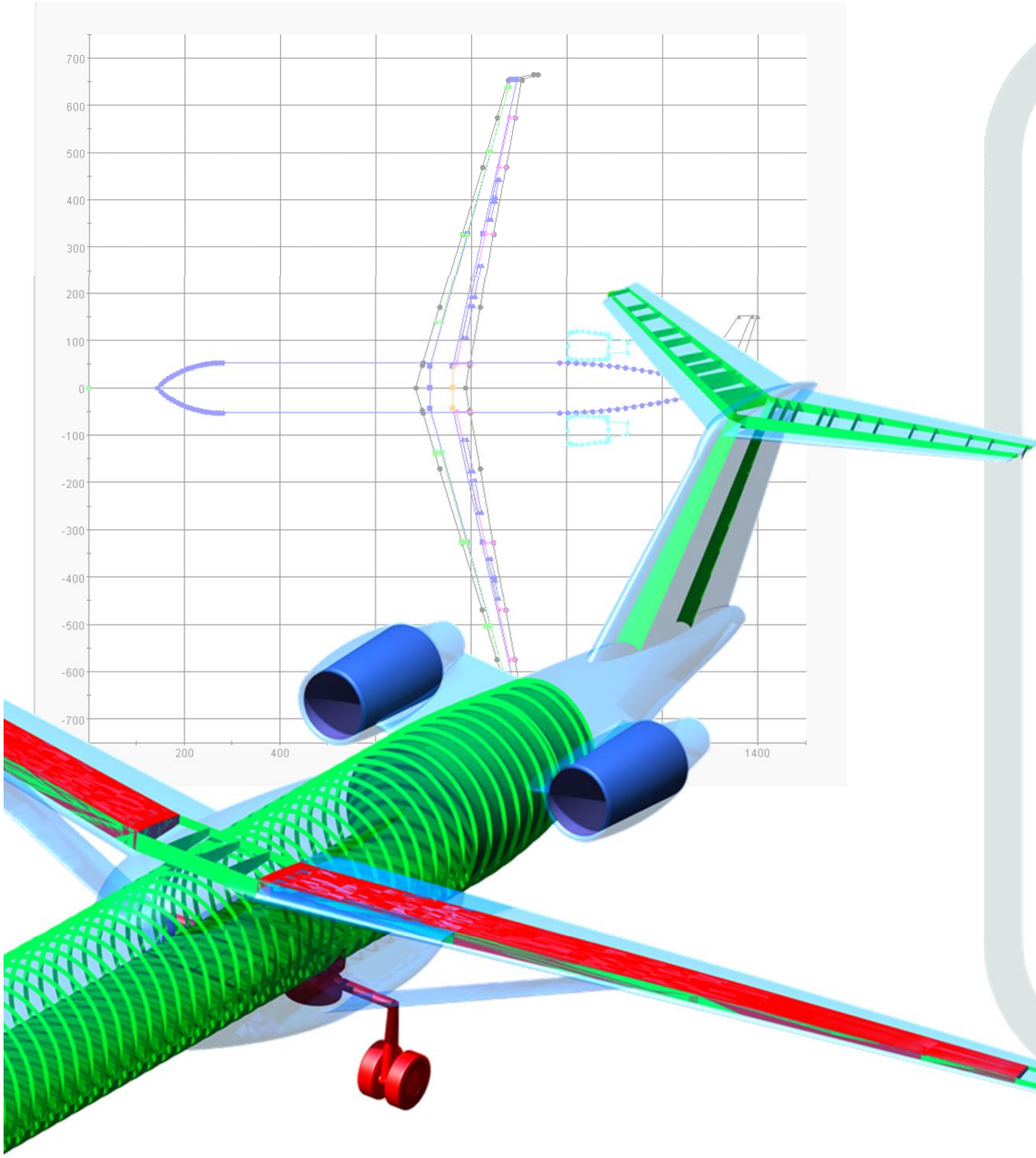

Conceptual Design of a Strut-Braced Wing Configuration

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Advanced Design

Product Development Engineering, Aerospace

Bombardier

UTIAS National Colloquium on Sustainable Aviation

22 June 2017

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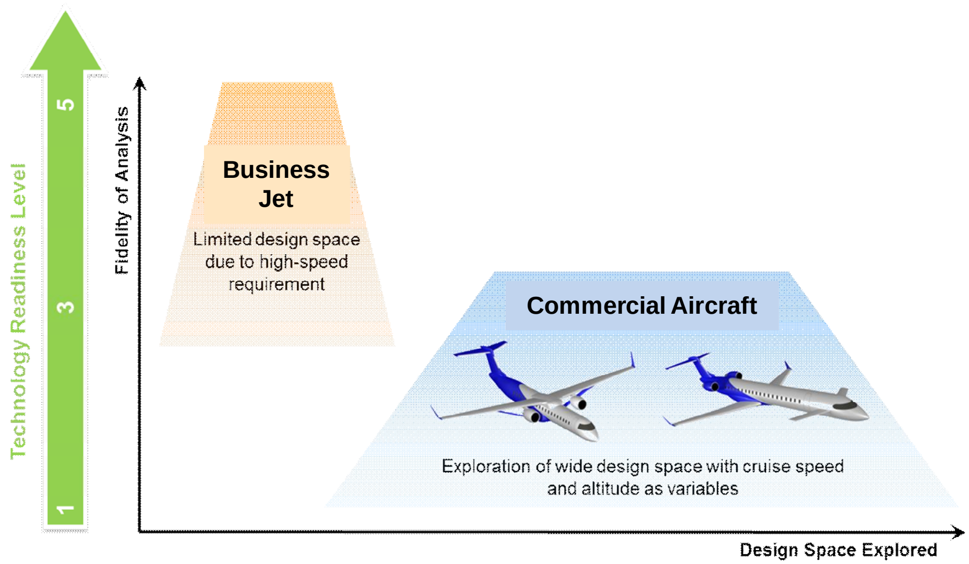
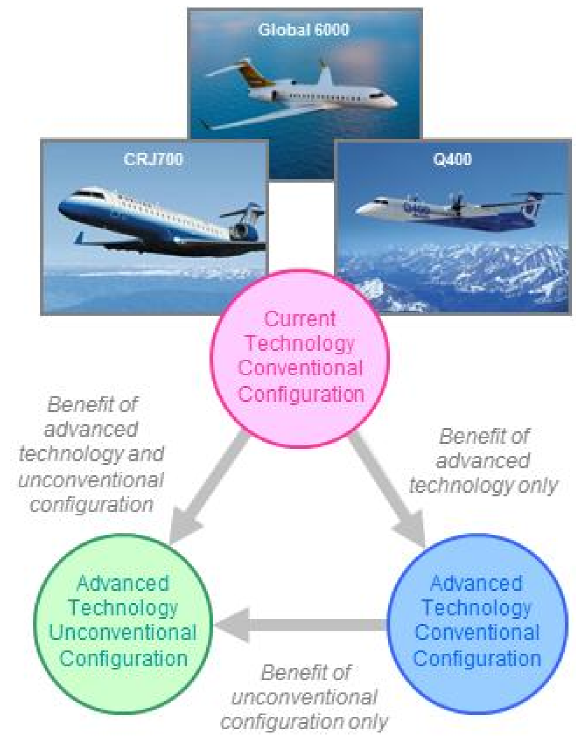
Environmentally Focused Aircraft Study

- **Environmentally Focused Aircraft (EFA) study objective:**
  - Significantly reduce environmental impact (emissions, local air quality and community noise) by evaluating alternative long-range business jet and commercial aircraft configurations
- **Technology assumption:**
  - Consistent with EIS 2030-2035
- **Aircraft requirements:**
  - Based on existing Bombardier products





EIS Entry-Into-Service

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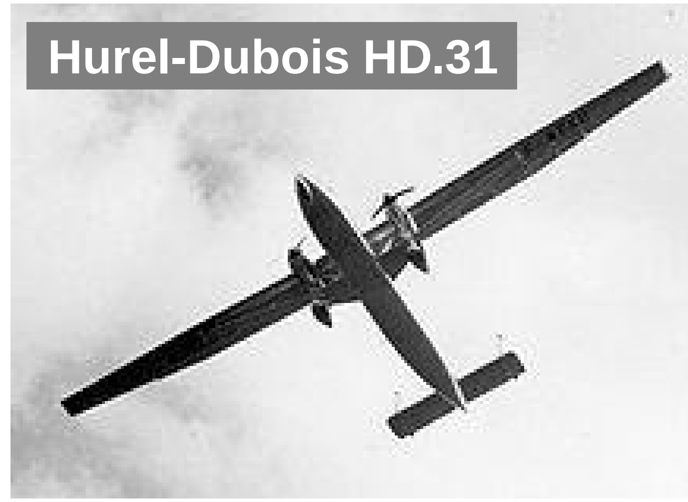
The History of the Strut-Braced Wing

Hurel-Dubois HD.31


Hurel-Dubois HD.31

Shorts 360


Cessna Caravan

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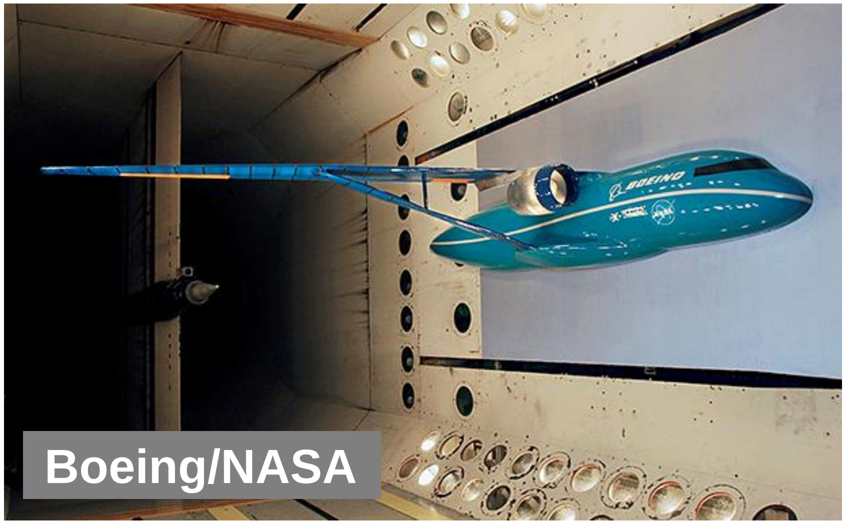
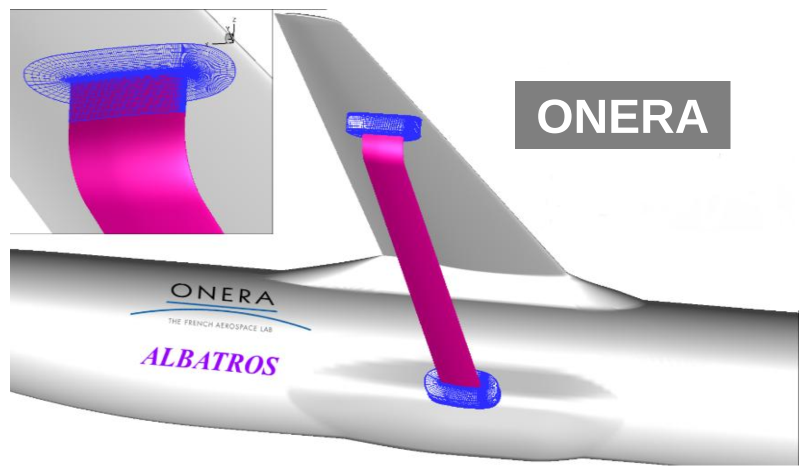
Recent Research Efforts





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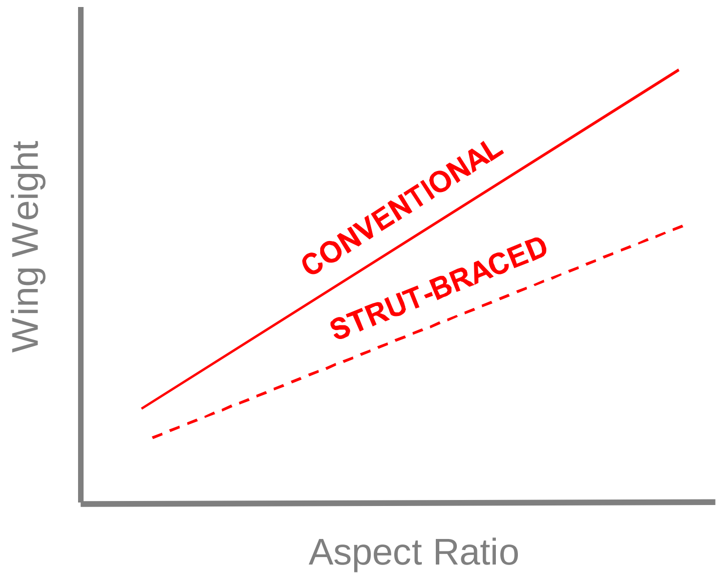
Why a Strut-Braced Configuration?

- Optimum wing aspect ratio is a compromise between wing weight and drag
- Strut-braced wing configuration allows reduced wing weight at a given aspect ratio
- Allows optimization to higher aspect ratios with large reductions in induced drag
- Other studies suggest 5-10% fuel burn savings compared to equivalent conventional configuration



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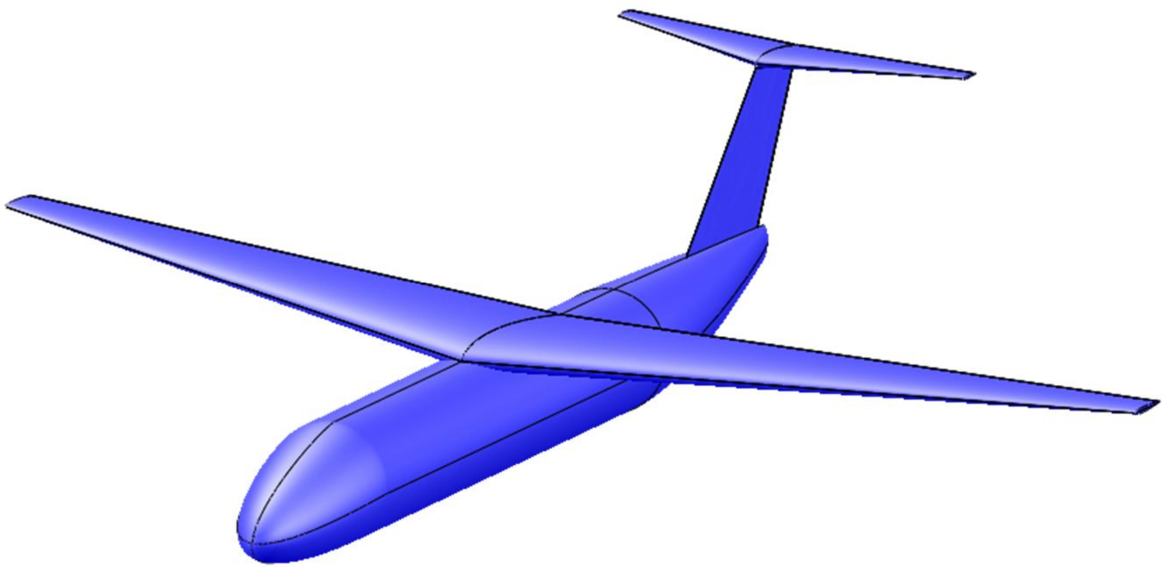
Why a Strut-Braced Configuration?

- Start with a conventional wing geometry



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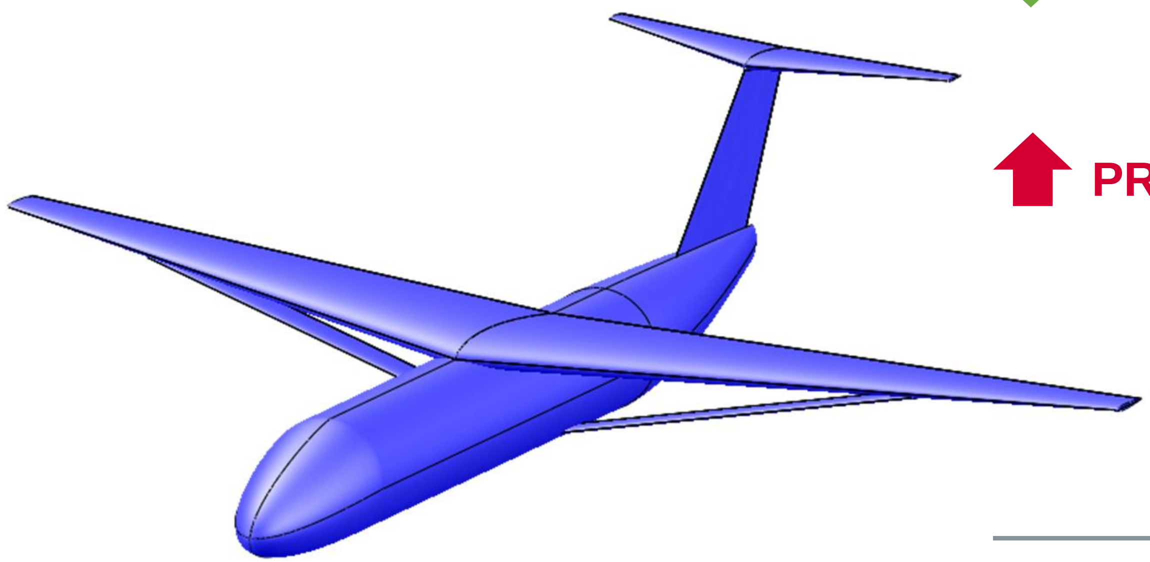
Why a Strut-Braced Configuration?

- Start with a conventional wing geometry
- Add a strut



WING WEIGHT (↓)

PROFILE DRAG (↑)

FUEL BURN (↑)

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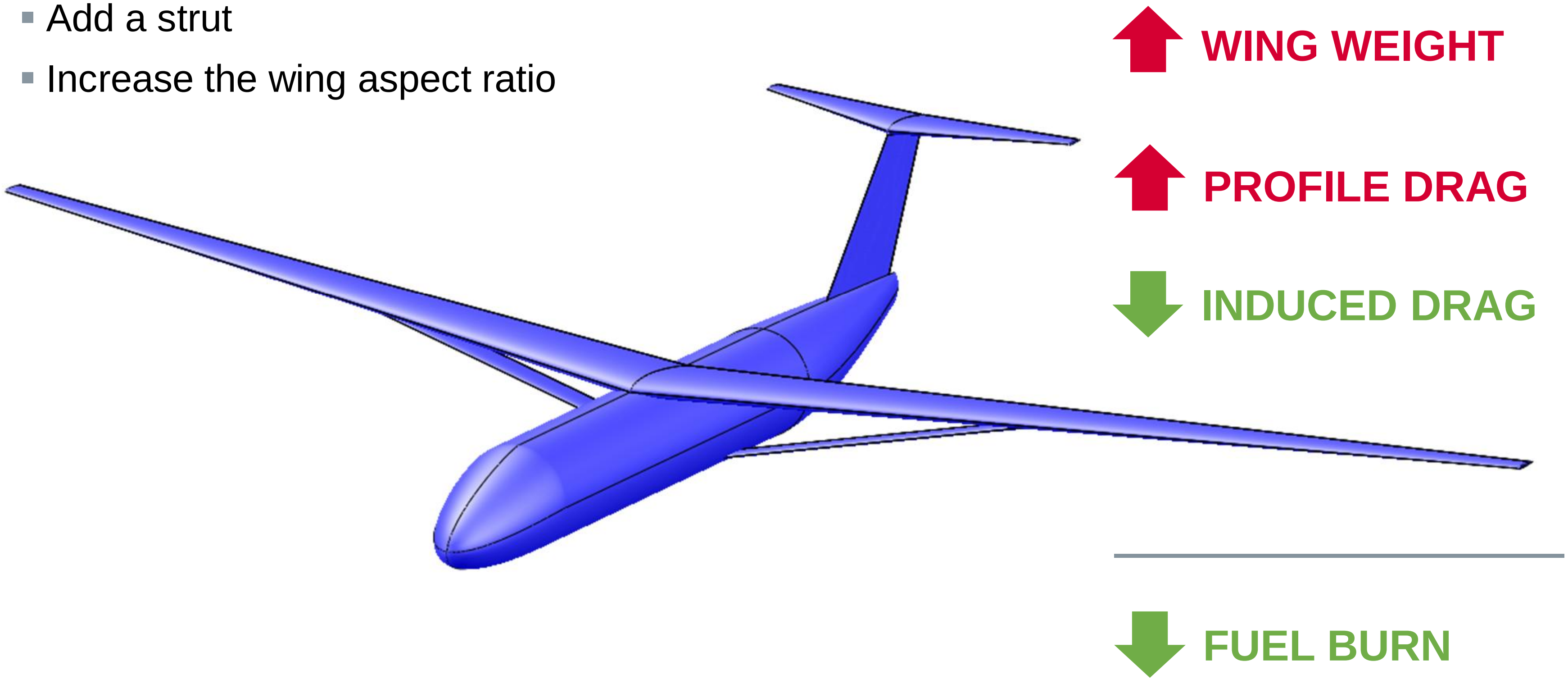
Why a Strut-Braced Configuration?

- Start with a conventional wing geometry
- Add a strut
- Increase the wing aspect ratio



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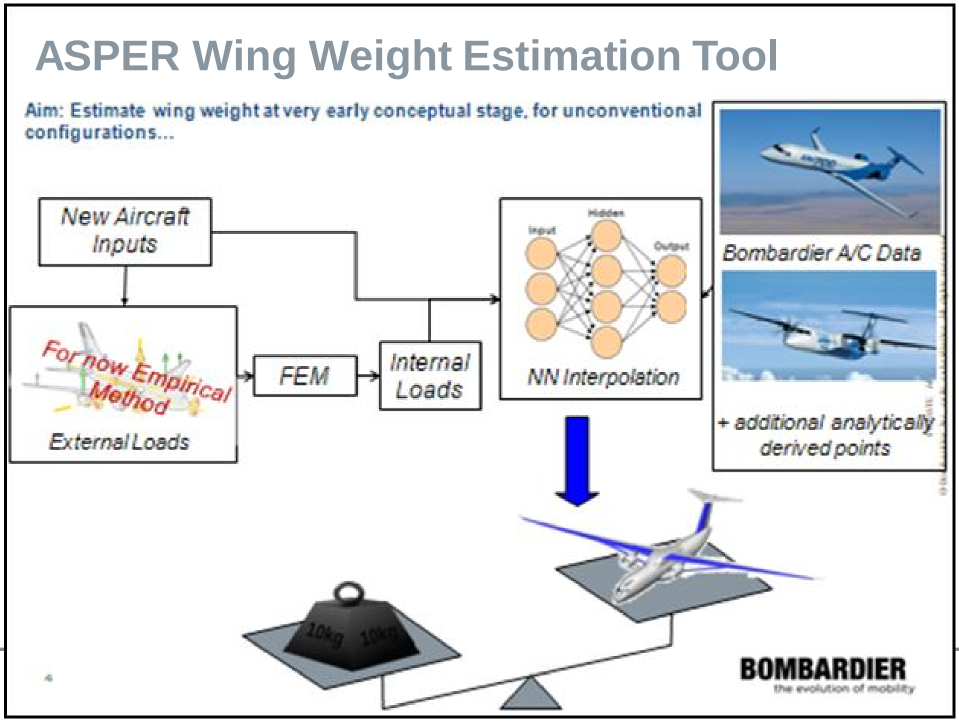
ASPER Wing Weight Estimation Tool

- The primary challenge in modelling strut-braced configurations is estimating wing structural weight
- Little or no data exists for such configurations
- Dependent on physics-based analysis methods, but need short run-time to allow wide design-space exploration
- Bombardier has developed the ASPER tool for strut-braced wing weight estimation



SBW Strut-Braced Wing

FEM Finite Element Model

Initial Strut-Braced Wing Solution

- Implemented ASPER within CMDO aircraft design tool to generate initial SBW solution
- Specified Mach 0.7 cruise speed
- Created GFEM structural model of this configuration and sized using same loads predicted by ASPER
- SBW GFEM used as validation case for ASPER

SBW Strut-Braced Wing

CMDO Conceptual Multi-Disciplinary Design Optimization

GFEM Global Finite Element Model

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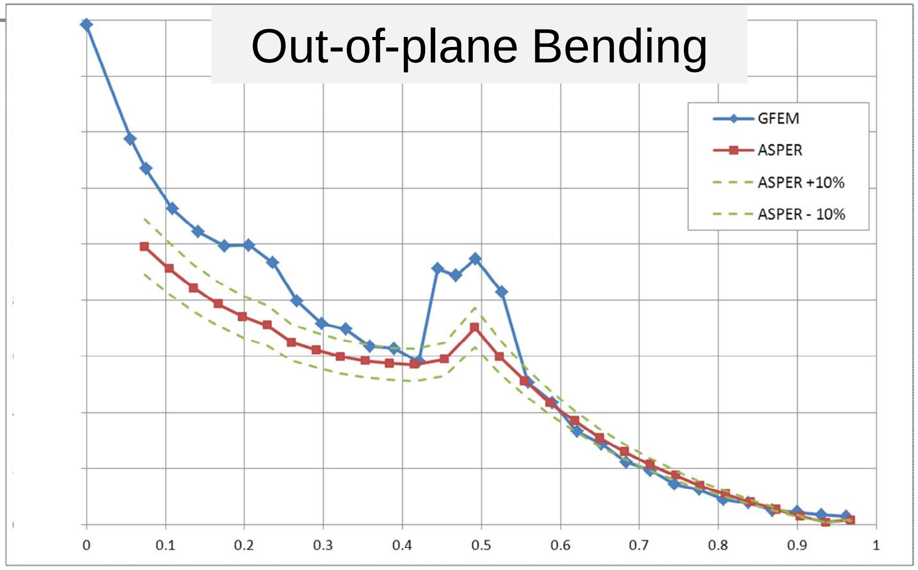
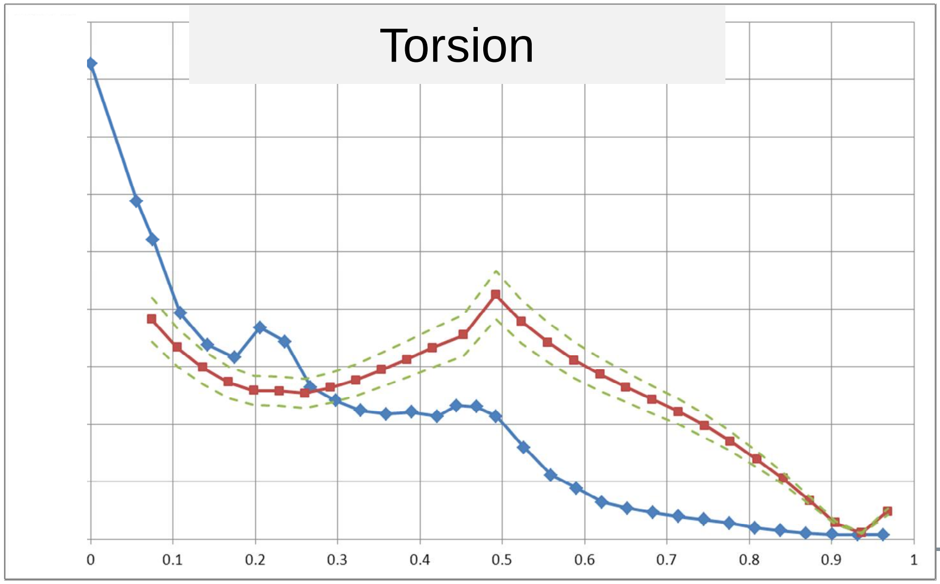
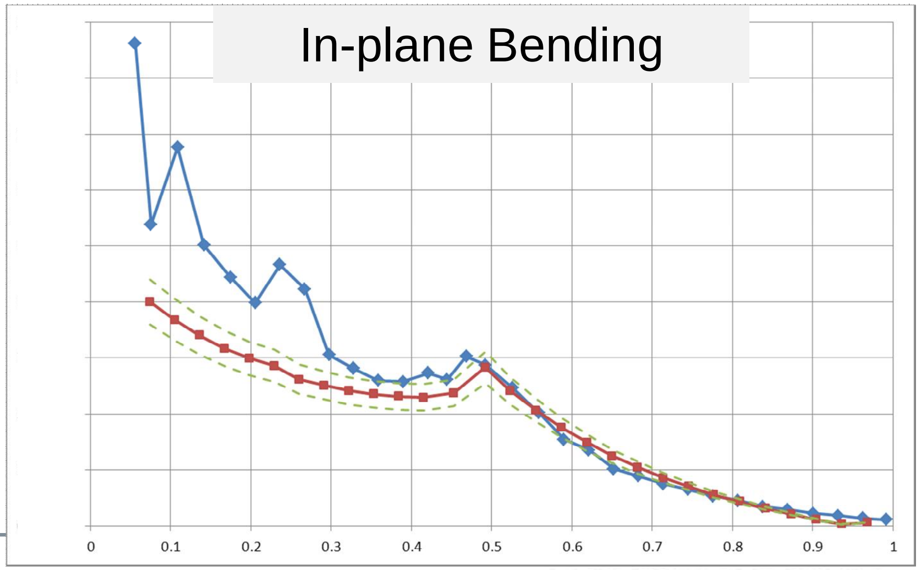
ASPER Validation: Stiffness

- Compared stiffness from ASPER and GFEM
- Bending stiffness reasonable match
- Torsional stiffness less impressive







GFEM Global Finite Element Model

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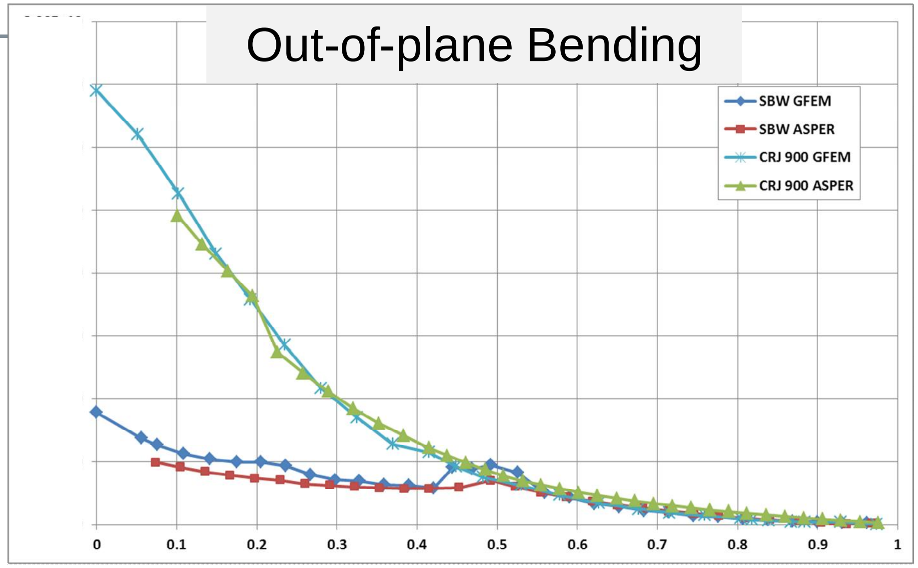
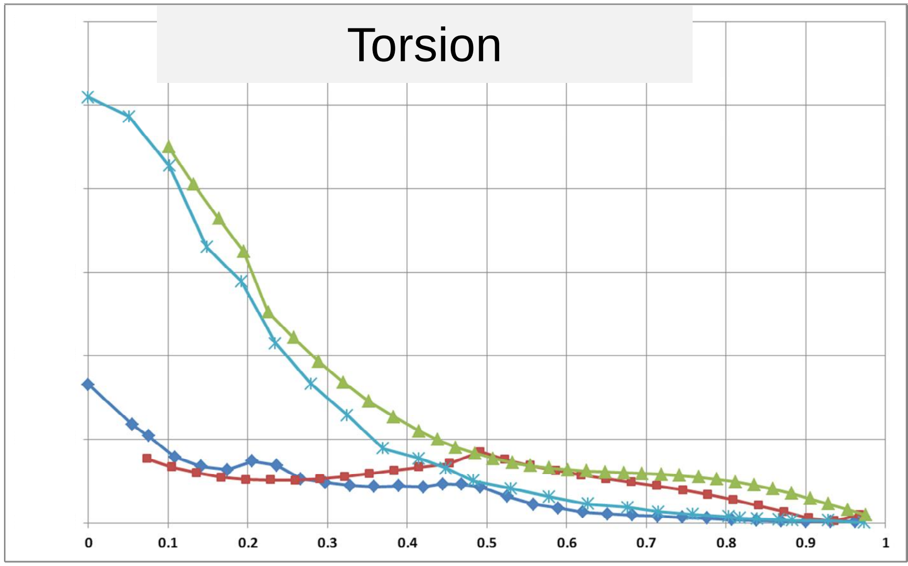
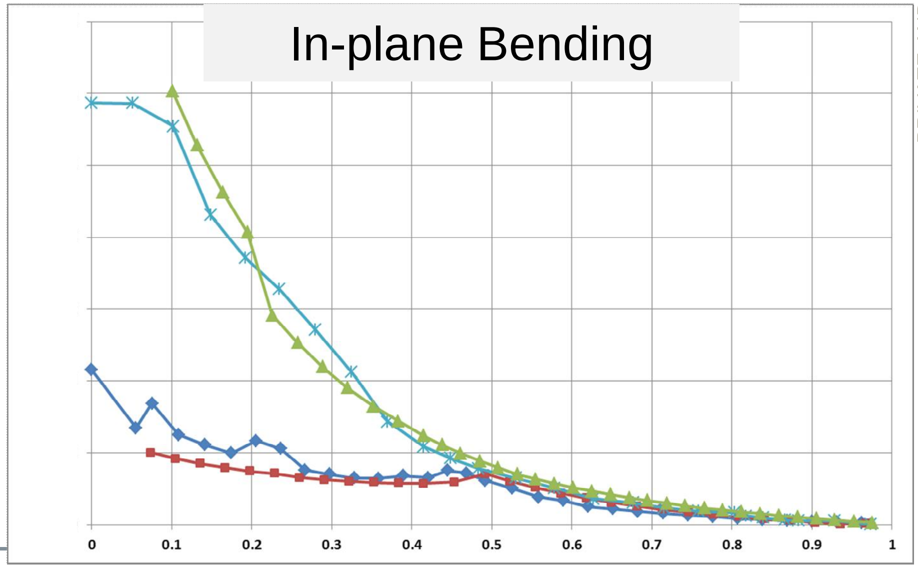
ASPER Validation: Stiffness

- Then compared to similar plots for a conventional wing
- ASPER is shown to do a good job of capturing the big differences in stiffness due to the strut







SBW Strut-Braced Wing

GFEM Global Finite Element Model

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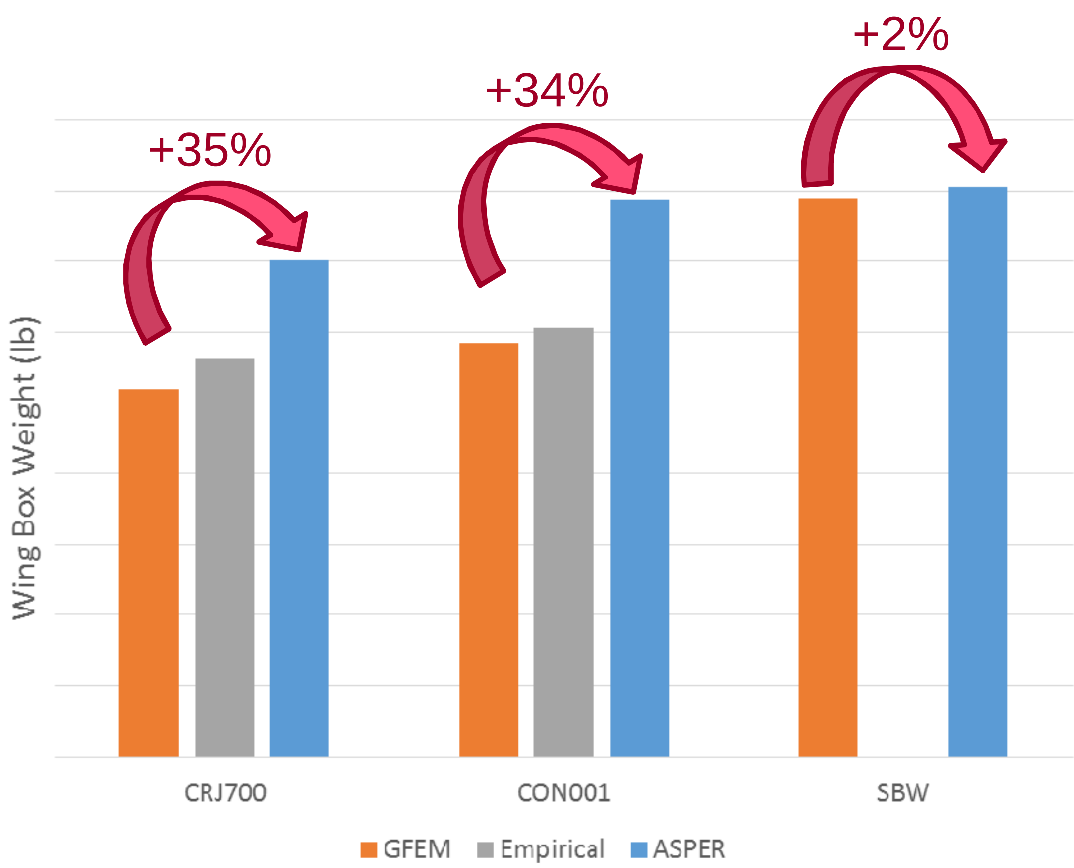
ASPER Validation: Weight

- ASPER wing weight estimate compared to GFEM based estimate for multiple configurations
- CMDO empirical method also compared (non-strut only)
- ASPER agrees well with SBW GFEM
- ASPER over-predicts wing weight for conventional wings by 35%



SBW Strut-Braced Wing

CMDO Conceptual Multi-Disciplinary Design Optimization

GFEM Global Finite Element Model

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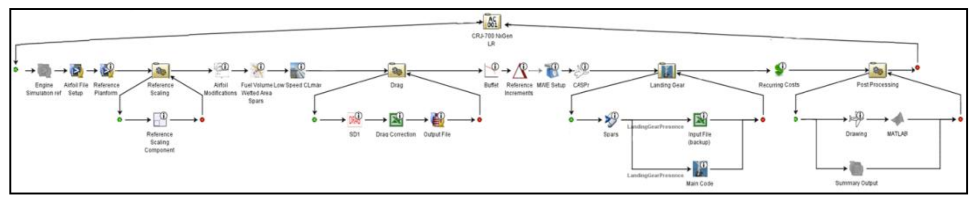
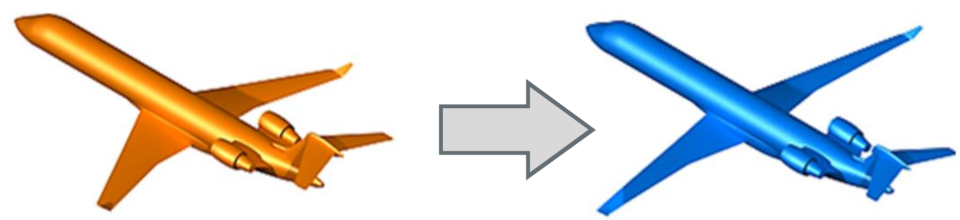
Application of Conceptual Multi-Disciplinary Optimization (CMDO)

- EFA study makes use of Bombardier's CMDO capability
- CRJ700 used as reference aircraft and optimization start point
- Design Variables
  - Wing geometry (area, aspect-ratio, sweep, thickness to chord)
  - Engine scale factor
- Constraints
  - Design range
  - Take-off field length
  - Single engine climb gradient
  - Approach speed
  - Fuel volume
  - Landing gear integration
- Objective
  - Minimum operating cost



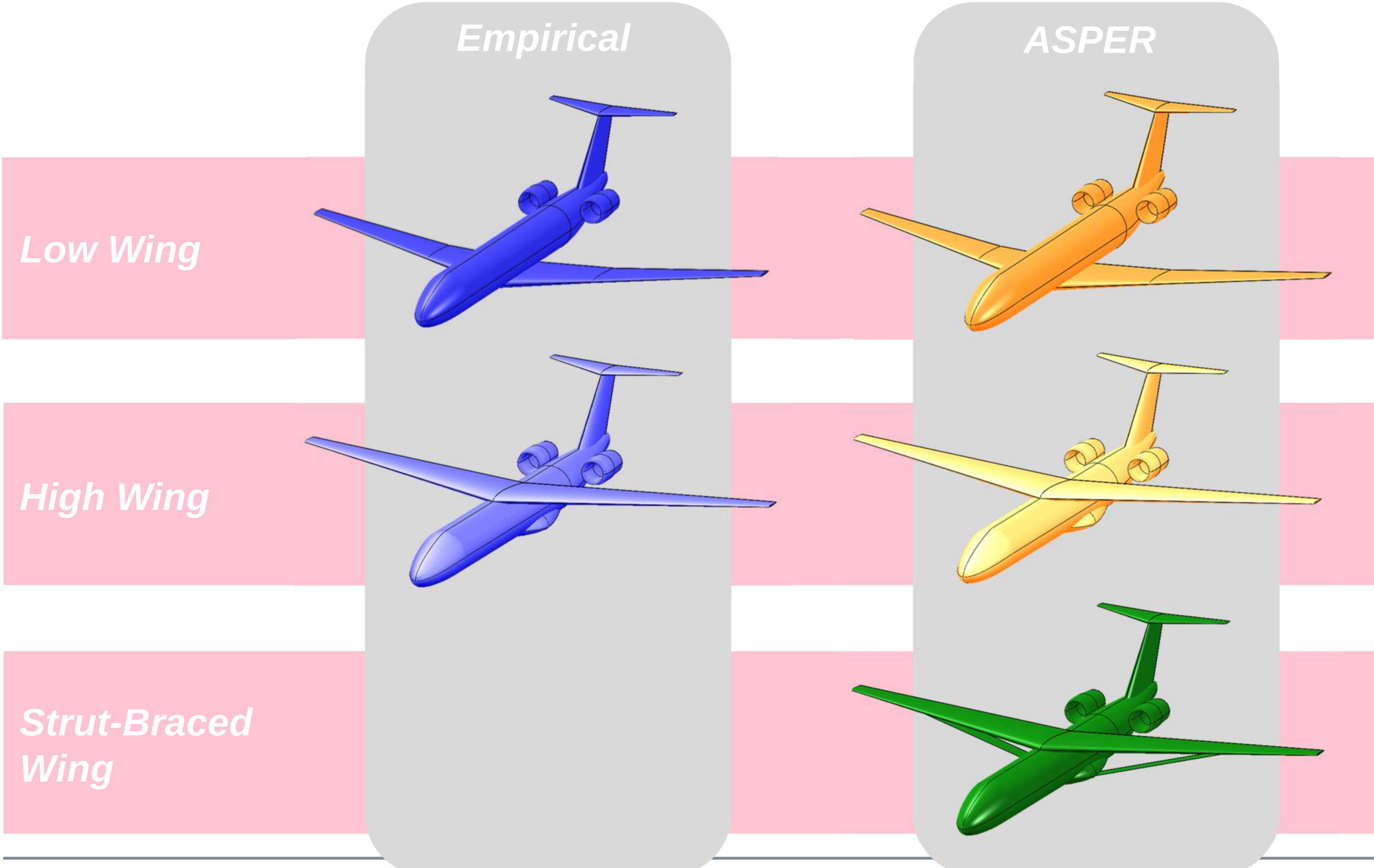
CMDO Workflow



Initial Geometry (CRJ700) **Optimized Geometry**

CMDO Conceptual Multi-Disciplinary Design Optimization

CMDO Sizing Cases



CMDO Conceptual Multi-Disciplinary Design Optimization

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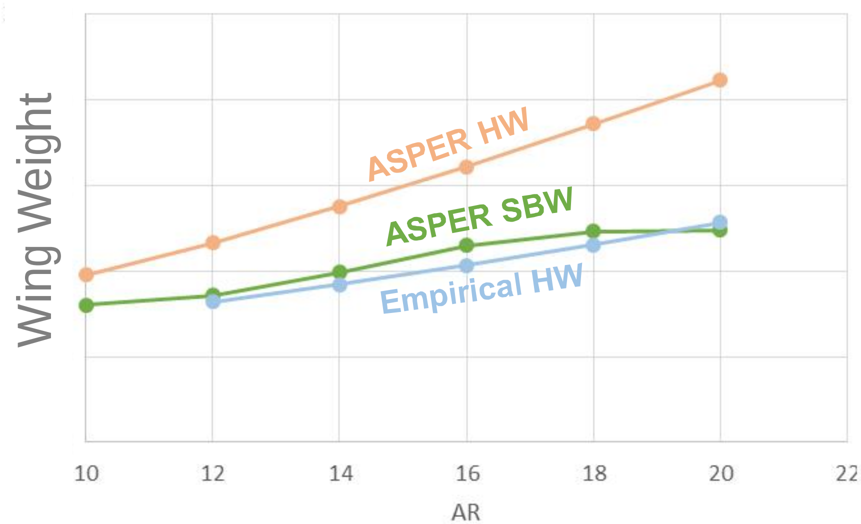
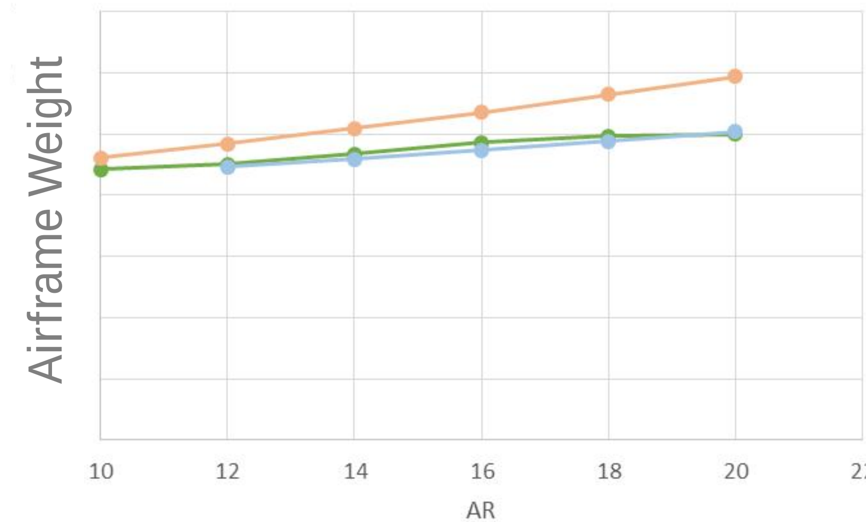
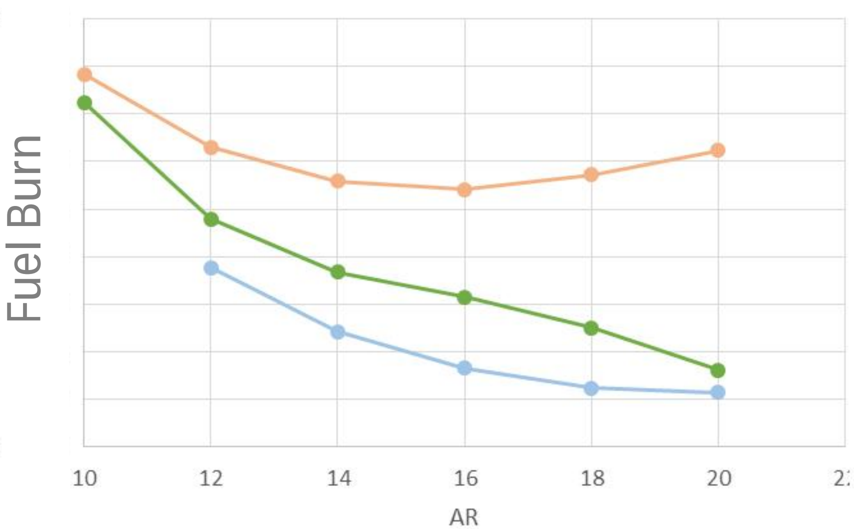
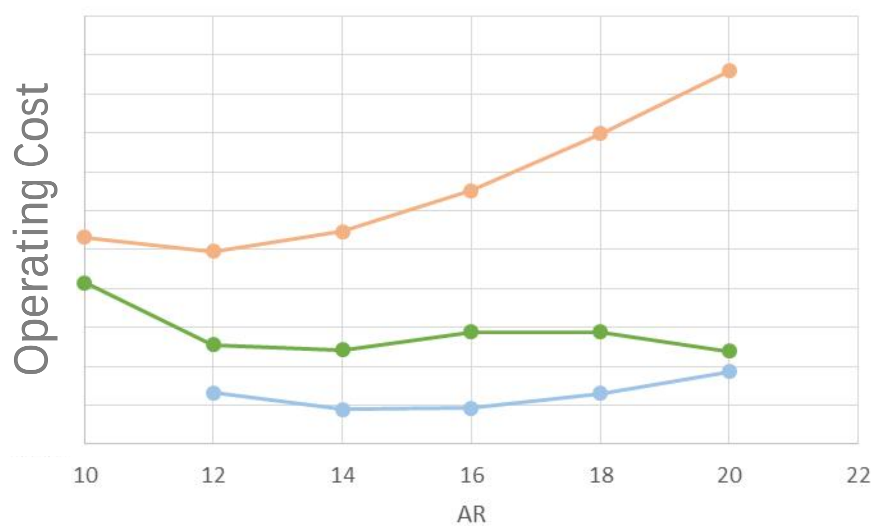
Sensitivity to Wing Aspect Ratio









SBW Strut-Braced Wing

HW High Wing

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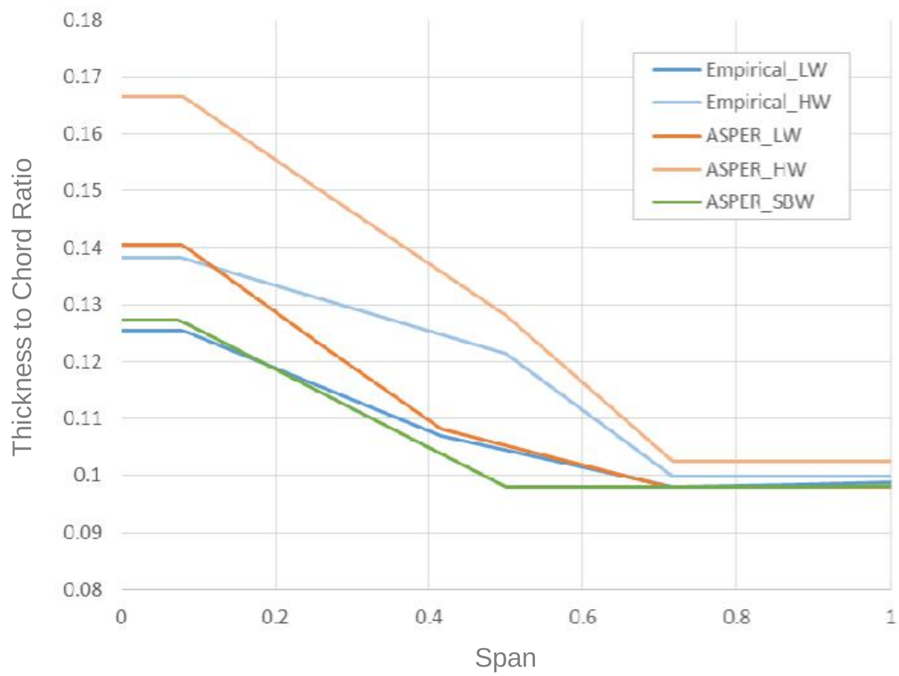
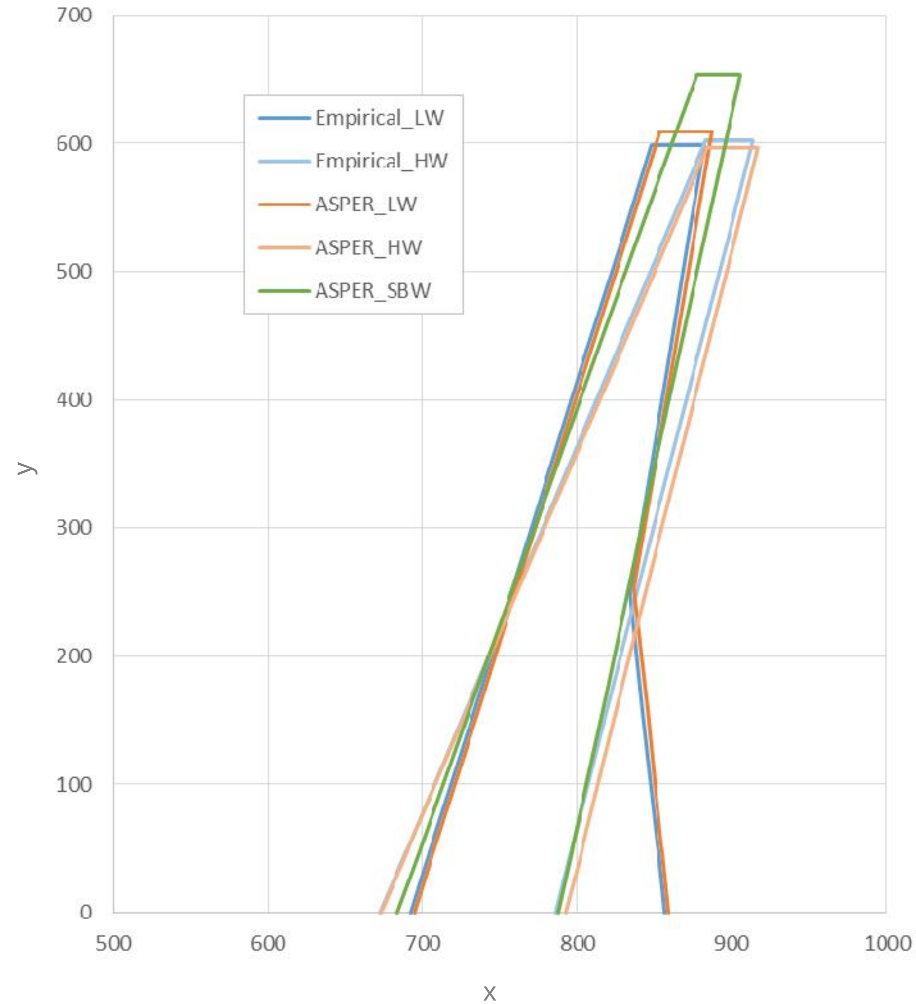
CMDO Optimization Results

	Wing Area	Aspect Ratio	Sweep
Empirical LW	662	15.1	12.6
Empirical HW	600	16.8	17.5
ASPER LW	669	15.4	12.6
ASPER HW	629	15.7	17.6
ASPER SBW	600	19.8	14.9





SBW Strut-Braced Wing
HW High Wing
LW Low Wing

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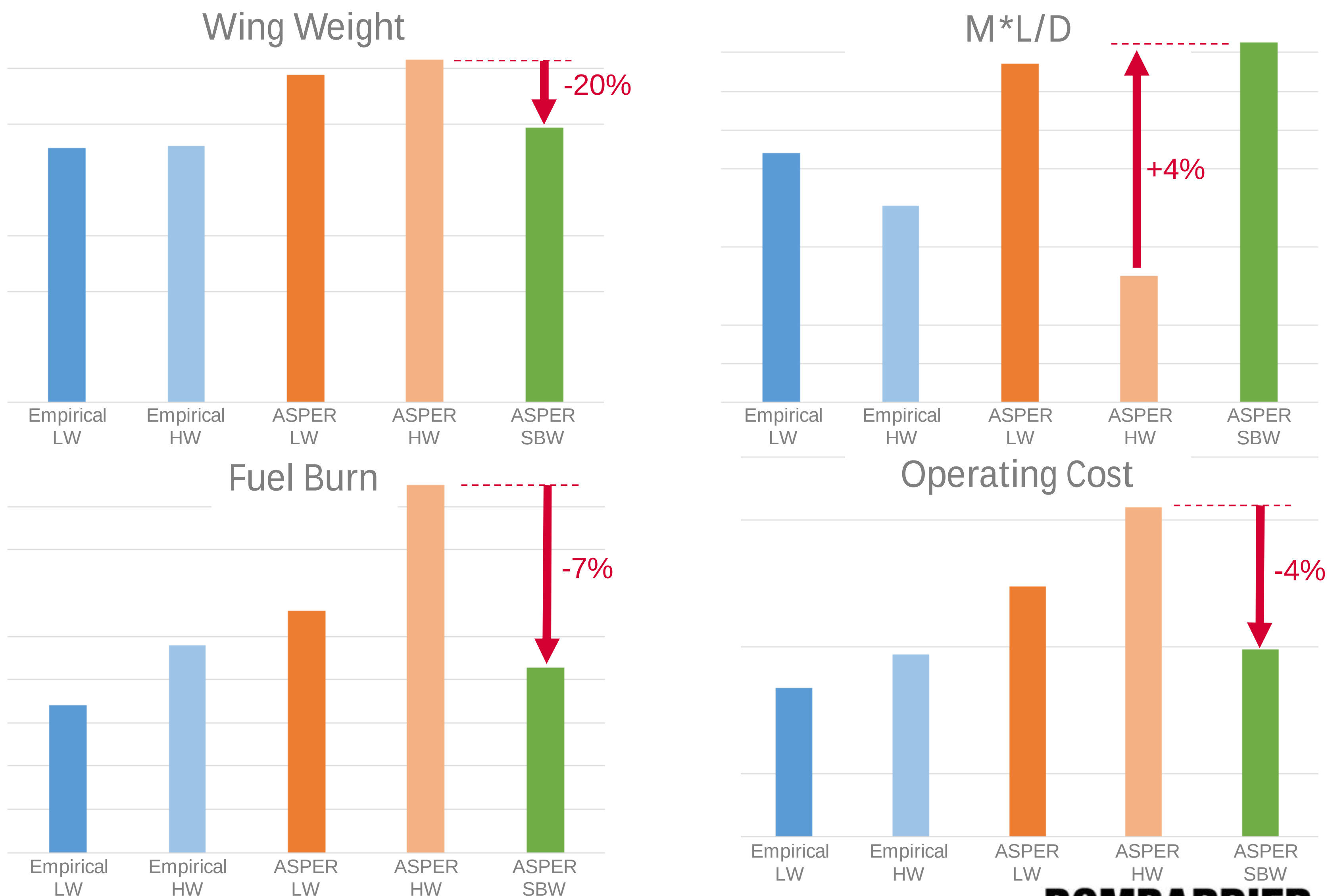
Comparison of CMDO Optimized Solutions



SBW Strut-Braced Wing
M*L/D Mach * Lift to Drag ratio
HW High Wing
LW Low Wing

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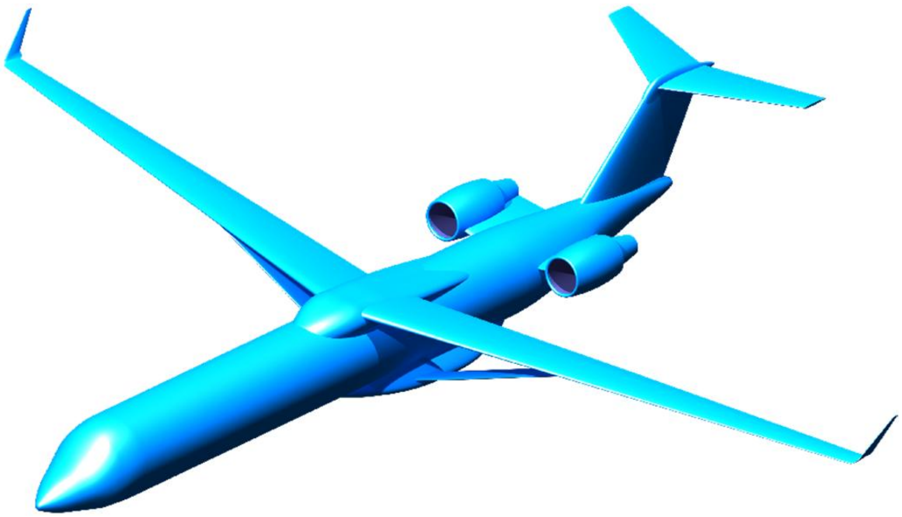
Conclusions

- Strut-braced wing CMDO solution has been generated
- SBW offers 7% fuel burn reduction compared to conventional solution (ASPER, high-wing)
- Benefit falls to 3% compared to low-wing configuration (ASPER)
- SBW has higher fuel-burn than conventional low-wing (Empirical)
- True benefit (or not) of SBW configuration is hard to judge due to wing weight uncertainty
- Significant discrepancy between empirical and ASPER weight estimates needs to be resolved

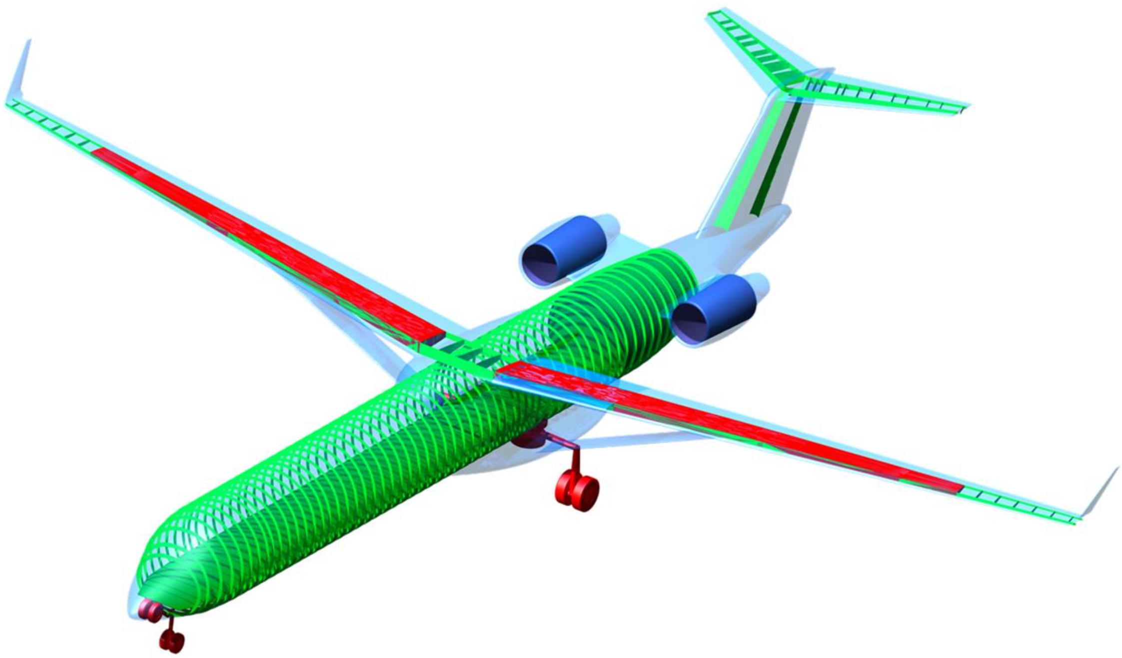


CMDO Conceptual Multi-Disciplinary Design Optimization

SBW Strut-Braced Wing

Next Steps

- Loads will be generated using aero-structural model
- New GFEM will be created for latest configuration
- GFEM based wing weight estimate will be used to validate ASPER prediction
- Aerodynamic design of wing and strut to validate empirical drag polar



GFEM Global Finite Element Model

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