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MDAO for Conceptual Aircraft Design at Northrop Grumman

Phoenix Integration
Model Based System Engineering (MBSE) Workshop

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Outline

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Note: We will attempt to answer the following questions from a military aircraft designer perspective:

- Why Multi-Disciplinary Analysis & Optimization (MDAO)
- What is MDAO?
- How to Implement MDAO?
- Application Example
- Lessons Learned
- Concluding Remarks

Strategic Application of MDAO and MBE to Realize Potential Large Return-on-Investment (ROI)

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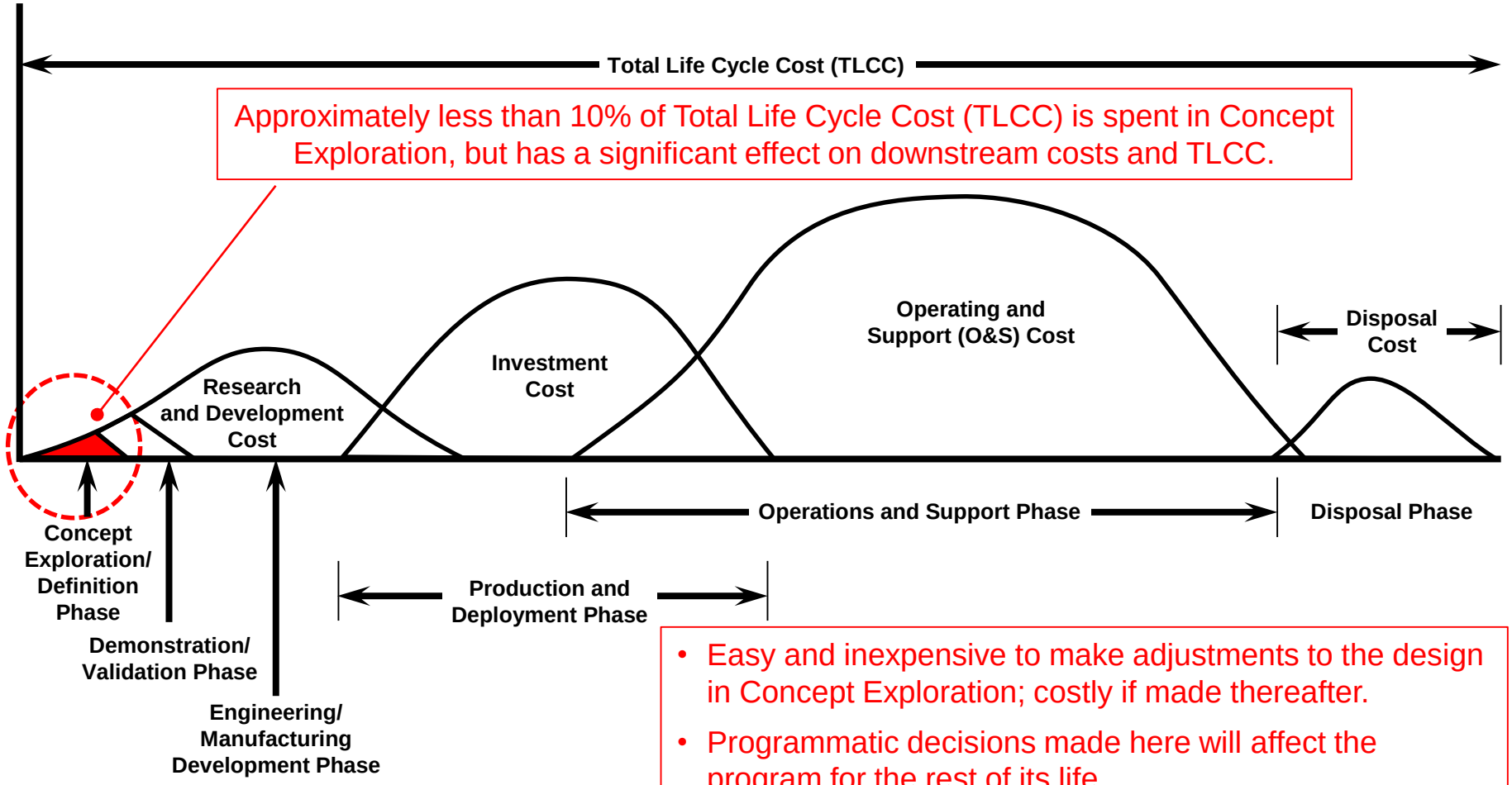

- Easy and inexpensive to make adjustments to the design in Concept Exploration; costly if made thereafter.
- Programmatic decisions made here will affect the program for the rest of its life.

How do you make the best engineering and programmatic decisions in concept exploration to maximize affordability?

Strategic Application of MDAO and MBE to Realize Potential Large Return-on-Investment (ROI)

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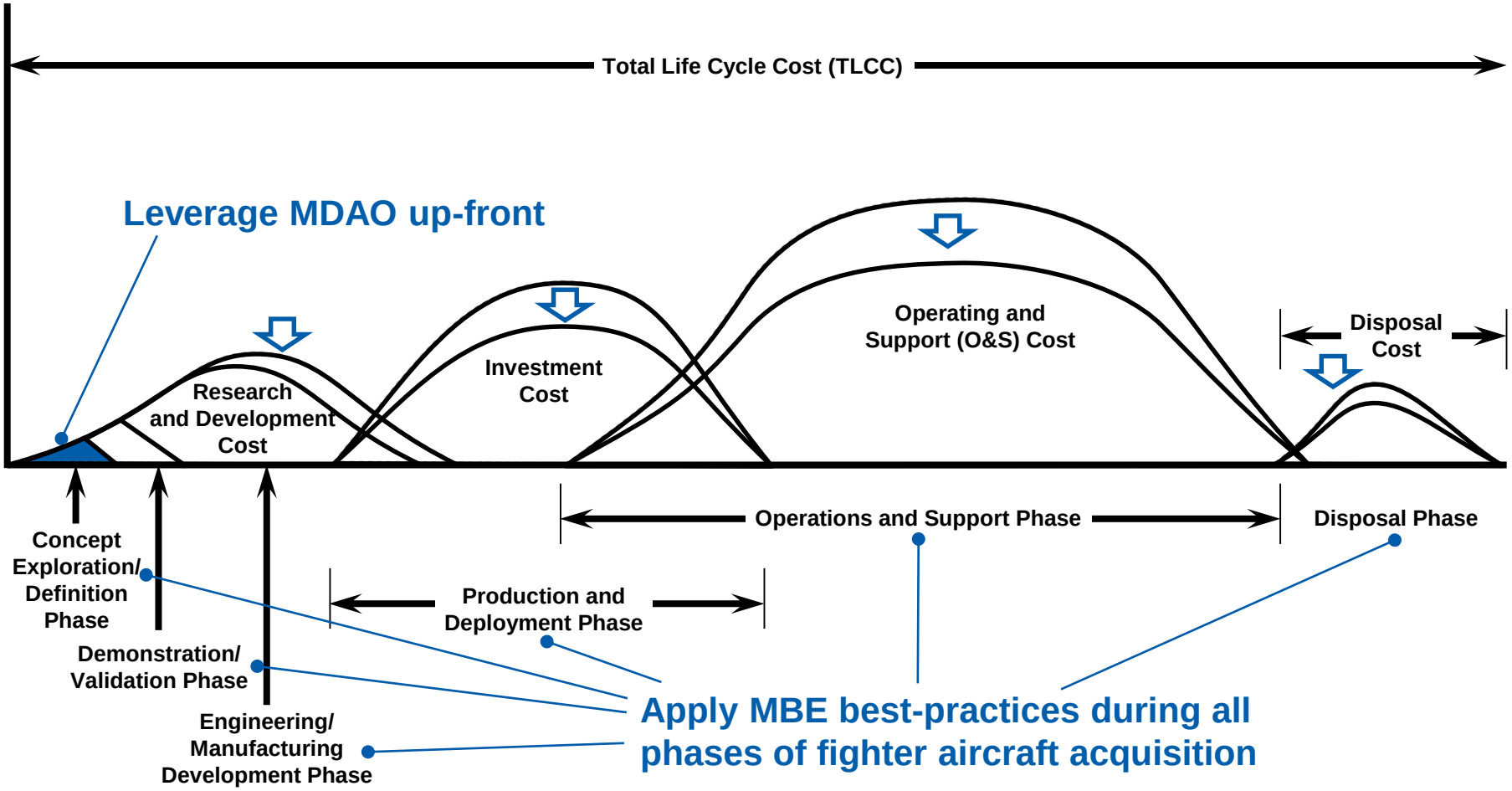
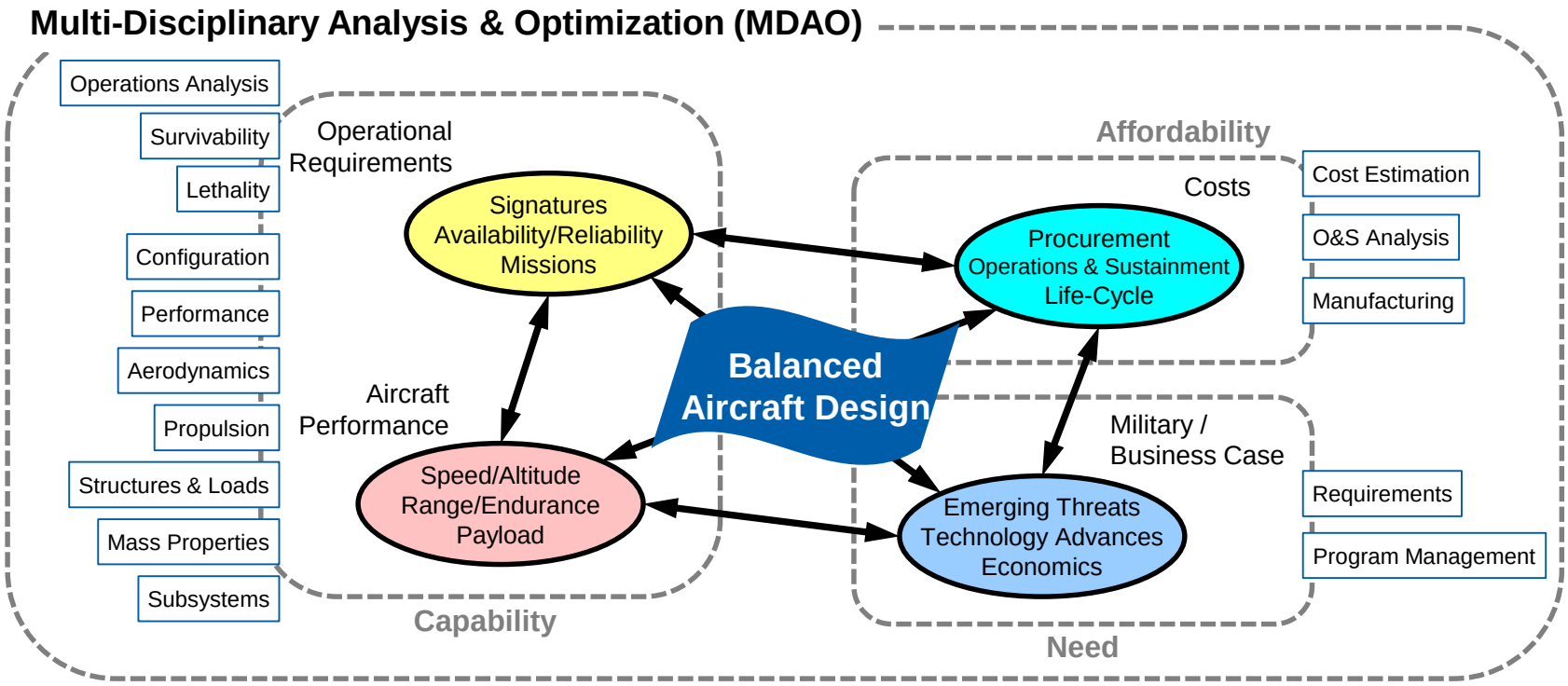


Leveraging MDAO early in Concept Exploration and applying MBE best-practices during all phases of military aircraft acquisition could result in huge payoffs of TLCC reduction

Military Aircraft Design is a Complex Process



MDAO enables the designer/analyst to efficiently and confidently search for and achieve the best balance of maximum capability and affordability in response to the Warfighter's needs

Numerical / Computational Approach

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A process, methodology, philosophy…not a specific tool or a group of people… a framework…

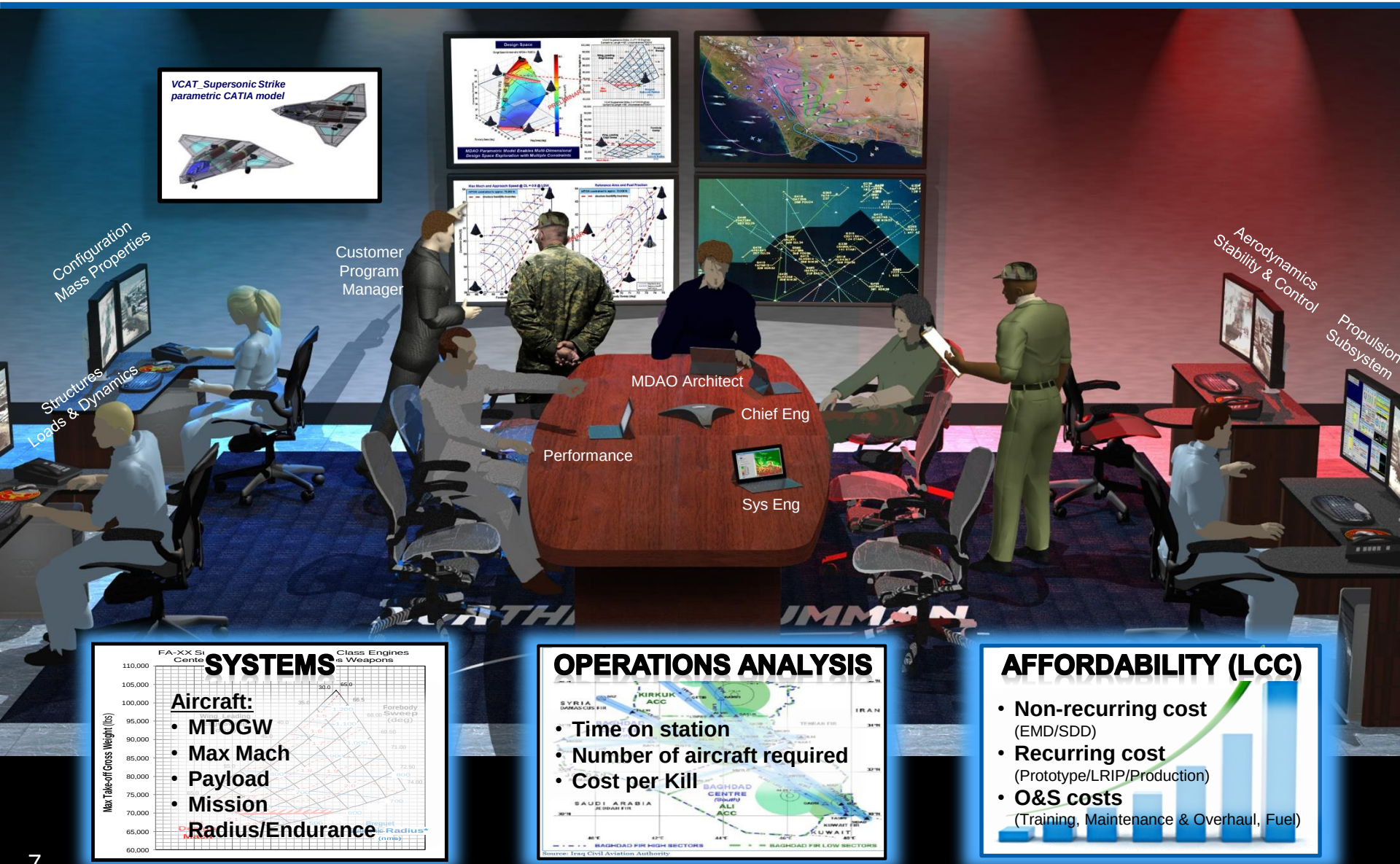
An approach to connect multiple disciplines together to create one cohesive analysis…

- Facilitates improved engineering efficiencies
- Helps explore and visualize larger design spaces
- Enables better understanding of complex design interactions
- Provides sensitivities for varying:
  - Engineering disciplines' parameters
  - System requirements

MDAO facilitates deciding what ***factors*** to change and to what ***levels***, tracking and recording the ***responses***, when everything influences everything else

What is MDAO?

Enabler of Real-Time Stakeholder Interaction



SYSTEMS

Aircraft:

- MTOGW
- Max Mach
- Payload
- Mission Radius/Endurance

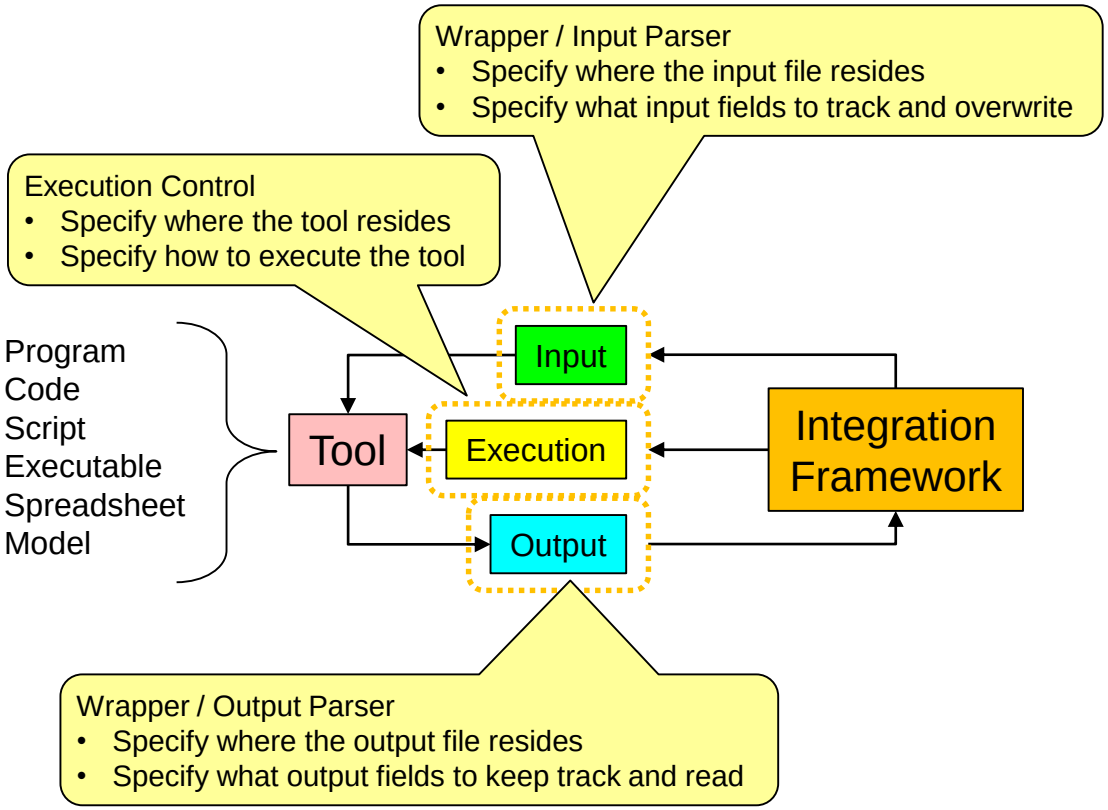
OPERATIONS ANALYSIS

- Time on station
- Number of aircraft required
- Cost per Kill

AFFORDABILITY (LCC)

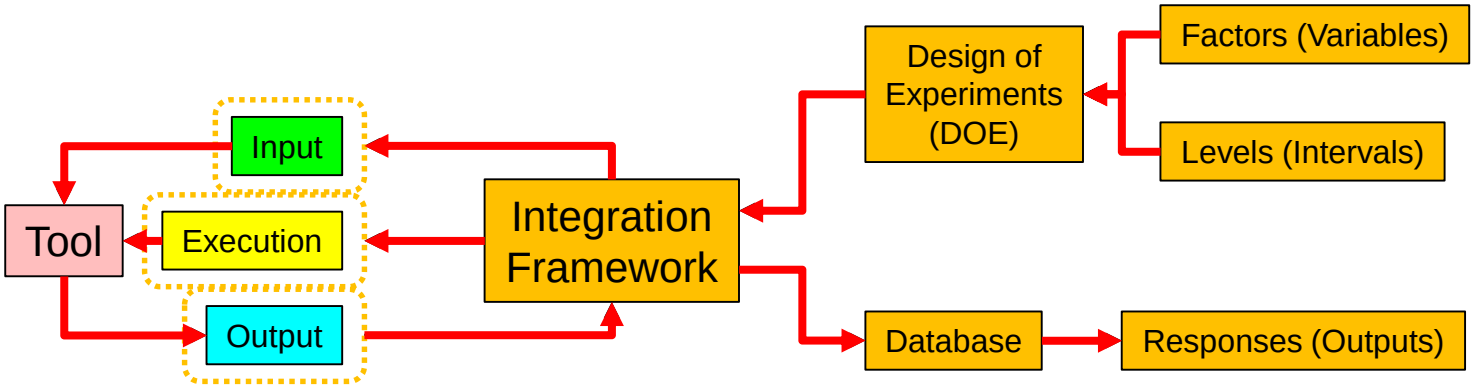
- **Non-recurring cost** (EMD/SDD)
- **Recurring cost** (Prototype/LRIP/Production)
- **O&S costs** (Training, Maintenance & Overhaul, Fuel)

Tools Integration



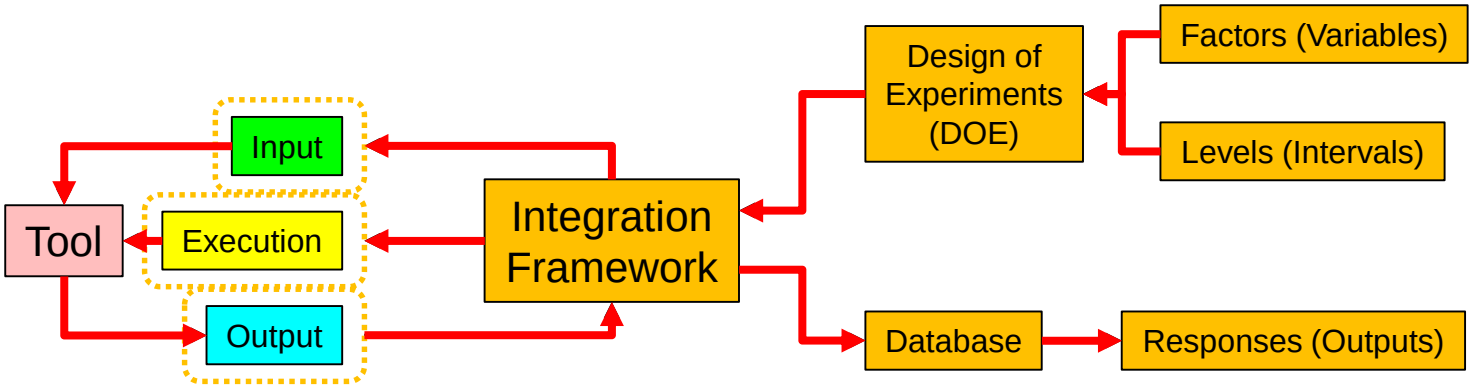
Once integrated, the tool is considered “wrapped” and can be executed automatically by the Integration Framework

Design Process Automation / Design Space Exploration



Once the design process is automated, this enables Design Space Exploration with a variety of Design of Experiments (DOE) techniques

Design Process Automation / Design Space Exploration



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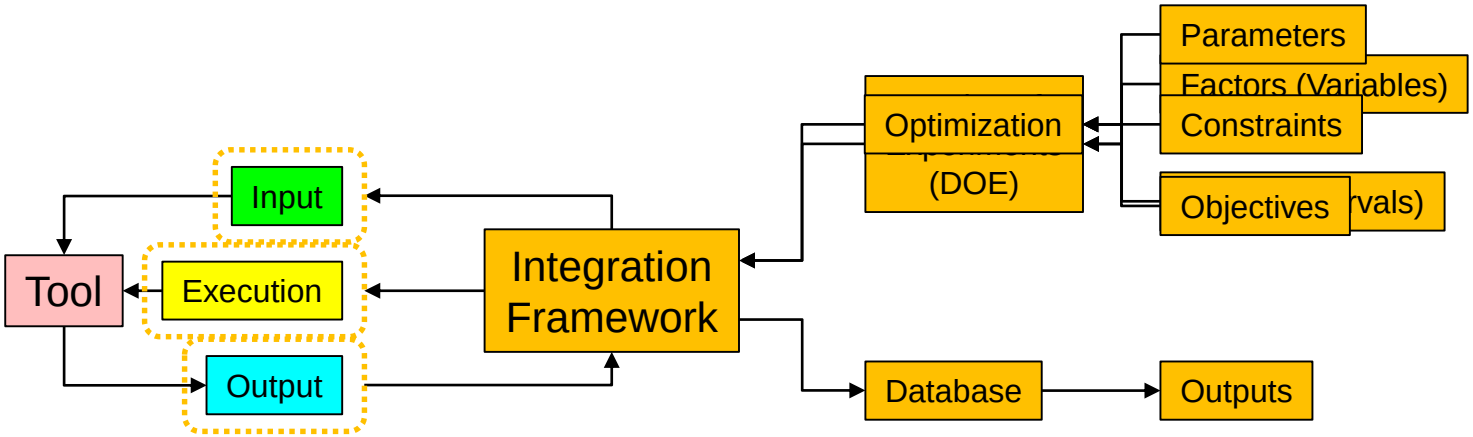
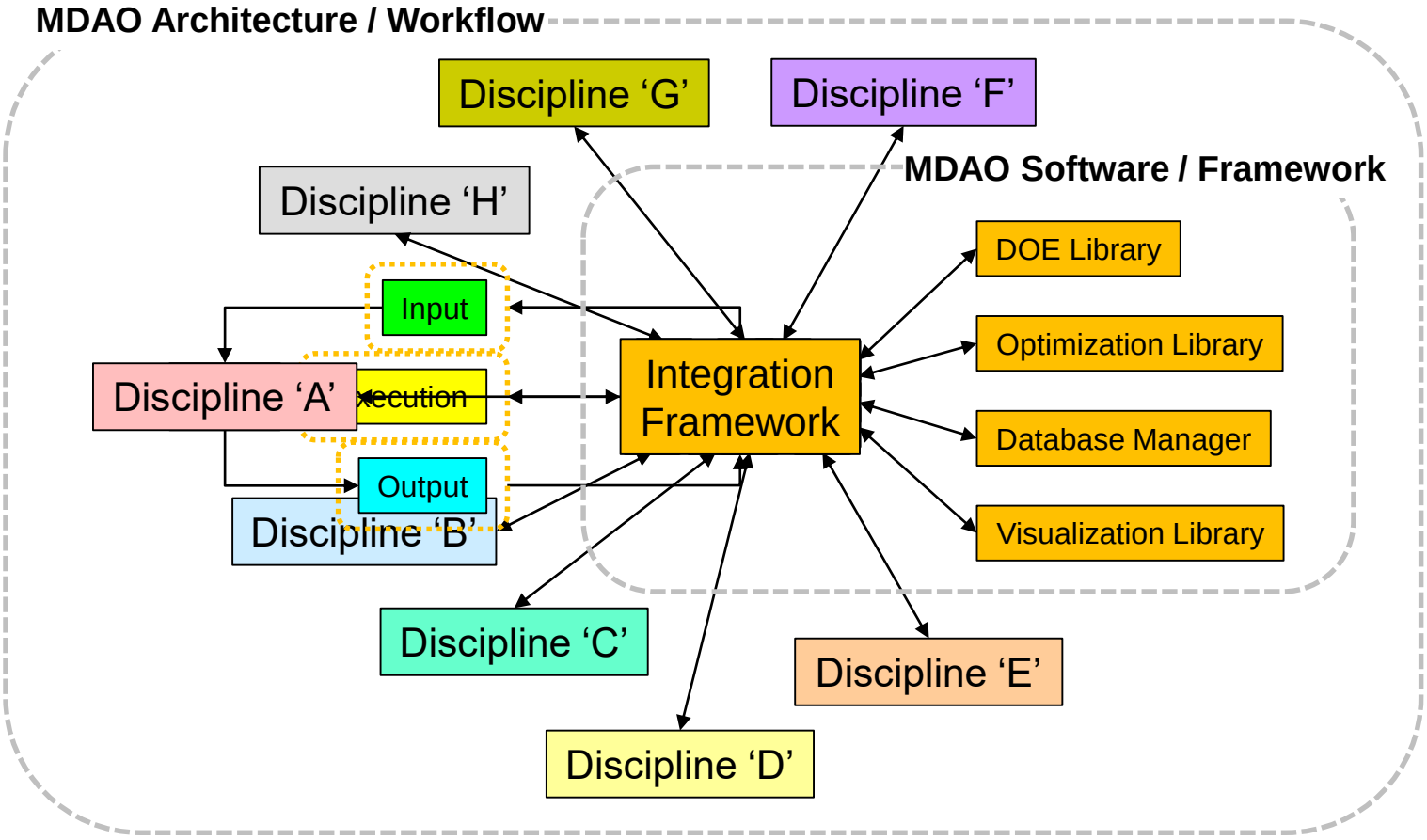
Design Process Optimization



Once the design space has been explored, a variety of Optimization techniques may be applied to find local/global maximums and minimums of some specified objective function, subject to given constraints, in the design space

Executing Multi-Disciplinary Tools in Concert



Utilizing Phoenix Integration’s ModelCenter® software, NGC MDAO capability is achieved through the integration of internally approved and calibrated models, with buy-in from seasoned aircraft design and analysis experts

Disciplined and Organized Process Workflows

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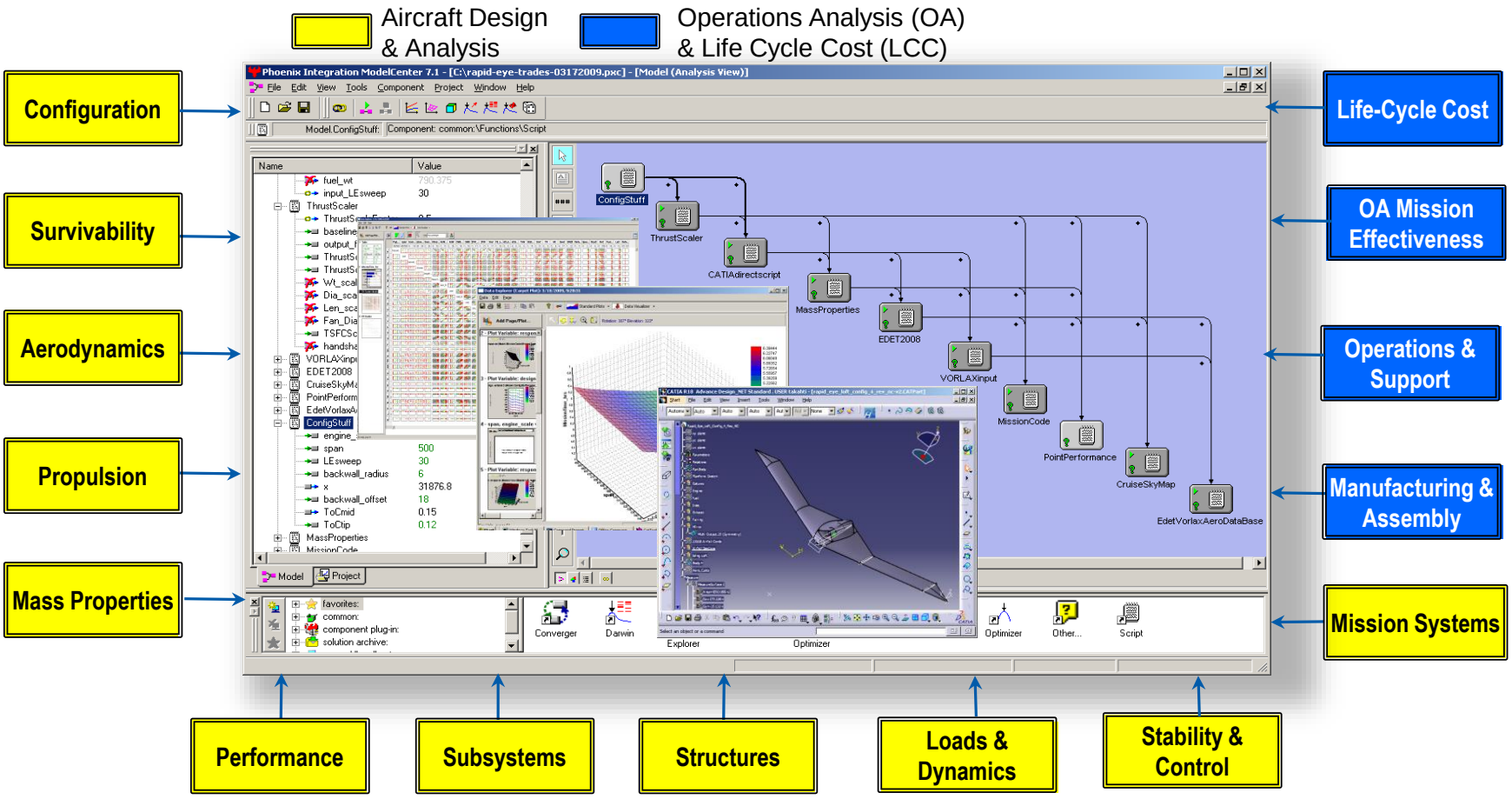
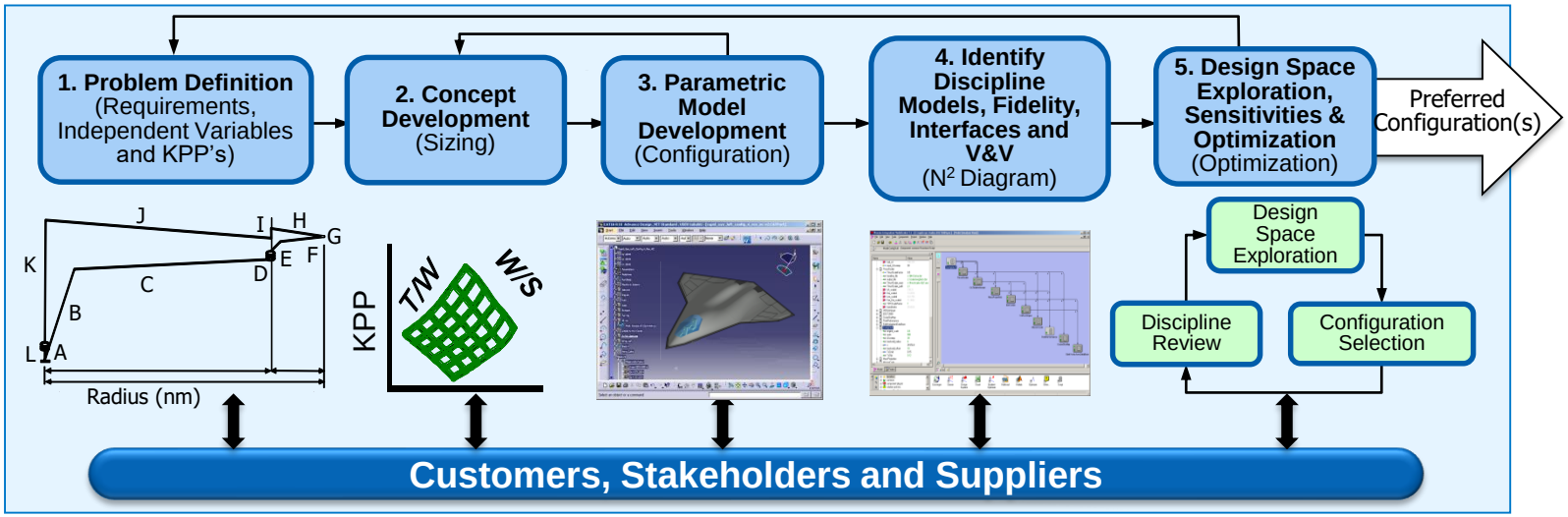


MDAO framework systematically links CAD and analytical systems, with Life Cycle Cost and Operations Analysis, to provide a more disciplined approach

Development and Execution Detail

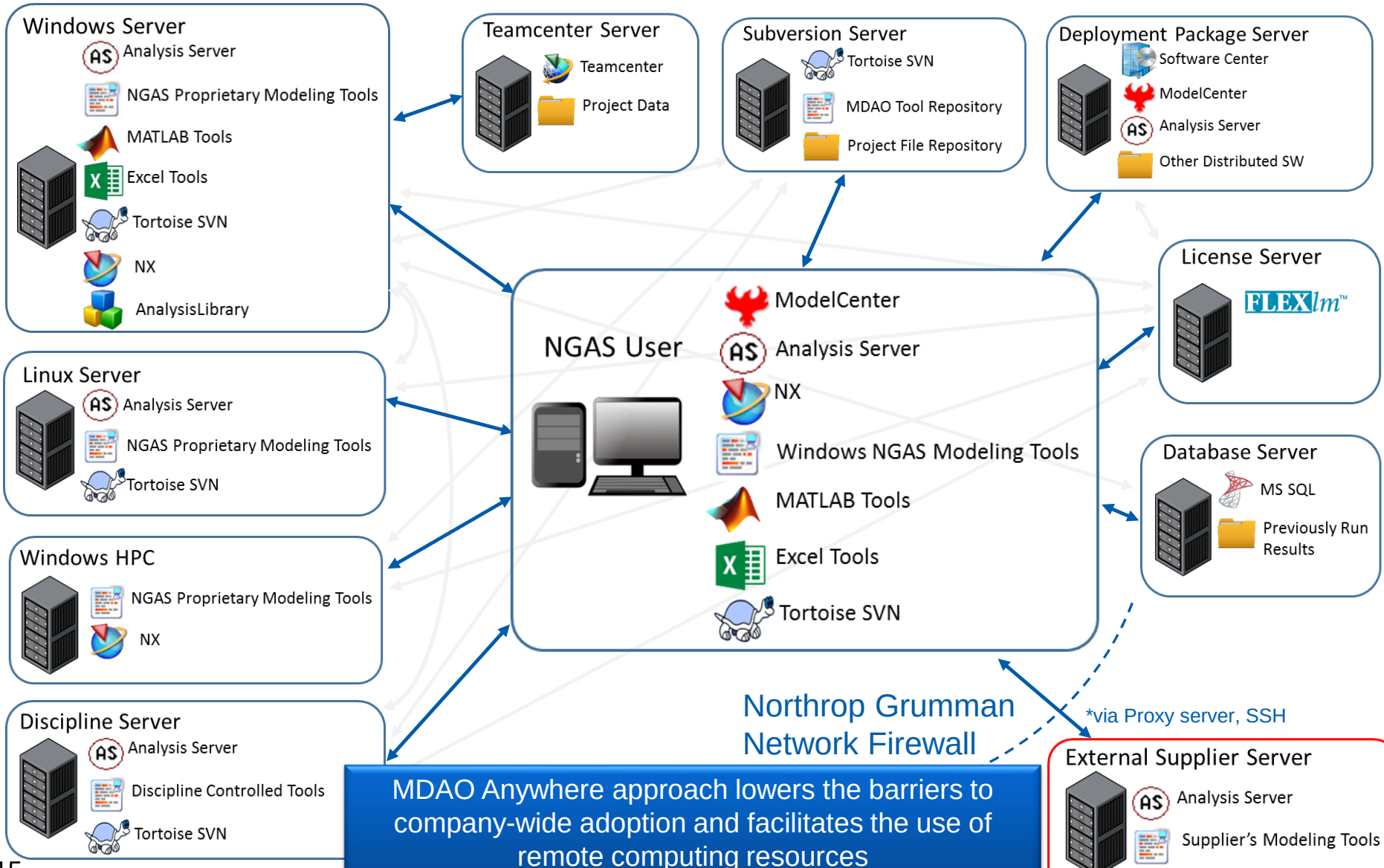


1. Problem Definition
2. Concept Development (sizing)
3. Parametric Model Development (configuration)
   – Develop parametric CAD model
4. Identify Discipline Models, Fidelity levels, Model Interfaces, Verification and Validation (V&V)
   – Develop N^2 Diagram by integrating discipline analysis tools
5. Design Space Exploration, Sensitivity Analysis, Constraint Assessment and Optimization Trade Studies
   – Down select to Preferred Configuration(s)

As MDAO model evolves from Conceptual to Preliminary and Detailed design, it involves more constraints, increasing fidelity models, and more SME interactions

How to Implement MDAO?

Hardware / Software MDAO Architecture



Example Integration: ESAVE N² Model

(Efficient Supersonic Air Vehicle Exploration)

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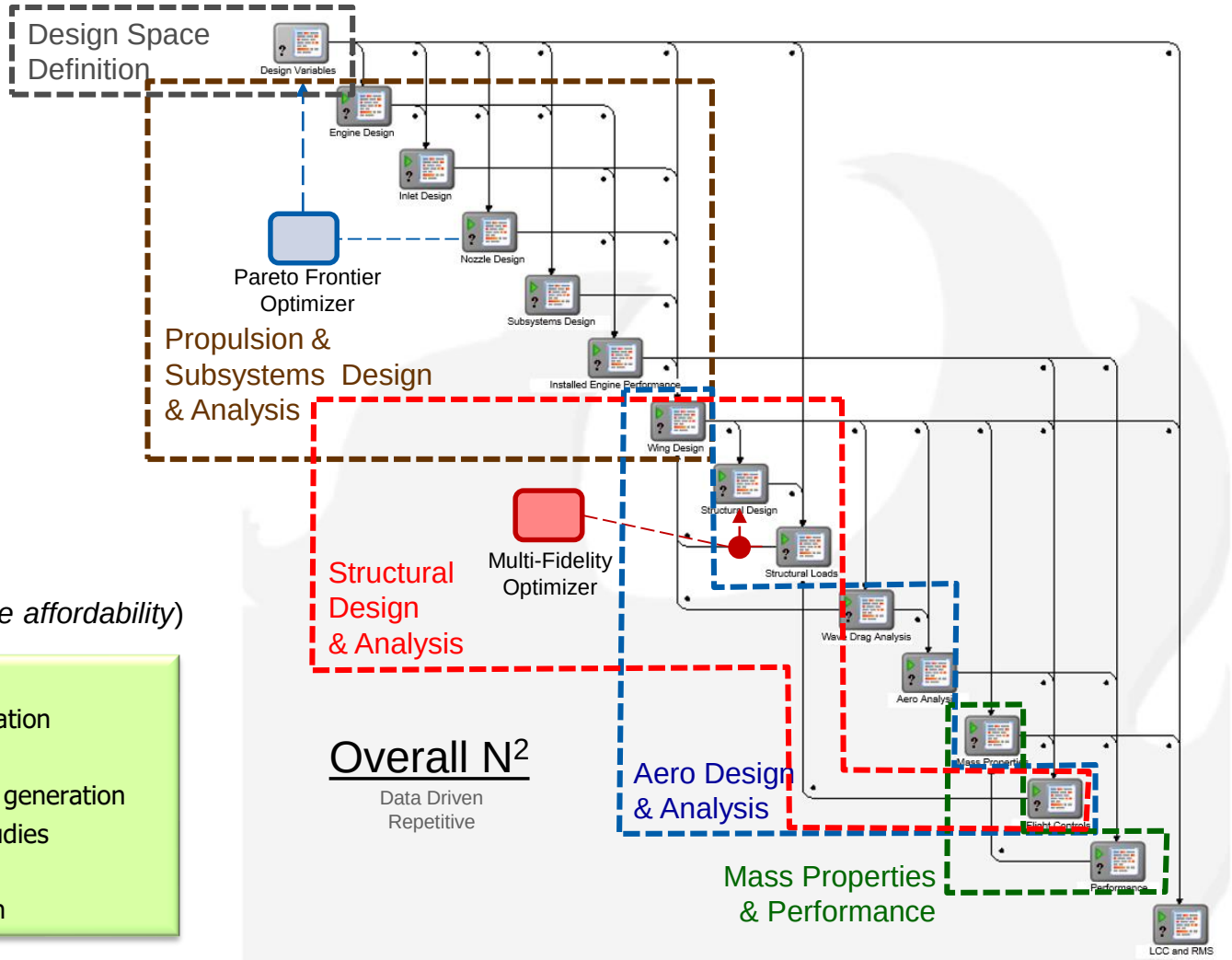
- **Requirements**
  - Mission
  - Structures
  - Flight Controls
- **Constraints**
  - Propulsion
  - Structures
  - Flight Controls
- **Variables**
  - Vehicle
  - Propulsion
- **Objective**
  - Minimize TOGW (*maximize affordability*)

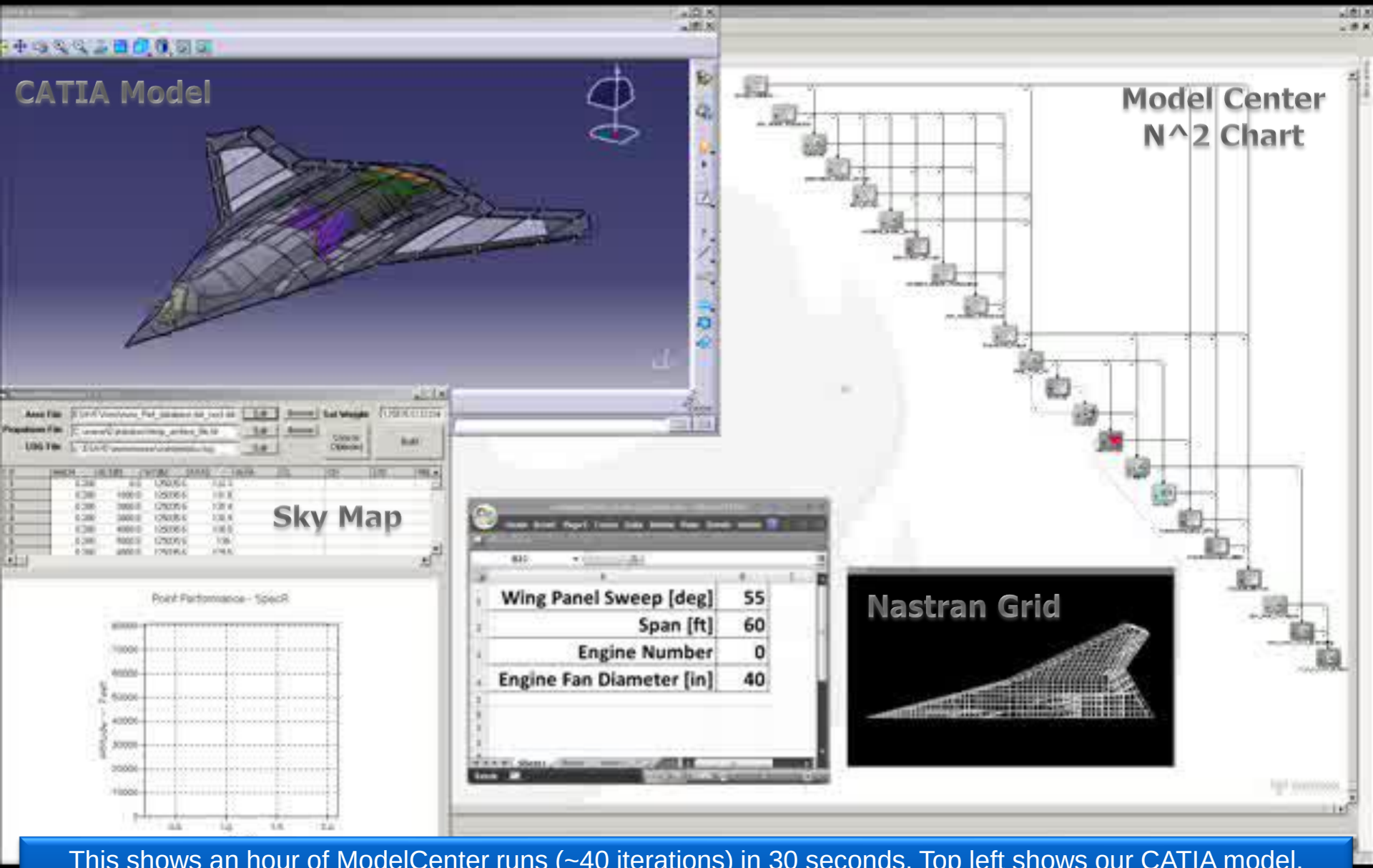


MDAO Design / Analysis Modes

- Interactive design space exploration
- Design of Experiments (DoE)
- Response Surface Model (RSM) generation
- Local vs. global optimization studies
  - Pareto frontier optimizer
  - Gradient based vs. line search

N² Architecture couples disciplines in both inner and outer loops and supports a wide range of trade studies and optimization methods

ESAVE MDAO Model Animation



This shows an hour of ModelCenter runs (~40 iterations) in 30 seconds. Top left shows our CATIA model. Bottom left shows a sky map of specific range at MTOW. Bottom right shows the NASTRAN grid.

History of MDAO Applications and Support

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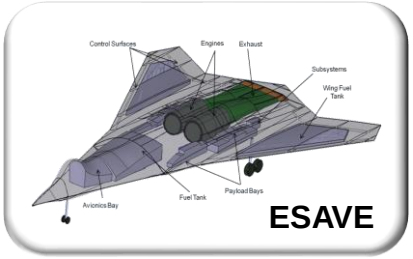
- CRAD: LCCM, TERN, AETD, ONR VCAT
  (LCCM=Low Cost Cruise Missile, TERN=Tactically Exploited Reconnaissance Node, AETD=Adaptive Engine Technology Development ONR=Office of Naval Research, VCAT=Variable Cycle Advanced Technology)
- IRAD: F-X, FA-XX, UCLASS, NGAS Proprietary Programs
  (F-X=Fighter-Experimental, FA-XX=Fighter/Attack Experimental, UCLASS=Unmanned Carrier-Launched Airborne Surveillance and Strike)
- ONR VCAT NUCAS, NAVAIR/ONR VCAT NGAD
  (NUCAS=Notional Unmanned Combat Air System, NGAD=Next Generation Air Dominance)
- AFRL ESAVE MDAO Program
  (AFRL=Air Force Research Laboratory, ESAVE=Efficient Supersonic Air Vehicle Exploration)
- AFRL RCEE
  (RCEE=Revolutionary Configurations for Energy Efficiency)
- NASA N+2 ERA Sizing Study - Scaled Test-bed Vehicle
  (ERA=Environmentally Responsible Aviation)
- AFRL HEETE Project: Propulsion study
  (HEETE=Highly Energy Efficient Turbine Engine)
- HALE Program MDAO Models Deployment
  (HALE=High Altitude Long Endurance)
- Support: Airframe Digital Twin, Hypersonics



MDAO is a ***critical technology*** and ***key-enabler*** at NGC for producing aerospace configuration designs with ***maximized capability*** and ***affordability***

Lessons Learned from Deployment

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- **Simultaneous Top-Down and Bottoms-Up approach** – Motivated engineers with time to work is a powerful thing
- **Fail quickly** – Most great ideas don't take much time to implement and try out
- **Retain tribal knowledge** – Because it is easy to quickly try out new ideas, tribal knowledge builds quickly, meaning a lot of knowledge can be lost if there is high turnover
- **Document, document, document** – New users are delicate; treat them well with good docs
- **V&V and mentoring become more important** – ModelCenter® makes your codes easier to run by more users, which skips much of the traditional learning process
- **Open up the tools, make them accessible**

These should be done anyway, but automation makes them more critical

Concluding Remarks

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- MDAO enables engineers to ***explore*** large conceptual fighter design spaces in a ***fraction of the time*** over traditional approaches, resulting in ***better trades*** **and better design**.
- Engineers spend more time analyzing the data, rather than generating it, resulting in progressively ***higher quality solutions***.
- Exploring the design space earlier gives engineers and program management a ***deeper understanding*** of the design.
- The quantitative and qualitative knowledge generated gives leadership better ***visibility*** into the risks and challenges involved, enabling them to make ***informed*** and ***pro-active*** programmatic decisions.
- This in turn fosters a better ***rapport*** with the customer, allowing them to shift from “Are you doing this correctly?” to “What if?” type questions.

Phoenix Integration’s ModelCenter® software has enabled NGC to conduct MDAO quickly, accurately, and efficiently

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