

Model-Based Engineering and Cyber-Physical Systems

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GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2017



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Parker Aerospace

NORTHROP GRUMMAN

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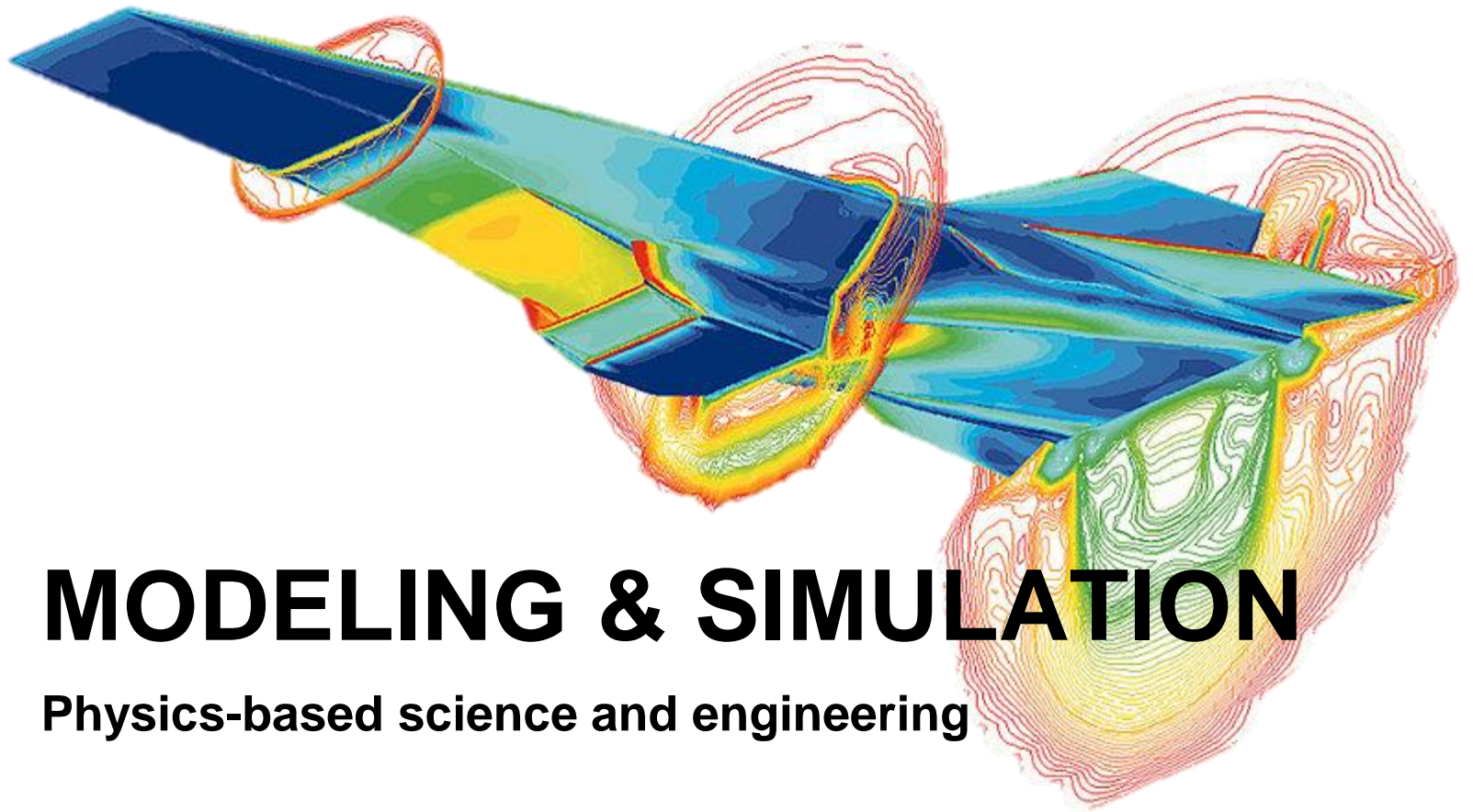
BOEING





PRODUCT CONCEPT

An Example



MODELING & SIMULATION

Physics-based science and engineering



Newton's Second Law

$$F = ma$$

1D EQUATION

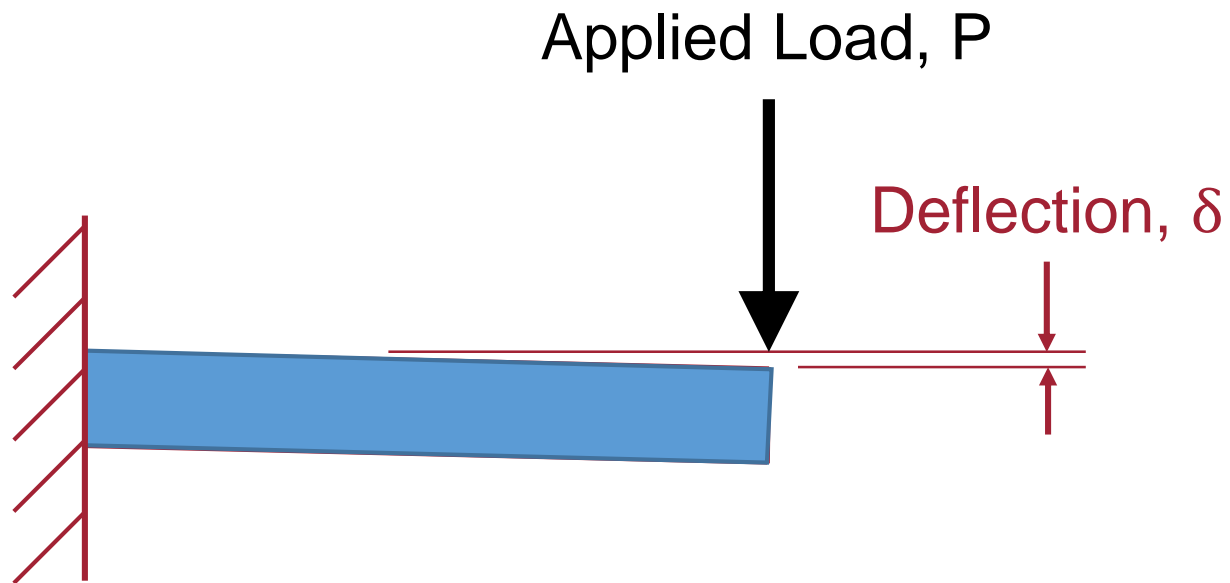
2D Physical Model

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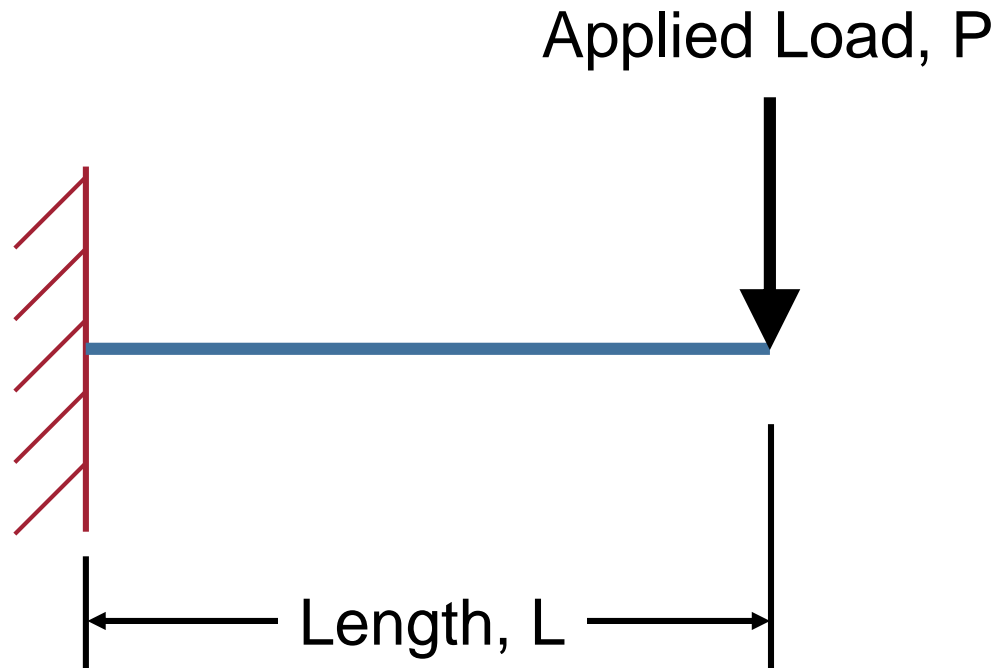
2D Physical Model

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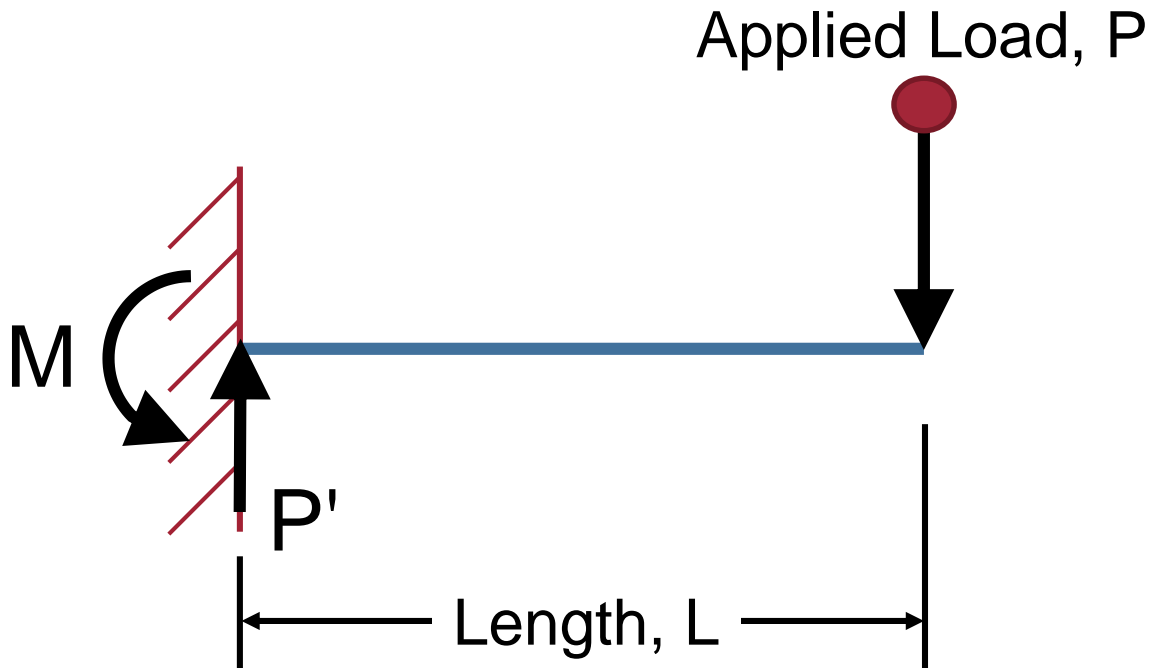
2D Physical Model

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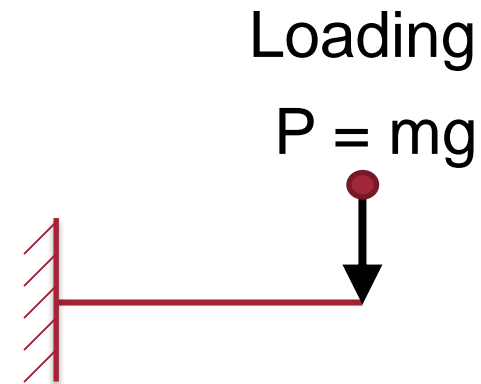
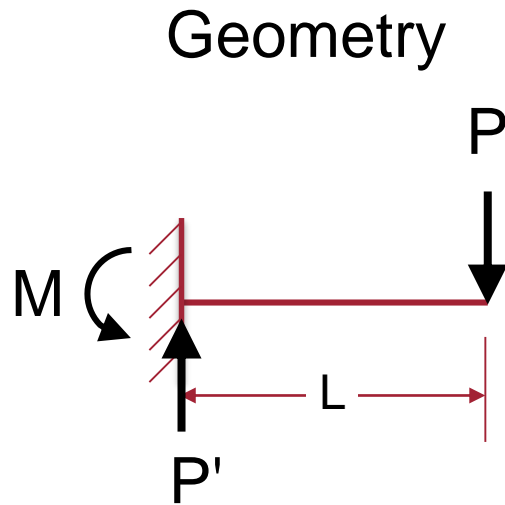
2D Physical Model

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2D Physical Model

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Vertical Force, $P' = mg$

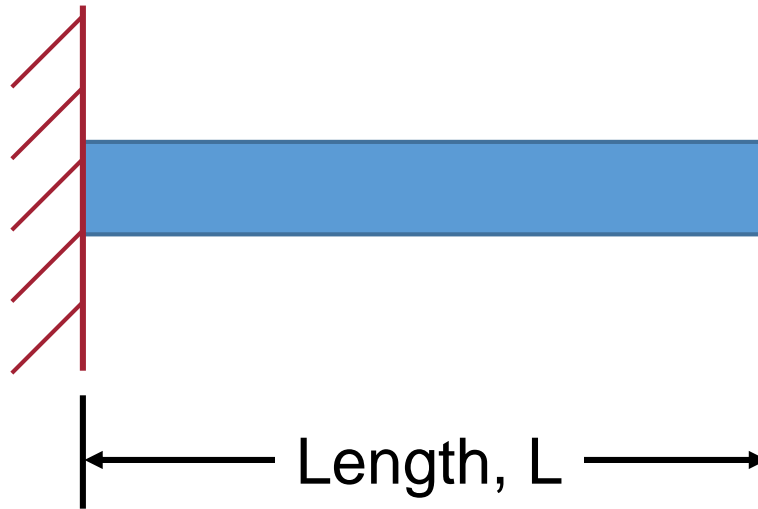
Rotational Force, $M = mgL$

2D PHYSICAL MODEL

3D Geometry Model

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Structural Rigidity



A red circular cross-section with diameter d . A blue arrow points to the diameter. Dashed lines indicate the center and axes.

$$I = \frac{\pi d^4}{64}$$

A red square cross-section with side length b . Dashed lines indicate the center and axes.

$$I = \frac{bh^3}{12}$$

A red triangular cross-section with height h and base b . Dashed lines indicate the center and axes.

$$I = \frac{bh^3}{36}$$

3D Analysis Model

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Material Stiffness



Aluminum



Steel



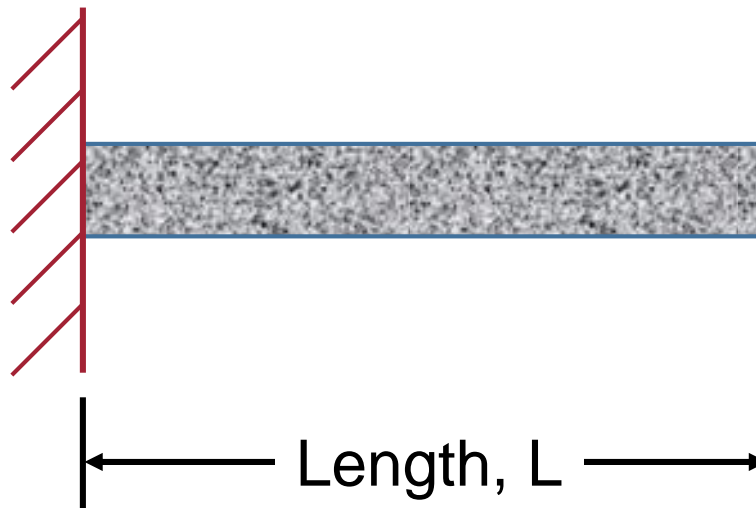
Titanium



Composite

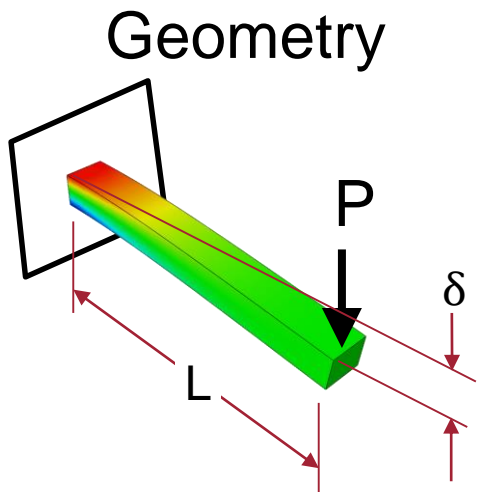


Wood

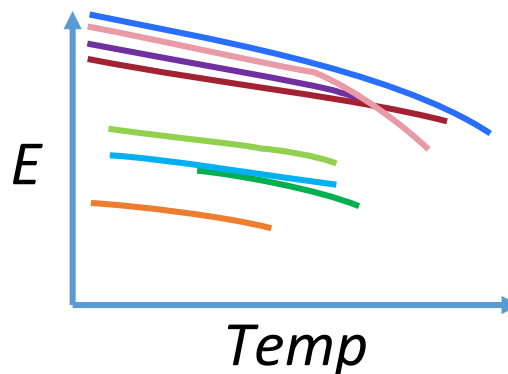


3D Analysis Model – Deflection

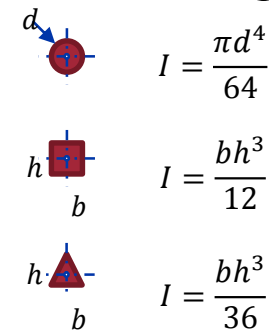
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Material Stiffness



Structural Rigidity



$$\text{Deflection, } \delta = \frac{PL^3}{3EI}$$

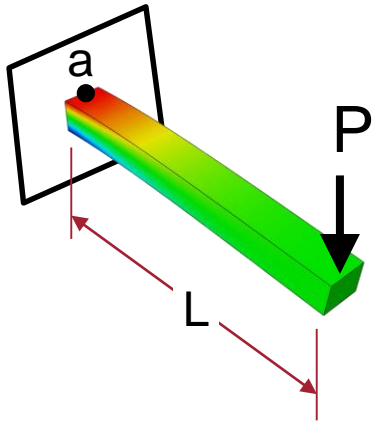
P is the Applied Force
L is the Length
E is the Material stiffness
I is the Structural rigidity

3D ANALYSIS MODEL

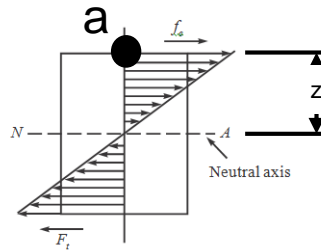
3D Analysis Model – Stress

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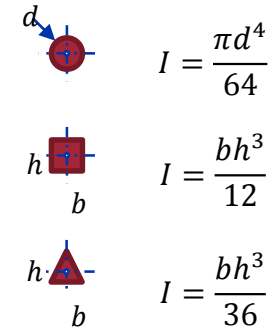
Geometry



Structural Shape



Structural Rigidity



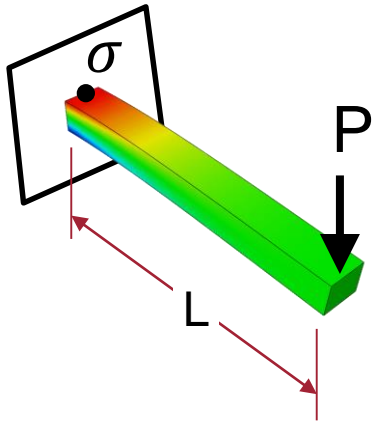
$$\text{Stress, } \sigma_a = \frac{\text{bending moment}}{\text{section modulus}} = \frac{PL}{I/z}$$

3D ANALYSIS MODEL

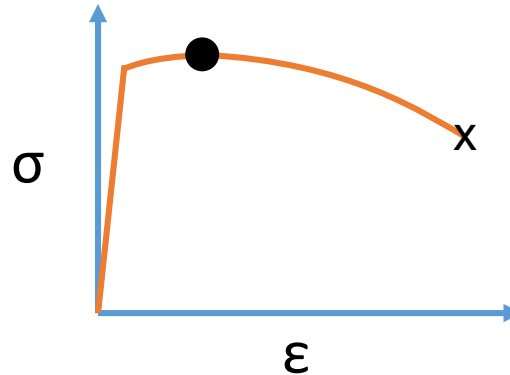
3D Simulation

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Stress



Material Strength



Safety Factor

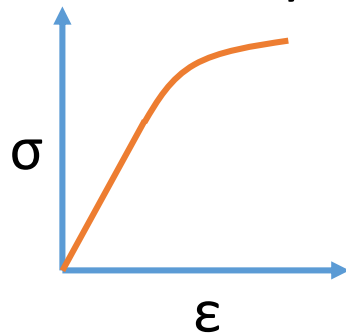
- 1.25 Unmanned
- 1.4 Spacecraft
- 1.5 Aircraft

$$\text{Margin of Safety} = \frac{\text{Material Strength}}{\text{Stress} * \text{Safety Factor}}$$

3D Structural Simulations

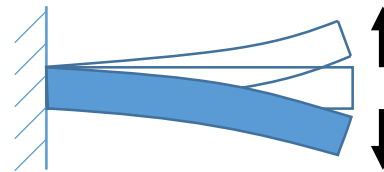
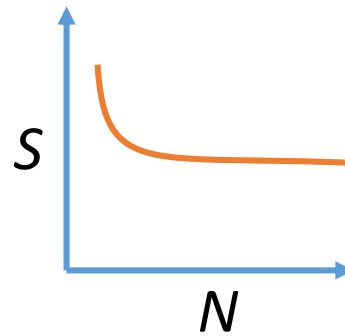
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Margin of Safety



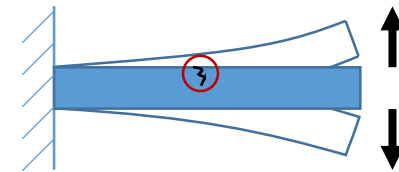
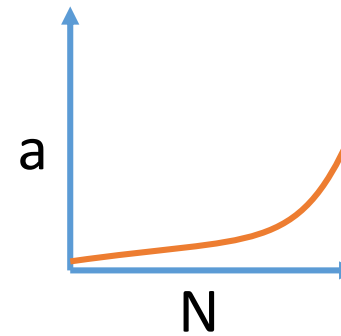
Static
(σ - ϵ)

Structural Life



Fatigue
(S-N)

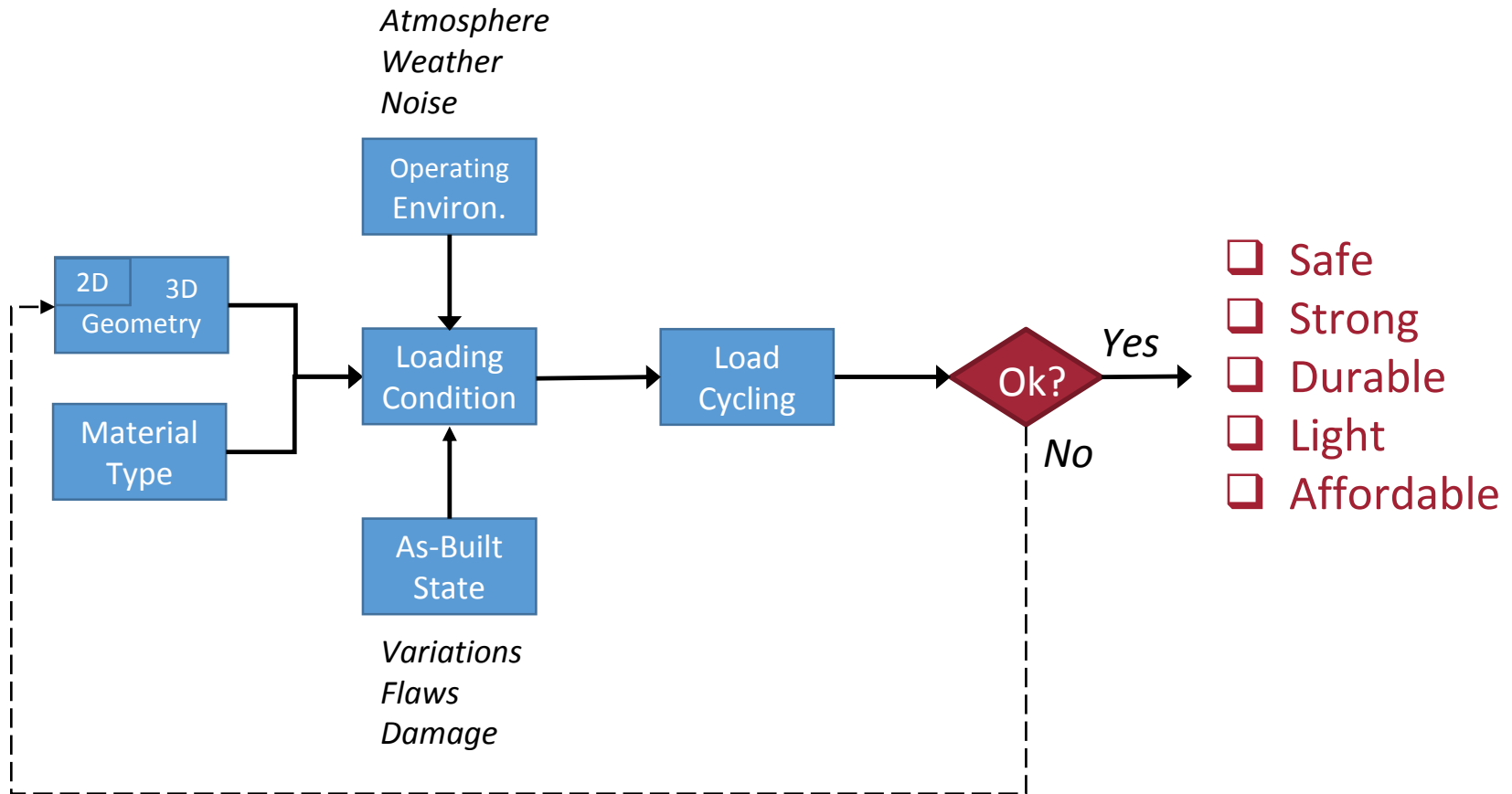
Inspection Interval



Fatigue Crack
Growth (da/dN)

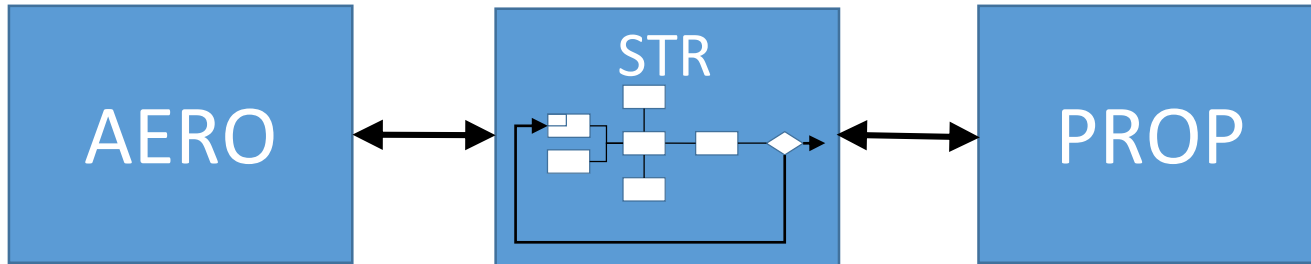
Functional Model

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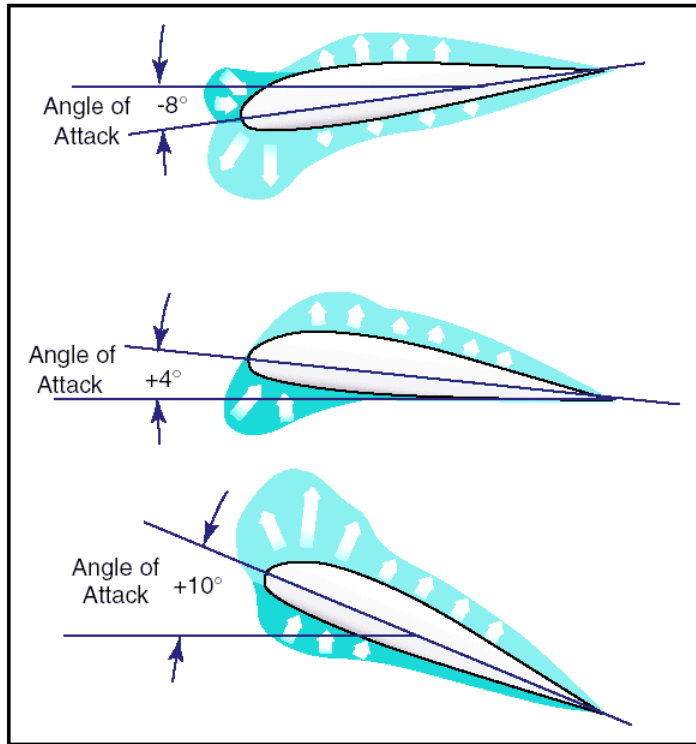
Multifunctional Model

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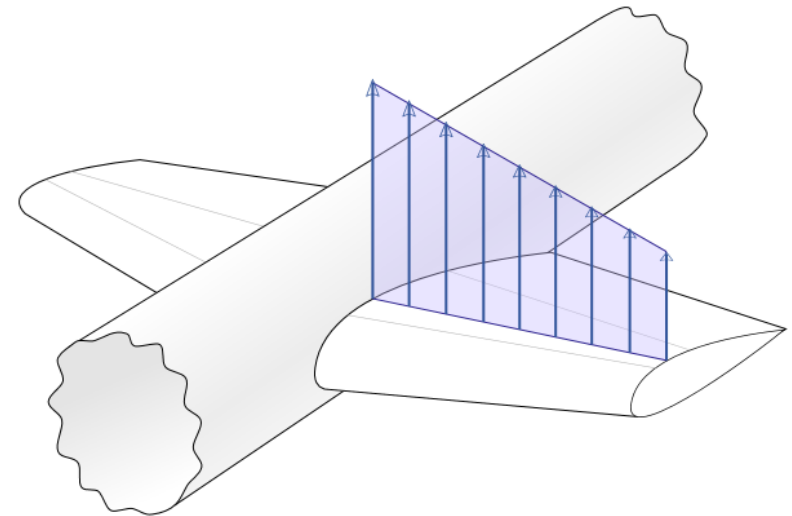


Aerodynamic Model

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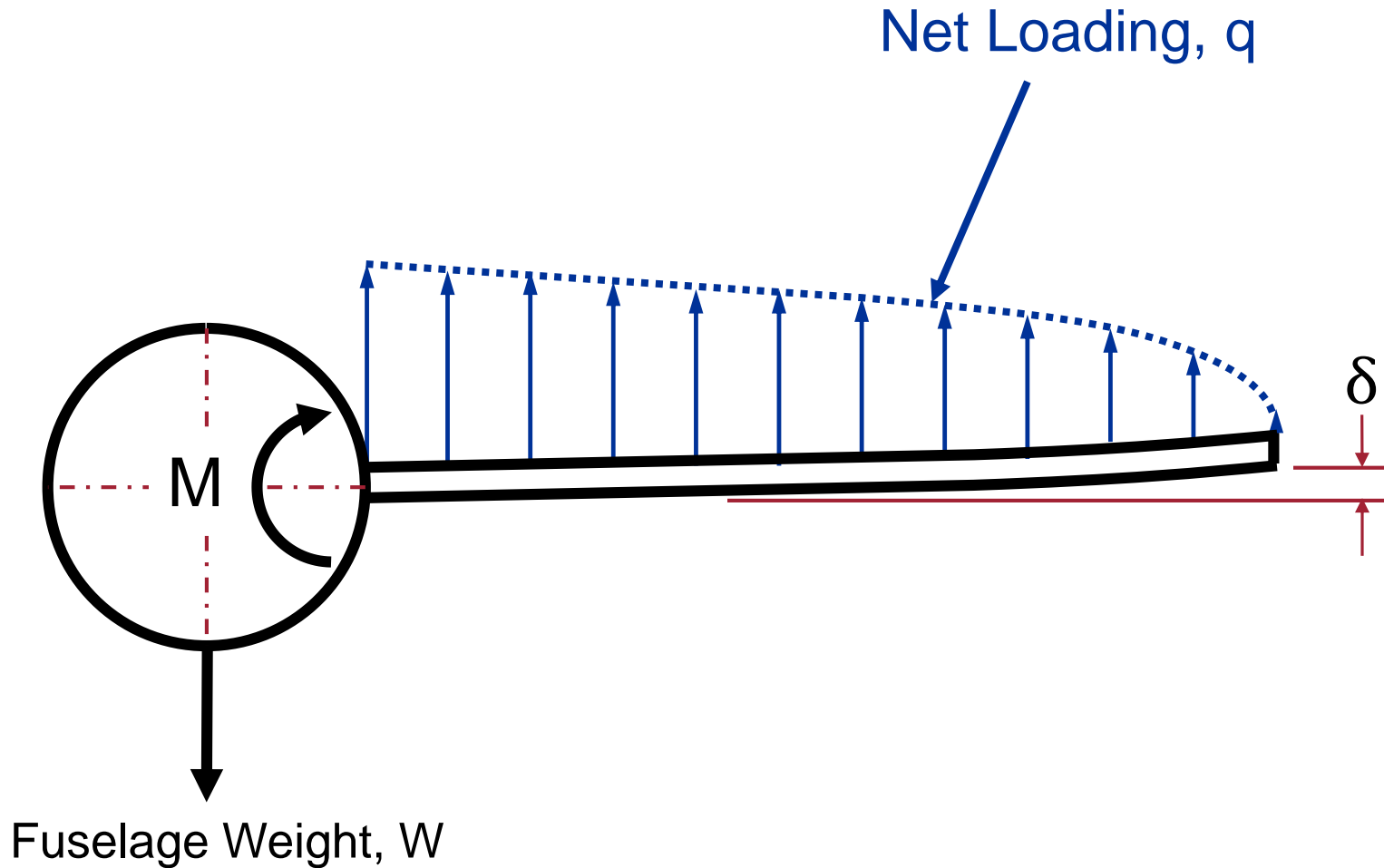
Airfoil geometry and orientation



Wing loading

Wing Cantilever Beam Model

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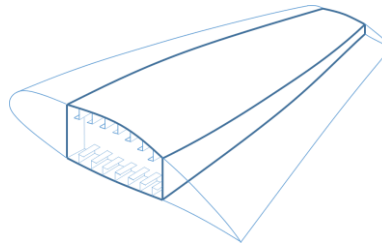
Aero-Structural Model

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Fuselage Weight



Wing Geometry

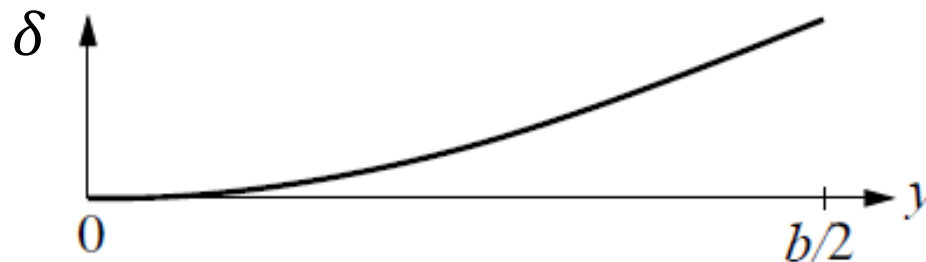


Airfoil Geometry



$$\delta = 0.018 \frac{W}{\epsilon \tau (\tau^2 + \epsilon^2)} (1 + \lambda)^3 (1 + 2\lambda) \frac{b}{c^4}$$

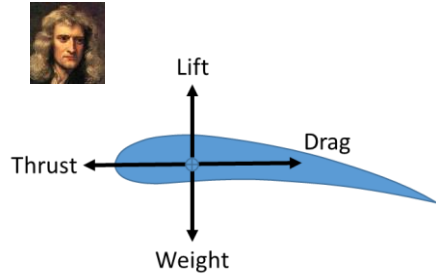
Wing Tip Deflection



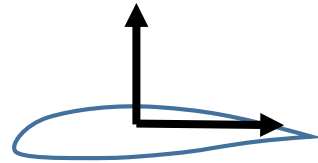
Breguet Range Equation

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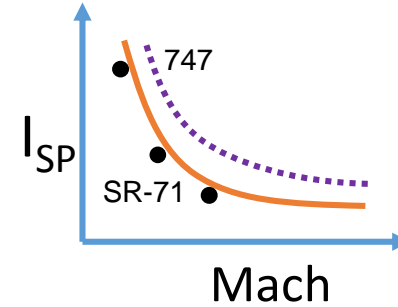
Newton's 1st Law



Aerodynamics



Engine



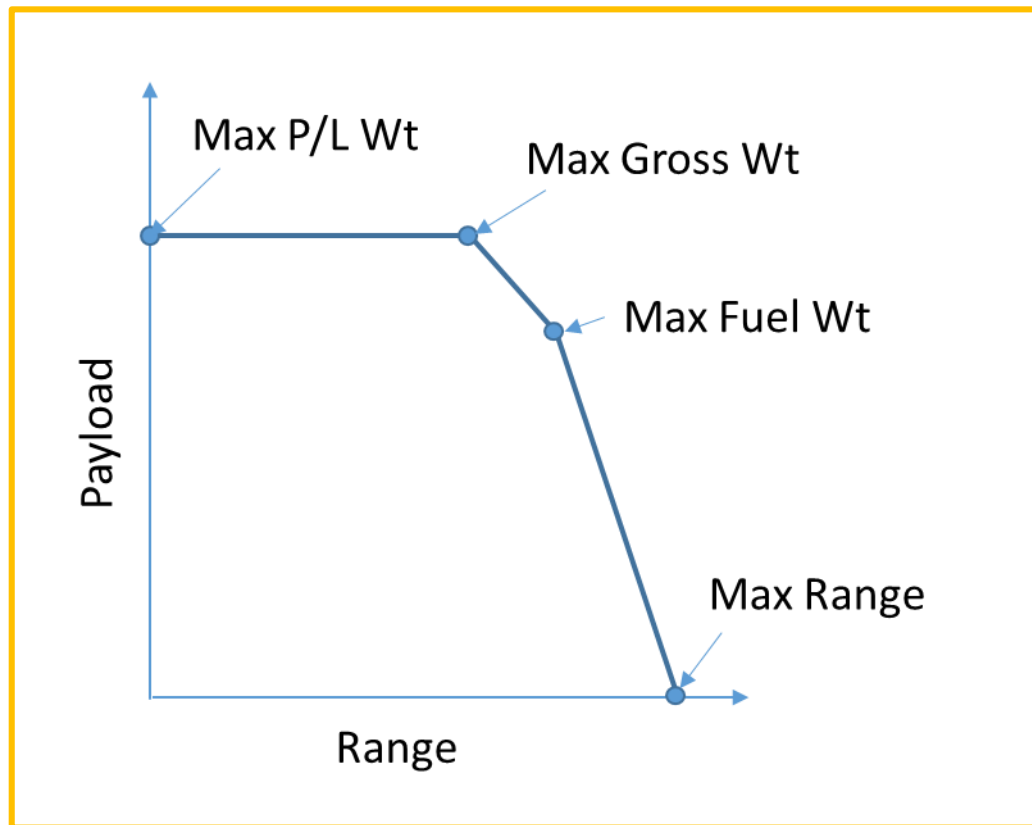
Fuel Capacity



$$\text{Range} = V \cdot \frac{L}{D} \cdot I_{sp} \cdot \ln\left(\frac{W_i}{W_f}\right)$$

Trade-Offs

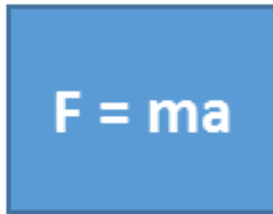
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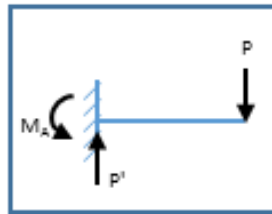
MISSION SIMULATION

Models and Simulations

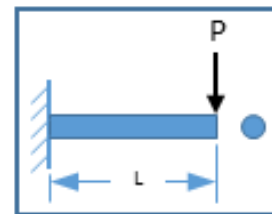
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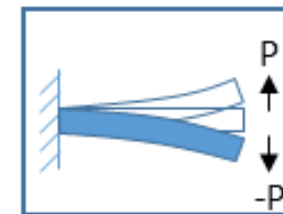
1D Equation



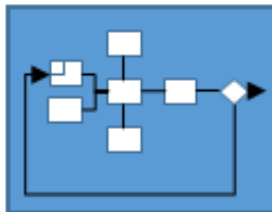
2D Physical Model



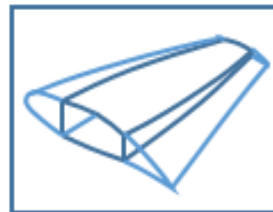
3D Geometry Model



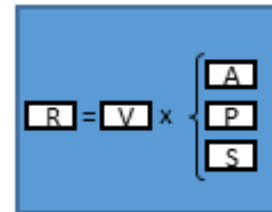
3D Analysis Model



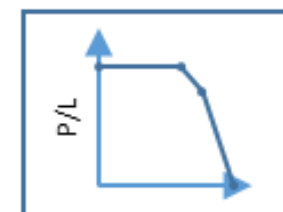
Functional Model
(physics-based)



Multi-Functional Model



Performance Model



Mission Simulation

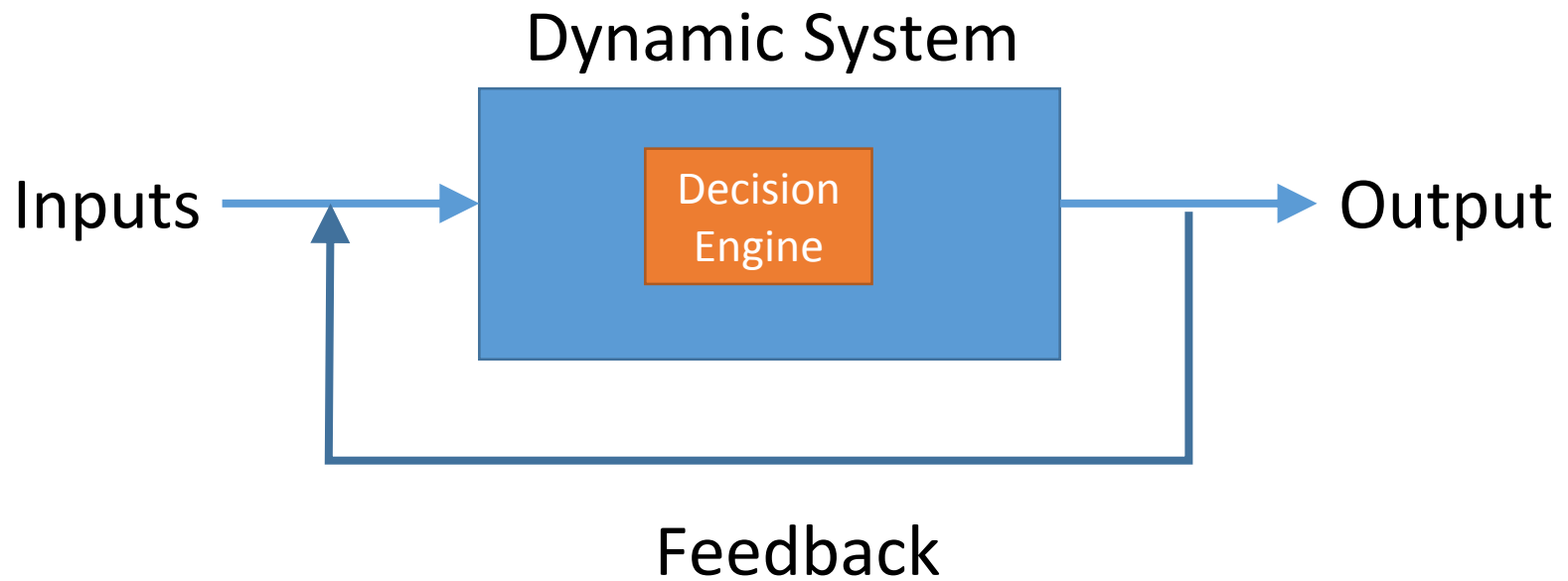


DIGITAL TWIN OF PRODUCT

As-Built Simulation with Cyber-Physical Linkage

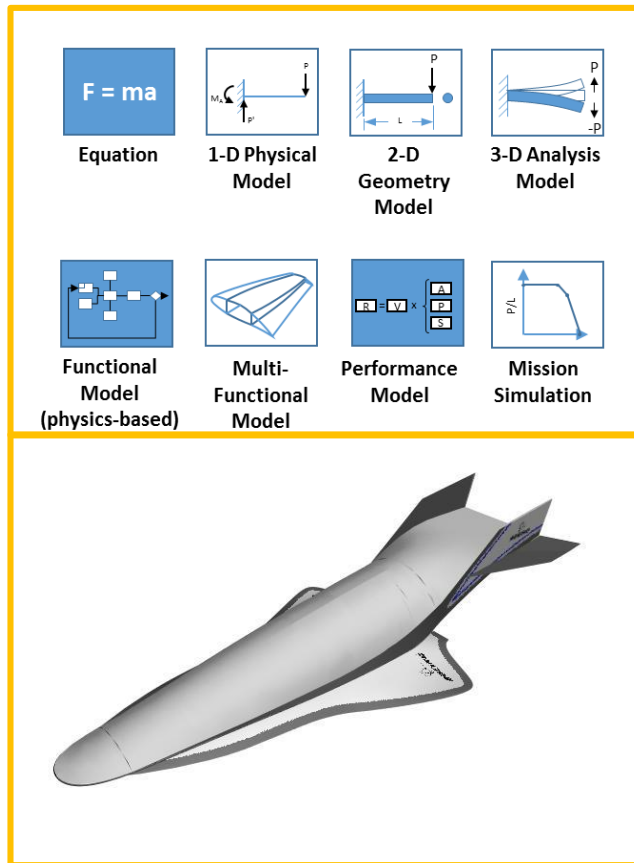
Control Theory

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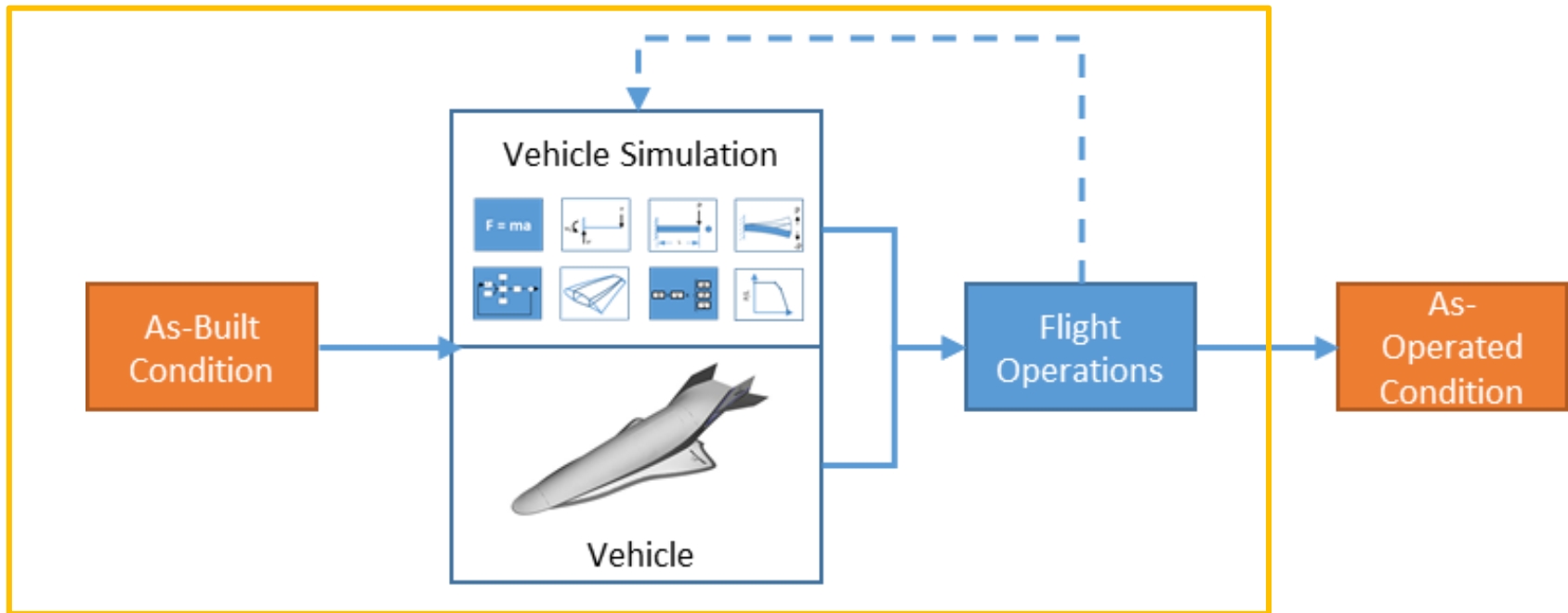
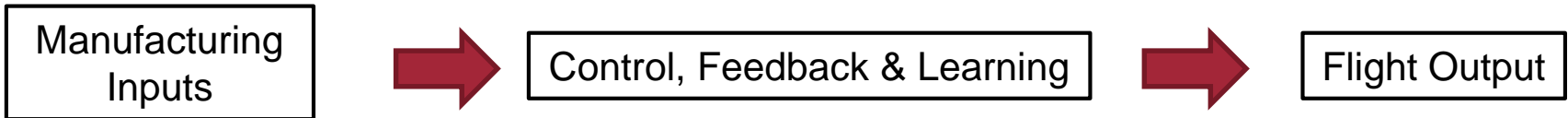
Cyber-Physical System

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Simulation (Decision Engine)

Physical System



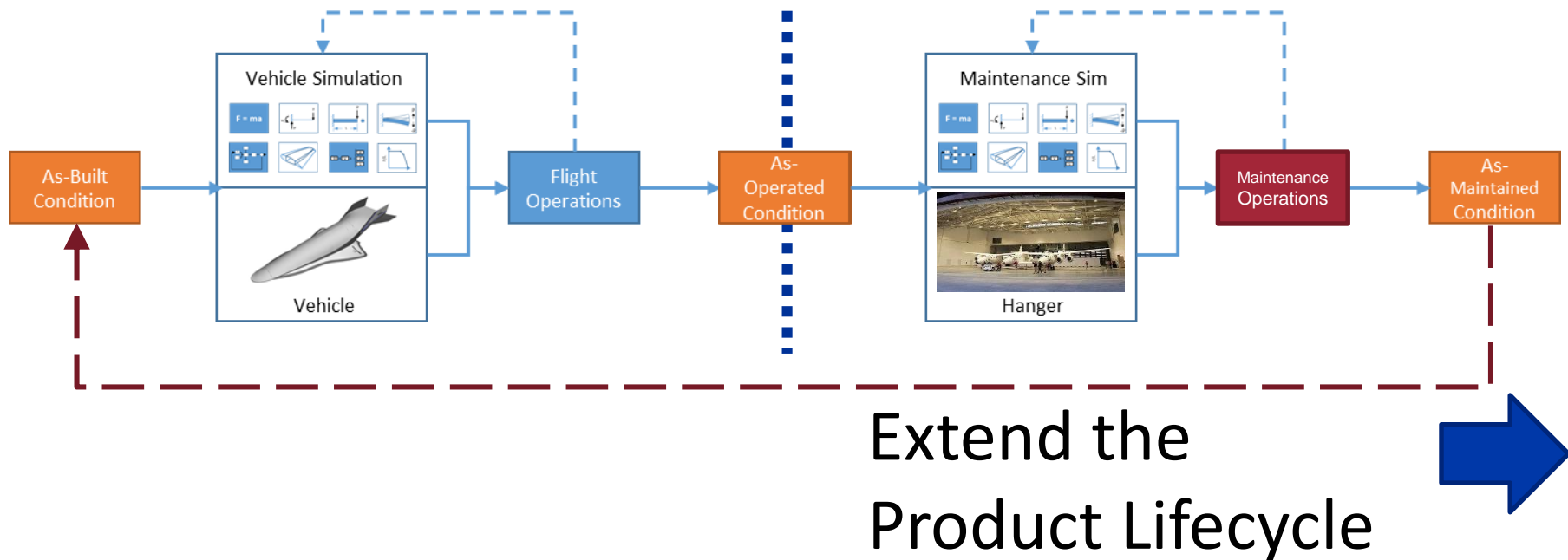
DIGITAL TWIN

Product Lifecycle Management

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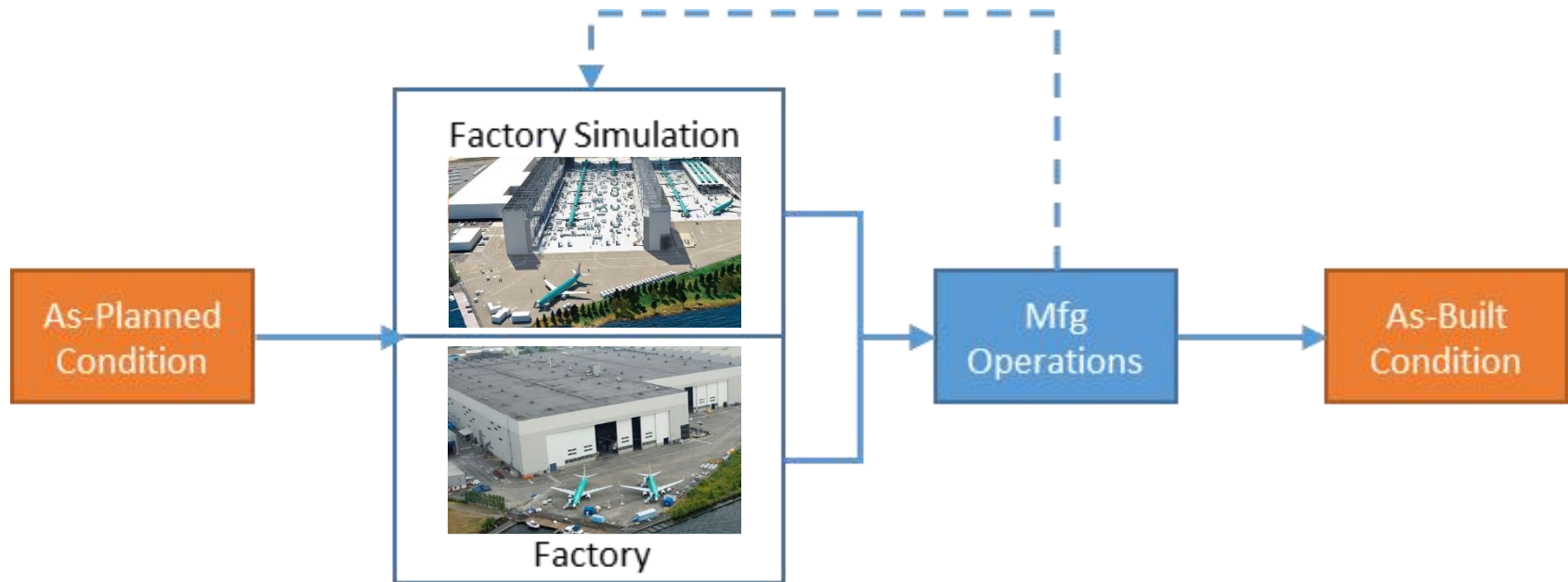
VEHICLE

MAINTENANCE

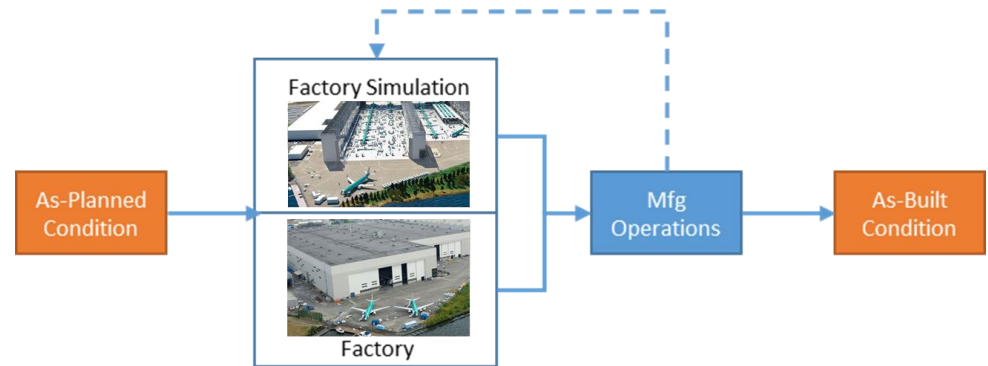






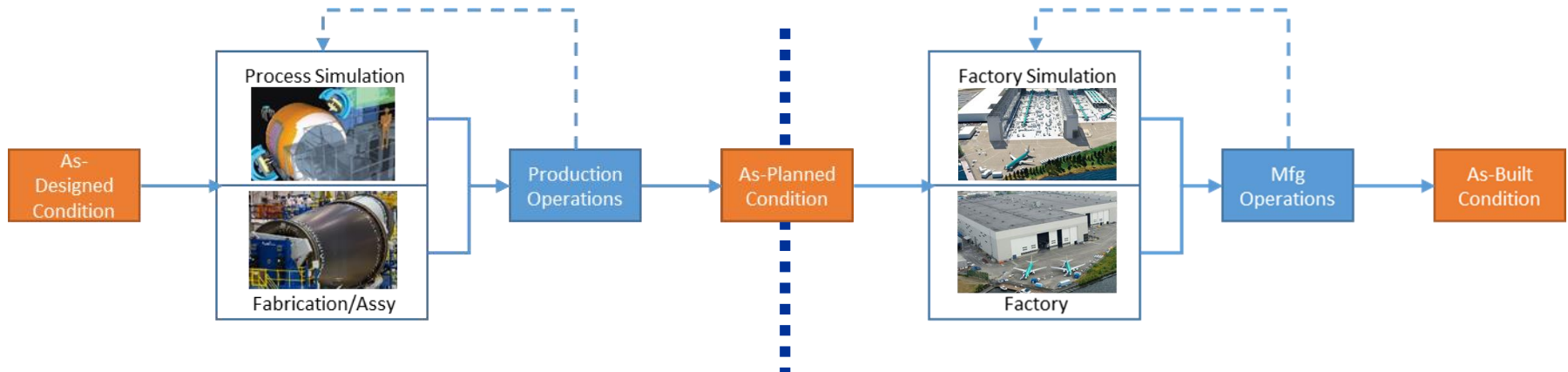


FACTORY



MANUFACTURING

FACTORY



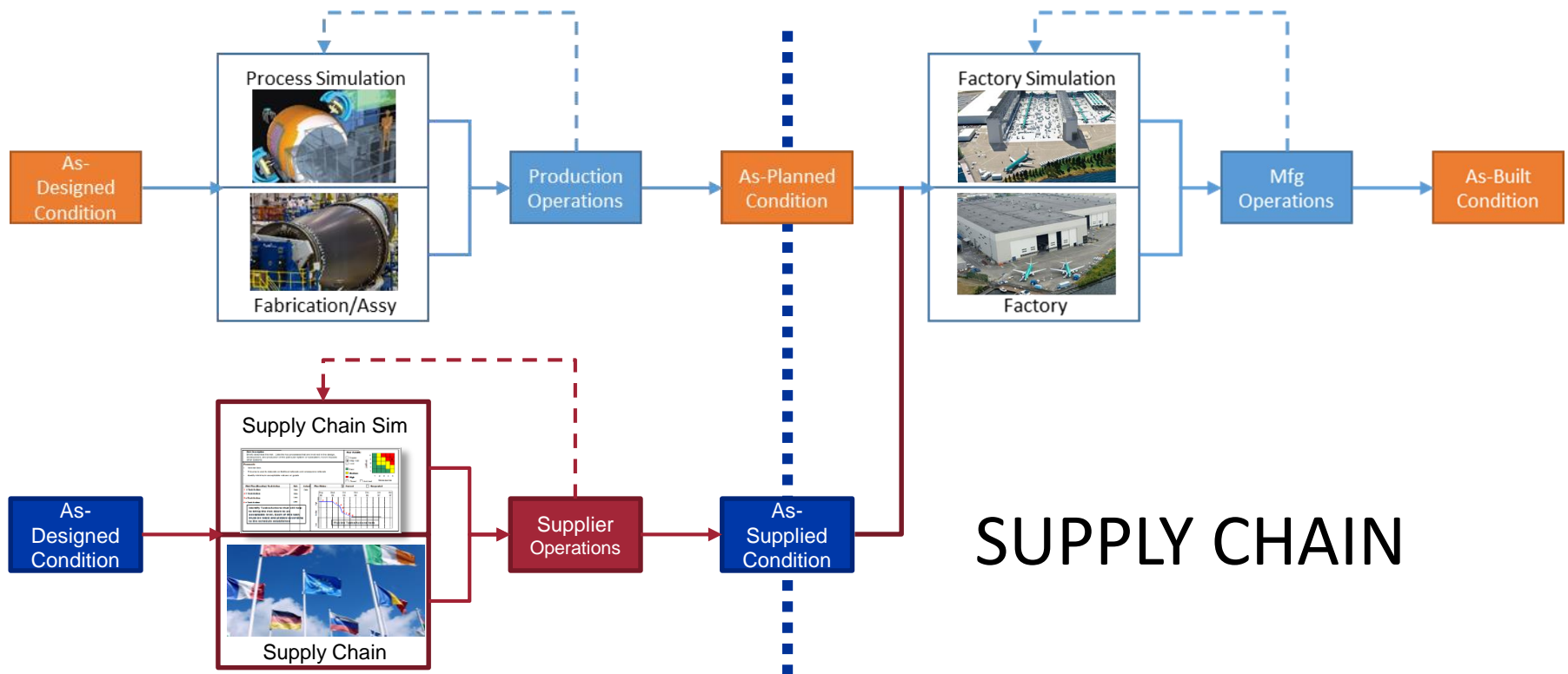
 Extend the Product Lifecycle

Manufacturing Operations Management

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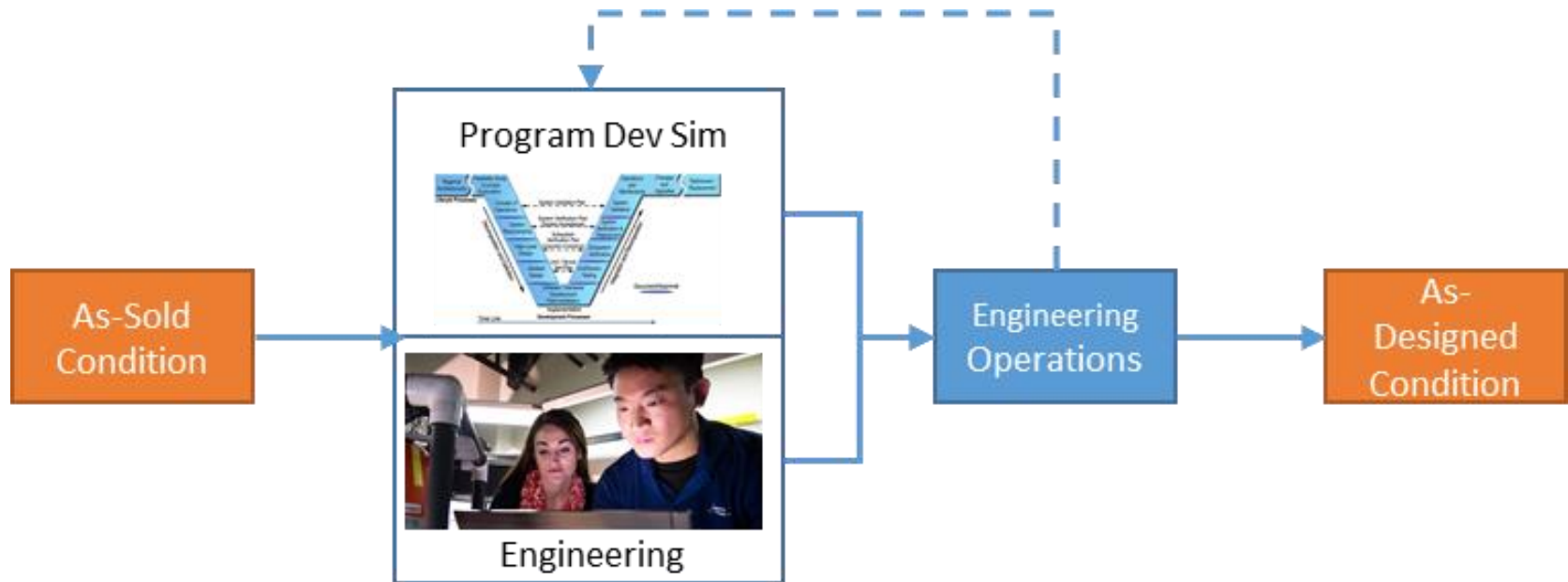
MANUFACTURING

FACTORY



SUPPLY CHAIN

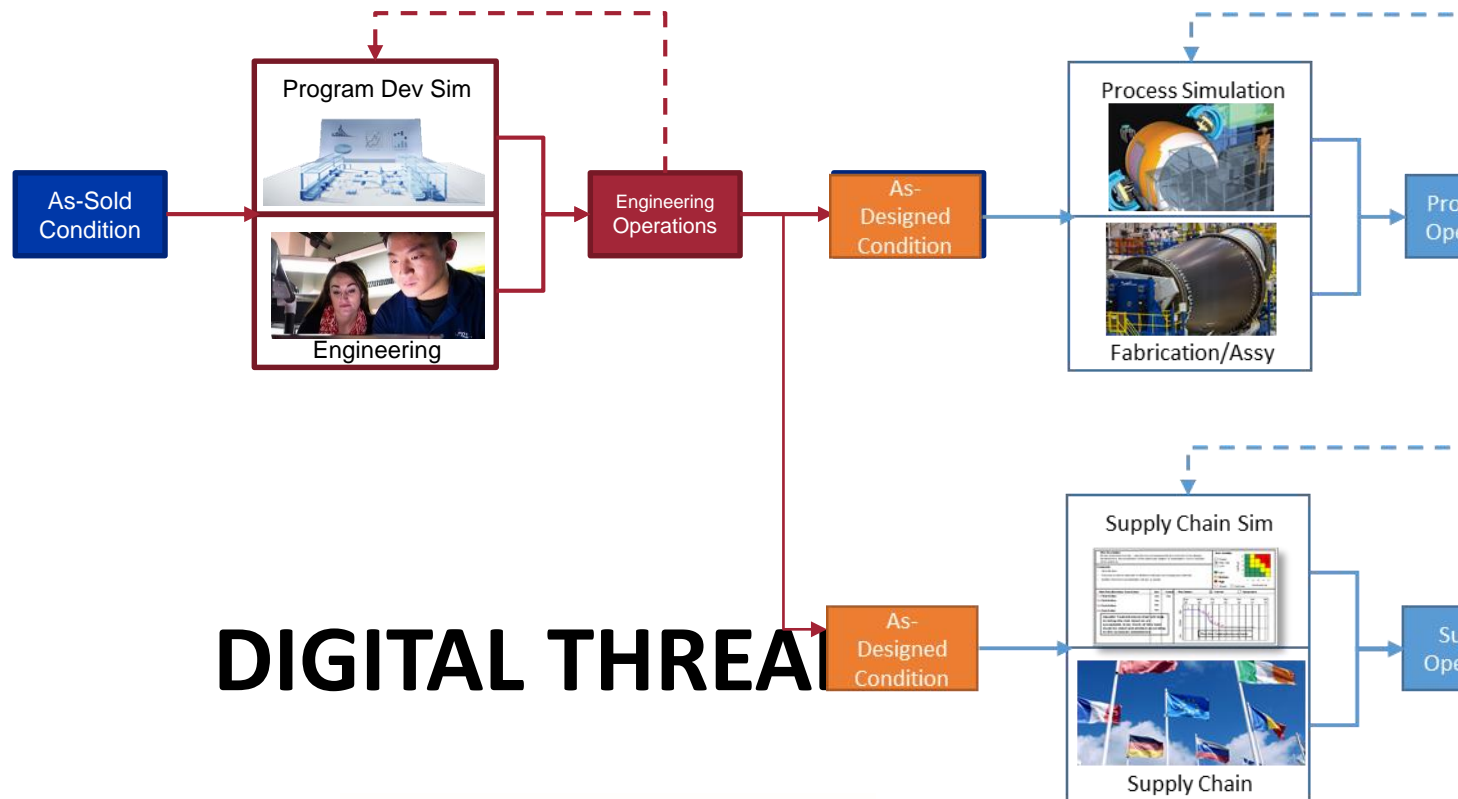
ENGINEERING



MODEL-BASED ENGINEERING

ENGINEERING

MANUFACTURING



DIGITAL THREAD

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