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.
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

<table>
<thead>
<tr>
<th>Trade-off Criteria</th>
<th>Internal Tank</th>
<th>External Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Weight</td>
<td>Lighter</td>
<td>Heavier</td>
</tr>
<tr>
<td>Tank Geometry</td>
<td>Simpler cylindrical or box structure</td>
<td>More complex, conformal structure</td>
</tr>
<tr>
<td>Tank Loads</td>
<td>Fluid inertia only</td>
<td>Aerodynamic &amp; inertia</td>
</tr>
<tr>
<td>Tank Fairings</td>
<td>Small, or not req’d</td>
<td>Large External</td>
</tr>
<tr>
<td>Fuselage Geometry “Obstacles”</td>
<td>Flt Ctls, Hydraulics, Keel &amp; Wingbox structs</td>
<td>Main Landing Gear</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>No issue</td>
<td>Possible issue</td>
</tr>
<tr>
<td>Emergency Landing/ Crashworthiness</td>
<td>9G Fwd tank restraint req’d for flight crew</td>
<td>No internal hazard for flight crew.</td>
</tr>
</tbody>
</table>
### Internal vs External Tank

**Trade-offs... cont’d**

<table>
<thead>
<tr>
<th>Trade-off Criteria</th>
<th>Internal Tank</th>
<th>External Tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venting/Pressurization</td>
<td>From Cabin air? Or pressure-assisted?</td>
<td>External venting only</td>
</tr>
<tr>
<td>Doors/Flow Rates</td>
<td>Smaller</td>
<td>Larger</td>
</tr>
<tr>
<td>Flow Rates</td>
<td>Worse flow</td>
<td>Better flow</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Difficult to remove? Internal tank leakage?</td>
<td>Easily removable? No internal leakage</td>
</tr>
</tbody>
</table>
Tank Location & CG
Tank “Sloshing” effects
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

- Increased “g” vs Transport
- Reduced “Vfe” vs Transport
- 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

[Diagram showing flight characteristics and operations stages]

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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.

\[
DRF = \frac{N_{OEM}}{N_{AT}}
\]
Damage Rate Factors

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

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

Walker Eqn
(S-N Curve)

\[
D = \frac{N}{E} = N \left(\frac{\sigma_{\text{max}} (1-R)^m}{C}\right)^a
\]

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

\[
\frac{\frac{da}{dN}}{1} = \sum_{i=1}^{n_1} N_i \left(\frac{\sigma_{\text{max}_i} (1-R_i)^m}{C}\right)^p
\]

\[
\frac{\frac{da}{dB}}{2} = \sum_{i=1}^{n_2} N_i \left(\frac{\sigma_{\text{max}_i} (1-R_i)^m}{C}\right)^p
\]

Log Linear Fatigue Damage

Log Linear Crack Growth

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

Paris Eqn
(da/dN-deI-K Curve)
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

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

- ACCvert
- ALTcapt
- CASlh
- CTLflaps
- Ret Tank
- Ret Door
- AIRgnd

- FLAPS = RETRACT
- ENROUTE FLAPS = EXTEND
- FLAPS = EXTEND
- FLAPS = RETRACT

- AIRGND SWITCH = OFF
- AIRGND SWITCH = ON

- FF DROP = DRET QTY > 250 lbs

- TAXI
- ASCENT
- CRUISE
- PREDROP
- PSTDROP
- CR_DROP
- DESCENT
- LANDING

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Operational Loads Monitoring

Example – RJ85 IONODE OLM System 2015 data

2-D Flight Parameter Trace

3-D Flight Path Visualization
Widespread Fatigue Damage

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

• ...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)
WFD LOV Sites – L188
“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 flts/yr x 20 yrs = 4,000 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 flt cycles