MDO for Aircraft Design at Bombardier Aerospace

Pat Piperni
Advanced Product Development
Bombardier Aerospace

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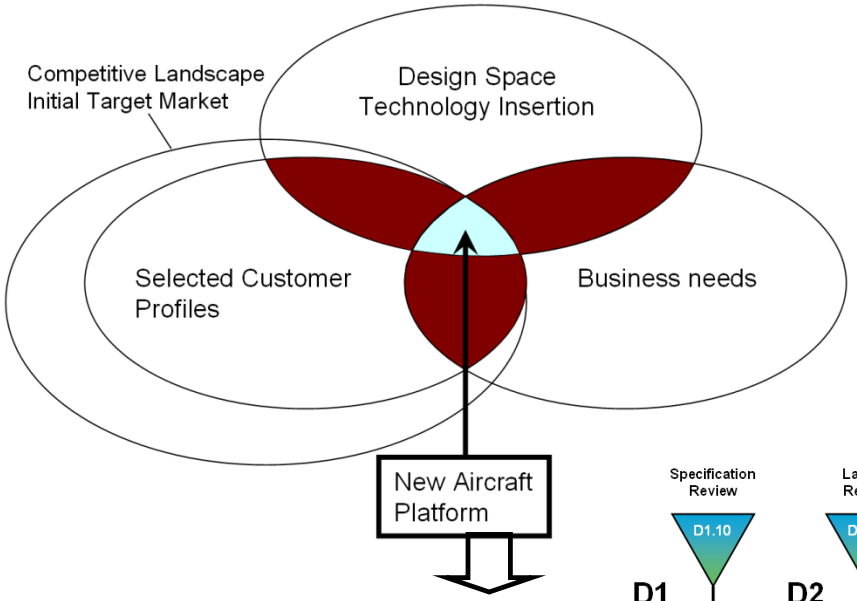
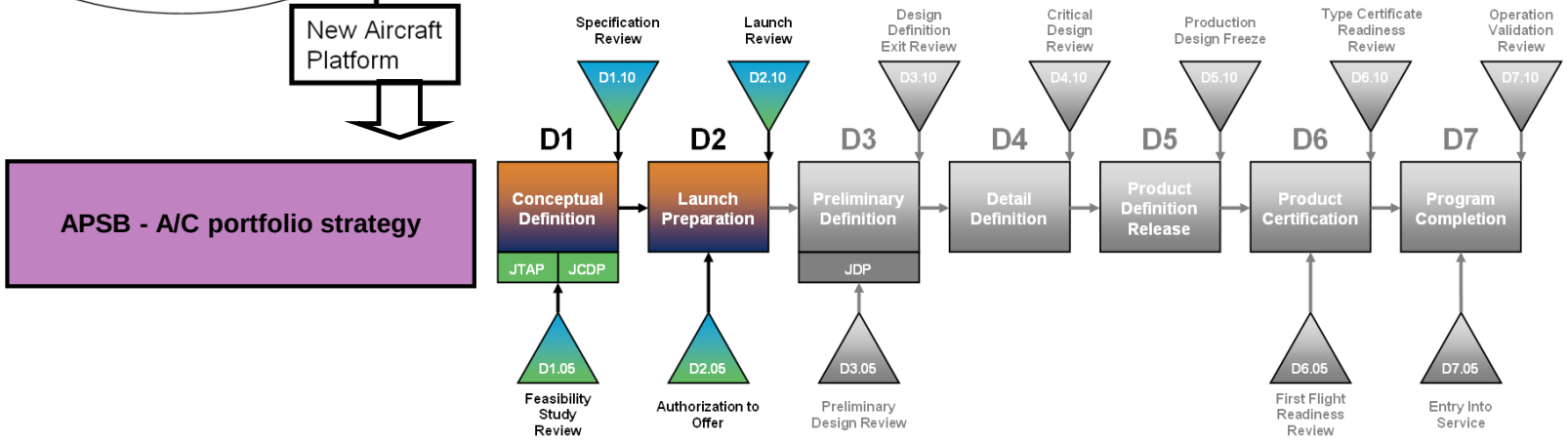
How do we Implement MDO in a Complex Product Development Environment?

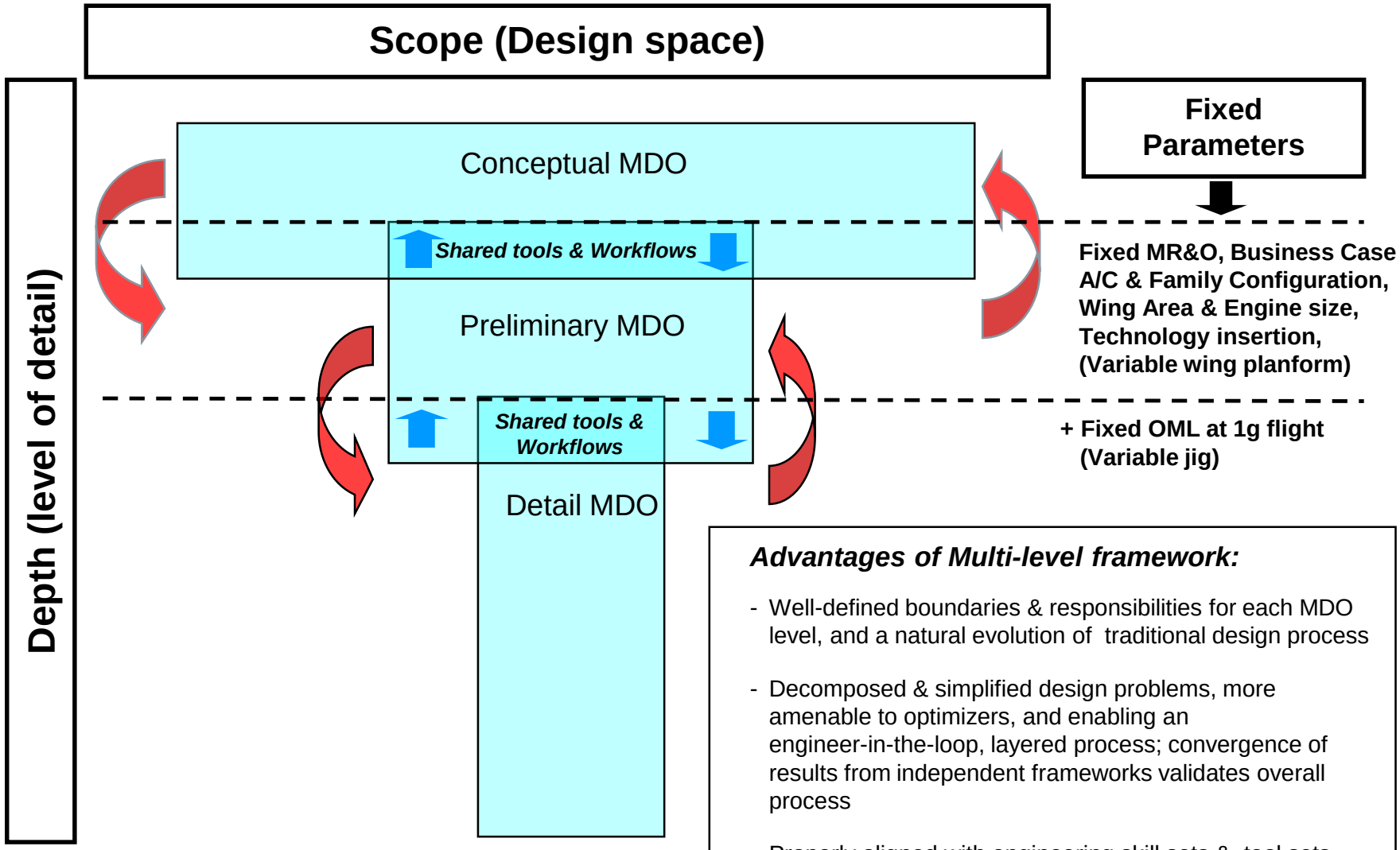


- Different aircraft design stages have different design objectives, amount of data, & timescales, and require different skill sets.
- Different tools are needed for different aircraft design stages
- The appropriate level of detail must be employed at each stage
- Problem formulation is key, and must be developed by subject matter experts



JTAP: Joint Technical Assessment Phase
JCDP: Joint Conceptual Definition Phase
JDP: Joint Definition Phase

MDO must Accommodate an Increasing Level of Detail as the Design Space Narrows..



Advantages of Multi-level framework:

- Well-defined boundaries & responsibilities for each MDO level, and a natural evolution of traditional design process
- Decomposed & simplified design problems, more amenable to optimizers, and enabling an engineer-in-the-loop, layered process; convergence of results from independent frameworks validates overall process
- Properly aligned with engineering skill sets & tool sets, and objectives of different aircraft design stages

Definition of MDO Levels and Objectives

- **Conceptual MDO**
  - **Operator: Advanced Design**
  - Objectives: Design space exploration, optimization of MR&O and Business Case, sizing of airframe and engine, integration of major systems, and optimization of operations; development of design knowledge, down-selection to promising configurations, and definition of performance targets
- **Preliminary MDO**
  - **Operator: Advanced Aerodynamics**
  - Objectives: Application of MDO with high-fidelity aerodynamic tools to develop detailed aero lines of the configuration defined in Conceptual MDO; validation of Conceptual MDO, and further development of configuration and design knowledge
- **Detail MDO**
  - **Operator: Advanced Structures**
  - Objectives: Application of MDO with high-fidelity structural analysis tools to develop detailed structure based on configuration and aero lines developed above; validation of Conceptual & Preliminary MDO, and further development of configuration and design knowledge

➢ ***Multiple departments contribute at each MDO level, in iterative process***

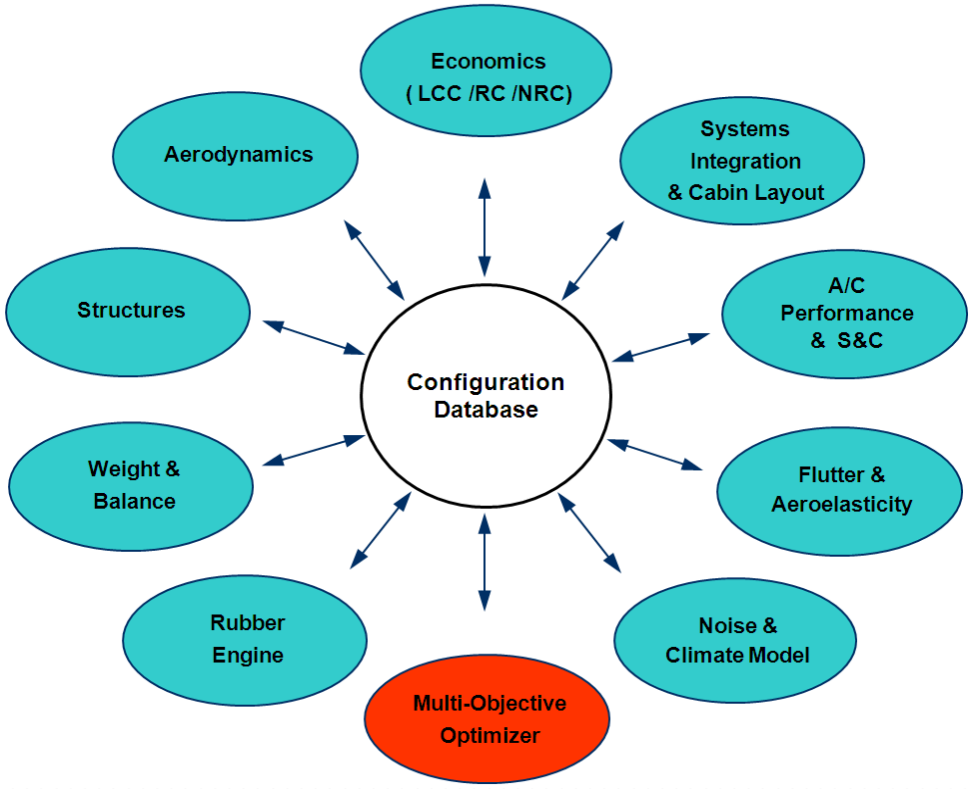
Definition of Multi-Level, Multi-Fidelity Analysis Tool Set

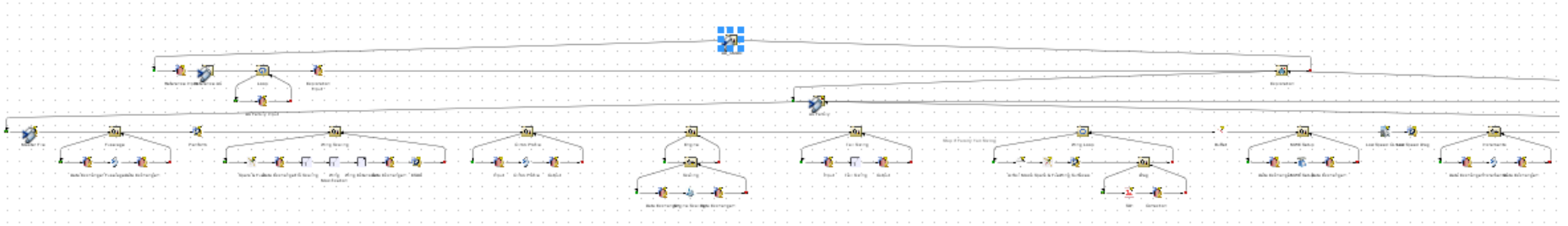
MDO Level	Fidelity	Aerodynamics	Structures	Propulsion	Loads	TBD
	L0	Knowledge-based aerodynamics	Knowledge-based weight prediction	Fixed architecture, scaled engine model		Dynamics, S&C, Systems, Acoustics, etc.
CMDO	L0.5	L1 Surrogate Models			Scaled Loads	
	L1	Quasi-3D methods (3D VLM / Panel method + 2D High-Fidelity CFD)	Smeared-skin models	Variable architecture, generic rubber engine	No. of load cases < 10	
	L1.5	L2 Surrogate Models		Surrogate model(s) from Engine supplier(s)	L2 Surrogate Models	
PMDO	L2	Mid-to-High Fidelity CFD (3D TSD to RANS)	GFEM	Real engine model (fixed)	10's of load cases	
	L2.5	L3 Surrogate Models			L3 Surrogate Models	
DMDO	L3	RANS	GFEM → DFEM		100's of load cases	

All analysis tools must be validated by subject-matter experts, within context of targeted fidelity level and design objectives

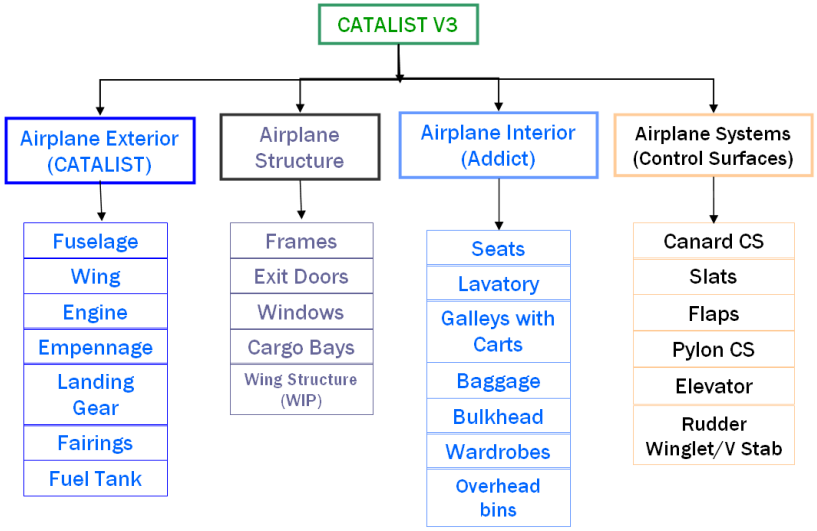
MDO Capability must Include all Critical Disciplines..

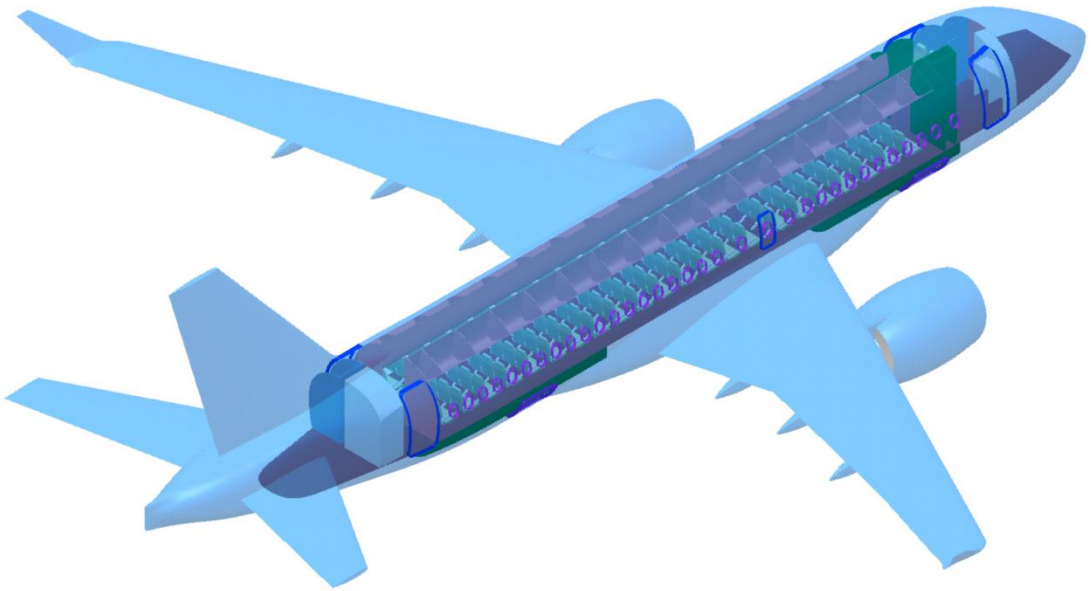
- All critical disciplines are modeled in automated optimization environment, including both technical and financial metrics
- A multi-fidelity, multi-level, variable complexity approach is used, including knowledge-based methods, surrogate models, and high-fidelity physics-based analysis tools, as appropriate for each aircraft design phase





Sample Tools & Processes in MDO Framework: Aircraft Parametric Geometry Modeler

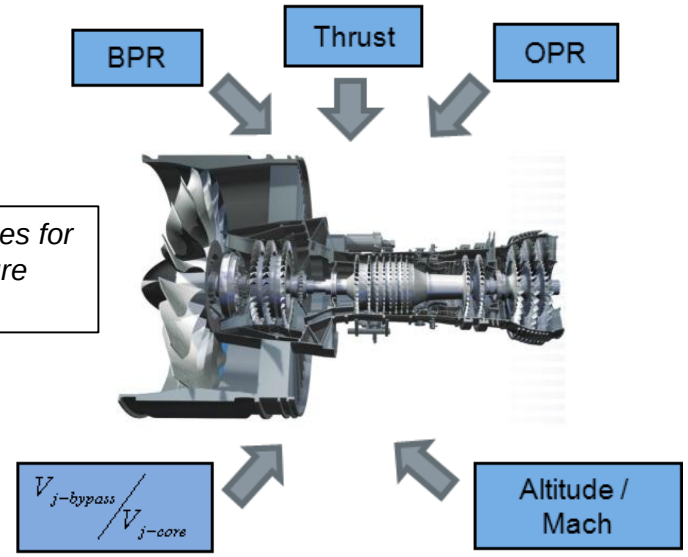


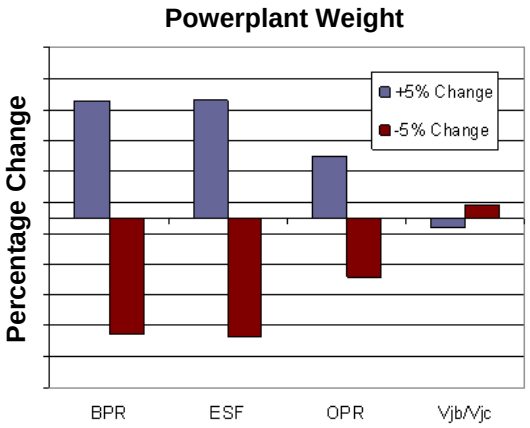


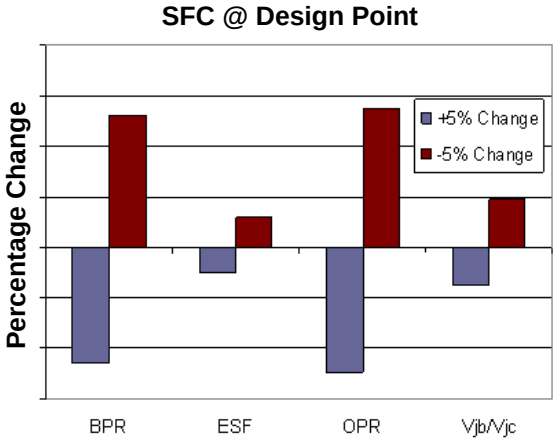
- Rapid Parametric Modeling using CATIA Automation
- Large library of scalable, pre-defined components available (seats, windows, nacelles, pylons, landing gears, etc.)
- Complete a/c can be modeled in <1-2 days
- Over 140 a/c have been modeled

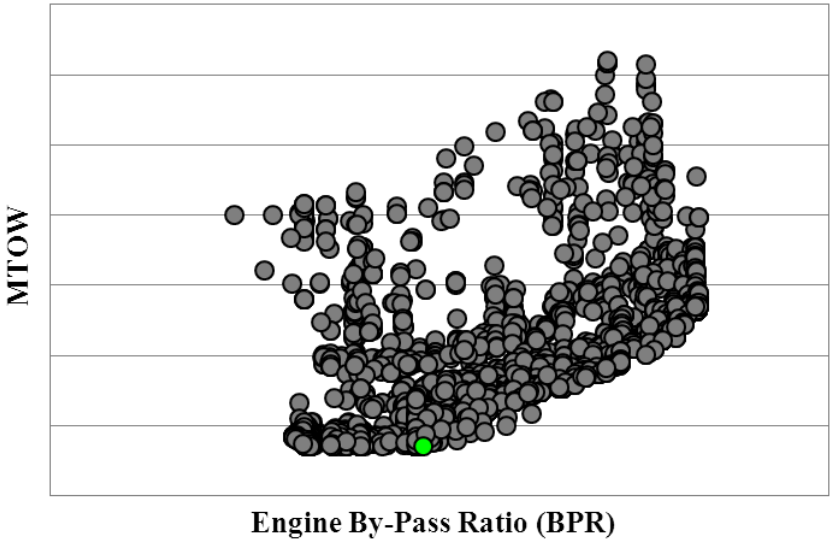
Sample Tools & Processes in MDO Framework: Variable-Architecture Engine Models

Design Variables for Var. Architecture Engine Model

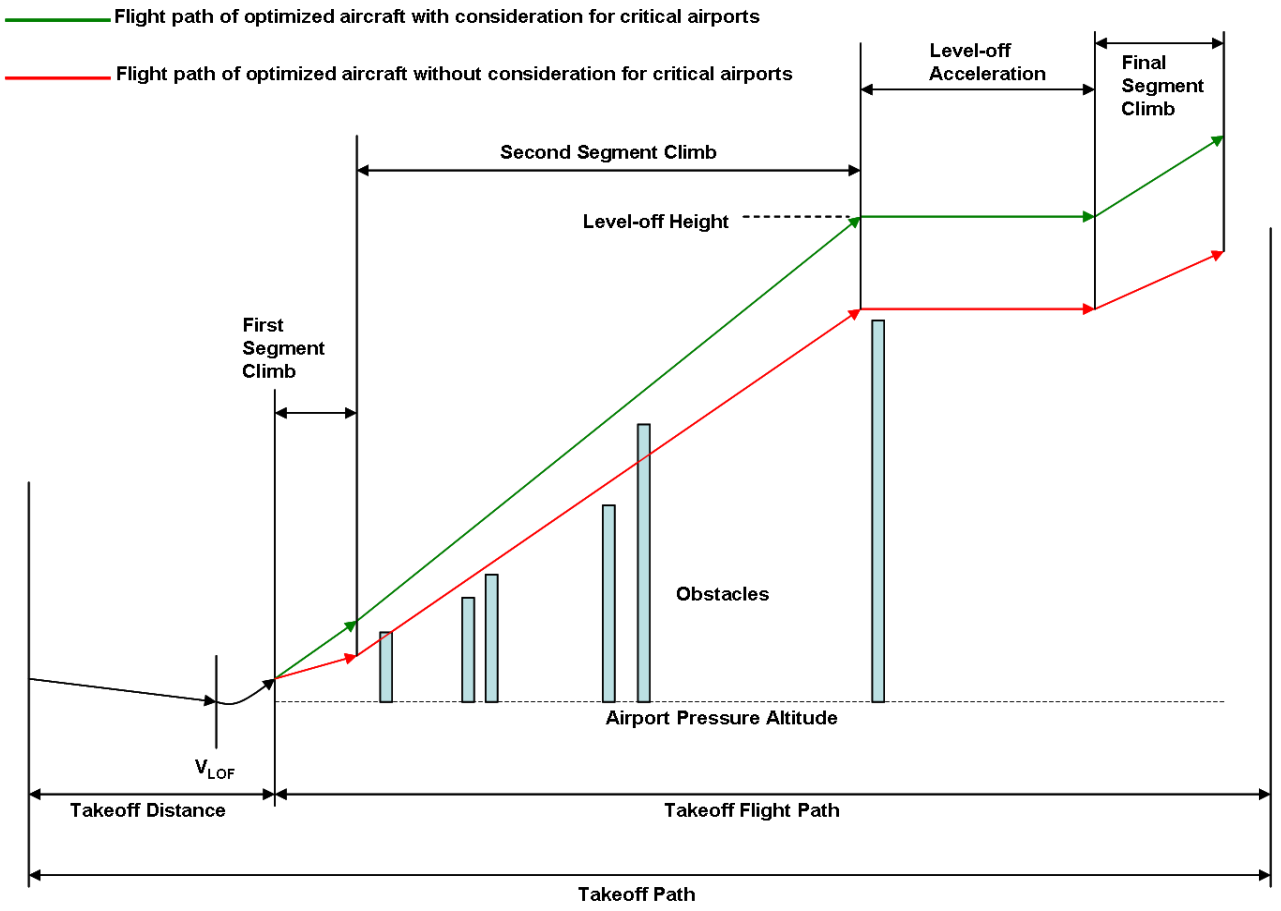






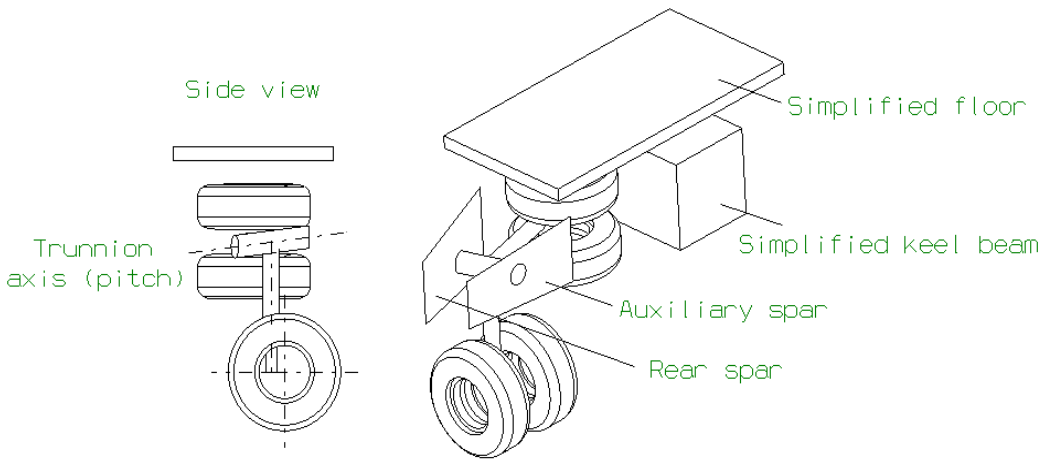


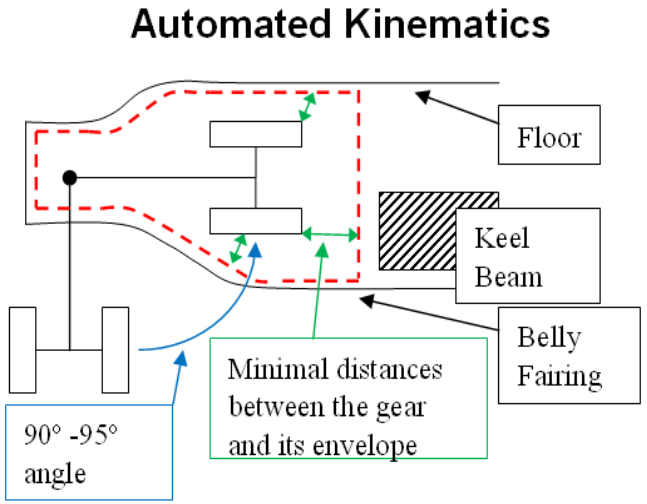
Sample Tools & Processes in MDO Framework: Aircraft Mission & Field Performance Analysis

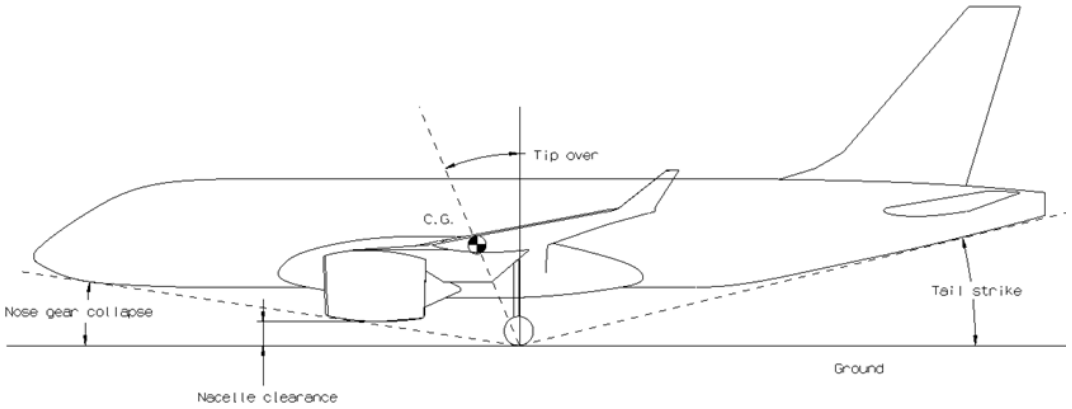


MDO framework can handle multiple critical airports in optimization process

Sample Tools & processes in MDO Framework: Aircraft Systems: e.g. Landing Gears

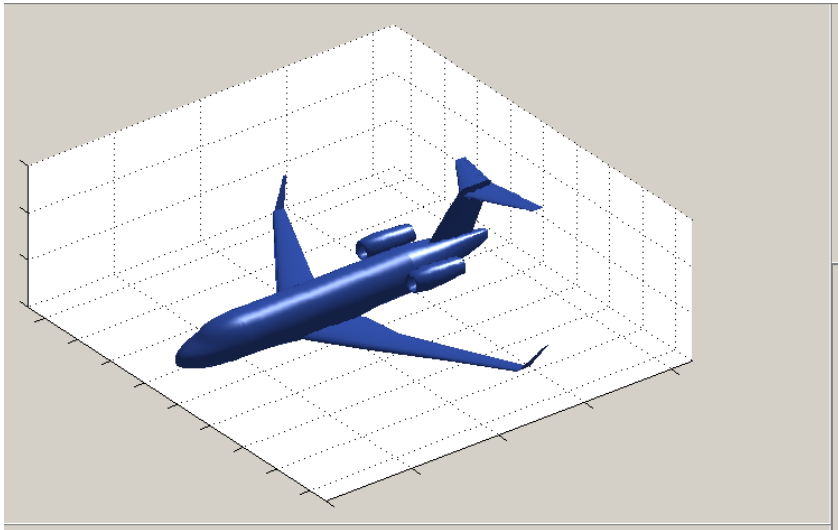


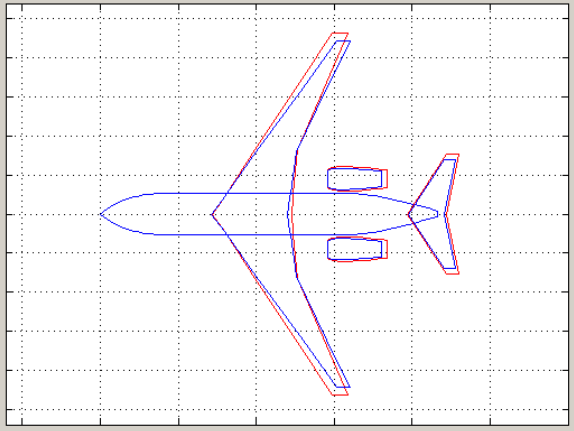


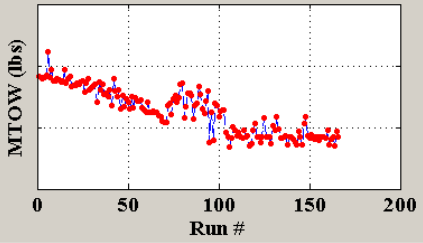


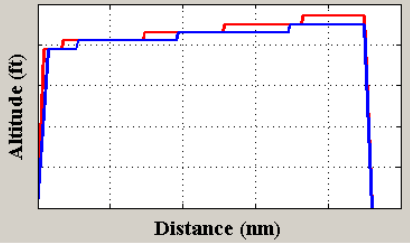
Landing gear height and position prediction within 1-2%

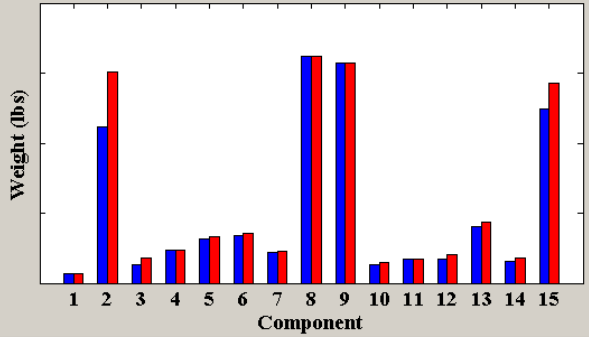
Sample MDO Process in Conceptual Design Stage: Tracking Both Technical & Economic Metrics



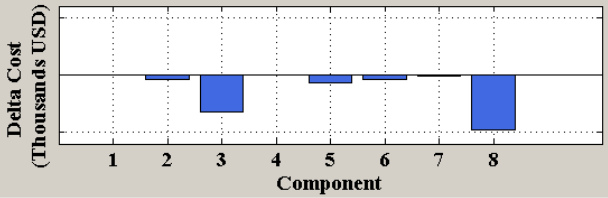




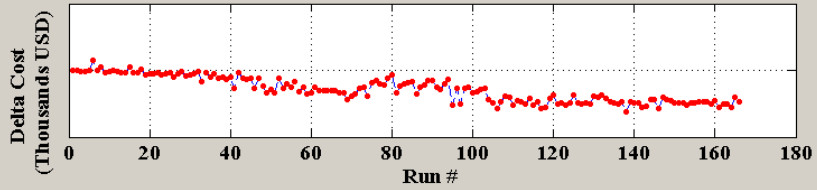




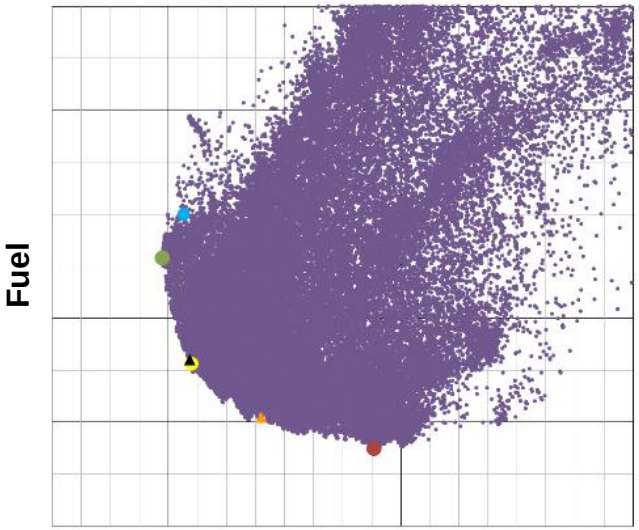
	Component
1	APU
2	Dry Engine
3	Engine Accessories
4	ECS and Anti-Ice
5	Electrical
6	Flight Controls
7	Fuel System
8	Fuselage
9	Furnishings
10	Hydraulics
11	Instruments/Avionics
12	HT
13	Landing Gear
14	VT
15	Wing

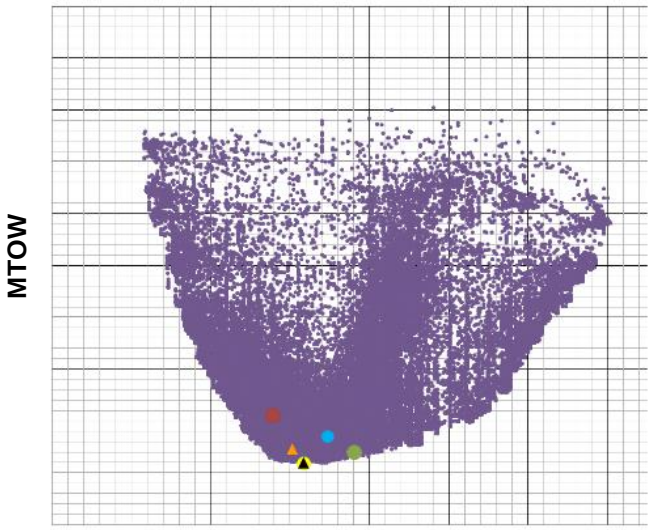


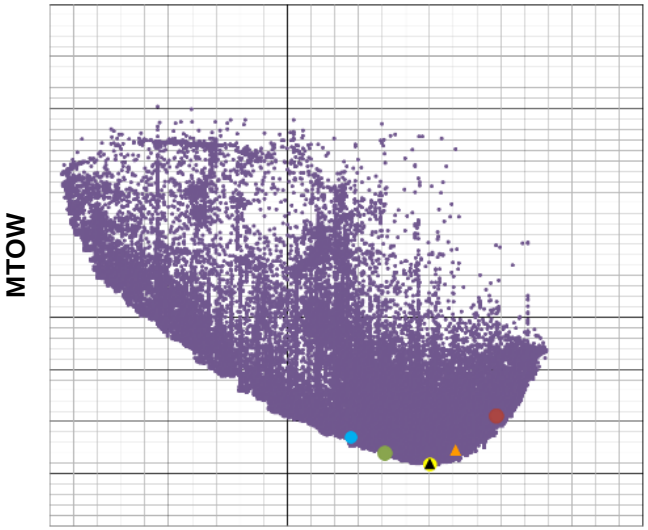
	Component
1	Cockpit
2	Empennage
3	Engine
4	Fuselage
5	Wing
6	Nacelle
7	LG
8	Total



Design Space Exploration using Evolutionary Multi-Objective Optimization (EMO)





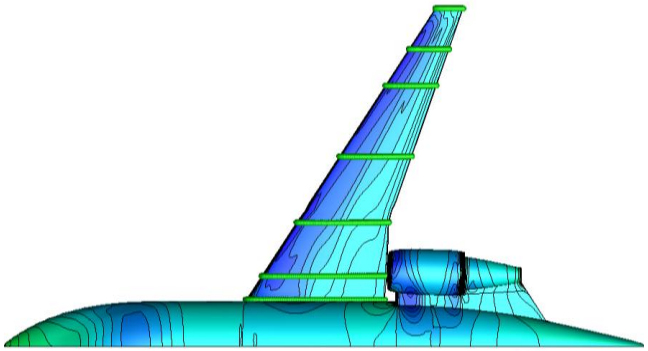


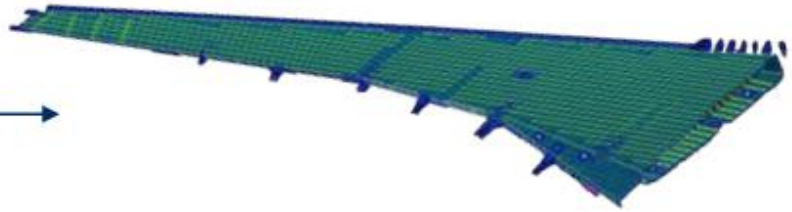
Promising Aircraft Configurations are Down-Selected for High-fidelity Preliminary & Detail MDO, in Iterative Process

3D RANS + Adjoint
~150 design Variables

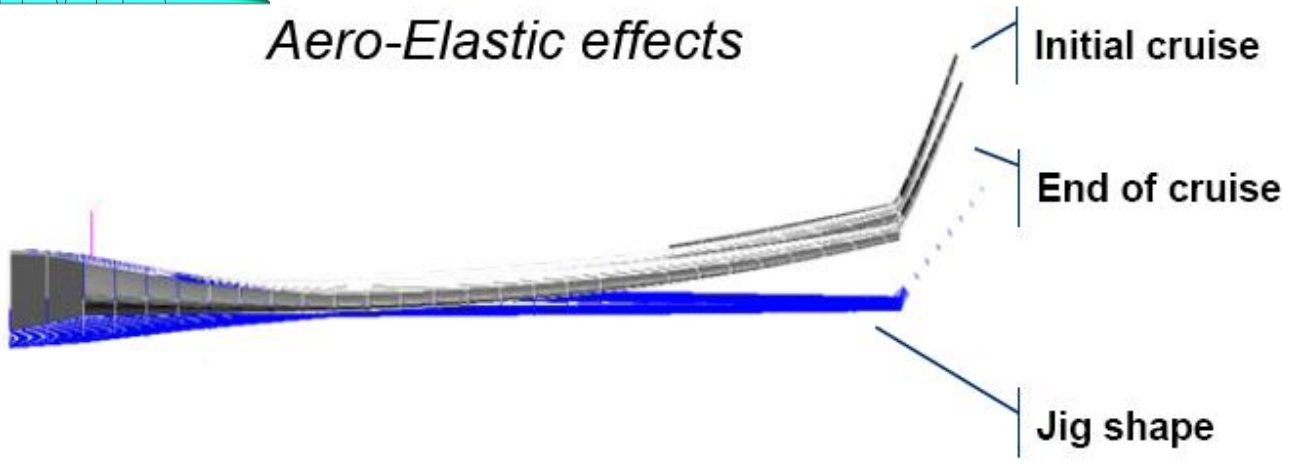
FEM
Structural Analysis

9000 design variables)





Aero-Elastic effects



Questions ?