Environmentally Focussed Aircraft: Regional Aircraft Study

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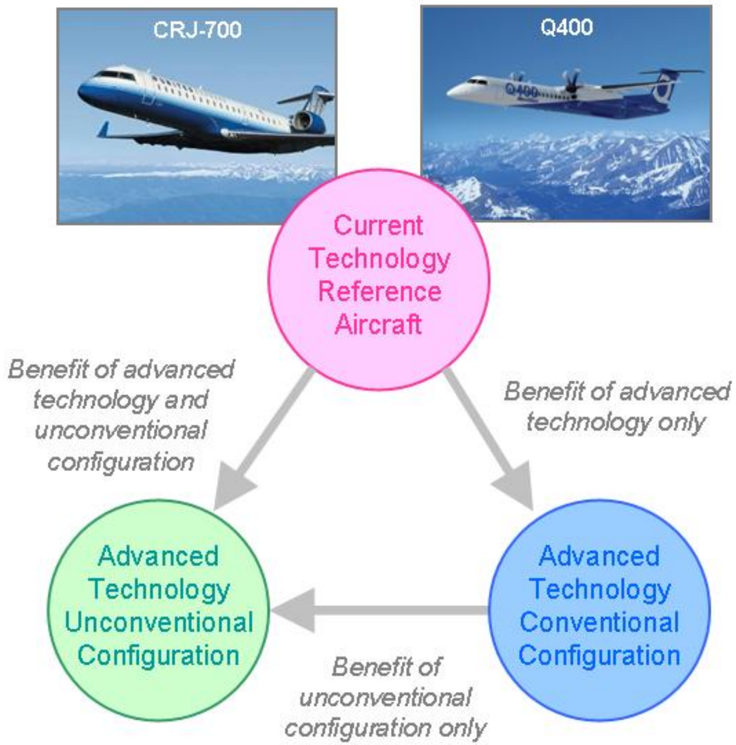
Environmentally Focussed Aircraft

- EFA is Conducting Studies into Future Regional Aircraft Concepts
  - Assumed EIS 2025
- Aim is to reduce environmental impact
  - GHG emissions, local air quality, noise
  - Current focus on climate impact
  - What level of reduction in climate impact is possible?
  - What is the impact on operating cost?
- Consider cruise Mach and altitude as design variables, not requirements
  - Cruise Mach 0.5 – 0.85
  - ICA 18,000ft – 41,000ft
- Intend to quantify incremental benefits
  - Optimized aircraft using current technologies
  - Impact of advanced technologies
  - Impact of unconventional configurations



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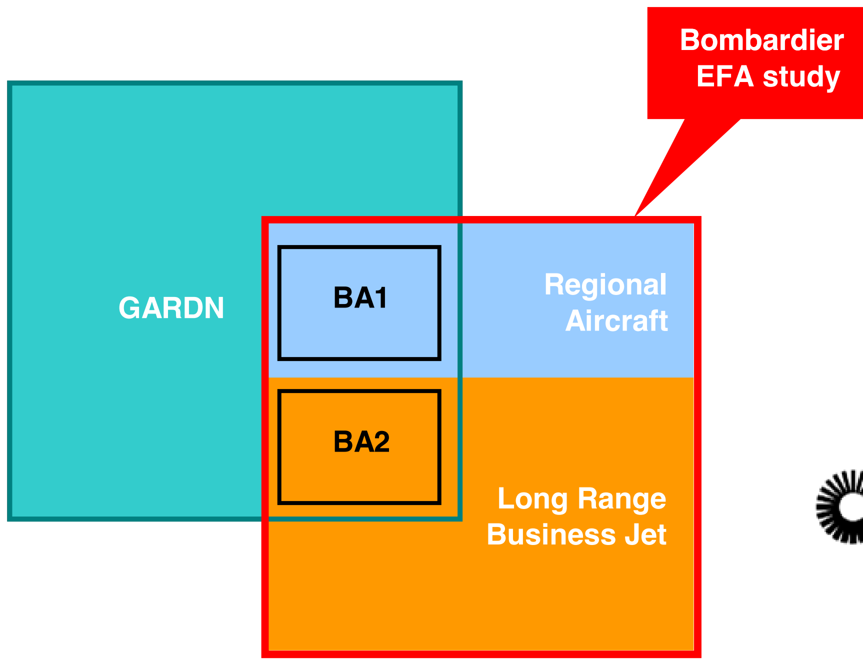
Project Funding

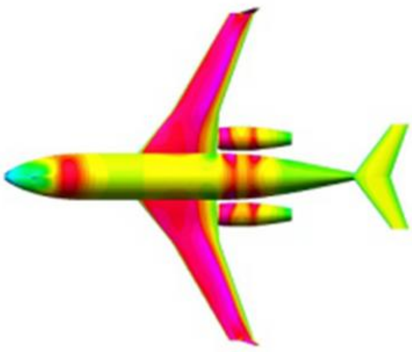
- The EFA program began in 2008 and is funded primarily by Bombardier's Strategic Technology portfolio budget
- A portion of the EFA program is funded by GARDN



Pratt & Whitney Canada
A United Technologies Company

Conceptual Multi-disciplinary Design Optimization (CMDO)

- EFA study makes use of Bombardier's Conceptual MDO capability to size aircraft configurations
- Chosen reference aircraft used for methods calibration and optimisation start point
- Design Variables
  - Engine scale factor
  - Wing geometry (area, aspect-ratio, sweep, thickness to chord, TE crank angle, flap deflection @ TO)
  - Cruise Mach
  - Initial Cruise Altitude
- Constraints
  - Max range
  - High-speed mission (% range at +M0.04)
  - Balanced field length
  - Approach speed
  - WAT limit
- Objectives
  - Minimum MTOW
  - Minimum DOC
  - Minimum fuel-burn
  - Minimum climate impact



Initial geometry

Optimized Geometry

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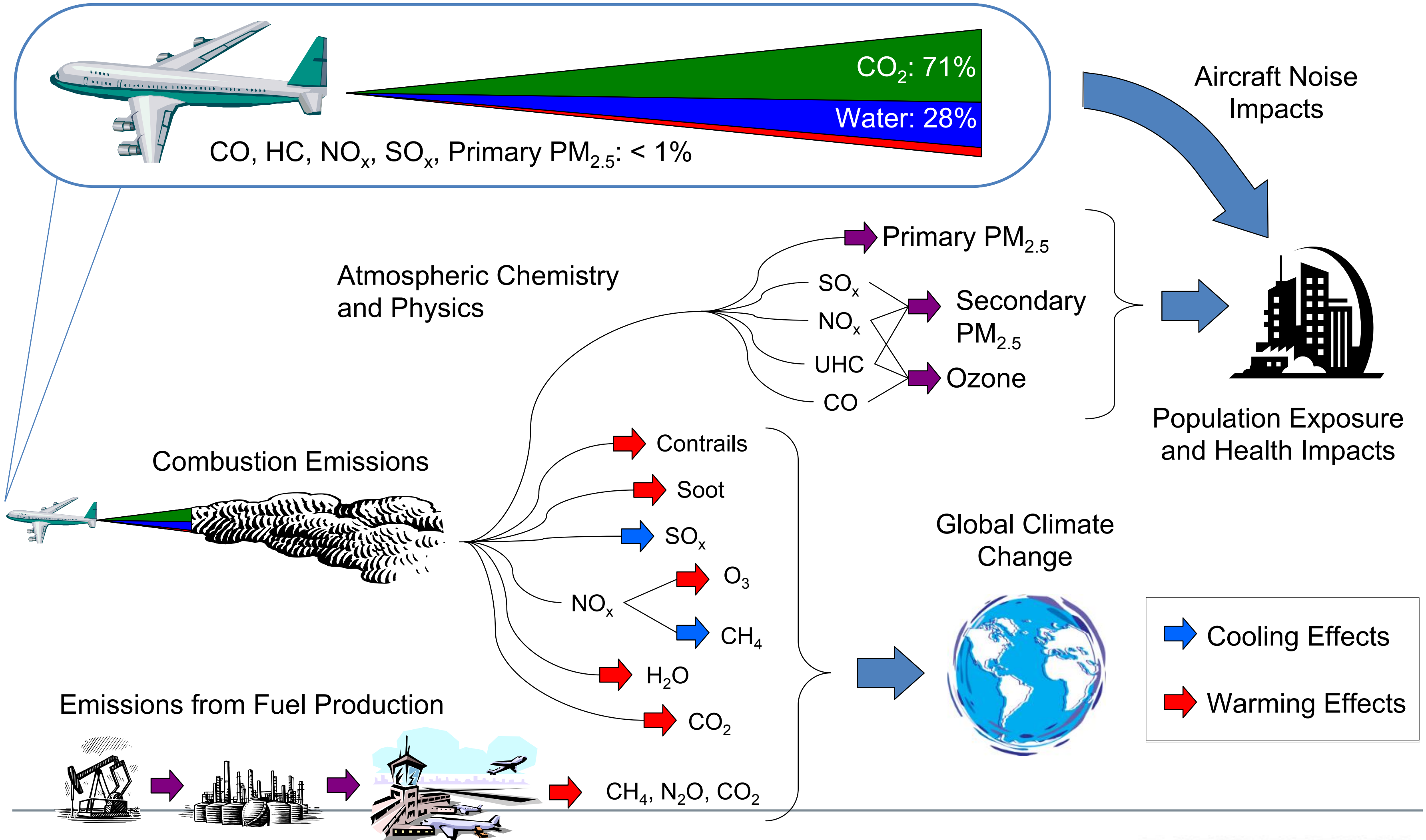
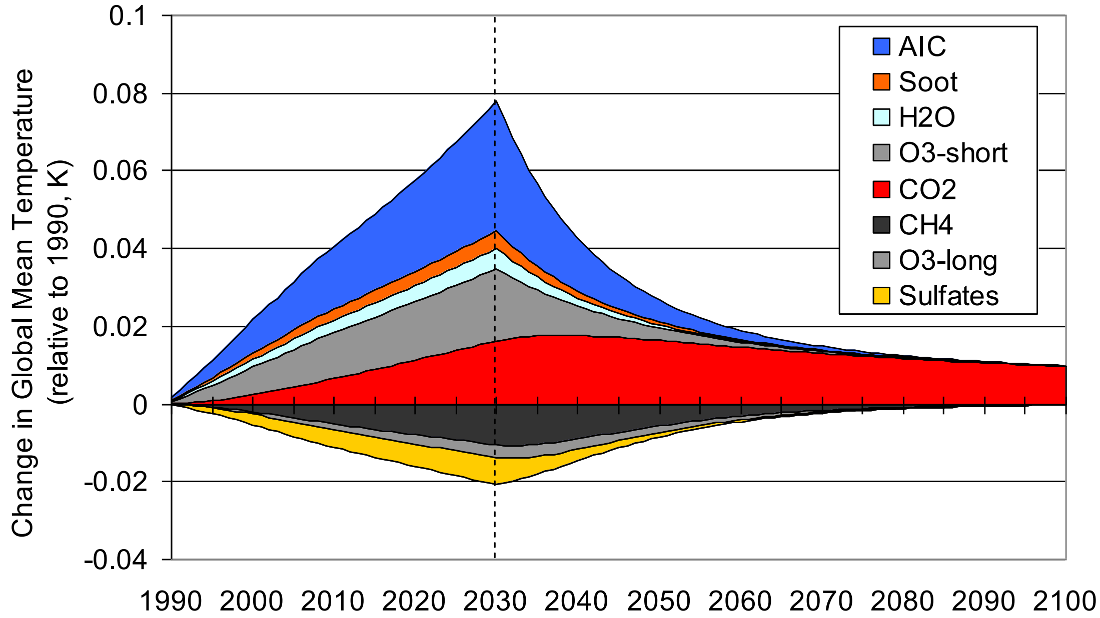
Environmental Impacts



CMDO Workflow Development

Quantifying Climate Impact

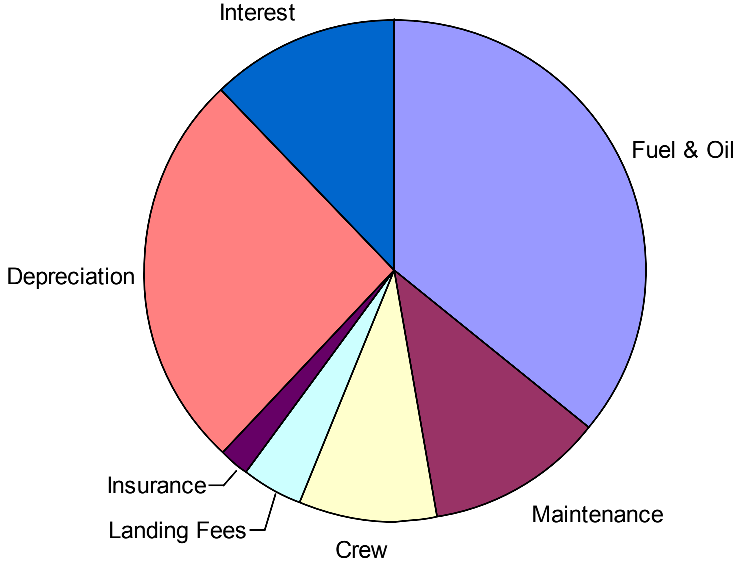
- Developed tool to quantify climate impact of given aircraft design
  - Includes all climate emissions not just CO2
  - Quantifies global temperature change from impulse emission over 100 years
  - Can represent uncertainty of emissions impact



CMDO Workflow Development

Operating Cost Estimation

- DOC components
  - Fuel, oil & lubricants
  - Crew
  - Maintenance
  - Landing fees
  - Insurance
  - Financing
  - Depreciation
- Aircraft Price
  - Price correlated to productivity (function of range, pax, speed, cabin volume, TOFL)
- Impact of cruise speed on operating cost
  - Have assumed revenue per flight not affected by cruise speed
  - Have assumed fixed flight hours per year, regardless of speed
  - Hence slower aircraft have increased ownership cost *per mission* (due to less missions per year)
  - Hence slower aircraft has higher DOC per mission (for same AC price and COC)
  - This captures the lower productivity of the slower aircraft



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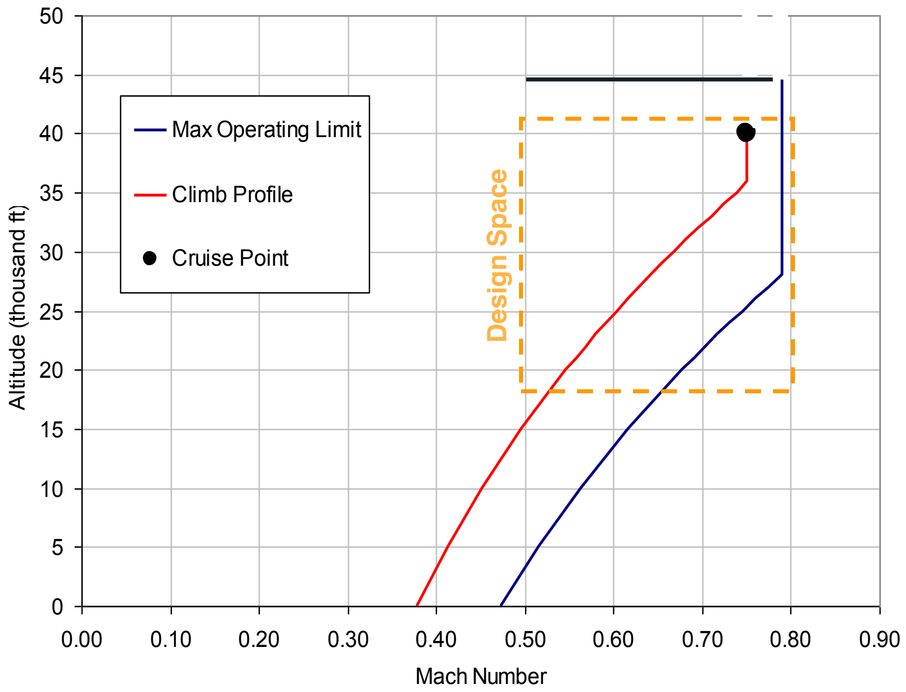
CMDO Workflow Development

Variable cruise Mach and altitude

- Cruise Mach and ICA defined as design variables
- Climb/descent profile and flight envelope defined as a function of chosen Mach/ICA
  - $M_{MO} = M_{LRC} + 0.06$
  - $M_D = M_{MO} + 0.07$
  - $V_{MO} = M_{MO}$ @ 70% specified ICA
  - $V_D = V_{MO} + 60kt$
  - Max Ceiling = ICA + 5000ft



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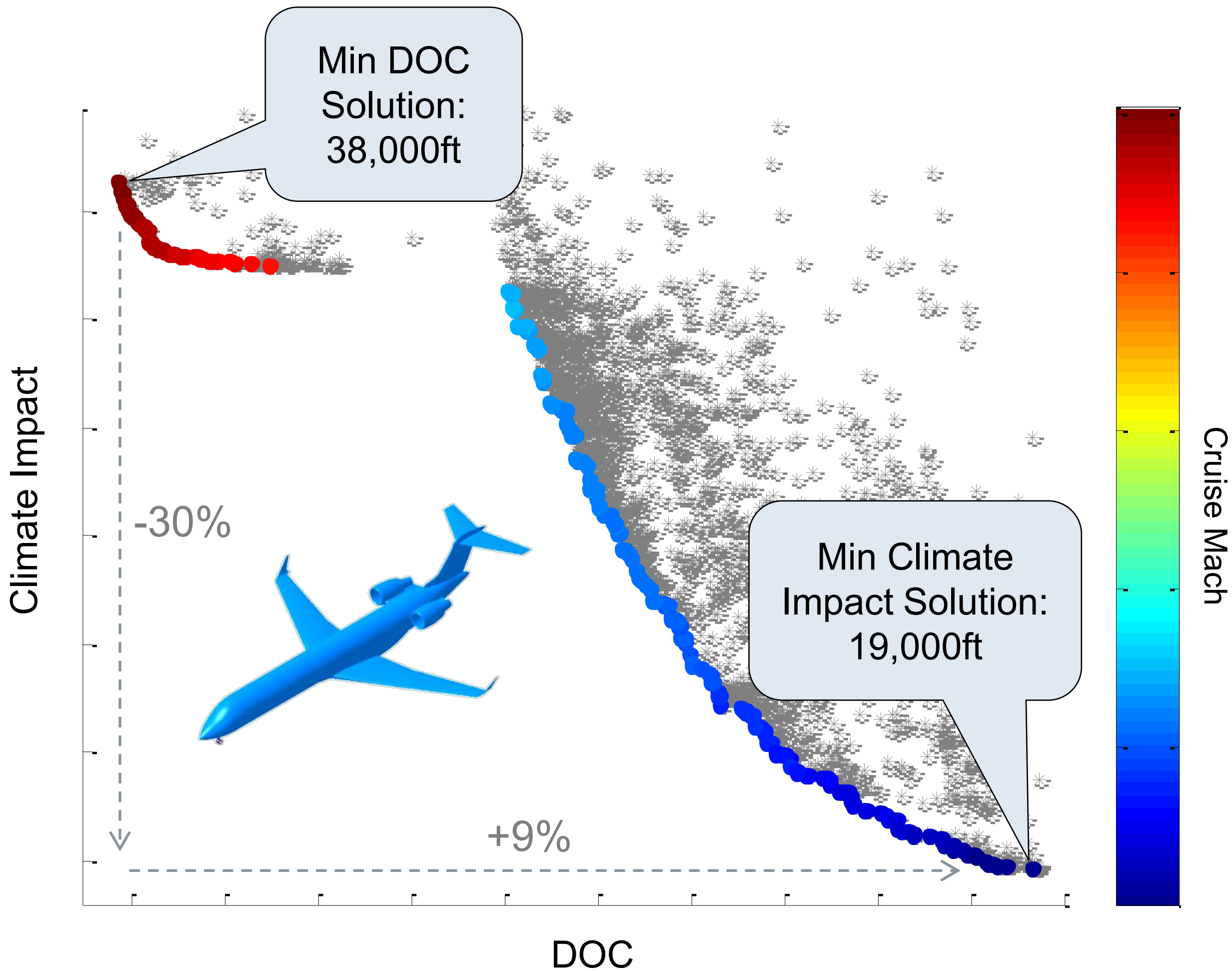
Design-Space Exploration Results

Trading Climate Impact with Operating Cost



- Assumes no technology improvement over the CRJ700
- Climate Impact represents temperature change resulting from all emissions, not just CO_2
- Minimising Climate Impact is achieved by reducing cruise altitude to prevent contrail generation and limit NOx effects
- Fuel-burn is actually higher for min Climate solution than min DOC due to low altitude cruise
- DOC increases as Climate Impact is reduced due to higher fuel-burn and increased time dependant costs (maintenance and crew)

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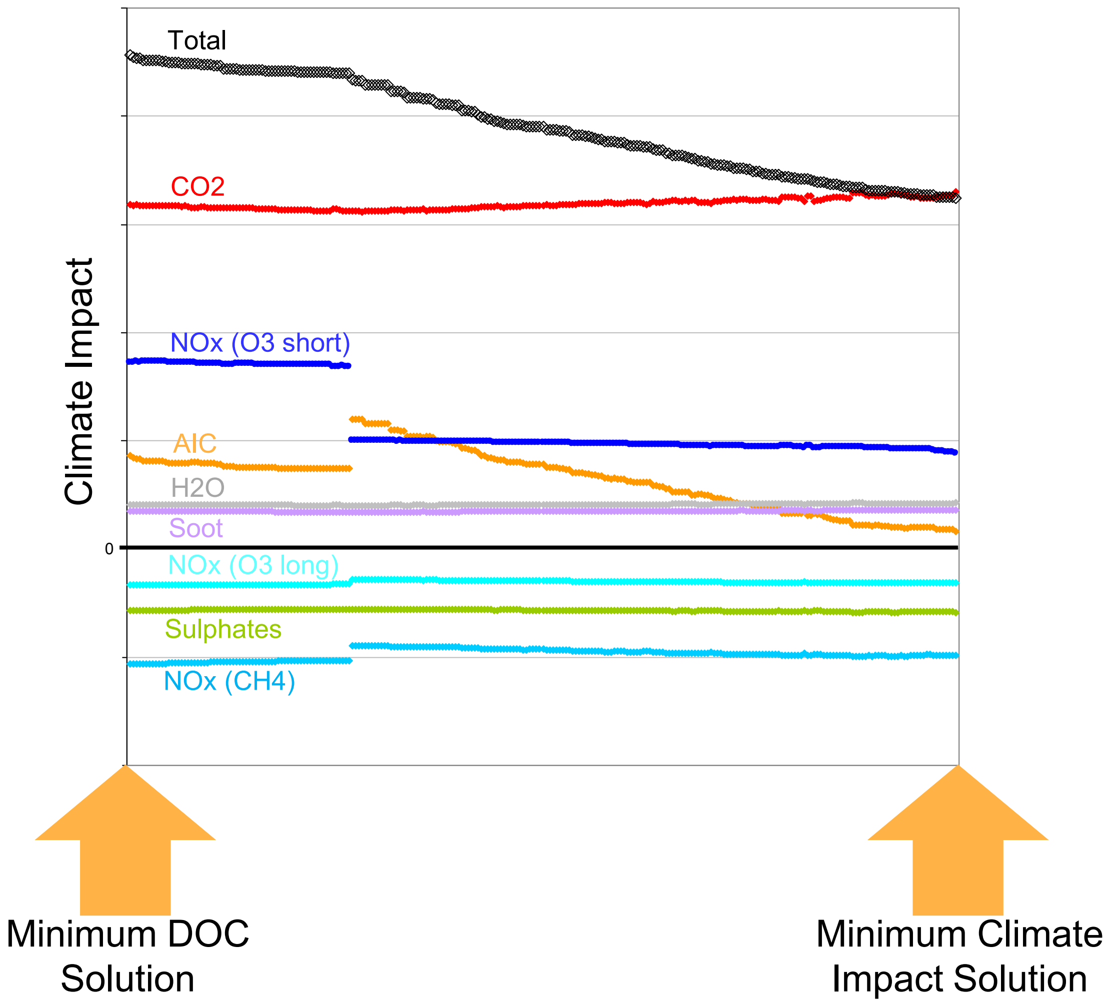
Design-Space Exploration Results
Breakdown of Climate Impact



- Results show that CO_2 is the most potent climate impact emission
- NOx effect is comprised of both warming and cooling components
- NOx and AIC effects are strongly altitude dependant
- Significant reduction in cruise altitude largely removes NOx and AIC effects
- Is climate impact the most appropriate metric?

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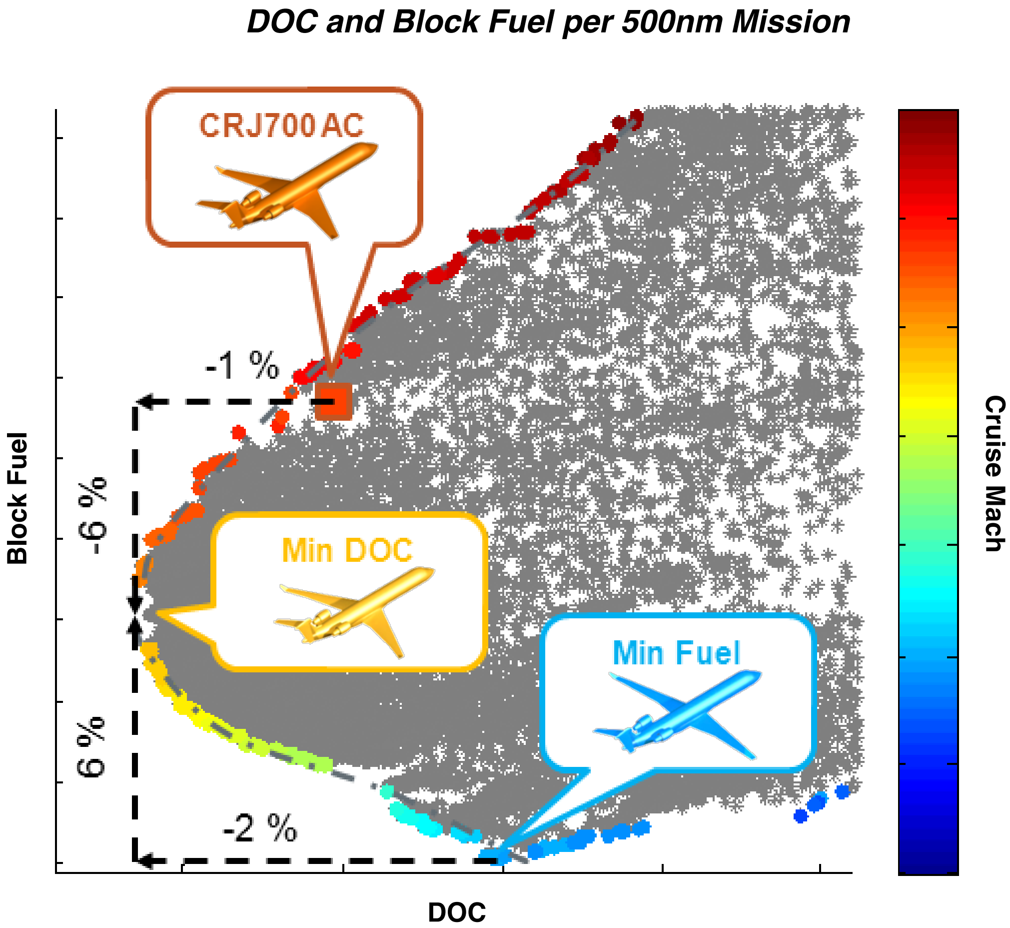
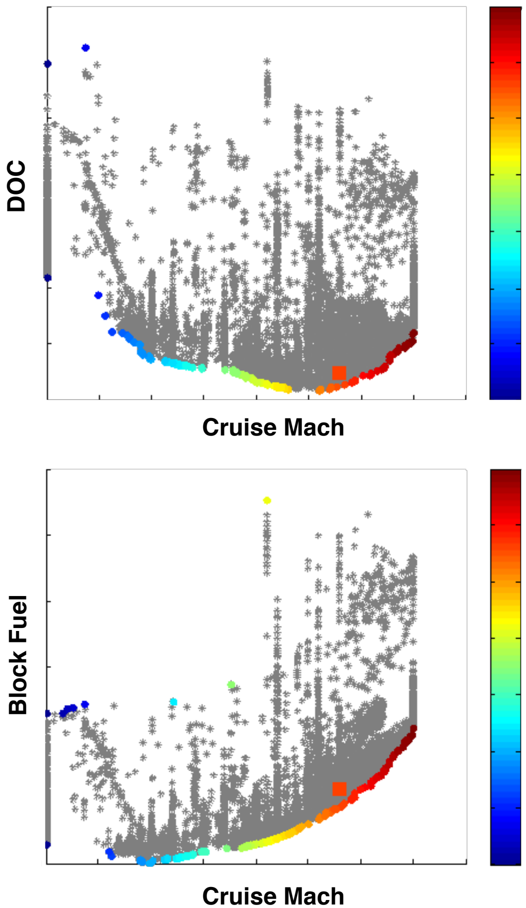
Design-Space Exploration Results
Trading Fuel-Burn with Operating Cost





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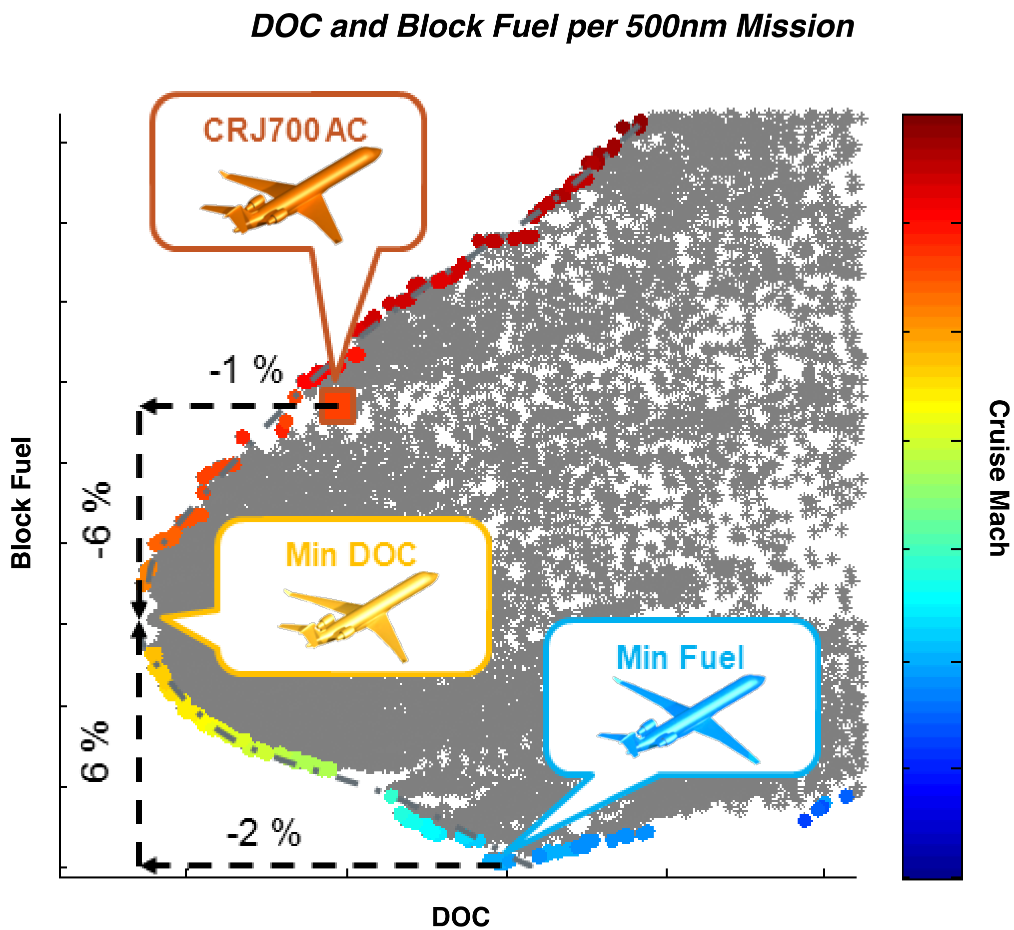
Design-Space Exploration Results
Trading Fuel-Burn with Operating Cost



- Results assume $3/USG fuel price (2011 average)
- Significant fuel burn reduction is possible while also reducing operating cost by reducing cruise Mach
- Further reduction in cruise Mach offers further fuel burn reduction but with increased operating cost
- Optimization solutions are effectively min fuel aircraft at a given cruise Mach whereas CRJ700 is closer to min MTOW
- Min DOC solutions do not address OEM business case needs

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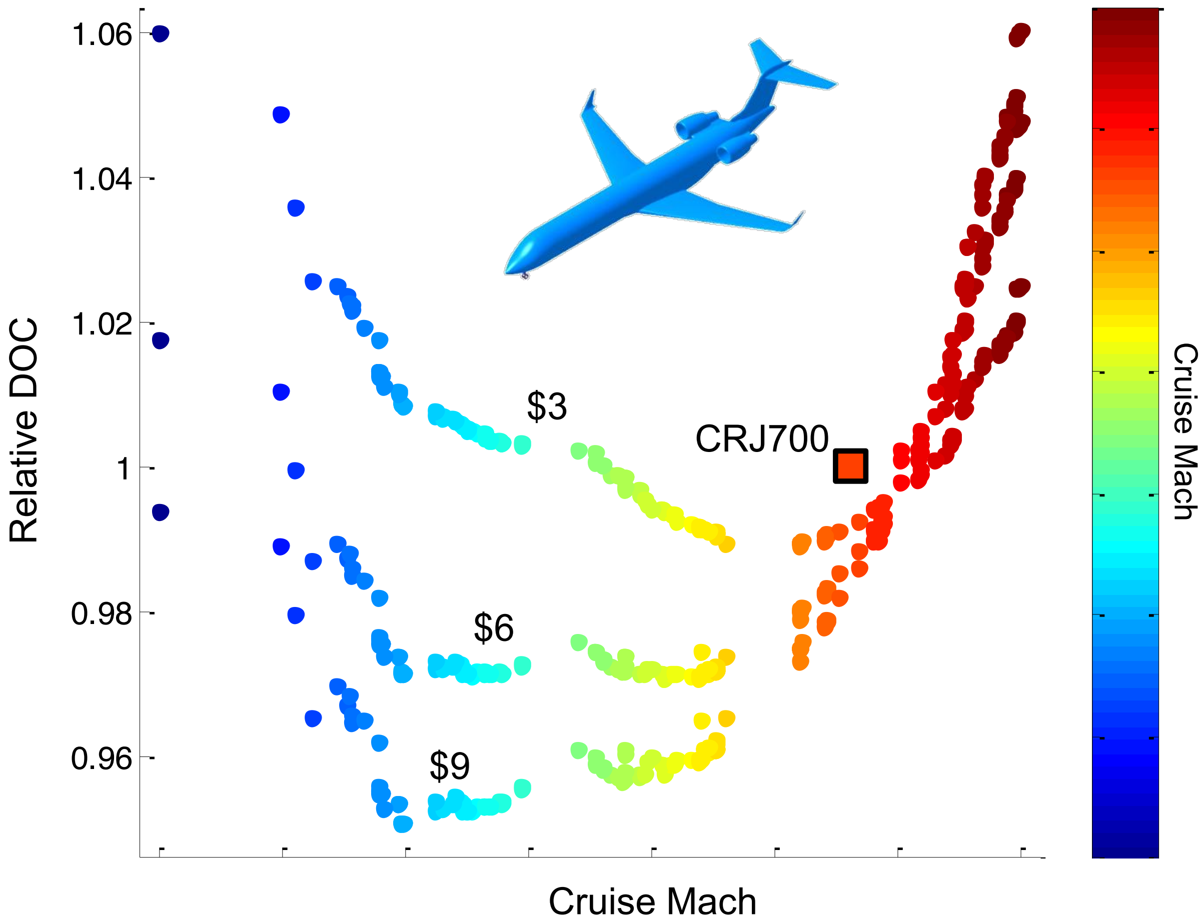
Design-Space Exploration Results
Variation in Fuel Price



- Three values of fuel price considered
  - $3/USG (2011 average)
  - $6/USG (EIA high price prediction for 2030)
  - $9/USG (extreme case)
- All results relative to CRJ700
- Cruise Mach for minimum DOC falls with increasing fuel price
- Can identify a robust cruise Mach based on expected fuel price variation over aircraft life
- Variation in fuel price can also represent possible environmental taxes

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Regional Aircraft Configurations

- Three conventional reference configurations were established during a 2011 study
  - Engine on fuselage (Baseline CRJ700)
  - Engine on low-wing
  - Engine on high-wing
- Each configuration was subject to manual design process
  - Revised wing and fuselage mass estimates based on engine location
  - Rebalancing with new engine location
  - Resizing of empennage
  - Revised wetted areas
  - Revised CLmax for high-wing configuration
- Each configuration has been implemented in the CMDO workflow as a reference aircraft
  - Geometry
  - Mass breakdown
  - Wetted areas
  - Drag calibration
  - High lift characteristics

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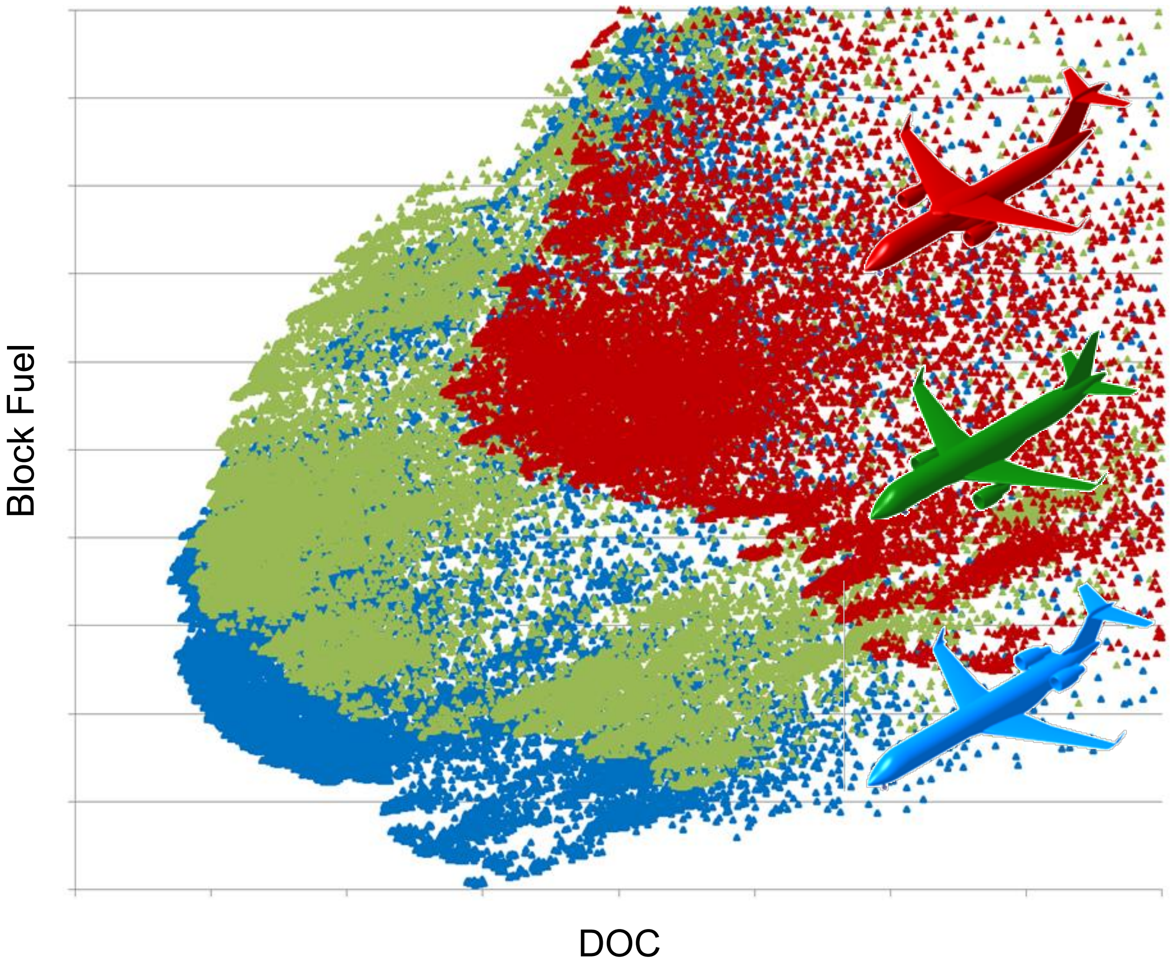
Design-Space Exploration Results
Comparison of Aircraft Configurations



- Comparison of three aircraft configurations
- Multiple optimization runs performed to generate 50,000+ solutions per configuration
- $3/USG fuel price assumed (2011 average)
- Engine on high-wing configuration (red) performs less well due to increased drag of additional belly fairings
- Advantage of engine on fuselage configuration (blue) at lower Mach is thought to be due to different fuselage mass estimation method – requires further investigation

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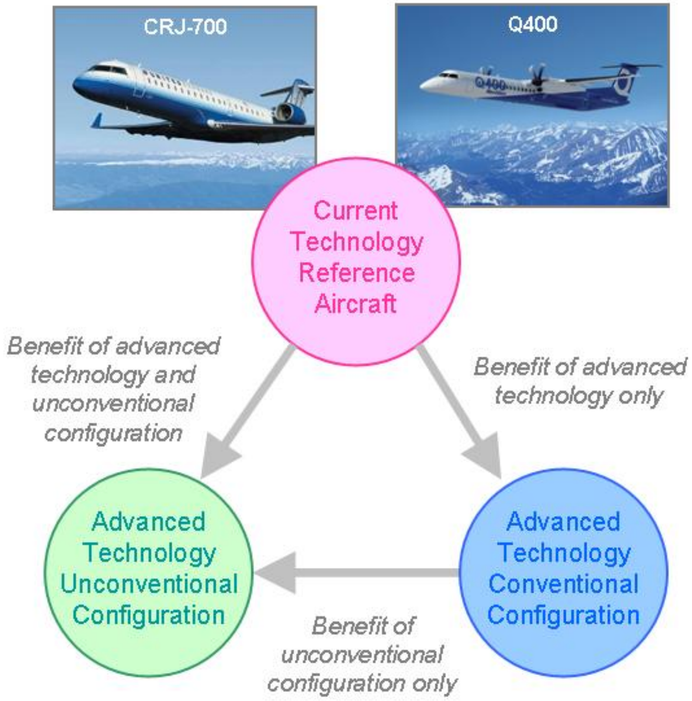
Next Steps: Advanced Technology Conventional Configurations

- Design-space exploration will be repeated using advanced technologies
- Objective is to quantify the emissions and DOC reductions possible by 2025 without departing from a conventional airframe configuration
- Need to define assumptions for each discipline
- Propulsion
  - Advanced high bypass-ratio turbofan
  - Open rotors
  - Novel architectures
  - Advanced turboprop
- Aerodynamics
  - Advanced design tools and methods
  - Laminar flow
- Structures
  - Advanced design tools and methods
  - Composite materials
- Systems
  - More electric / bleedless architecture
  - Highly Integrated Systems (HIS) / Integrated Modular Architecture (IMA)



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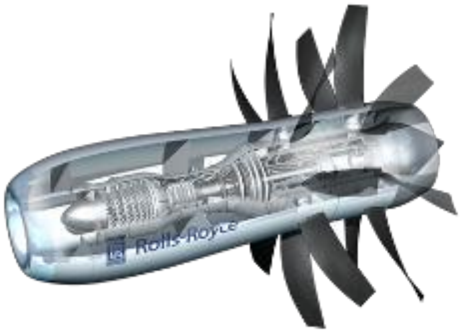

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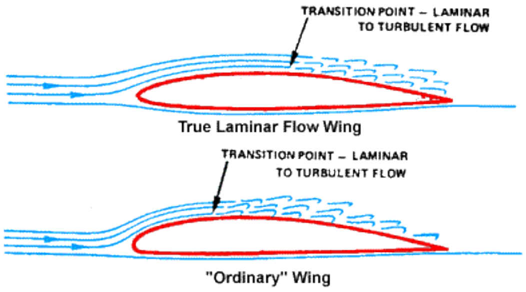

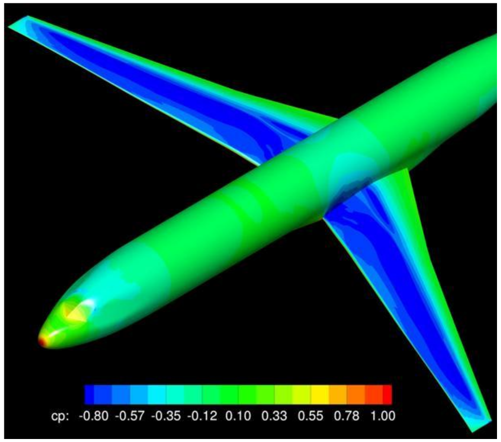

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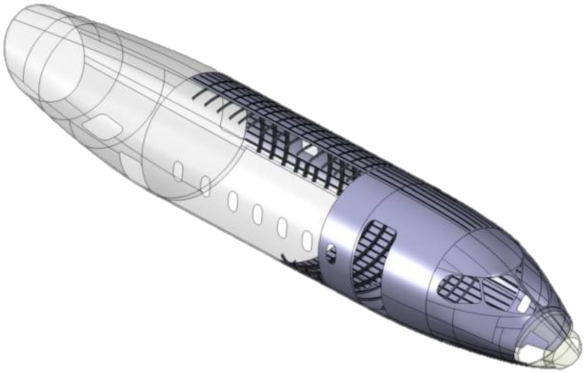

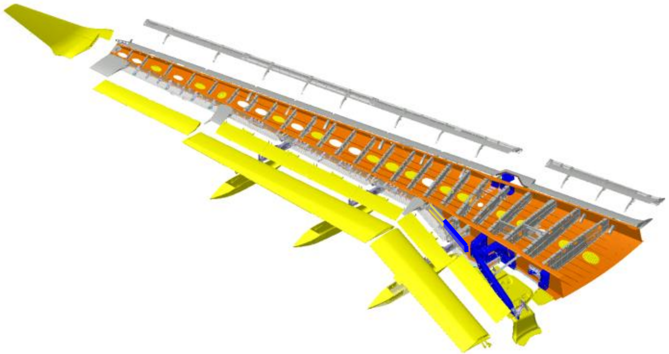

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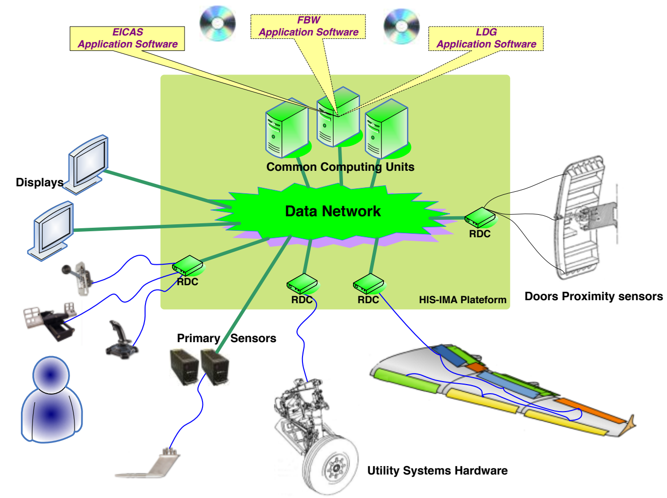

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Next Steps: Unconventional Configurations

- What level of climate impact reduction can be achieved by utilising unconventional aircraft configurations?
- Configurations of interest
  - Strut-braced wing
  - Joined/box-wing
  - 3-surface/canard
  - Blended-wing
  - Lifting fuselage
- Dependant on physics-based analysis methods
  - Wing mass tool capable of rapid assessment of strut-braced and joined-wings is under development
  - Vortex lattice aerodynamic methods will be employed to predict lift, drag and stability of canard, 3-surface and joined-wing configurations

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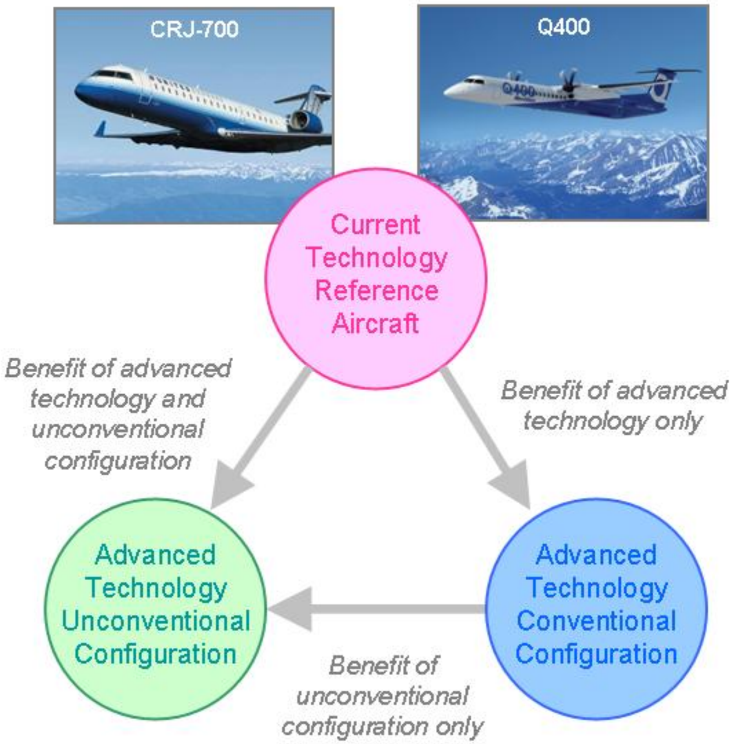
Conclusions

- Conceptual MDO tool has been further developed to meet EFA project needs
  - Climate impact analysis
  - Variable cruise Mach and altitude
  - Revised DOC methods
- Design-space exploration for EIS 2000 conventional configurations complete
  - Significant reduction in climate impact is possible by reducing cruise altitude
  - Both fuel-burn and operating cost can be reduced by lowering cruise Mach
  - Variation in fuel price has been explored
- Design-space exploration for EIS 2025 conventional configurations in progress
- Physics based structures and aerodynamics tools under development for unconventional configurations



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