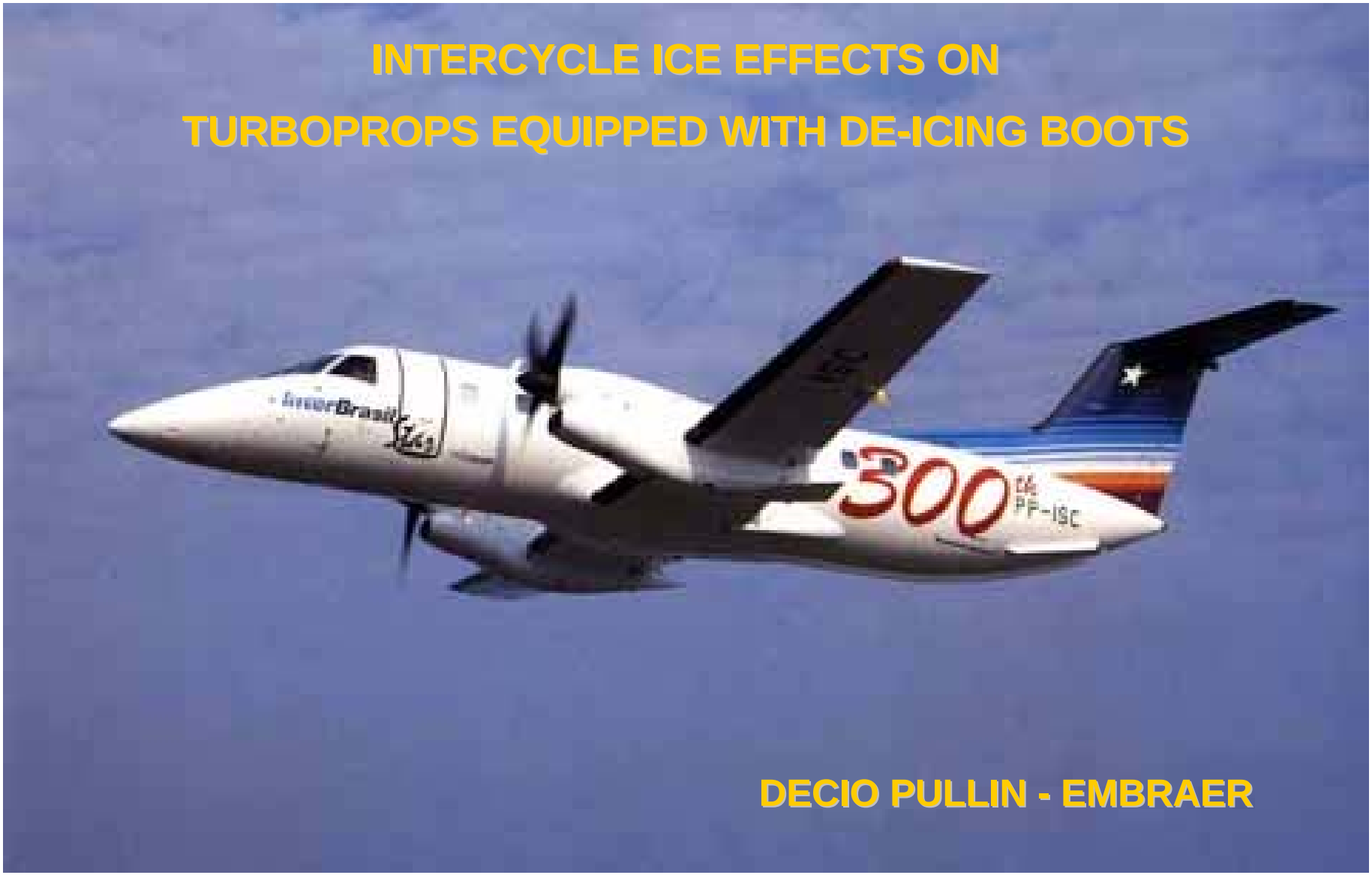
INTERCYCLE ICE EFFECTS ON TURBOPROPS EQUIPPED WITH DE-ICING BOOTS



DECIO PULLIN - EMBRAER

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Intercycle Ice Effects

CONTENTS

- Introduction
- Icing Tunnel Tests
- Ice Shapes Determination
- Flight Tests Preparations
- Flight Tests Results
- Impacts on the AFM
- Conclusions

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

INTRODUCTION

- **Following the Flight 3272 loss of January 9, 1997 near Monroe, Michigan, the FAA initiated research into the thin layers of rough ice and similar icing that may accumulate between de-ice boot cycles (Intercycle ice) and their effects on aircraft performance.**

- **After several discussions, Embraer agreed to a collaborative icing research program with the FAA.**

- **Icing Tunnel tests were performed with a Hybrid model to obtain Intercycle Ice Shapes.**

- **Simulated Ice Shapes were produced and installed on an EMB-120 prototype airplane and their effects on aircraft performance were measured.**

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Icing Tunnel Tests

- **The Icing Tunnel Tests were performed at the BF Goodrich Icing Tunnel located in Uniontown, OH, USA**

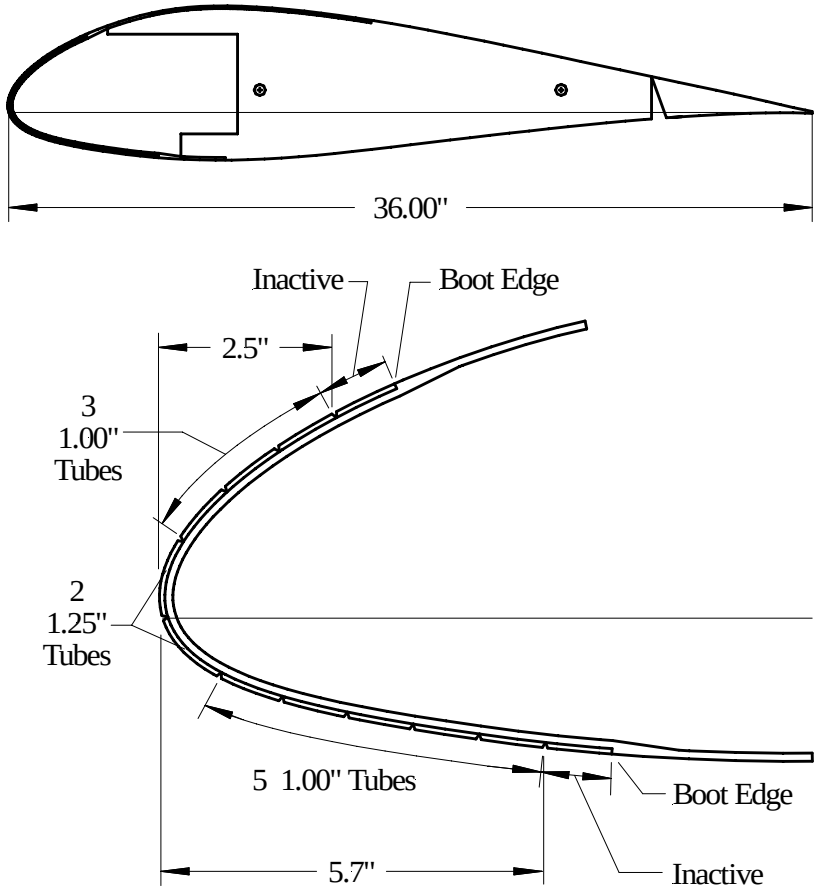
- **A “Hybrid” 2D wing tip NACA 23012 airfoil was produced using the same leading edge boots as the full scale aircraft.**

- **Several Appendix C icing envelope corner points were simulated with boot cycles of 1 and 3 minutes actuation timer.**

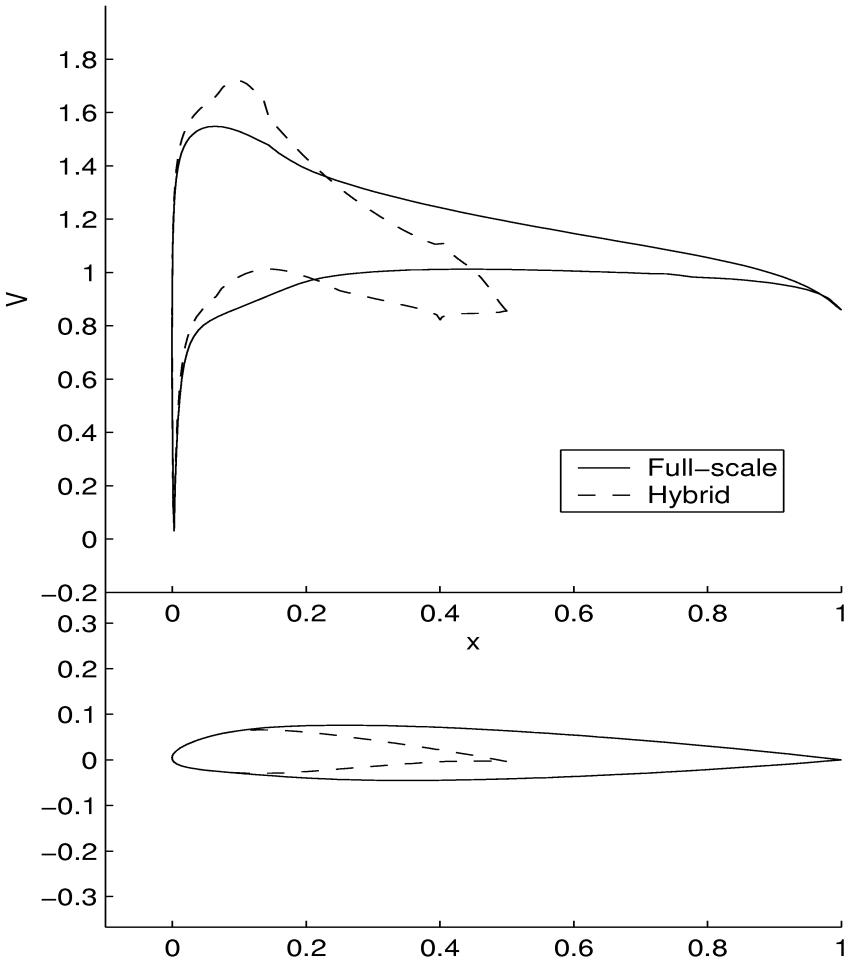
- **The most critical ice shape was selected (run 5/6 or 4/1) which represented a 3 minute boot cycle in the continuous maximum icing cloud**

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Icing Tunnel Tests



Hybrid Airfoil Construction



Full-scale and hybrid airfoil velocity distributions at 4° angle-of-attack, 2° flap setting, and 12.8 x 106 Reynolds number.

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

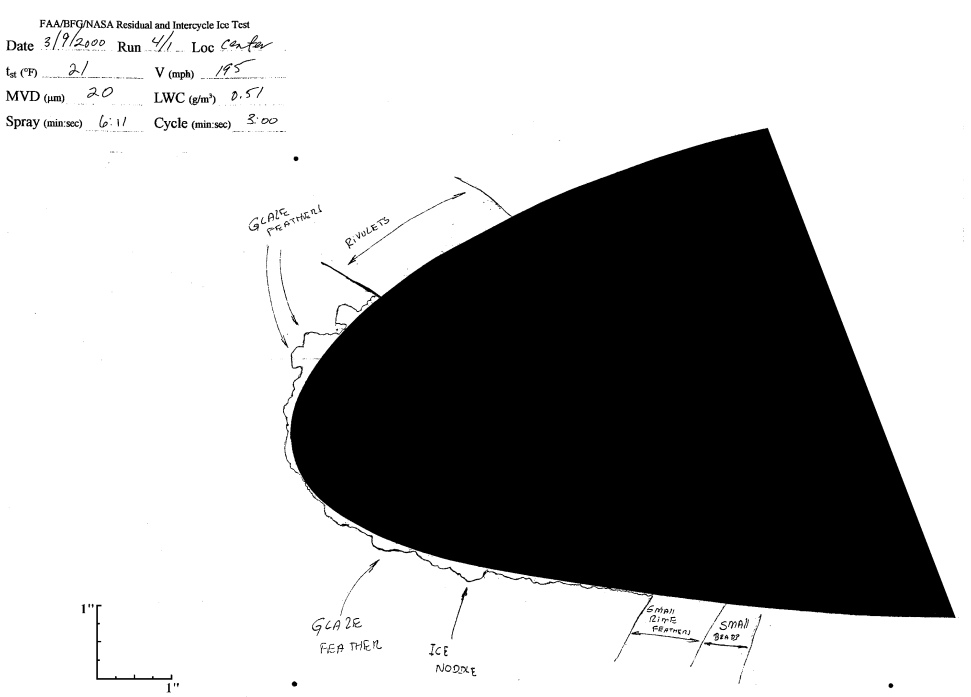
Icing Tunnel Tests

HYBRID MODEL INSTALLED IN THE BF GOODRICH TUNNEL

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Icing Tunnel Tests

Runs 5/6 and 4/1 were equivalent. There was no trace for run 5/6, only mold



Run 5/6 picture: Tstat = 21 F
MVD = 20; LWC = 0.51
3 min. cycle; AOA = 4 deg

Run 4/1 Trace: Tstat = 21 F
MVD = 20; LWC = 0.51
3 min. cycle; AOA = 4 deg

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Ice Shapes Determination

SIMULATED ICE SHAPE (Left side of pictures) VS FAA MOLDS
(Run 5/6 - UPPER SURFACE)

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Ice Shapes Determination

SIMULATED ICE SHAPE (Left side of pictures) VS FAA MOLDS
(Run 5/6 - LOWER SURFACE)

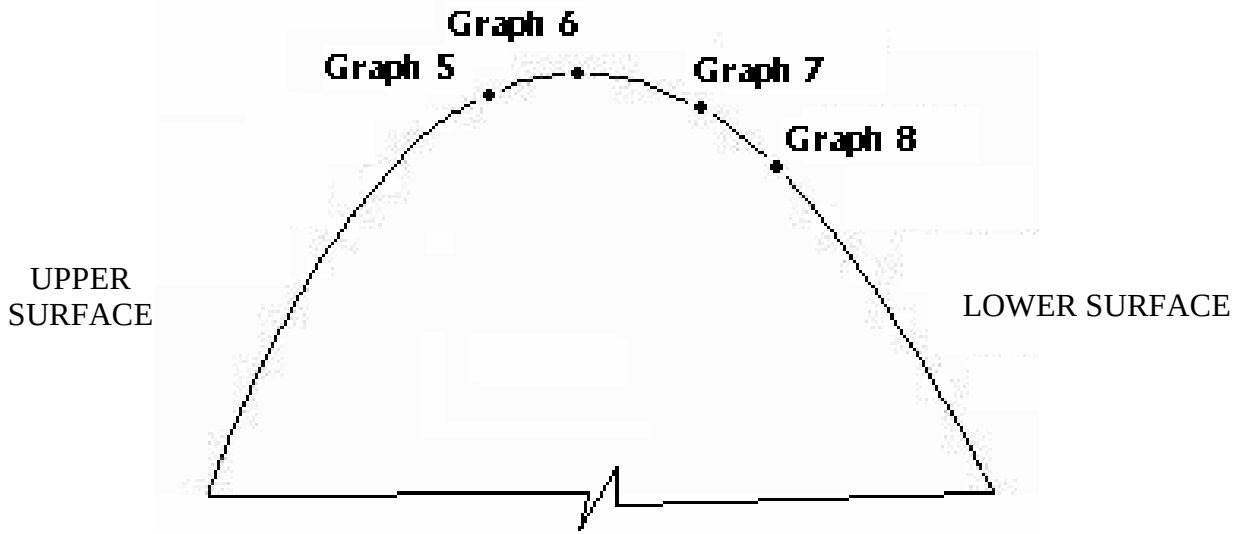
THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Ice Shapes Determination

➢EMBRAER PRODUCED 3 MODELS TO VERIFY SIMULATED ICE SHAPE ROUGHNESS.

➢THE ROUGHNESS OF THE SIMULATED ICE WAS DEFINED THROUGH THE COMPARISON OF ROUGHNESS MEASUREMENTS OF THE FAA/BFG/NASA INTERCYCLE AND RESIDUAL ICE TESTS (RUN 5/6) USING MOLD, AND ROUGHNESS MEASUREMENTS OF THE EMBRAER MANUFACTURED SIMULATED ICE SHAPES.

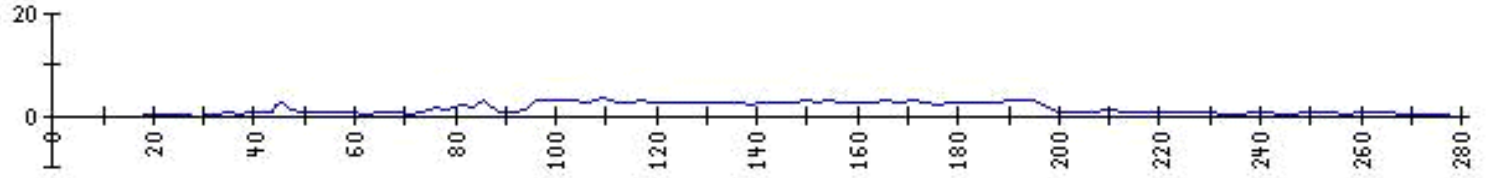
➢THE GRAPHS OF THE ROUGHNESS WERE THE RESULTS OF SPANWISE MEASUREMENTS AT THE POINTS DEFINED IN THE FIGURE BELOW.



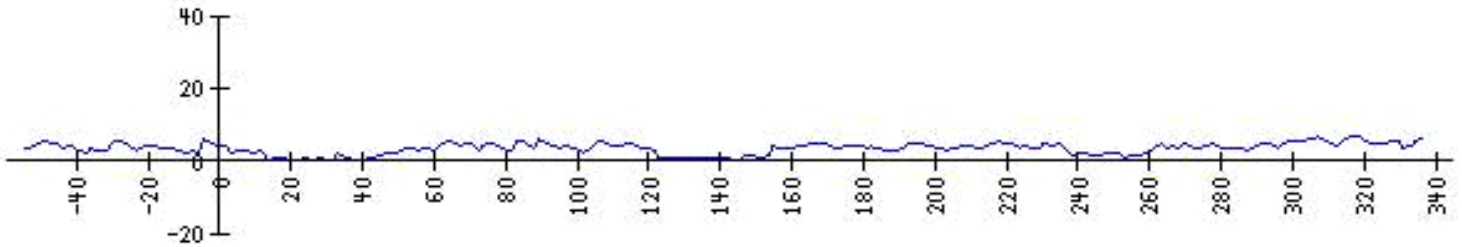
THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Ice Shapes Determination

➢ **ROUGHNESS COMPARISION RESULTS (Example)**



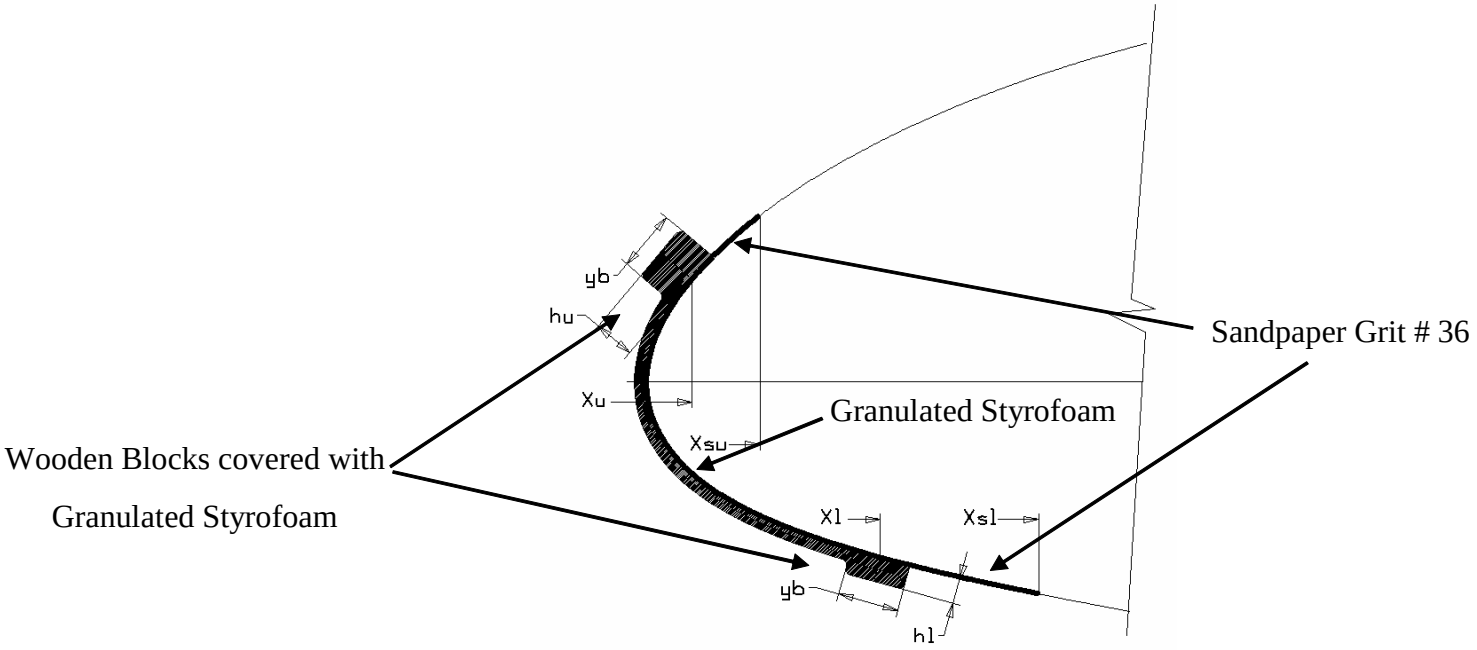
➢GRAPH 7 – FAA MOLD



➢GRAPH 7 – EMBRAER MOLD

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Ice Shapes Determination



EMB-120 SIMULATED ICE SHAPES KEY DIMENSIONS

- THE ICE IMPINGEMENT LIMITS AND BETA ON THE WING REFERENCE 5 FEET CHORD SECTION WERE DEFINED BY MEANS OF THE ONERA ICING CODE

- FOR OTHER WING SECTIONS THE ONERA ICING CODE WAS USED TO DEFINE THE ICE IMPINGEMENT LIMITS AND BETA FOR EACH SECTION, BY EXTRAPOLATING THE ICE SHAPES

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Ice Shapes Determination

- **Simulated Intercycle ice shapes on the EMB-120**

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Flight Tests Profile

- A baseline flight (without ice shapes) generated the reference data.

- Several slow downs were performed up to the shaker and pusher in all flaps and gear configurations.

- Slow downs with the auto pilot connected in altitude hold up to the shaker activation and A/P automatic disconnection.

- In turn (30 deg of bank) slow downs were also performed up to the shaker and pusher with A/P on and off.

- Level flight stabilizations in different airspeeds were performed in order to obtain the drag increment due to ice.

THIS INFORMATION IS EMBRAER S/A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Flight Tests Results: General Assessment

- **The stall handling characteristics of the airplane were not modified with the intercycle ice shapes.**

- **An increase in shaker and stall speeds were observed.**

- **The airspeed margin between shaker and pusher activation was reduced below the 7% minimum required by certification.**

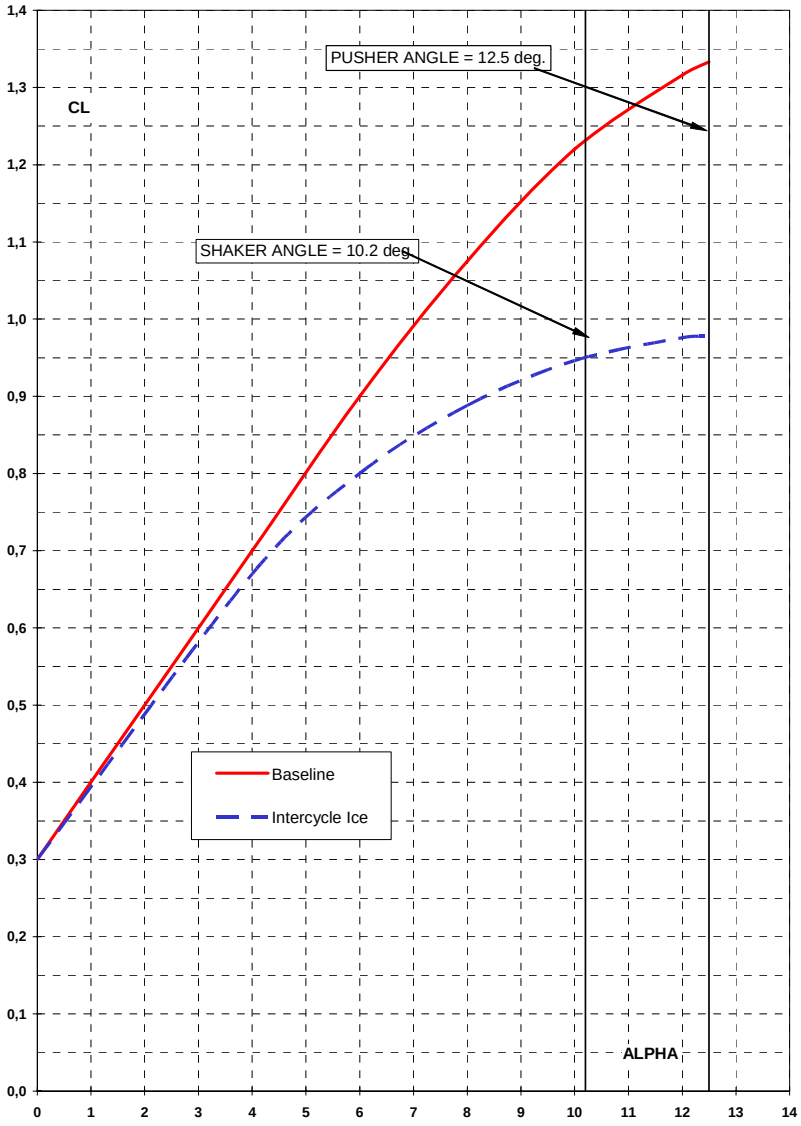
- **The Stall Warning Computer shaker AOA firing angles had to be reduced in order to recover the required margin.**

- **Shaker Autopilot deactivation during slow downs in Altitude Hold Mode did not cause any disturbance in pitch or roll.**

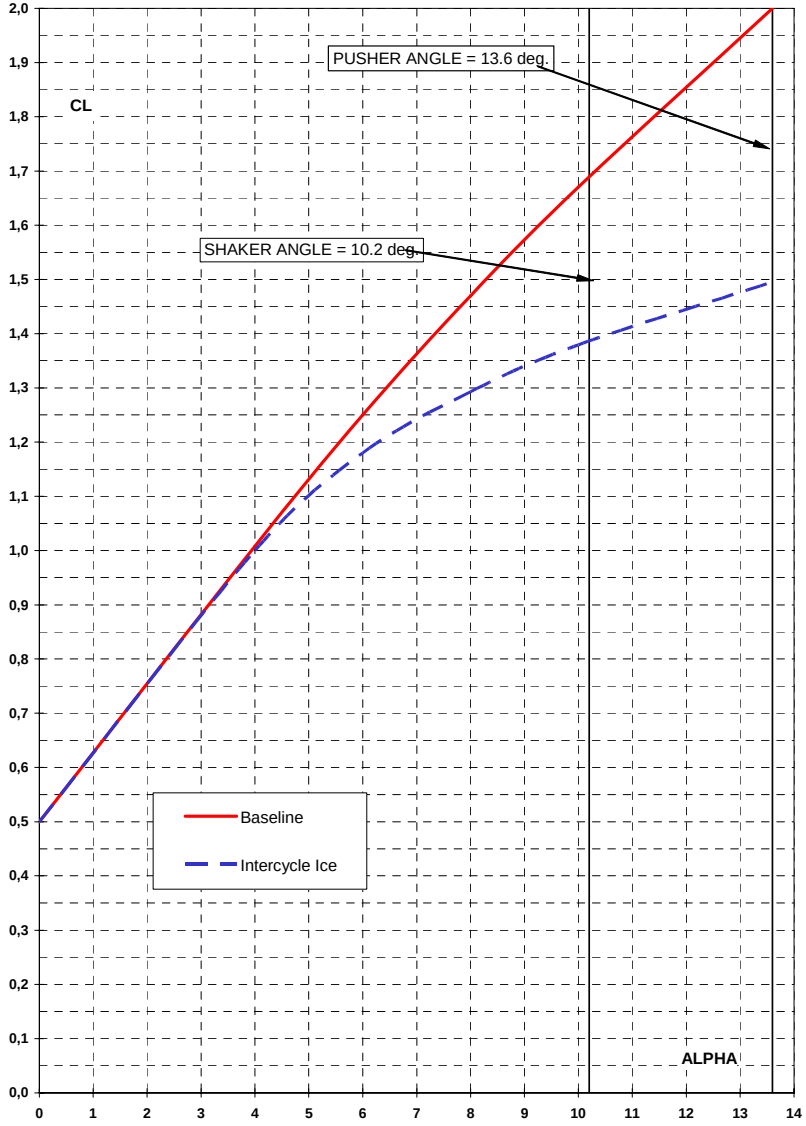
THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Flight Tests Results: LIFT

EMB-120 CL x ALPHA (FLAP 0)
(CL Corrected for Normal Acceleration)

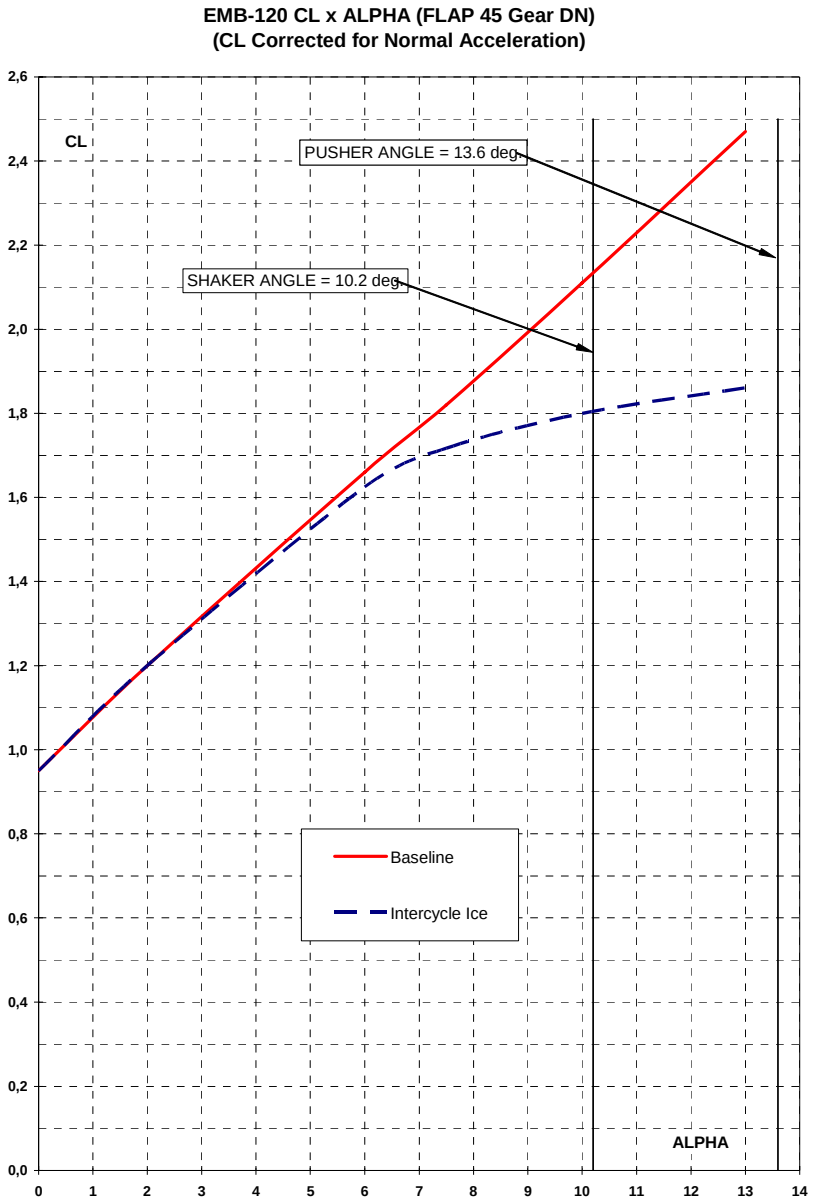


EMB-120 CL x ALPHA (FLAP 15 - Gear UP)
(CL Corrected for Normal Acceleration)



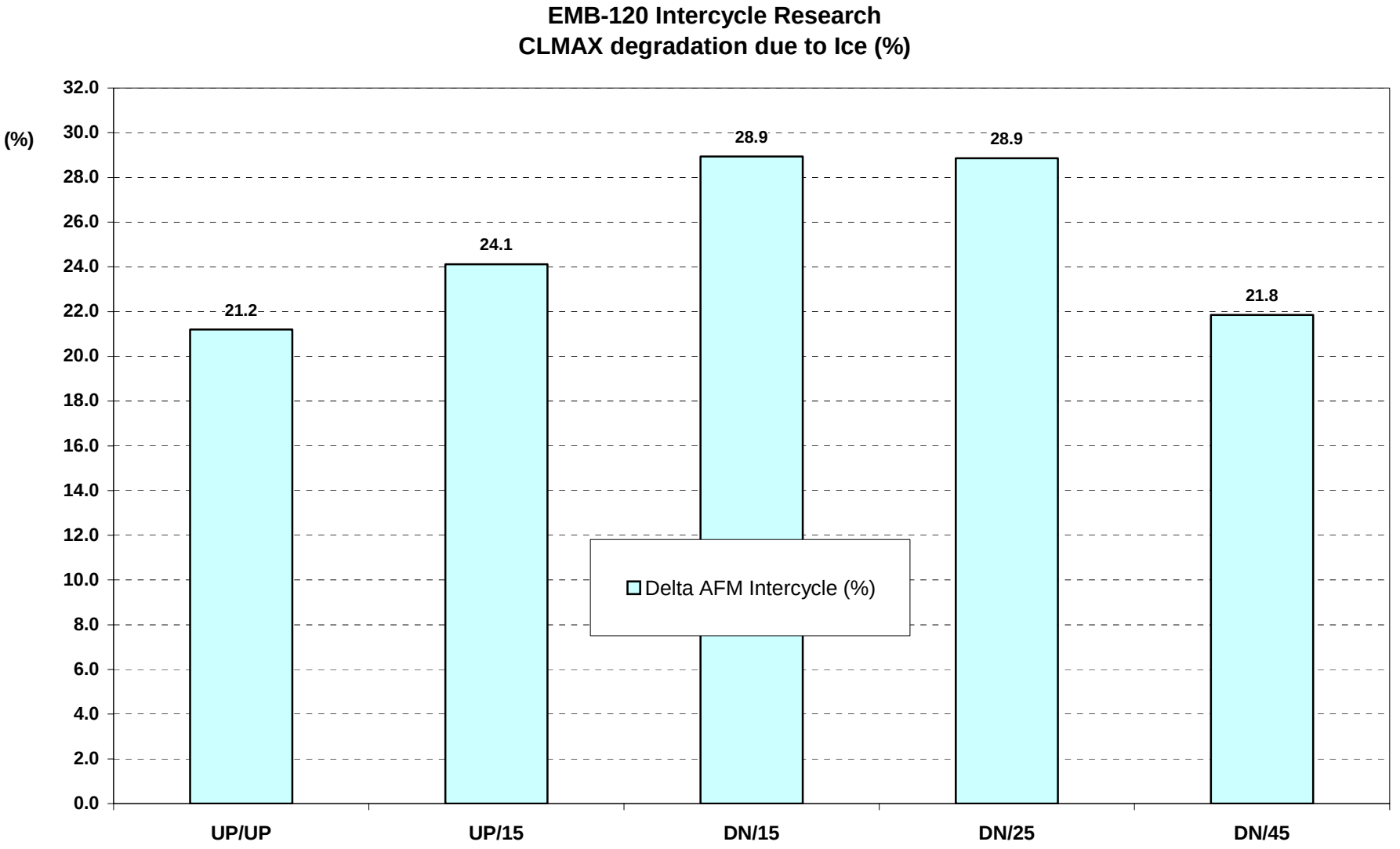
THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Flight Tests Results: LIFT



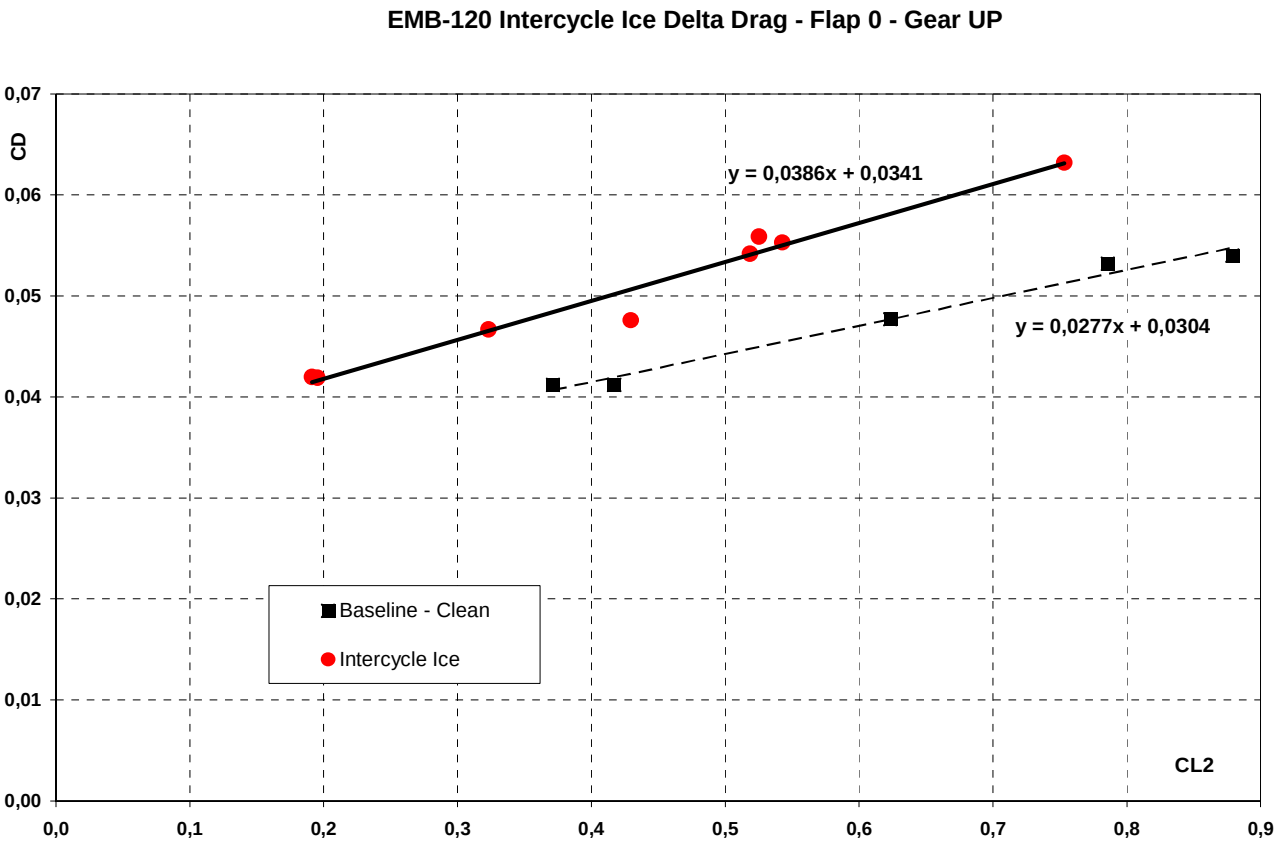
THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Flight Tests Results: LIFT



THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

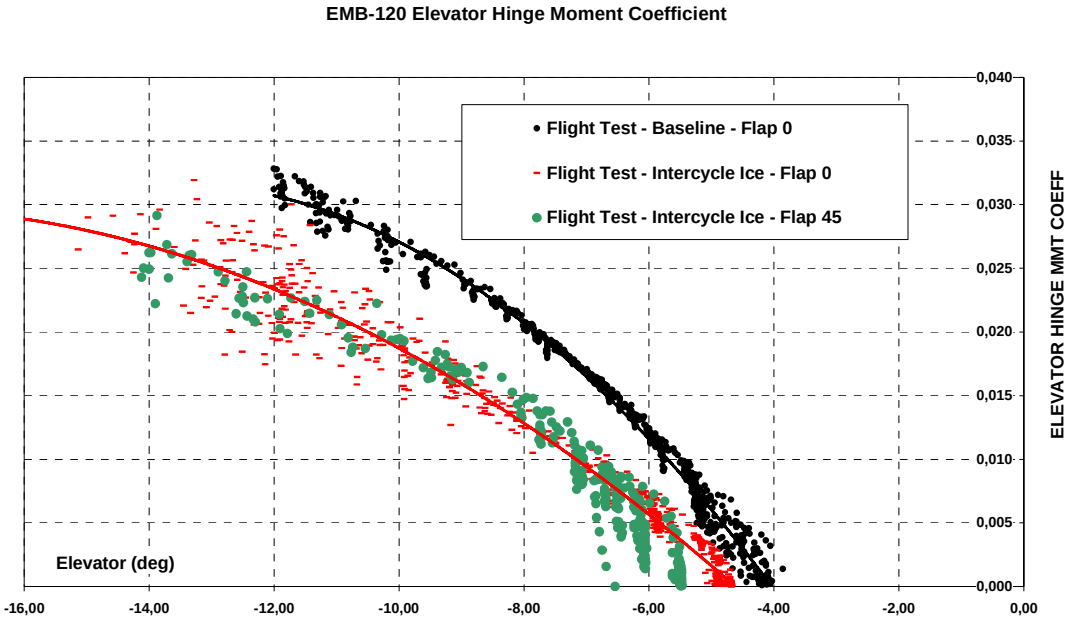
Flight Tests Results: DRAG



- **Drag increment due to Intercycle Ice for Flap 0 = 89 Drag Counts**

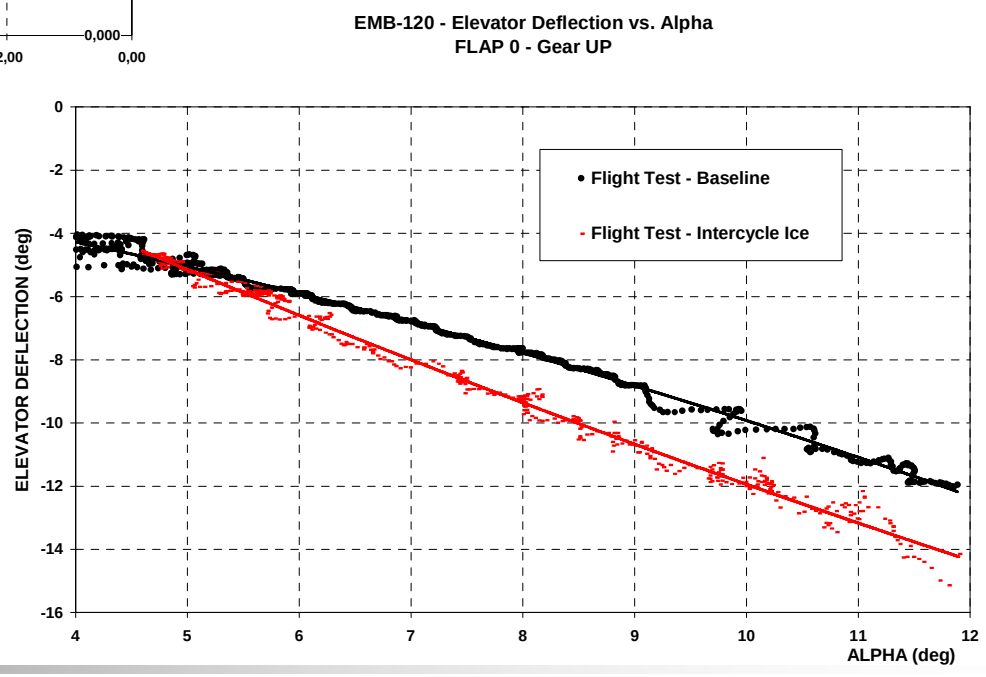
THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Flight Tests Results: Elevator



- **A reduction of elevator hinge moment was observed**

- **More elevator was required to trim the airplane**



THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Impacts on the AFM

•Shaker and stall speeds for icing conditions were increased for each flap position according to a table introduced on the respective charts.

• Reference speeds were increased for icing conditions (+ 15 KIAS for flap 25 and
+ 10 KIAS for flap 45).

• New charts for icing conditions were added:

- Approach Climb and Landing Climb Gradients
- Maximum Landing Weight – Approach Climb and Landing Climb Limited
- Landing Field Lengths
- Maximum Landing Weights – Brake Energy Limited

• The new charts must be used “In case of ice accretion or ice remaining on the wing leading edges after boot actuations”.

• The above limitations applied to a typical high altitude airport in icing conditions and at typical landing weights, reduce the maximum landing capacity of the airplane by 2 PAX

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

Conclusions

- **A methodology was created to perform the icing tunnel tests, generate the simulated ice shapes, install it on the airplane, perform the flight tests and obtain the necessary results to assess Aircraft Flight Manual and Operational Procedures for the intercycle icing conditions.**

- **The results demonstrated that the stall characteristics of the airplane were not modified by intercycle ice, but an increase in the shaker and stall speeds and a reduction of the shaker to pusher margins were observed.**

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN

THANK YOU

THIS INFORMATION IS EMBRAER S.A. PROPERTY AND CANNOT BE USED OR REPRODUCED WITHOUT WRITTEN