EASA De-Icing Fluid Tests on a Horizontal Stabilizer Section at the NRC Propulsion and Icing Wind Tunnel

Presented by Catherine Clark, P.Eng.
23 March 2015
NRC Aerospace – Reducing Aviation Icing Risks

Contributions from Marco Ruggi, Eng., APS Aviation Inc.

National Research Council Canada
Conseil national de recherches Canada

Agenda

DIFT Research Project Definition (1120h – 1200h)

- Project Summary (Background, Objectives, Participants, Timeline)
- Task T1 – Literature Review
- Task T2 – Model Design and Construction
- Task T3 – Development of Test Procedures
- Task T4 – Main Test Program (Set-up and Calibrations)
- Task T5 – Data Reduction

DIFT Research Project Results (1315h – 1400h)

- Task T4 – Main Test Program (Schedule)
- Task T5 – Data Analysis

De-Icing Fluid Tests
Research Project Definition

National Research Council Canada
Conseil national de recherches Canada

Project Summary

Project Summary
Background

- In recent years, a number of incidents have been reported where aircraft have had difficulty rotating during take-off after the application of thickened anti-icing fluids on the horizontal stabilizer.
- Similar incidents have occurred throughout Europe and North America and the appropriate aviation regulatory agencies are interested in identifying the cause of the problem and finding ways to mitigate it.
- EASA contracted the NRC in November 2013 to perform de/anti-icing fluid wind tunnel testing on a full-scale 2D horizontal stabilizer model

Project Summary
Background

- This presentation is the final deliverable to EASA from the NRC as outlined in the project contract (EASA.2013.C22)
- The presentation provides an overview of the project; further details are provided in a written report given to EASA
- A copy of the reduced data and videos from all the test runs has been provided to EASA

Project Summary
Objectives

Primary Objective:

- To understand the effects of anti-icing fluids on a horizontal stabilizer during take-off rotation.

This objective is achieved by simulating several types of take-off runs inside the NRC wind tunnel using a model representative of a horizontal stabilizer with anti-icing fluids applied to it.

Project Summary
Participants

National Research Council Canada

- Main contractor responsible for project under the NRC Aerospace Portfolio - Reduction in Aviation Icing Risk Program
- Main Contact: Catherine Clark, P.Eng., M.A.Sc.

APS Aviation

- Sub-contracted by NRC to provide their expertise in the development and execution of the research program
- Main Contact: Marco Ruggi, Eng. M.B.A.

Transport Canada Transportation Development Centre (TDC)

- Provided horizontal stabilizer that matched EASA specifications
- Main Contacts: Yvan Chabot / Antoine Lacroix / Howard Posluns

Project Summary
Timeline

Project divided into five (5) tasks

Task	Start Date	End Date
T1. Literature review and analysis	November 2013	January 2014
T2. Model design, construction and instrumentation	December 2013	October 2014
T3. Development of test program and procedure	May 2014	November 2014
T4. Testing phase	15 Dec. 2014	20 Dec. 2014
T5. Data reduction, analysis and reporting	January 2015	February 2015

Project Summary
Timeline

Project progress was also tracked using milestones

Milestone	Target Date	Completed
M1. Contract signed	T_o	21 November 2013
M2. General project meeting	T_o + 1 month	28 November 2013
M3. First progress review meeting	T_o + 2 months	23 January 2014
M4. Model geometry approval	T_o + 2 months	10 February 2014
M5. Delivery of interim report	T_o + 10 months	17 October 2014
M6. Second progress review meeting	T_o + 12 months	5 November 2014
M7. Presentation of project to SAE G12 AWG	Ongoing	Oct. 2013, April 2014, Oct. 2014
M8. Completion of test program	T_o + 13 months	20 December 2014
M9. Delivery of final report	T_o + 15 months	21 February 2015
M10. Presentation of results to EASA	-	23 March 2015

Task T1 - Literature Review

November 2013 – January 2014

Task T1 - Literature Review

Incidents of Elevator Control Restrictions at Take-Off

An incident occurred on 11 January 2010 at Helsinki/Vantaa Airport in Finland, involved a BAe ATP cargo aircraft.*

The aircraft underwent a two-step de-icing/anti-icing process to remove existing ice, frost and snow and prevent ice from re-forming on critical aircraft surfaces. All pre-flight checks were normal.

Excessive forces were required to pull back the control column. The pilot continued to pull the control column as far back as possible with no aircraft response, at which point the take-off was aborted and the aircraft taxied back to the hanger.

Other incidents with similar circumstances have been identified through a search of aircraft incident databases and were identified in an earlier presentation.

*Swedish Accident Investigation Board. (2011). *Final report RL 2011:16e. Serious incident to aircraft SE-MAP at Helsinki/Vantaa Airport in Finland, on 11 January 2010.*

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Task T1 - Literature Review
Common Factors

- All aircraft had been de-iced in preparation for flight using Type II or Type IV anti-icing fluid
- All incidents took place during winter conditions
- Aircraft weight and balance were within acceptable limits
- No technical/mechanical faults could be identified in the aircraft
- Full elevator travel had been confirmed in rudder checks before and after incidents

Task T1 - Literature Review

Common Factors

- Turboprop aircraft with unpowered flight controls (low rotation speed, direct feel of difficulties unlike powered flight controls)
- Problems arose at speeds around rotation speed (V_R)
- Elevator movement was restricted and/or felt very stiff to maneuver in connection with takeoff rotation
- Incidents were often accompanied by ‘Standby Controls’ and/or ‘Split’ warnings

Task T1 - Literature Review

Preliminary Research into Contributing Factors

The Swedish Accident Investigation Board study concluded that the following factors may have contributed to the elevator restriction incidents on take-off:

- Residual deicing fluid of Type II or IV
- Average elevator clearance below permitted minimum for aircraft type
- Unknown impact of propeller slipstream
- Remnant of fluid in the hinge gap, where the polymers probably have not been fully affected by the airflow's shear forces
- Altered or restricted flow of air through the gap
- Altered aerodynamic pressure conditions around horizontal stabilizer

Task T2 – Model Design and Construction

December 2013 – October 2014

Task T2 – Model Design and Construction

Model Geometry

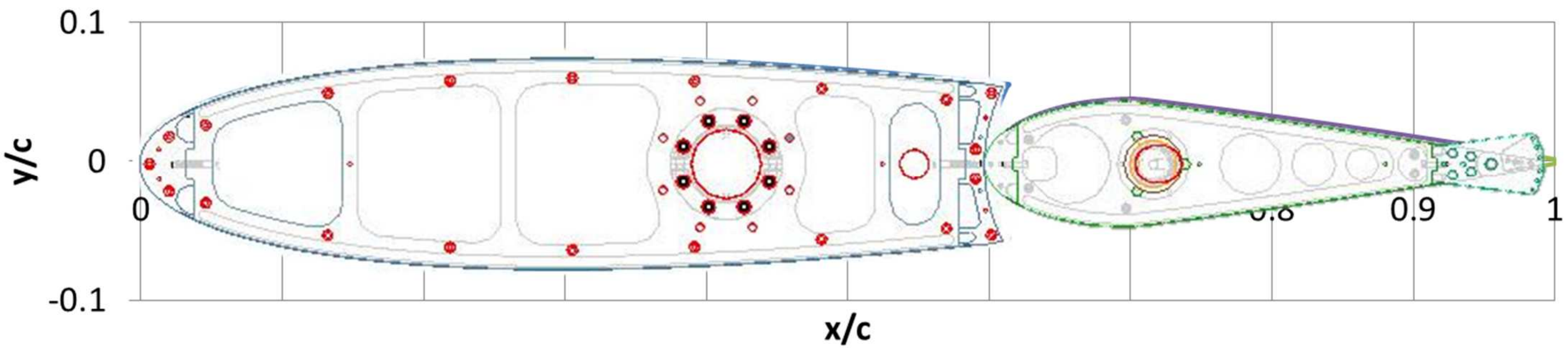
The model geometry and functionality is based on guidelines from the literature review, EASA tender specifications, and information supplied by aircraft manufacturers.

The final model design does not match any existing aircraft tail geometry exactly, but it is similar to appropriate aircraft in terms of size, profile and non-dimensional parameters.

Task T2 – Model Design and Construction

Model Geometry

- NACA 0015 airfoil profile
- c_{HS} = 1.82 m (6 ft)
- c_E/c_{HS} = 0.4
- c_{TT}/c_{HS} = 0.05
- Elevator capable of deflecting ±25°



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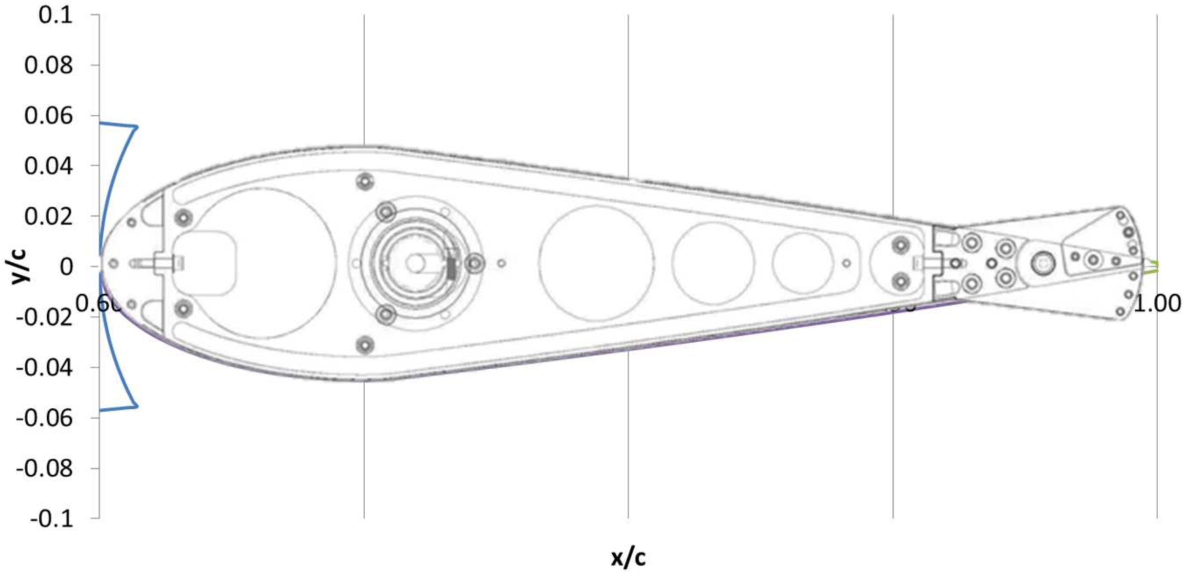
Task T2 – Model Design and Construction

Model Geometry

- Elevator pivot point at $0.3c_E$ measured from the elevator leading edge
- Circular profiles on trailing edge of main element, trailing edge of elevator, and leading edge of trim tab
- Elliptical leading edge profile on elevator



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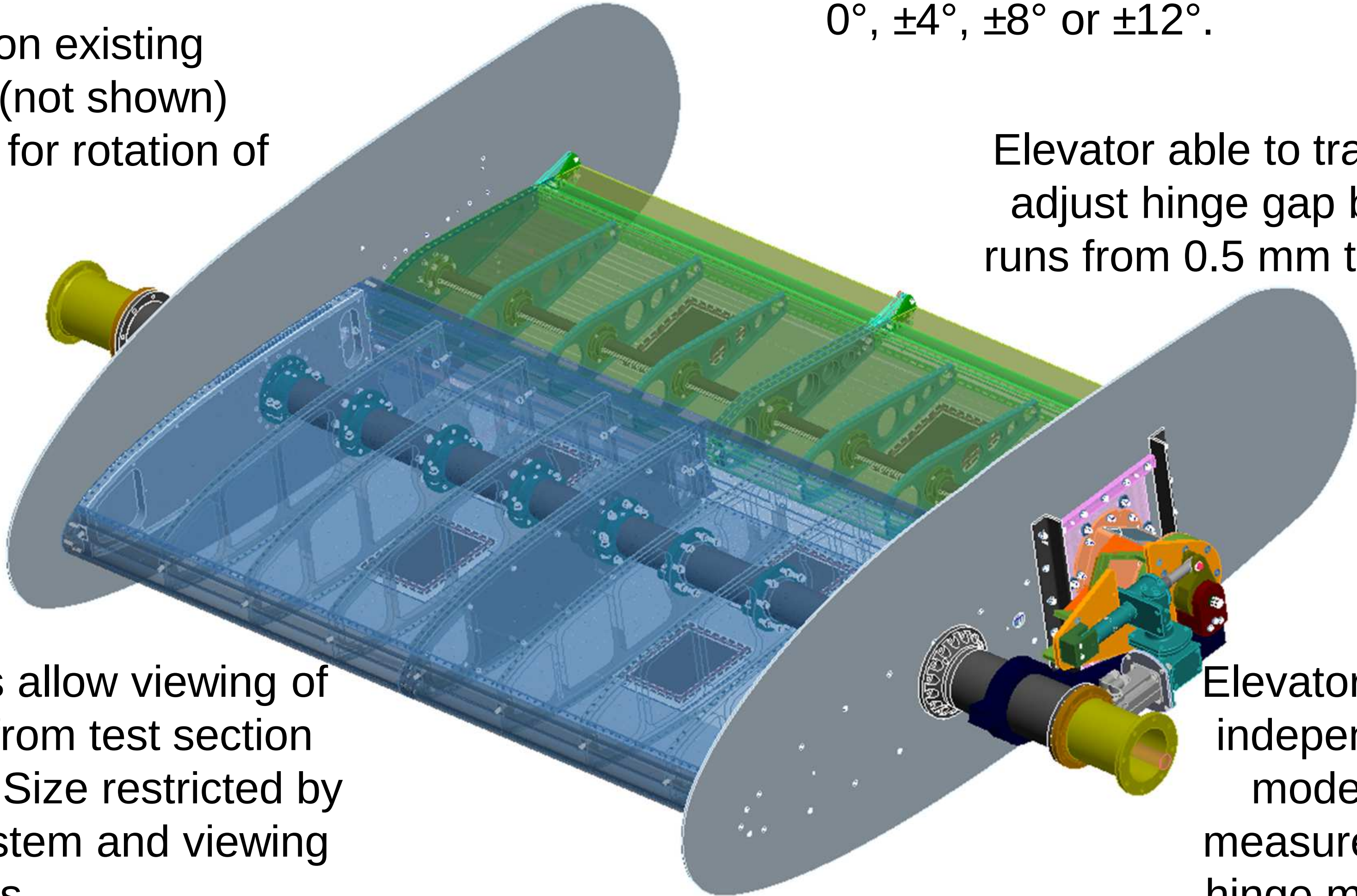
Task T2 – Model Design and Construction
Model Detailed Design

Trim tab can be manually set to 0°, ±4°, ±8° or ±12°.

Mounted on existing balances (not shown) that allow for rotation of model.

Elevator able to translate to adjust hinge gap between runs from 0.5 mm to 10 mm.

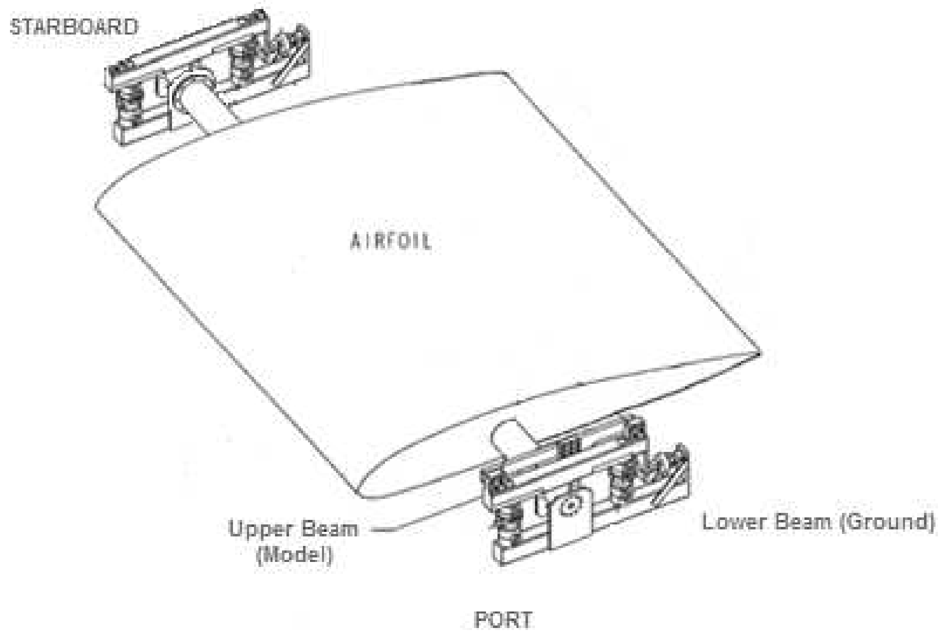


Endplates allow viewing of surfaces from test section windows. Size restricted by gantry system and viewing constraints.

Elevator rotation independent of model, with measurement of hinge moments.

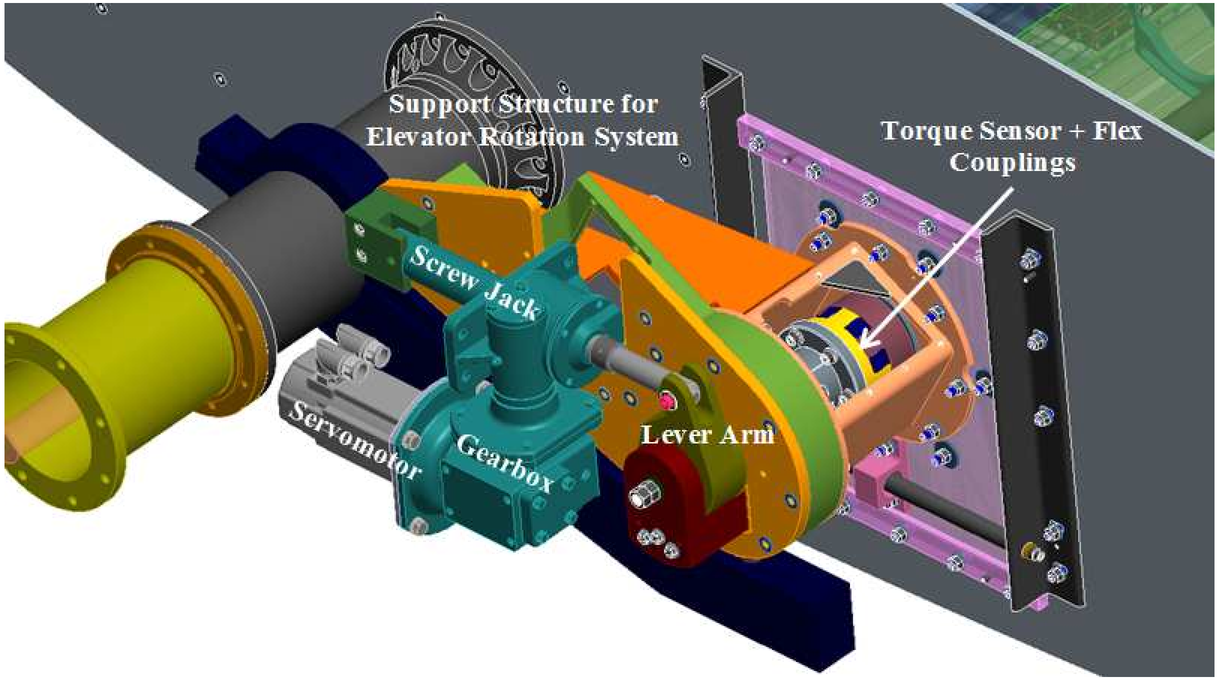
Task T2 – Model Design and Construction
Side-Wall External Balances

- External balances measure the aerodynamic loads on the model (lift, drag and pitching moment)
- Port balance is connected to a motor and gearbox that controls the model pitch angle
- Starboard balance rotates freely on a bearing



Task T2 – Model Design and Construction
Elevator Rotation

- Servomotor drives a screwjack and lever arm to rotate elevator from the port side while starboard side rotates freely (±25°)
- Maximum deflection rate of 5.5°/s
- Elevator hinge moment measured using torque sensor



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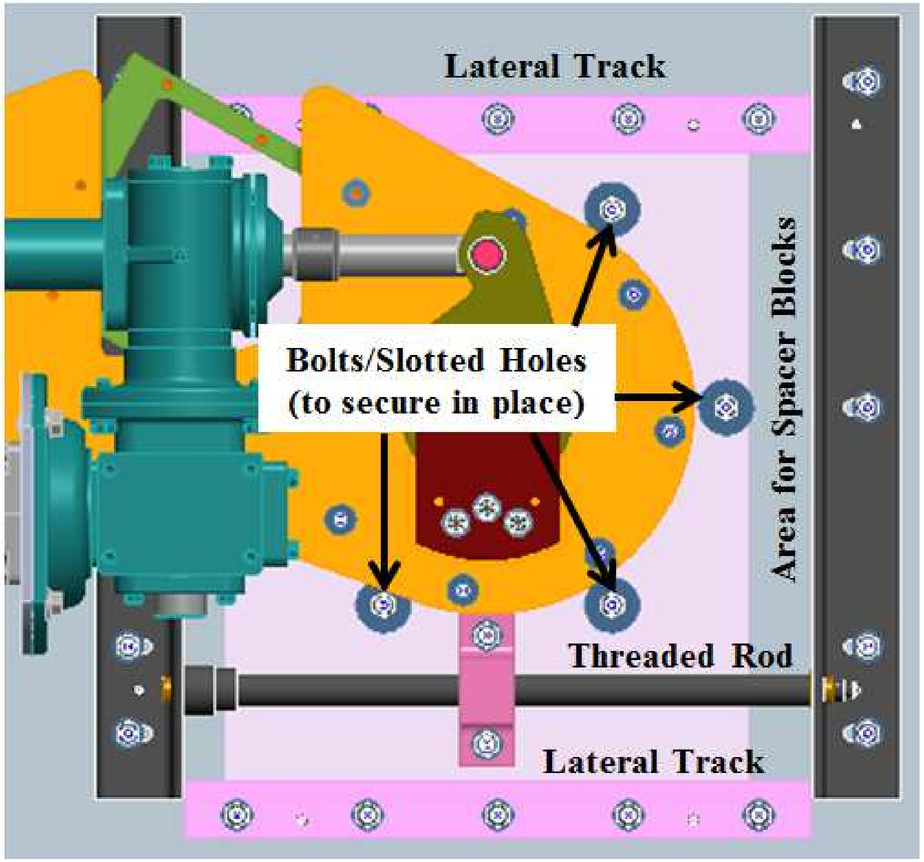
Task T2 – Model Design and Construction

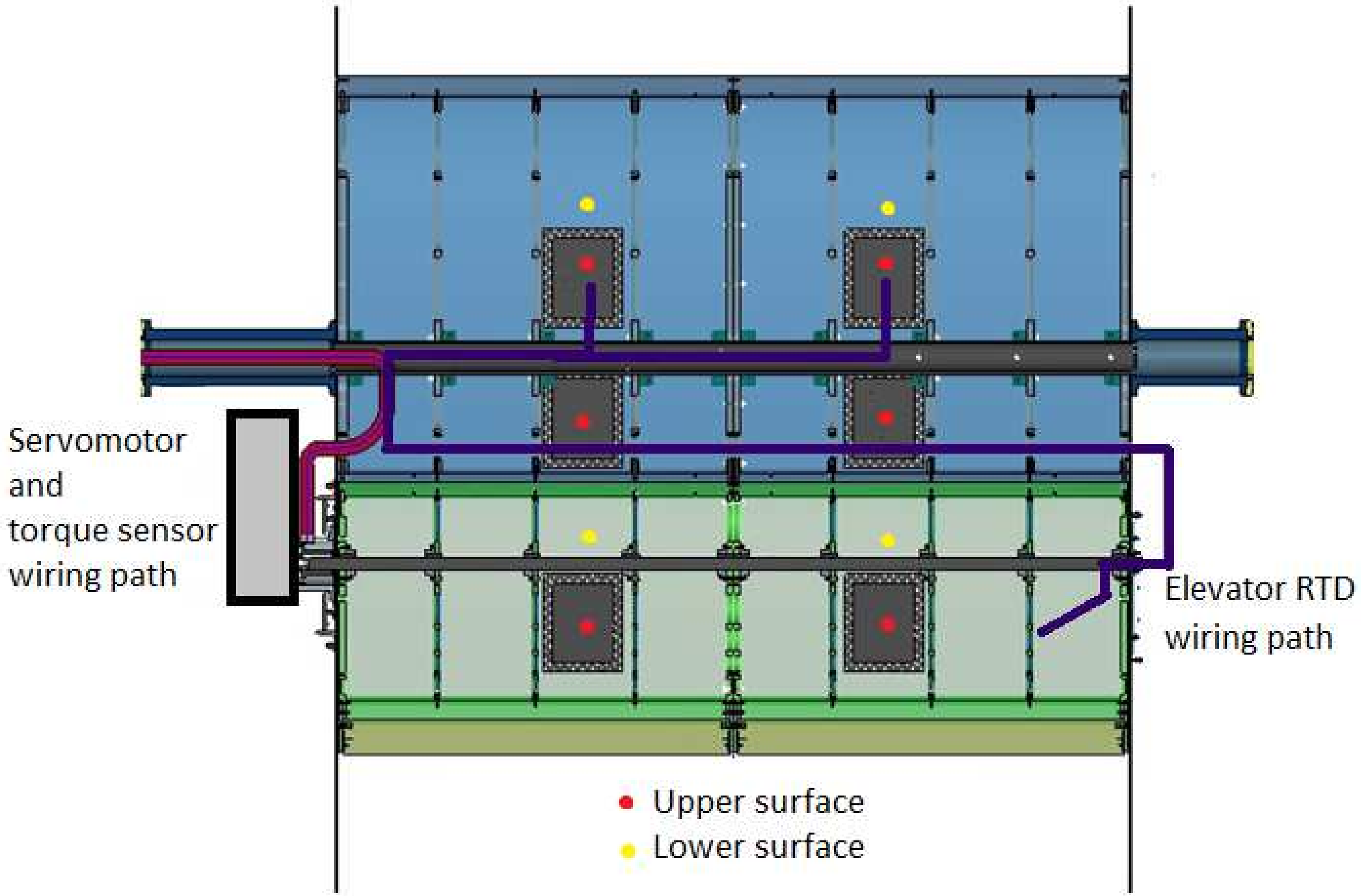
Elevator Translation

- Threaded rod on each side of model used to move position of elevator
- Position is set using measured spacer blocks
- Once in place, position is secured using screws



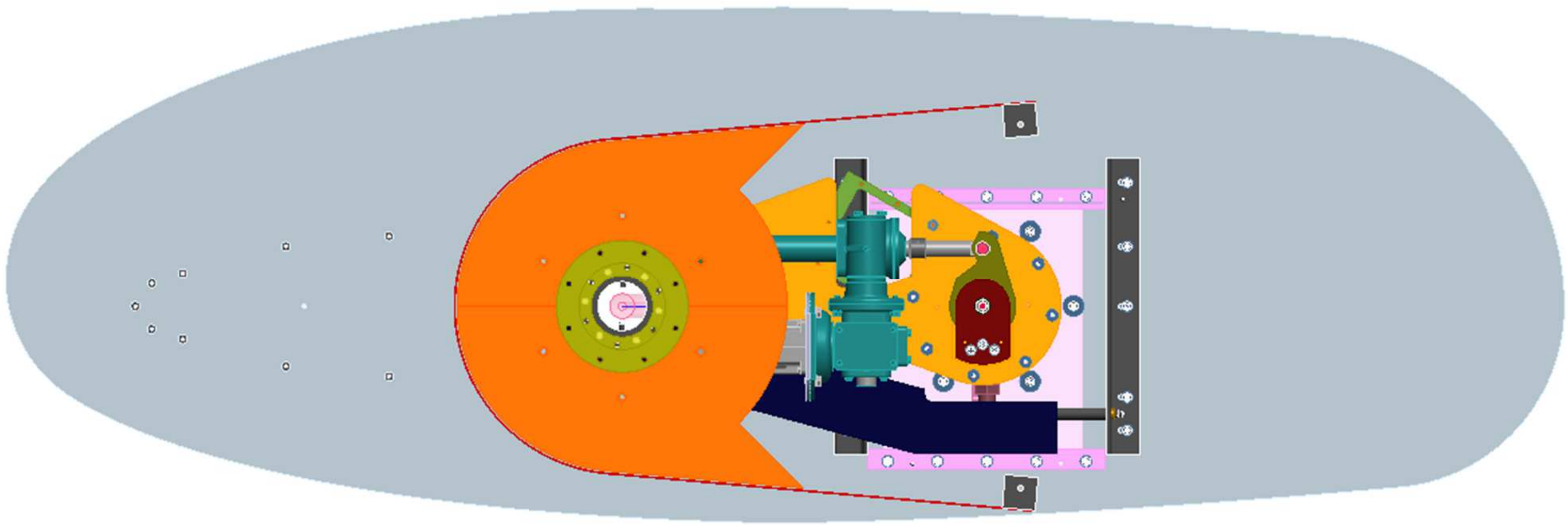
Task T2 – Model Design and Construction
Temperature Measurements

- Ten RTDs installed inside the model measure the surface temperatures



Task T2 – Model Design and Construction
Aerodynamic Fairings

- Fairings are symmetric on port and starboard sides of model
- Cover the elevator traverse and rotation assemblies, and shafts that connect them to the balances
- Designed to remove aerodynamic load from these components



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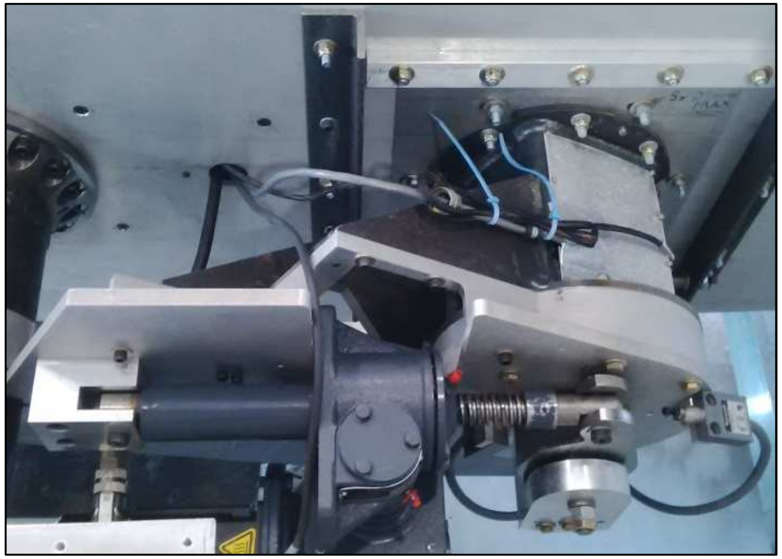
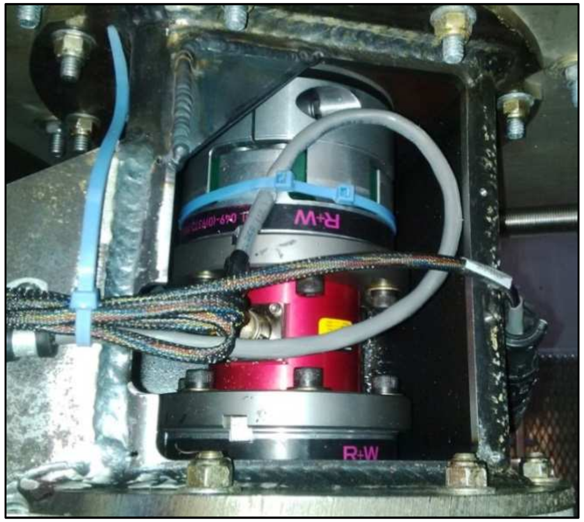
Task T2 – Model Design and Construction

Manufacturing – Main Element and Elevator

Task T2 – Model Design and Construction
Manufacturing – Elevator Traverse and Rotation System





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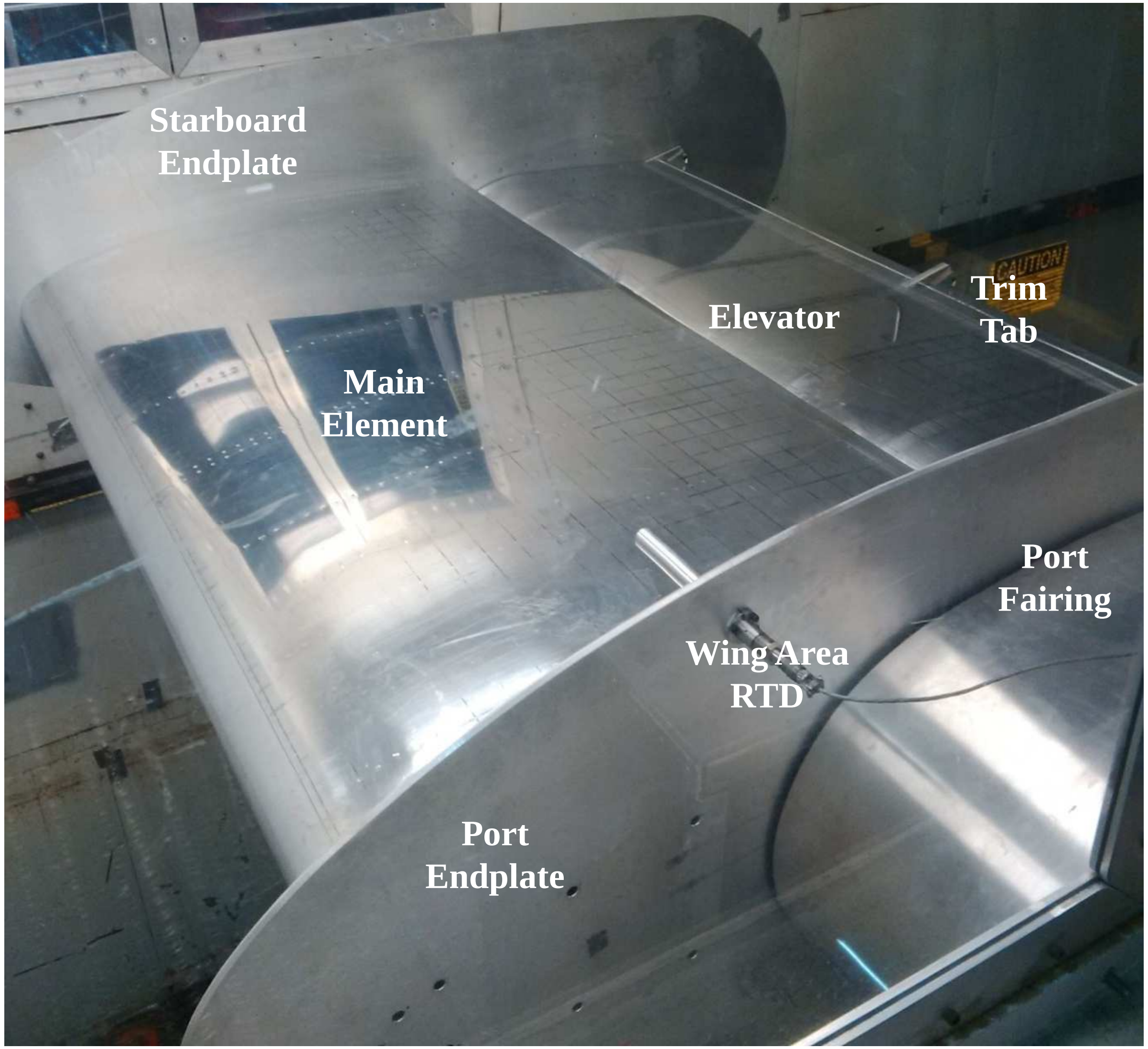
Task T2 – Model Design and Construction
Manufacturing



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Task T3 – Development of Test Procedures

May 2014 – November 2014

Task T3 – Development of Test Procedures

Take-off Elevator Deflection Profiles

Multiple elevator deflection profiles were considered and tested in order to determine the conditions where the fluids may have the most adverse influence on the aircraft rotation.

The elevator deflection is positive for trailing-edge down.

Task T3 – Development of Test Procedures

Wind Tunnel Acceleration Profiles

Wind Tunnel Acceleration Profiles

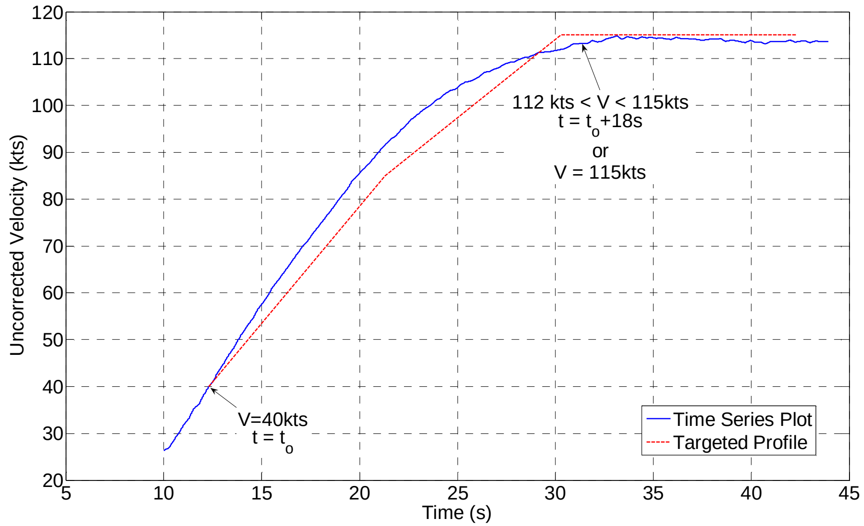
- Fluid is not significantly affected by shear forces at low speeds
- The ramp of the wind tunnel isn't linear below 40 kts
- For these reasons, the timing for each take-off profile is triggered when V = 40 kts and the data below that speed is discarded

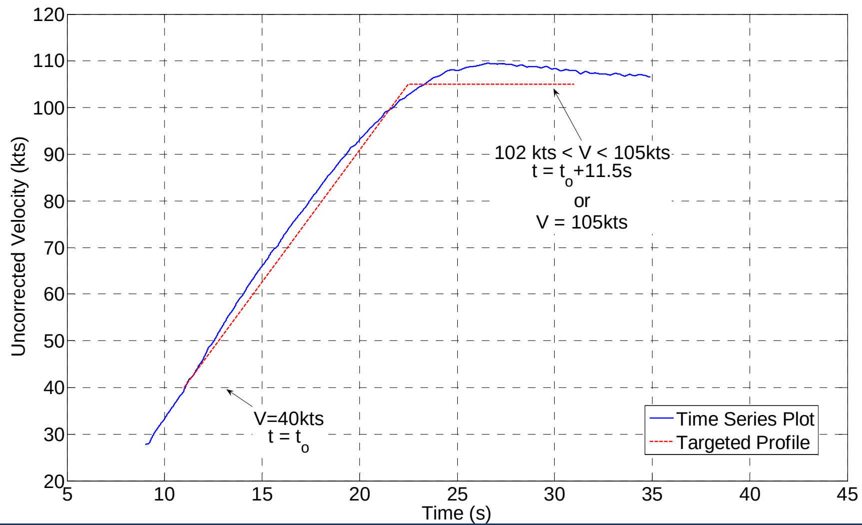
Task T3 – Development of Test Procedures

Wind Tunnel Acceleration Profiles

Wind Tunnel Acceleration Profiles

- 105 kts and 115 kts rotation speed acceleration profiles
- Rotation trigger for elevator main rotation is based on both time and speed





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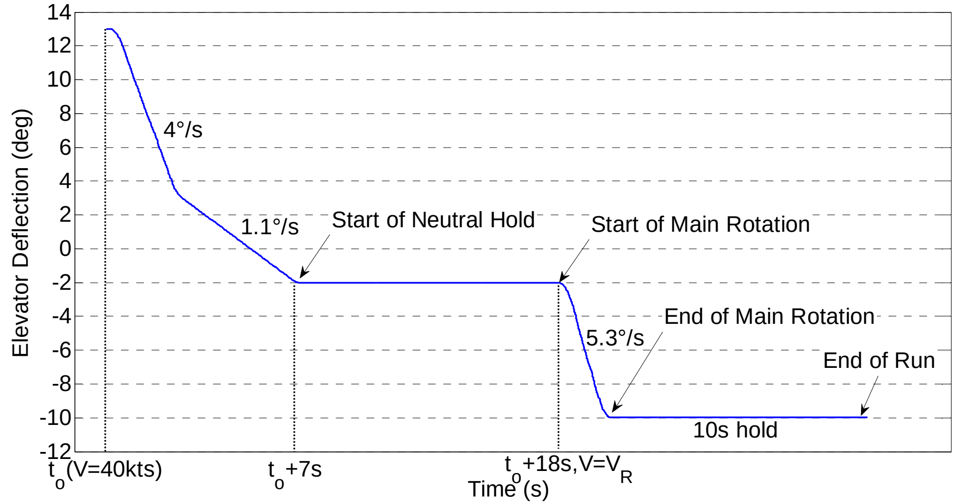
Task T3 – Development of Test Procedures

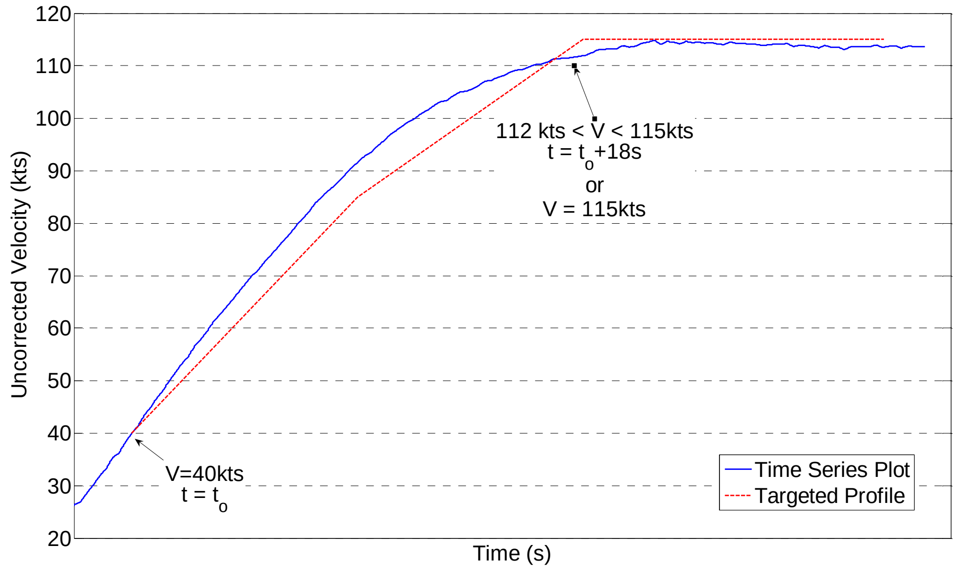
Take-off Elevator Deflection Profiles

Scenario 1

Heavy aircraft at maximum take-off weight with a center of gravity forward of its maximum permitted position.

The horizontal stabilizer needs to generate a high value of negative lift in order to rotate the aircraft.



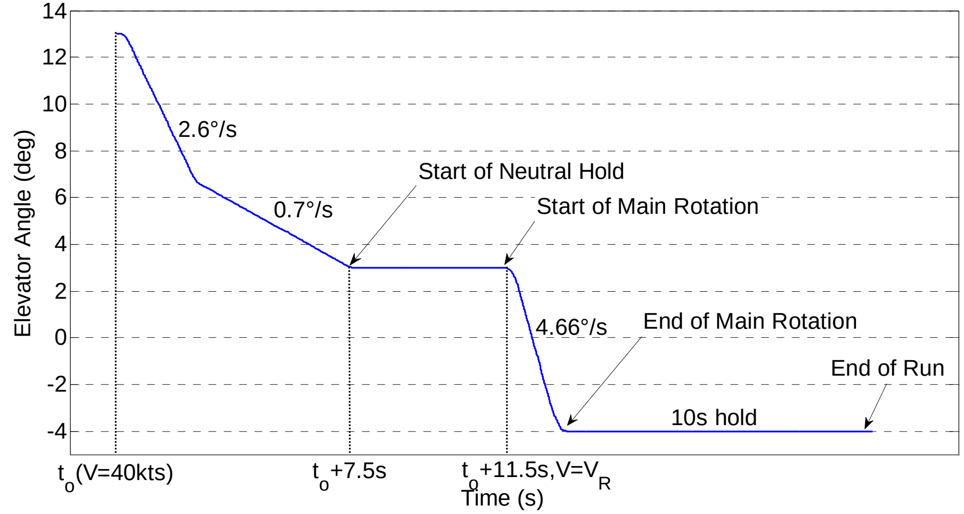


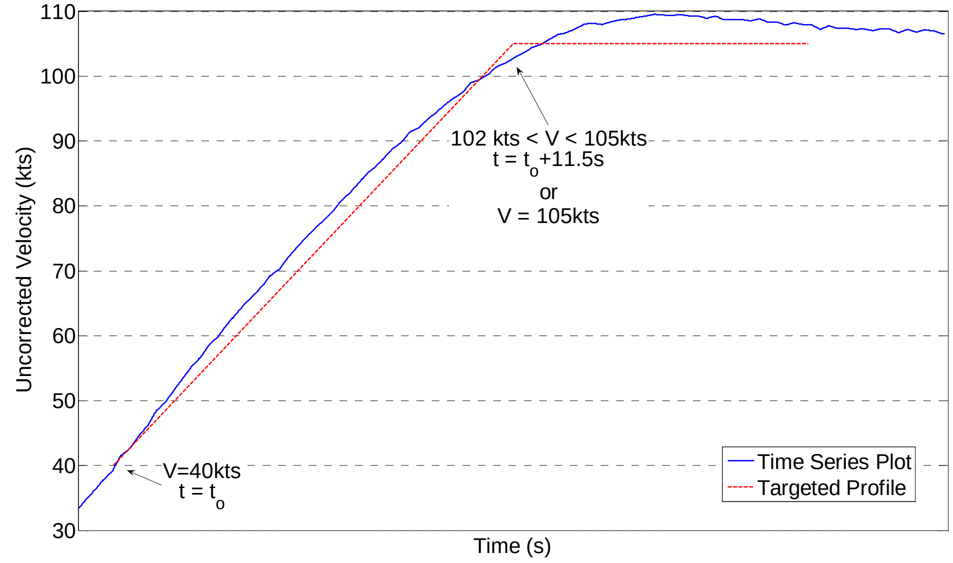
Take-off Elevator Deflection Profiles

Scenario 2

Light aircraft with a center of gravity towards the back, within permitted limits.

The aircraft accelerates quickly and there is minimal time for the fluids to shear off the horizontal stabilizer.

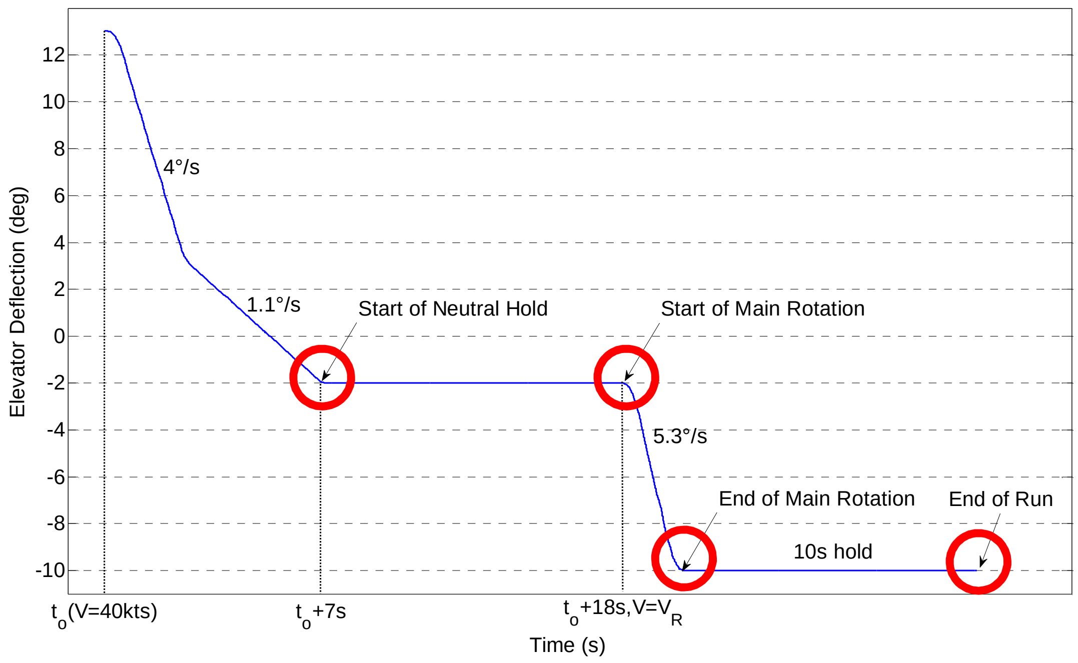




Task T3 – Development of Test Procedures
Evaluation Criteria

Control Law Evaluation Points:

- Point 1 - Start of neutral hold
- Point 2 - Start of main rotation
- Point 3 - End of main rotation
- Point 4 - End of run



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Task T3 – Development of Test Procedures

Evaluation Criteria

Column Force Evaluation Criteria

- Establish the elevator hinge moment (C_h) generated by the dry horizontal stabilizer during a wind tunnel run.
- For the wet horizontal stabilizer cases outlined in the test plan, perform runs using the same velocity profile, acceleration profile and elevator deflection law as the dry case.
- Compare C_h for the wet and dry cases at the identified evaluation points. A 50% increase in C_h for high speeds ($V > 0.7V_{max}$) is considered a *positive* case, fulfilling the control force evaluation criteria.

Task T3 – Development of Test Procedures

Evaluation Criteria

Elevator Effectiveness Evaluation Criteria

- Establish the downwards force (C_l) generated by the dry horizontal stabilizer during a wind tunnel run.
- For the wet horizontal stabilizer cases outlined in the test plan, perform runs using the same velocity profile, acceleration profile and elevator deflection law as the dry case.
- Compare C_l for the wet and dry cases at the identified evaluation points. A 10% decrease in C_l for high speeds ($V > 0.7V_{max}$) is considered a *positive* case, fulfilling the elevator effectiveness evaluation criteria.

Task T3 – Development of Test Procedures

Evaluation Criteria

The +50% C_h and -10% C_l criterion were best-guess estimates on the actual increase in hinge moment and elevator lift reduction experienced by pilots and were agreed upon by EASA with support from the NRC, APS, TC and NASA.

Task T3 – Development of Test Procedures

Testing Methodology

Phase 1: Establish Evaluation Criteria

Perform dry horizontal stabilizer runs to measure the baseline aerodynamic performance of the model that will be used to calculate the column force and elevator effectiveness evaluation criteria.

Phase 2: Identify Contributing Variables

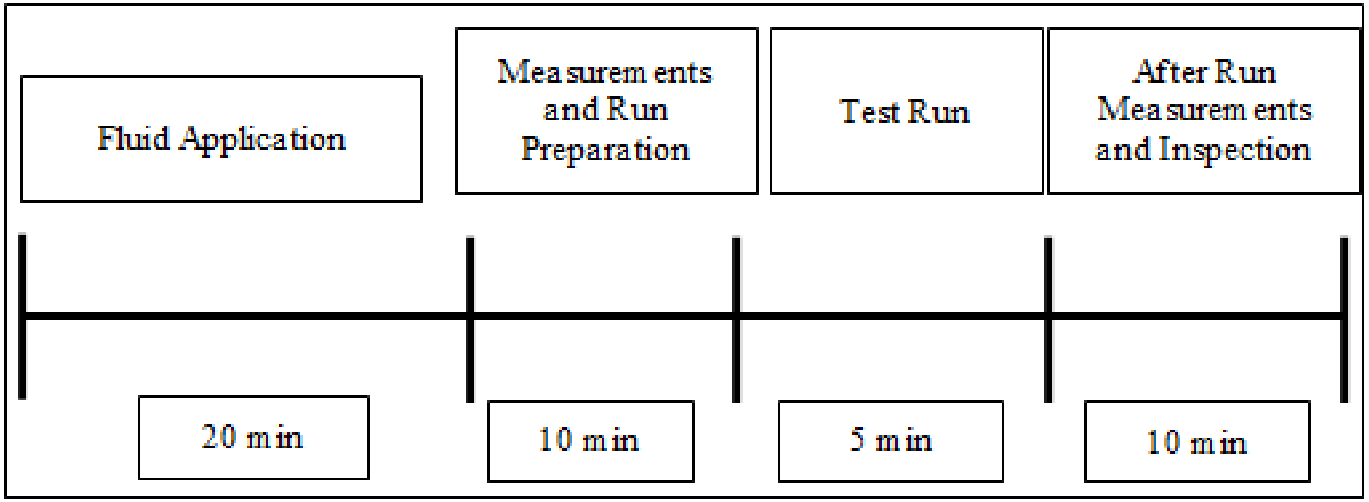
Attempt to reproduce rotation difficulties based on conditions identified in the literature survey with thickened anti-icing fluid. Systematically vary stabilizer-elevator gap, outdoor air temperature, fluid type, take-off law and control column applied-force law to identify variables that contribute to rotation difficulties.

Phase 3: Attempt to Rectify Rotation Difficulties

Repeat conditions that led to rotation difficulties with variations to parameters that may help rectify the issues.

Task T3 – Development of Test Procedures
Test Procedures

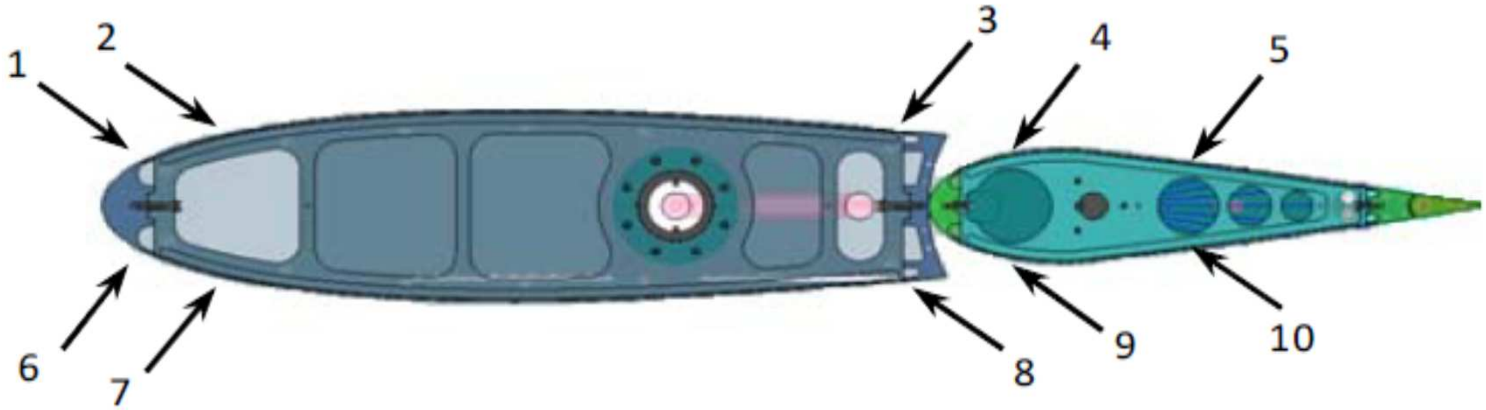
Order of Operations for a Typical Test Run:



Task T3 – Development of Test Procedures
Test Procedures

The fluids were poured, rather than sprayed, on the model so that the application process would not apply a shear stress to the fluid and potentially change its viscosity. This methodology was appropriate given the relatively small surface area of the model and the goal of minimizing the amount of fluid flowing off it.

The locations of the fluid thickness, brix, and skin temperature are shown below.



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Task T3 – Development of Test Procedures

Fluid Selection

- Fluid selection was based upon a review of relevant information available from incident reports and holdover time guidelines.
- Some fluids identified in the incident reports are no longer commercially available, in which case newer generations of the same or similar fluids were selected.
- A 50/50 diluted Type IV fluid was selected as a substitute for the Type III fluids identified from accident reports, as it has the appropriate low viscosity.

Fluid	Dilution	Measured Viscosity (mPa-s)	Comment
IV-A75	75/25	36,000	Highest viscosity
IV-L	100/0	15,760	
II-F	100/0	13,600	
III-P50	50/50	5,320	Lowest viscosity
I	60/40	n/a	

Task T4 – Main Test Program

December 2014

Task T4 – Main Test Program
Facility Description

- Propulsion and Icing Wind Tunnel is located at the NRC Montreal Road Campus in Ottawa, ON, Canada
- Open-circuit wind tunnel, naturally cold in winter months
- Insert reduces test section height from 6m to 5m, allowing for a top speed of 115kts
- NRC Aerodynamics Laboratory is ISO 9001:2008 certified


Task T4 – Main Test Program
Facility Description

- Collection system in diffuser allows testing with glycol fluids
- Gantry system allows access to model in the test section using ladders and the doors on the third floor of the building
- Viewing platform provides safe and stable visual access to model

Task T4 – Main Test Program

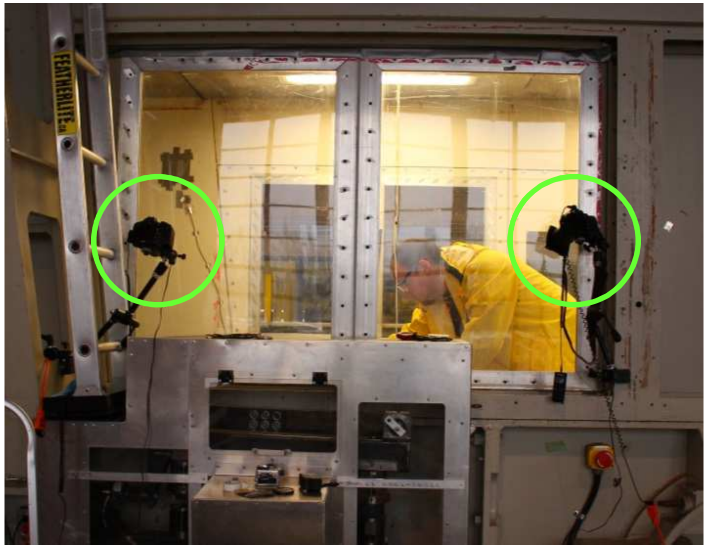
Facility Description

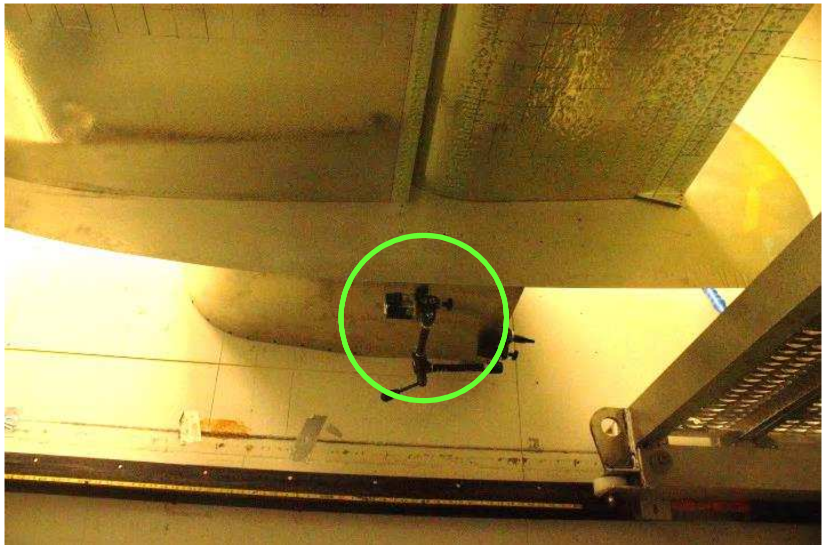
- There are two roof-mounted cameras and one floor-mounted camera with pan, tilt and zoom capability used to record the fluid flow-off the upper surface of the model for each run

Task T4 – Main Test Program
Camera Positions

- Observation windows on either side of the test section were used to capture the flow using Canon DSLR cameras for second-by-second photography and wide-angle filming of model

- A GoPro camera was mounted under the model near the elevator hinge line and was used for wide-angle filming of fluid-flow off during the test runs





Task T4 – Main Test Program
Calibrations

- In accordance with NRC quality control system, all required instrumentation was calibrated appropriately (pressure transducers, temperature sensors, torque sensor, load cells)

- Test section calibration completed by placing a pitot-static probe in the centre of the empty test section and measuring the probe and wind tunnel pressures at a number of different fan speeds

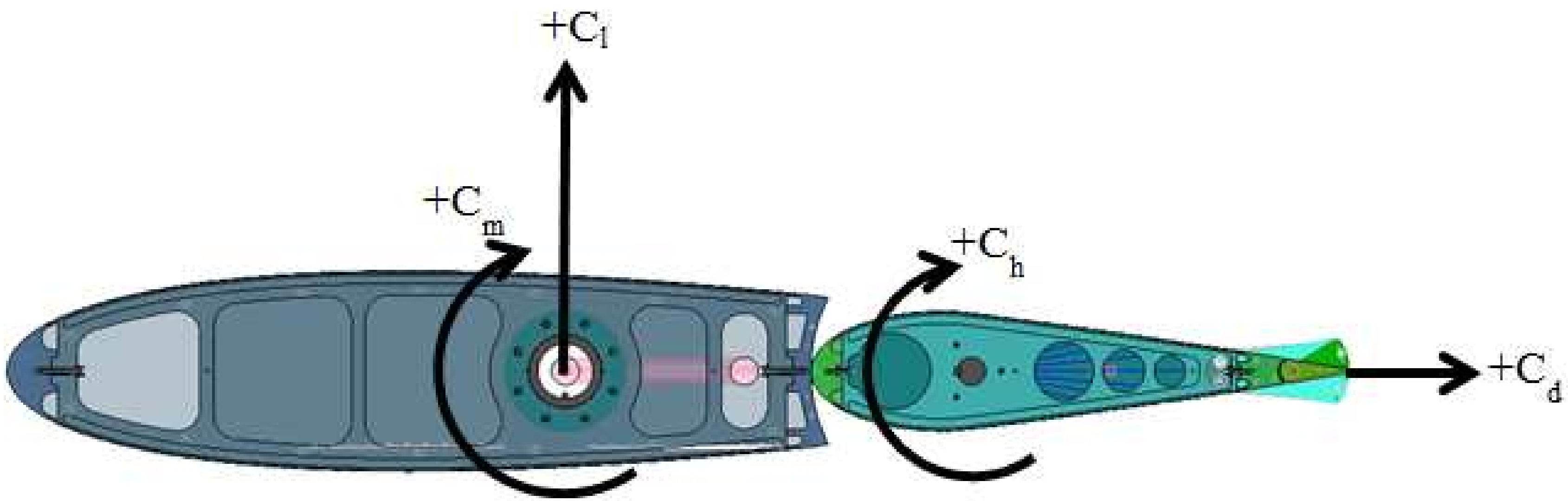
- External balances were calibration in-situ using a balance calibration rig loaded with dead weights

- The torque sensor was calibrated by the manufacturer and this calibration was verified after installation using dead weights

Task T5 – Data Reduction

December 2014

Task T5 – Data Reduction
Sign Conventions



Task T5 – Data Reduction

Calculation of Aerodynamic Parameters

Dynamic pressure and velocity calculations:

$$M = \sqrt{5\left(\frac{P_{T,TS}}{P_{S,TS}}\right)^{\frac{2}{7}} - 1}$$

$$q = 0.7 P_{S,TS}\ M^2 * 1000 \quad [\text{Pa}]$$

$$\rho = 1.225\left(\frac{P_{S,TS}}{101325}\right)\left(\frac{288.15}{T_{TS}}\right) \quad [\text{kg/m}^3]$$

$$V_u = \sqrt{\frac{2q}{\rho}} \quad [\text{m/s}]$$

Task T5 – Data Reduction

Calculation of Aerodynamic Parameters

Lift, drag and pitching moment coefficient calculations:

$$C_l = \frac{L}{\frac{1}{2}\rho V^2 A} \qquad C_d = \frac{D}{\frac{1}{2}\rho V^2 A} \qquad C_m = \frac{PM}{\frac{1}{2}\rho V^2 A\, c_e}$$

Elevator hinge moment coefficient calculation:

$$C_h = \frac{H_e}{\frac{1}{2}\rho V^2 S_e c_e}$$

Task T5 – Data Reduction
Blockage Corrections

- NRC uses a Matlab program developed in-house to reduce the data files into engineering units and aerodynamic coefficients

- This data reduction program includes the standard two-dimensional wind tunnel corrections for solid blockage, wake blockage and streamline curvature

End of Morning Presentation

Coming up after the lunch break:

- Main test program overview
- Video and time series data analysis and interpretation
- Analysis of data
- Summary and recommendations

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