Intelligent Control for Green Aviation

{We Don't Make Green Aviation,
We Make Green Aviation Better, Safer, and for Less}

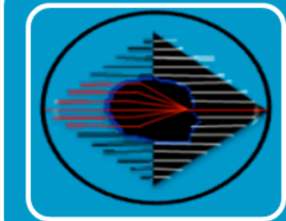
Kalmanje KrishnaKumar

kalmanje.krishnakumar@nasa.gov

Principal Investigator

Integrated Resilient Aircraft Control (IRAC) Project

Presentation Outline



Intelligent Control

- Control
- Intelligent Control
- Capabilities

Applications

- Better
- Safer
- For Less

Spin-offs

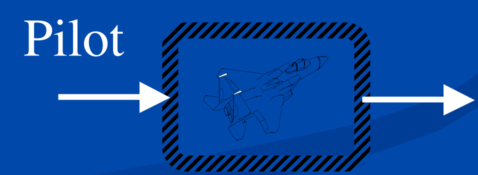
- Green Energy
- Intelligent Transportation

Progression of Flight Control

At the outset of their experiments, the Wright Brothers regarded control as the unsolved third part of "the flying problem".

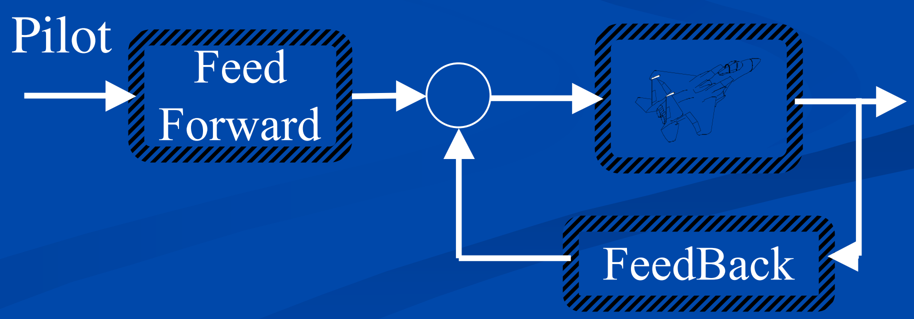
Open-Loop Control

- High Pilot Workload

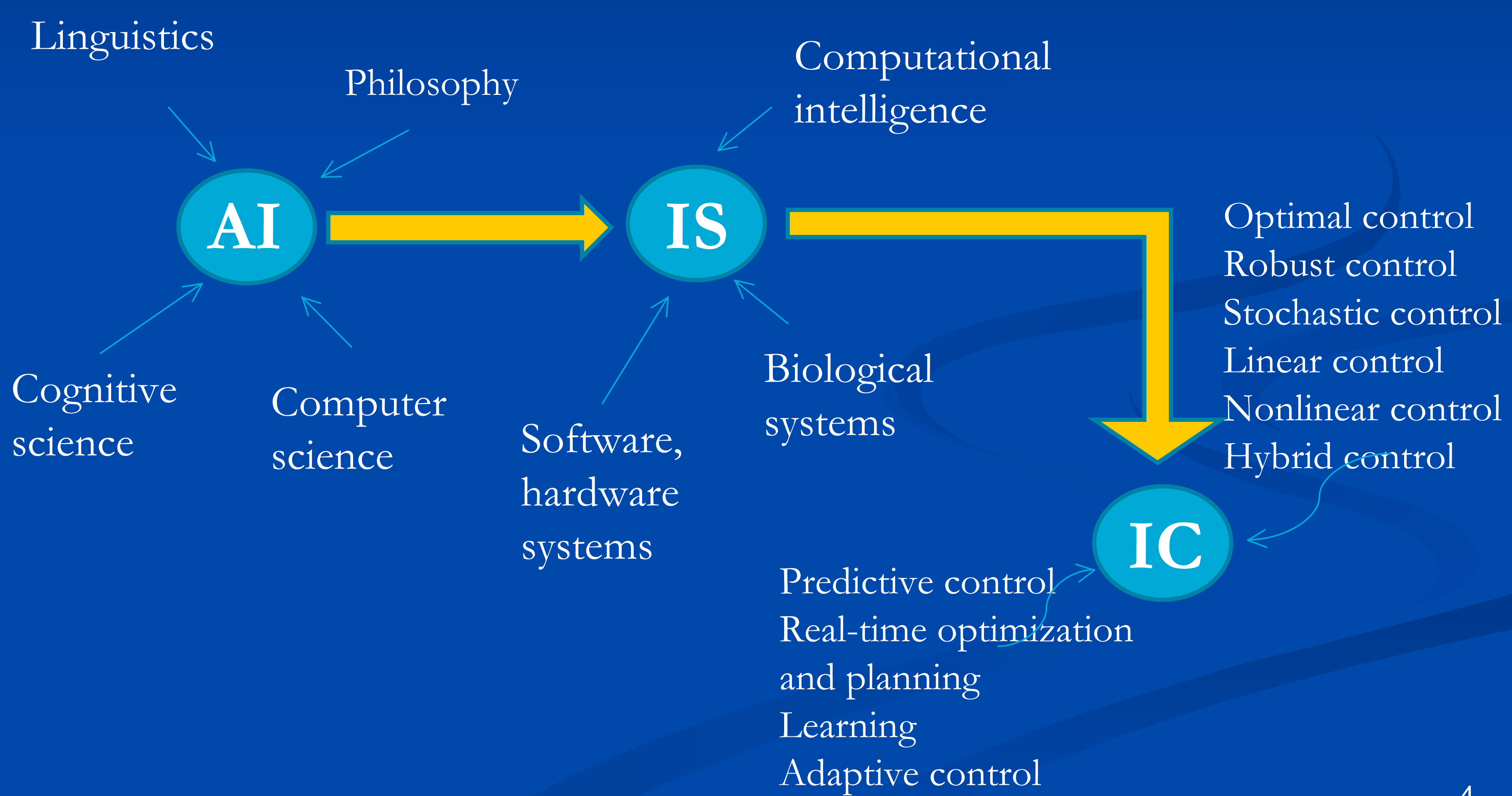


Closed-Loop Control

- Decreased Pilot Workload
- Robustness to noise and small uncertainties
- Excessive gain scheduling
- Does not handle large plant changes



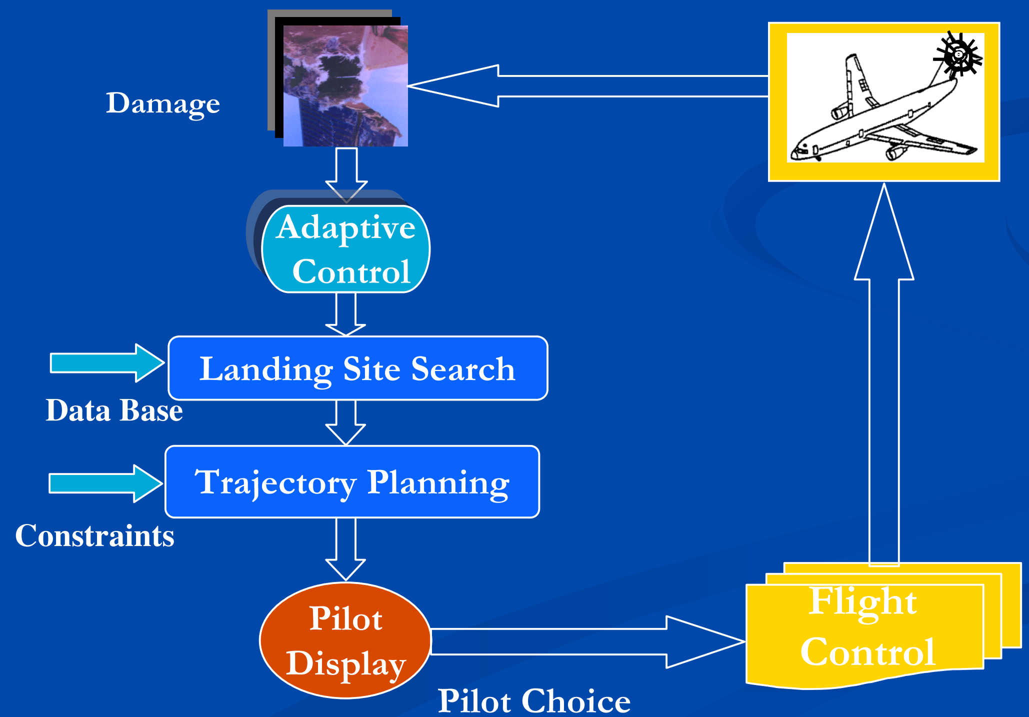
Artificial Intelligence
Intelligent Systems
Intelligent Control



Intelligent Control

AI → IS → IC

The objective of an intelligent controller is to achieve intelligent behavior that enables higher degrees of autonomy.

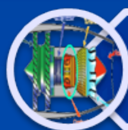


Capabilities

- Autonomy Enabler - Uncertainty handling, Fault-tolerant, Reconfigurable
- Enabler for required performance (fuel, emissions, noise)
- Real-time optimization (flight path, minimum drag, etc.)
- Data-rich, Model-poor environments
- Stability, maneuverability, and safe landing, Consistent handling qualities
- Plug-and-play Avionics, Rapid prototyping, Reusability Across Platforms
- Integrated flight and propulsion control

Application Examples


Safe Flight


Engine Control

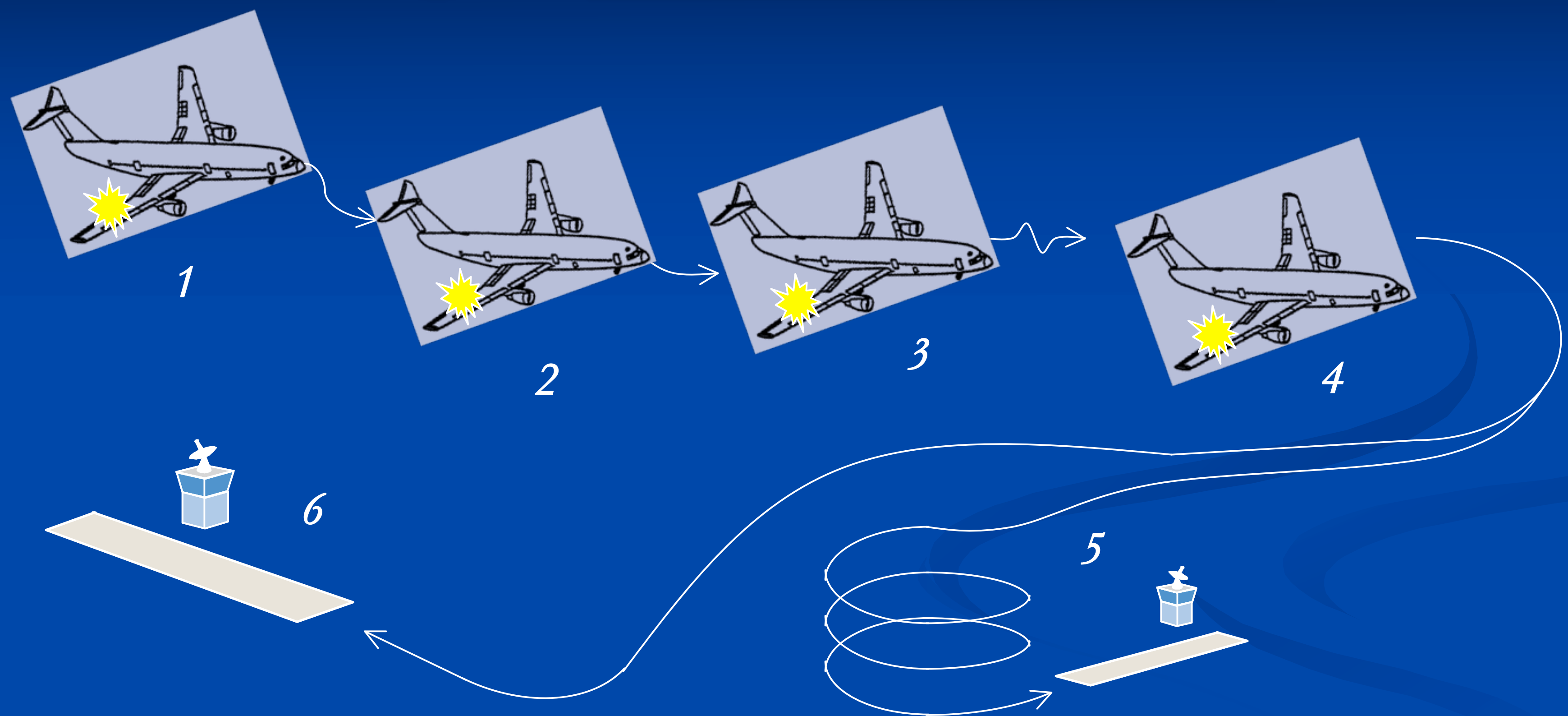

CESTOL Intelligent Control


Payload-directed Flight

iPnP Intelligent Plug and Play Avionics (*iPnP*)

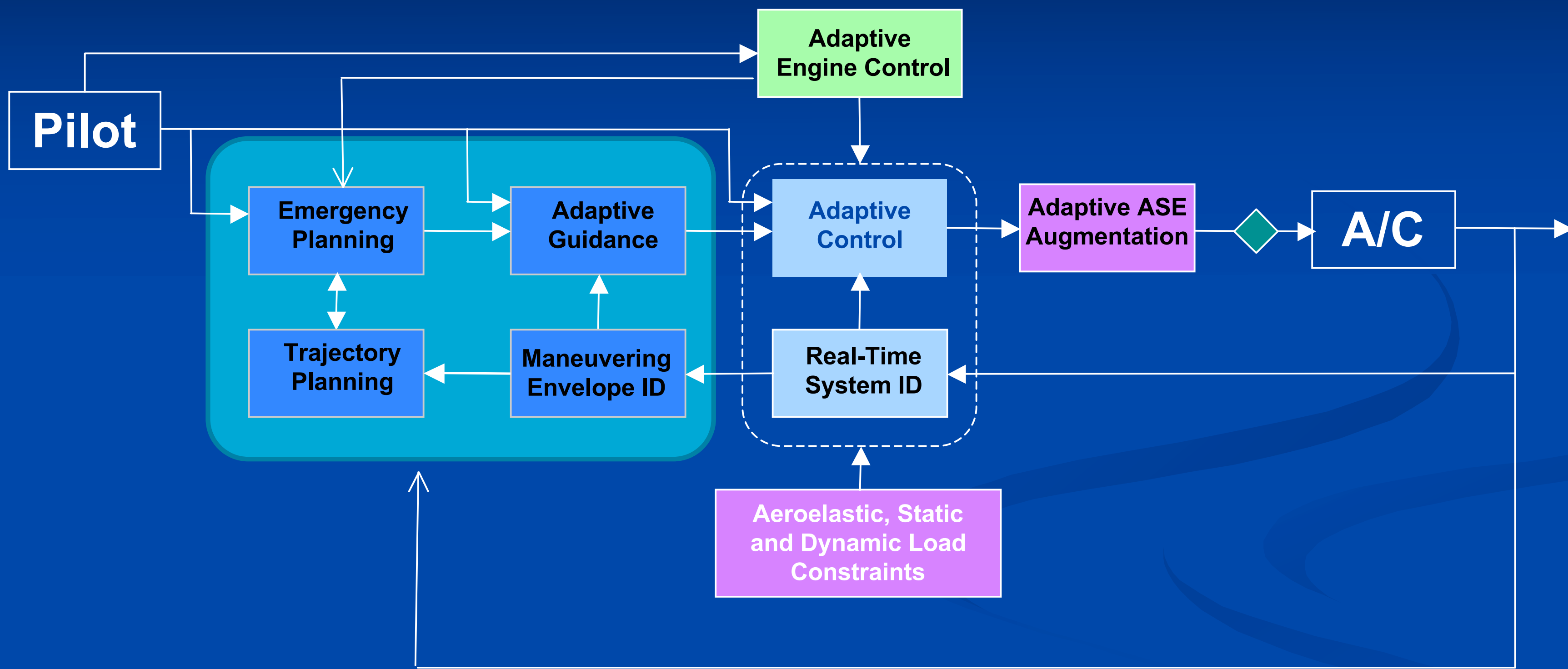
Safe Flight

Stability, maneuverability,
and safe landing



1. *Aircraft incurs damage/failure(s) resulting in aerodynamic changes*
2. *Adaptive control recovers from upsets and stabilizes the aircraft*
3. *Perform assessment of flight and maneuvering envelope*
4. *Generate robust flyable trajectories that comply with constraints*
5. *Construct a prioritized list of flight plan options to potential landing sites*
6. *Provide autopilot & flight director capability to follow trajectory*

Flight Control Architecture



Aircraft stabilization – inner loop adaptive control

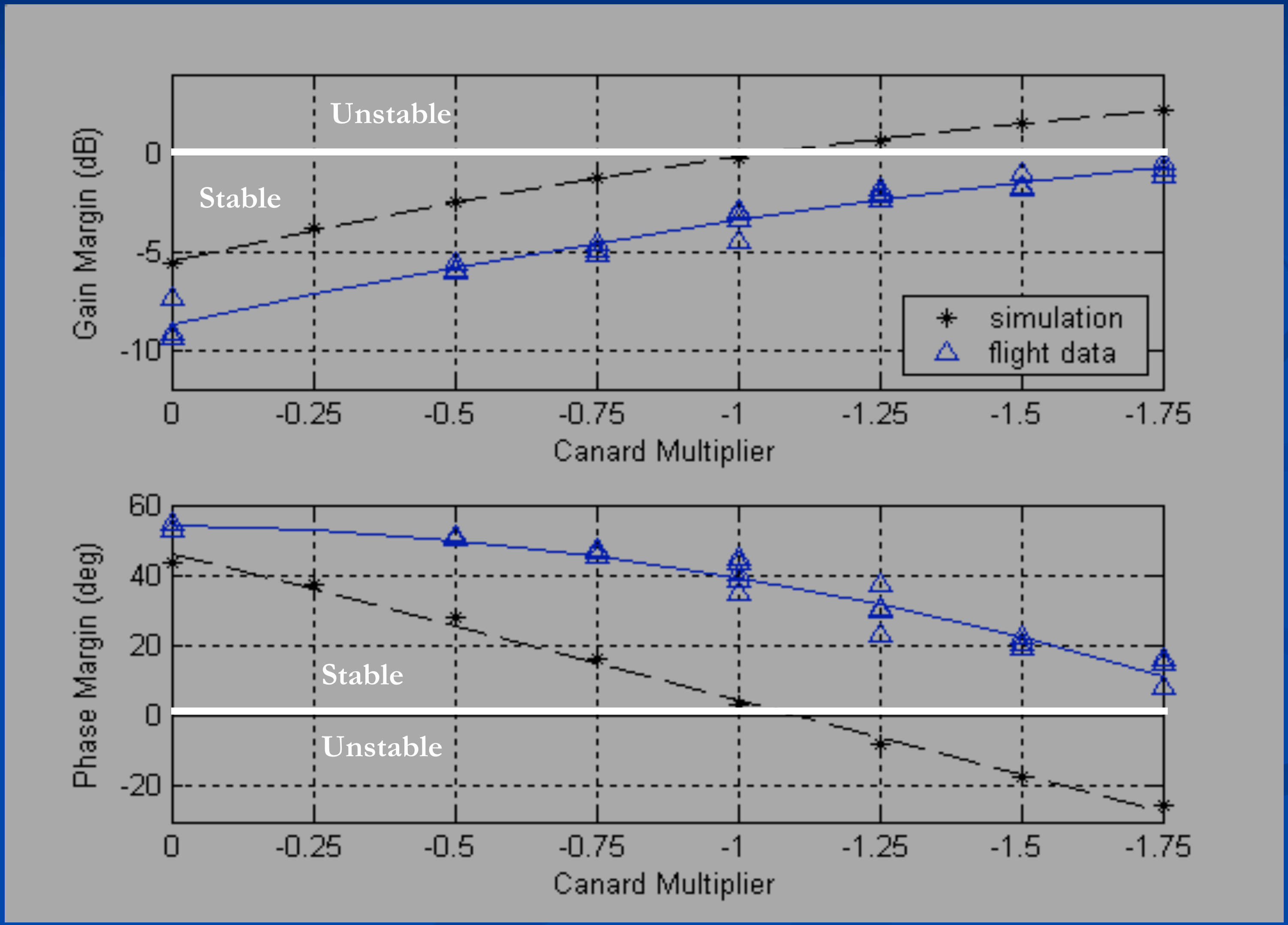
Maneuverability in reduced flight envelope

Safe landing – flight planning and flight management system (FMS)

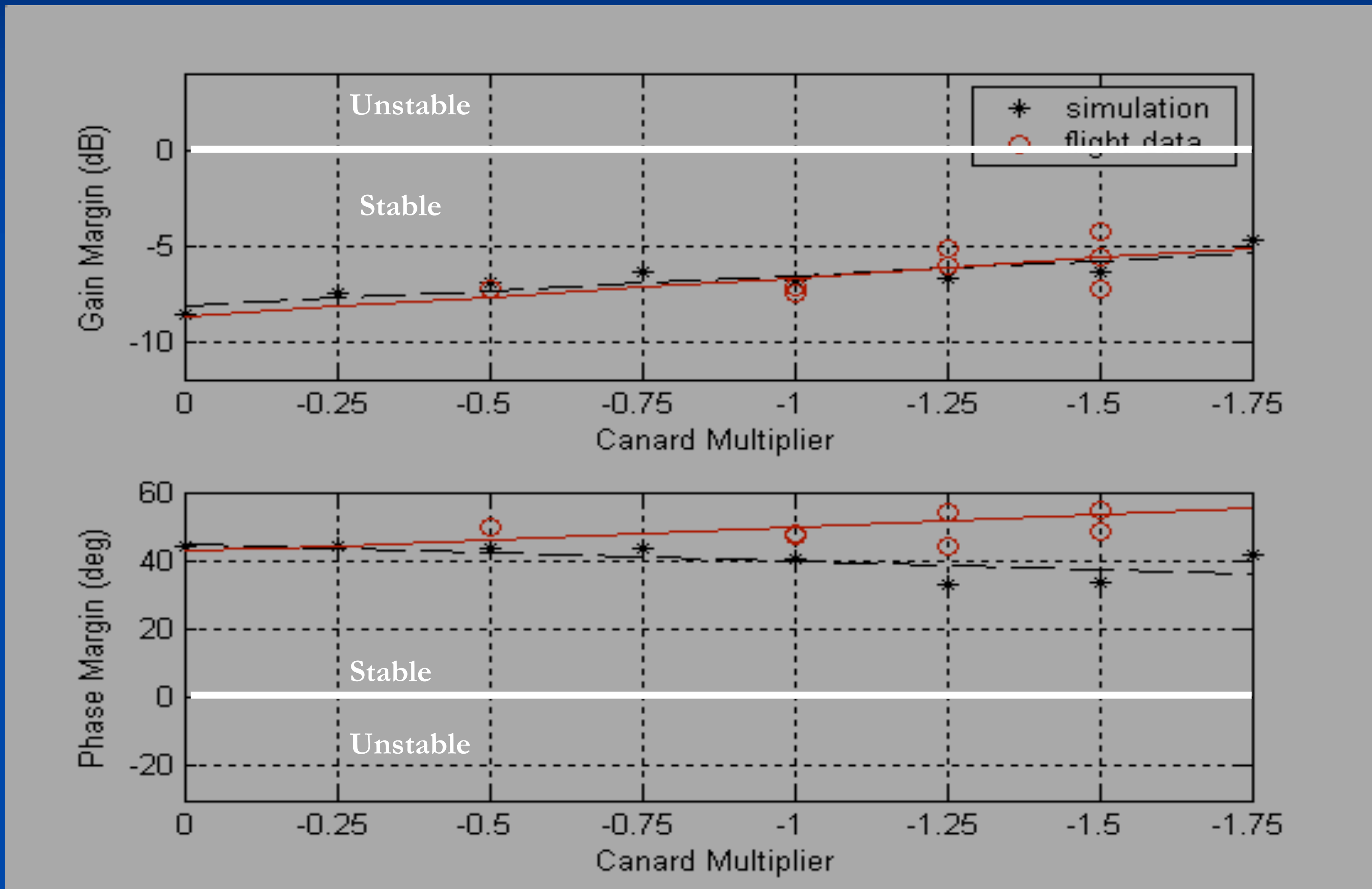
F-15 837 Flight Test – Consistent Stability Margins

- **Direct-Adaptive Flight Control System**
  - Two adverse conditions:
    - Symmetric Canard Response (A matrix)
    - Right Stabilator Lock (B matrix)
  - Two flight conditions:
    - 20K ft, M=0.75; 25K ft, M=0.90

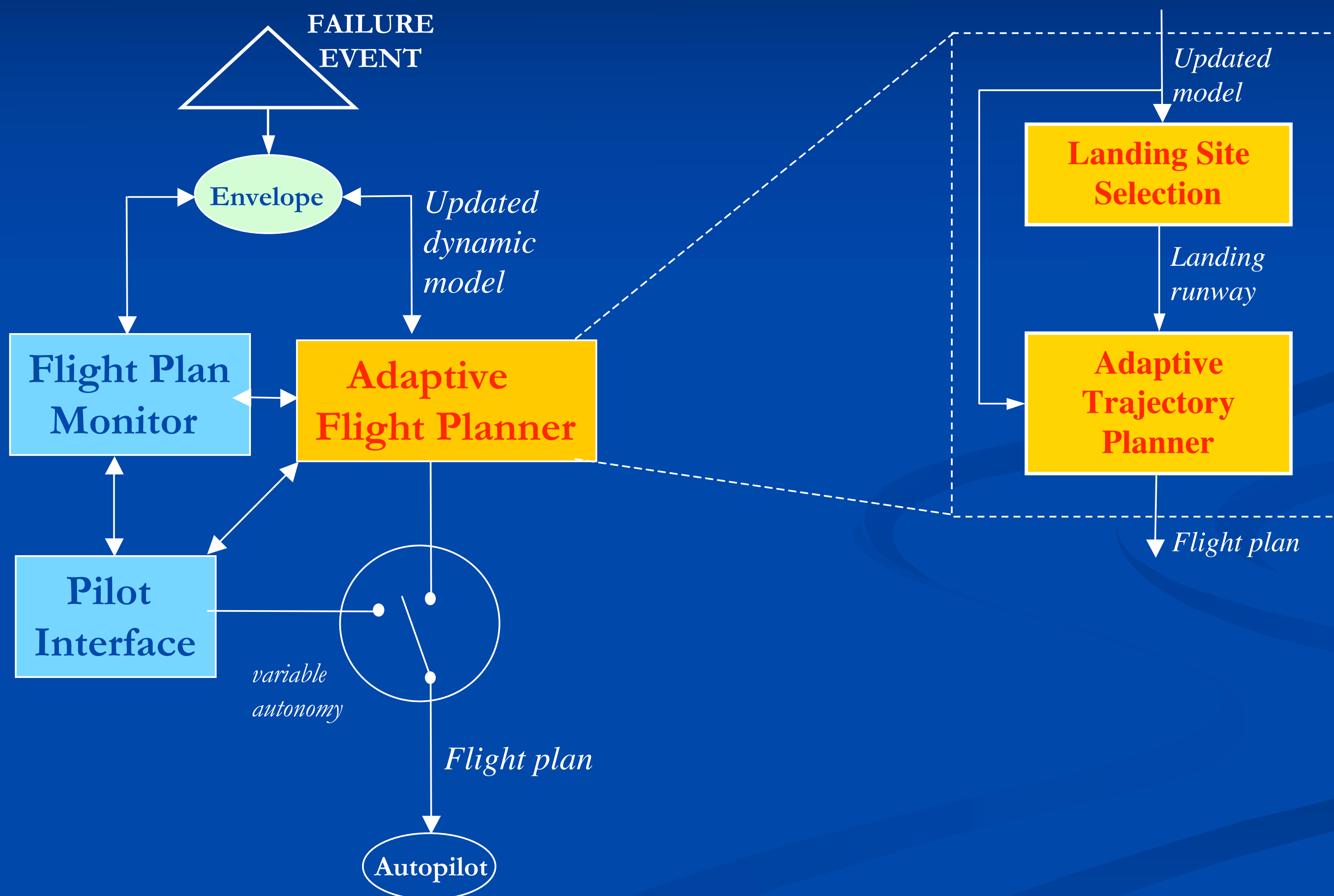
Stability Margin Trends
Symmetric Stab Loop, Adaptation Off



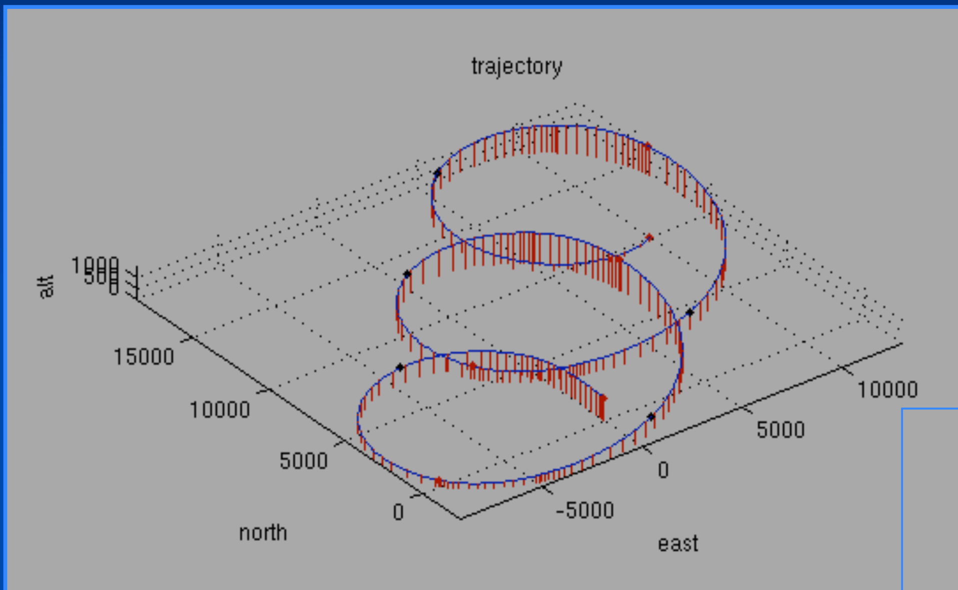
Stability Margin Trends
Symmetric Stab Loop, Adaptation ON



Flight Planning for Safe Landing

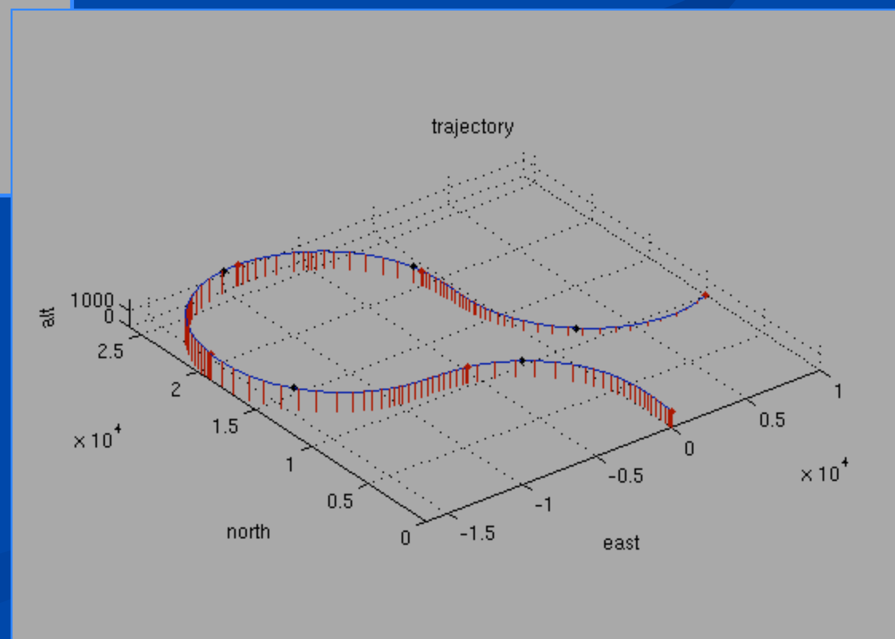


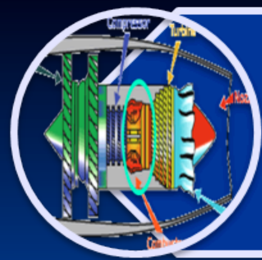
Case Study: 15° Rudder Jam



Restricted envelope

Expanded (less conservative) envelope





Engine Control

Lean Combustion Instability

Challenges:

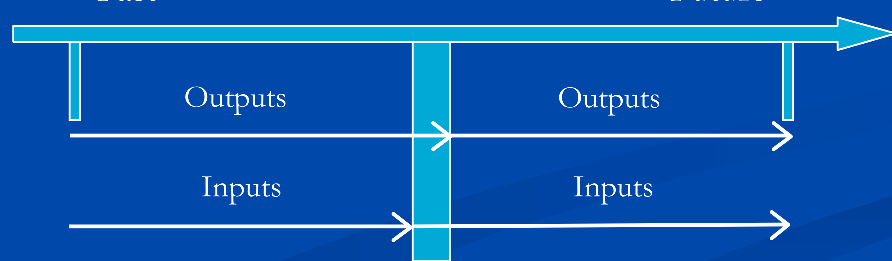
❖Only pressure and fuel flow measurements are available.

❖Inherently unstable and noisy system

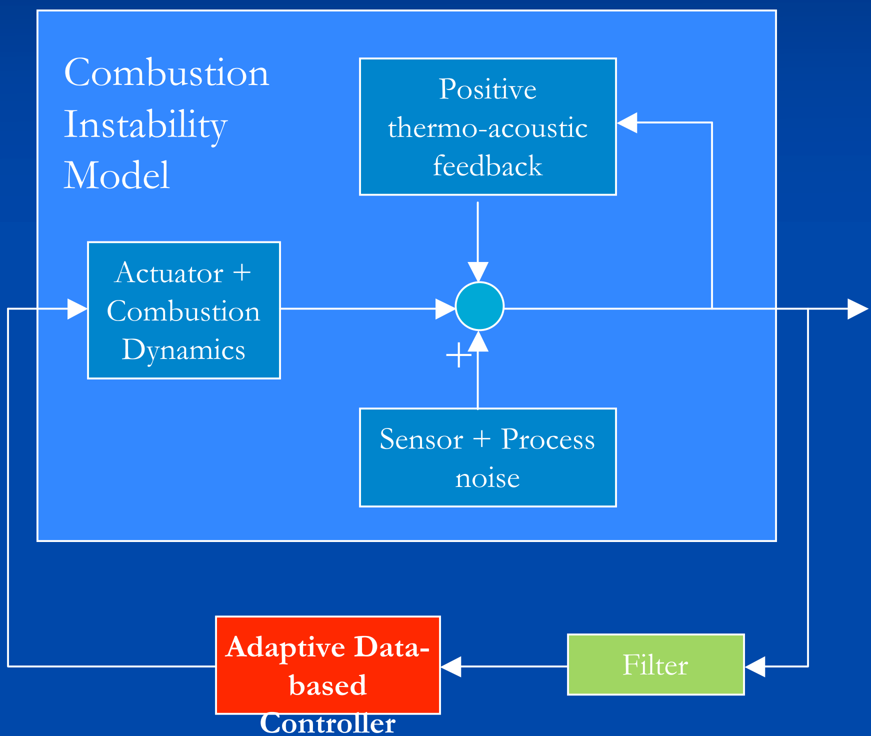
❖Adapt the controller across the envelope controlled operation

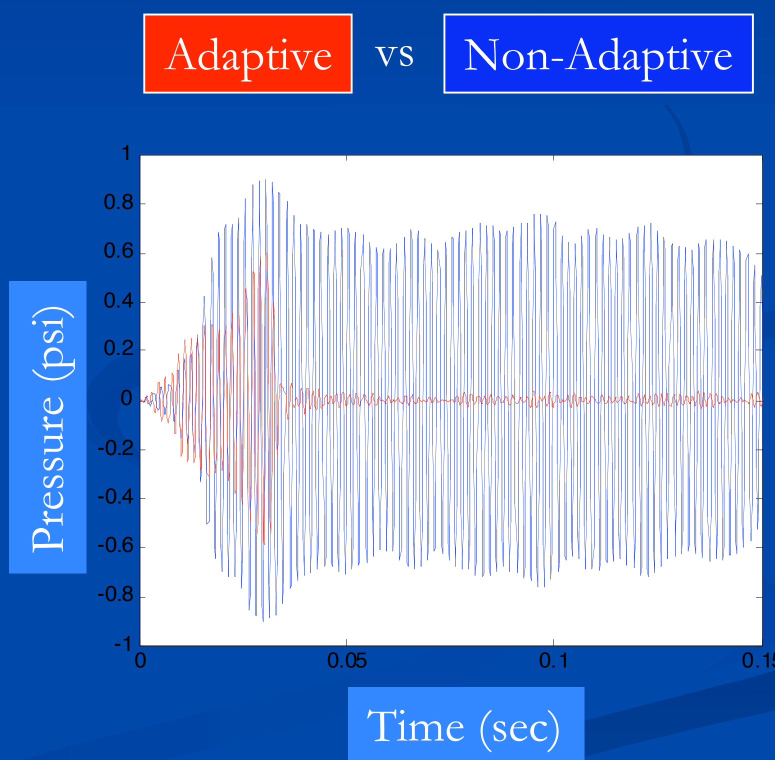
Intelligent control

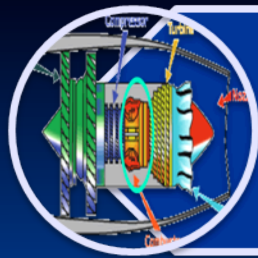
❖A theoretically grounded **data-based optimal control** design that is insensitive to disturbances and noise



Next Gen Combustion Control – Direct Adaptive Control





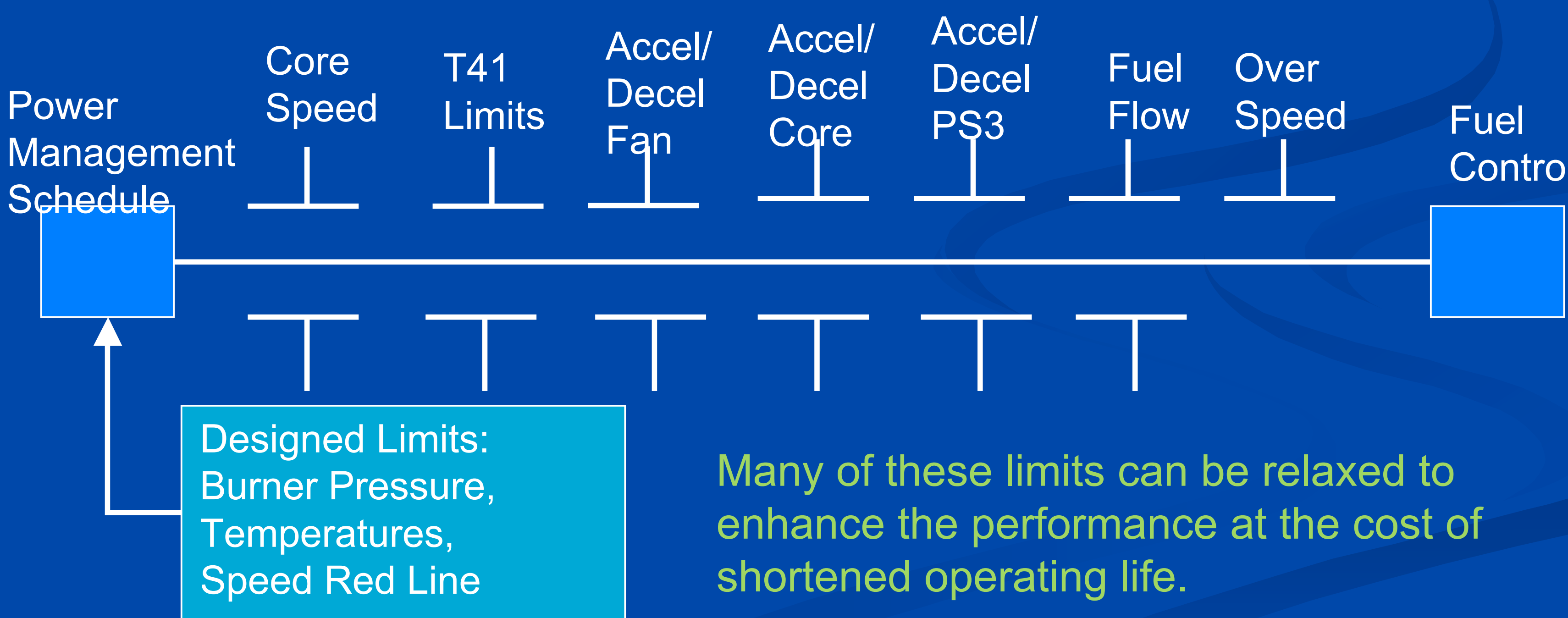


Engine Control

Integrated Flight Propulsion Control

Green designs will require engines to better integrate with the flight control system

- Respond faster
- Generate more thrust for short periods of time

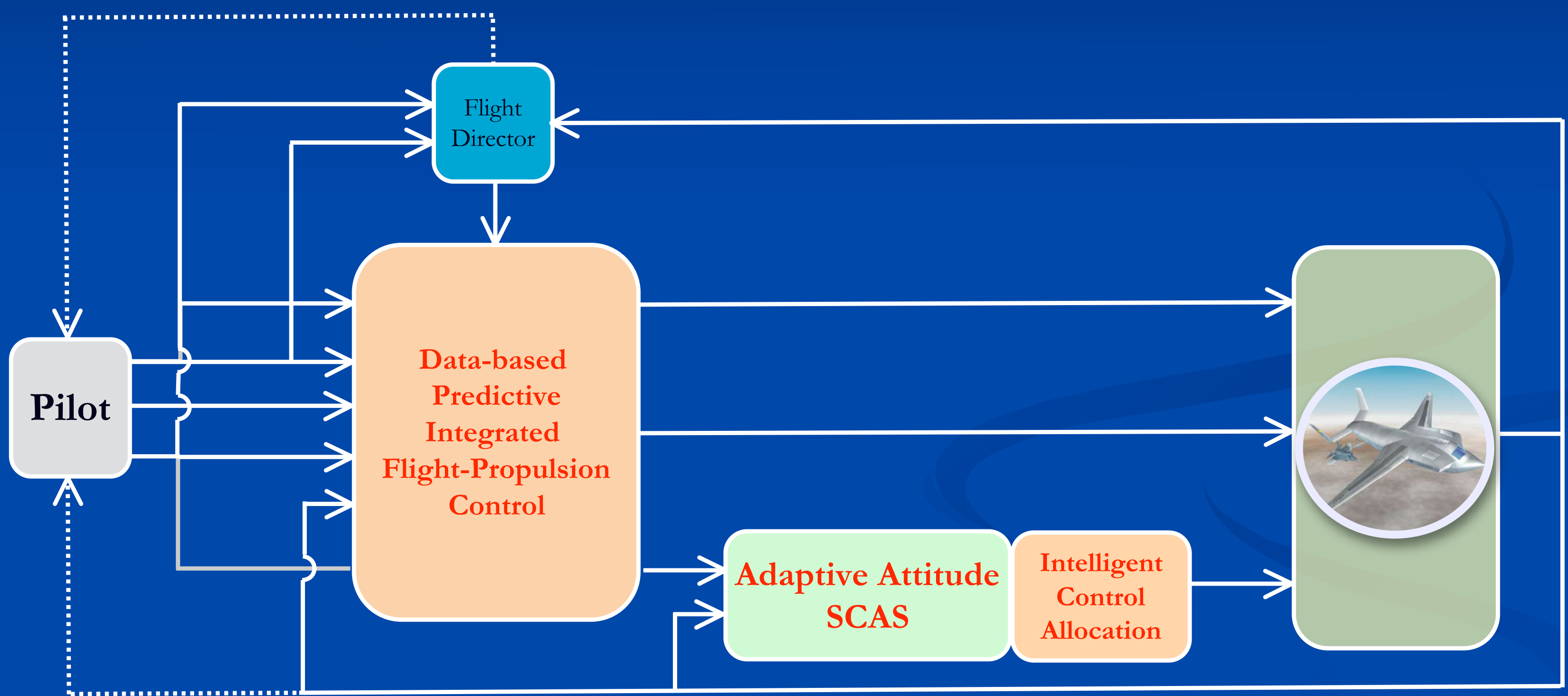


Many of these limits can be relaxed to enhance the performance at the cost of shortened operating life.

CESTOL Intelligent Control

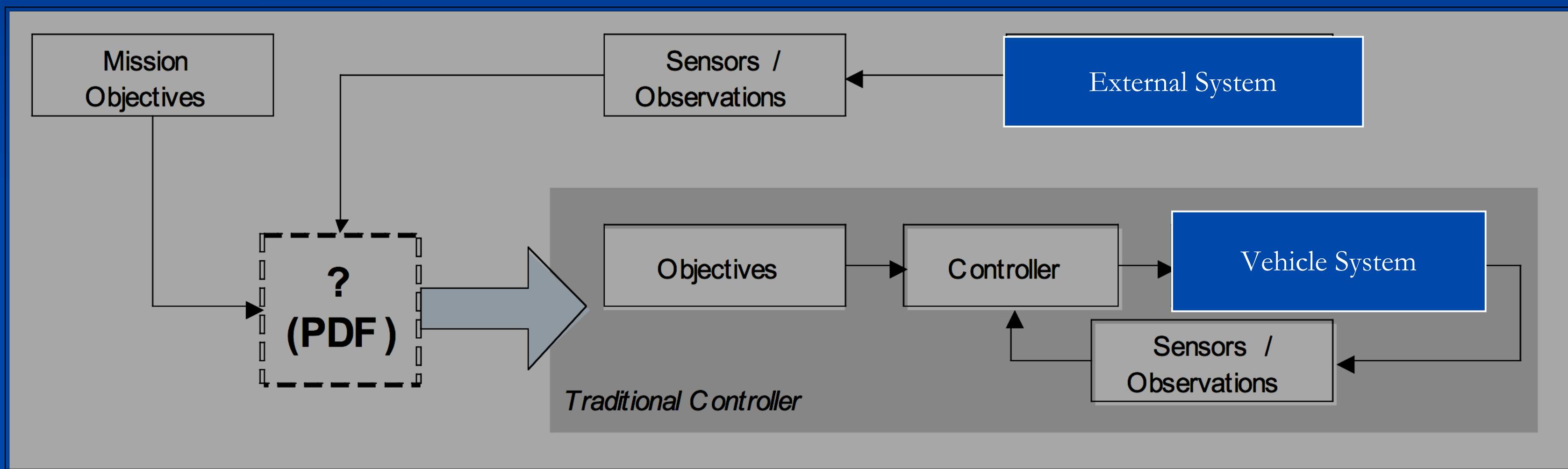
- CESTOL technology challenges
  - Engine/aero-dynamic coupling
  - Control redundancy and non-linear coupling
  - Control saturation
- Engine-out condition is a critical point of failure
- Extended flight envelope
- Transition to/from flight on the backside region of the airspeed vs. power-required curve
  - Unconventional flight path angle and angle of attack on approach

CESTOL
Intelligent Control Architecture



Payload-directed flight

- Direct control loop closure around payload sensors.



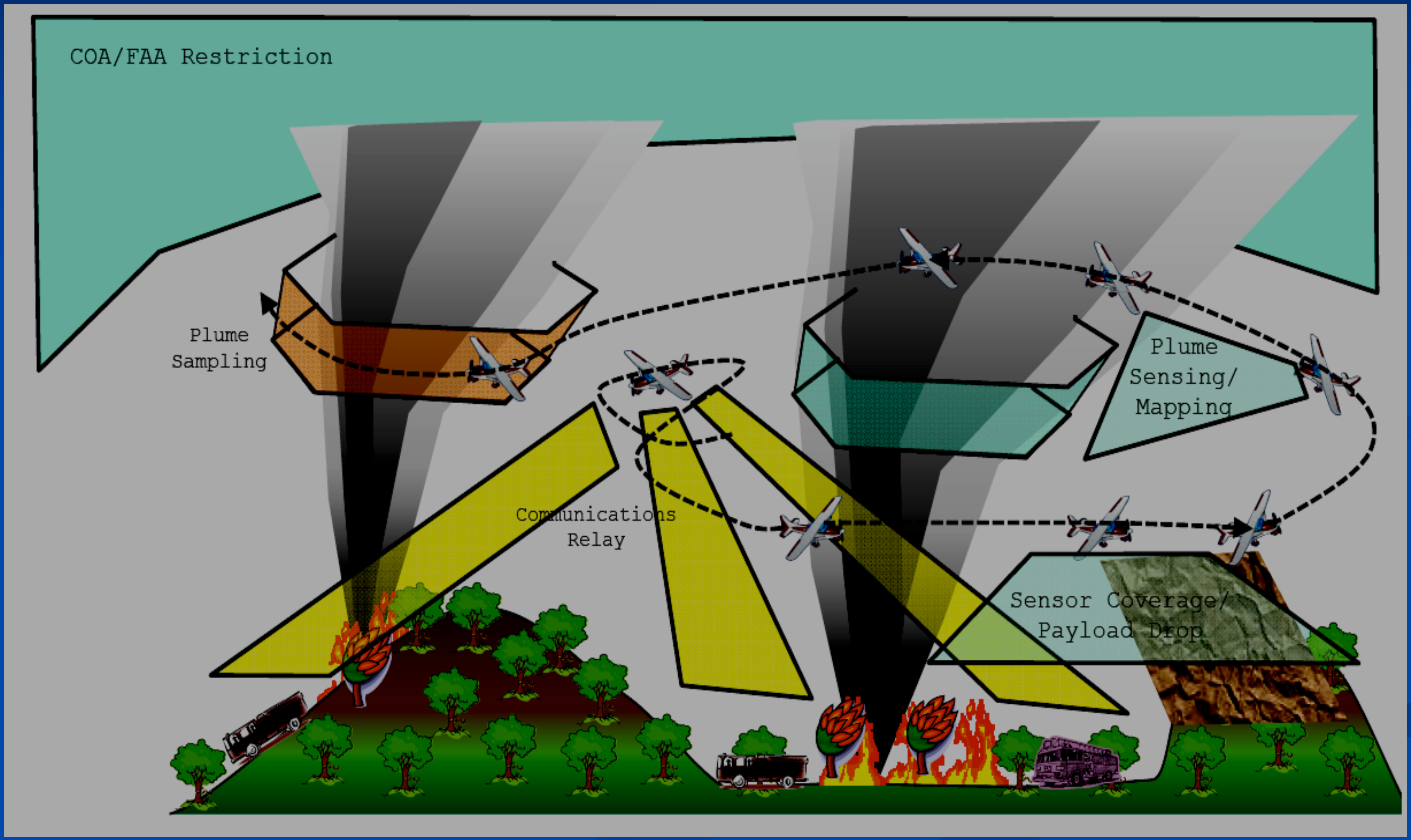
Science Applications

- Atmospheric and ocean Monitoring
- Fire monitoring

Airspace applications

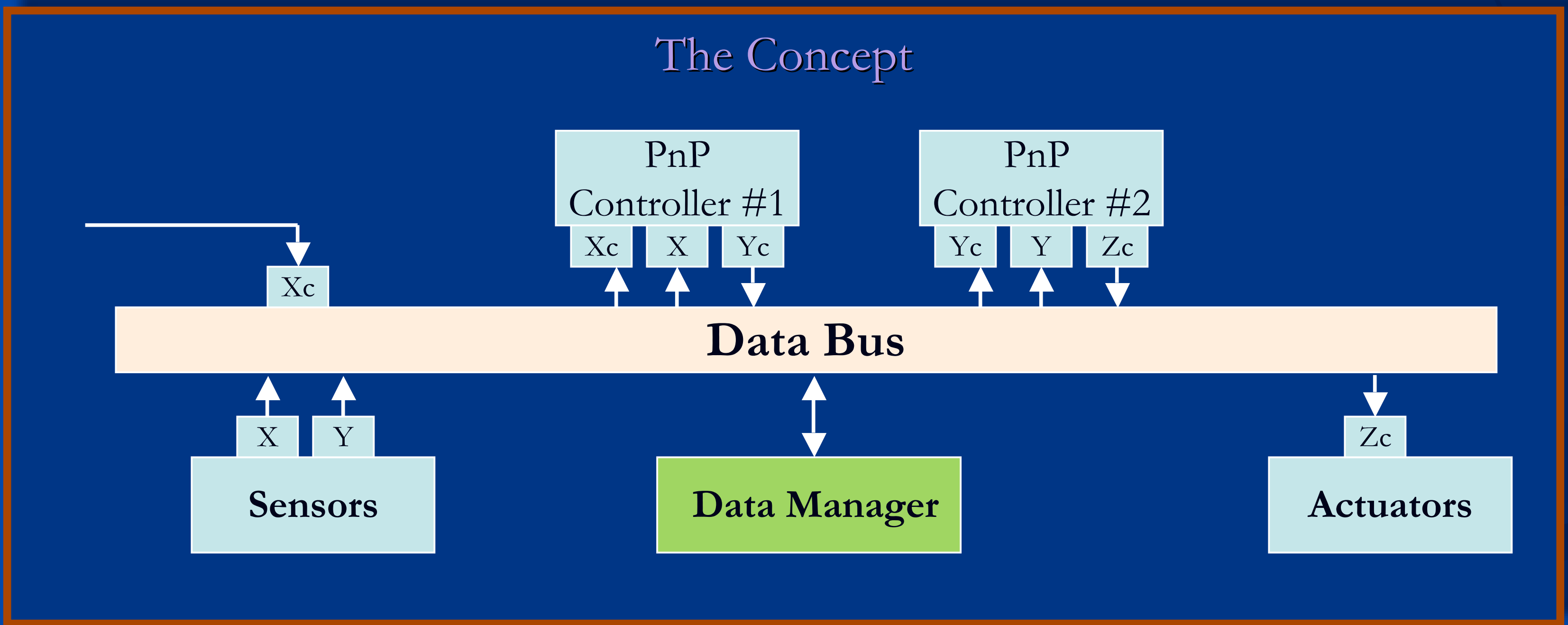
- Formation flight
- Autonomy for unmanned cargo A/C

Example Mission

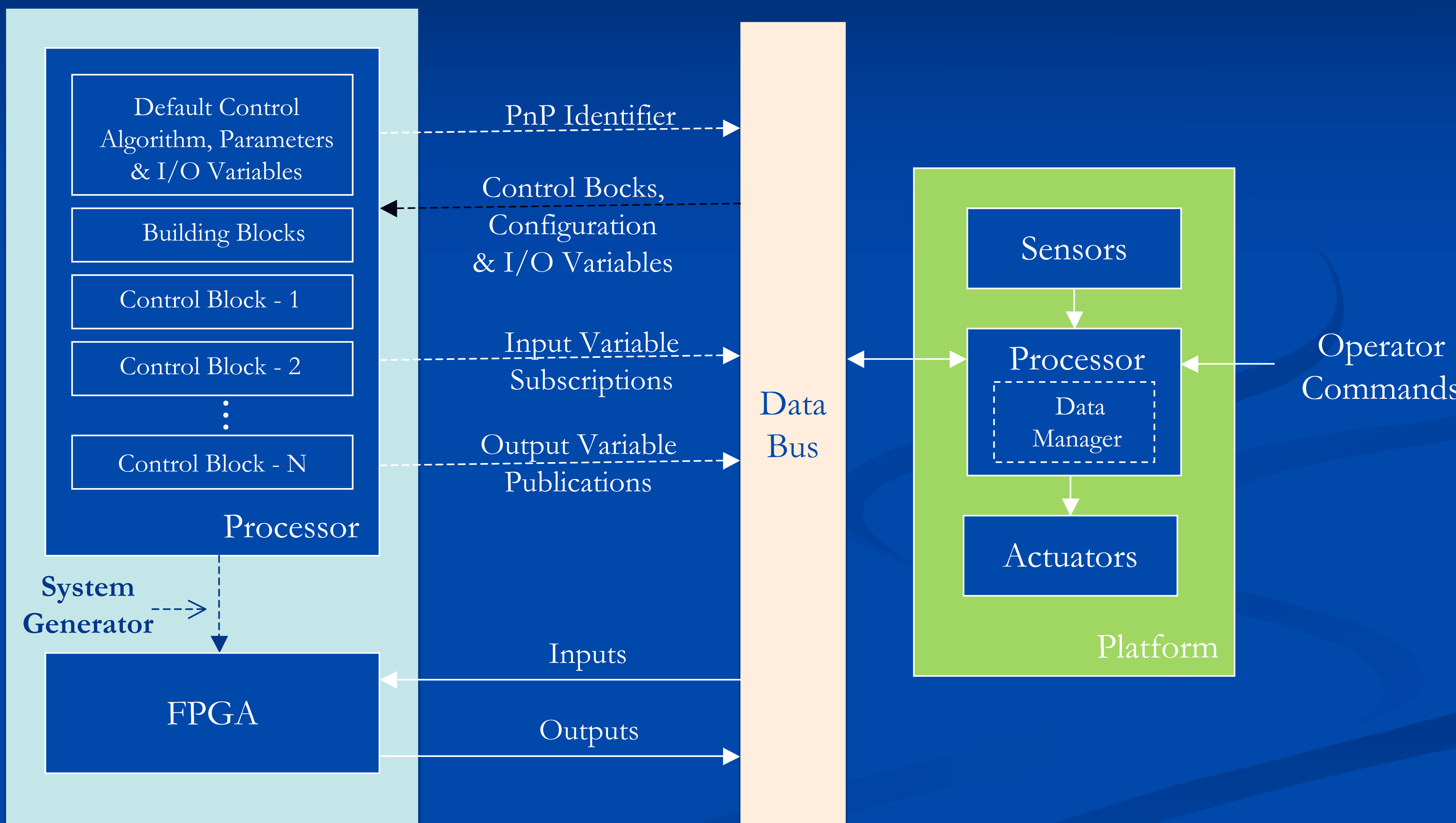


Intelligent Plug and Play Avionics (*iPnP*)

iPnP refers to the ability of the avionics system to automatically configure plugged components for functional reuse.

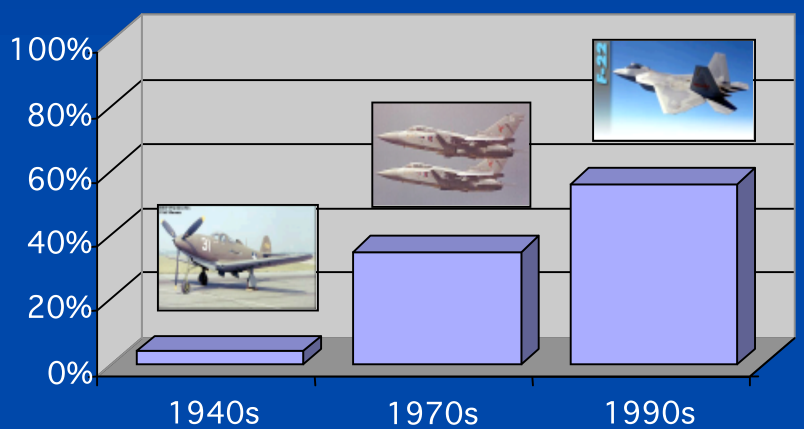


iPnP Architecture Concept



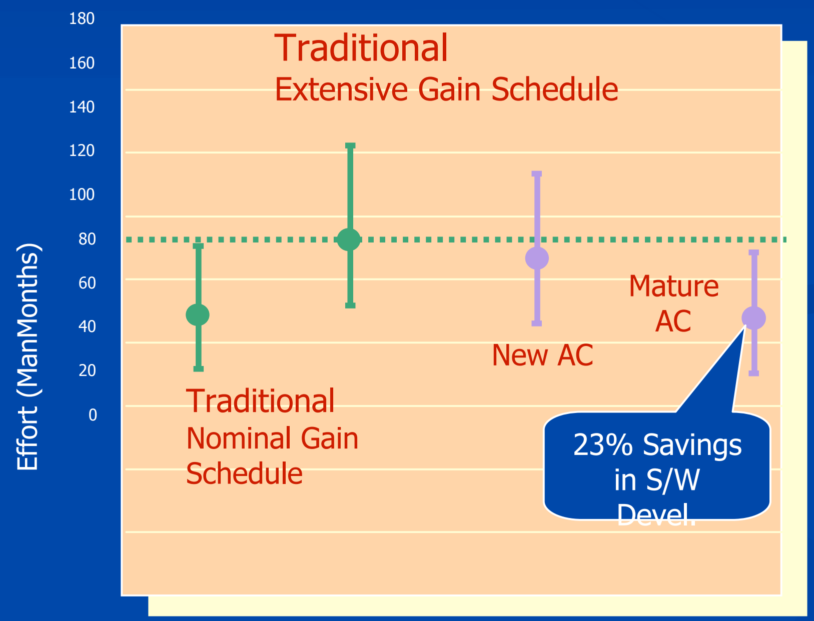
Benefits of *iPnP*

Avionics cost growth



Avionics Cost Example from Aeronautics (% Total)

Modular and reusable Avionics will reduce the cost



Reusable hardware will reduce software dependency

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- Better
  - Performance (real-time optimization)
  - Payload-directed
  - Integrated flight and propulsion control
- Safer
  - Uncertainty handling
  - Consistent handling qualities
  - Reduce Pilot workload
- For Less
  - System modeling -Physics Vs Data
  - Reusable, plug and play controllers
  - Analytical redundancy