Validation Ice Crystal Icing Engine Test in the Propulsion systems Laboratory at NASA Glenn Research Center

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### PSL Icing Session Summary

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Presentation Overview

- Test Facility: Propulsion Systems Laboratory (PSL)
- Test Article: ALF502-R5
- Test Objectives: Primary, Secondary, Additional
- Additional Test Observations
Propulsion Systems Laboratory
NASA Glenn Research Center, Cleveland, OH
Propulsion Systems Laboratory Test Cell Three (PSL-3) Schematic

**Icing Configuration**

1. **Steam Injection**
   - Externally compressed and conditioned air
   - Flow Direction

2. **Water Injection**
   - Plenum Pressure
   - Plenum
   - To Contraction Duct

**Ducting Configuration**

1. **From Plenum**
2. **Contraction Duct**
3. **27:1 Area Duct**
4. **Station 1**
5. **Approx. 25 ft. to water injection plane**
6. **Station 2**
7. **Engine**
8. **Exhaust**
9. **Desired Pressure Altitude**
Inaugural Ice Crystal Icing Engine Test Rig in PSL-3
ALF502-R5 Installed on a BAe-146 aircraft
Revenue Service Field Events
1997 Flight Test Points
Test Points Conducted in PSL Feb. 2013
Engine Cut-away View
LF01 Internal Flow Path Instrumentation

Aft Looking Forward

P_{static} taps

Anti-ice Air

1 2 3 4 5
FLT850 Roll back of ALF502-R5 (LF01) During 1997 Flight Testing

1997 FT 850 Flight Test Video of Roll back showing IGV ice accretion
Primary Objective: Achieved Successfully
Calibrate and Reproduce known significant 1997 flight test points:
1. FLT 850 (Roll back)
2. FLT 855 (No Roll Back)
FLT850 Fan, Compressor, Throttle and Cloud Traces

PSL Test Point FLT850 Video of Roll back showing IGV Ice Accretion

%N1, %N2, Cloud, %PLA

Time

%N1  %N2  Cloud  PLA

1X TWC
Plane 4 Thermocouple traces showing Flight Test (top) vs PSL Test (bottom)

In cloud temperature

Cloud on lower plot only

Time

Temperature
Rollback Indicators Chart - roll back test point

PSL-3, FLT850-2

Cloud On

Initial T/C Decrease

1X TWC

Secondary T/C Decrease

Time
Rollback Indicators Chart --- no rollback test point

PSL-3, FLT855-1

Cloud On

Rise and Fall → accumulation and shedding?

Initial T/C Decrease only

1X TWC

Time
Secondary Objective: Achieved Successfully
Reproduced selected revenue service field events

1. Successfully turned on and off a roll back point
Revenue Service Test Point— no Roll back

PSL-3, RS-1a

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1X TWC

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Time

---

Load

---

%N1, %N2, Cloud, %PLA, Temperature, Pressure

---

1X TWC
Revenue Service Test Point – Roll Back

PSL-3, RS-1b

![Graph showing various data points and lines representing different parameters over time.](image)
Additional Objectives: Achieved Successfully

1. Demonstrated repeatability of PSL
2. Generated Engine data for selected facility and engine operational parameters
   1. Facility: Cloud Total Water Content (TWC)
   2. Facility: Cloud Mean Volumetric Diameter (MVD)
   3. Facility: Low Altitude Test Point
   4. Engine: Anti-Ice System
Total Water Content – Strong influence on rollback/rate of ice build up
Varying TWC for RB Test Point FLT850

TWC1 < TWC2 < TWC3

Increasing TWC
Mean Volumetric Diameter Weak effect on rate not onset of ice build-up

Varying MVD for RB Test Point RS-4, a,b,c,d

Increasing MVD

Cloud On
IBUA

6% LOAD Difference

MVD1 < MVD2 < MVD3 < MVD4

Cloud off for individual test points
Mean Volumetric Diameter no effect on onset of ice build-up
Varying MVD for NRB Test Point FLT855-1,2,3

Cloud on

Cloud off MVD3 only

MVD1 < MVD2 < MVD3
Low Altitude Test Point

Low Altitude Uncommanded Reduction of Thrust

- %N1
- %N2
- Plane 1 AVG T/C
- Plane 2 AVG T/C
- Plane 3 Avg T/C
- Plane 4 Avg T/C
- Cloud
- Physical N1 adjmt.
- IBUA
- Cloud off

Time

Load

%N1, %N2, Cloud, %PLA, Temperature, Pressure
Anti-ice System Influences onset of ice build up

Anti-ice on/off  FLT850 Test Point

Cloud On

Cloud Off
Additional Test Observations

1. Flameout Test Point  
2. Possible Surge Test Point  
3. Mineral Deposits Flow Path Hardware  
4. Hardware Damage  
5. Heated spinner liquid water layer  
6. Ice buildup aft of heat probes in tunnel flow path
Flameout Test Point – Individual Plane 1 & 2 T/C’s Shown

Flameout Test Point Plane 1 and 2 T/C's

Possible Ice Sheds
Repeat Flameout Test Point–Individual Plane 1&2 T/C’s Shown

Repeat of Flameout Test Point Plane 1 and 2 T/C's

Possible Ice Sheds
Surge Test Point – Individual Plane 1 T/C’s Shown

Surge Test Point Plane 1 T/C's

Possible Ice Shed
Mineral Deposits on flow path hardware
Hardware damage that occurred during a full roll back PSL test point
Liquid Water Layer off of heated spinner

Spinner
Heated Tip

Liquid Water Layer

Anti-ice Off
Ice forms aft of heated probes in the flow path
Summary

- Validated a New Facility R&D Capability
  - Successfully calibrated / duplicated known flight test events
  - Successfully recreated known revenue service field events
  - Demonstrated repeatability
- Strong correlation demonstrated: Cloud TWC and rate of ice buildup/rollback
  - Demonstrated ability to turn on/off ice buildup / rollback by adjusting TWC
- Weak correlation demonstrated: Cloud MVD and rate of ice buildup/rollback
  - No affect on the onset of ice build up
- Rollback indicator chart developed → initial reduction of thrust occurs prior to N1 reduction due to restricted core air flow
- Engine anti-ice system required to be on for roll back to occur
- Demonstrated ability to build up ice at low altitudes using NASA tools to predict tunnel ambient temperature
PSL-3 Engine Icing Validation Test Team
Back-up Slides
Loss of Thrust begins in Core Flow Path – not from N1 reduction

Engine Parameters Normalized by Maximum Measured Value

PSL-3, FLT850-2

[Graph showing engine parameters over time]
Flameout Test Point – Average Plane T/C’s Shown

Flameout Test point

Flameout

Non-uniform ice shed?

%N1, %N2, Cloud, %PLA, Temperature, Pressure

Load

Time

%N1
%N2
Cloud
PLA
Plane 1 AVG T/C
Plane 2 AVG T/C
Plane 3 Avg T/C
Plane 4 Avg T/C
Ps
Load
Repeat Flameout Test Point – Average Plane T/C’s Shown

Repeat of Flameout Test Point

More uniform ice shed?
Surge Test Point – Average Plane T/C’s Shown

Surge Test Point

%N1, %N2, Cloud, %PLA, Temperature, Pressure

Load

-Time

Surge?

Ice shed?
Reverse flow rivulet

Normal air flow direction

Rivulet flow direction

Rivulet