CONCEPTUAL AND PRELIMINARY DESIGN OF HIGH ASPECT RATIO AIRCRAFT CONFIGURATIONS: RESULTS AND OUTLOOK

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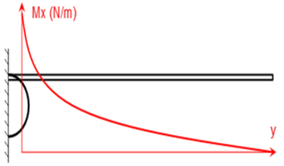
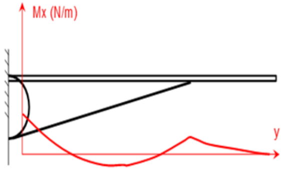
INTRODUCTION

- Rationale of High Aspect Ratio Wing (HARW), Advanced Cantilever Wing Configuration (CNT), Strut-Braced Wing (SBW) and flared folding wingtips (FFWT):
  - HARW permits better aerodynamic efficiency: $\frac{L}{D}_{max} = \frac{1}{2}\sqrt{\frac{e\ \pi\ AR}{CD_0}}$ (reduced lift-induced drag)

  - But at the cost of higher wing weight (cantilever)
  - FFWT alleviates aerodynamic loads by allowing floating wingtips
  - SBW enables to achieve HARW with limited wing weight penalty



cantilever



SBW

- Top Level Aircraft Requirements for an A321LR-like aircraft:
  - Range: 7400 km (4000 NM)
  - Payload: 18t (200 pax)
  - Mach: 0.78

- Development of an Overall Aircraft Design (OAD) approach combining conceptual design and high-fidelity aerodynamic and structural analyses

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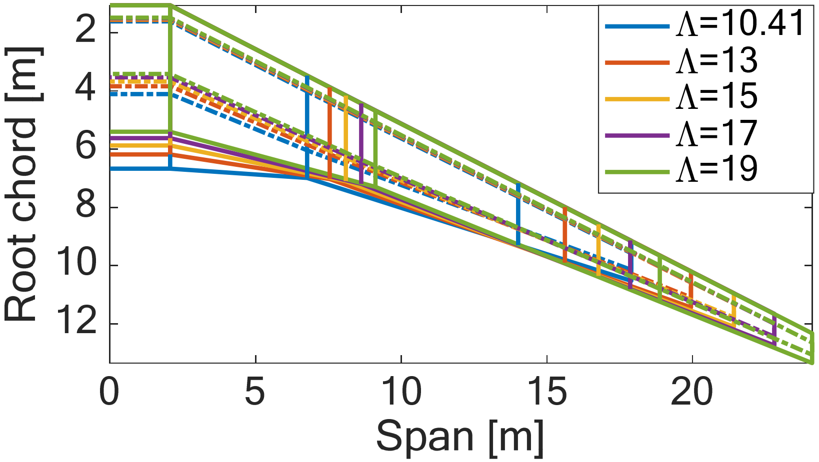
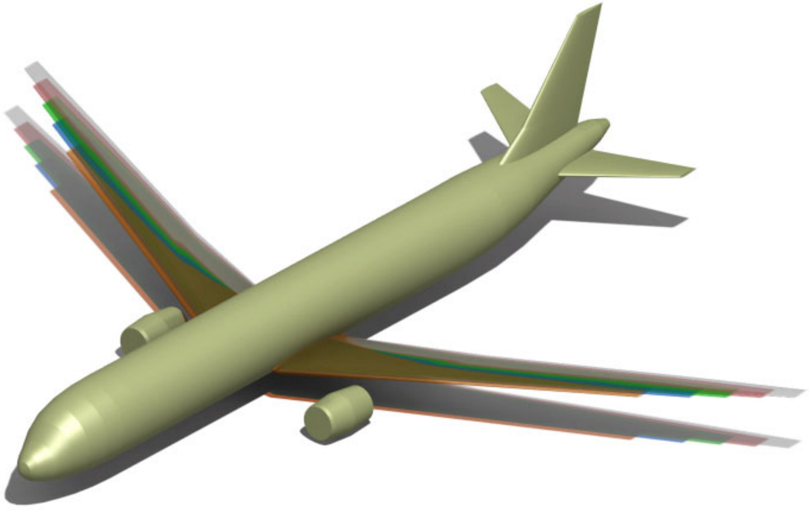
CNT CONFIGURATION: THE STRATEGY

- Generation of a family of increased aspect ratio wings: the wing surface, the engine position and taper ratio are kept constant, AR is modified.
- MDO sizing including both maneuvers and gust load conditions (CS25), for both Aluminum and Composites cases using NeOpt tool.
- An increased AR reduces the induced drag term, but the WRBM increases and what about emissions? There is room for trade-off studies

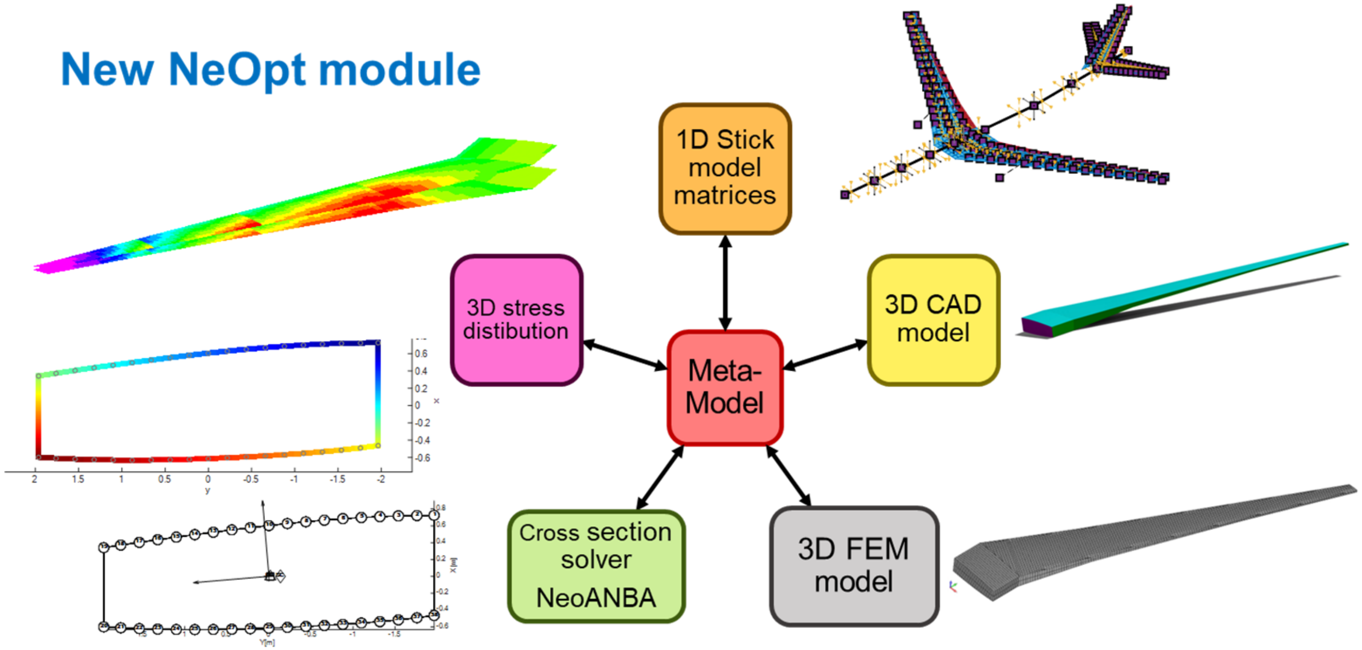




TOOLS ADOPTED AND RESULTS SUMMARY

- Through the meta-model it is possible to generate several models, update existing ones and post-process analysis results.

New NeOpt module



Meta-Model

1D Stick model matrices

3D stress distibution

3D CAD model

Cross section solver NeoANBA

3D FEM model

MDO application to cantilever wing Maneuver + Gust + Flutter requirements
Aspect Ratio analyzed = 10 to 19
Use of **tailored high strength composite** reduces the weigh increase with AR by 35%
Drag performance in line with the theoretical predictions
If emissions included into the MDO process, the **max obtainable AR is 15**, corresponding to a **block fuel reduction of 3%** w.r.t. AR of Reference

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LESSONS LEARNED

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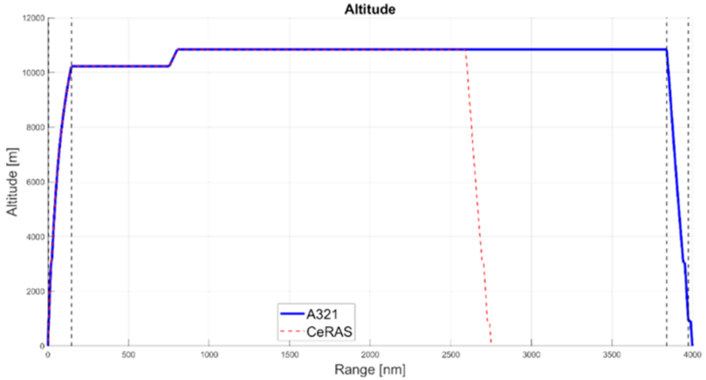
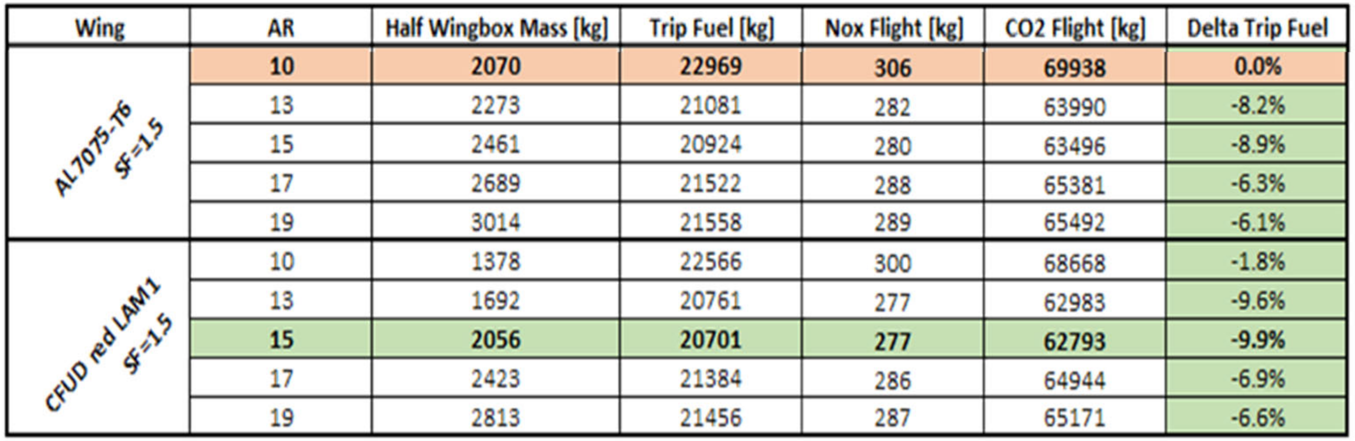
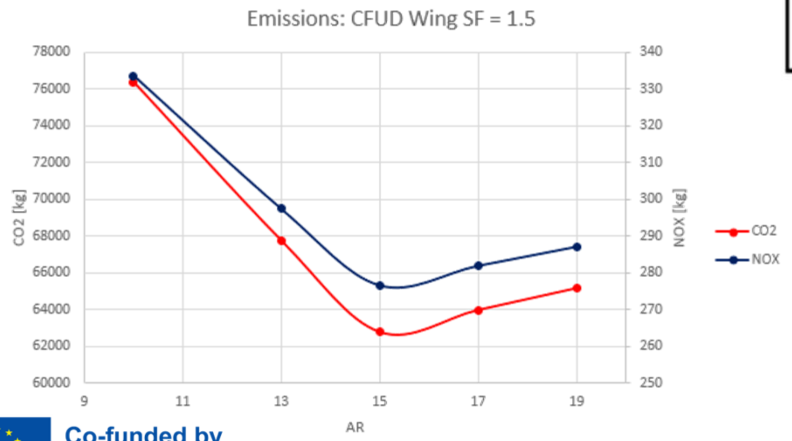
The emissions calculation is based on CFD based drag estimation and a modified version of Breguet formula, including the complete flight mission, for a 4000 NM typical mission.





Wing	AR	Half Wingbox Mass [kg]	Trip Fuel [kg]	Nox Flight [kg]	CO2 Flight [kg]	Delta Trip Fuel
AL7075-T6 SF=1.5	10	2070	22969	306	69938	0.0%
	13	2273	21081	282	63990	-8.2%
	15	2461	20924	280	63496	-8.9%
	17	2689	21522	288	65381	-6.3%
	19	3014	21558	289	65492	-6.1%
CFUD red LAM1 SF=1.5	10	1378	22566	300	68668	-1.8%
	13	1692	20761	277	62983	-9.6%
	15	2056	20701	277	62793	-9.9%
	17	2423	21384	286	64944	-6.9%
	19	2813	21456	287	65171	-6.6%



Due to the mass penalty with increased AR, the optimal value in terms of fuel burn saving and total emissions is **AR=15**

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U-HARWARD: Second Dissemination Event: May 24, 2022

Innovation IBK

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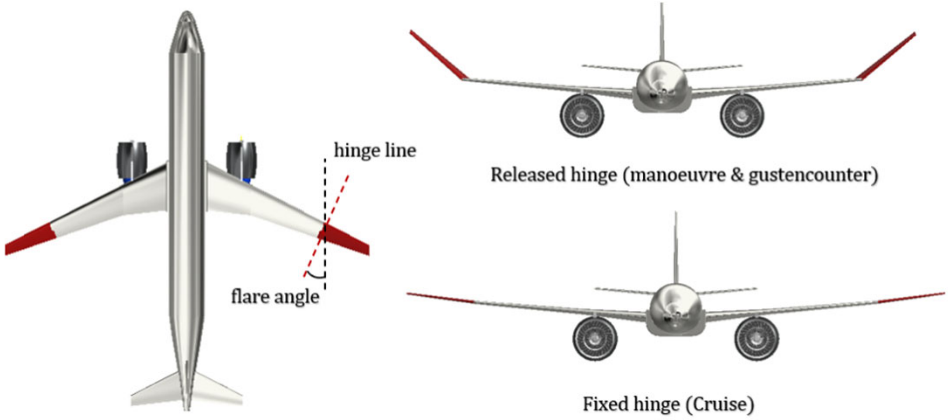
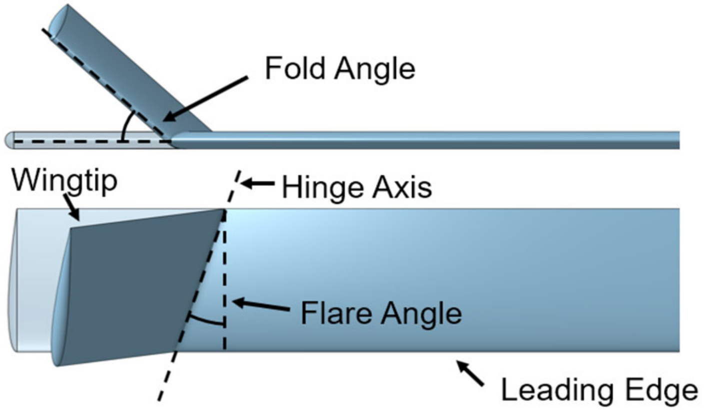
FWT CONFIGURATION

- Semi Aeroelastic Hinge concept enables aircraft with high aspect ratio wings to fit into airport gates and also exhibit gust loads alleviation and improved roll performance
- Wingtip local AoA reduces with increasing fold angle due to flare angle not being in streamwise direction - self-balanced in-flight
- Fixed hinge during cruise for the maximum aerodynamic efficiency
- Hinge released during severe loadings e.g. manoeuvre and gust encounters to reduce dynamic loads - structural efficiency

Semi aeroelastic hinge concept



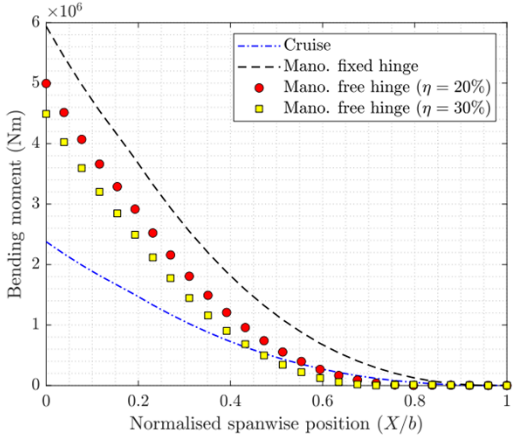


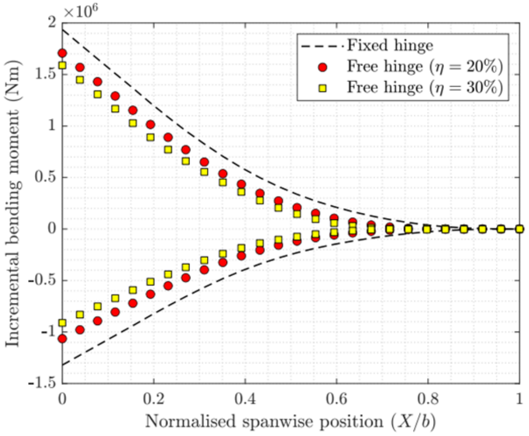
Conventional FWT

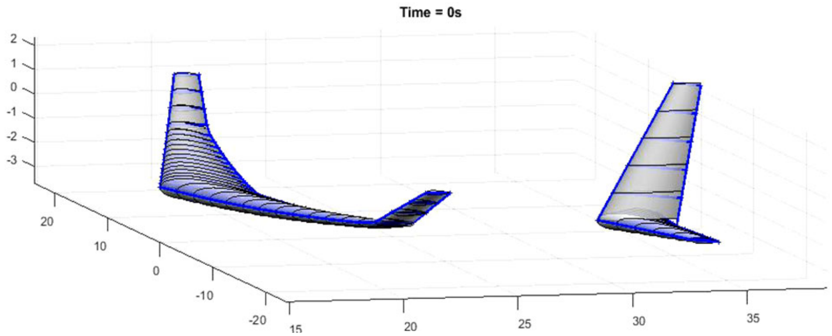

Lockheed S-3 Viking


B777-X

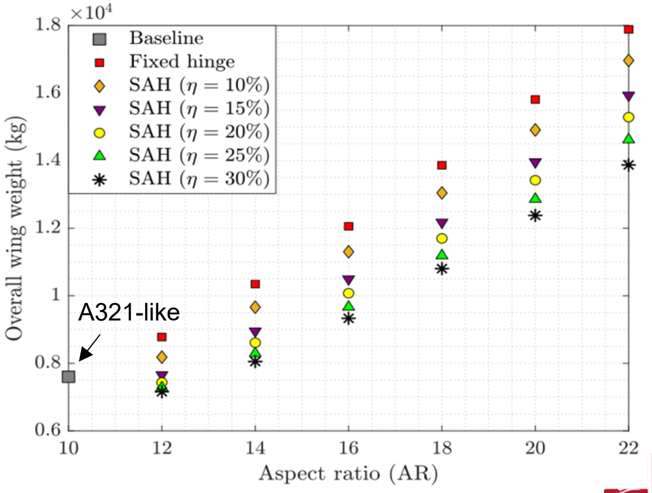
LOADS ALLEVIATION BENEFIT





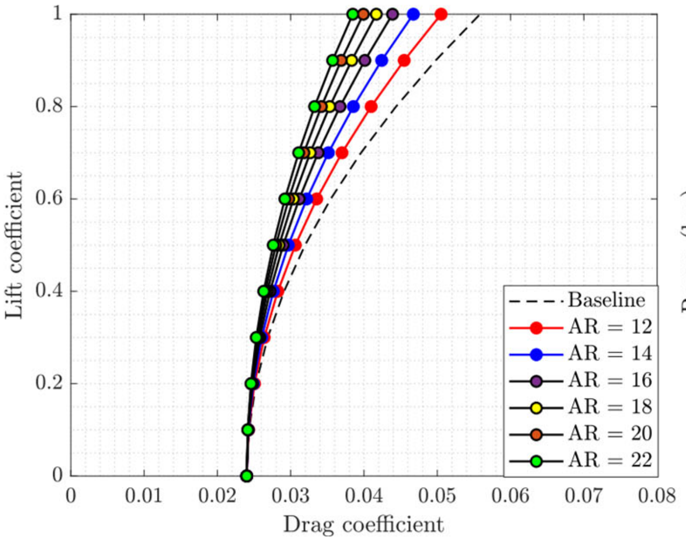


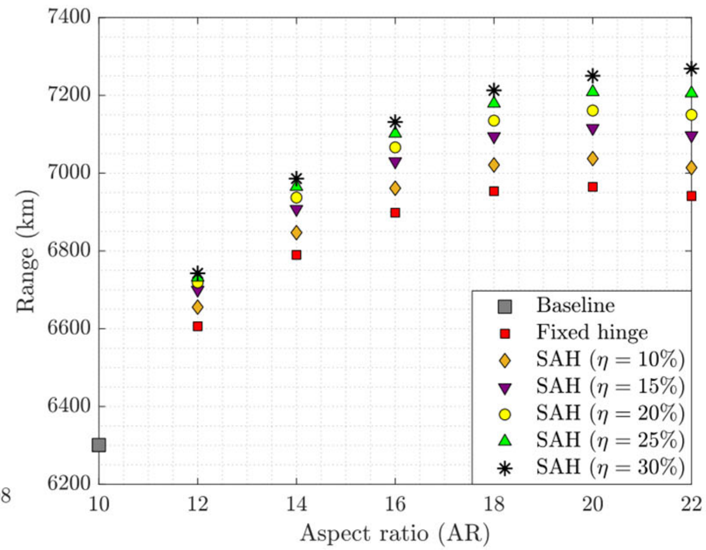
- Study performed to investigate aircraft weight and performance for different AR and wingtip size
- Significant reduction in the wing bending moment by releasing the hinge during manoeuvre (2.5g) and gust (1-Cosine)
- Reduction of the design loads leads to the decrease in wing weight
- Improved load alleviation was achieved by moving the hinge position inboard



IMPROVED AIRCRAFT PERFORMANCES

- Aerodynamic benefit obtained from increasing wing aspect ratio is compromised by the weight penalty
- Weight penalty is significantly mitigated by SAH
- Optimum performance was seen at approx. AR=19
- 5% improvement in aircraft range compared to conventional high aspect ratio designs

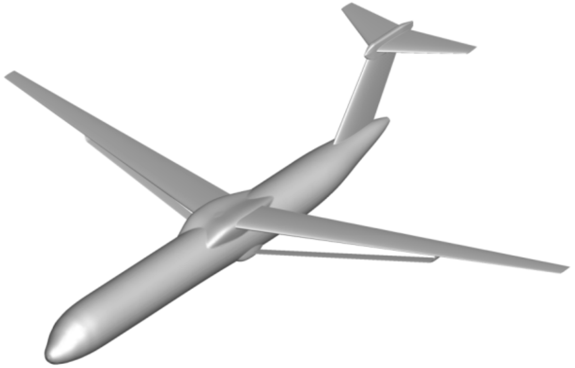




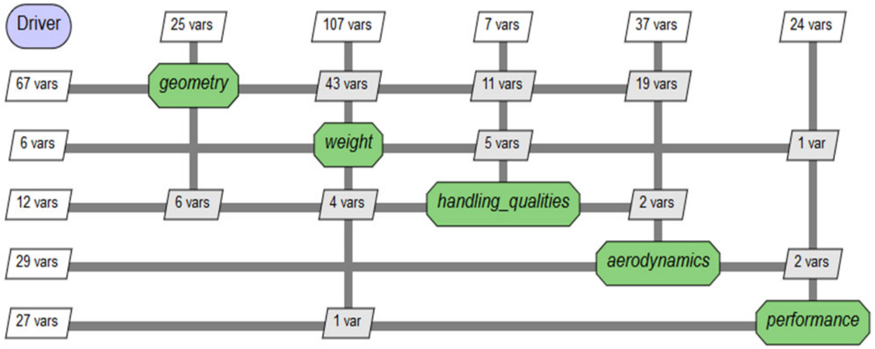
$$\text{Range} = \frac{V}{SFC\ g}\frac{L}{D}\ln\left(\frac{W_i}{W_f}\right)$$

SBW CONFIGURATION

- The assessment of the benefit of strut-braced wings is done using following assumptions:
  - Rear engines
  - Reduced wing sweep angle (17.5° at 25% chord)
  - Thin airfoil (thickness=10%)
  - No buckling on strut



- OAD computations done using FAST OAD



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STRUCTURAL ANALYSIS FOR WEIGHT EVALUATION

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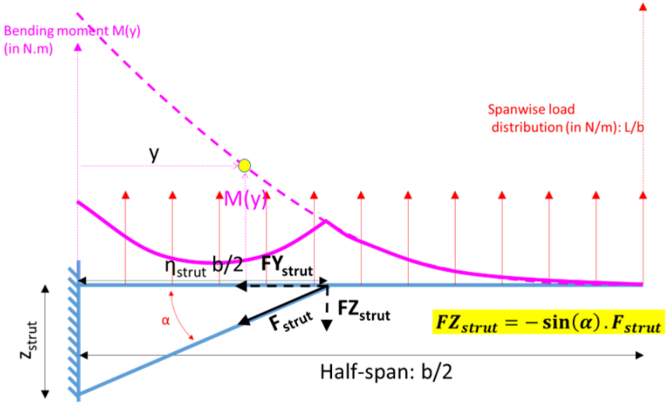
A simple analytical beam-like model of SBW was developed based on

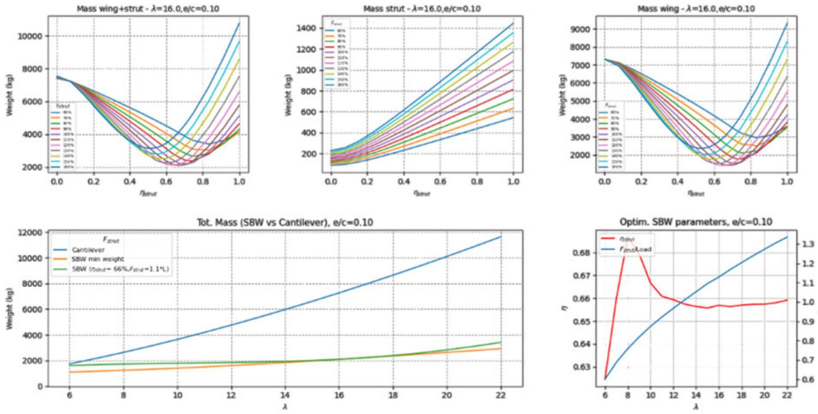
- Spar caps/web, skins and strut (in traction) analytical sizing
- Static loads (-1g and +2.5g manoeuver): elliptical distribution or VLM calc.

And used for:

- Primary structure weight estimation at conceptual aircraft design
- Preliminary investigation of the SBW from a structural perspective: effects of AR, strut attachment location, strut traction force, wing-box thickness, …



Analytical model of force/moment distributions in wing / strut



Example of parametric analysis of AR impact on wing + strut weight
(optimization of spanwise strut attachment and strut traction

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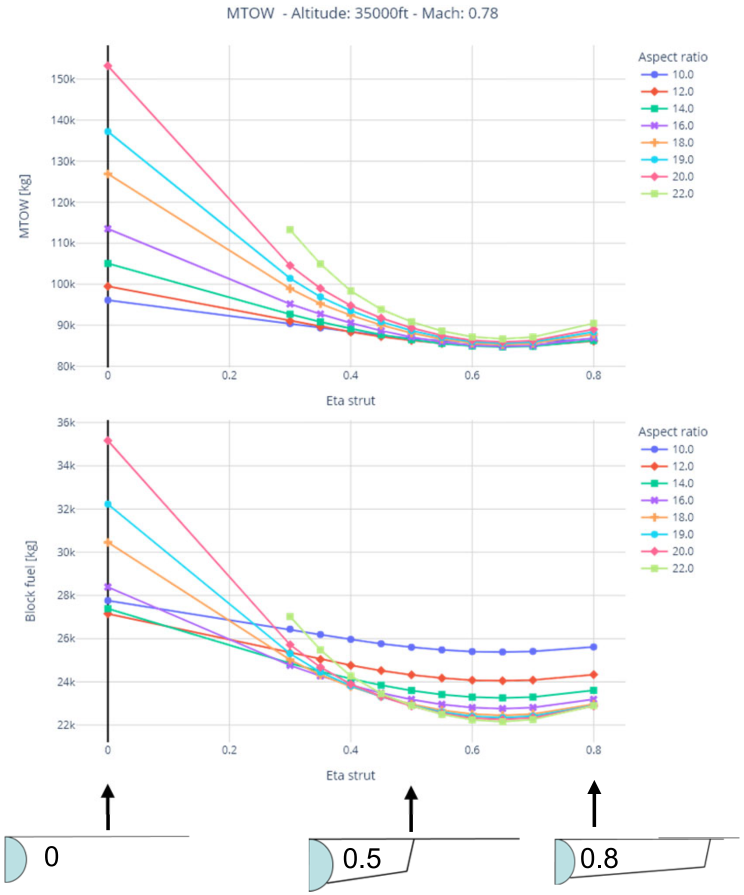
OAD RESULTS OF THE SBW



Investigations of AR impacts on **block fuel for the SBW concept**

🟦 Conf 0: Tube-and-wing, AR=9.5, under-wing engines
🟥 Conf 1: Tube-and-wing, AR=9.5, rear-fuselage engines
🟩 Conf 2: Tube-and-wing, AR=19, rear-fuselage engines
▨ Conf 2.1: SBW, junction at 65%, AR=19, rear-fuselage engines

Mass breakdown comparison for different aircraft concepts

Needed block fuel is reduced by 16% between c2.1 and c0

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CONCLUSIONS

- At OAD level:
  - Using a cantilever wing with new technologies (tailored high strength composite), aspect ratio of 15 should be optimal in terms of fuel consumption
  - Using flared folding wing tips, with the provided load alleviation and the associated mass reduction, the optimal aspect ratio is estimated at 19
  - Using strut-braced wing, with the assumption of no compression loads sustained by the strut, the estimated optimal aspect ratio is also around 19

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