Conceptual Design of a Strut-Braced Wing Configuration

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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

![Diagram showing the design space explored for both business jets and commercial aircraft, with a focus on advanced technology configurations.]
The History of the Strut-Braced Wing

Hurel-Dubois HD.31

Shorts 360

Cessna Caravan

Hurel-Dubois HD.31
Recent Research Efforts

Boeing/NASA

Virginia Tech

ONERA

Boeing/NASA
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.
Why a Strut-Braced Configuration?

- Start with a conventional wing geometry
Why a Strut-Braced Configuration?

- Start with a conventional wing geometry
- Add a strut

- WING WEIGHT
- PROFILE DRAG
- FUEL BURN
Why a Strut-Braced Configuration?

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

- WING WEIGHT
- PROFILE DRAG
- INDUCED DRAG
- FUEL BURN
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
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

AR: 14
Sweep: 13°

SBW Strut-Braced Wing
CMDO Conceptual Multi-Disciplinary Design Optimization
GFEM Global Finite Element Model
ASPER Validation: Stiffness

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

**Out-of-plane Bending**

**Torsion**

**In-plane Bending**

**SBW** Strut-Braced Wing

**GFEM** Global Finite Element Model
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
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 Sizing Cases

- Low Wing
- High Wing
- Strut-Braced Wing

Empirical

ASPER
Sensitivity to Wing Aspect Ratio Ratio

Wing Weight

Airframe Weight

Fuel Burn

Operating Cost

SBW Strut-Braced Wing
HW High Wing
CMDO Optimization Results

<table>
<thead>
<tr>
<th></th>
<th>Wing Area</th>
<th>Aspect Ratio</th>
<th>Sweep</th>
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<tbody>
<tr>
<td>Empirical LW</td>
<td>662</td>
<td>15.1</td>
<td>12.6</td>
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<tr>
<td>Empirical HW</td>
<td>600</td>
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<tr>
<td>ASPER LW</td>
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<tr>
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<tr>
<td>ASPER SBW</td>
<td>600</td>
<td>19.8</td>
<td>14.9</td>
</tr>
</tbody>
</table>

SBW Strut-Braced Wing
HW High Wing
LW Low Wing
Comparison of CMDO Optimized Solutions

Wing Weight

-20%

Fuel Burn

-7%

Operating Cost

-4%

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