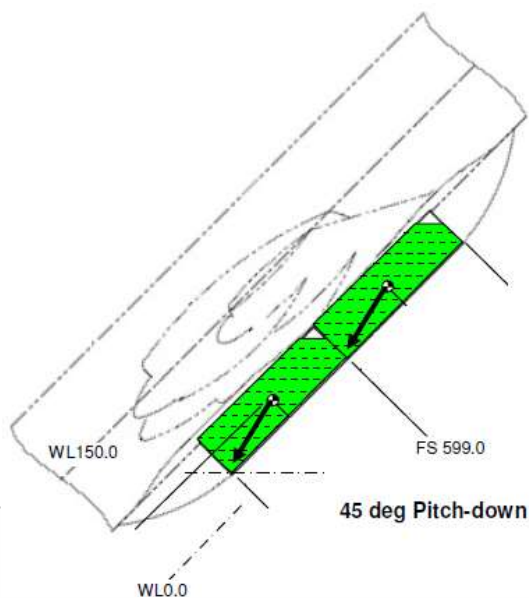
Tank “Sloshing” effects



Retardant Tank Fluid-tight Compartments



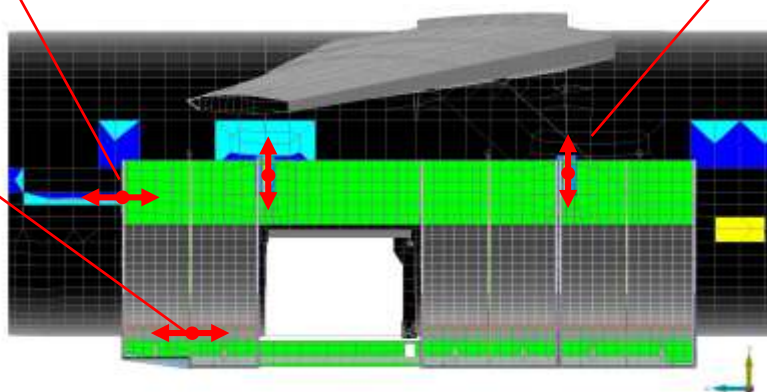
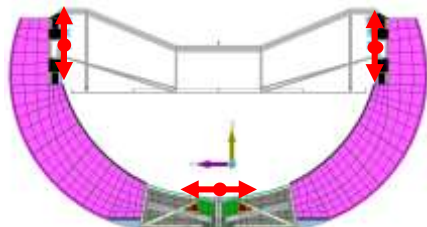
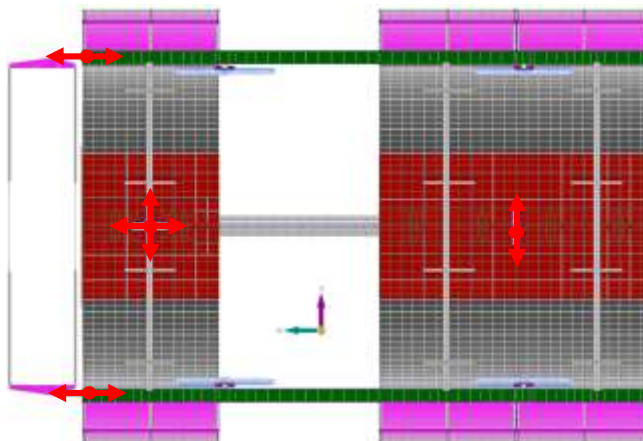
Retardant Tank Fluid-tight Compartments



Airframe weight reductions



Tank-to-Airframe Connections



Tank-to-Airframe Connections



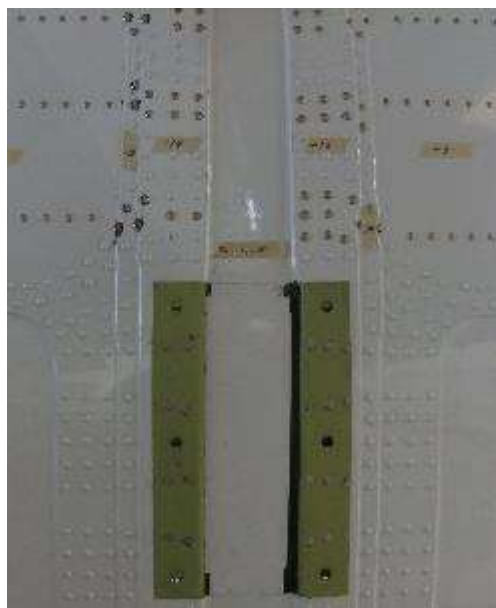
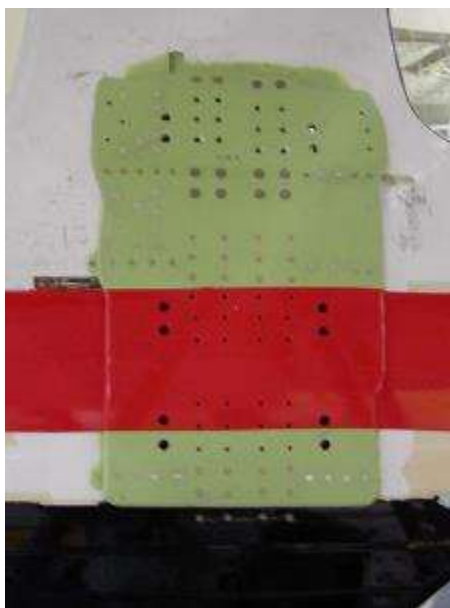
Fuselage Holes & Penetrations

- Large fuselage openings are often needed for fluid discharge in internal tank installations.



Fuselage Holes & Penetrations

- External tank installations require much smaller fuselage penetrations for mounting and installation.



Some Regulatory Considerations

- Restricted Category Operations
 - Airtankers vs other “Special Mission” aircraft
 - Specific rules in AC525-012, Appendix A
- Special Conditions of Airworthiness
 - Limit Maneuvering Load Factors (3 and 3.25g reqts)
 - Performance Alleviations (credit for disposable pyld)
- Alternate Means of Compliance
 - “Stall-before-G” approach
 - Characterizing the Gust & Maneuver Environment
 - “Flight Envelope expansion” approach

Special Conditions of Airworthiness

- Special Conditions of Airworthiness (SCA) for Restricted Category Aircraft
- Additional Transport Canada (TCCA) regulations for Airtankers above basic Part 25 Transport Category requirements (based on AC525-012, Appendix A)
- Most notably, increased “Limit Maneuvering Load Factors” vs FAR 25 requirements:
 - +3.0g Flaps-up, and,
+3.25g Flaps-down (Appendix A, A3(a)), or
 - a suitable alternative...(Appendix A, A3(b))

Alternate Means of Compliance

- Excerpt from SCA 2005-003, Appendix A.3 below.

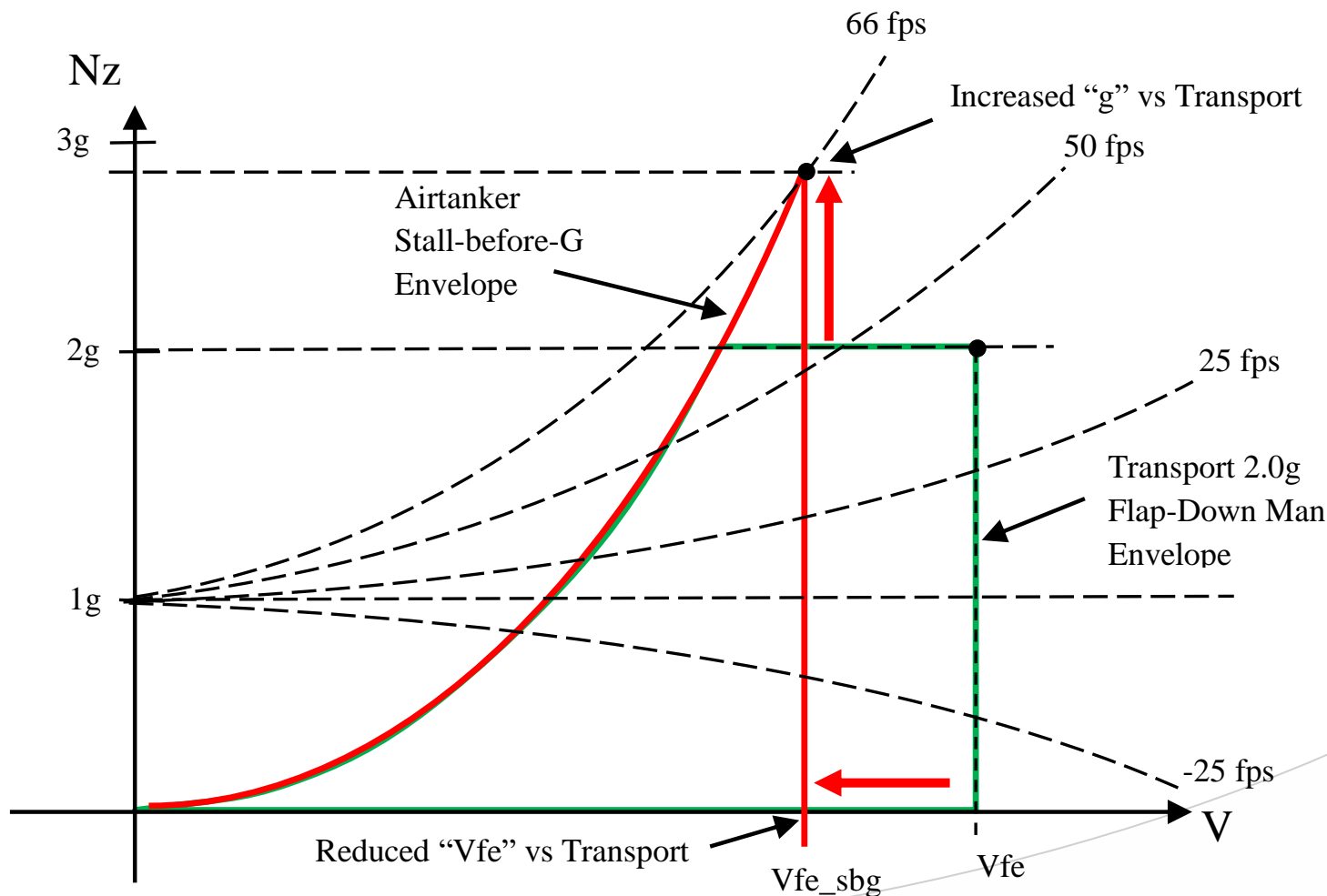
(b) Alternate Manoeuvring and Gust Conditions:

In lieu of the manoeuvring load factors specified in (a) above, the applicant may use alternate manoeuvring and gust envelopes which have been shown to be appropriate and which, when associated with operating limitations will provide for safe operation of the aircraft.

Any such proposed manoeuvring envelope should conservatively encompass specific manoeuvring occurrences peculiar to the fire-fighting activities. Likewise, the gust envelope should take into account the response of the aircraft to atmospheric turbulence of the maximum intensity likely to be encountered in the vicinity of a fully developed fire.

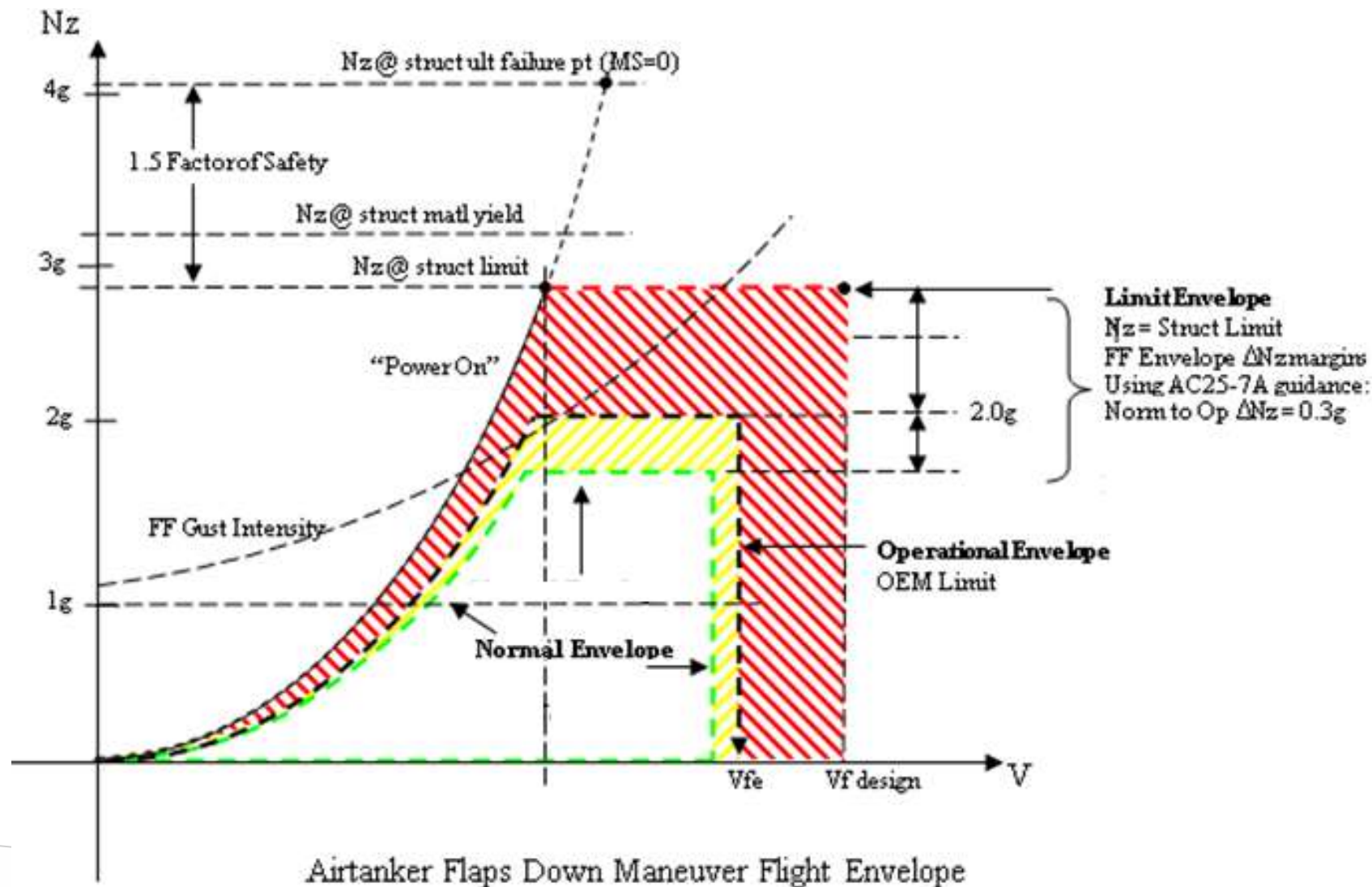
- ...so what are appropriate and safe manoeuvring and gust envelopes for fire-fighting activities?

“Stall-before-G” Approach



Airtanker Flaps-Down “Stall-before-G” Flight Envelope

“Flight Envelope Expansion” Approach

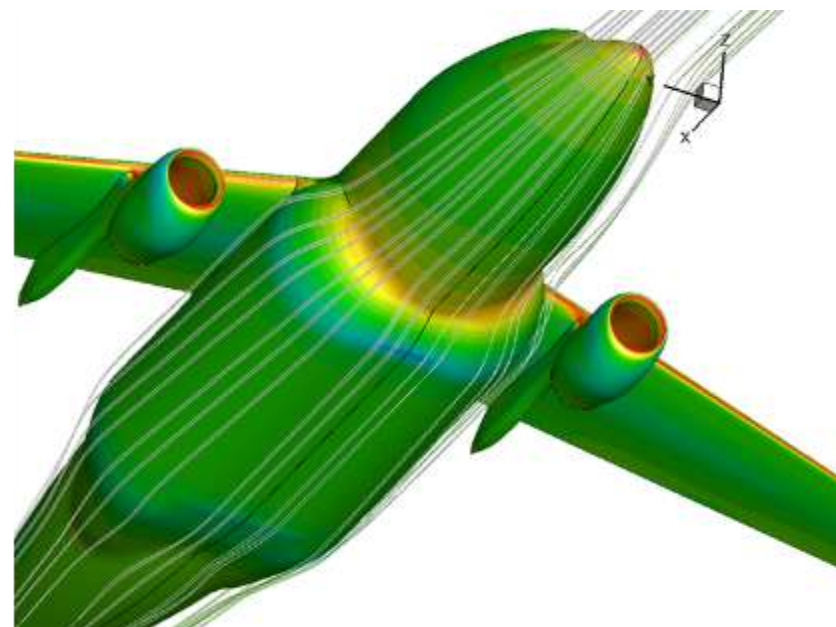
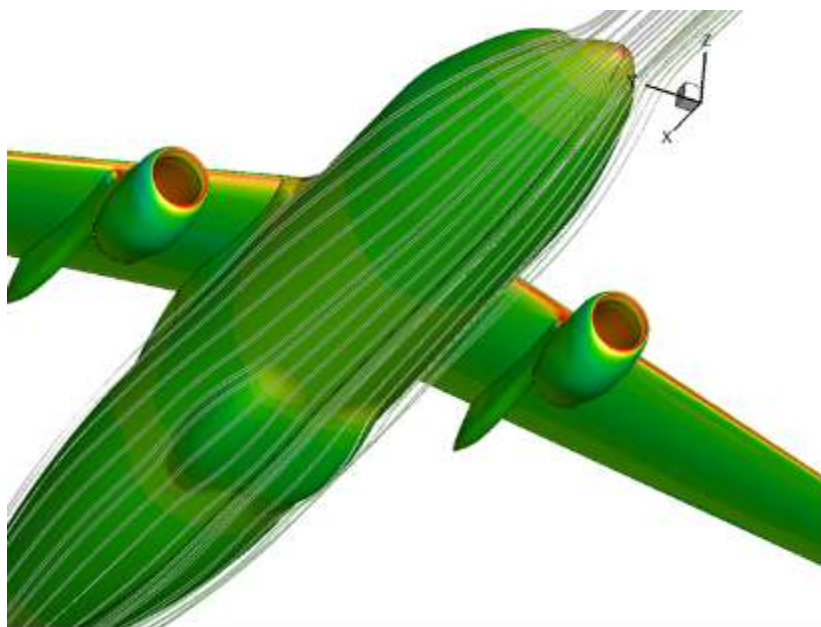


Flight Envelopes & External Loads

- Potential Aerodynamic Effects
- Gust Envelopes
 - Vertical and Lateral Gust
 - Head-on Gust
- Maneuver Envelope
 - Increased Maneuvering Limits
- Additional Flaps-Down considerations
 - “Mission” flaps, not “En-route” flaps
 - Flap Speed restrictions
- “Other” Loads considerations
 - Airloads on Tank and Fairings
 - Crashworthiness

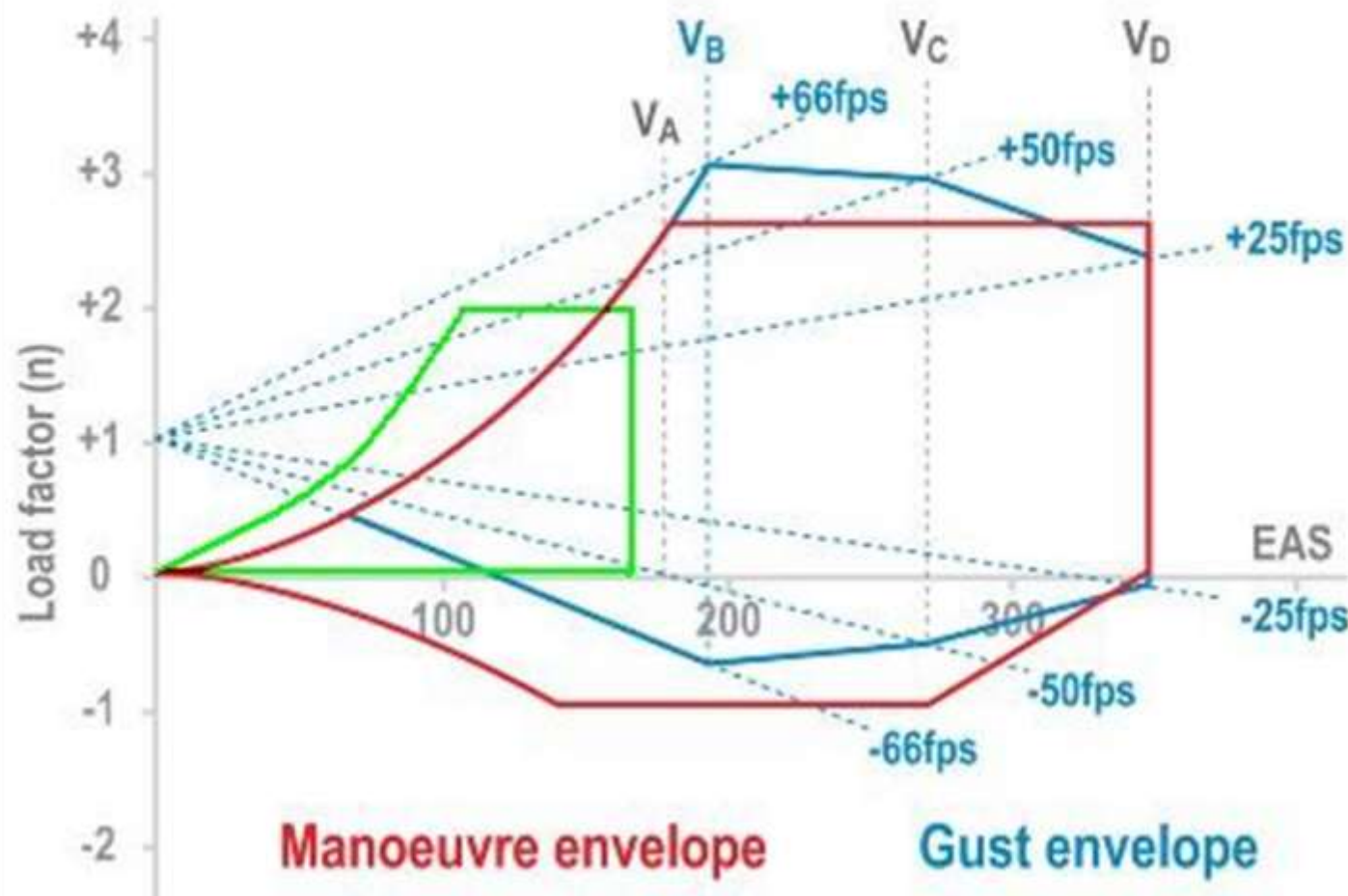
Aerodynamic Effects

- Potential aerodynamic impact of an external tank installation:



Gust and Maneuver Envelopes

Transport Category Flight Envelope



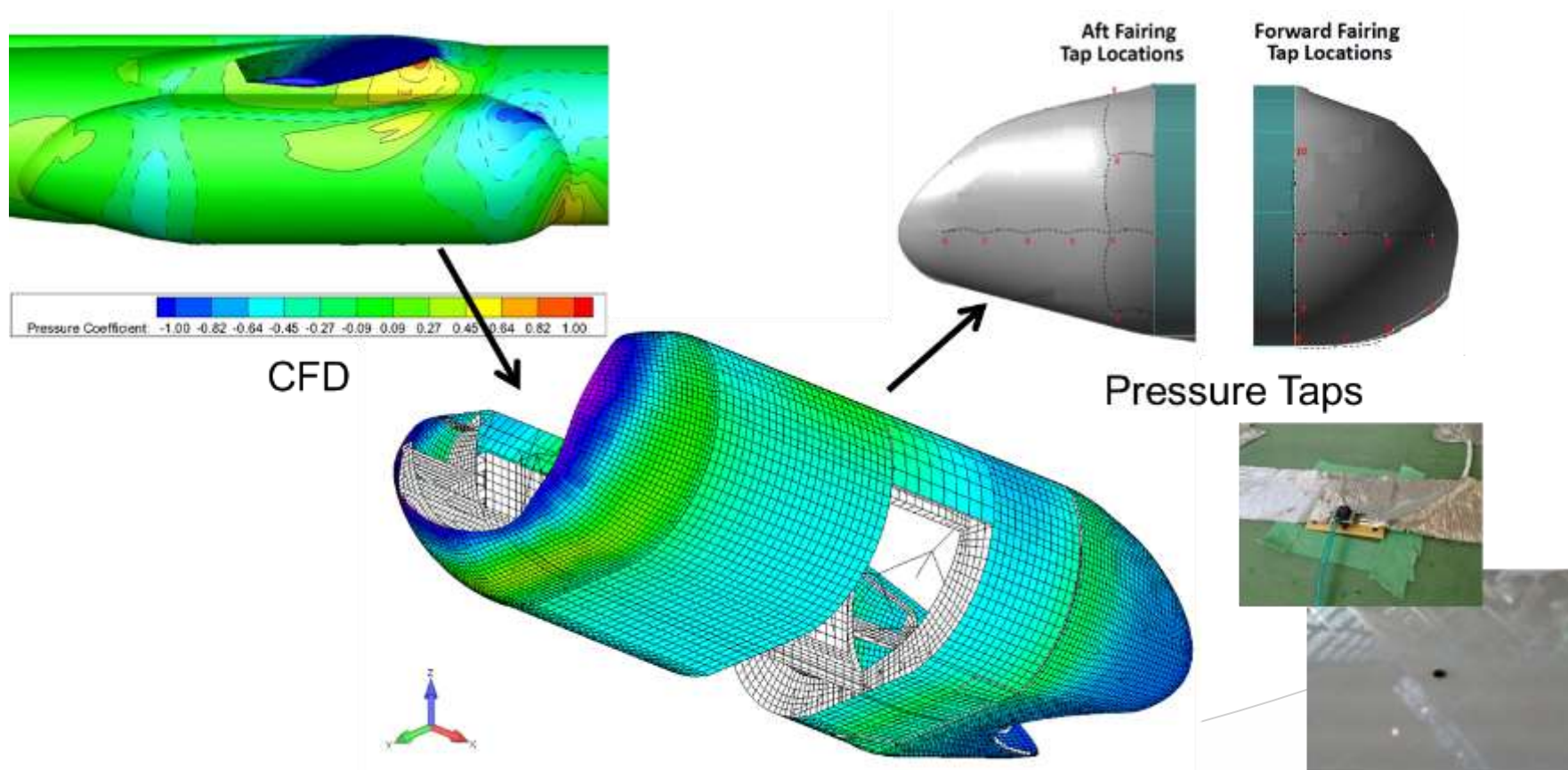
Flaps Down Loads

Additional Design Considerations are:

- “Mission” Flaps vs full “En-route” Flaps.
 - Appropriate Maneuver “g” for Fire-fighting vs 2.5 g En-route requirements.
- Flap Speed restrictions.
 - Reduced Vfe speeds to manage airframe loads.
- Head-on gust.
 - Adequate margins for Fire-fighting gust intensities.

“Other” Loads Effects

- Local Airloads on (External) Tank & Fairing



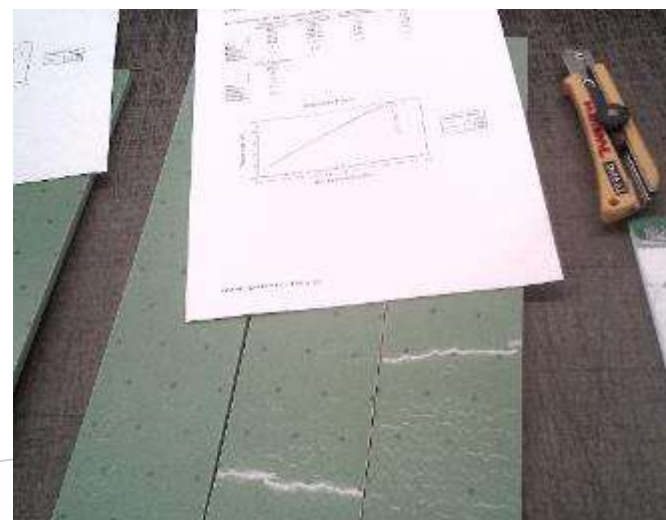
Static Structural Analysis

- Airframe vs Tank Analysis
 - FEM for internal loads redistribution vs direct stress analysis.
 - Analysis using OEM + Industry Standard methods.
 - Tank Fairing challenges (ie. operating temp, bird strike, lightning strike, composite matl quals).

External Tank Fairings

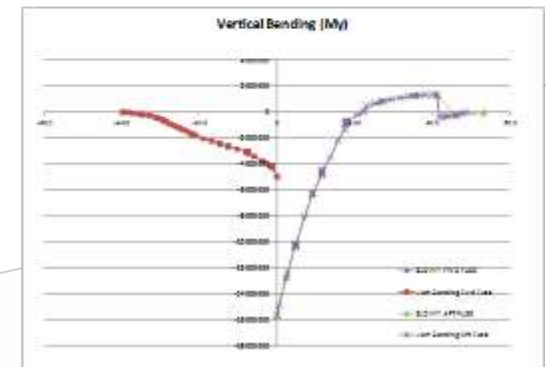
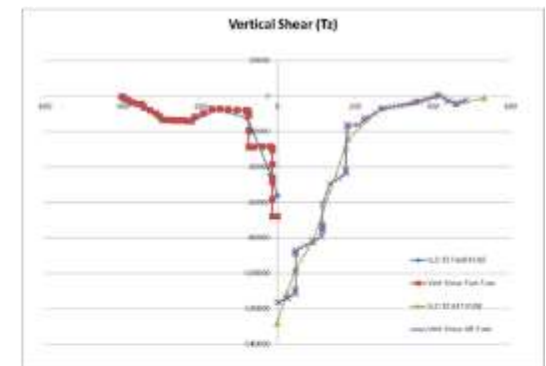
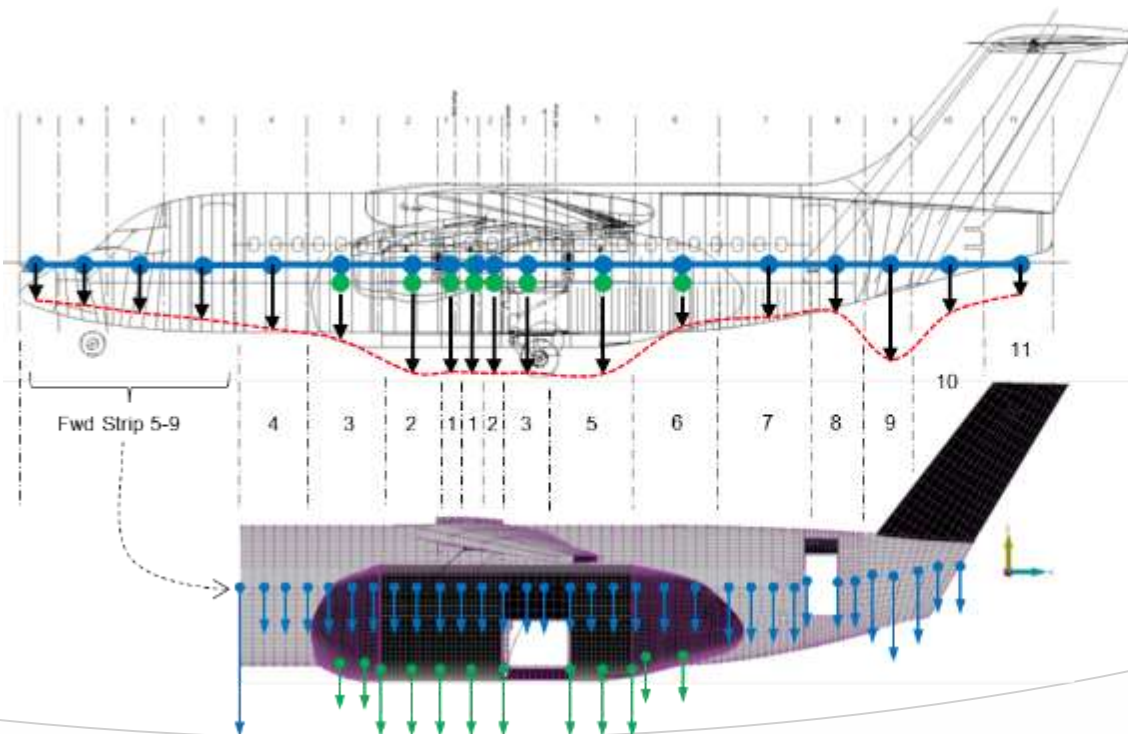


Tank Fairings...construction.



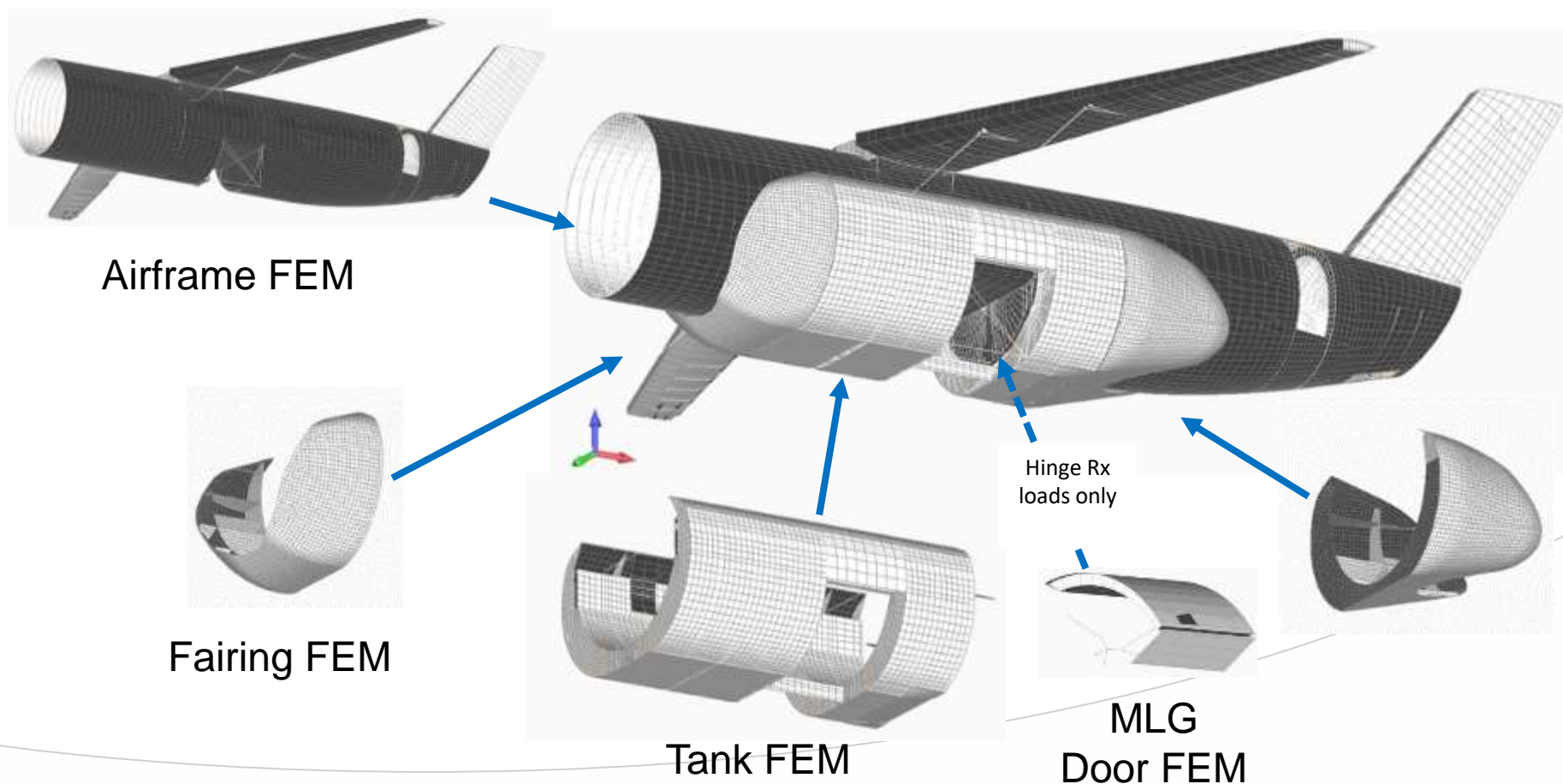
External Loads Model -> FEM Internal Loads Model

- Proportionately split external air & inertia loads between airframe, tank & fairing elements.



“Integrated” Finite Element Model

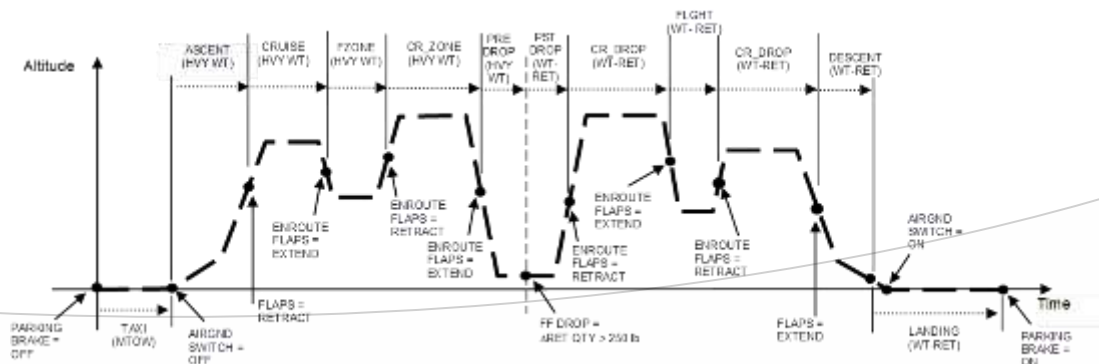
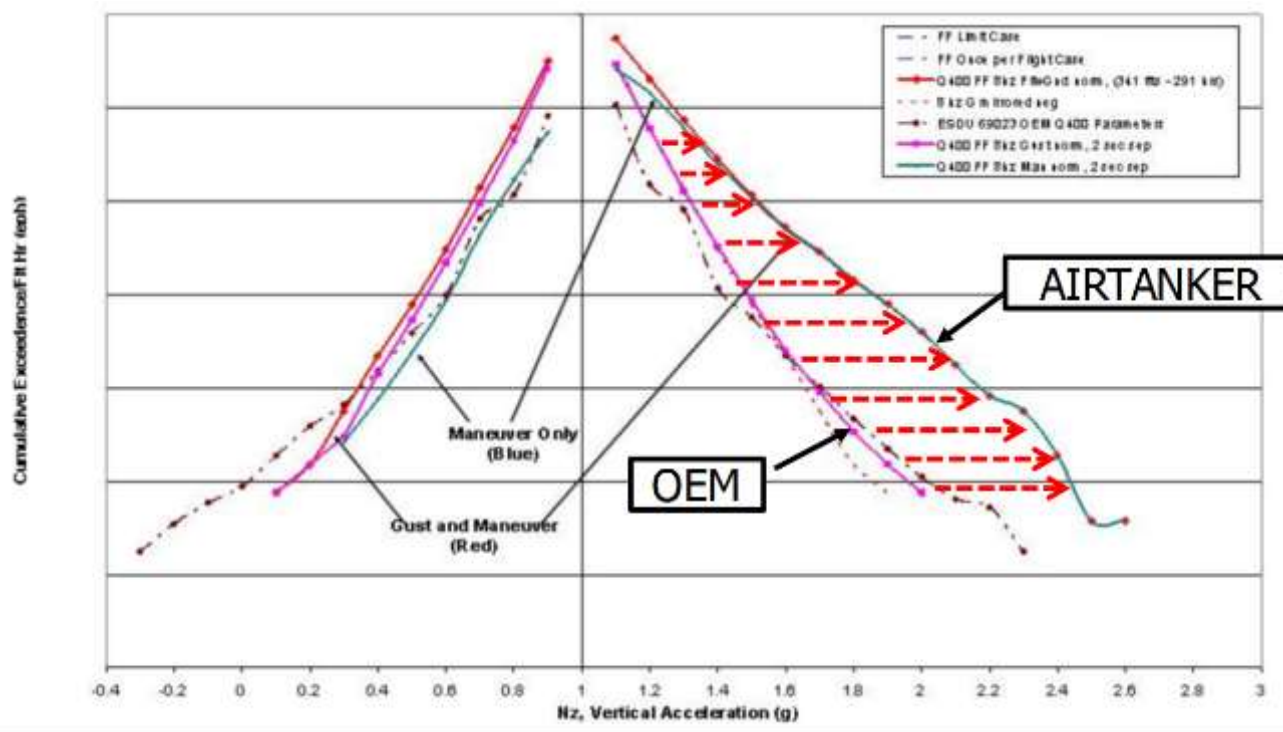
- Combined airframe-tank-fairing FE model.



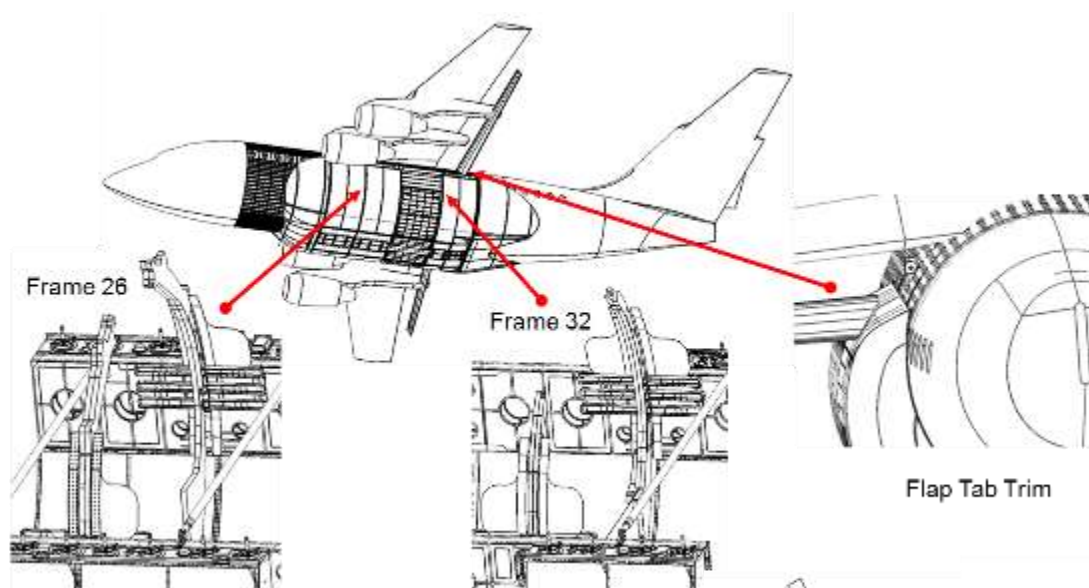
Fatigue & Damage Tolerance

- Airtanker Mission Spectra
- Primary vs Secondary Structures
 - Airframe & Tank Attachments (primary)
 - Tank Shell & Fairings (secondary)
 - Modified & Unmodified PSE's classification
- Damage Rate Factors (DRF)
- Continuing Airworthiness Program (CAP)
- Operational Loads Monitoring (OLM)
- Widespread Fatigue Damage (WFD)
 - “Classic” aircraft example: L188
 - “Modern” aircraft examples: Q400, RJ85

Airtanker Mission Spectra

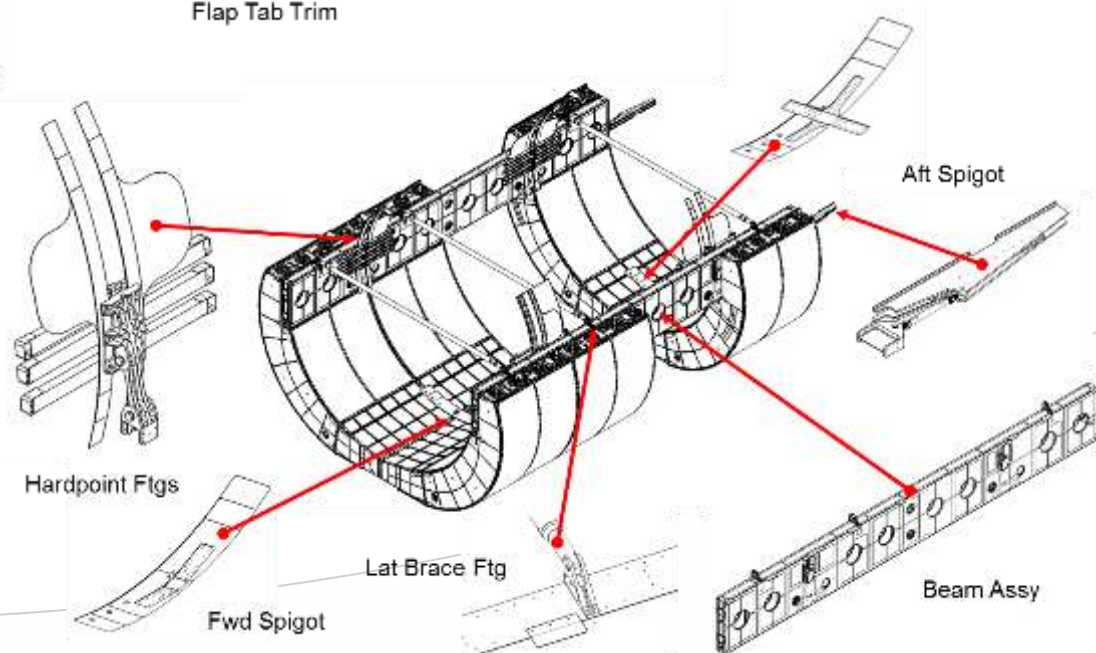


Primary Airframe + Tank Structures



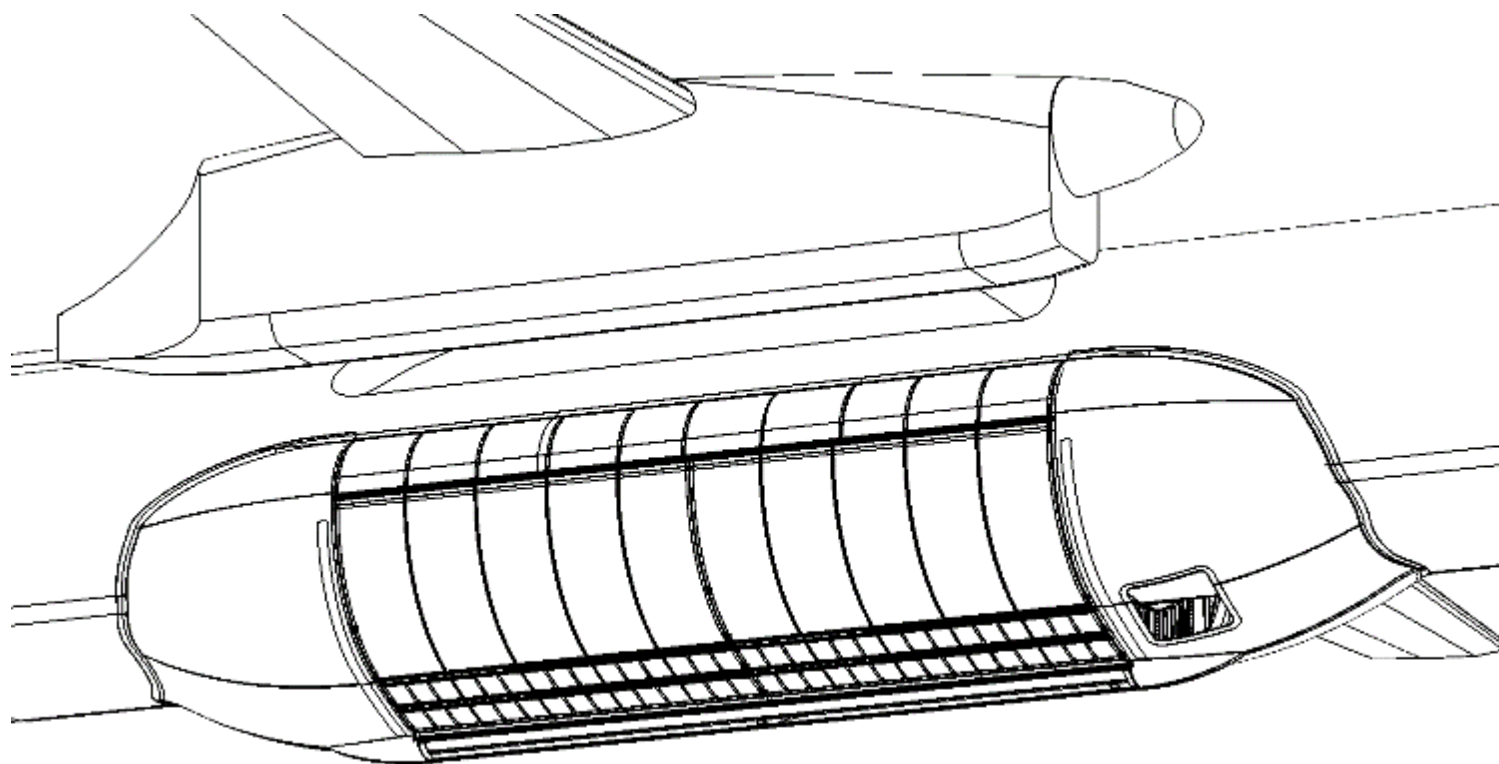
- Modified Airframe PSE Sites

- New Tank PSE Sites



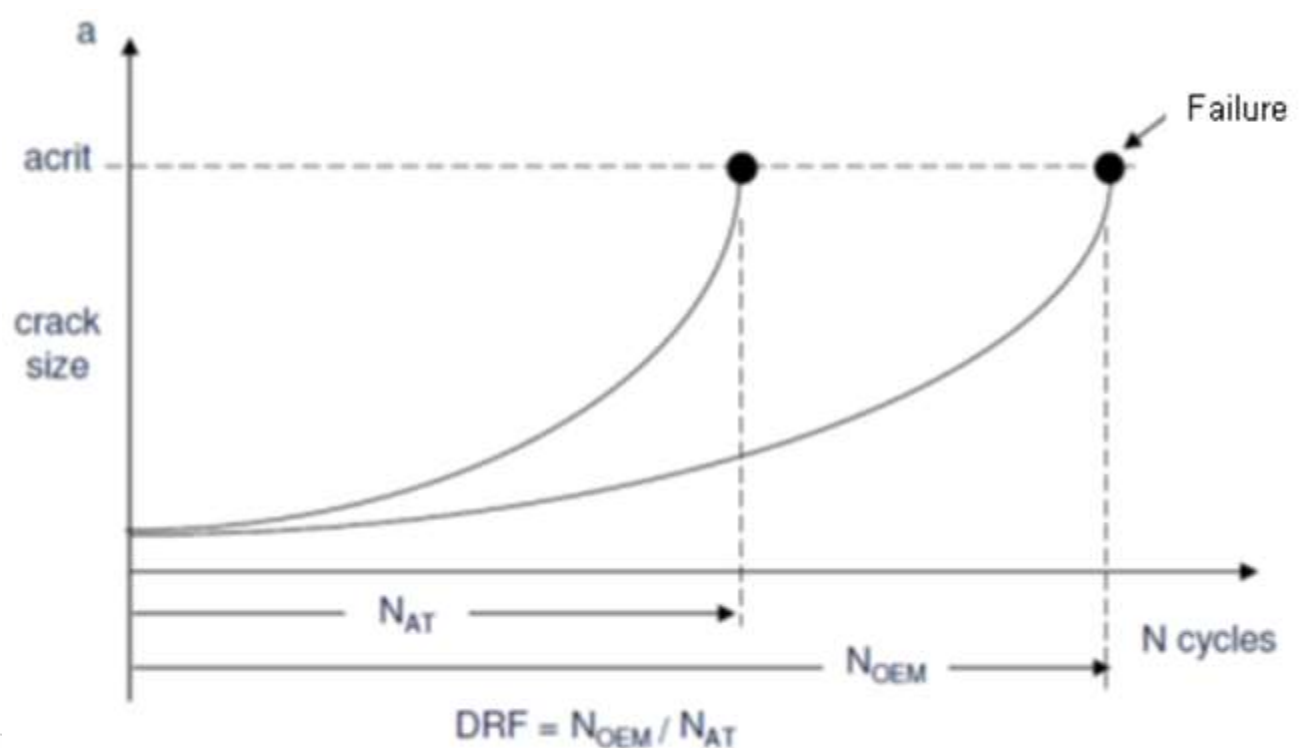
Secondary Tank Structures

- Remaining Tank Shell & Fairings.



Damage Rate Factors

- Airtanker “Damage Rate Factor” (DRF) used to account for more fatigue damage and reduce Maintenance Inspection Intervals



Damage Rate Factors

- Stress Spectra Level Comparisons
 - Used extensively by OEMs to compare relative fatigue damage or crack growth between 2 fatigue spectra

Log Linear Fatigue Damage

$$E = \frac{C}{(\sigma_{\max} (1-R)^m)^a}$$

Walker Eqn
(S-N Curve)

$$D = \frac{N}{E} = N \frac{(\sigma_{\max} (1-R)^m)^a}{C}$$



$$\frac{D_1}{D_2} = \frac{\sum_{i=1}^{n_1} \left[N_i (\sigma_{\max i} (1-R_i)^m)^a \right]}{\sum_{i=1}^{n_2} \left[N_i (\sigma_{\max i} (1-R_i)^m)^a \right]}$$

Log Linear Crack Growth

$$\frac{da}{dN} = C(\Delta K)^p$$

Paris Eqn
(da/dN-delK Curve)

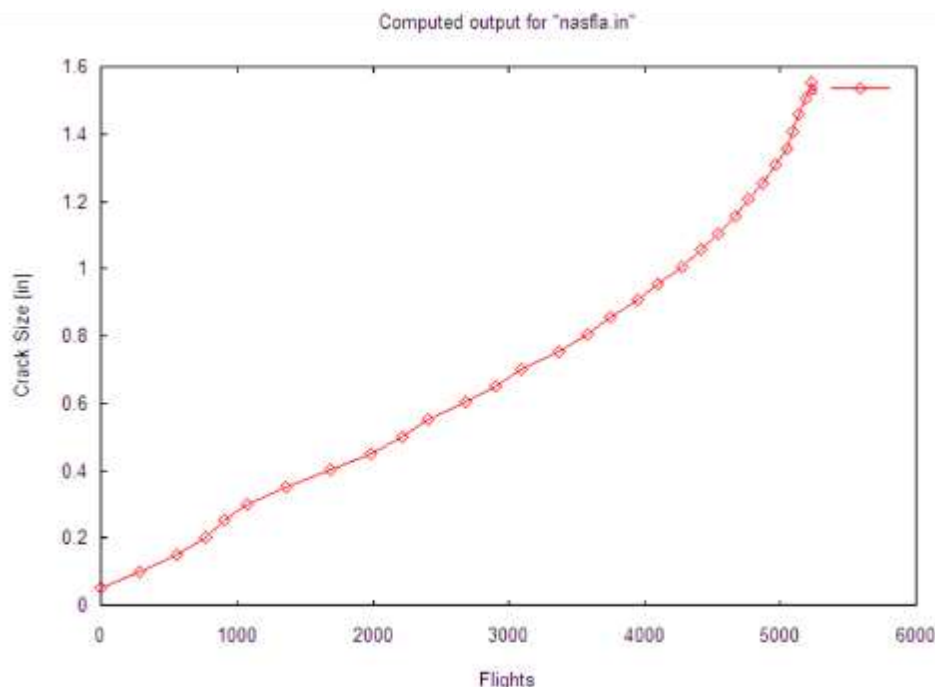
$$\begin{aligned} \frac{da}{dN} &= C(\Delta K (1-R)^{m-1})^p \\ &= C(\Delta \sigma \sqrt{\pi a} (1-R)^{m-1})^p \end{aligned}$$



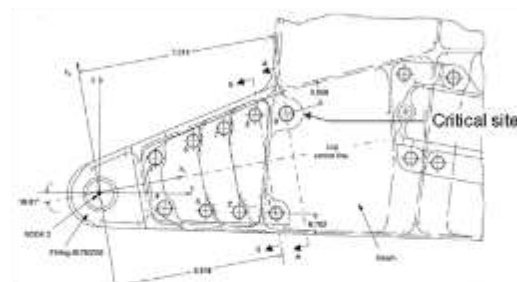
$$\frac{\left(\frac{da}{dN} \right)_1}{\left(\frac{da}{dN} \right)_2} = \frac{\sum_{i=1}^{n_1} \left[N_i (\sigma_{\max i} (1-R_i)^m)^p \right]}{\sum_{i=1}^{n_2} \left[N_i (\sigma_{\max i} (1-R_i)^m)^p \right]}$$

Damage Rate Factors

- Relative Crack Growth Comparisons



Example: Q400 Airtanker
 PSE (400)575003 Flap Track 1 Beam
 Ref PR 1-3320.2.3.20.1



$$DRF_{threshold} = \frac{cycles_{transport}}{cycles_{firefighting}} = \frac{24,300}{5,226} = 4.65$$

$$DRF_{repeat} = \frac{cycles_{transport}}{cycles_{firefighting}} = \frac{20,500}{5,226 - 905} = 4.74$$

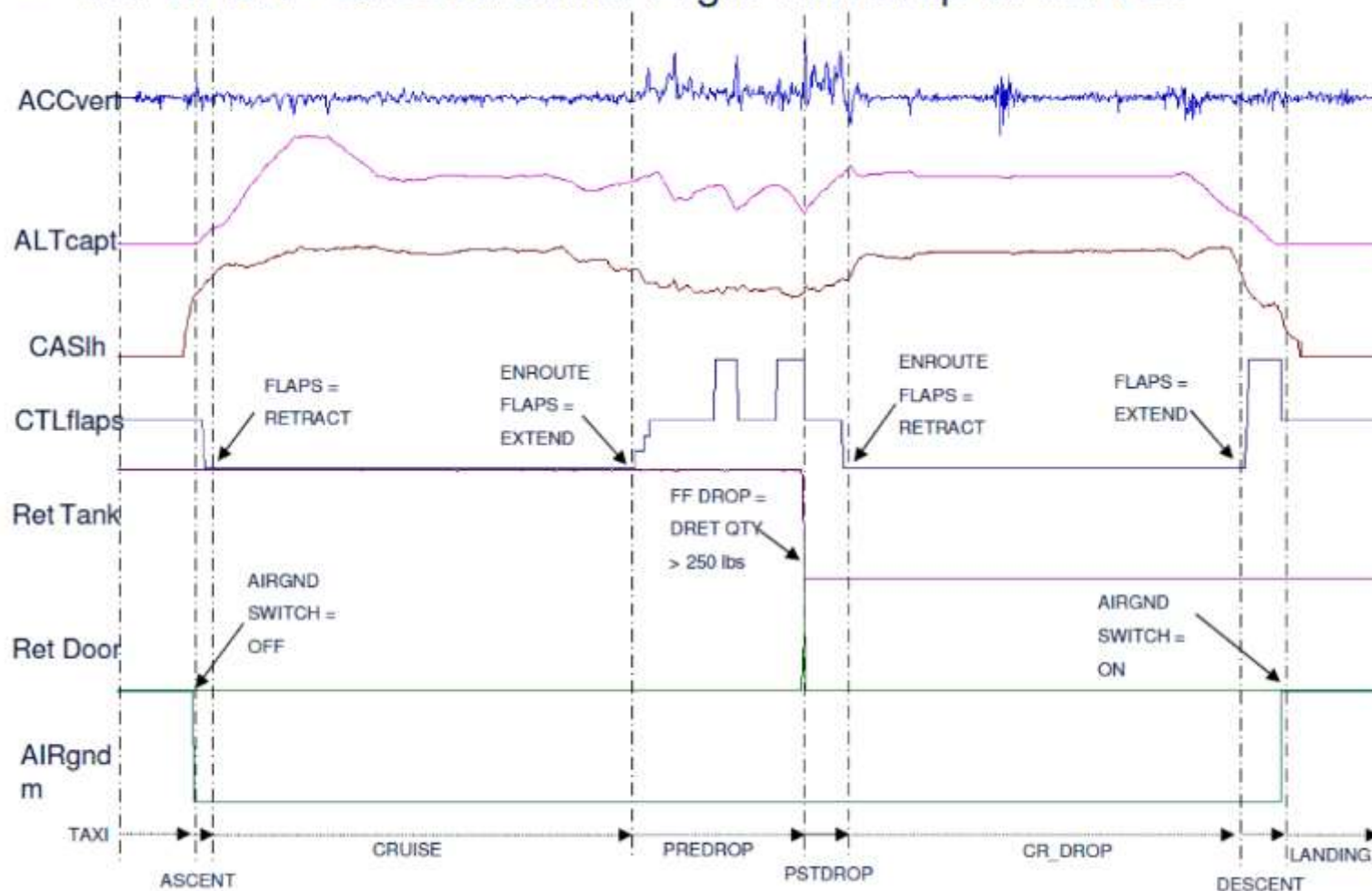
The crack grew to 1.52 inches in 5,226 cycles. The crack was of inspectable size (0.25 inches, per the OEM assessment) after 905 firefighting cycles.

Continuing Airworthiness Program

- For Airframe -> usually supplemental additions to OEM maintenance program.
- For Tank & Attachments -> new maintenance requirements.

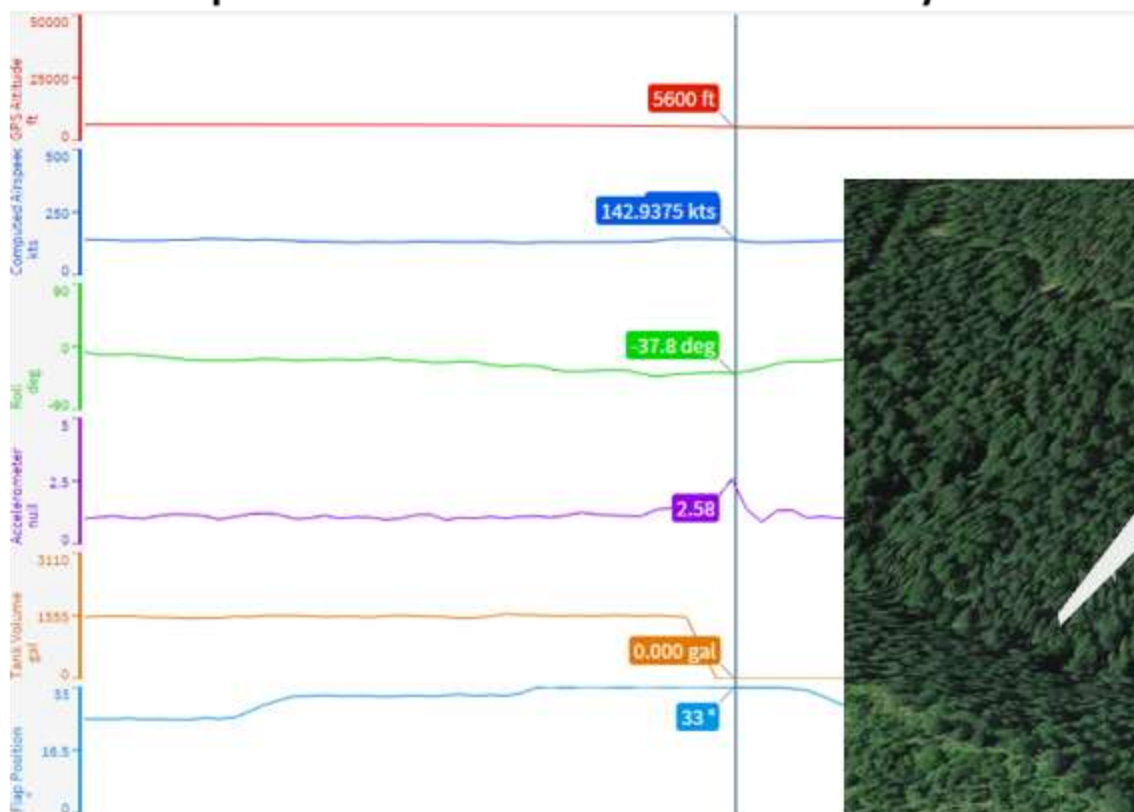
Operational Loads Monitoring

- i.e. DFDR - Q400 Airtanker Flight with Drop 4040F105



Operational Loads Monitoring

Example – RJ85 IONODE OLM System 2015 data



3-D Flight Path Visualization



2-D Flight Parameter Trace

Widespread Fatigue Damage

- ...So, what does this mean from an “Airtanker” perspective?



18 July 2002, P4Y-2, N7520C, Estes Park, Colorado

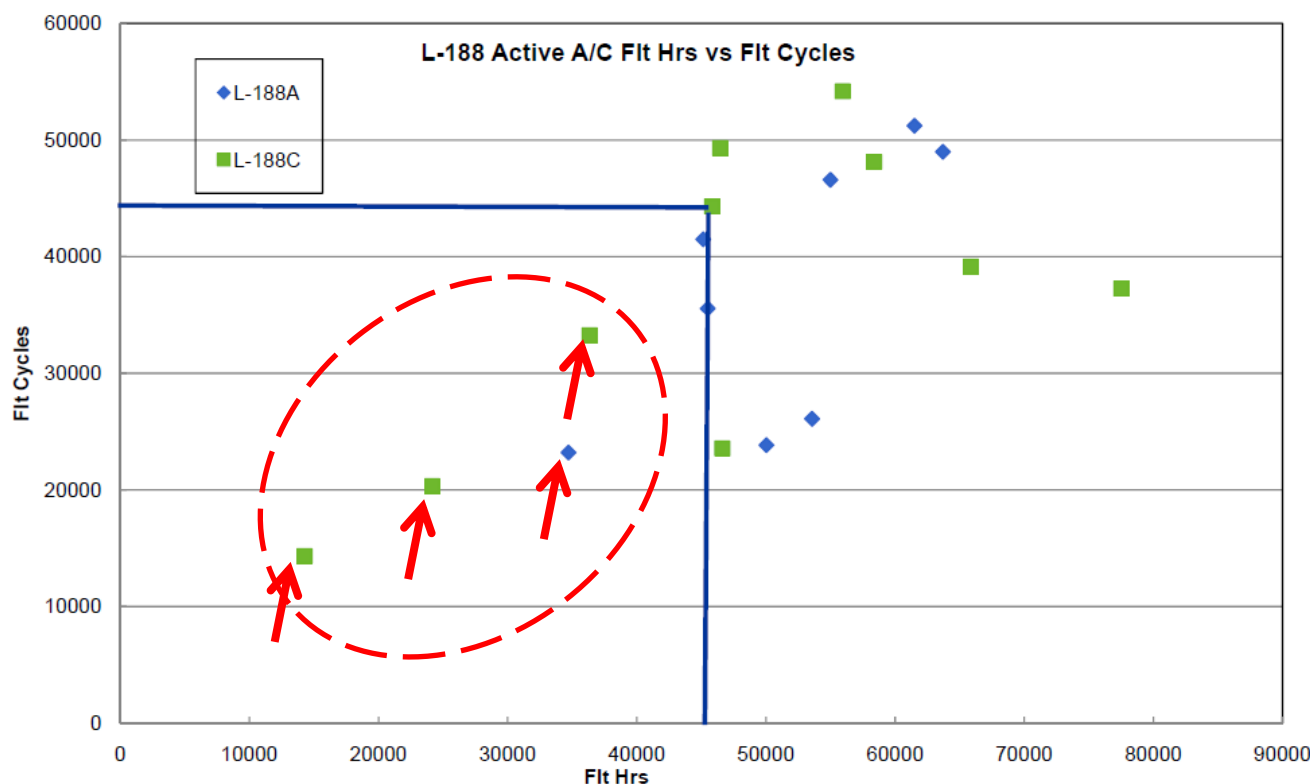
17 June 2002, C-130A, N130HP, Walker, California



- ...and more importantly, how to prevent this!

“Classic” WFD Example - L188

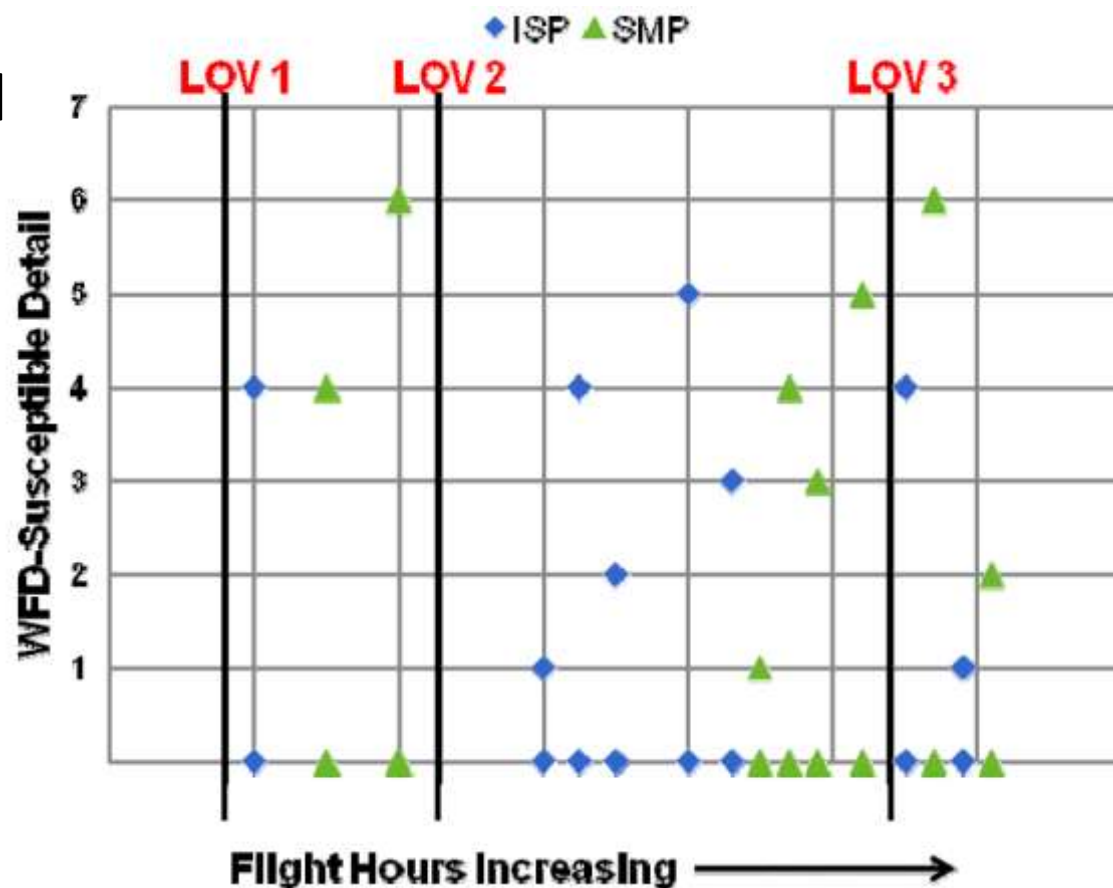
- Only 4 “active” L188’s remain within 27,000 flt cycle/45,000 flt hr LOV limits.

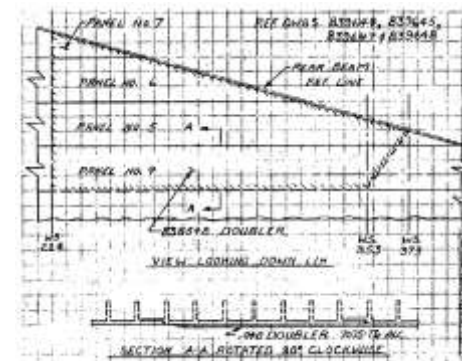


WFD – L188

- 3 Critical LOV sites re-assessed in-detail for L188 Airtanker:

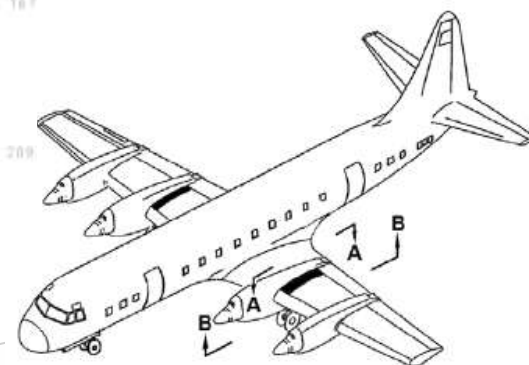
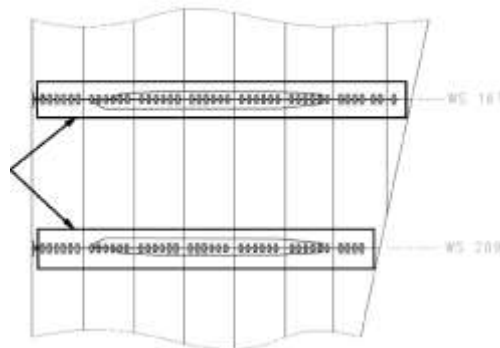
1. Wing Root Joint @ BL 65
2. MLG Rib Feet @ WS 167/209
3. Wing Skin LEAP Doublers
4. Fuse Splice Jnt (not critical for unpressurized a/c)





The drawing includes two views of the hull structure:

- SECTION A-A:** A longitudinal section of the hull. It shows a series of vertical stiffeners supporting the hull plating. The section is bounded by station lines FS 571 at the bow and FS 695 at the stern. Two arrows labeled 'C' point to the stiffeners. Vertical dimension lines on the left and right indicate the height of the hull structure.
- VIEW B-B:** A transverse section of the hull. It shows the cross-section of the hull plating and stiffeners. The section is bounded by station lines BL 65 at the bow and BL 65 at the stern. The drawing shows the internal structure of the hull, including the stiffeners and the hull plating.



“Modern” WFD Example – RJ85

- Basic RJ85 Design Life = 40,000 flt cycles
- With Life Extension Program (LEP) = 60,000 flt cycles
- Airtanker Design Life Target = $200 \text{ flts/yr} \times 20 \text{ yrs} = 4,000 \text{ AT cycles}$
- Typical Airtanker DRF = (5 to 7) x AT cycles
- RJ85 Airtanker Design Life = 20,000 to 28,000 flt cycles
- Typical Life at Conversion (ie E2270) = 31,500 flt cycles
- Post Conv Life remaining = $60,000 - 31,500 = 28,500 \text{ flt cycles}$