Development of NOVA Aircraft Configurations for Large Engine Integration Studies

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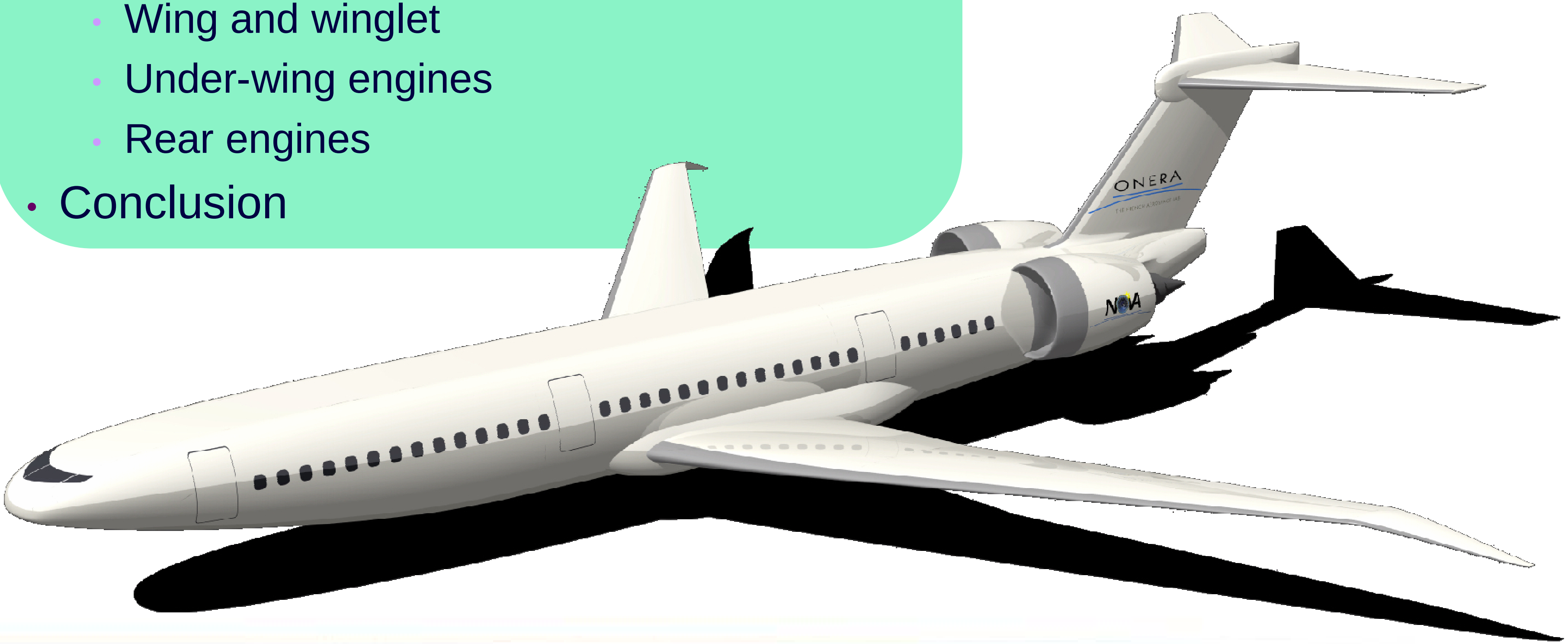
ONERA
THE FRENCH AEROSPACE LAB

return on innovation

Outline

- Introduction
- Conceptual study
- Aerodynamic performance evaluation tools
- Design of the NOVA configurations
  - Fuselage
  - Wing and winglet
  - Under-wing engines
  - Rear engines
- Conclusion



UHBR engine integration challenge

- How to integrate next generation UHBR engines on future aircraft?
  - How big/heavy will 2025 engines be?
  - Where can they be positionned?
  - What benefit on overall performance?

- ONERA developed the NOVA configurations :
  - to evaluate innovative integration options for UHBR engines on relevant airframes
  - to serve as a test case, both numerically and experimentally, for new in-house performance assessment tools

Pros and cons of UHBR engines

+ more fuel efficient	- heavier
+ quieter	- larger

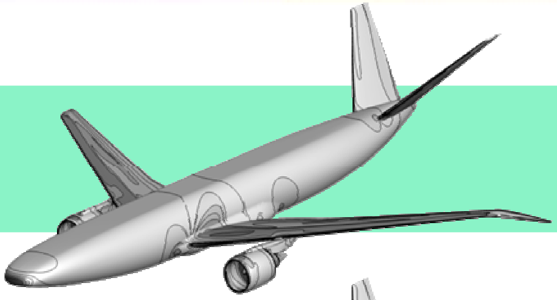
Selected mission

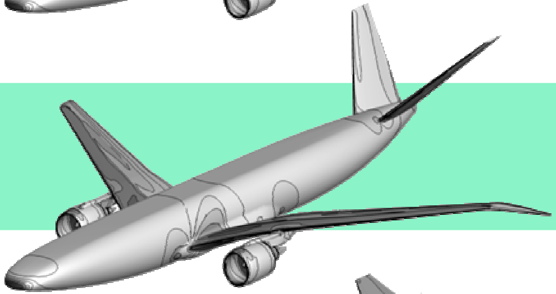
- 180 passengers (in a 2-class layout)
- Mach 0.82 @ 37000 ft
- 3000 NM

FPR=Fan Pressure Ratio
BPR=ByPass Ratio
UHBR=Ultra High ByPass Ratio

Targeted architectures

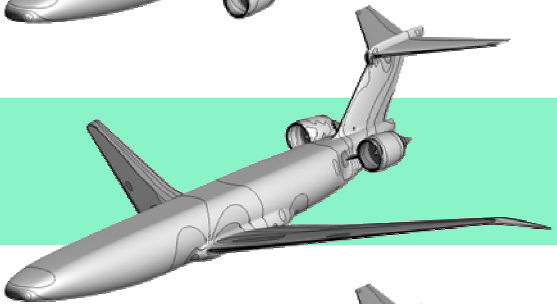
- Baseline
  - Wide lifting fuselage
  - High AR wing
  - Downward oriented winglets
  - UHBR engine

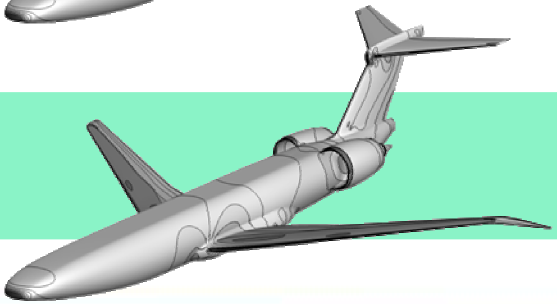




- Gull wing
  - Increased inner wing dihedral to limit landing gear length

- Podded
  - Engines mounted on aft fuselage side





- BLI
  - Engine inlet ingesting the fuselage boundary layer

O.Atinault, Development of the NOVA configurations, 5th SCAD 2015 – Naples

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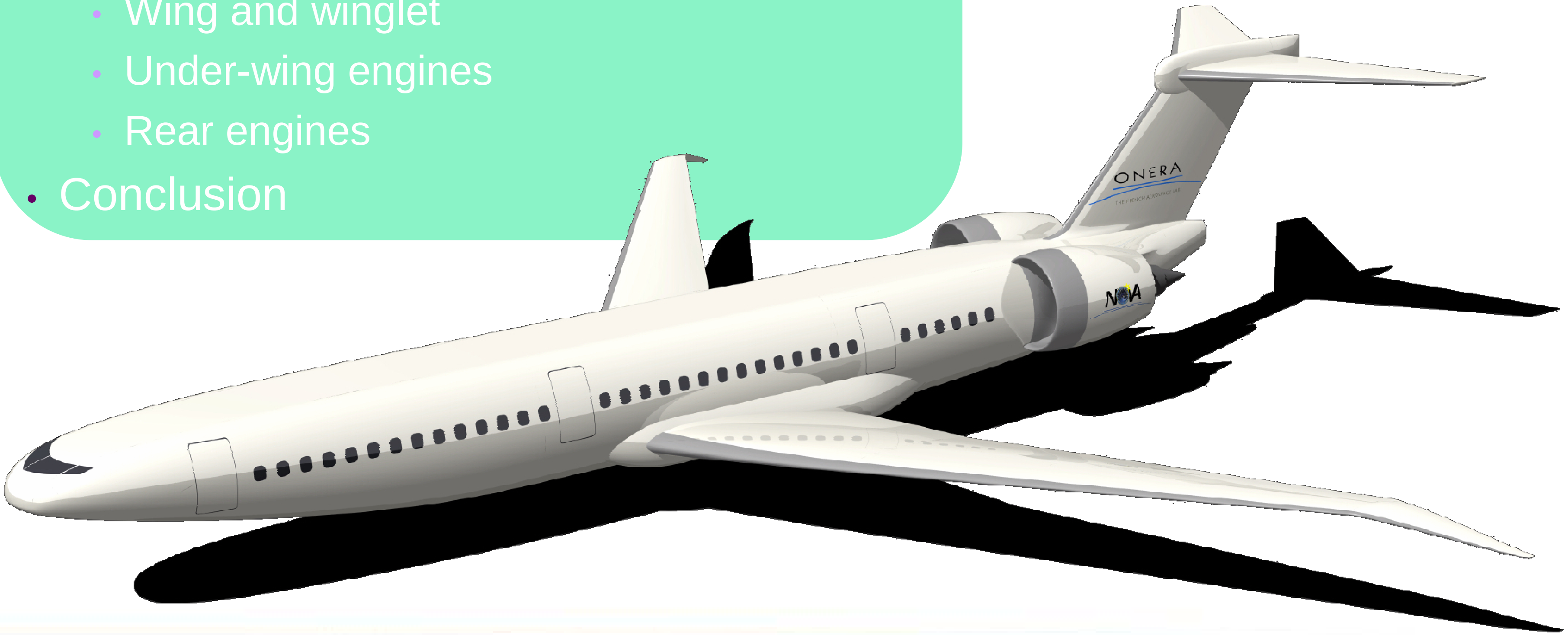

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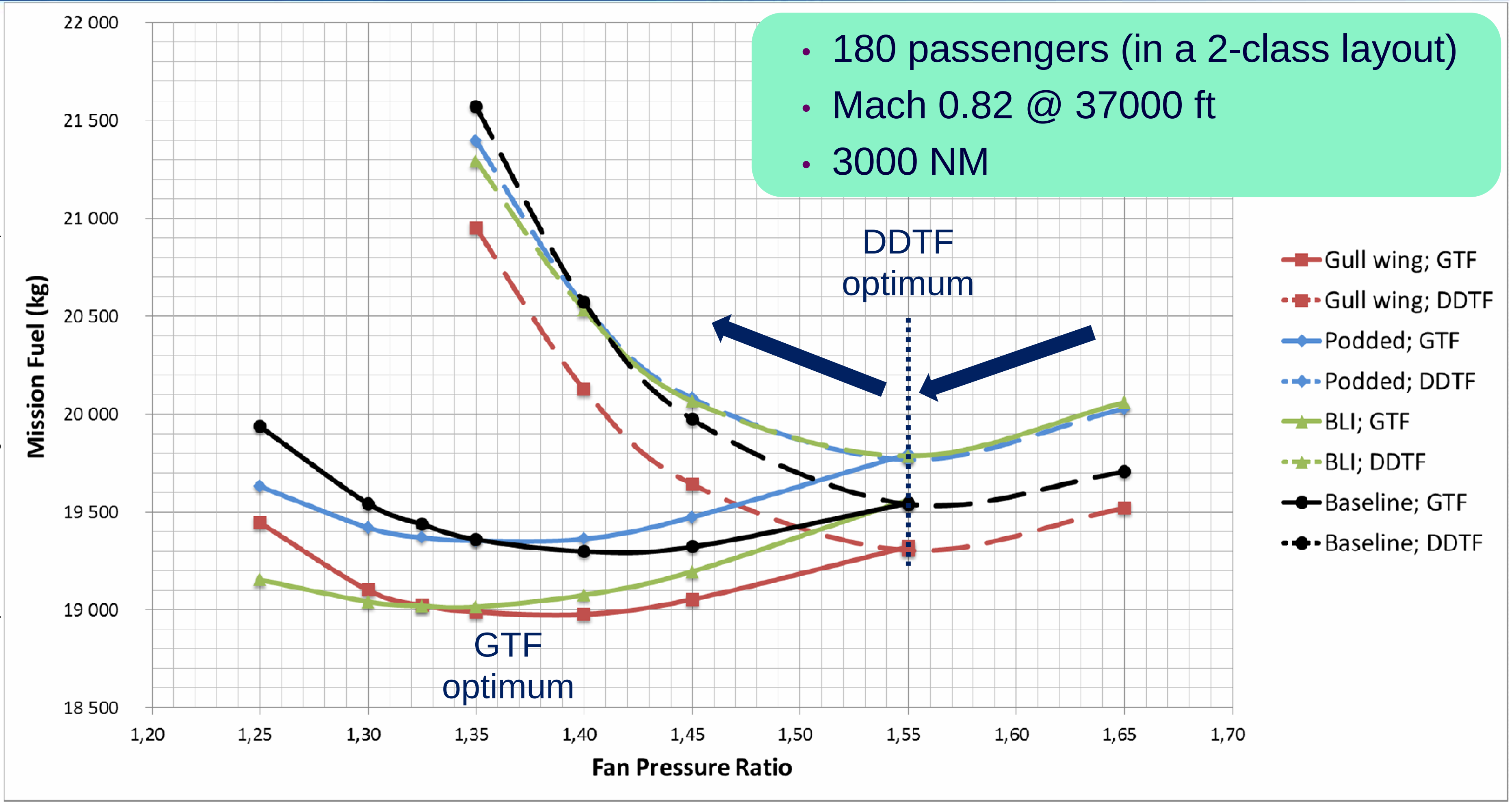
Mission fuel vs FPR



- 180 passengers (in a 2-class layout)
- Mach 0.82 @ 37000 ft
- 3000 NM

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- Switching from DDTF to GTF allows to capitalize on the potential of lower FPR for propulsive efficiency improvement

DDTF=Direct-Drive TurboFan
GTF=Geared TurboFan

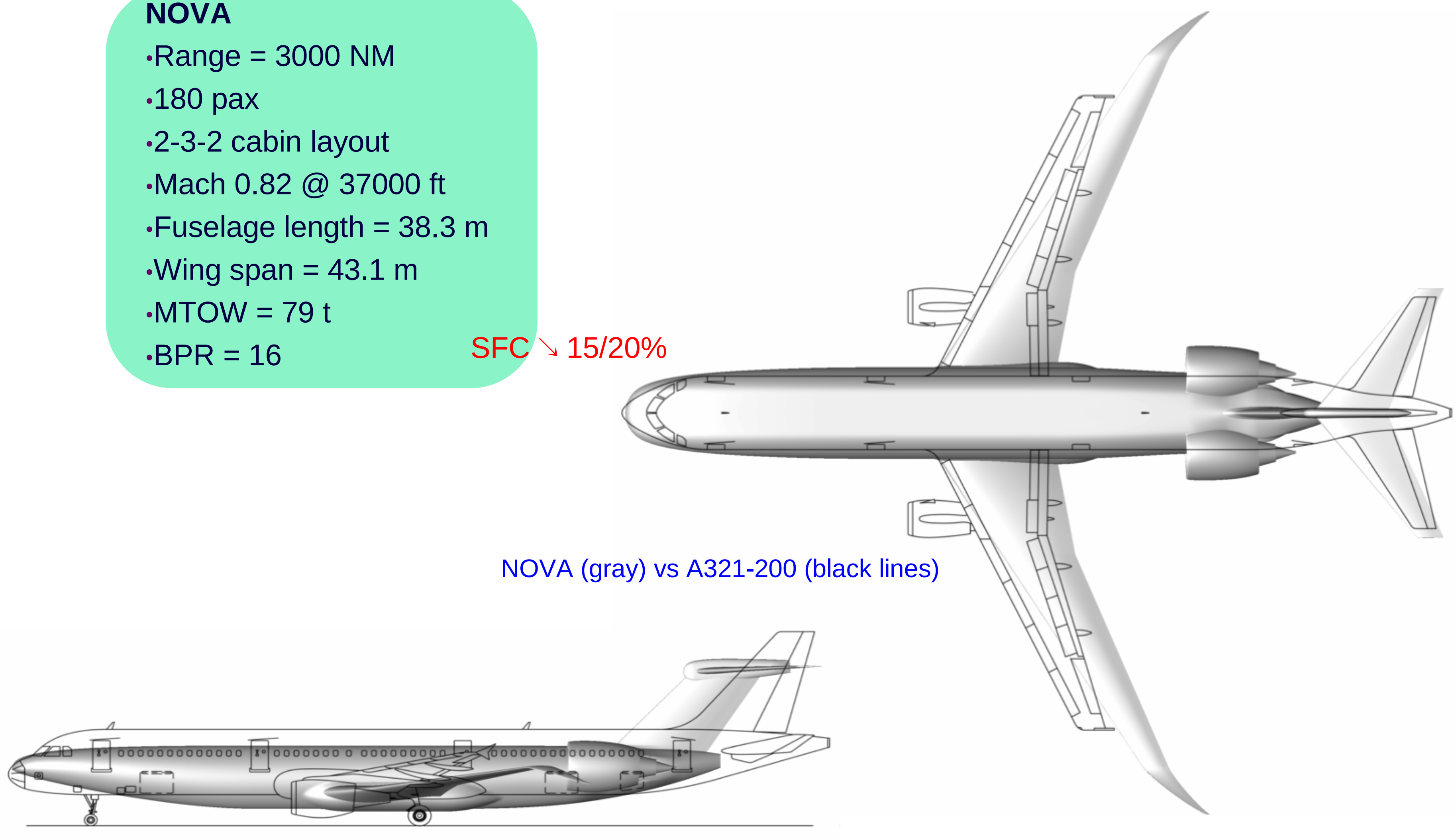
Dagget, D., Brown, S., and Kawai, R., "Ultra-Efficient Engine Diameter Study," NASA/CR-2003-212309.
Guynn, M., et al., "Engine Concept Study for an Advanced Single-Aisle Transport," NASA/TM-2009-215784.
Guynn, M., et al., "Refined Exploration of Turbofan Design Options for an advanced Single-Aisle Transport," NASA/CR-2011-216883.

NOVA compared to existing aircraft

NOVA

- Range = 3000 NM
- 180 pax
- 2-3-2 cabin layout
- Mach 0.82 @ 37000 ft
- Fuselage length = 38.3 m
- Wing span = 43.1 m
- MTOW = 79 t
- BPR = 16

SFC ↘ 15/20%



NOVA (gray) vs A321-200 (black lines)

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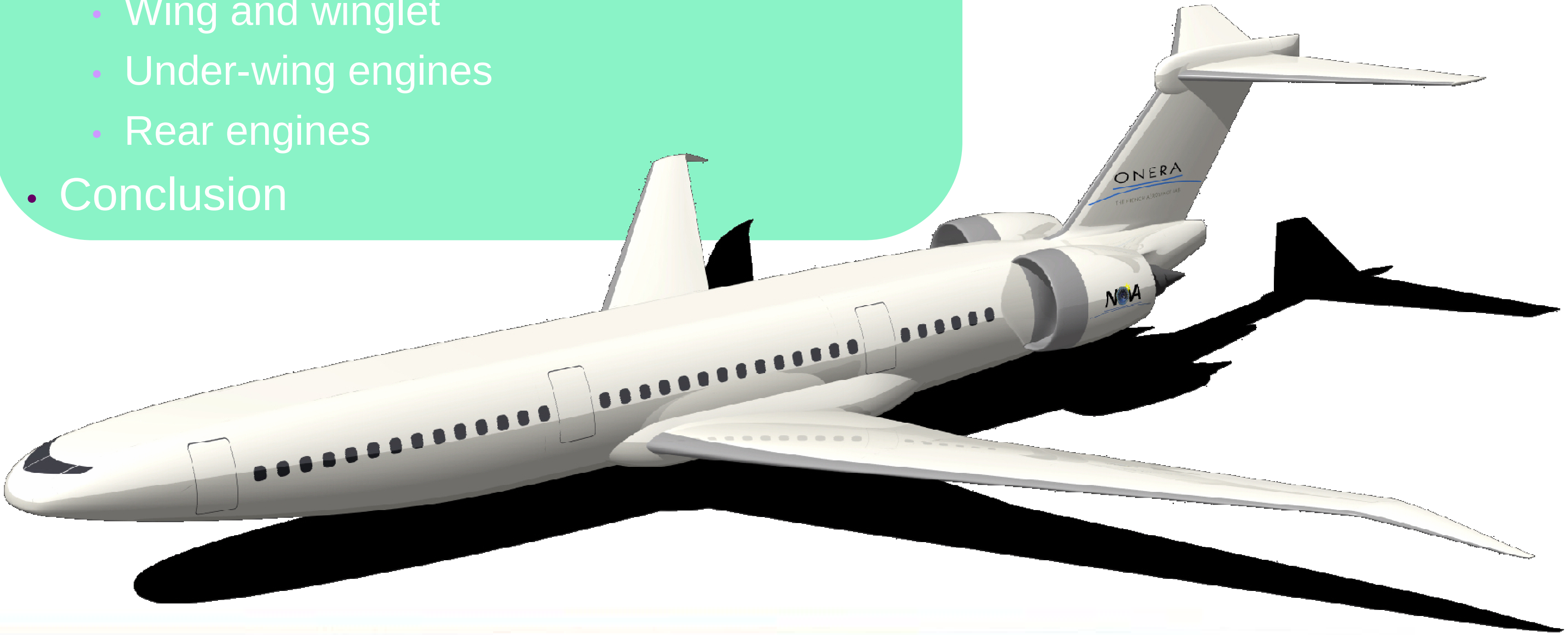
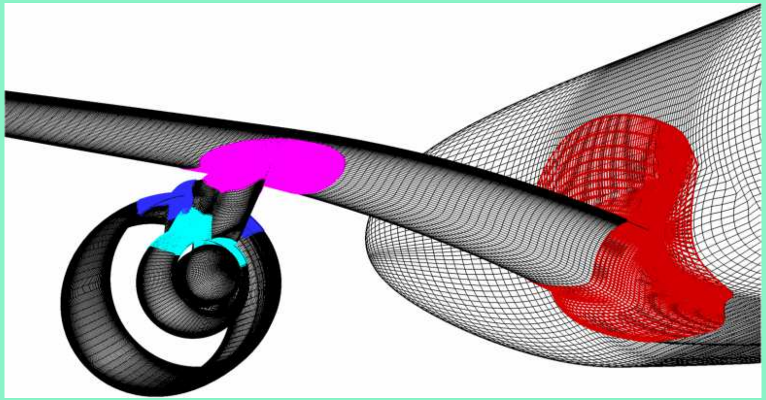


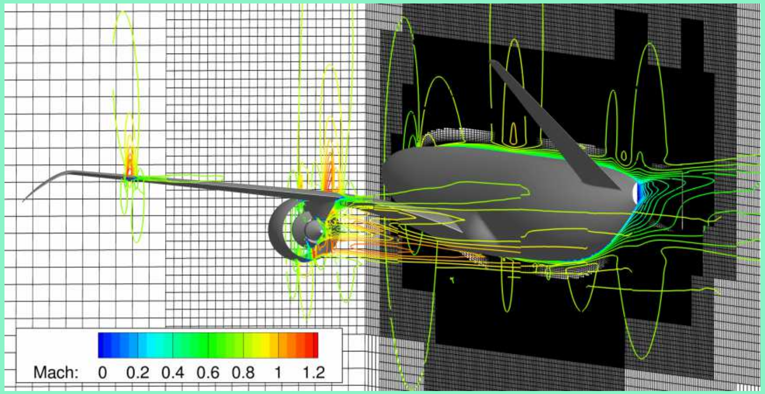
CFD mesh generation

- Use of structured grids for their capacity to accurately predict flow features
- Use of advanced grid generation methods to reduce the mesh generation effort



- A complex geometry is split into simpler elements (ex: fuselage/wing/nacelle/pylon…)
- Each element is meshed separately (Chimera approach)
- Collar grids are used to mesh the junction regions

- Off-body adaptive Cartesian grids are then automatically generated around the geometry using an octree approach
- Near body and off-body grids are finally assembled
- CFD calculations are carried out with the in-house ***elsA*** flow solver



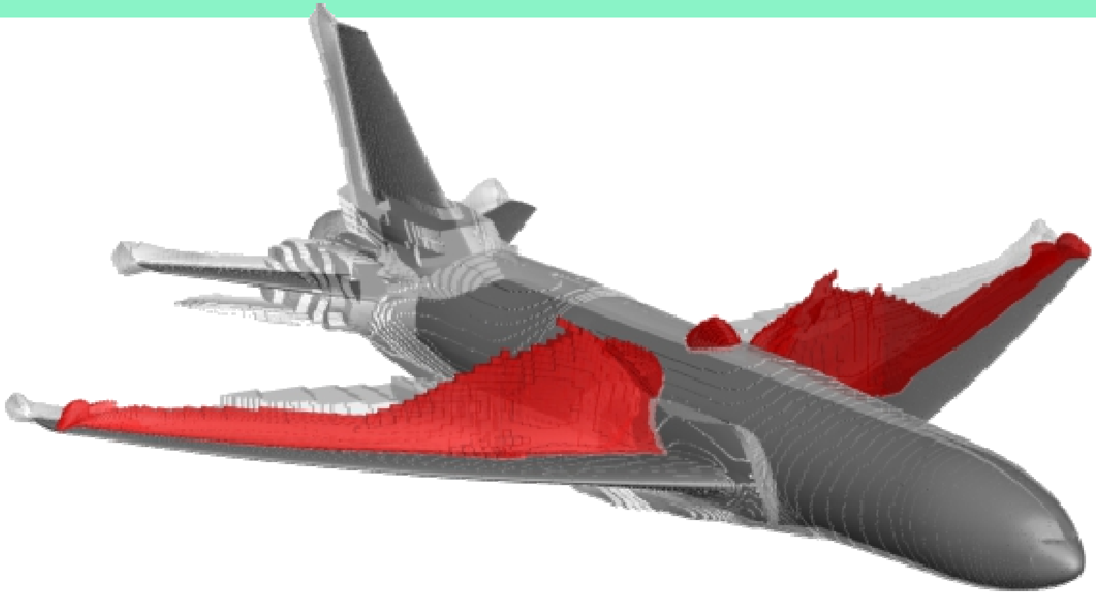
O.Atinault, Development of the NOVA configurations, 5th SCAD 2015 – Naples

Hue, D., Péron, S., Wiart, L., Atinault, O., Gournay, E., Raud, P., Benoit, C., and Mayeur J., “Validation of a near-body and off-body partitioning methodology for aircraft aerodynamic performance prediction,” Computers and Fluids, 2015

Far-field drag extraction tool *ffd72*

ffd72

- ONERA in-house post-processing tool for far-field drag extraction
- Provides a physical drag breakdown into viscous (CDvp + CDf), wave (CDw) and lift-induced (CDi) components and allows to eliminate the spurious drag (numerical drag)
- Very useful to assess the quality of a mesh or in a design process to provide physical understanding of drag generation



Wave (red) and viscous (gray) drag integration volumes calculated by *ffd72* on the CRM geometry (DPW series)

Hue, D., and Esquieu, S., “Computational Drag Prediction of the DPW4 Configuration Using the Far-Field Approach,” Journal of Aircraft, Vol. 48(5), pp. 1658-1670, 2011.

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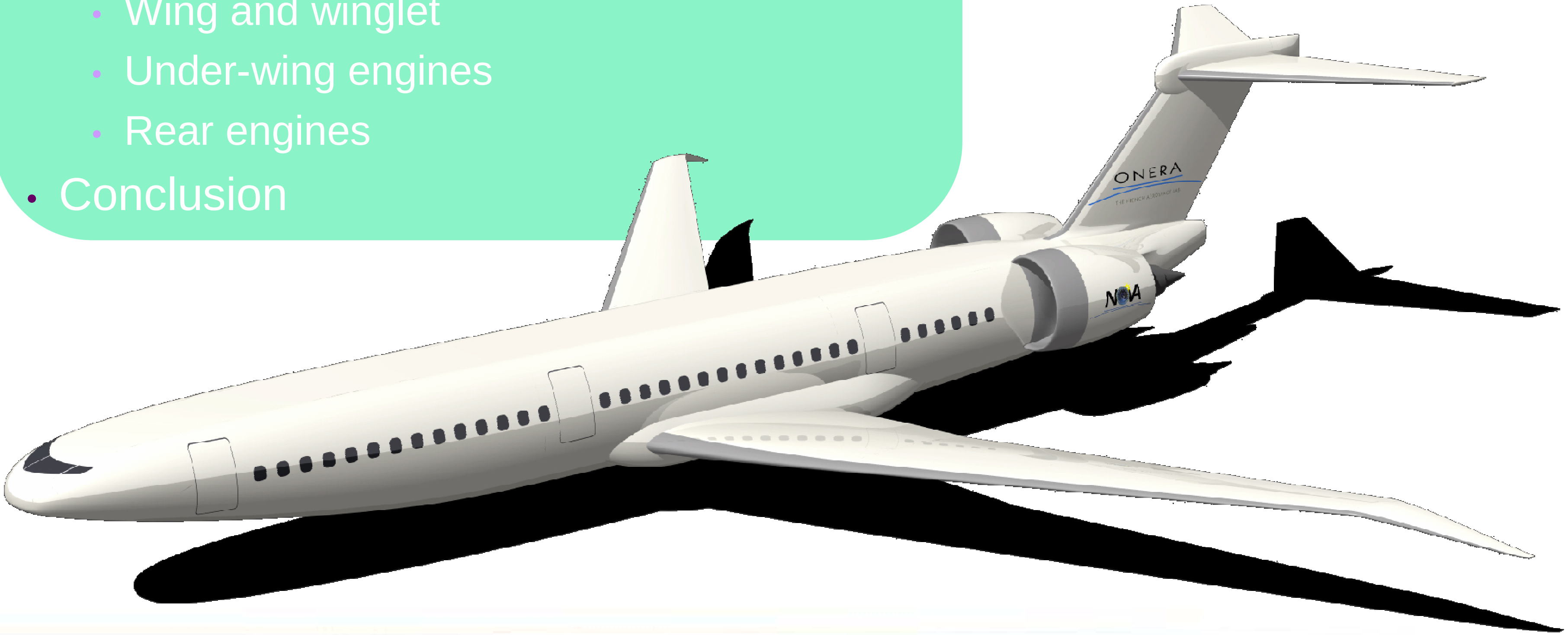


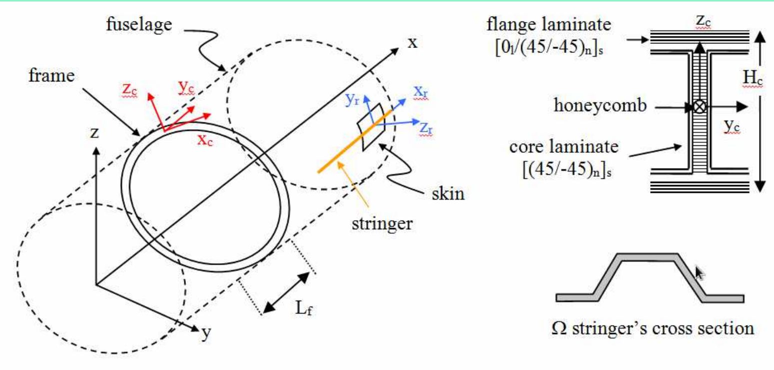
Fuselage

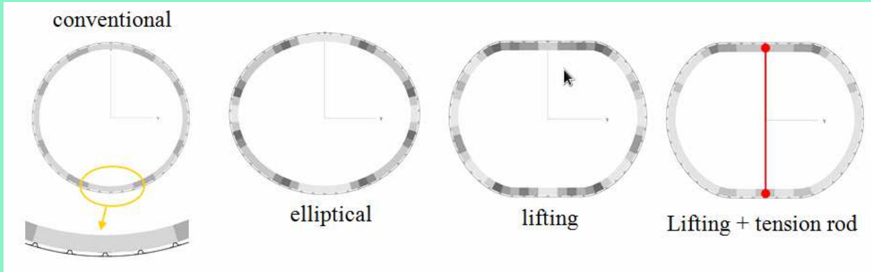
- Two wide (and short) fuselage geometries were designed and evaluated both aerodynamically and structurally

Elliptical / Lifting

Structural analysis

•Finite Element analysis has been conducted to evaluate the mass penalty due to non-cylindrical fuselage entirely manufactured with composite materials





Fuselage frames calculated by finite elements

•The elliptical and lifting fuselage sections are heavier per unit length but a 2-3-2 cabin layout allows to shorten the fuselage by 14% compared to a single-aisle

Fuselage weight	Conventionnal	Elliptical	Lifting	Lifting + tension rod
per unit length	reference	+23%	+29%	+18%
per unit area	reference	+0.7%	+5%	-4%

- Due to superior aerodynamic performance the lifting fuselage was preferred for NOVA

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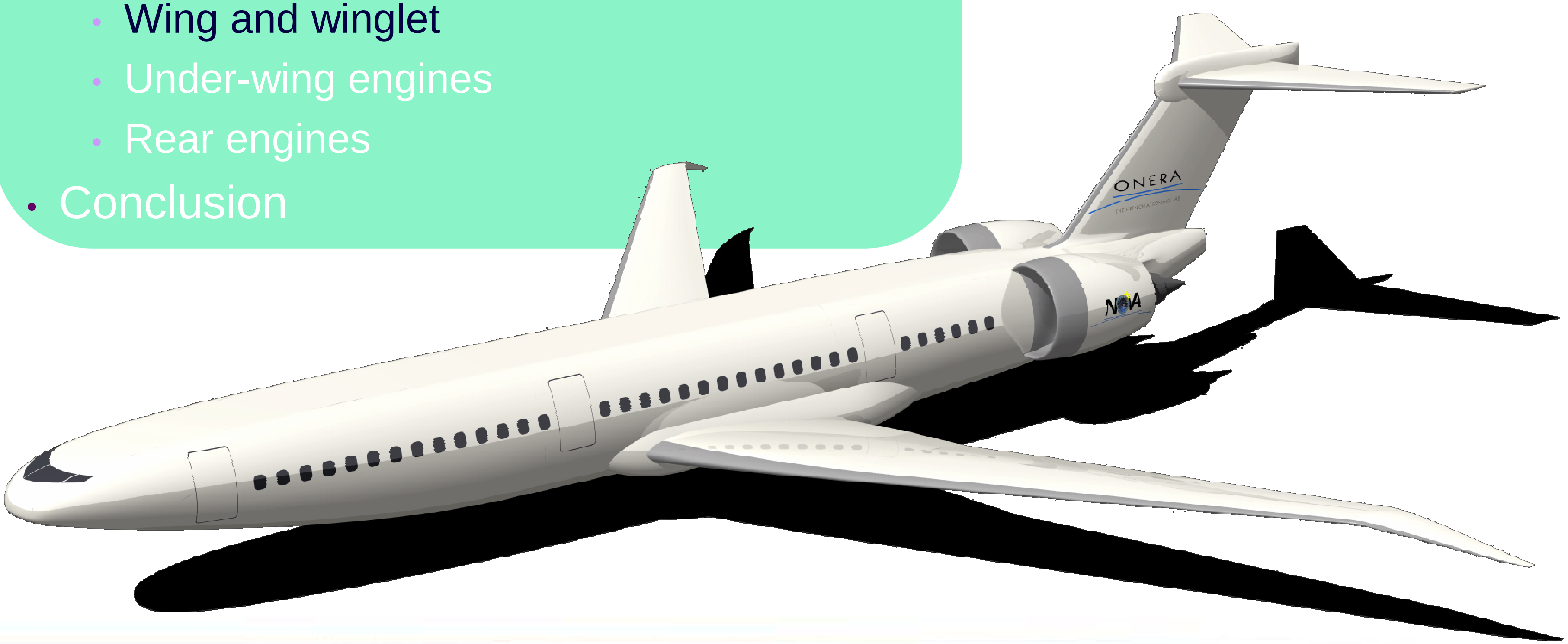
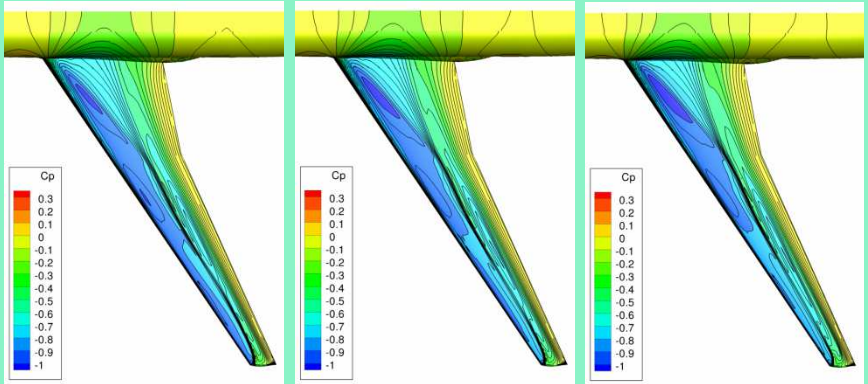


Baseline wing & winglet

CL=0.5, M=0.82



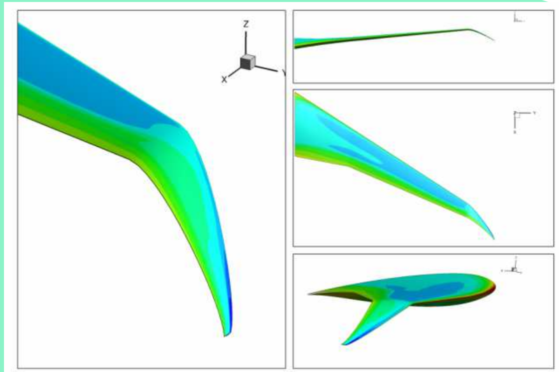
γ =0° γ =-1,5° γ =-2,5°

- Wing designed using automatically generated 3D RANS meshes
- Belly- fairing designed to prevent a corner junction flow separation
- Wing/body setting angle (γ) investigated thanks to collar grids

Reference surface = 145 m² / Sweep angle = 30°

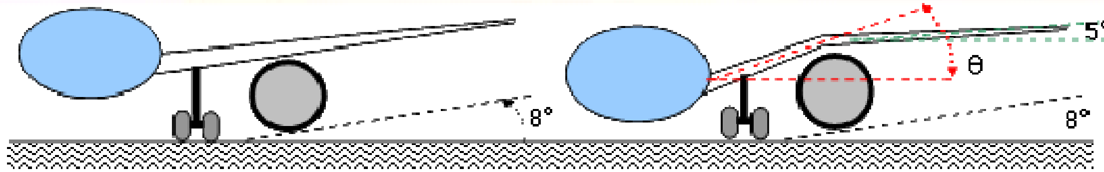
W/O winglet	**W/ winglet**
• Wing span = 38.1 m	• Wing span = 43.1 m
• Aspect ratio = 9.9	• Aspect ratio = 12.8

- Winglet designed to combine the advantages of a downward pointing winglet and a raked wingtip
- Shape obtained by numerical optimization (gradient based method) taking advantage of *ffd72* physical drag breakdown capabilities



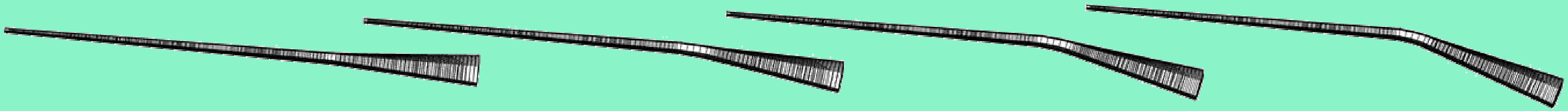
Gull wing

- Principle: accomodate UHBR engines with limited landing gear length to save mass

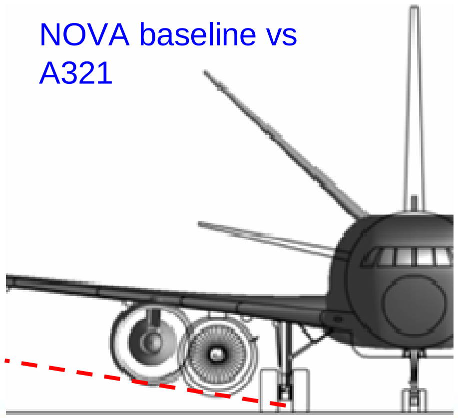


Structural analysis

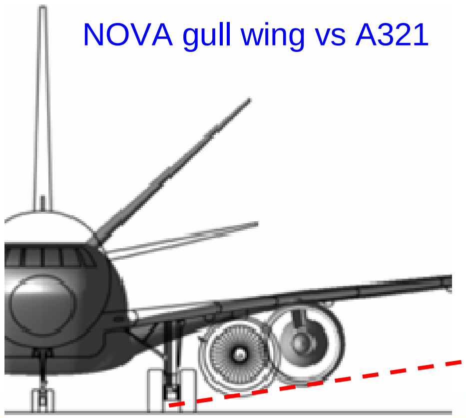
- Finite Element analysis has been conducted to evaluate the mass penalty due to a double dihedron wing entirely manufactured with composite materials
- 4 different wings have been modeled, with increasing θ values



θ	5°	10°	15°	20°	25°
Wing weight	reference	+0.1%	+4%	+6%	+8%



NOVA baseline vs A321



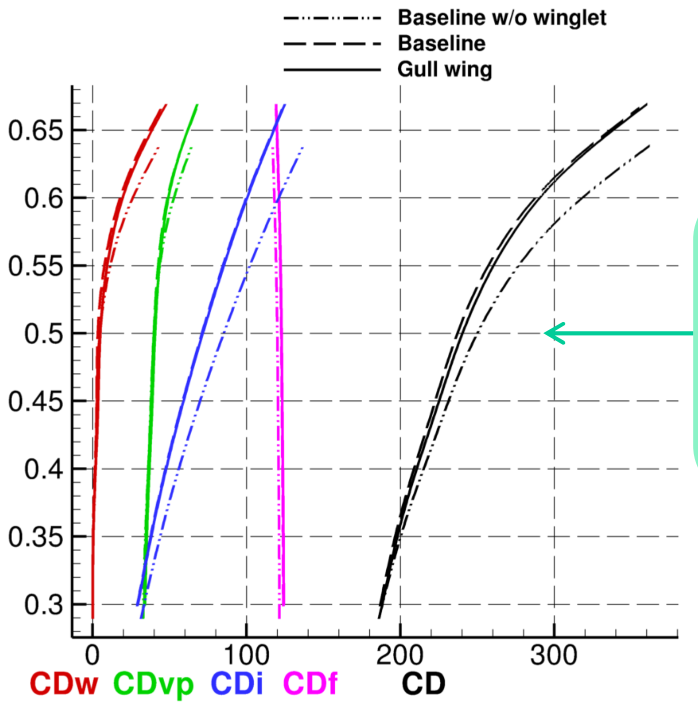
NOVA gull wing vs A321

NOVA gull wing (θ=12°) :

- Estimated mass penalty for gull wing reinforcement: **125 kg**
- Estimated mass saving on the landing gear: **250 kg** (50 cm shorter)

Aerodynamics of winglet & gull wing

- The winglet allows to reduce the lift induced drag component by 16%, with also a positive effect on wave drag, so that the total reduction amounts to 13 drag counts at cruise condition
- The aerodynamic performance of the designed gull wing is slightly reduced compared to baseline wing (in the order of 3 drag counts at cruise conditions)
- However, we feel confident that this aerodynamic penalty is not inherent to the gull wing shape itself and that it would be offset by an adaptation of the wing root airfoils



M=0.82 CL=0.5	CDw	CDvp	CDi	CDf	CD
Baseline w/o winglet	5 dc	40 dc	85 dc	120 dc	250 dc
Baseline	-25%	+0%	-16%	+2.5%	-5%
Gull wing	0%	0%	-16%	+2.5%	-4%

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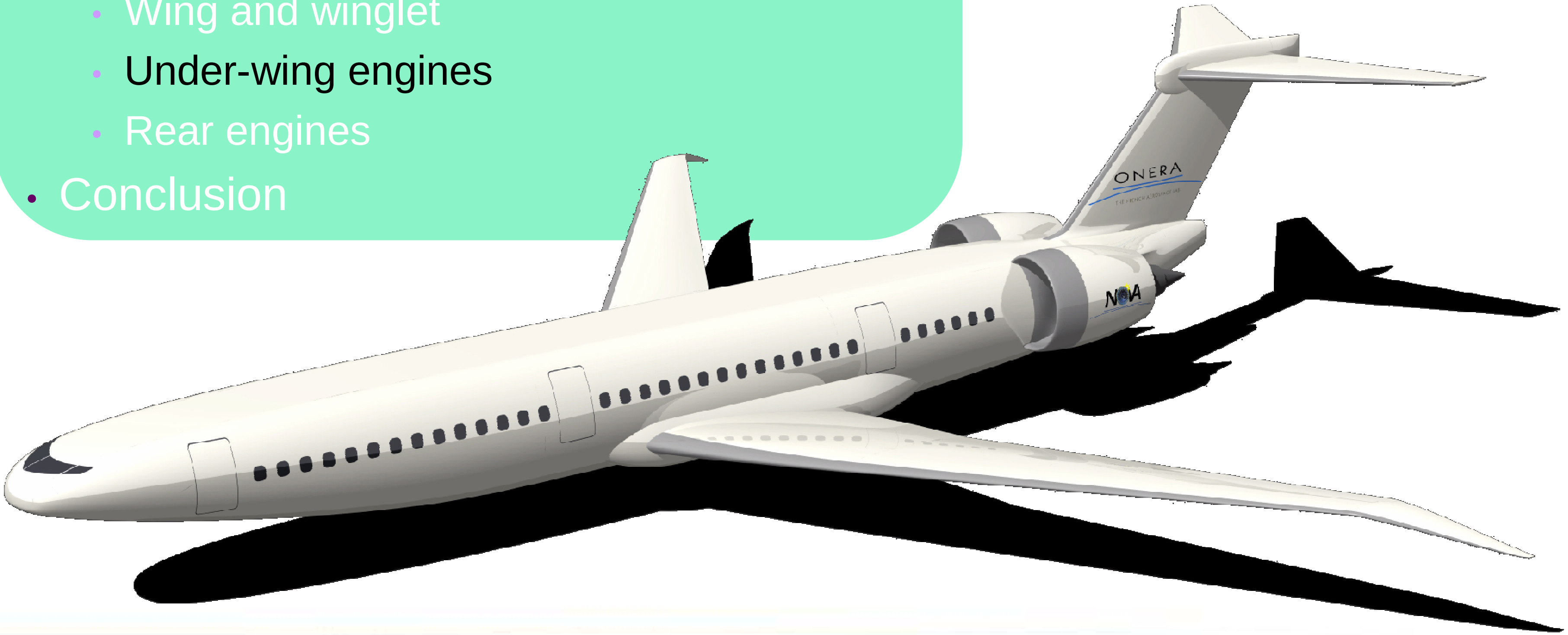
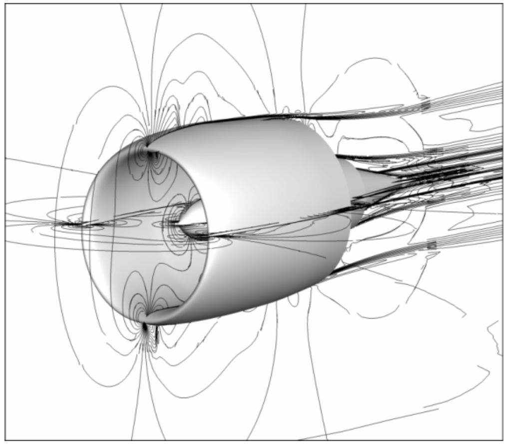


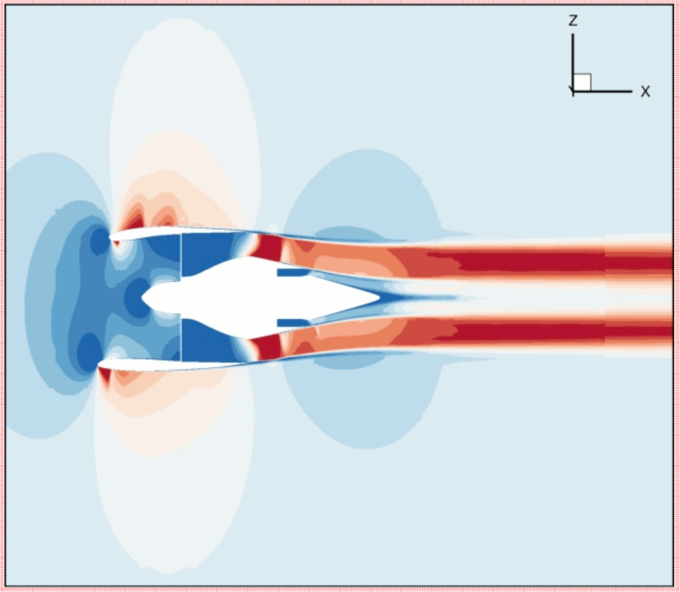
NOVA GTF engine

- The FPR=1.4 GTF engine was designed from scratch using thermodynamics considerations
- It features :
  - a length/diameter ratio of 2 combined with a short nacelle to mitigate the wetted area
  - slim nacelle cowls to limit weight and drag increase
  - a negative scarf inlet for community noise reduction



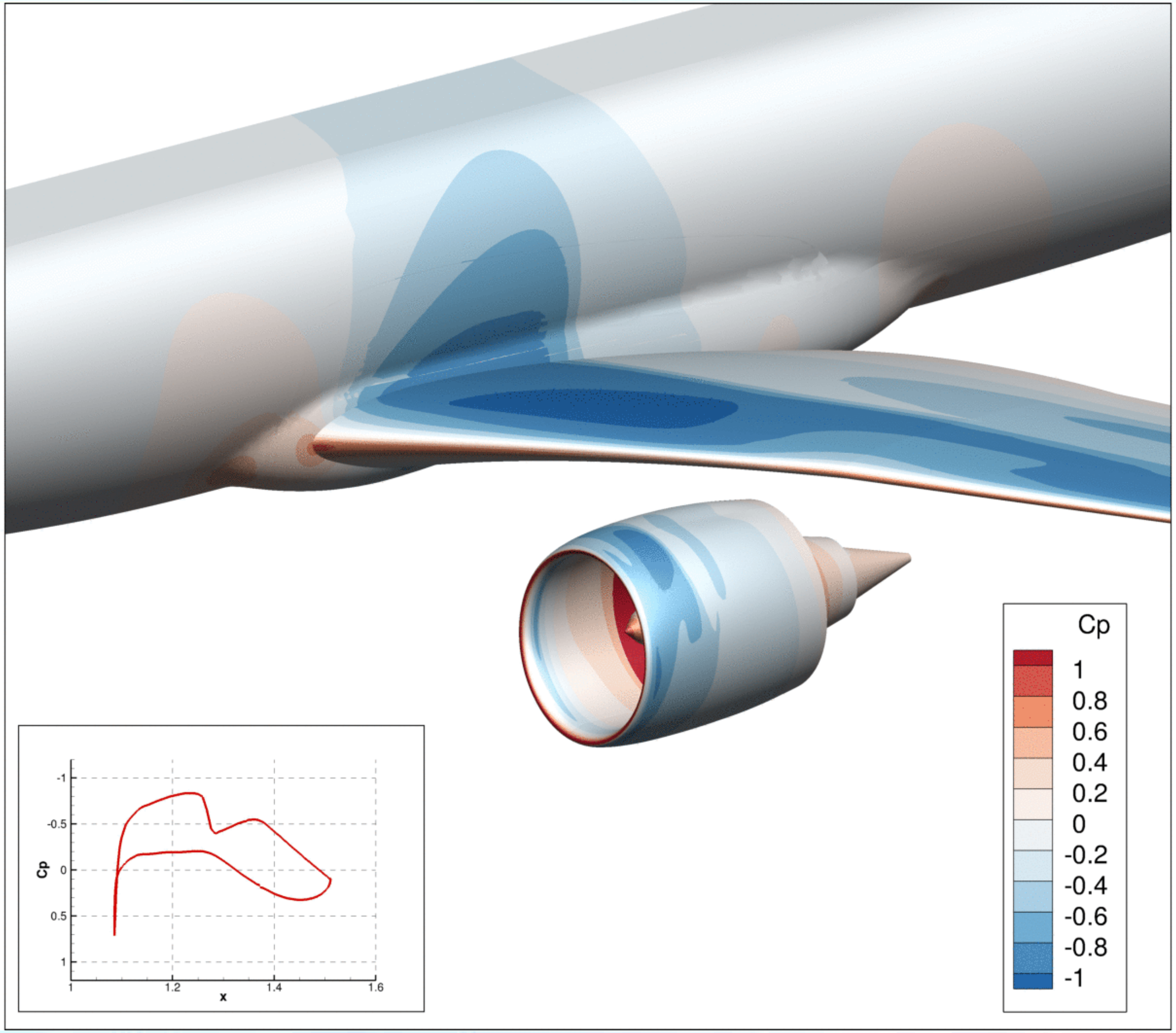
Cruise BPR	16
OPR	42
Fan diameter (m)	2.16
Cruise MFR (kg/s)	260
Cruise FPR	1.4

Key figures of the NOVA GTF engine

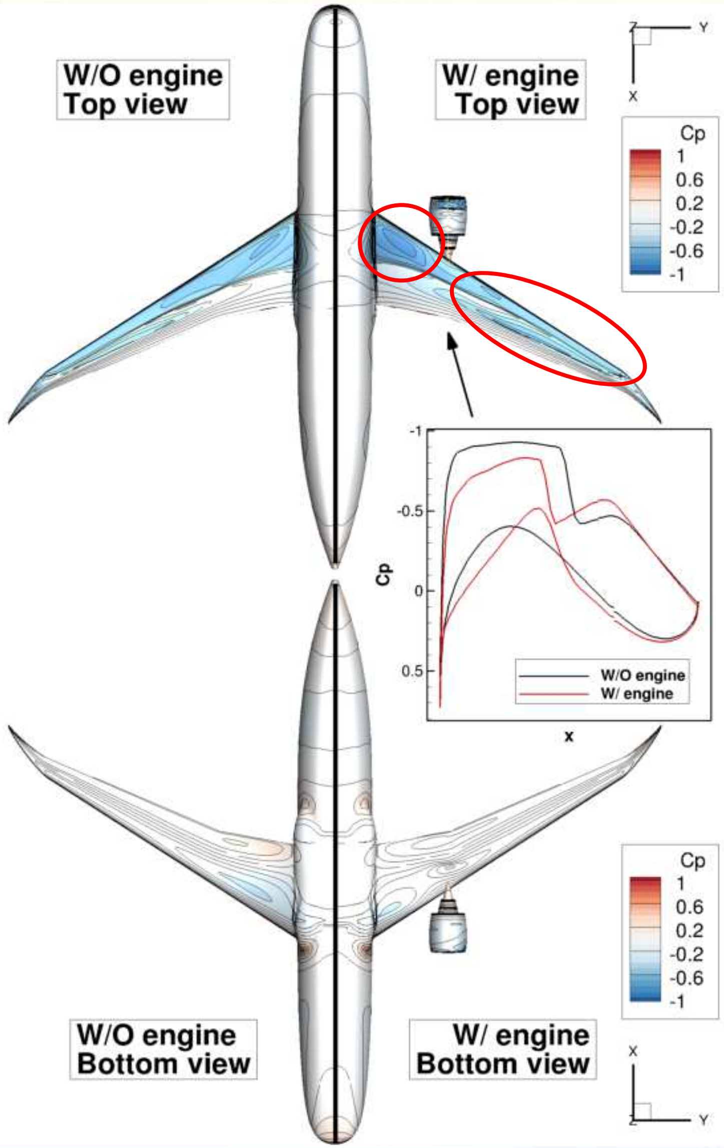


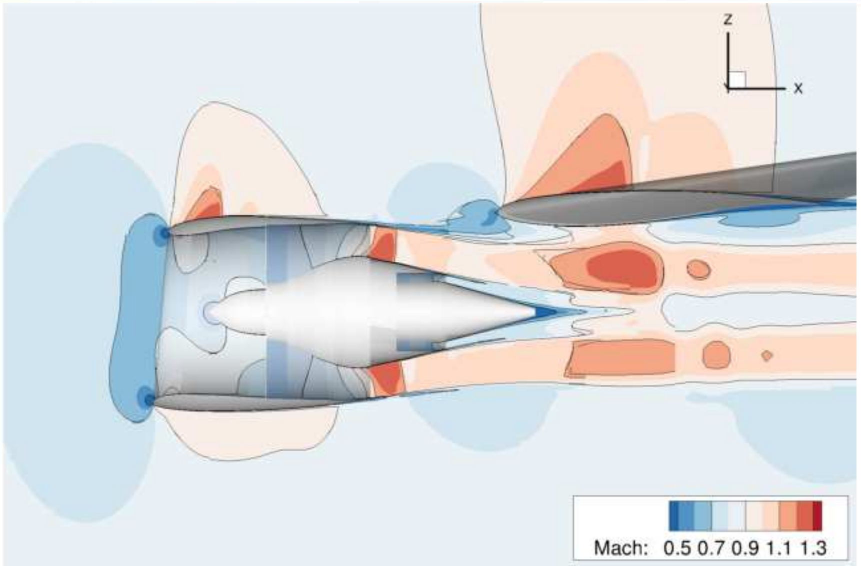
A thrust vectoring study for trim drag minimization can be found in the paper

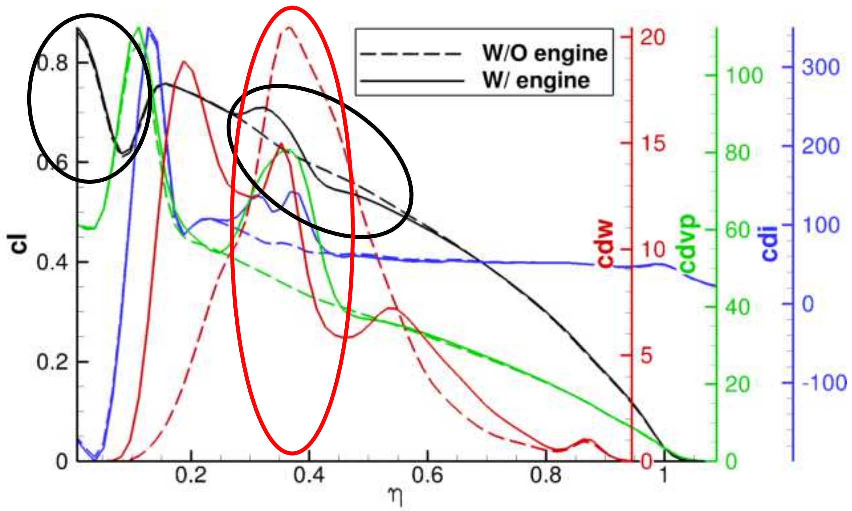
Effect of engine position on skin pressure



Selected position

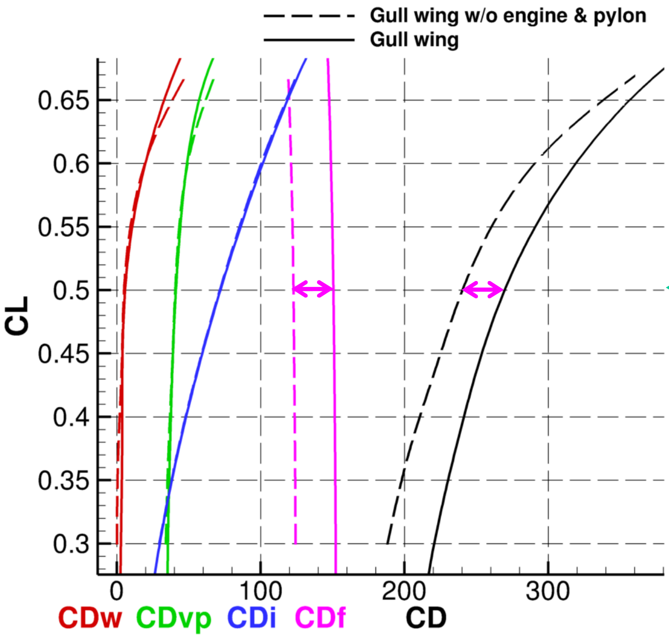


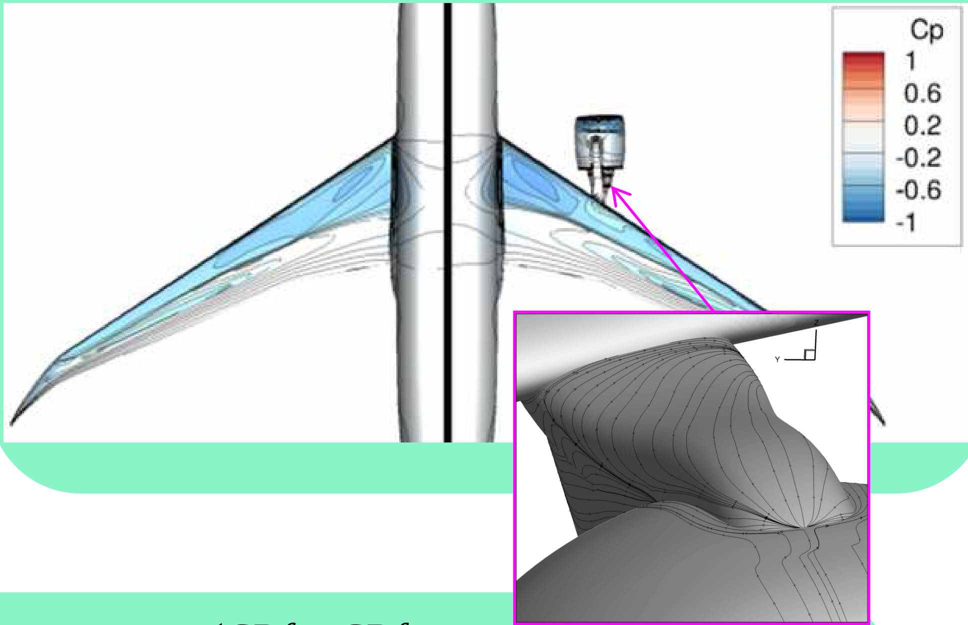




CL=0.5, M=0.82

Overall engine integration effect





$$Installation\ Drag = CD - CD_{w/o\ engines\ \&\ pylons} - (CDf - CDf_{w/o\ engines\ \&\ pylons})$$

M=0.82 CL=0.5	CDw	CDvp	CDi	CDf	CD	Installation drag
Gull wing w/o engine & pylon	5 dc	41 dc	72 dc	123 dc	**241 dc**	**X**
Gull wing	+0.7 dc	+0.4 dc	+0.5 dc	+27.8 dc	**+29.4 dc**	**+1.6 dc**

- Similar results were obtained on the baseline configuration (installation drag=1.2 drag count) and can be found in the paper

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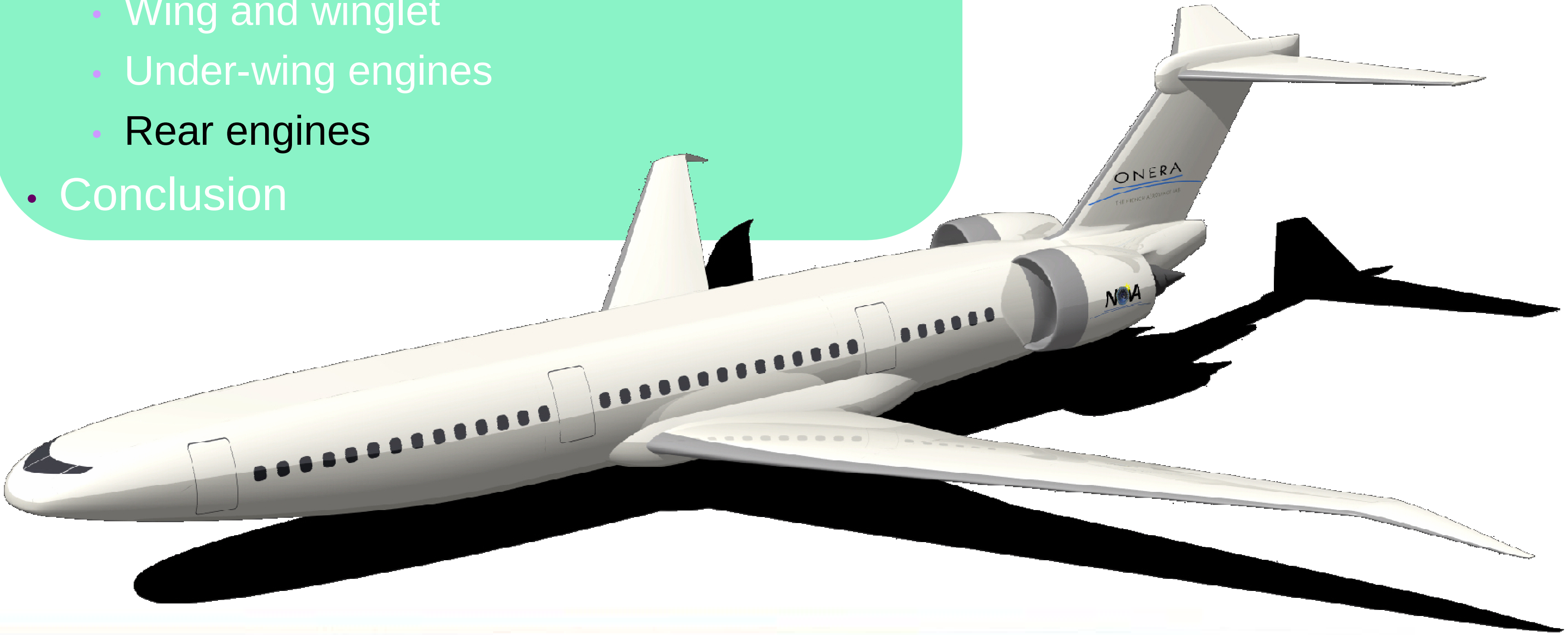


Podded configuration

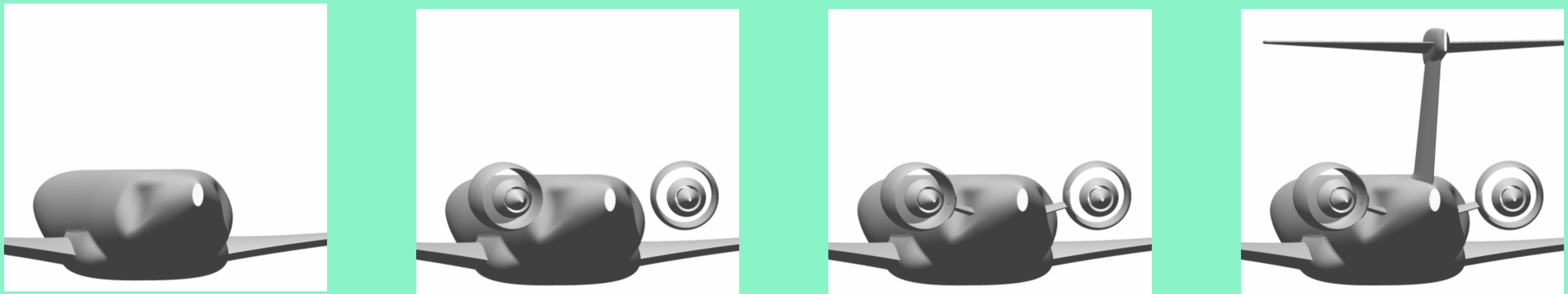
Pros and cons of rear engine mount

+ better wing aerodynamics	- loss of wing weight advantage
+ one engine inoperative case less critical for vertical tail sizing	- longitudinal balance

- This configuration is clearly intended as a reference for BLI benefits quantification

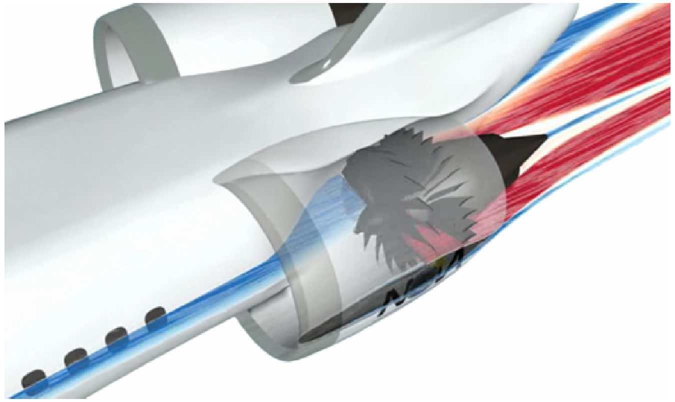
Design methodology

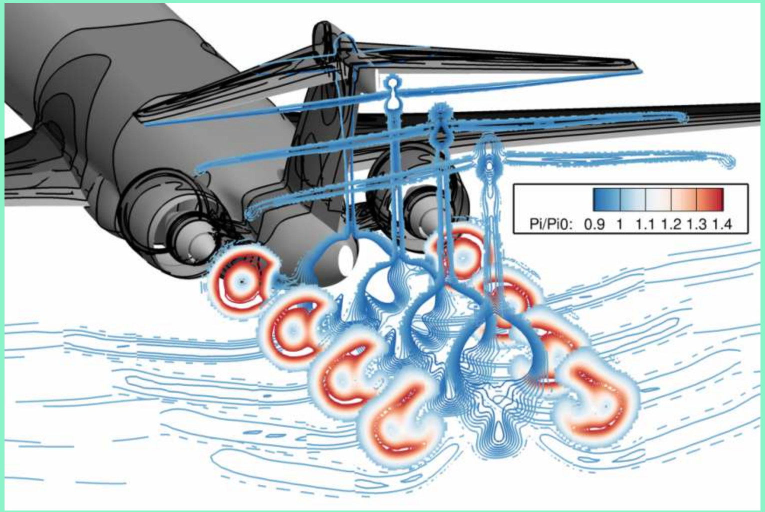
- Adapting existing components: baseline wing and belly-fairing shifted towards the aft fuselage; fuselage tail re-shaped to receive the pylons/engine
- Engine placement study conducted w/o pylon to mimimize nacelle/fuselage interference with the concern of limitating the pylon length
- Pylon designed from conventionnal symmetrical airfoil, tilted upward to cope with the wing downwash

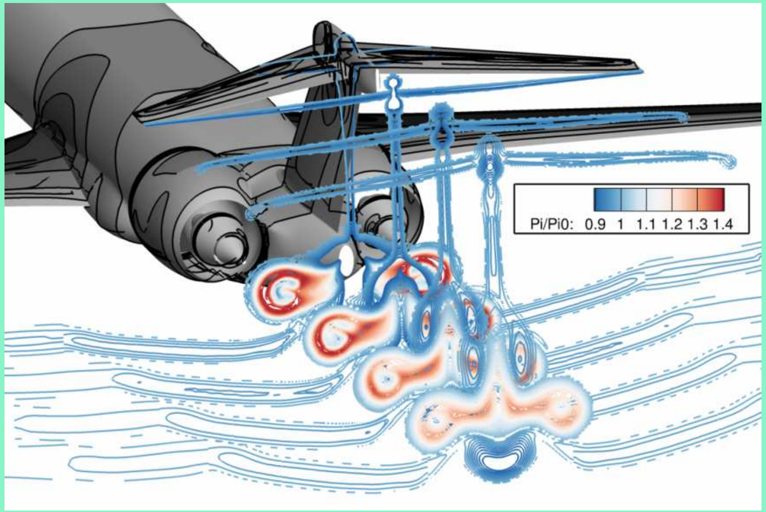


BLI configuration

- By embedding the engine into the fuselage, savings in fuel (due to reduced wetted area and jet/wake losses) and mass are expected
- Deliberately « agressive » design :
  - engine~40% buried
  - short inlet (inlet length/fan diameter ratio~1)







When ingesting the fuselage boudary layer, the engines tend to minimize the aircraft print in the surrounding airflow, indicating better thrust-drag balance

Arntz, A., "Civil Aircraft Aero-thermo-propulsive Performance Assessment by an Exergy Analysis of High-fidelity CFD-RANS Flow Solutions", PhD Thesis, Lille 1 University, 2014.

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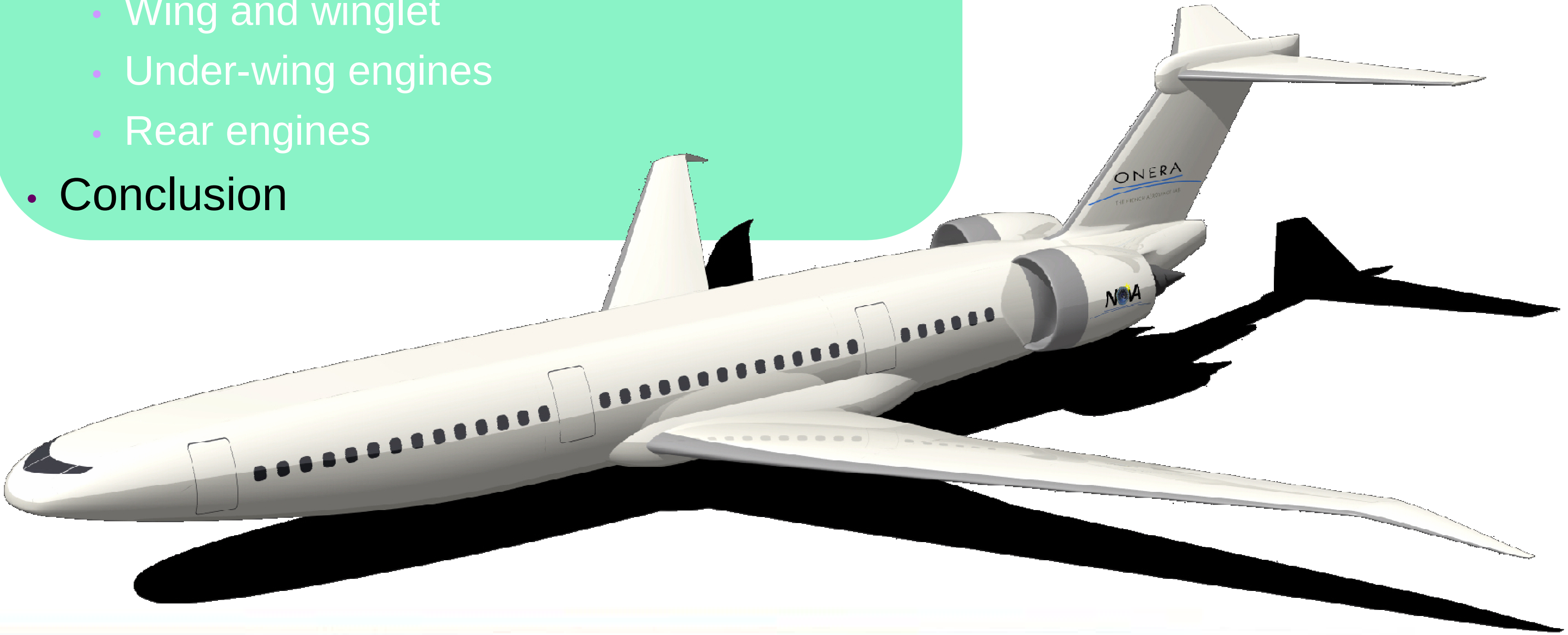
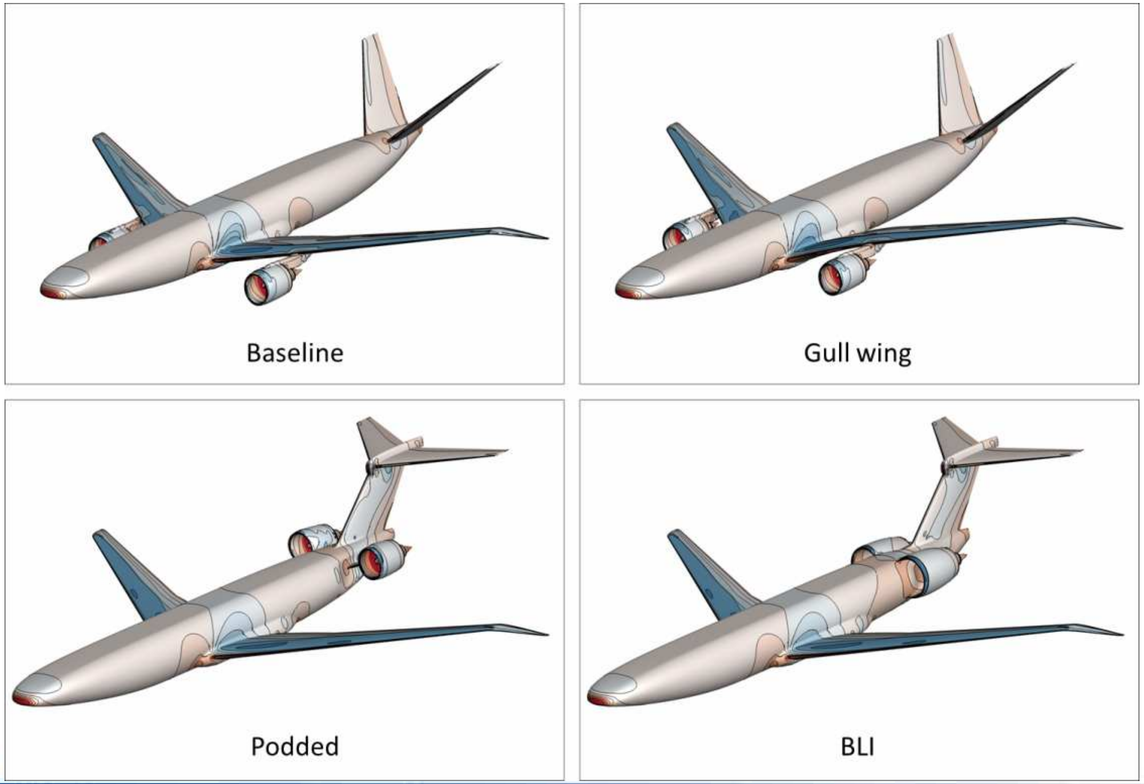


Conclusion

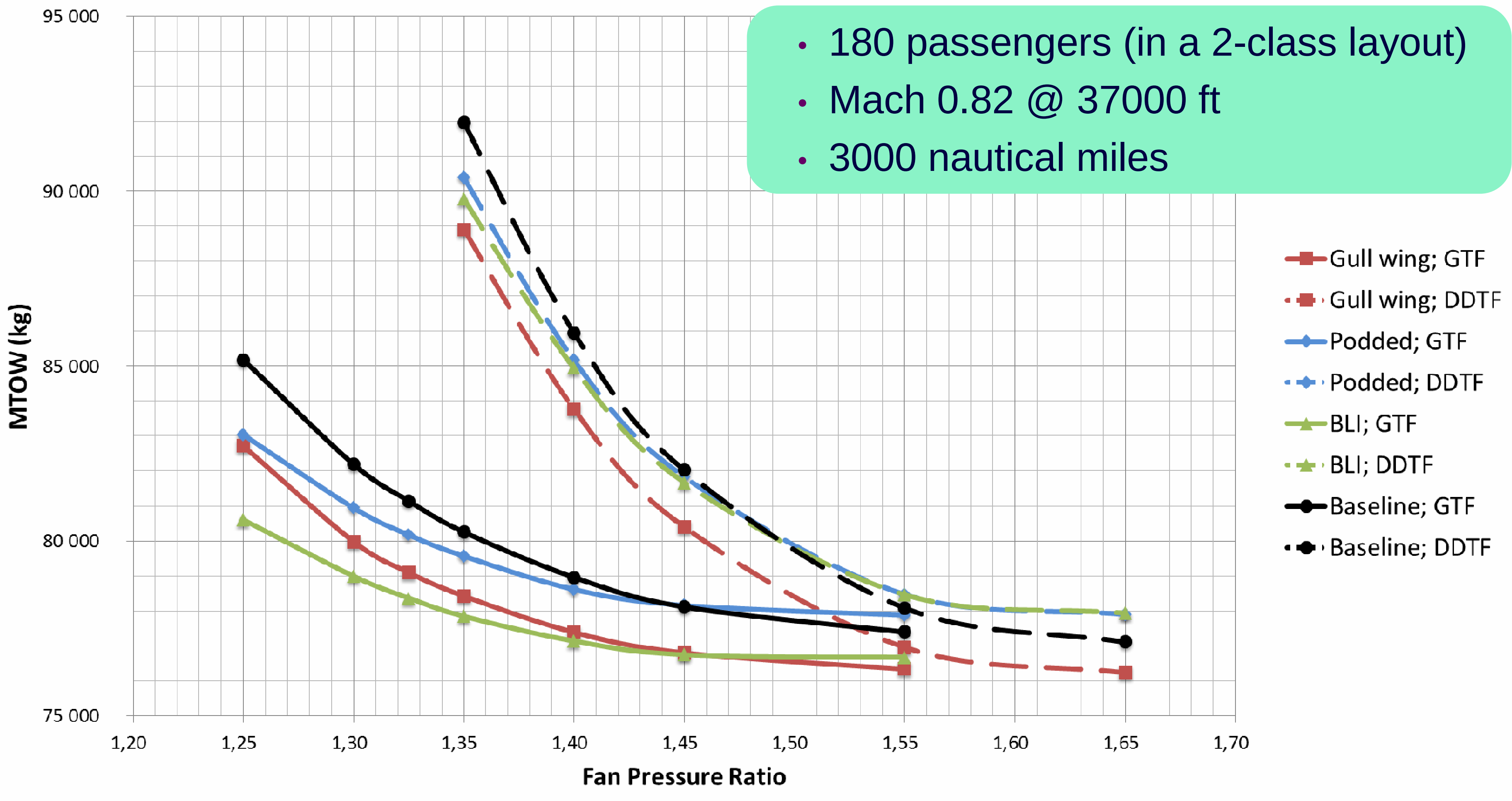
- The NOVA configurations explore innovative engine integration options
- They provide an appropriate platform for ONERA to pursue future studies in its various fields of expertise, such as flow control, advanced unsteady methods, acoustics, aeroelasticity or optimization
- New methods and tools have been developped for aerodynamic design
- More disruptive configurations such as strut-braced wing, box-wing or blended-wing-body are studied as well at ONERA



Any question?

MTOW vs FPR

- 180 passengers (in a 2-class layout)
- Mach 0.82 @ 37000 ft
- 3000 nautical miles



- The main advantage of GTF over DDTF is to delay the « mass divergence » encountered for low FPR

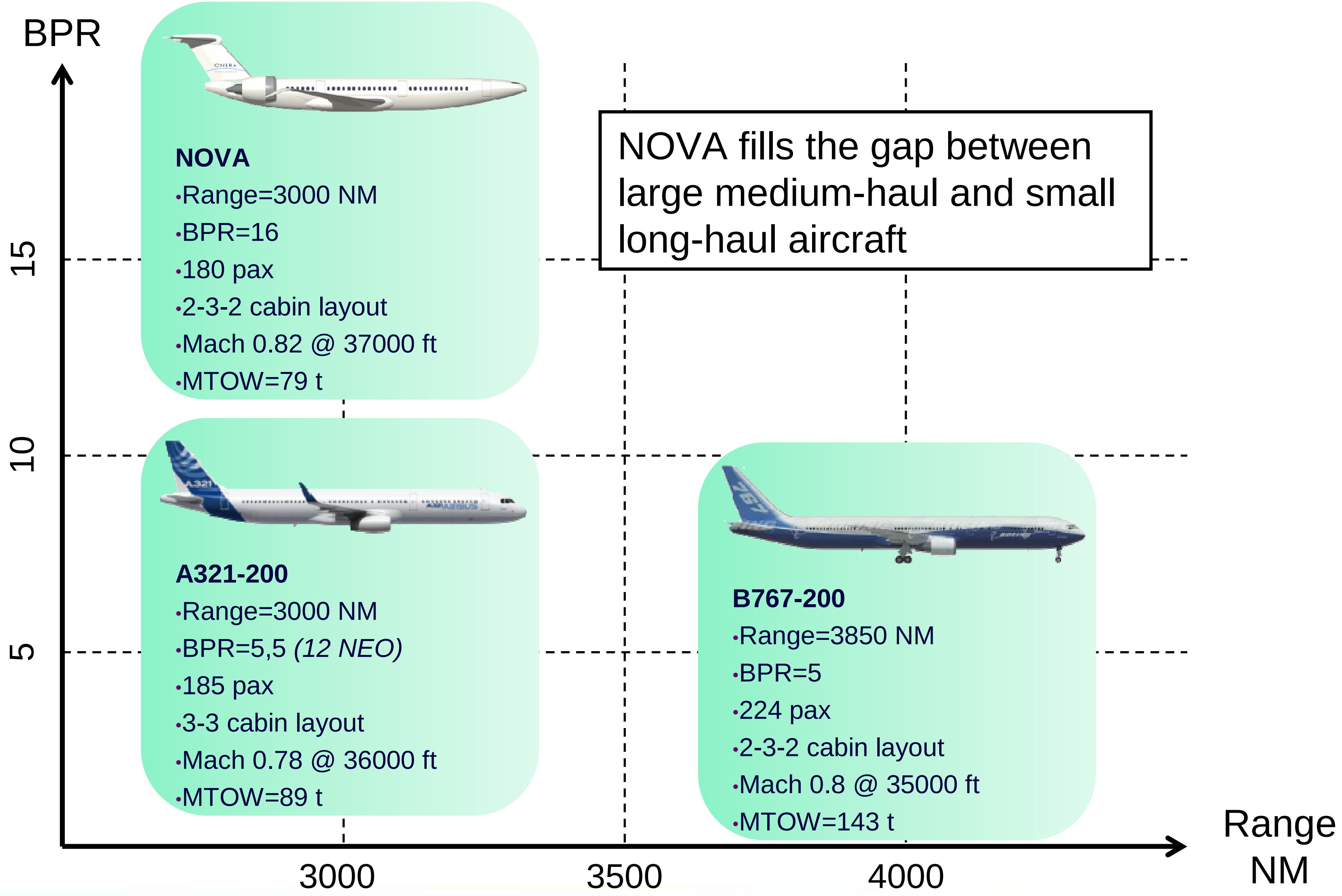
DDTF=Direct-Drive TurboFan
GTF=Geared TurboFan

NOVA compared to existing aircraft

	A321-200 *(NEO)*	NOVA (baseline)	B767-200
Npax	185	180	224
Cabin layout	3-3	2-3-2	2-3-2
Range (NM)	3000	3000	3850
Take-off runway length (m)	2560	2400	1768
Cruise Mach number	0.78	0.82	0.8
Cruise altitude (ft)	36000	37000	35000
Fuselage length (m)	44.51	38.3	48.5
Fuselage height (m)	4.14	3.9	5.41
Fuselage width (m)	3.95	4.9	5.03
Operating empty weight (kg)	48500	41600	80100
Maximum take-off weight (kg)	89000	79000	142900
Wing span w/o | w winglet (m)	34.1 | X *(35.8)*	38.1 | 43.1	47.6 | X
Reference surface (m^2)	122.6	145	283.3
Wing LE sweep angle (°)	25	30	31.5
Aspect ratio w/o | w winglet	9.5 | X *(10.4)*	9.9 | 12.8	8 | X
Fan diameter (m)	1.73 *(2.05)*	2.16	2.37
Nacelle diameter (m)	2.10 *(2.65)*	2.50	2.80
Thrust per engine SLS (lbf)	30000	28300	50000
Cruise FPR	1.75 *(1.5)*	1.4	1.64
Cruise BPR	5.5 *(12)*	16	5
OPR	35.4 *(40)*	42	23.4

- NOVA fills the gap between large medium-haul (ex: A321-200) and small long-haul aircraft (ex: B767-200)
- The same wing surface and engine (fan & core) are used for the 4 NOVA configurations

NOVA compared to existing aircraft



elsA and *ffd72* software

elsA settings

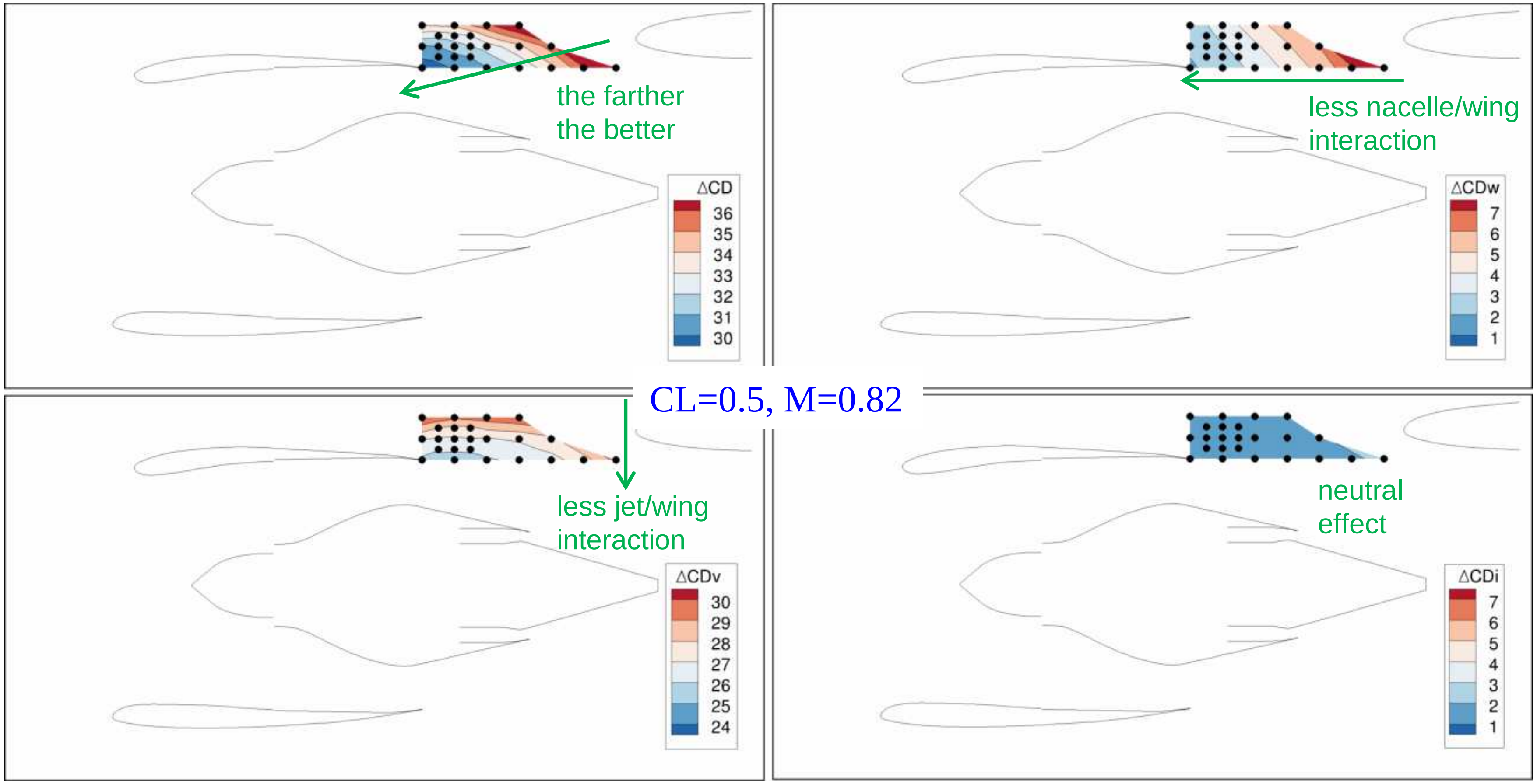
- ONERA in-house CFD solver
- RANS computations
- Cell-centered finite volume on structured multi-block meshes
- Time integration: Backward-Euler scheme with LU-SSOR relaxation
- Spatial discretization: Jameson's second-order centered scheme
- V-cycle multigrid technique
- Spalart-Allmaras turbulence model

ffd72

- ONERA in-house post-processing tool for far-field drag extraction
- Provides a physical drag breakdown into viscous (CDvp + CDf), wave (CDw) and lift-induced (CDi) components and allows to eliminate the spurious drag (numerical drag)
- Very useful to assess the quality of a mesh or in a design process to provide physical understanding of drag generation

Effect of engine position on drag components

- The FPR=1.4 GTF engine was designed from scratch using thermodynamics considerations
- It features a length/diameter ratio of 2, slim nacelle cowls and a negative scarf inlet



- If the engine location has substantially no effect on the induced drag component, the wave and viscous drag components are both impacted with Δ~6 drag counts each

Effect of pylon integration

CL=0.5, M=0.82