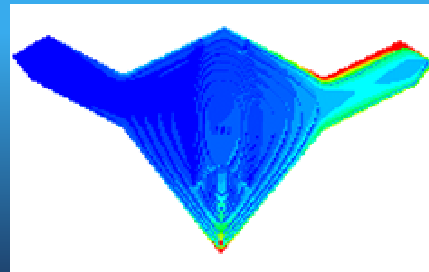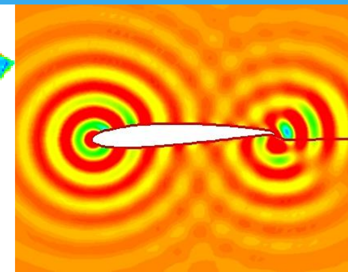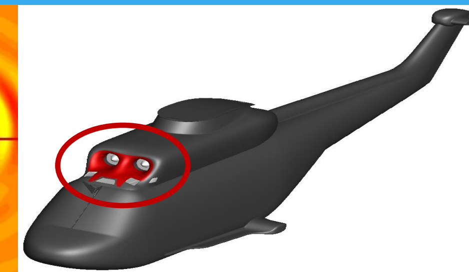

Contradictory design requirements in aircraft development: examples and solutions

September 8, 2016 (10:10-40 AM)

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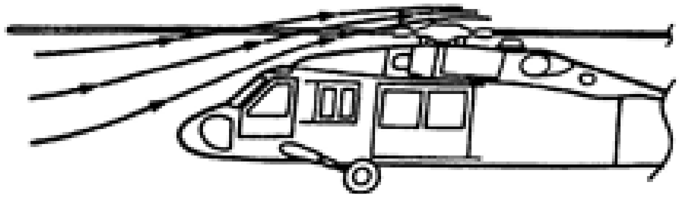
Part I: Background and introduction

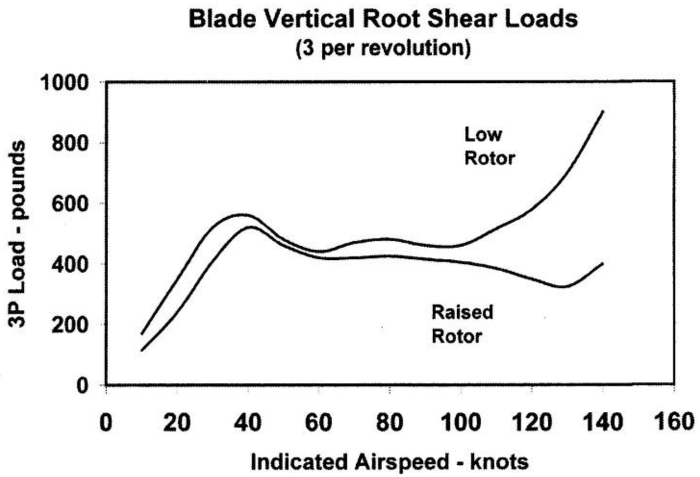
Background (UH-60 main rotor)

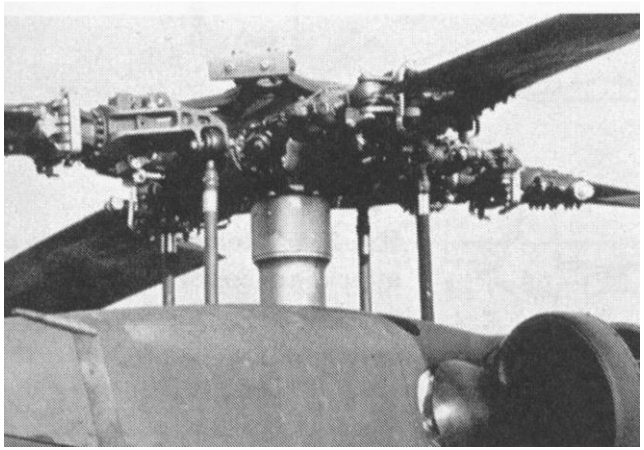
- The design requirements in the development of complicated system are often **contradictory**.
- In case of the Black Hawk (UH-60), the US army's high-priority requirement: **air transport capability** (using a C-130 cargo aircraft) demanding the main rotor close to the fuselage
- However, the **low rotor position created severe interference** flow conditions that could increase **required power** in forward flight significantly. What can you do?

Background (UH-60 main rotor)

- In order to resolve this contradictory requirement, the Sikorsky rotor designers invented an ingenious solution; a **two-position rotor system** based on a removal new part.
- The rotor shaft extender enabled the rotor location **15 inch higher during flight**, while it permitted the rotor to be **lowered for air transport**.

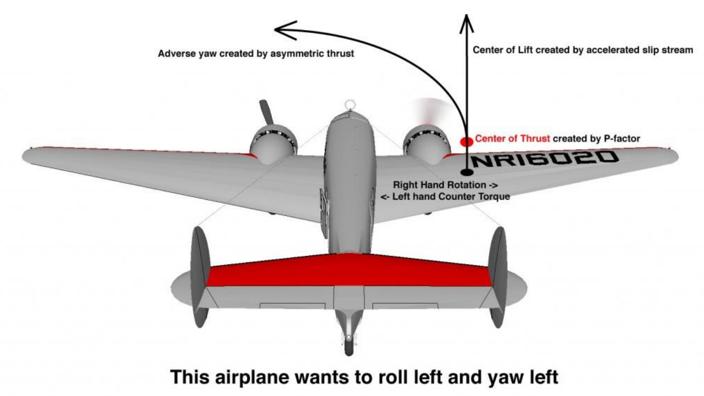


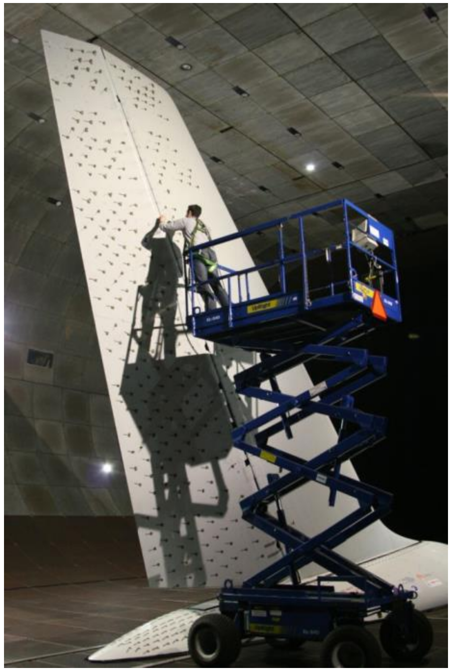




Background (size of vertical tail)

- In **one engine-out scenario** at take-off, the pilots need enough rudder power to counter the yaw moment. Thus, rudders are **designed oversized**.
- But if we can maintain laminar airflow over the rudder through tiny **sweeping jet actuators**, we make the rudder more effective, **making it smaller**.
- A smaller rudder creates **less drag and weighs less**, which increases fuel efficiency.





Background (new technologies)

- **Many similar situations** can be found in the development of complicated system like aircraft.

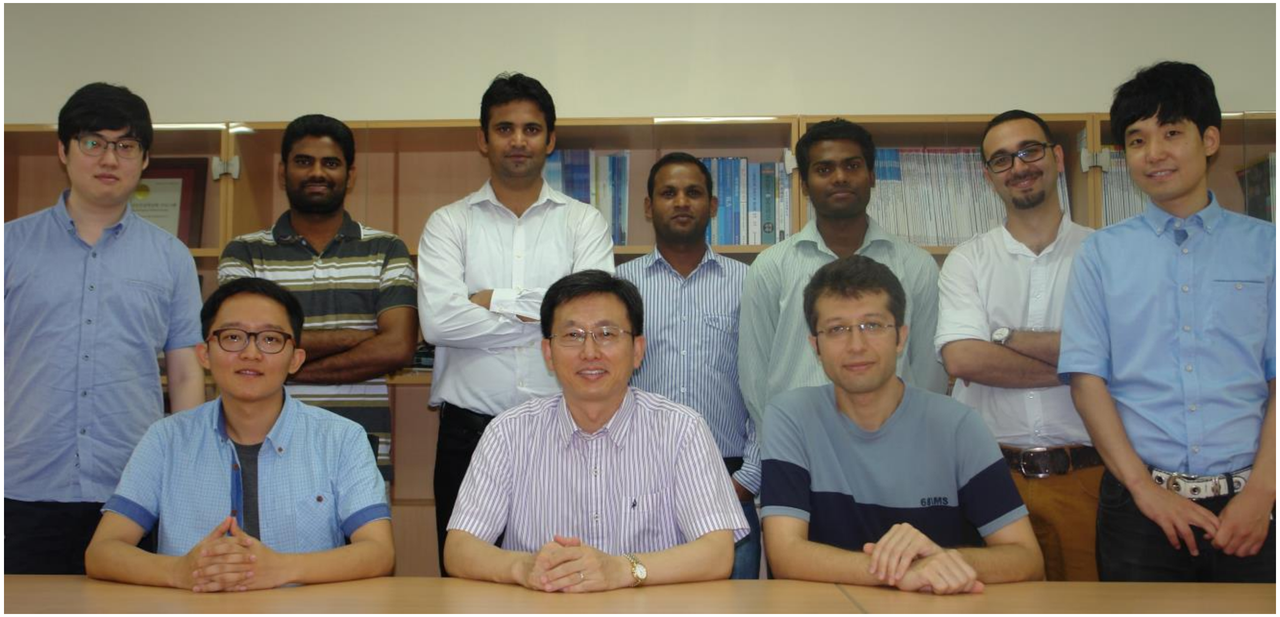
Background (winglet and bird's formation flight)

- It is possible to **decrease the induced drag by using winglets** to redistribute the strength of the trailing vortex sheet.
- A carefully designed winglet can produce **a gain in induced efficiency (and root bending moment as well as marketing)** at a **small cost in viscous drag and weight**.

Understanding of contradictory requirements

- Contradictory design requirements arise from the nature of **multi-function, multi-disciplinary, multi-objective** problem in complex system.
- The **mindset of the conductor** of an orchestra is required.

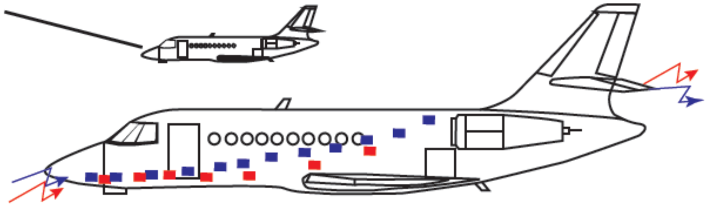
Part II: Works in GNU-ACML
(Examples of contradictory requirement)

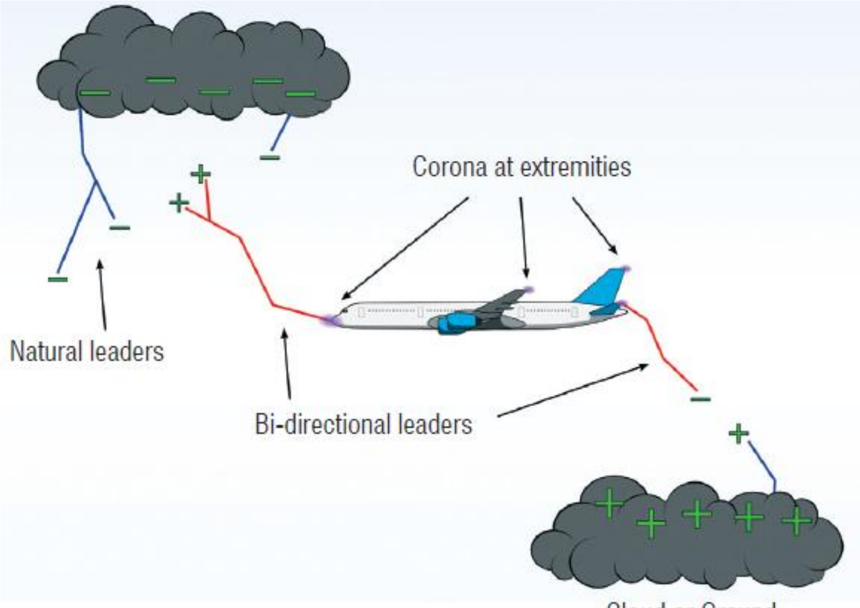


Aerospace Computational Modeling Lab.
http://acml.gnu.ac.kr

Lightning vs ice protection

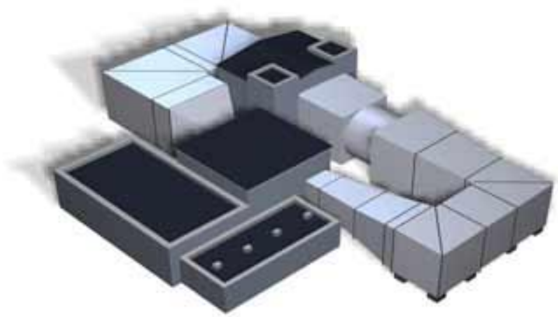
- Lightning is an atmospheric electrical phenomenon which deserves adequate protection design of aircraft.
- The effects of lightning are classified into **direct** (structural damage, fuel ignition) and **indirect** (interference to the electrical equipment).
- Materials with **low thermal conductivity** are required to **minimize the heat transfer**.





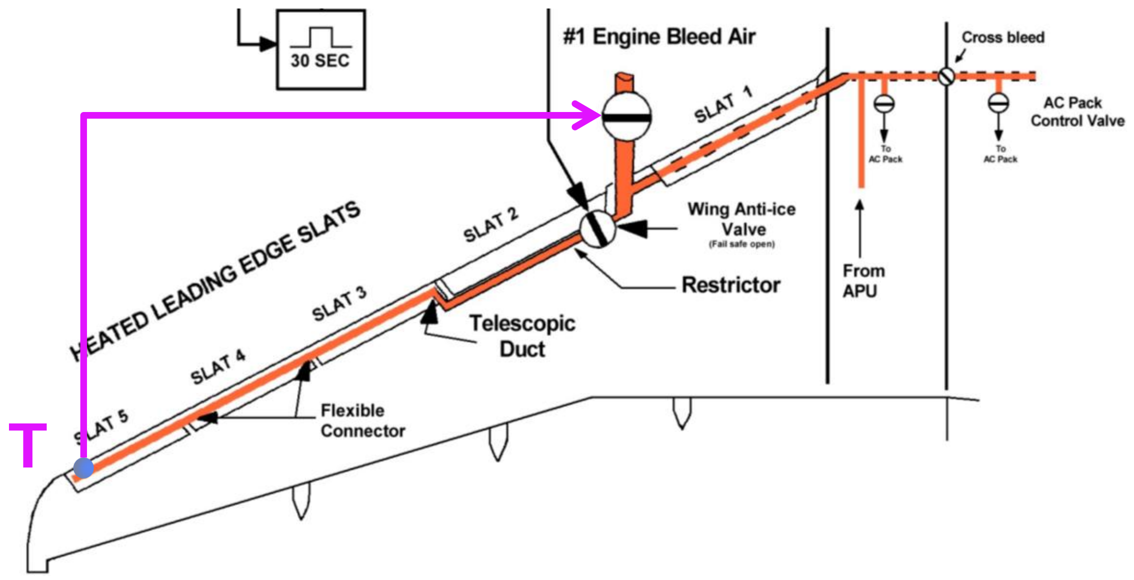
Lightning vs ice protection

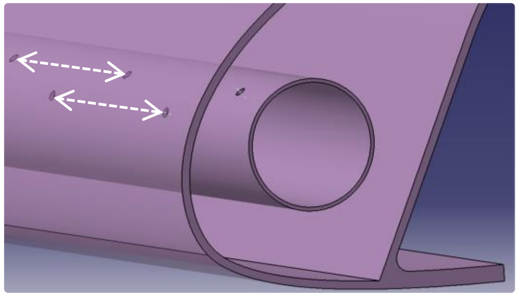
- Icing is an atmospheric phenomenon which also deserves adequate protection design of aircraft.
- Icing is a **key certification issue** related to aircraft safety.
- **Anti-icing** systems: **Prevent** the ice from forming/adhering
- **De-icing** systems: **Remove** the accumulated ice before incurring significant aerodynamic penalties



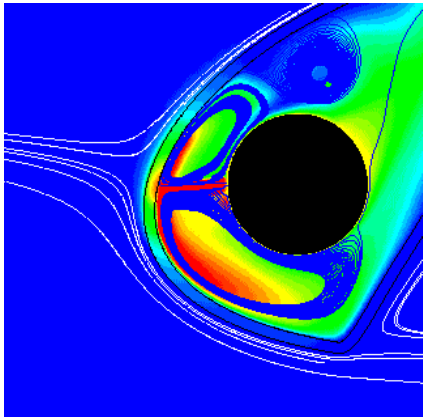
Lightning vs ice protection

- **Hot-air anti-icing** protection system: Materials with **high thermal conductivity** are required to **maximize the heat transfer** to prevent/remove the ice accreted on the aircraft skin.



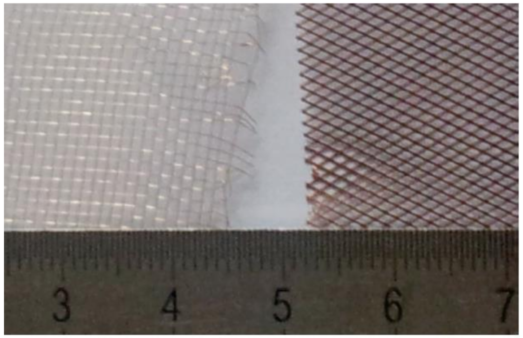


Piccolo tube

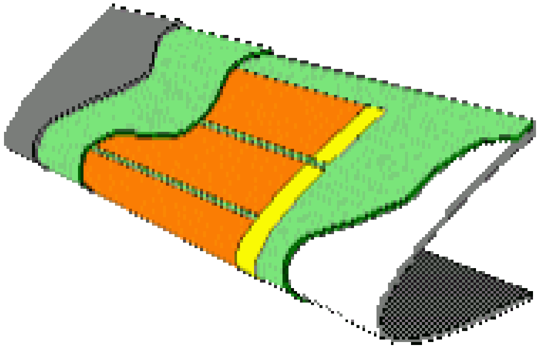


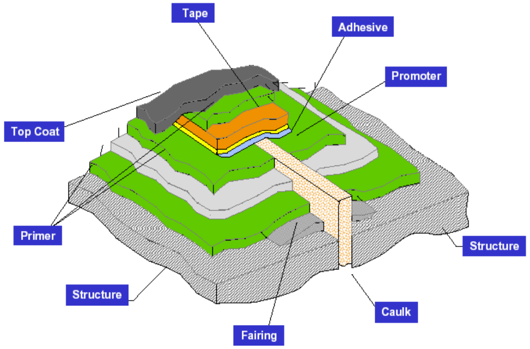
Lightning vs ice protection

- Multi-function in composite skin structure: **lightning** (copper foil), **icing** (electro-thermal pad), **RF stealth** (low-observable structure)



Left: bronze mesh (BM), right: expanded copper foil (ECF)

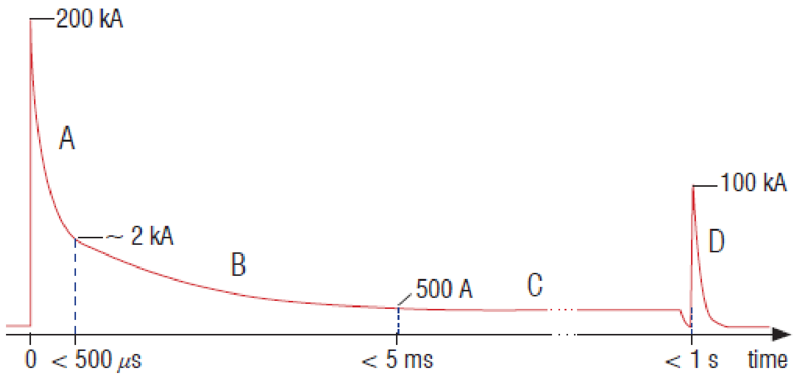


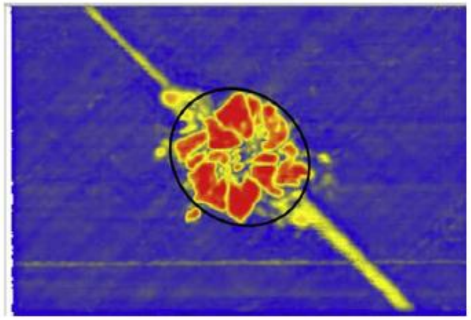


Gap Treatment

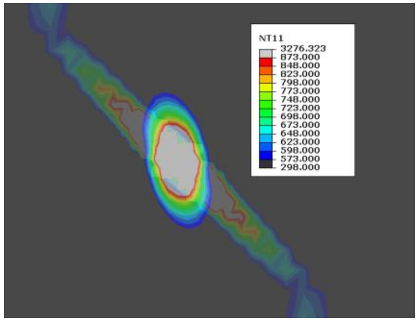
Lightning computational simulation

- ABAQUS for direct effect in an integrated fuel tank
- EMA3D for indirect effect in whole aircraft

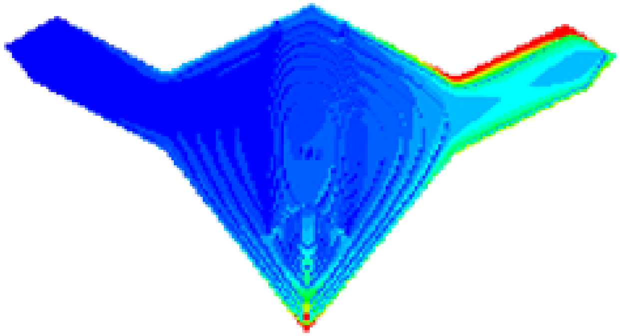




(b) Determination of delamination area from ultrasonic C-scan result



Simulation (ABAQUS)



Simulation (EMA3D)

Pitot-type air intake vs anti-icing system

- The **Pitot-type air intake** (with good total pressure recovery) **requires** an (electro-thermal) **anti-icing** system.

EC 725 Super Puma: Pitot intake

Bell 430: side mounted intake

Agusta A109: flush side intake

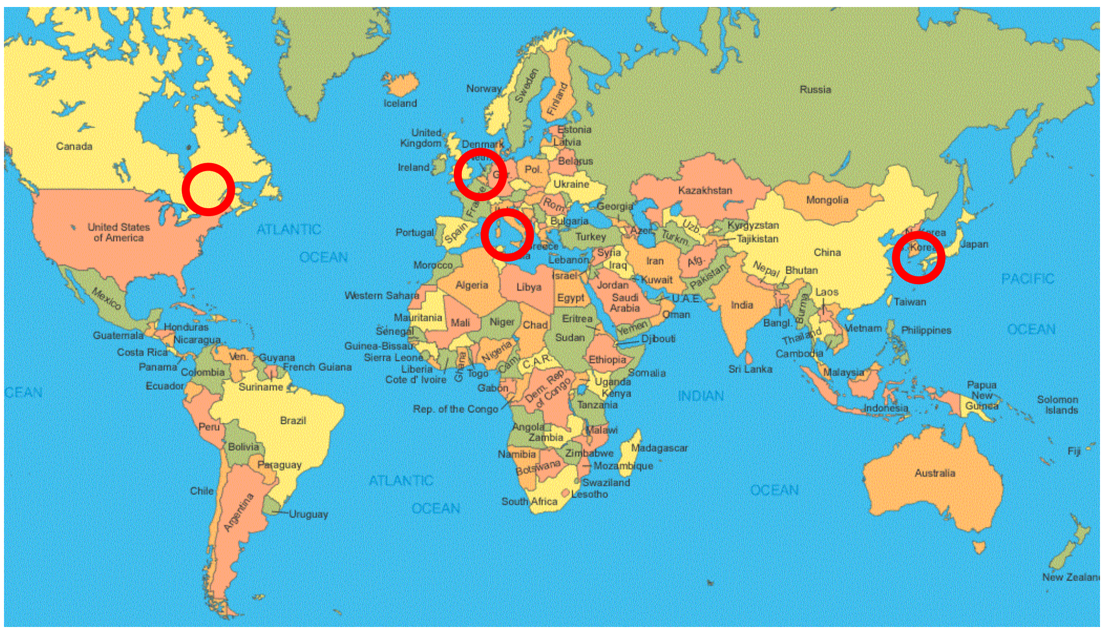
Mill Mi 24: radial inflow intake

Total pressure recovery
Distortion
Foreign object impact

Icing (ice ingestion
130 g for 2 minutes)

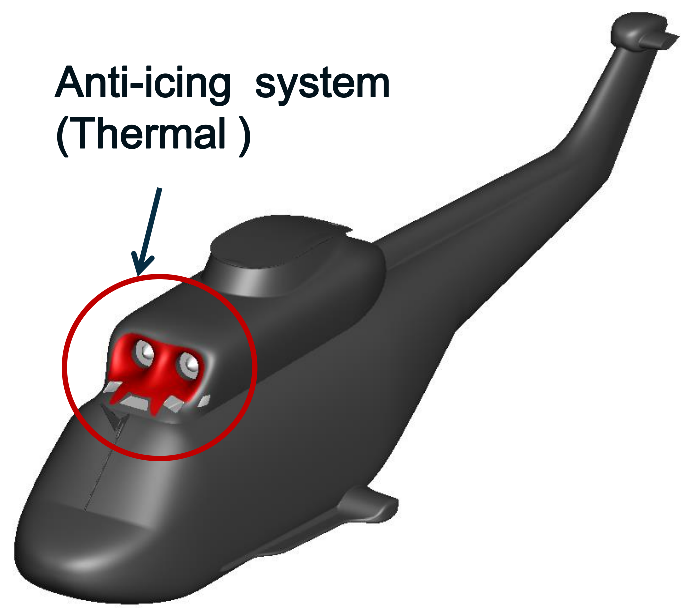
Pitot-type air intake vs anti-icing system

- **Korean Utility Helicopter (Surion)** program (through Korea Aerospace Industries Ltd.).
- Also in association with National Aerospace Laboratory of the Netherlands (NLR; icing wind tunnel model design).

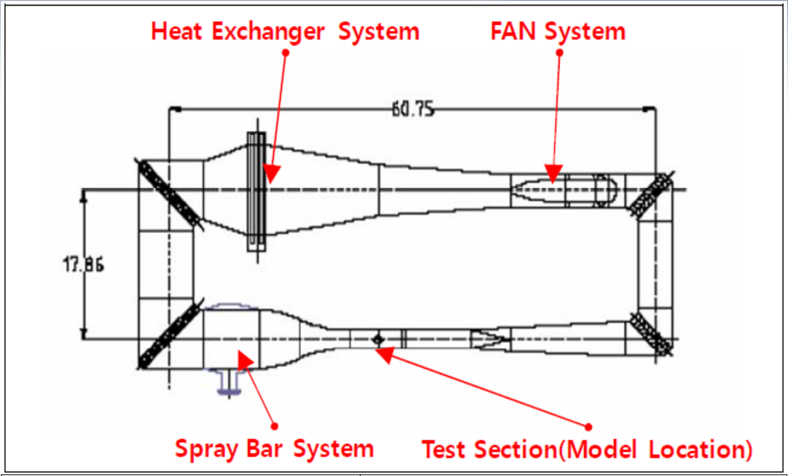


Pitot-type air intake vs anti-icing system

- Korean Surion helicopter with Pitot-type dynamic intake



Icing wind tunnel testing

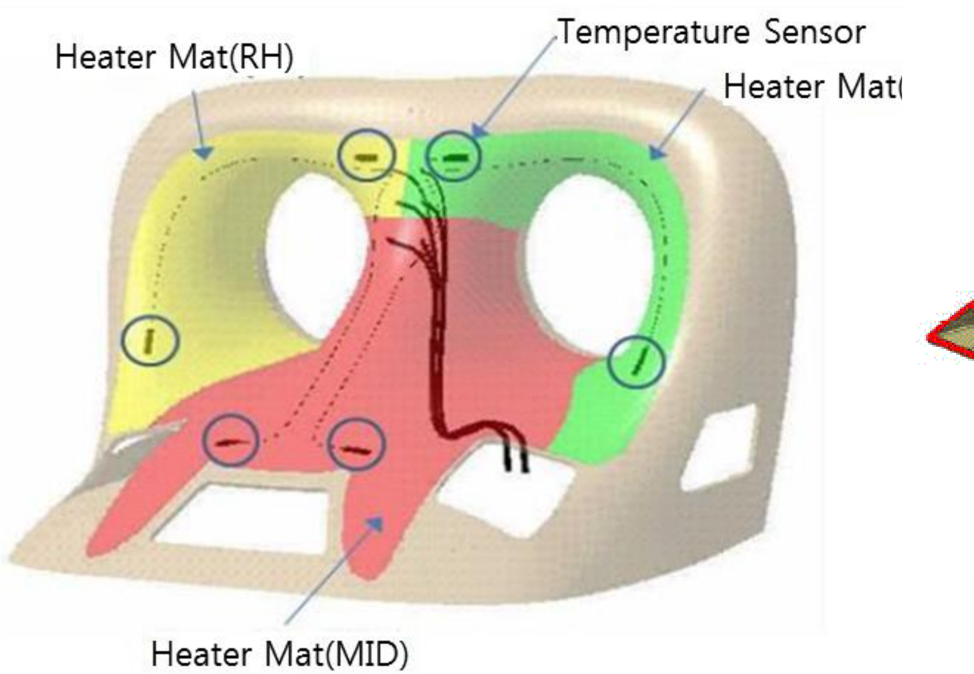


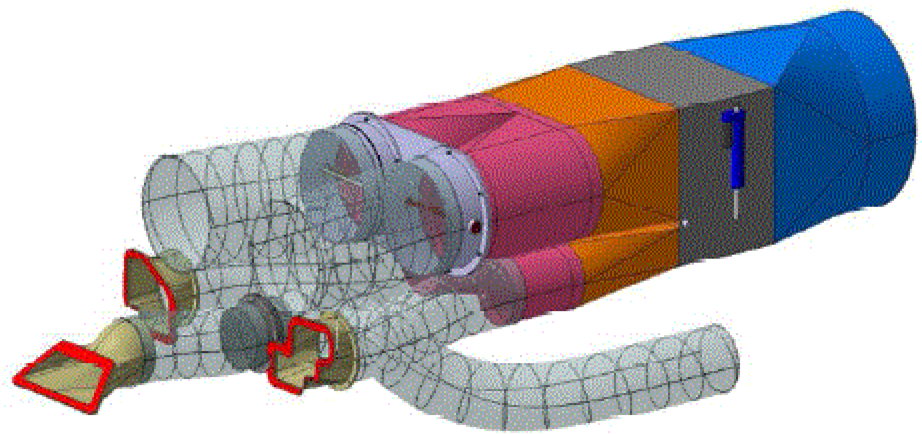
Item	Specification
Test Section Size	2.35 m (H) x 3.6 m (W) x 8.30 m (L)
Tunnel Type	Closed Circuit
Power	4.0 MW
Maximum Velocity	80 m/s (155.5 kts)
Mach Range	0.25
Temperature	-32 ℃
Pressure Altitude	7000 m (22,965 ft)

CIRA (Italian Aerospace Research Centre), CAPUA, Italy
1~2 cases / day; each case costing five digits $ (December, 2011)

Test model of electro-thermal anti-ice system

National Aerospace Laboratory of the Netherlands

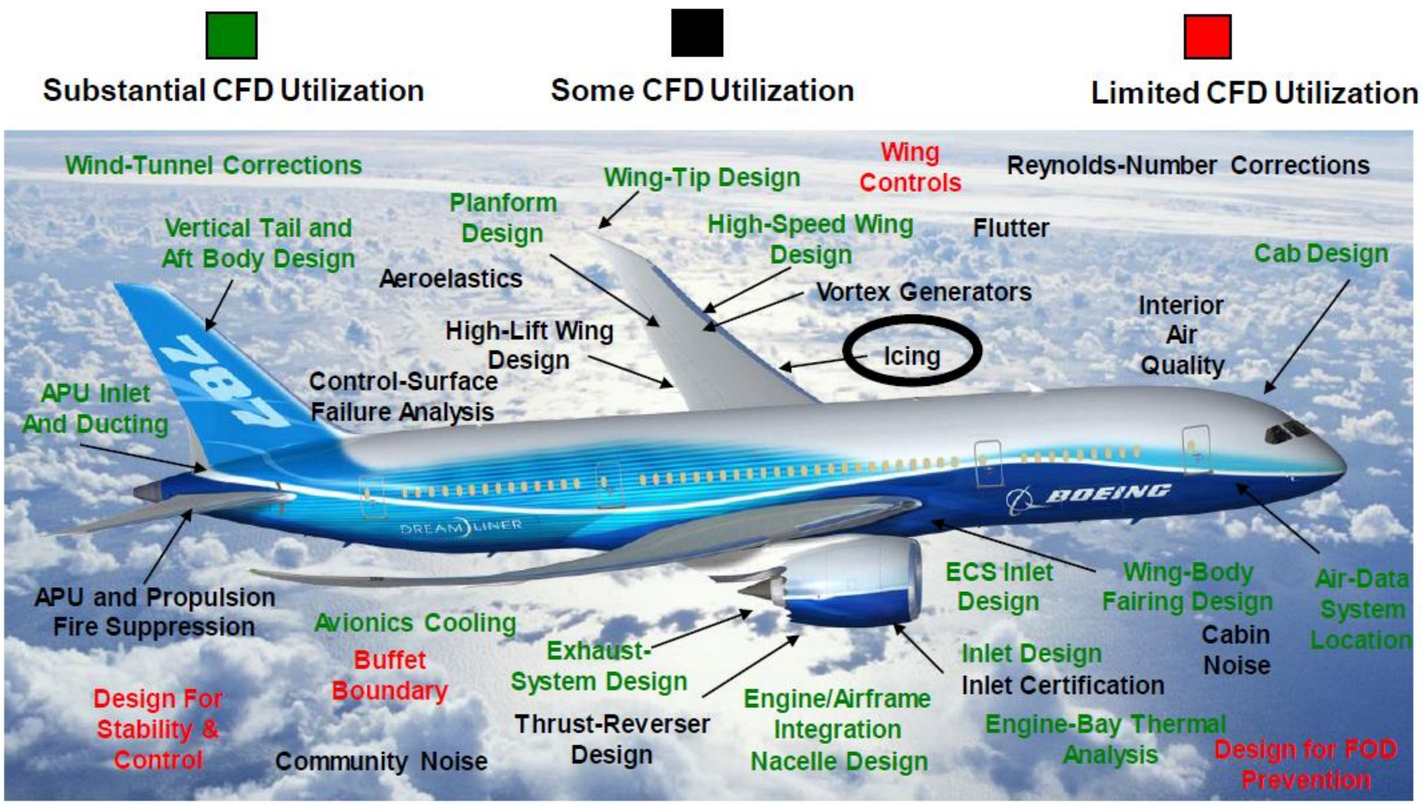




[Flow Suction System]

Icing computational simulation

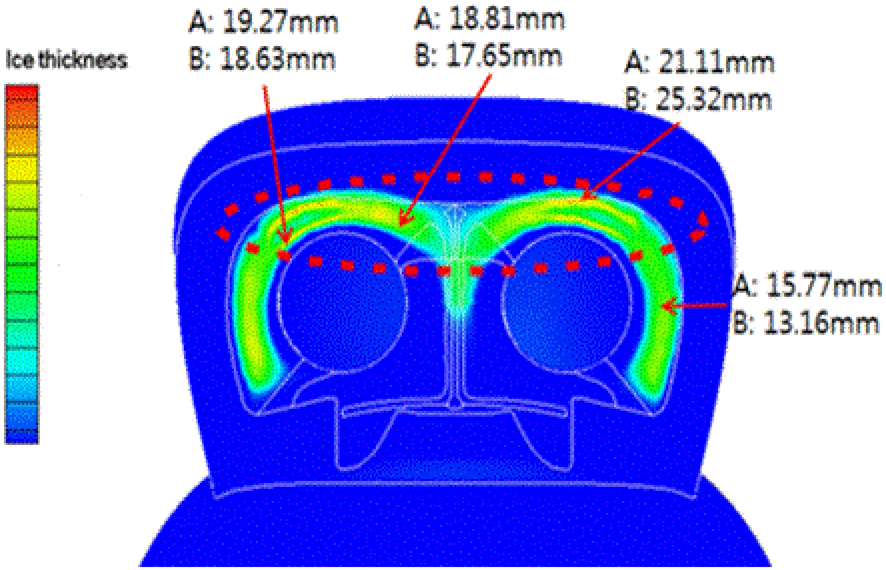
- CFD contributions to aircraft design (Boeing, 2014)

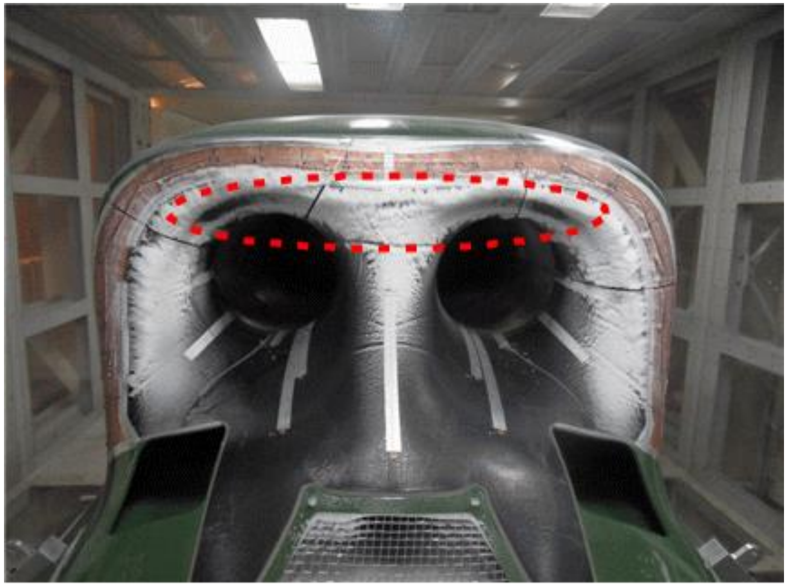


Enablers: High Performance Computing,
Physics-based Design/Analysis/Optimization

Icing computational simulation

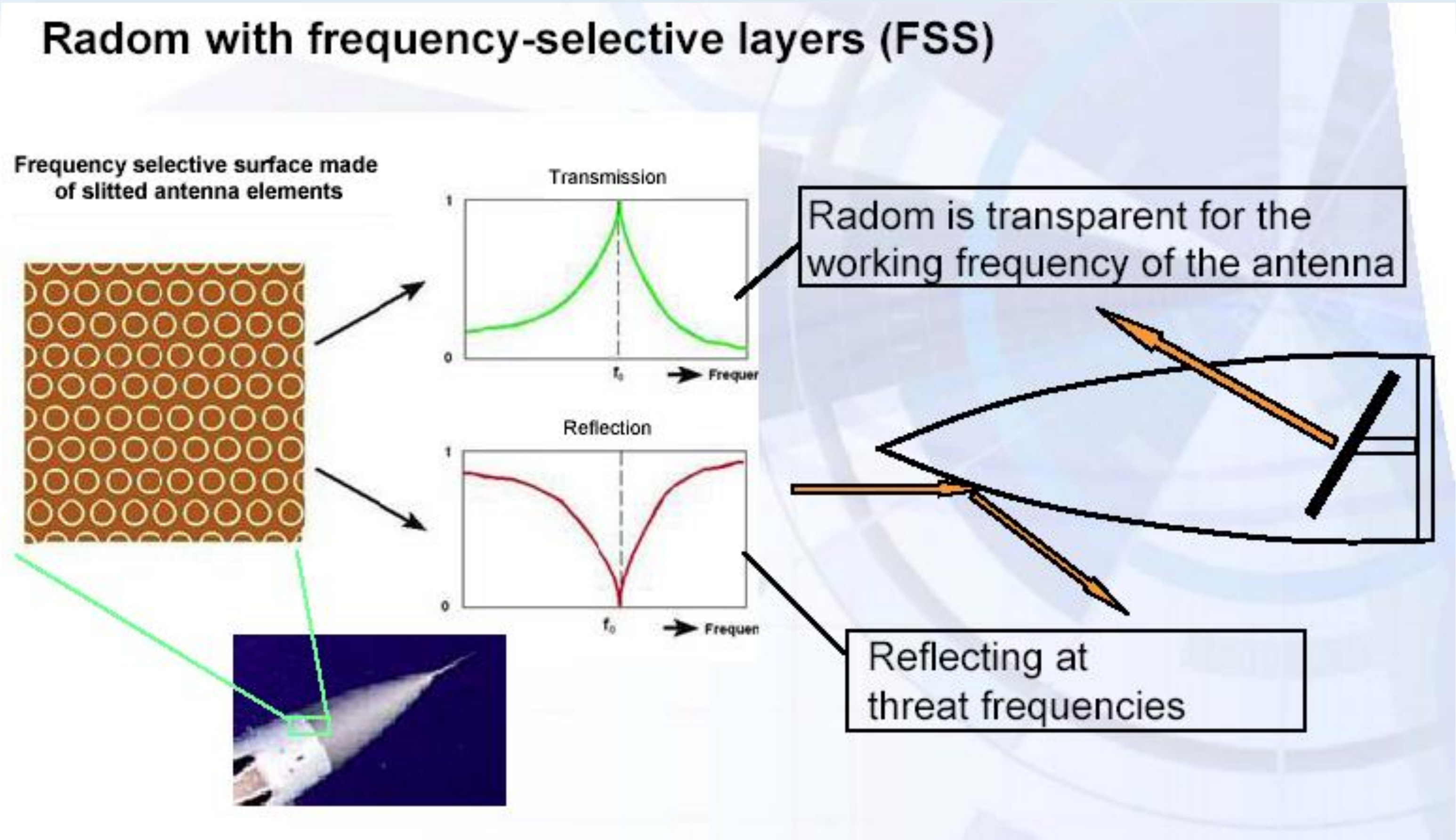
- Validation of icing CFD (FENSAP-ICE) prediction (heat-off mode)





The upper parts of intake with largest ice accretion.
Narrow region with small ice accretion between these parts.

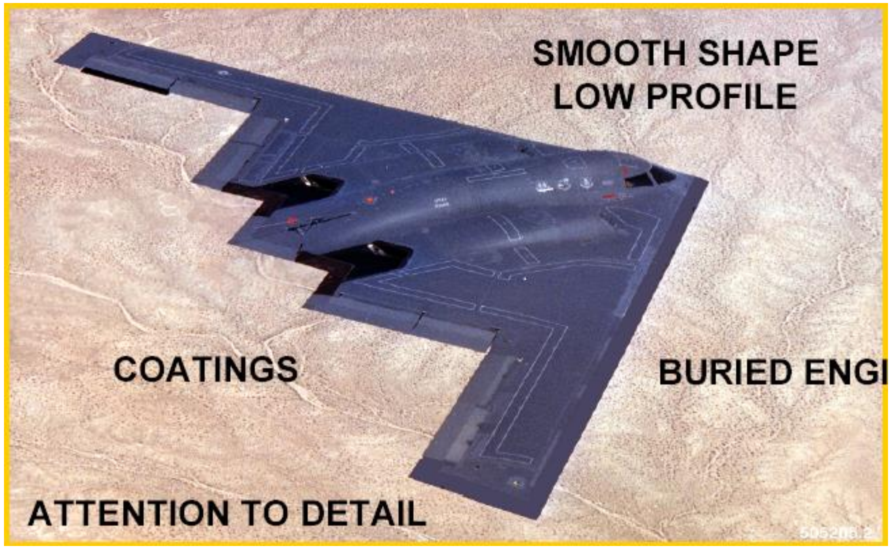
Contradictory requirements for Radome



RF low observability vs aerodynamic performance

- The requirements for radar stealth with **low radar cross section (RCS)** and aerodynamics with **low drag** are contradictory; **faceted** and **streamlined smooth** shapes.

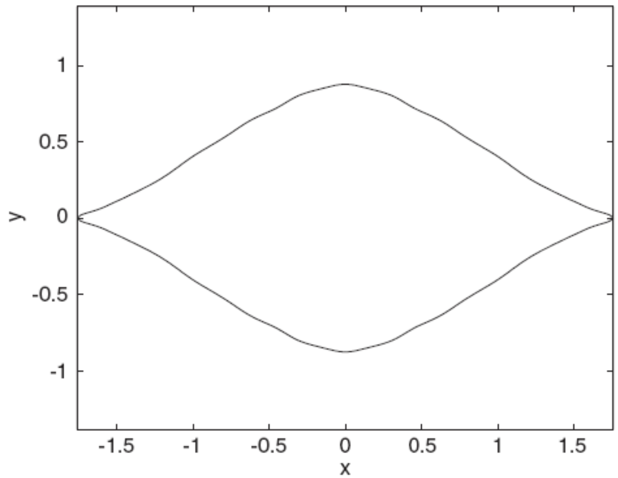
F-117



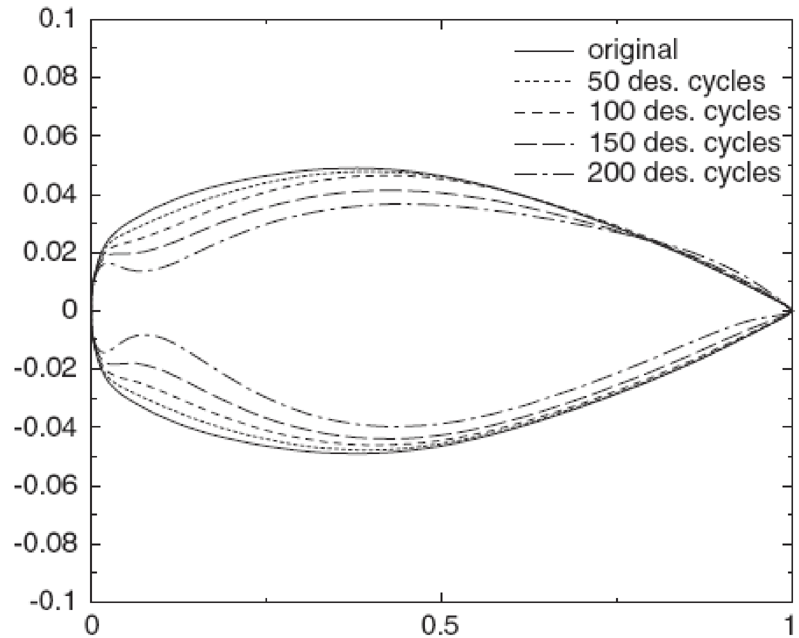
B-2

Simple RCS and drag optimization

- Simple combined (RCS and drag) shape optimization yields **unrealistic airfoil**.



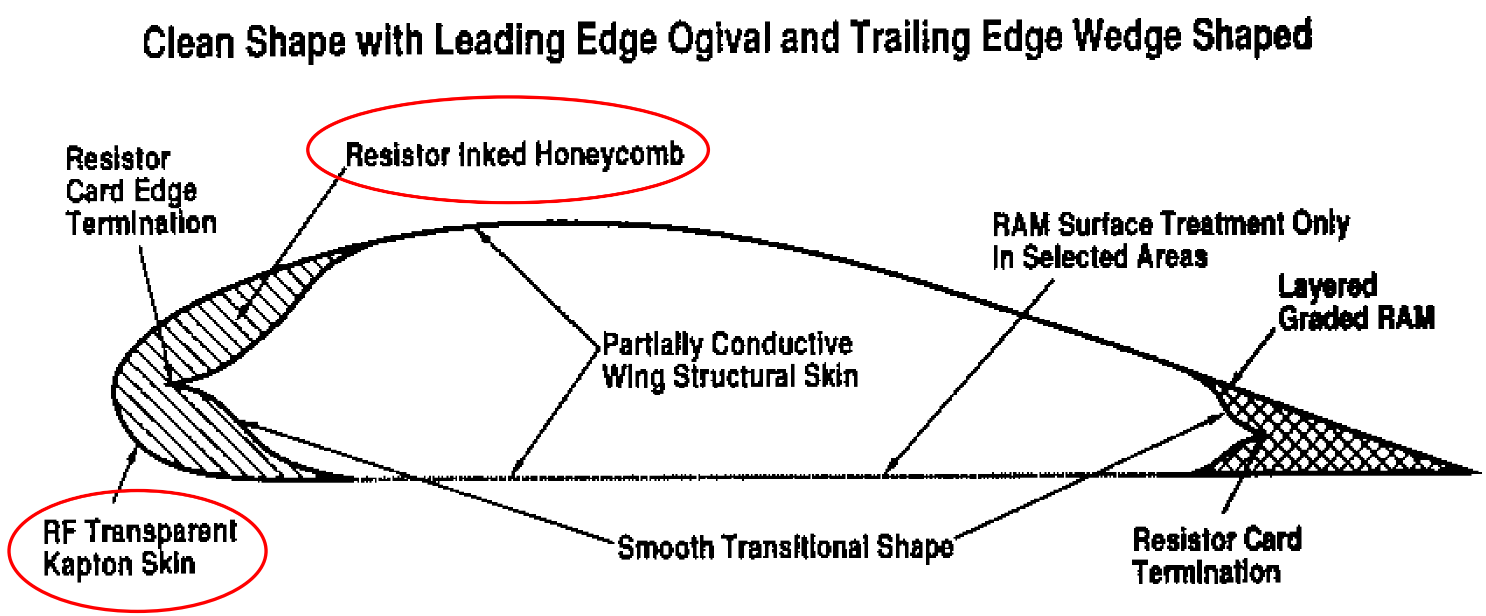
Shape optimized for TE and TM polarization with a penalty



Wing profile from the combined RCS and drag optimization with $\beta = 0.8$

Radar absorbing structure

- An ingenious solution to meet both requirements for radar stealth and aerodynamics is the **radar absorbing structure** (RAS).



Typical RCS edge treatments