Aircraft Icing

NASA Glenn Research Center

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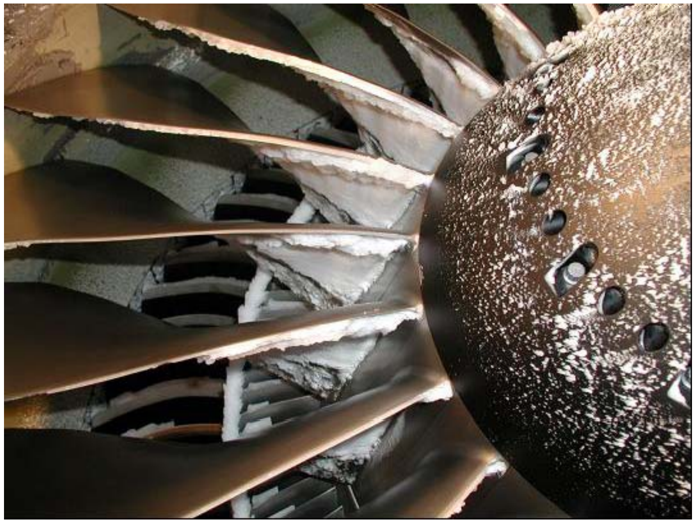
Aircraft Icing Incidents and Accidents

- New York City
- Chicago
- The Phillippines
- Brazil

Overview

- What is aircraft icing?
- How can it affect an aircraft?
- How can an aircraft be protected from icing?
- How might an icing test be set up?



Objectives

- Describe difference between ground and inflight icing
- List three types of ice
- List two effects of ice accretion on aircraft
- List three types of ice protection systems
- Setup an icing test of an ice protection system

What is aircraft icing?

- Ground icing
- **<u>In-flight icing</u>**

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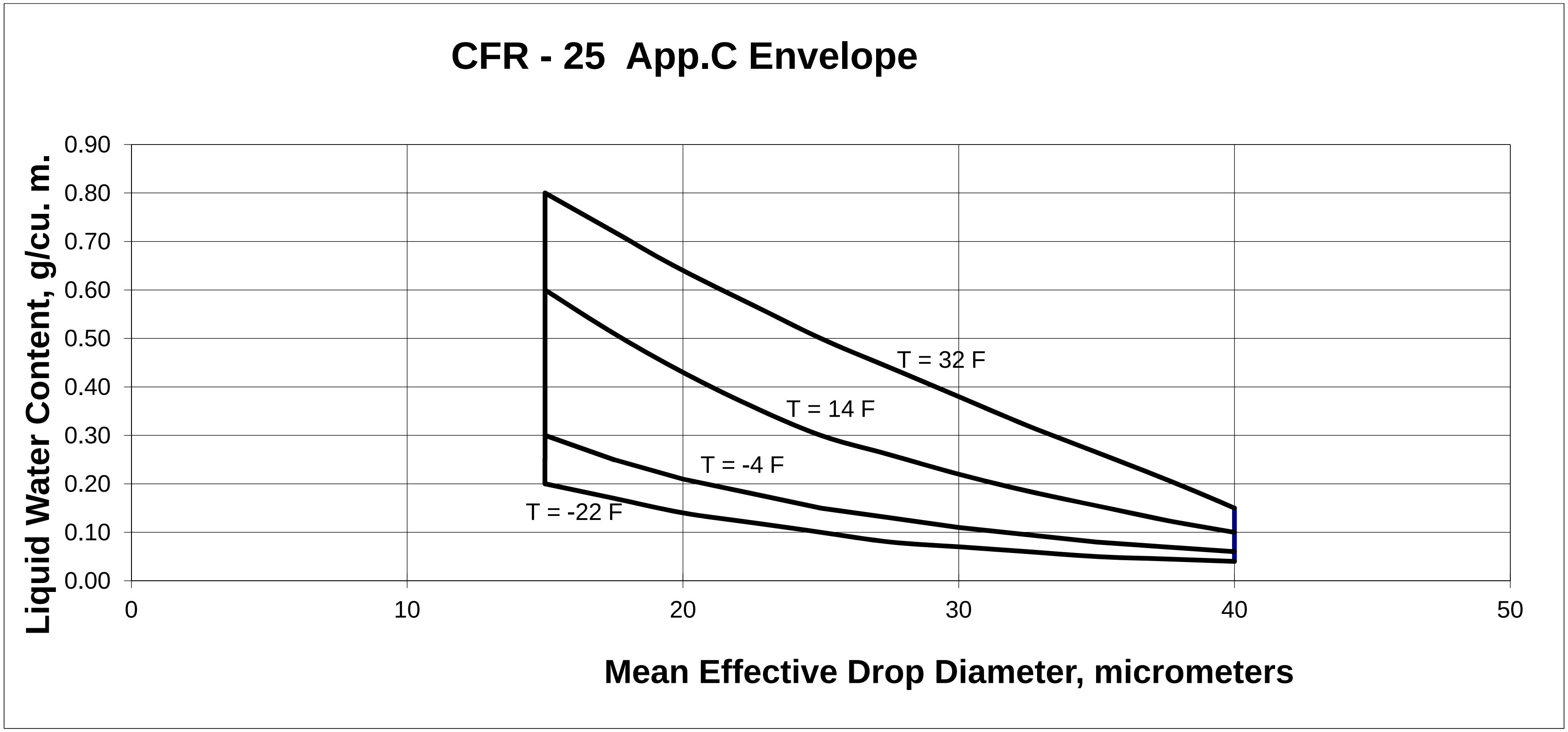
Basics of inflight icing:

(icing video here)

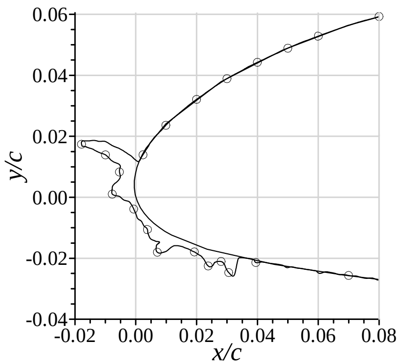
- Liquid droplets
  - o small ~ 10-40 micrometers
  - o supercooled to as low as -40 deg
  - o aircraft creates nucleation site
  - o rate of freezing and accretion depends upon air temperature, airspeed, amount of water per unit area in cloud
- Ice crystals
  - o small ~ 100 to 200 micrometers
  - o Bounce off surfaces unless partially or fully melted by local above-freezing environment
  - o accretion depends upon air temperature, airspeed, amount of water per unit area in cloud

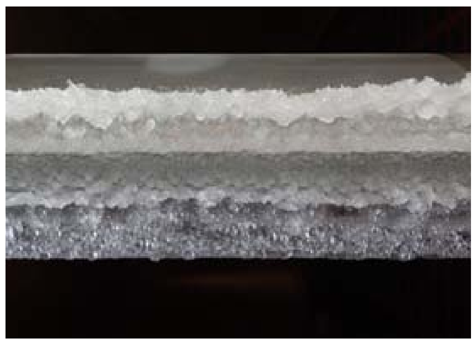
Aircraft icing envelopes



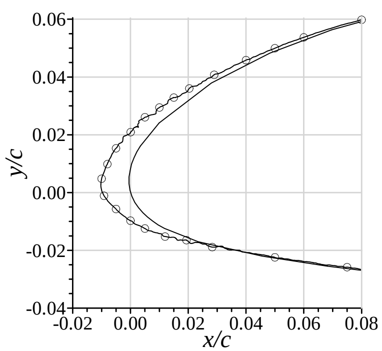
1. Pressure altitude range: SL to 22,000 ft
2. Maximum vertical extent: 6,500 ft.
3. Horizontal extent: standard 17.4 knots

Aircraft Inflight Ice Accretions





- Glaze Ice

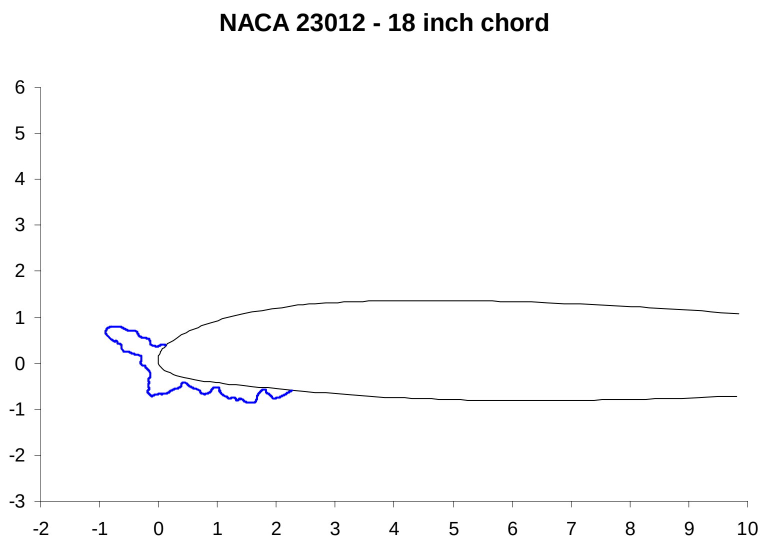


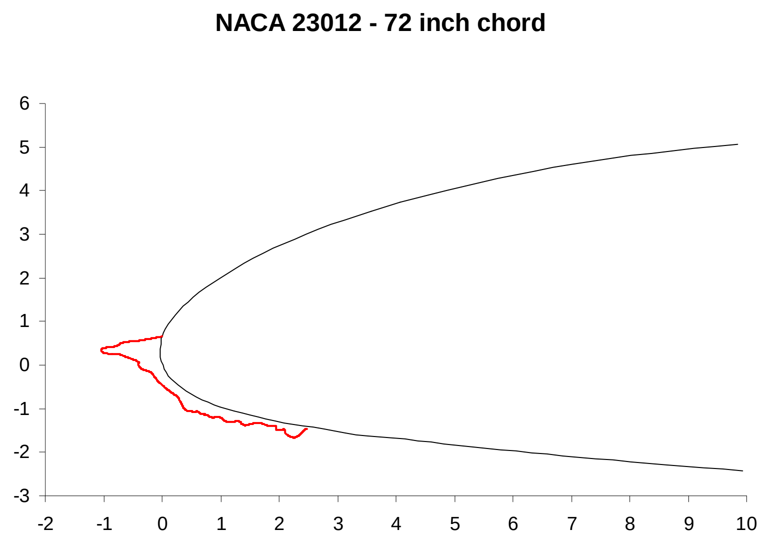
- Rime Ice

- Scalloped Ice

- Freeze on impact
- Flow before freeze

Ice Accretions



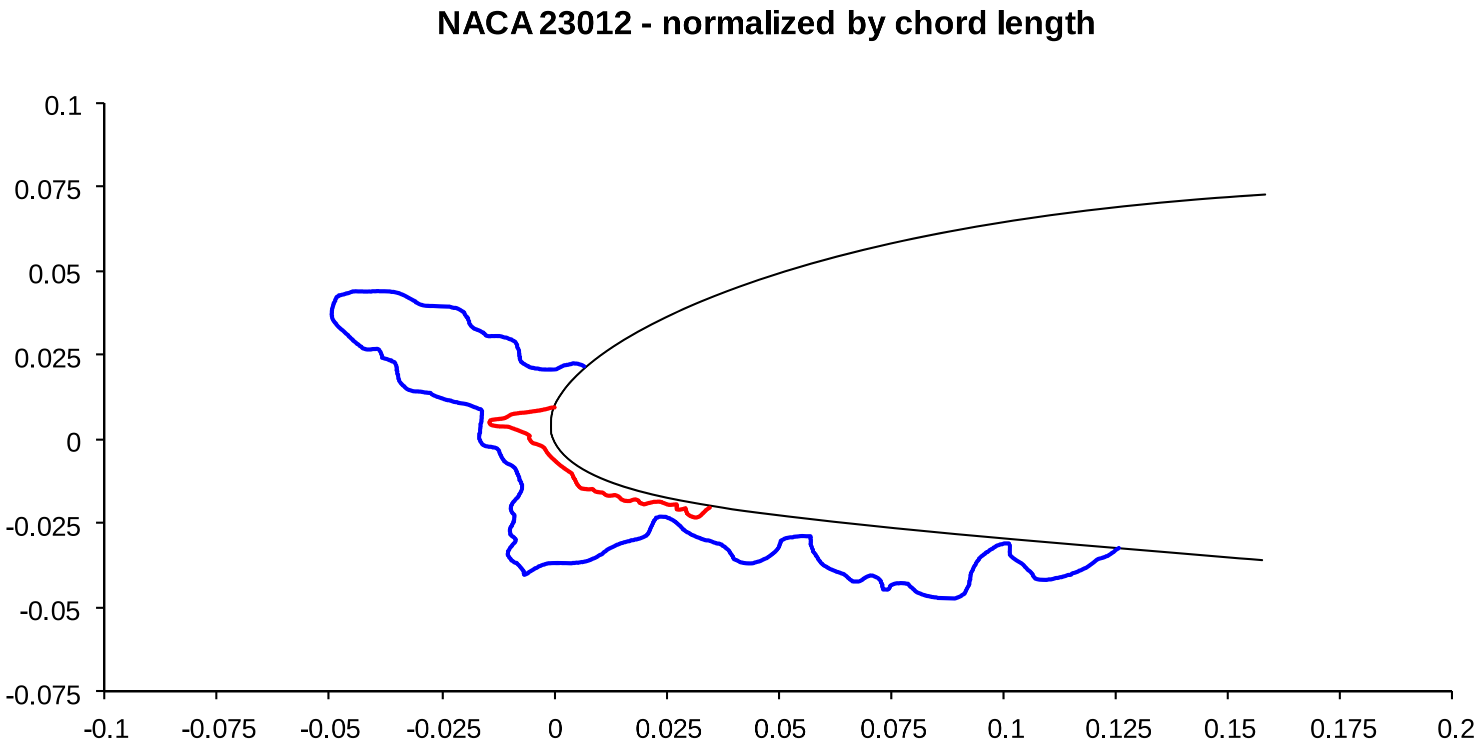


V = 175 kts
AOA = 5°
T_t = 28.0 °F
T_s = 20.8 °F

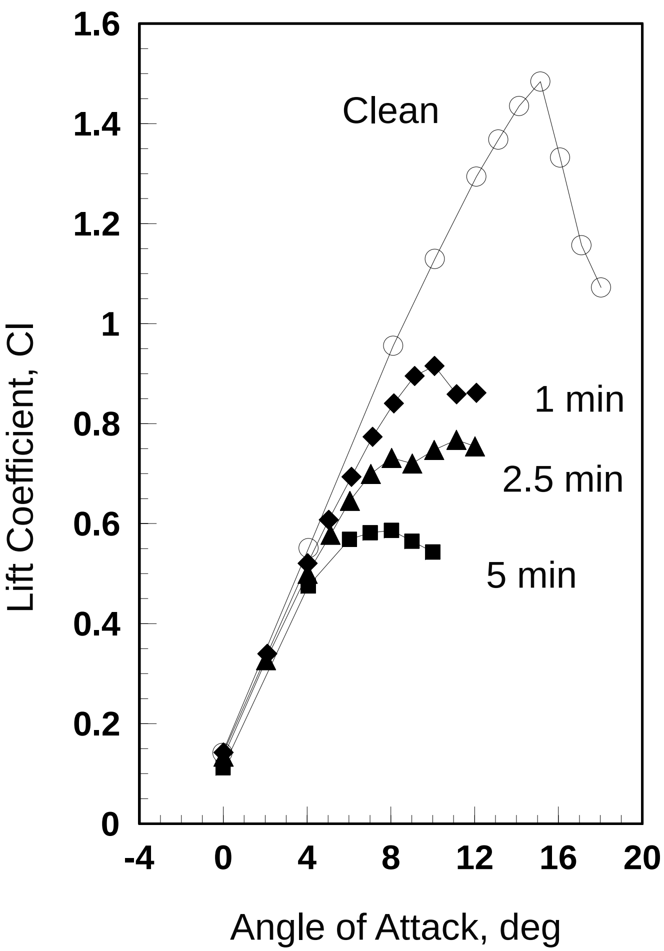
LWC = 0.64 g/m3
MVD = 15 um
Spray = 10 min

Same icing conditions - different size airfoils

Same icing conditions - different size airfoils



Icing effects - Length of Exposure



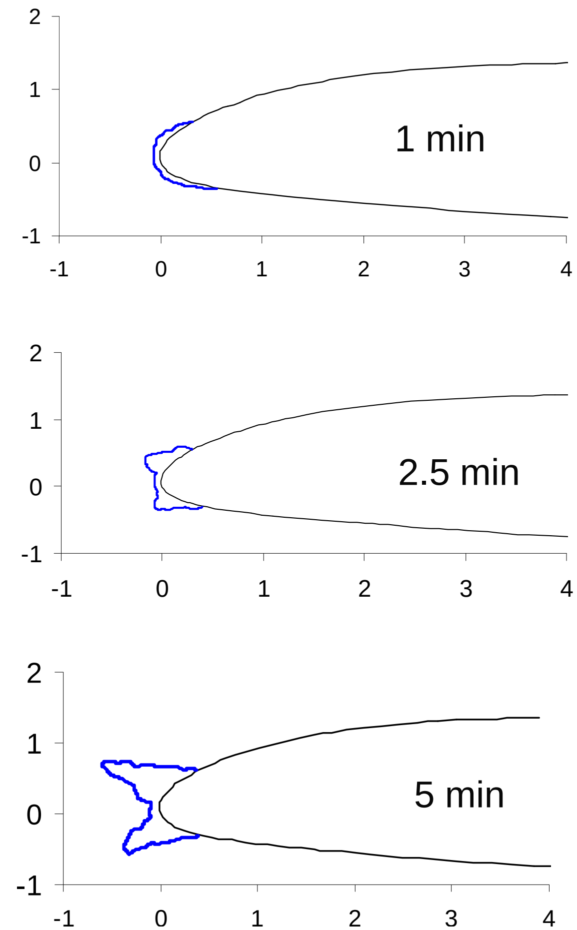
V = 200 kts

LWC = 0.75 g/m3

Tt = -2.2 deg C

MVD = 15 um

AOA = 2.0 deg



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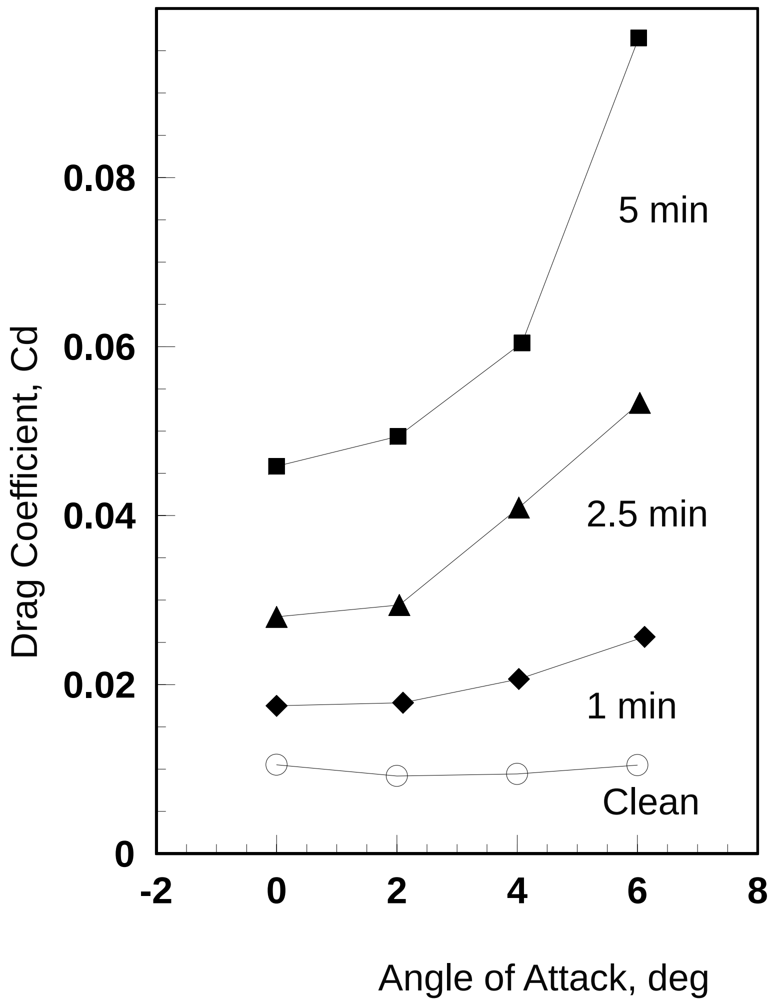

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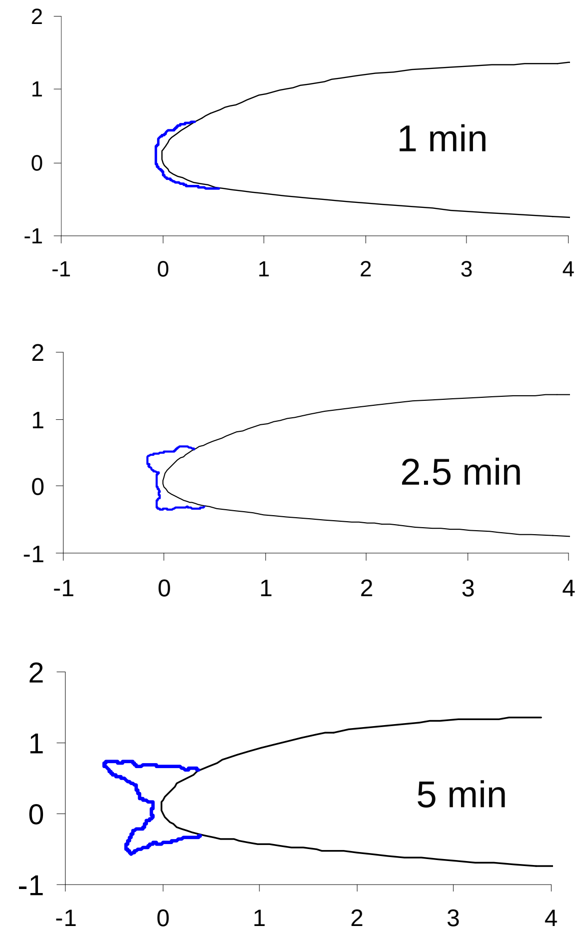
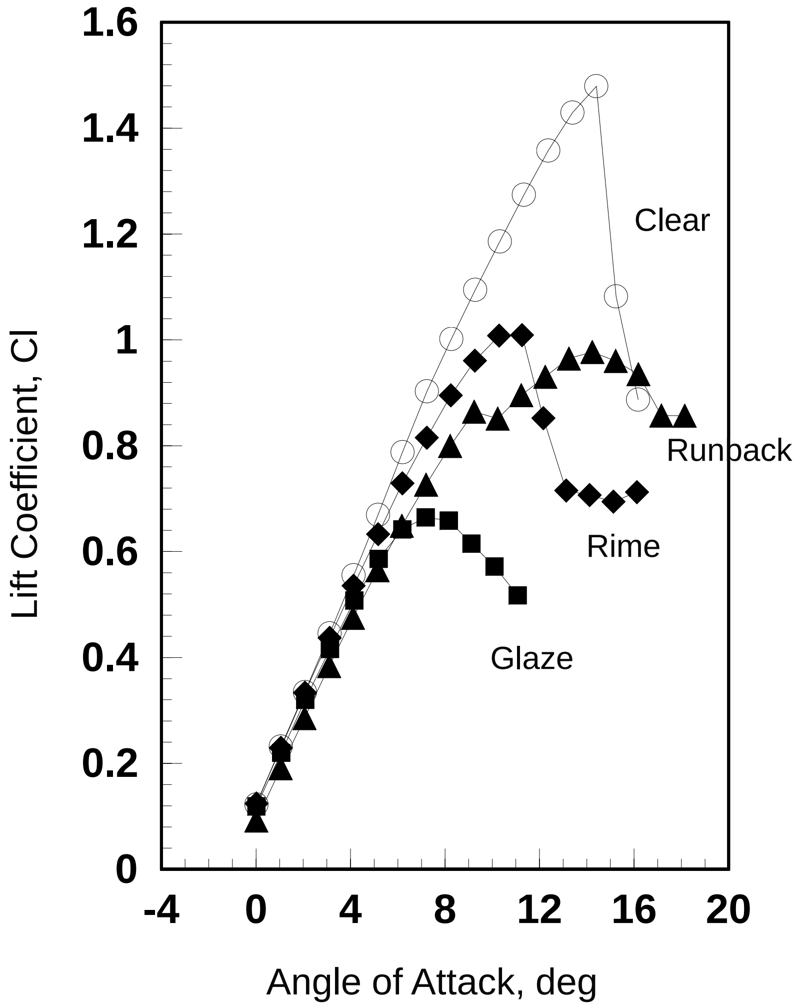
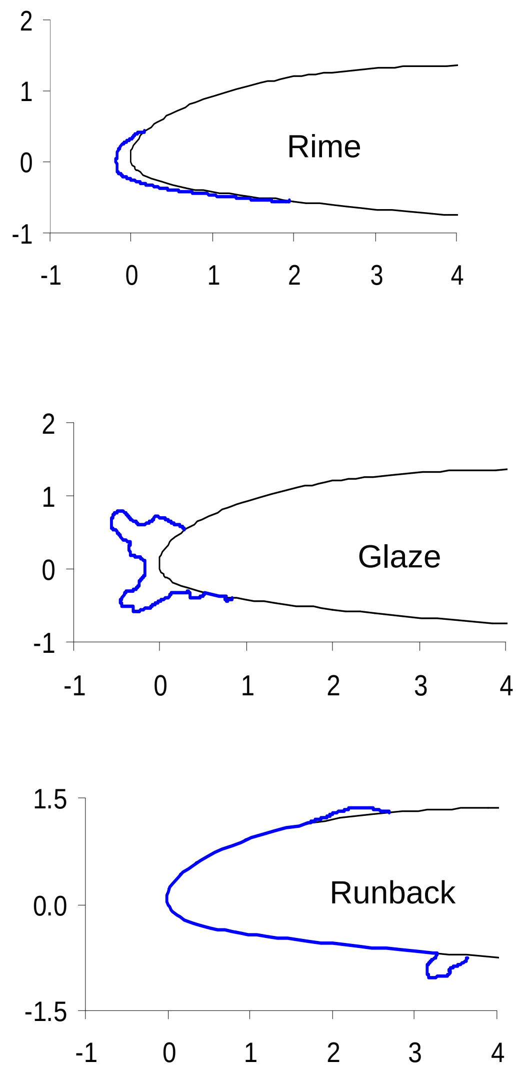
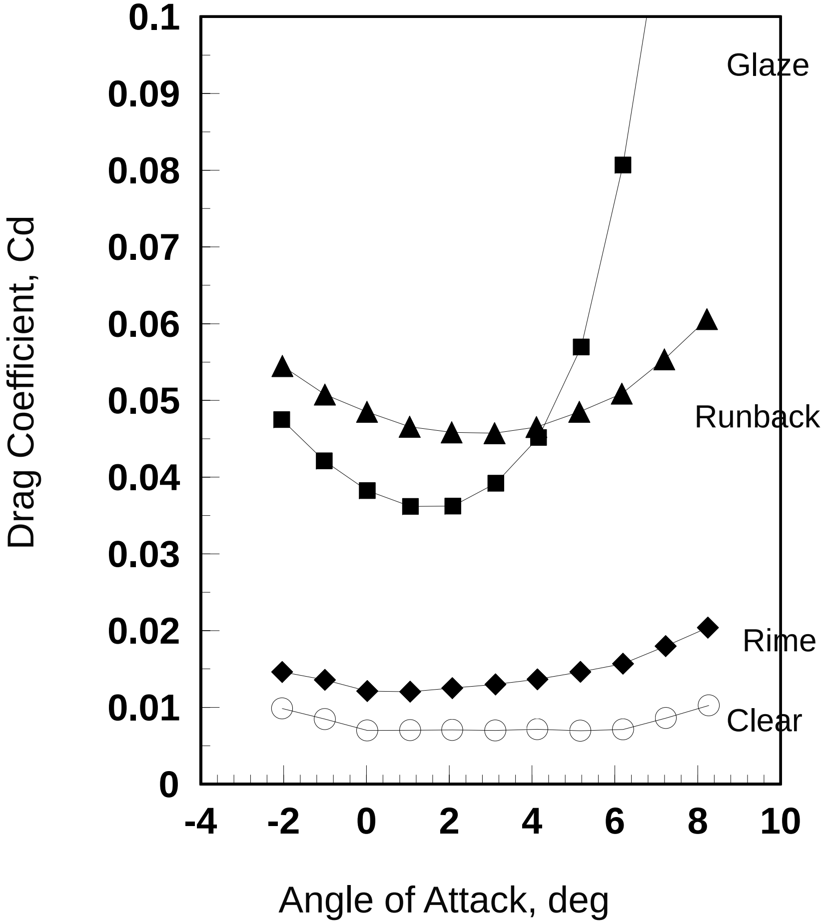


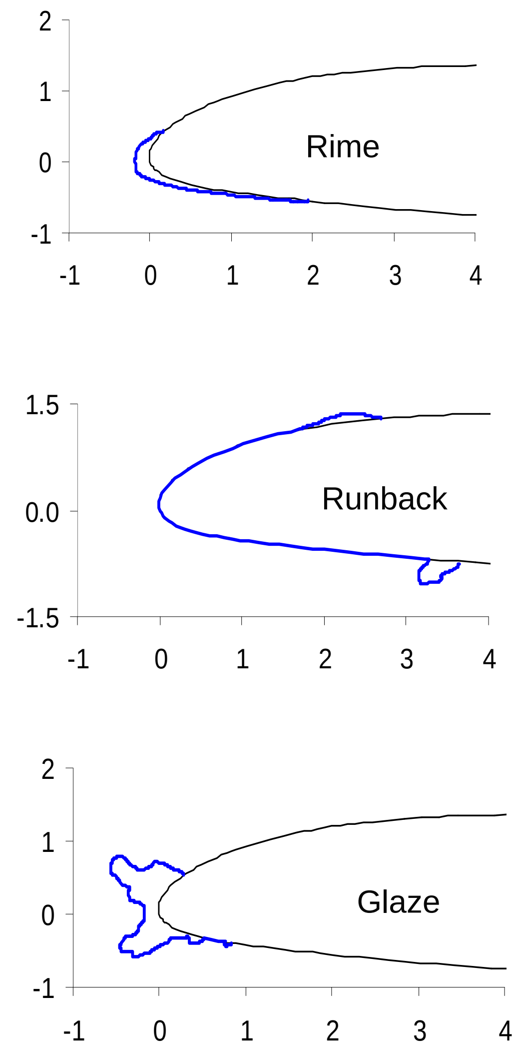
Icing effects – Type of Ice





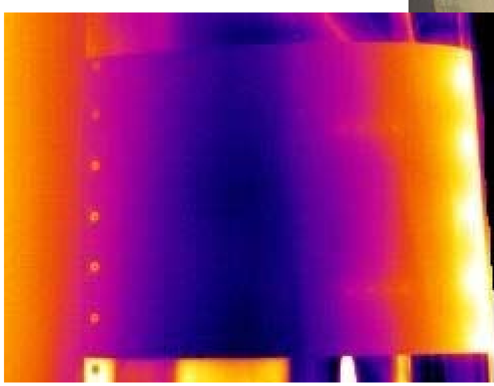
Icing effects – Type of Ice





How to protect aircraft from icing: Ice Protection Systems

- Thermal (evaporative and running wet)
  - o Heated-air
  - o Electrothermal
- Mechanical
- Freezing Point Depressant (FPD)



Test an Ice Protection System

- A new aircraft has been designed that incorporates a new bleed-air thermal ice protection system.
- Task: plan a test of the new ice protection system
- Steps involved include:

Select probable icing scenarios → Determine natural icing conditions → Select icing facility → Build model → Scale conditions for test in icing tunnel → Design test of IPS

Design test of IPS
- o Is design power adequate?
- o Is area coverage adequate?
- o Is ice contamination (if any) acceptable?

Select probable icing scenarios

- For this airplane, the phases of flight critical for icing are:
  - Hold
    - Warm – air temperature near freezing pt.
    - Cold – air temperature well below freezing pt.
  - Descent
    - Lower power available for icing protection

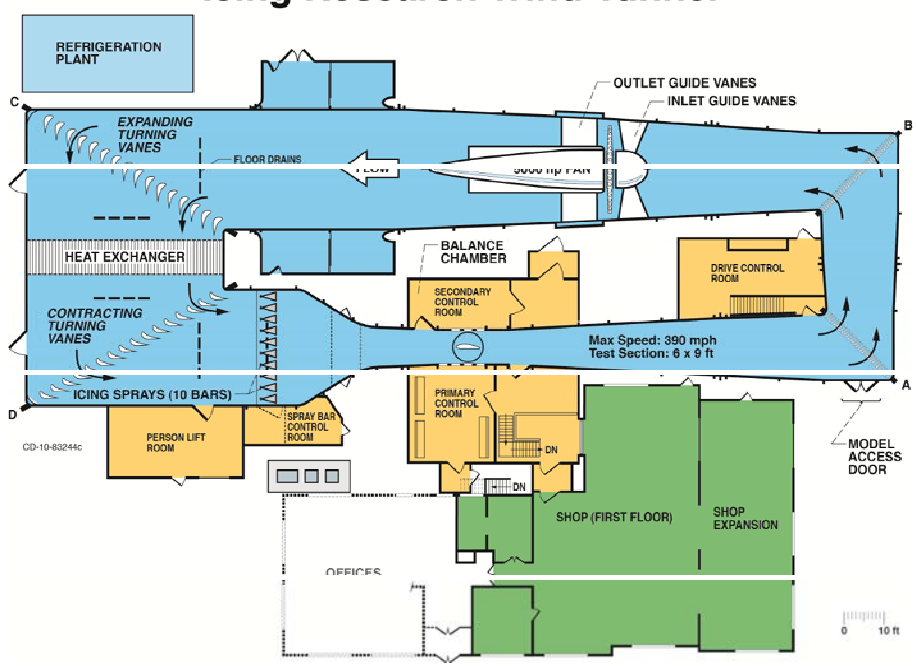
Select probable icing scenarios → **Determine natural icing conditions**

Flight phase	Alt., ft	V, kts	AOA	Ts, F	Tt, F	LWC	MVD
Warm Hold	15000	180	2	20	27.7	0.5	20
Cold Hold	15000	180	2	-22	-14.3	0.15	20
Descent	10000	180	-1	-4	3.7	0.15	20

Select probable icing scenarios → Determine natural icing conditions → **Select icing facility**

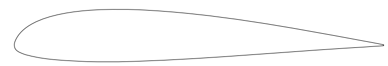
- Icing winds tunnels available both in the U.S. and abroad. Considerations:
  - o Size of tunnel
  - o Airspeed
  - o Temperature
  - o Cloud (LWC, MVD)
  - o Altitude capability
  - o Cost

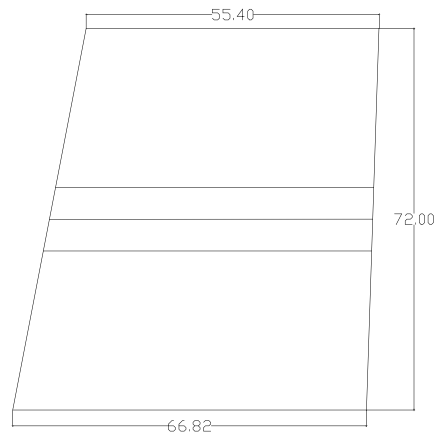
Icing Research Wind Tunnel

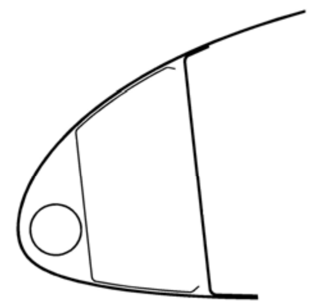


Select probable icing scenarios → Determine natural icing conditions → Select icing facility → **Build model**

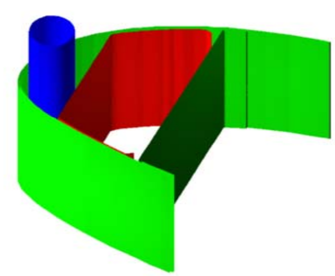
- Must fit in tunnel
- Must retain aspects of wing pertinent to icing – i.e. the leading edge must be closely representative of the aircraft’s
- Ice protection system must be representative







Bleed Air System



Select icing facility → Build model → Select probable icing scenarios → Determine natural icing conditions → **Scale conditions for test in icing tunnel**

Scaling

- Geometric
  - very little – greatly affects collection efficiency
- Cloud conditions
  - very little MVD, some LWC
- Altitude
  - Thermal IPS heat transfer
  - Water evaporation (mass transfer)

➢ How to account for this?
  - Similarity parameters
    - Heat transfer: Prandtl No. & Nusselt No.
    - Mass transfer: Schmidt No. & Sherwood No.

Reynolds analogy

- Momentum transfer, heat transfer, and mass transfer rates are similar
- If transfer rate for one can be established, the other two can be inferred
- Similarity holds only under certain conditions
- In aeronautics, momentum transfer (Reynolds number) is well established

  Heat transfer: Nusselt number = f(Re)

  Mass transfer, Sherwood number = f(Nu)

Method

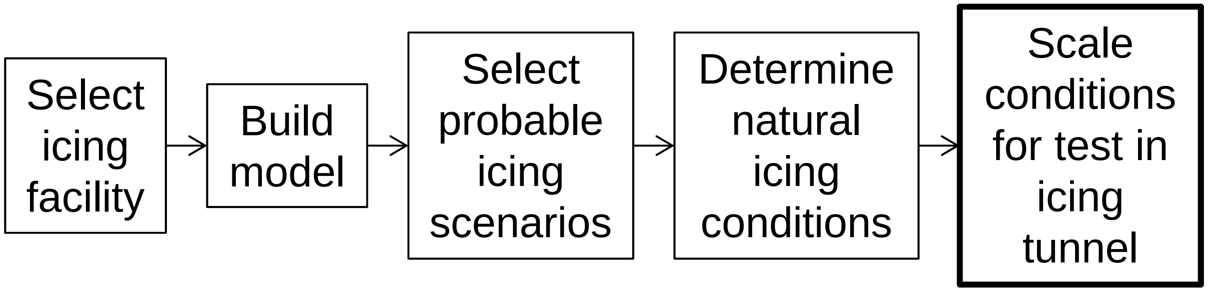
Match (flight and tunnel):

1. Reynolds number, $\mathrm{Re} = \dfrac{\rho V d}{\mu}$
2. Cloud parameters:

   a) Water loading, $M_w = LWC \times V \times \beta$

   b) Inertia parameter, $K = \dfrac{\rho_w \delta^2 V}{18 d \mu_a}$
3. Recovery temperature,

$$T_r = T_s(1.0 + r(\frac{(\gamma - 1)}{2})M^2)$$



Warm Hold	Alt., ft*	Palt, psia	V, kts	Ts, F	Tt, F	LWC	MVD	Re-2xr	mw	k0	Tr, F	Prantl	Nusselt	Schmidt	Sherwood
Ref	15000	8.287	180.0	20.0	27.7	0.50	20.0	128591	29.96	1.504	26.5	0.7113	356.7	0.6259	338.9
Scale	766	14.29	105.6	24.3	26.9	0.85	27.8	128591	29.96	1.504	26.5	0.7113	356.7	0.6271	339.2
Cold Hold															
Ref	15000	8.30	180	-22.0	-14.3	0.15	20.0	139772	9.024	1.523	15.5	0.7121	372.08	0.6267	353.5
Scale	823	14.26	106	-17.8	-15.1	0.25	27.8	139772	9.024	1.523	15.5	0.7120	372.06	0.6290	354.0
Descent															
Ref	10000	10.1	180	-4.0	3.7	0.15	20.0	164186	8.808	1.414	2.5	0.7118	403.19	0.6266	383.1
Scale	1074	14.13	129.8	-0.9	3.1	0.21	24.5	164186	8.808	1.414	2.5	0.7117	403.17	0.6277	383.4

Select icing facility → Build model → Select probable icing scenarios → Determine natural icing conditions → Scale conditions for test in icing tunnel → **Design test of IPS**
- Is design power adequate?
- Is area coverage adequate?
- Is ice contamination (if any) acceptable?

- Set test matrix to:
  - Investigate various bleed-air flowrates, pressures, and temperatures to determine adequacy and optimum operation
  - Help determine adequacy of jet location and distribution as well as extent of IPS coverage

Caveats

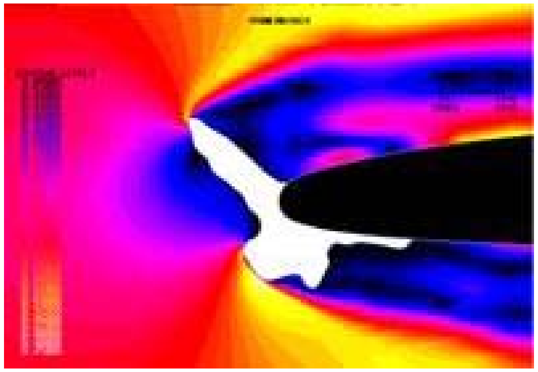
- Reynolds analogy assumptions valid?
    - o Boundary layer approximations are valid
    - o Pr and Sc $\approx$ 1
    - o $dp/dx \approx 0$

- Flight tests usually required to verify IPS operation

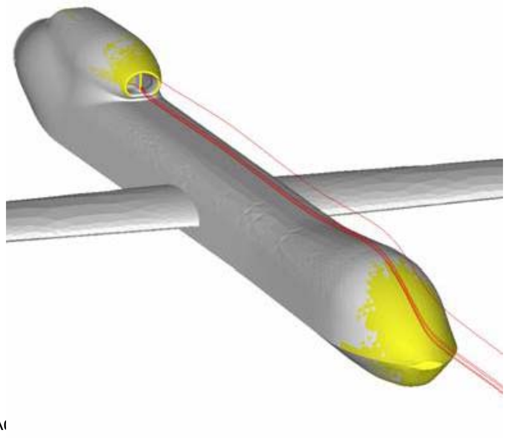
Why is NASA involved in aircraft icing?

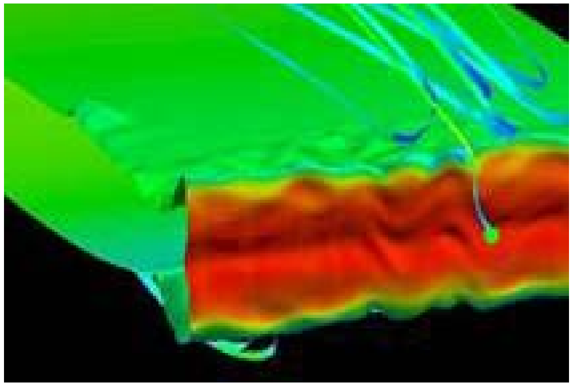
- National Advisory Committee for Aeronautics (NACA)
- Continues to conduct aeronautical research
    - o Aircraft Safety
    - o Fundamental Aeronautics
    - o Aeronautics Tests
    - o Integrated Systems
    - o Airspace Systems

What does NASA do?



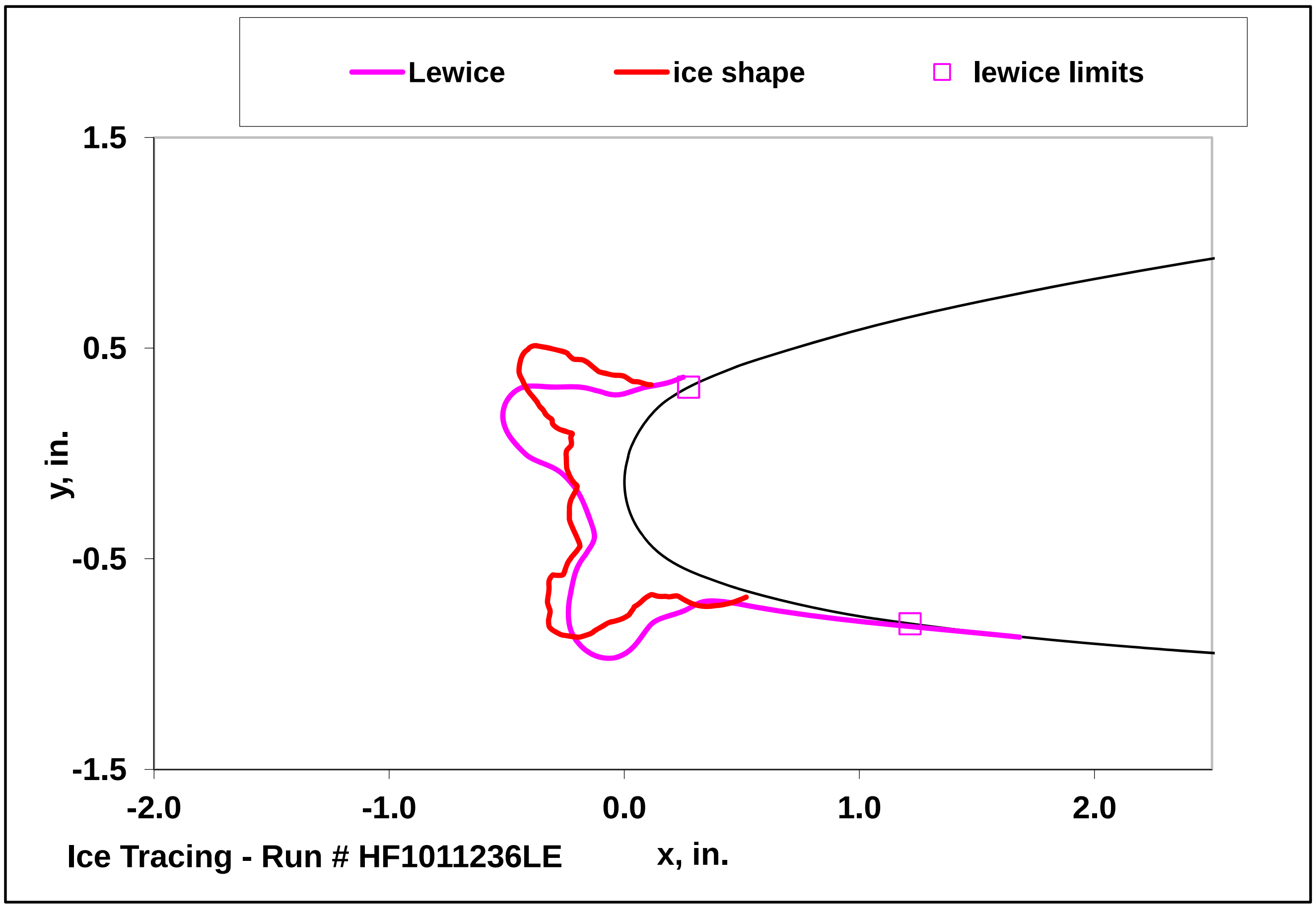
- Studies ice accretion process
- Investigates effects of ice on aircraft
- Develops engineering tools for use in designing and certifying aircraft for flight in icing conditions
- Promotes the development of ice protection systems
- All of the information presented here is from NASA-sponsored research





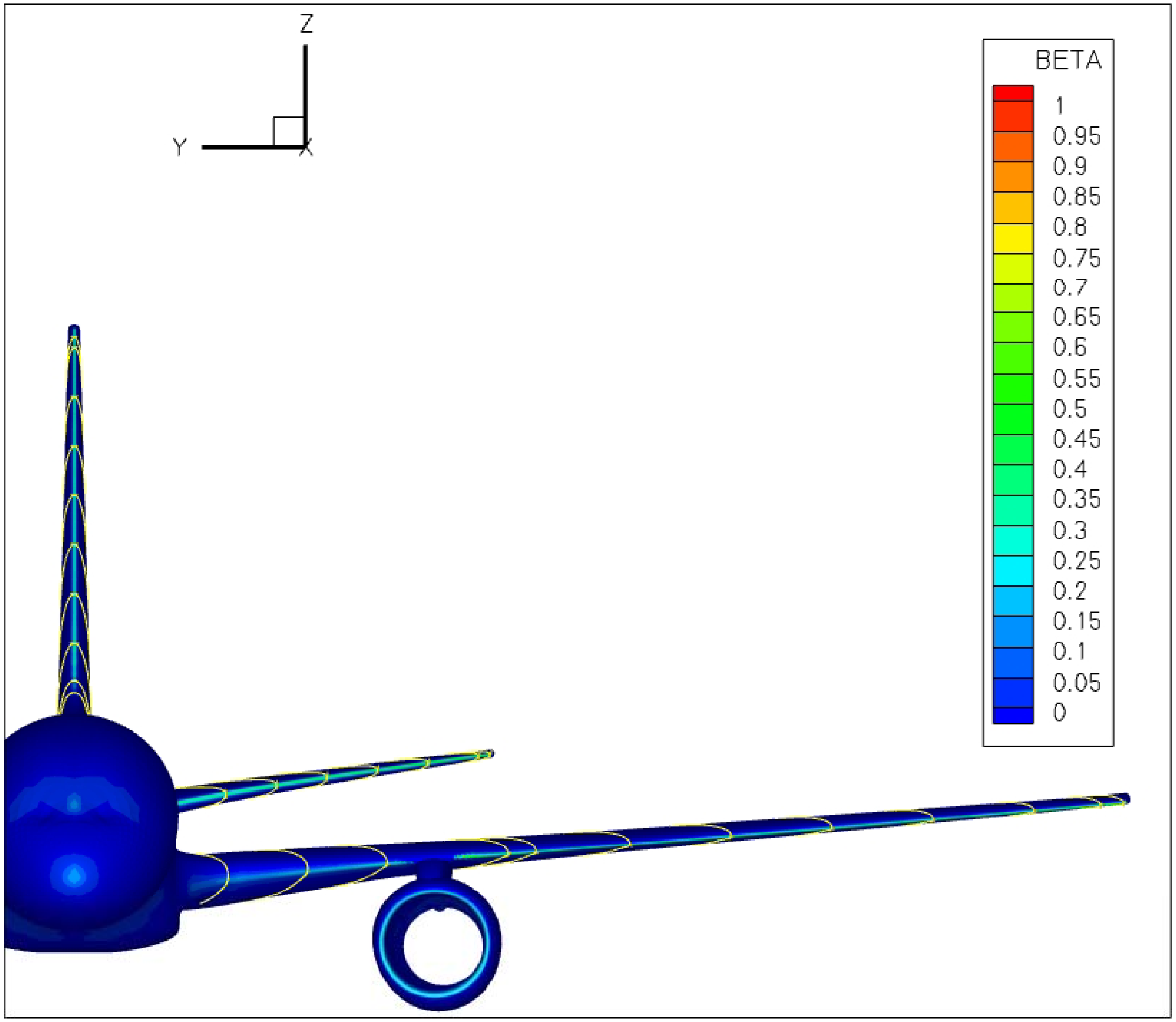
NASA Ice accretion simulation codes:

- LEWICE
- GLENNICE



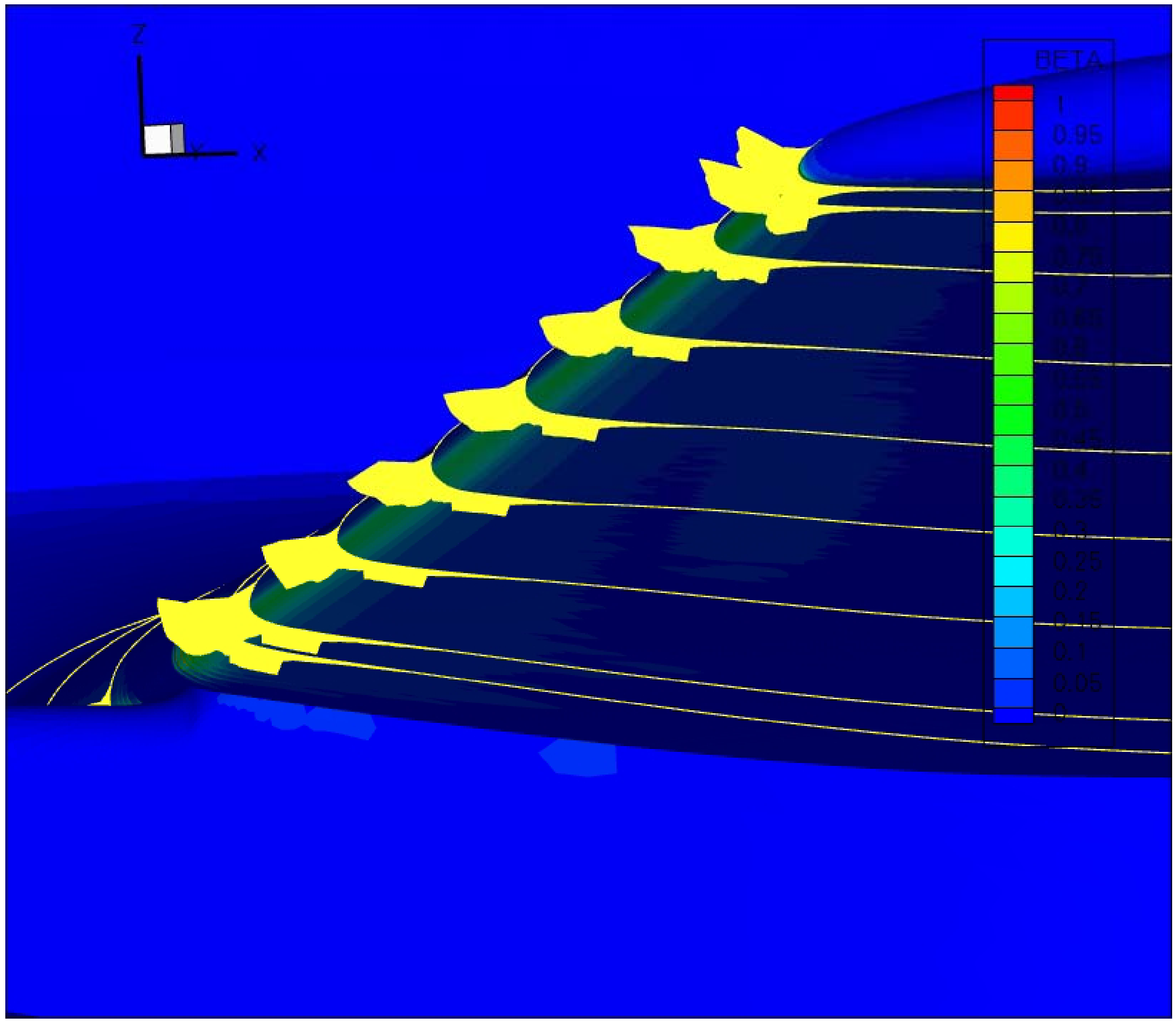
NASA Ice accretion codes, 3D:

LEWICE3D

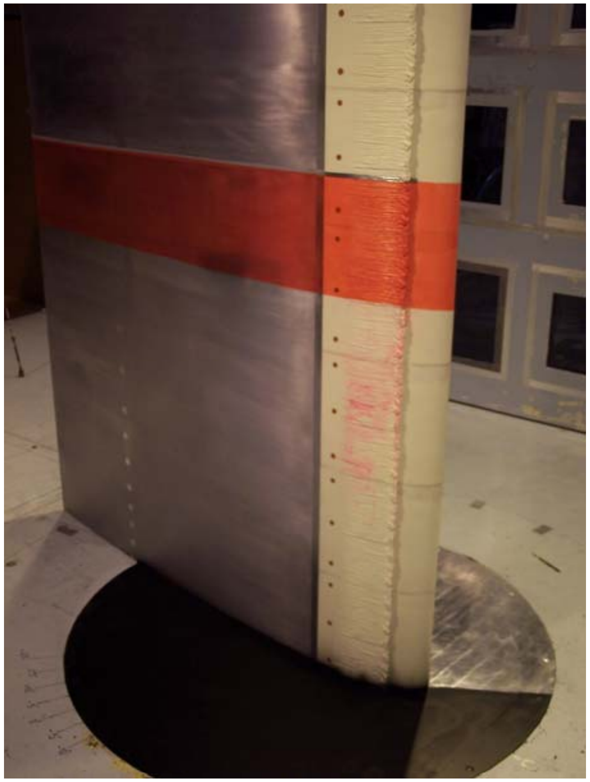


NASA Ice accretion codes, 3D:

LEWICE3D



NASA aerodynamic performance tests and fundamental flowfield investigations



Dry, aerodynamic wind tunnel studies are conducted using artificial ice shapes. The use of these methods allows for more thorough (real ice melts and sublimates) and cost-effective investigations.

Conclusions

- Describe difference between ground and inflight icing
- List three types of ice
- List two effects of ice accretion on aircraft
- List three types of ice protection systems
- Setup an icing test of an ice protection system

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