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THE FRENCH AEROSPACE LAB

Future of Transport Aircraft from an Aerodynamic Perspective

EUCASS-3AF 2022 conference, 30 June 2022, Lille

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Outline

- Introduction
  - Aircraft performance wrap-up
  - Why flying transonic
- New aircraft concepts overview
- Technologies for drag reduction
- Aeropropulsive performance improvements
- Needs for large scale ground testing
- Conclusion

Introduction

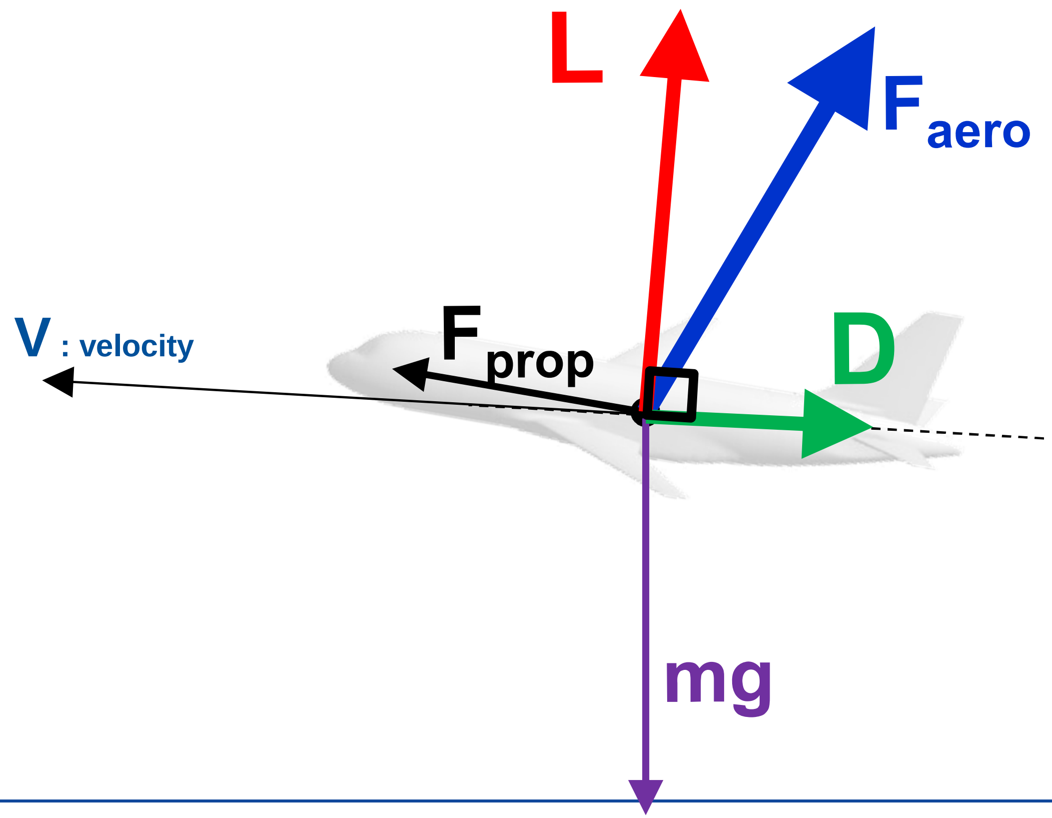
- Context:
  - Current airliners : tube-and-wing, low-wing with two under-wing high bypass ratio turbofans
- Objective:
  - «European Green Deal»: zero net emissions by 2050 and -55% by 2030 (%1990)

- How ?
  - Disruptive concepts : new aircraft architectures, new technologies (propulsion, aerodynamics, …)

- Aerodynamics is a key discipline for moving toward new concepts
  - Strongly contributes to overall aircraft performance
  - Directly impacts handling qualities -> certification, safety standards

Reminder: aerodynamic forces

- Forces equilibrium in steady cruise flight condition:



Lift

$$L = \frac{1}{2} \rho S V^2 C_L$$

Drag

$$D = \frac{1}{2} \rho S V^2 C_D$$

Lift over drag ratio

$$\frac{L}{D} = \frac{C_L}{C_D}$$

Bréguet-Leduc formula

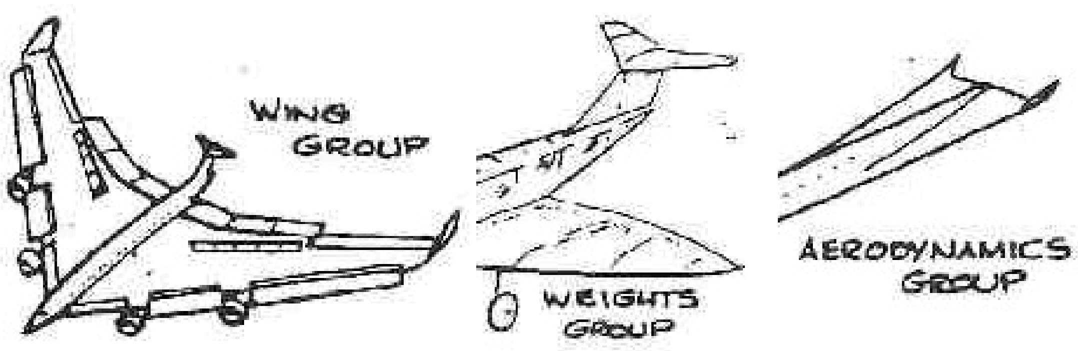
Aerodynamic

Structures

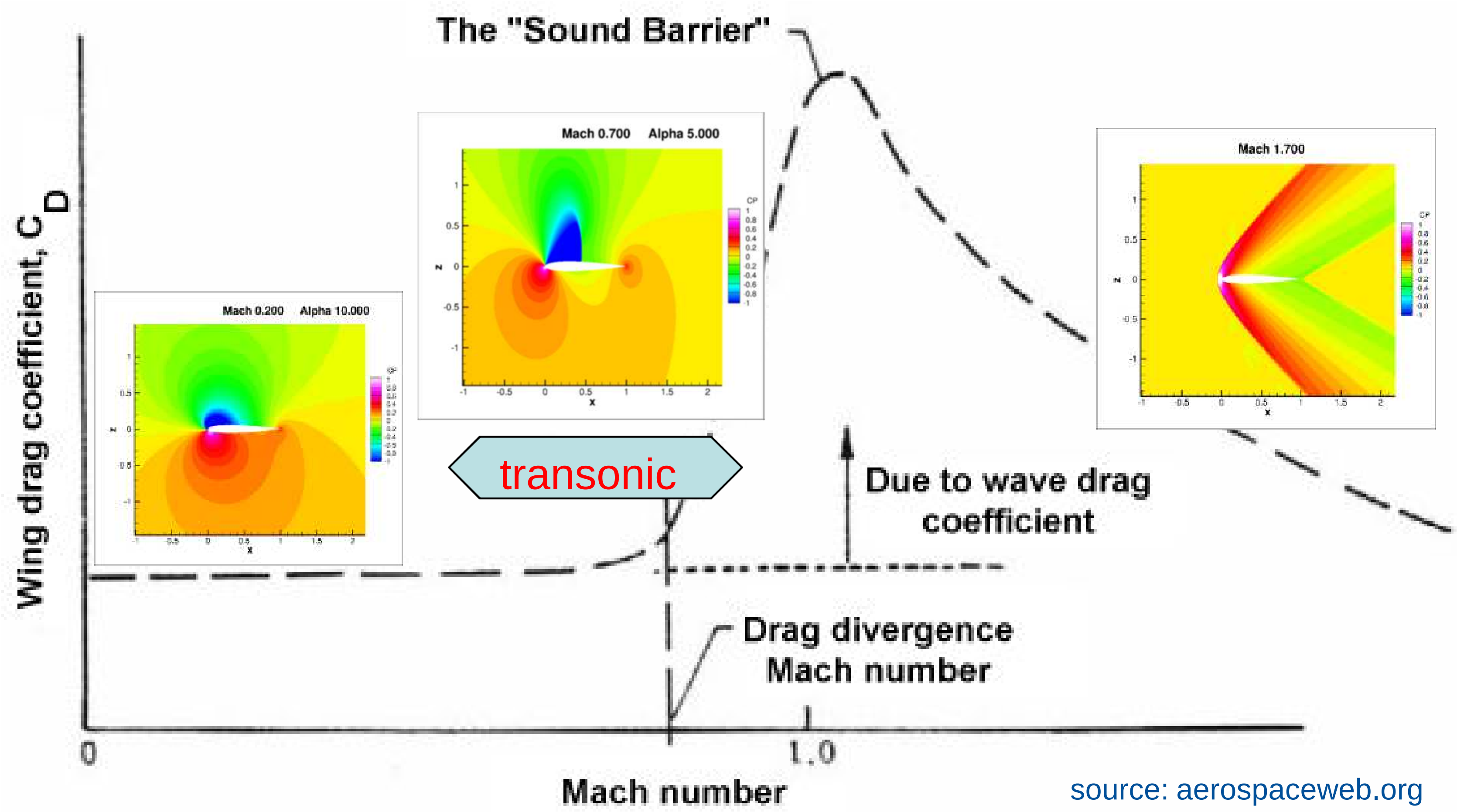
$$Range = c\ M\frac{L}{D}\frac{1}{g.SFC}\ln\left(\frac{W_{empty}+W_{fuel}}{W_{empty}}\right)$$

Propulsion

M: Mach number
g: gravity constant
SFC: specific fuel consumption (kg/s/dN)



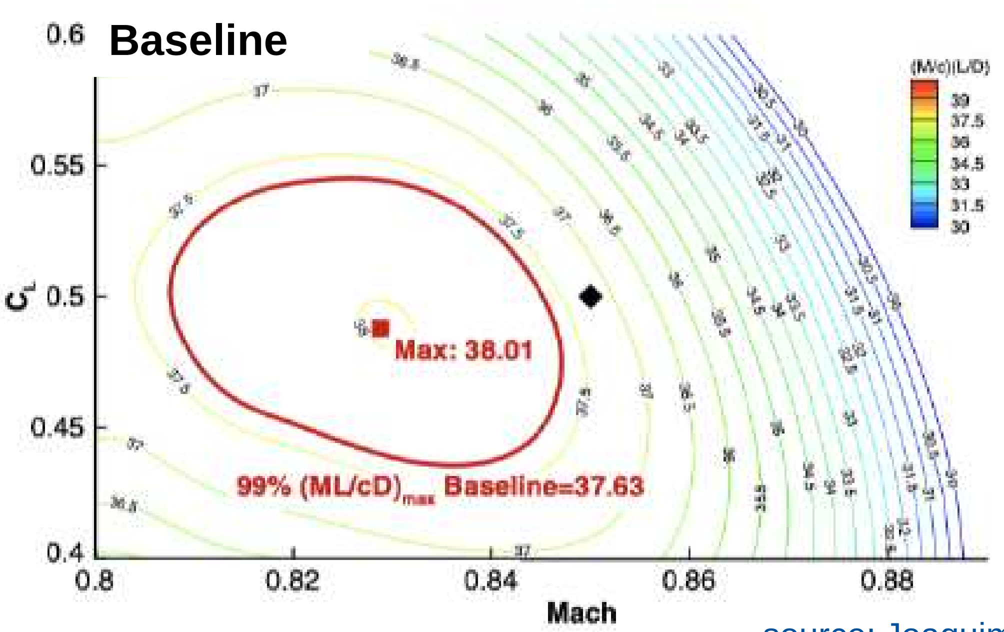
Choice of cruise speed

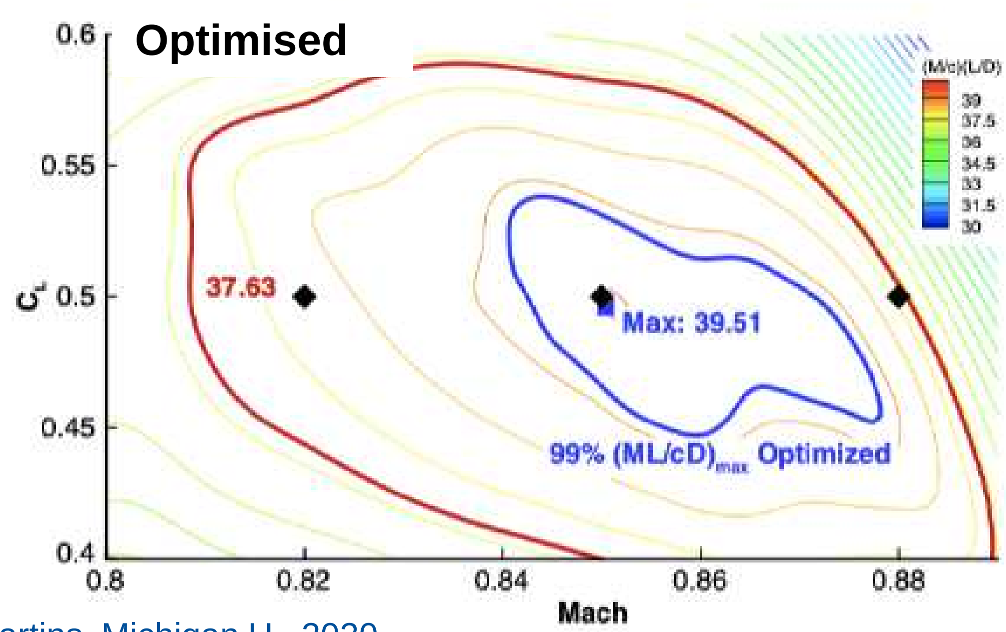


source: aerospaceweb.org

Why cruising at transonic speed

…to maximise $M\frac{L}{D}$ in: $$Range = c\ M\frac{L}{D}\frac{1}{g.SFC}\ln\left(\frac{M_{empty}+M_{fuel}}{M_{empty}}\right)$$





source: Joaquim Martins, Michigan U., 2020

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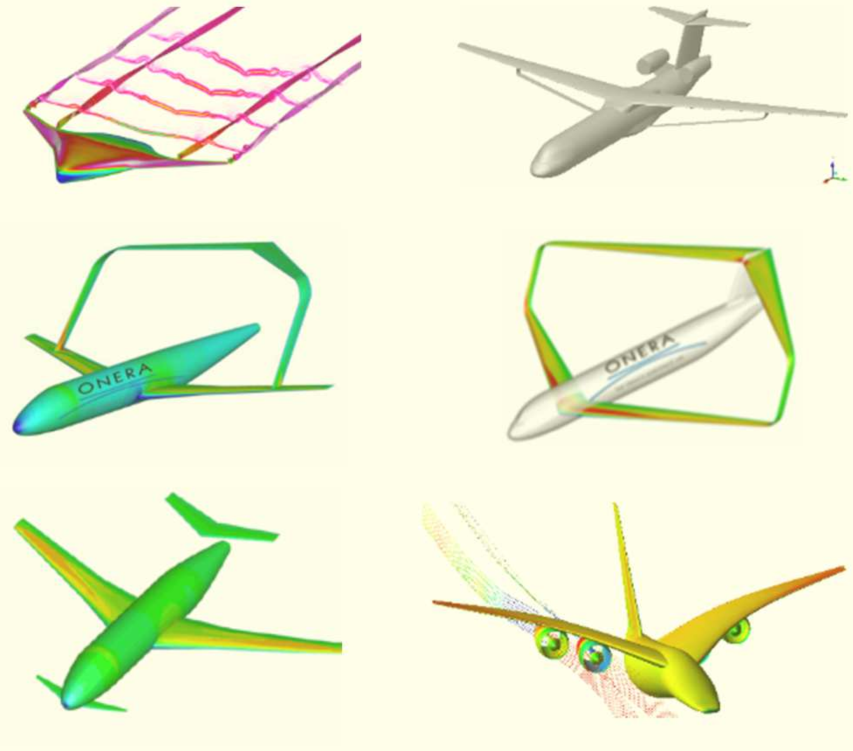
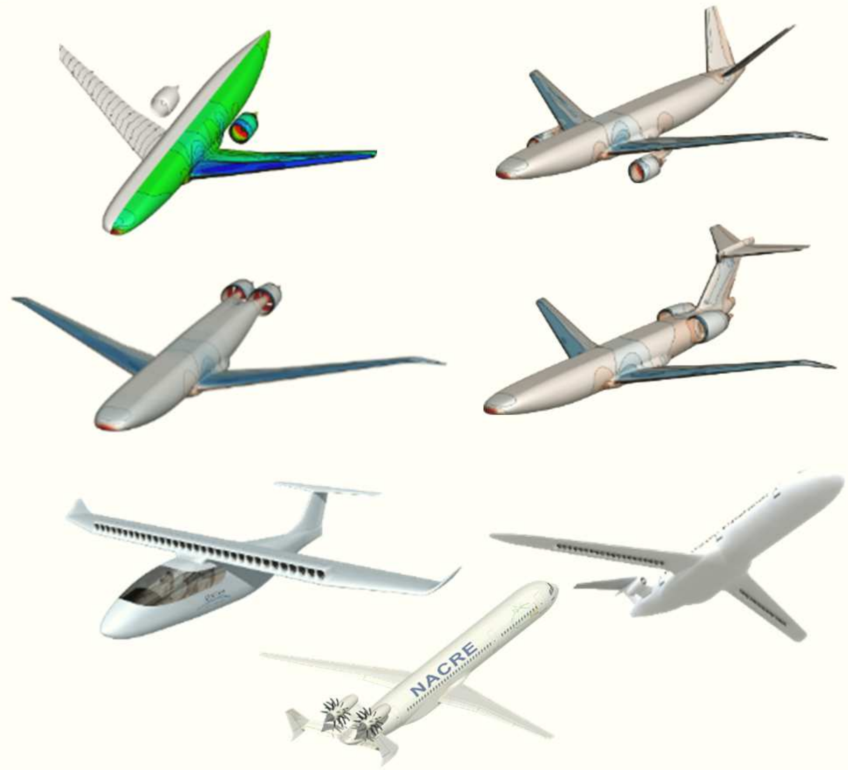
New aircraft concepts under investigation



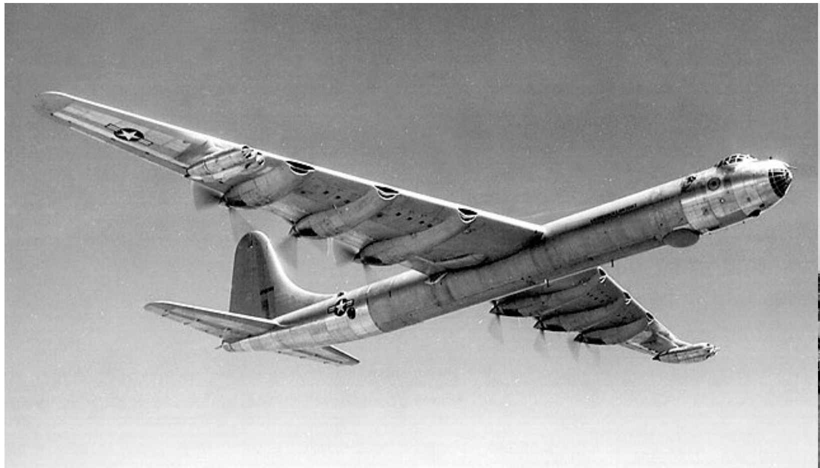
Airframe architecture



Propulsion integration

(Not so) new concepts

Some old ideas & concepts to be revisited with new technologies



Convair, 1946

Northrop, 1948

Hurel-Dubois, 1957

Blériot III, 1906

Heppner, 1941

NASA, 1960

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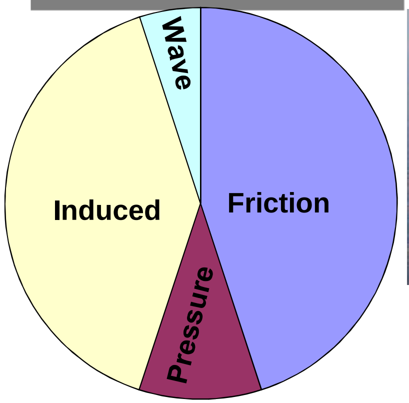
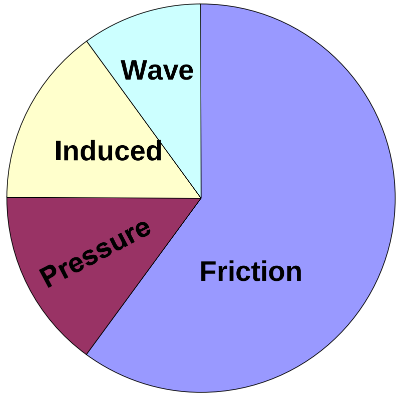
Drag breakdown

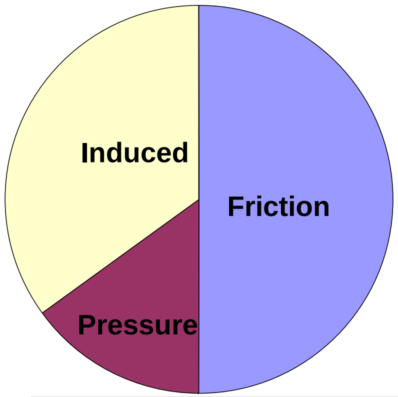
Airliners

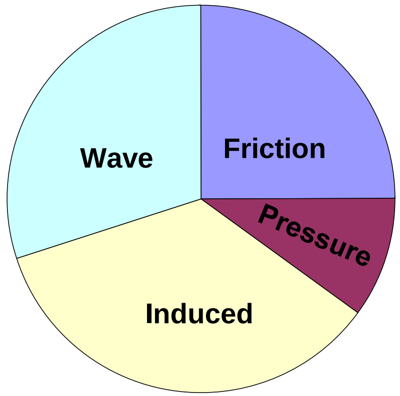


Bizjets



- Friction drag
- Viscous pressure drag
- Induced drag
- Wave drag





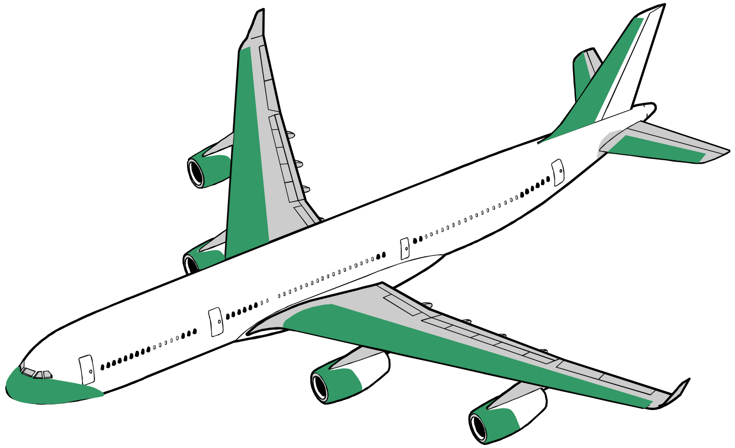
Regional A/C

Concorde

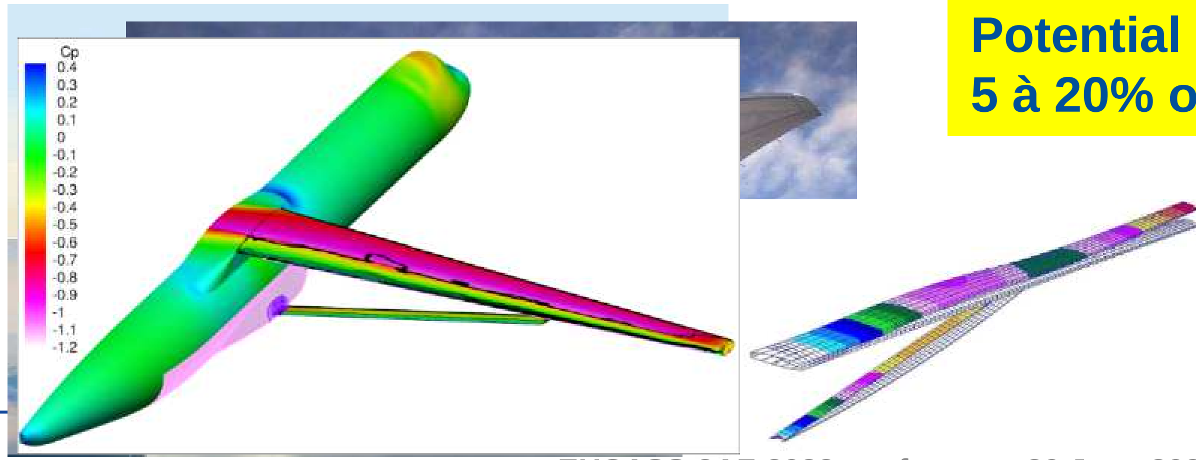
Drag reduction technologies

- Reducing friction drag: laminar flow, riblets,…

Potential gains:
5 à 15% of CD_{tot}



- Reducing lift-induced drag: higher wing aspect ratio, wingtip devices



Potential gains :
5 à 20% of CD_{tot}

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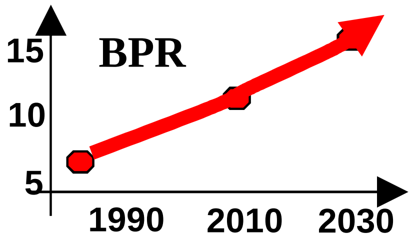
Improving propulsive efficiency (1/2)

$$\eta_{prop} = \frac{2\,V_\infty}{V_\infty + V_{jet}}$$

- **Engine Techno**
  - **UHBR turbofan (BR=By-pass Ratio)**



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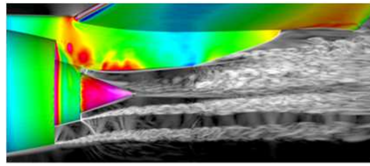
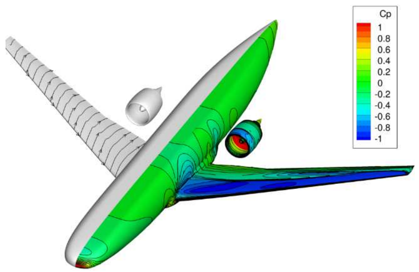
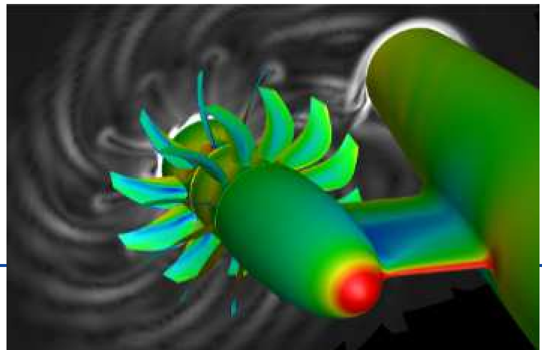


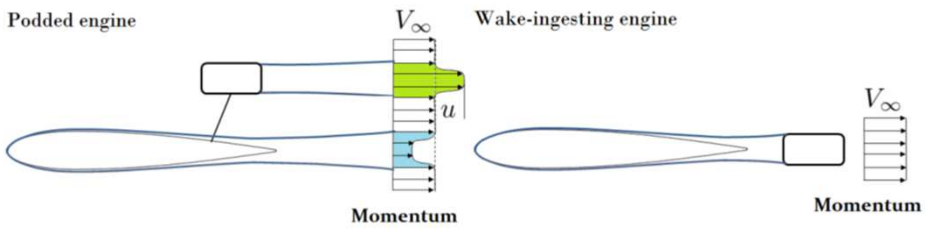


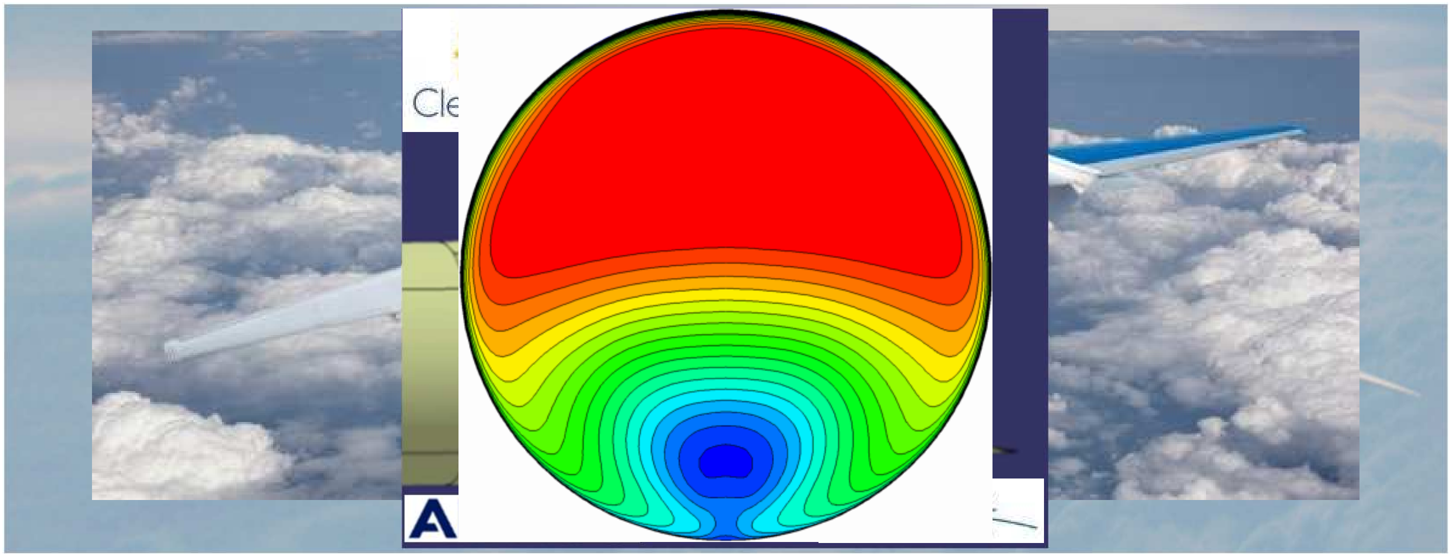
  - **Turboprop, Open Rotor and now Open Fan**



Improving propulsive efficiency (2/2)

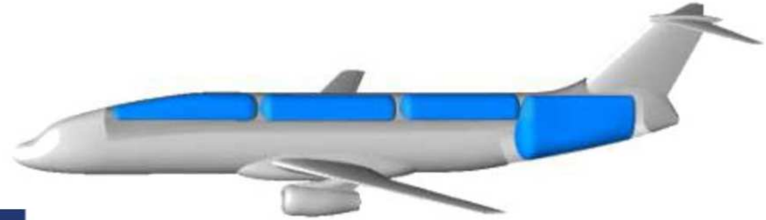
- **Engine integration**
  - **Boundary layer ingestion**





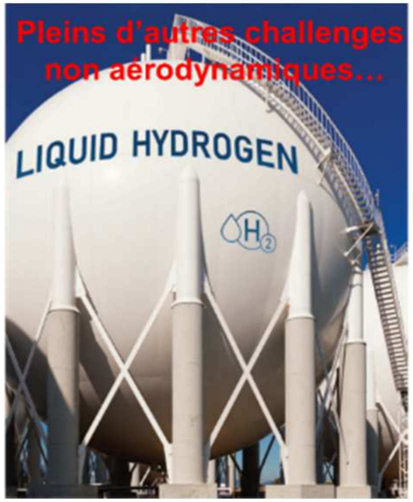
Electric distributed propulsion

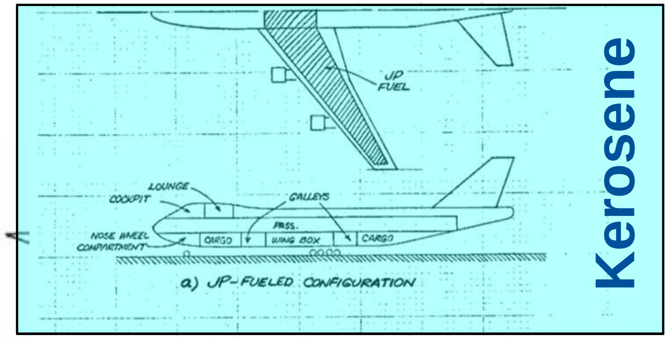
Cryoplane/LH2 propulsion : aerodynamic challenges



- Motivation : zero CO_2
- LH2 versus kerosene:

	LH2	Kerosene
Specific energy (MJ/kg)	142	43
Density (kg/m^3)	70	800
Volumic energy density (GJ/m^3)	10	34





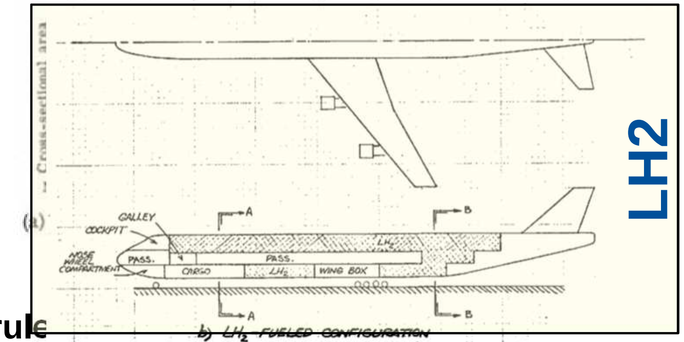


FIGURE 3. – 450 PASSENGER, 3500 N.MI. AIRPLANE.

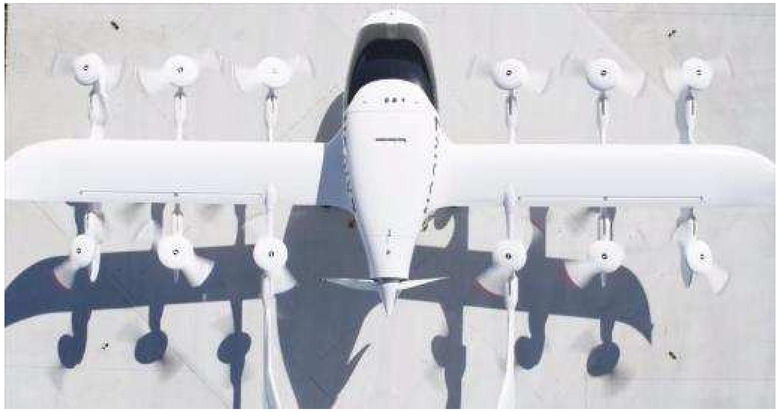
Area rule

- Challenges for aerodynamics:
  - Fuel volume : x 3 à x 4
  - Fuel tanks: pressurized and insulation
    - Wing tank : difficult
    - Fuselage tanks
  - Wetted surface↑ → Cd_{visc}
  - Volume ↑ → Cd_{wave}

-1 à -2 count on L/D

Distributed propulsion + Vertical Take-Off & Landing

- **With fixed wing**



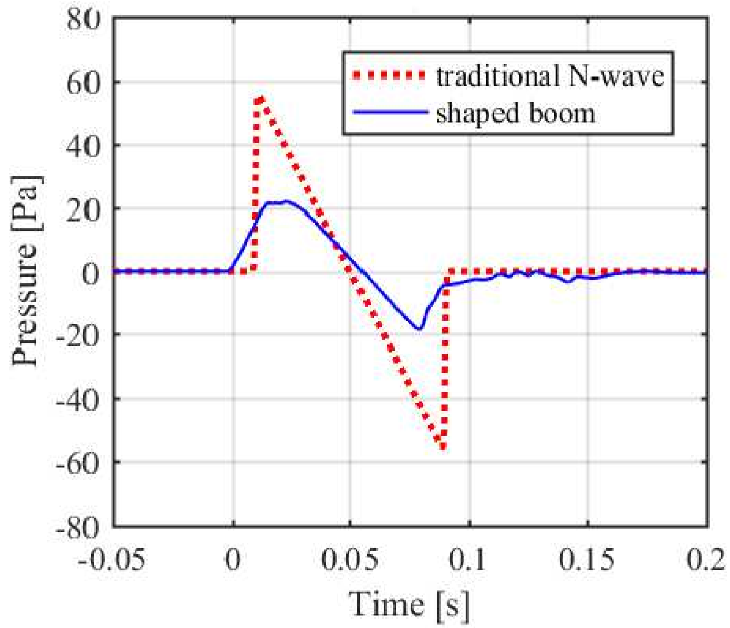
Low-Boom Supersonic aircraft

- Renewed interest for supersonic civil aircraft

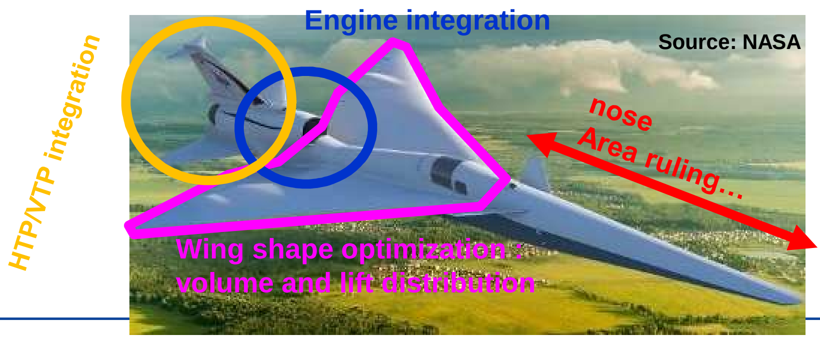
- Aerodynamic challenges

  Suppressing sonic boom (no «N-wave » on ground)

  … while offering good aerodynamic performances (cruise L/D)



- Aerodynamic shaping for low-boom



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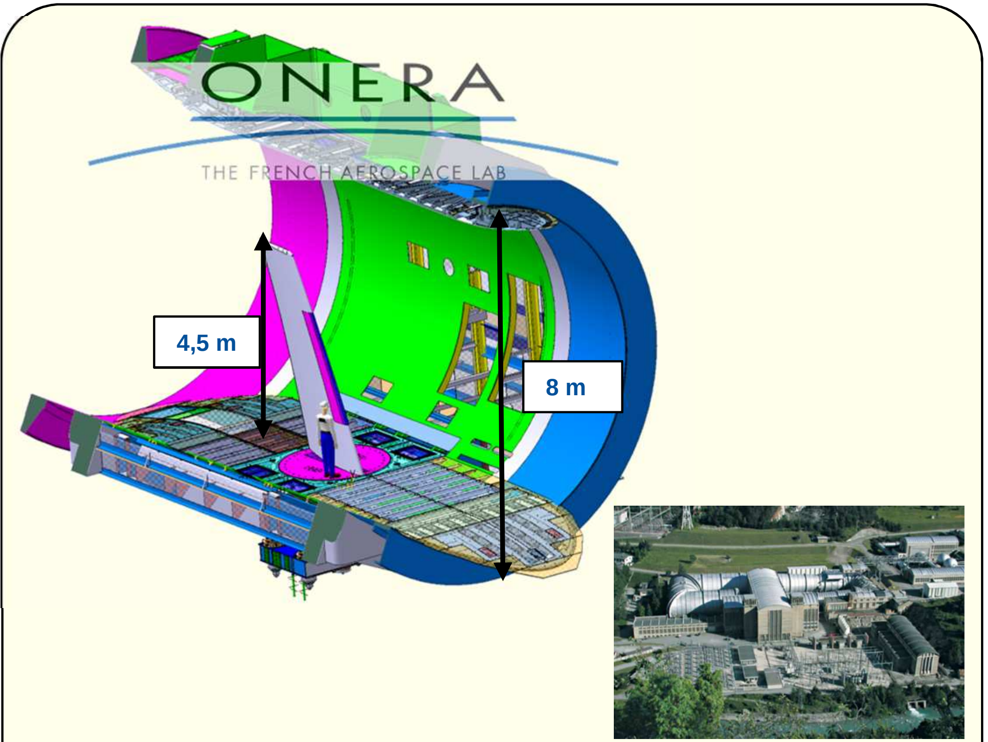
Hybrid Laminar Flow Control maturing through WT tests

- HLFC: promising technology for friction drag reduction that needs ***technology maturing and validation***
- Wind tunnel testing on **large scale models** is needed → HLFC Win project (CleanSky 2)

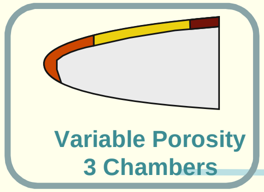


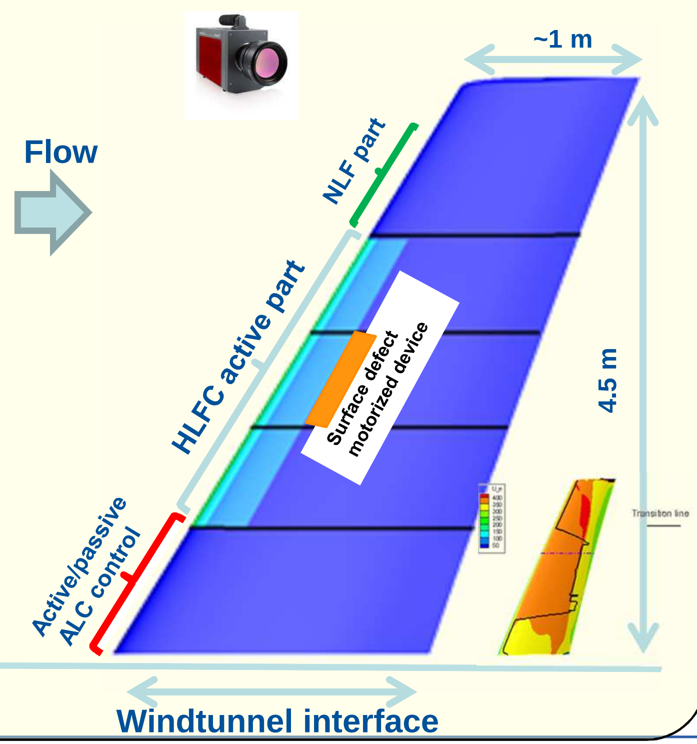
ONERA S1MA: Largest Transonic Atmospheric Wind tunnel
(Greenest wind tunnel in the world!)

IR diagnostics
for transition prediction

M ~ 0,83
Re_u~10.10^6 [1/m]
very low T_u

Realistic suction panels
(provided by Aernnova)
3-chamber layout
in the chordwise direction

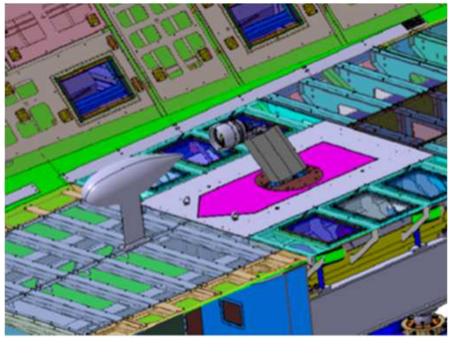


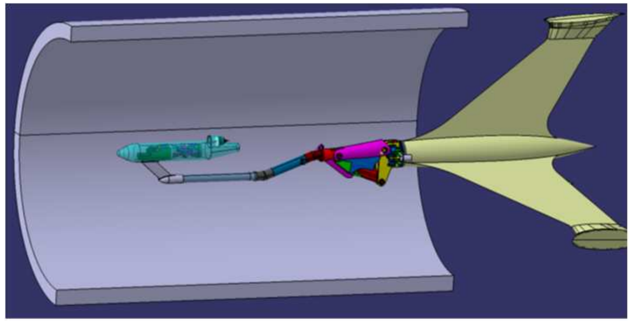


BLI technology maturing through experiments

dgac

The long way from the original idea to the actual application on the aircraft





L1 tests (2012):
- RAPRO2 (DGAC)
- ONERA L1 (2.4 m)
- Low-speed
- BLI performance benefits assess. (academic conf.)

BLINI tests (2022):
- SUBLIME (DGAC)
- ONERA S3Ch (0.8 m)
- Transonic
- Flow characterisation in BLI inlet

BLIST tests (2023):
- SUBLIME (DGAC)
- ONERA S1MA (8 m)
- Transonic
- BLI performance benefits assess. (academic conf.)

SAPAS tests (2024):
- SUBLIME/BEIR (DGAC)
- ONERA S1MA (8 m)
- Transonic
- BLI performance benefits assess. (realistic conf.)

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Conclusions

- Today's societal and environmental challenges calls for **technological breakthrough and innovative new concepts**

- ***Aerodynamics is a key discipline*** for the emergence of new aircraft concepts delivering high level of performances and high levels of safety

- ***Wind-tunnel testing at large scale*** is essential to bring any aerodynamic technology at sufficient level of maturity and enable future new aircraft concepts

Acknowledgments

Some of the projects illustrated in this presentation were funded by :

- French Civil Aviation Authority (DGAC)
- European Union through Clean Sky 2 Joint Undertaking

Thanks for your attention

Any question?