Development and Testing of Control Laws for the Active Aeroelastic Wing Program

Aerospace Control and Guidance
Systems Committee
Harbour Town Resorts
Hilton Head, South Carolina
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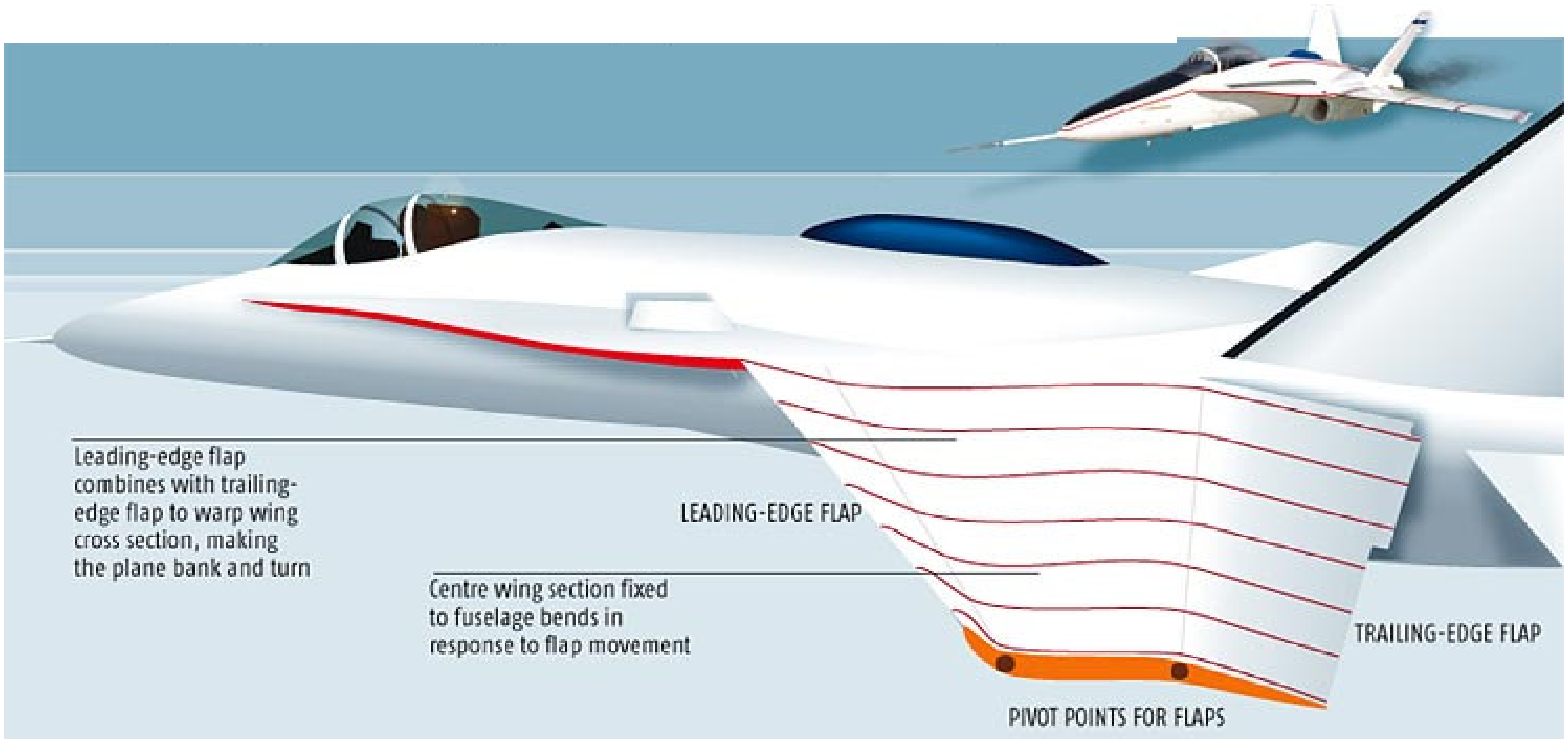
NASA DFRC

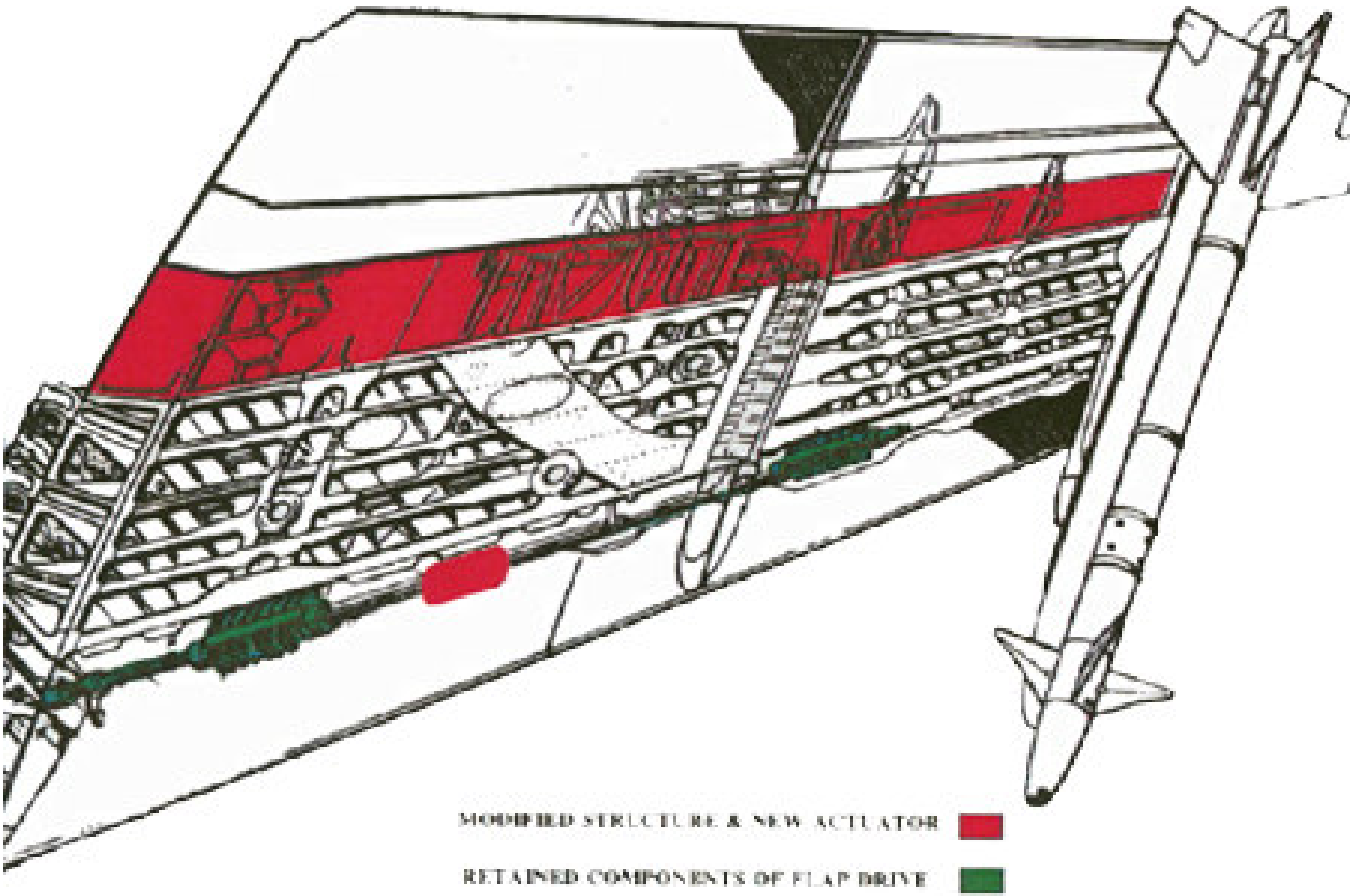
AAW Concept

Multiple leading and trailing edge control surfaces are optimally used to deform a lighter more flexible wing to achieve maneuver performance, load control, and drag or signature reduction objectives.

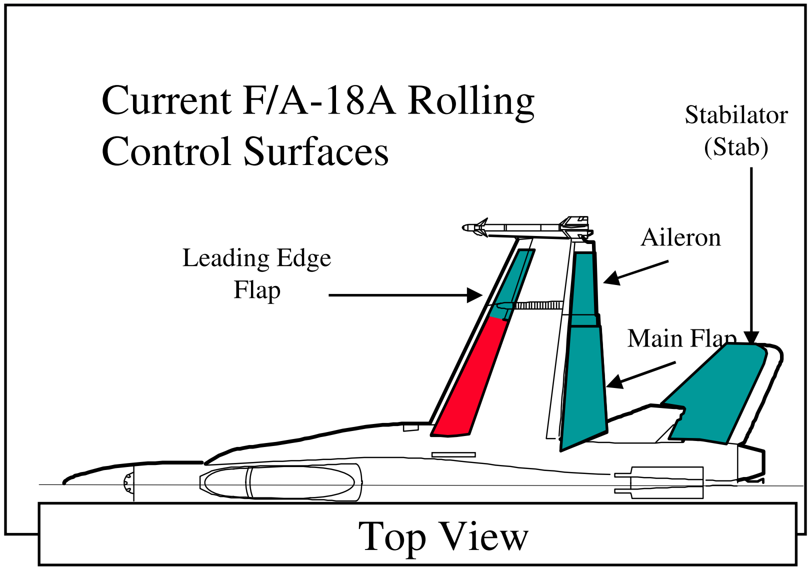


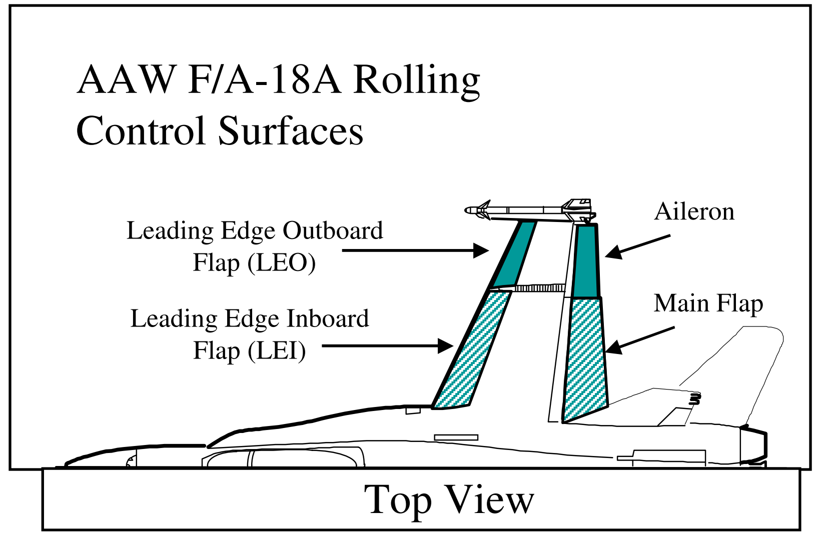
AAW MAKES THE ENTIRE WING A CONTROL SURFACE

Wing Modifications



AAW Control Surfaces for Aircraft Control



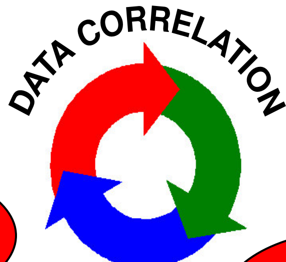


New Leading Edge Flap Drive Actuator allows the inboard and outboard leading edge flaps to be driven independently.

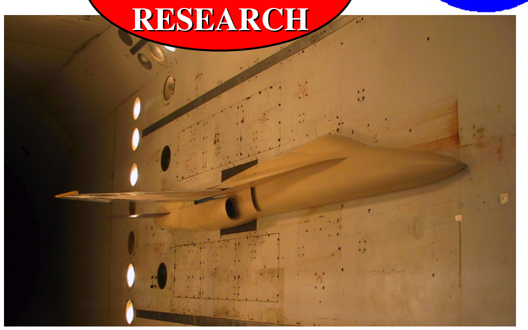
AAW Program Objectives and Approach

- *Validate AAW through full scale flight demonstration*
- *Develop AAW design guidance and methodology validation*

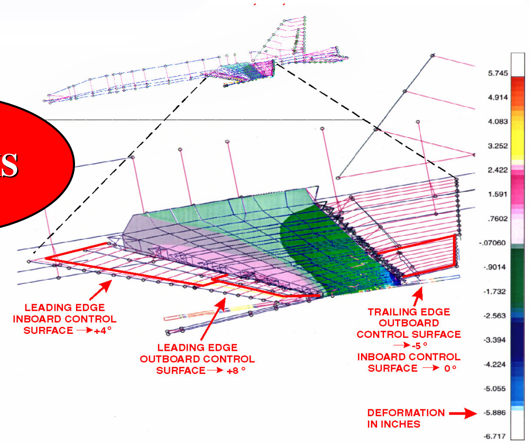
FLIGHT RESEARCH

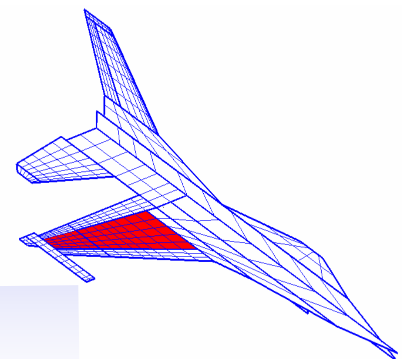


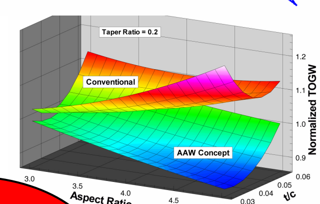
WIND TUNNEL RESEARCH



ANALYSIS







PARAMETRIC DESIGN STUDIES

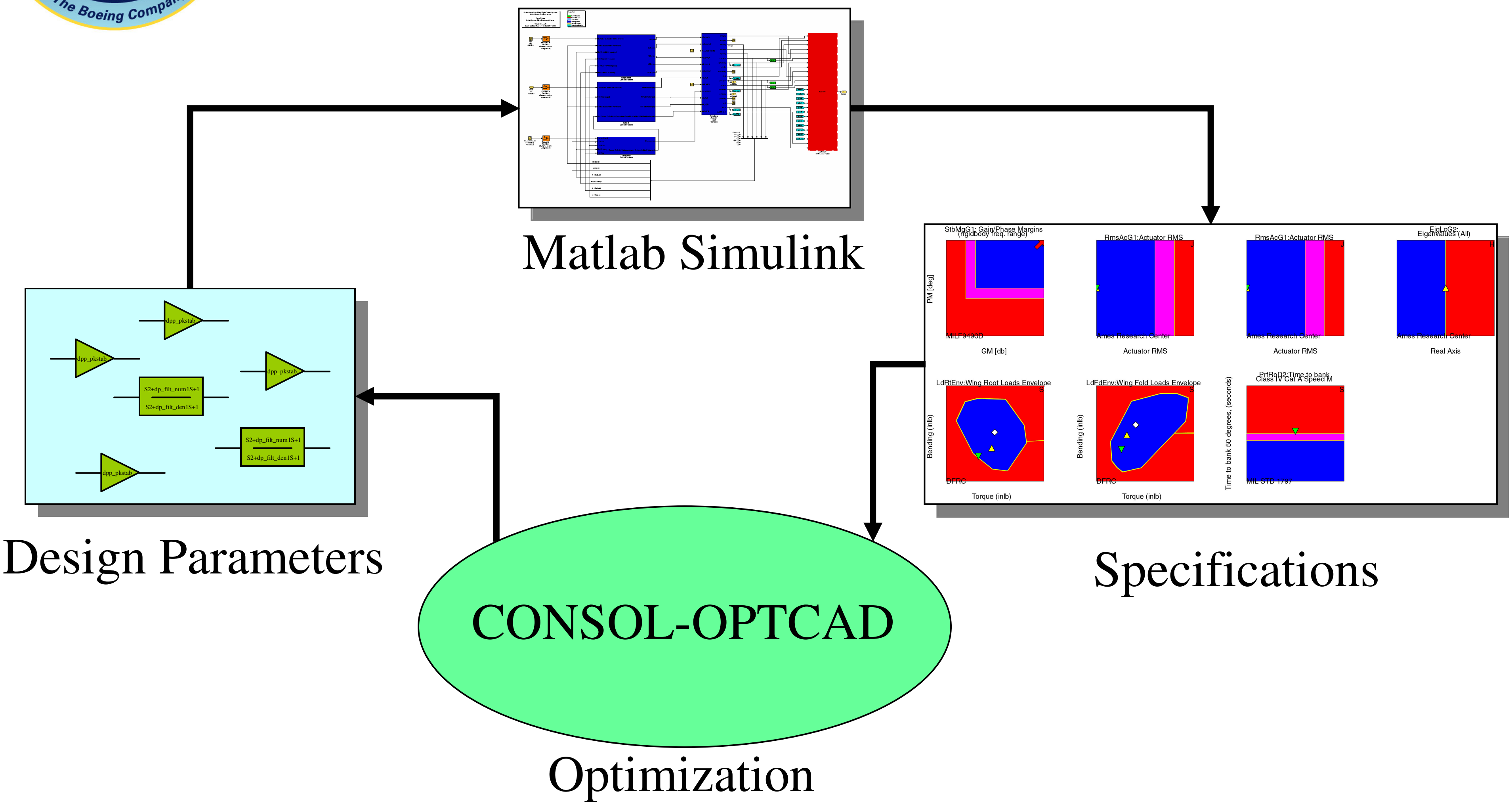
NASA Dryden Design Goals

- Maximize roll performance
- Maintain structural loads within design limits
- Maintain acceptable handling qualities
- Roll the aircraft using wing twist (where applicable)

Presentation Outline

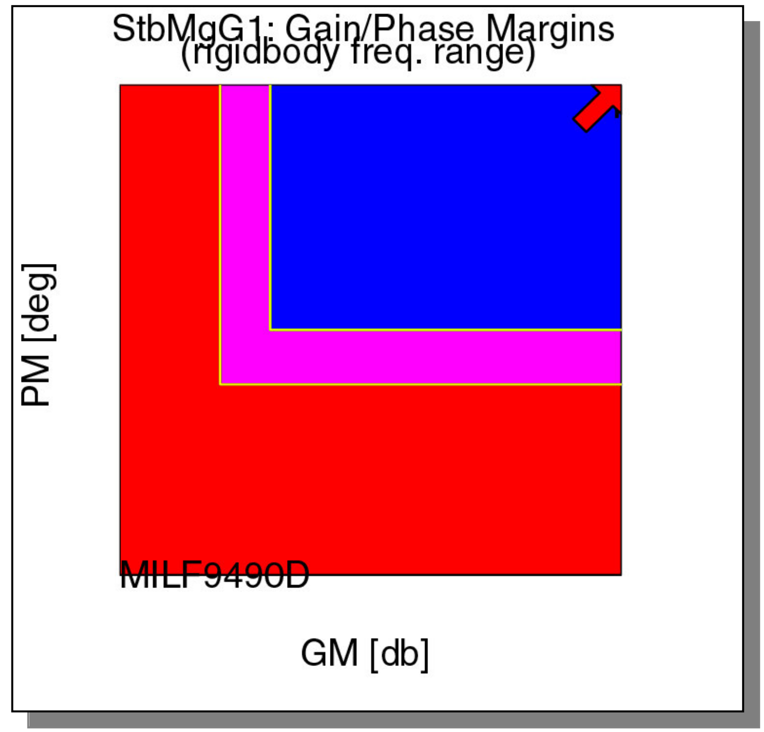
- ➢ Design Tool Overview: CONDUIT
- Control System Description
  - Longitudinal
  - Lateral
- AAW CONDUIT Specifics
  - Loads Model / Loads Specifications
  - Nonlinear Simulation
  - Optimizing CONDUIT
- Design Strategy
  - Twist Regions
  - Longitudinal Design
  - Lateral Design
- Results

CONDUIT Overview



CONDUIT Specifications

- Specification Types
  - Time history
  - Frequency domain
- Evaluation
  - Level 1,2,3
- Constraint Types
  - Hard
  - Soft
  - Objective
  - Summed Objective
  - Check Only



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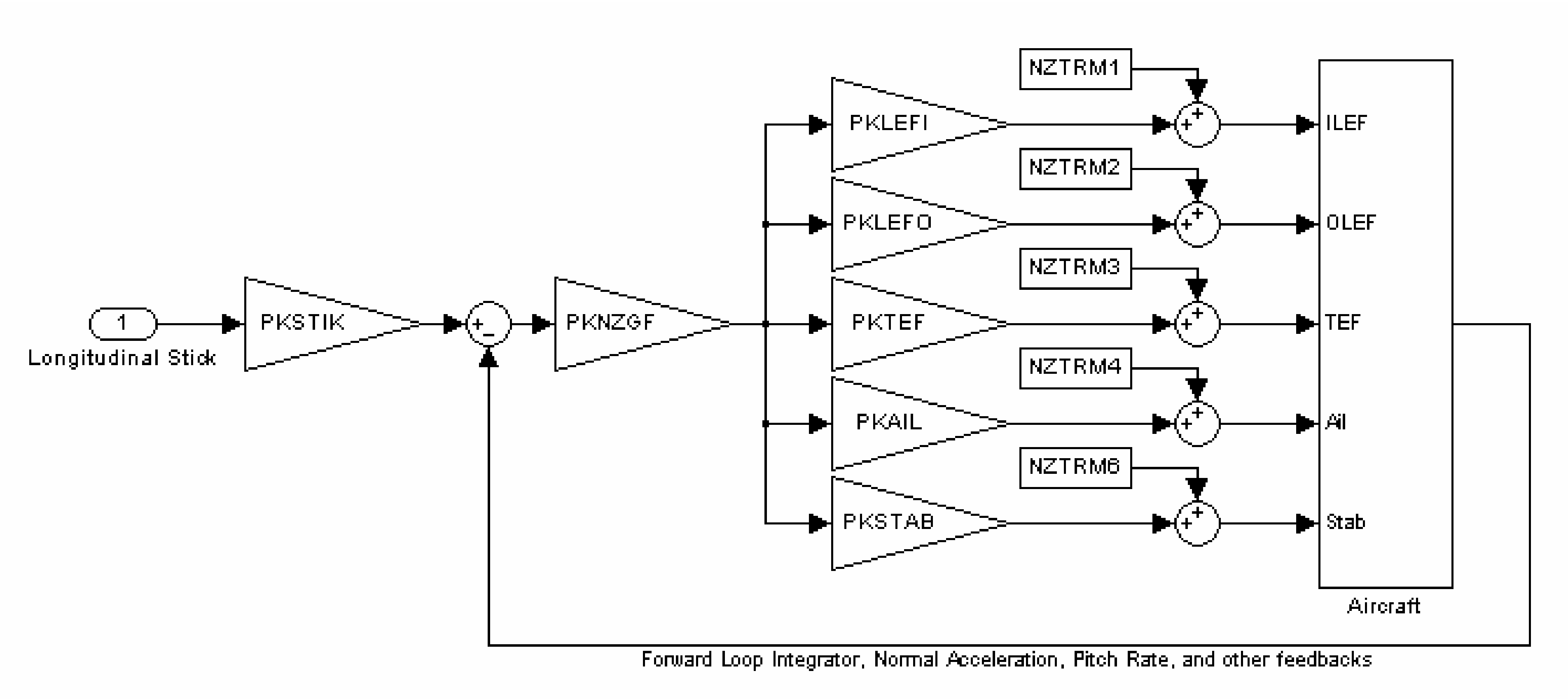
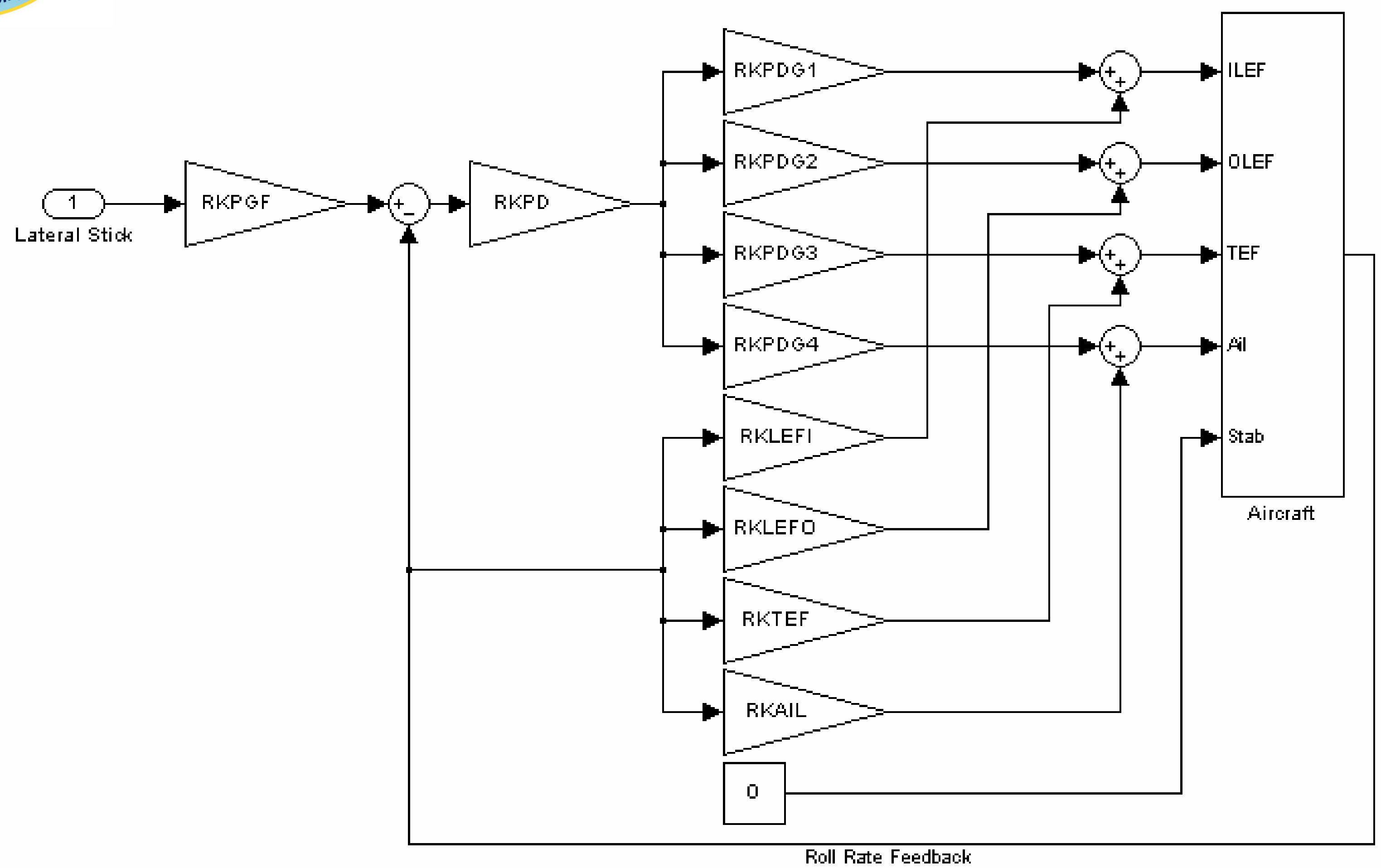
Longitudinal Controller



- Constrained to use Boeing Architecture

Lateral Controller



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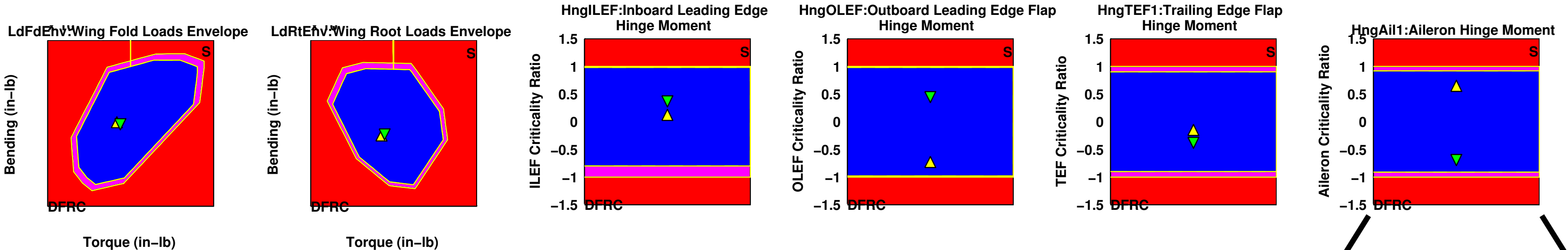
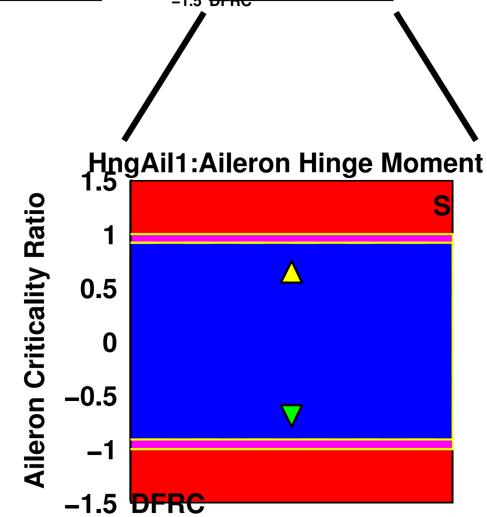
Loads Model

- Mathematical model identified using Phase I flight data
- 15 Aircraft states and surface deflections as inputs
- Predicts wing loads
  - Wing root / fold bending and torsion
  - Wing control surface hinge moments
- Incorporated into Matlab for use with CONDUIT

Load Specifications





- Wing Fold/Root Torsion and Bending
- Hinge Moments
  - ILEF
  - OLEF
  - TEF
  - Aileron
- Level 2 borders at 100% design limit
- Level 1 borders based on loads model uncertainties

Nonlinear Simulation Incorporation Into CONDUIT

- NASA AAW F/A-18 nonlinear simulation
  - Increased fidelity
  - Flight software used in design
  - Simulation run times comparable to Simulink
    - Faster execution time
    - Additional trim requirement
- Replaced Simulink time history simulations
- Simulink model used for linear analysis
  - Validated against RFCS flight code

Optimizing CONDUIT

- 32 time history simulations required for each evaluation of the AAW system
- Only 2 unique time histories
- Specifications always executed in order
- Modification of AAW CONDUIT Problem
  – First instance of each unique time history specification was modified to save data
  – Specifications to follow use saved data instead of rerunning time histories
  – 15 times improvement in run time for each evaluation
  – Hundreds of evaluations sometimes required for a complete optimization

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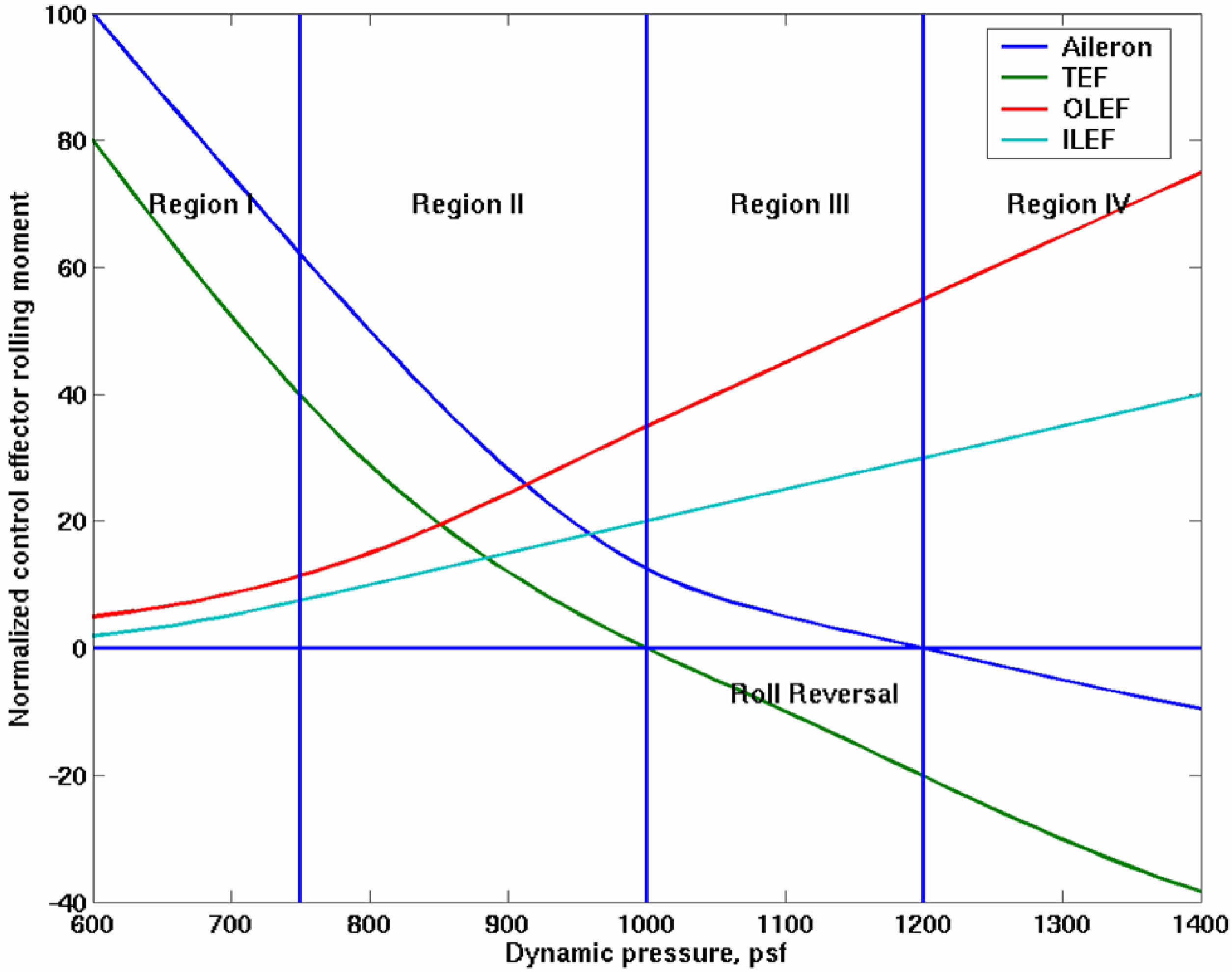
Control Effectiveness Regions



Longitudinal Design

- Requirements
  - Maintain loads within limits
  - Good handling qualities
  - Adequate pitch authority for planned maneuvers
- Design
  - Standard F/A-18 controller desired
  - Surface deflections measured at various G levels
  - Longitudinal gains set to mimic the F/A-18 longitudinal controller using Phase I WUT data
  - Worked surprisingly well
    - Matched standard F/A-18 control surface deflections
    - Exception: Allowed for negative collective LEF deflections

Lateral Design

- Design Goals
  - Maximize roll performance
  - Maintain structural loads within design limits
  - Maintain acceptable handling qualities
  - Roll the aircraft using wing twist (where applicable)

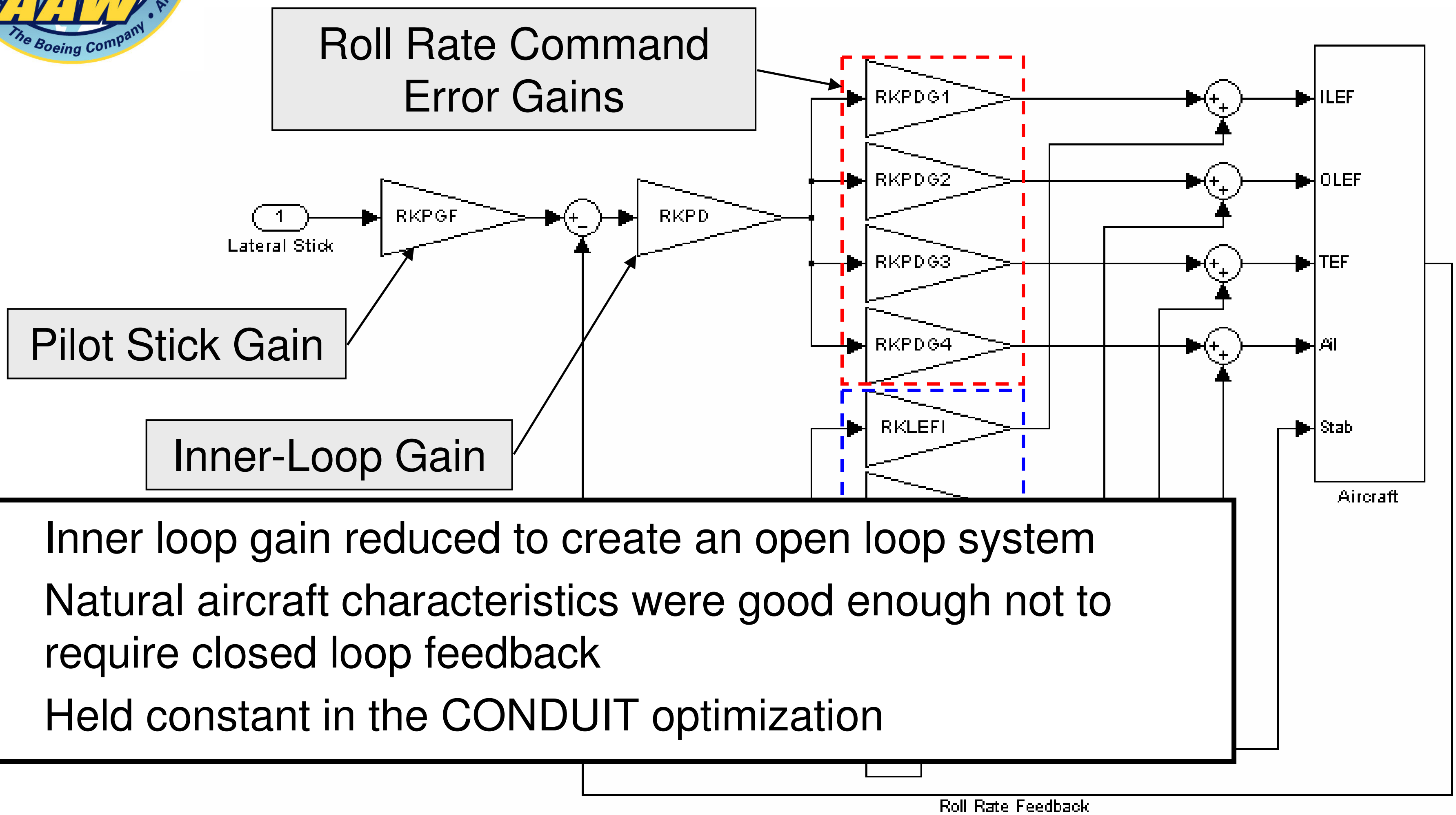
Final CONDUIT Specifications

Requirement	Constraint
Eigenvalues	Hard
Gain/Phase Margins	Hard
RFCS Engage Enforcement	Hard
Wing Fold/Root Loads	Soft
Control Surface Hinge Moments	Soft
Rolling Sideslip Excursions	Soft
Roll Rate Oscillations	Soft
Pilot Lateral Acceleration	Soft
Maximization of Roll Rate	Sum. Obj.
Time to Bank	Sum. Obj.
Surface Deflections	Check Only

Requirement	Constraint
Sideslip Visualization	Check Only
Roll Mode Time Constant	Check Only
Roll Equivalent Delay	Check Only
Vertical Tail Loads	Check Only
Lateral-Directional PIO	Check Only
Roll Mode Time Constant on Stick Centering	Check Only
Roll Equivalent Delay on Stick Centering	Check Only

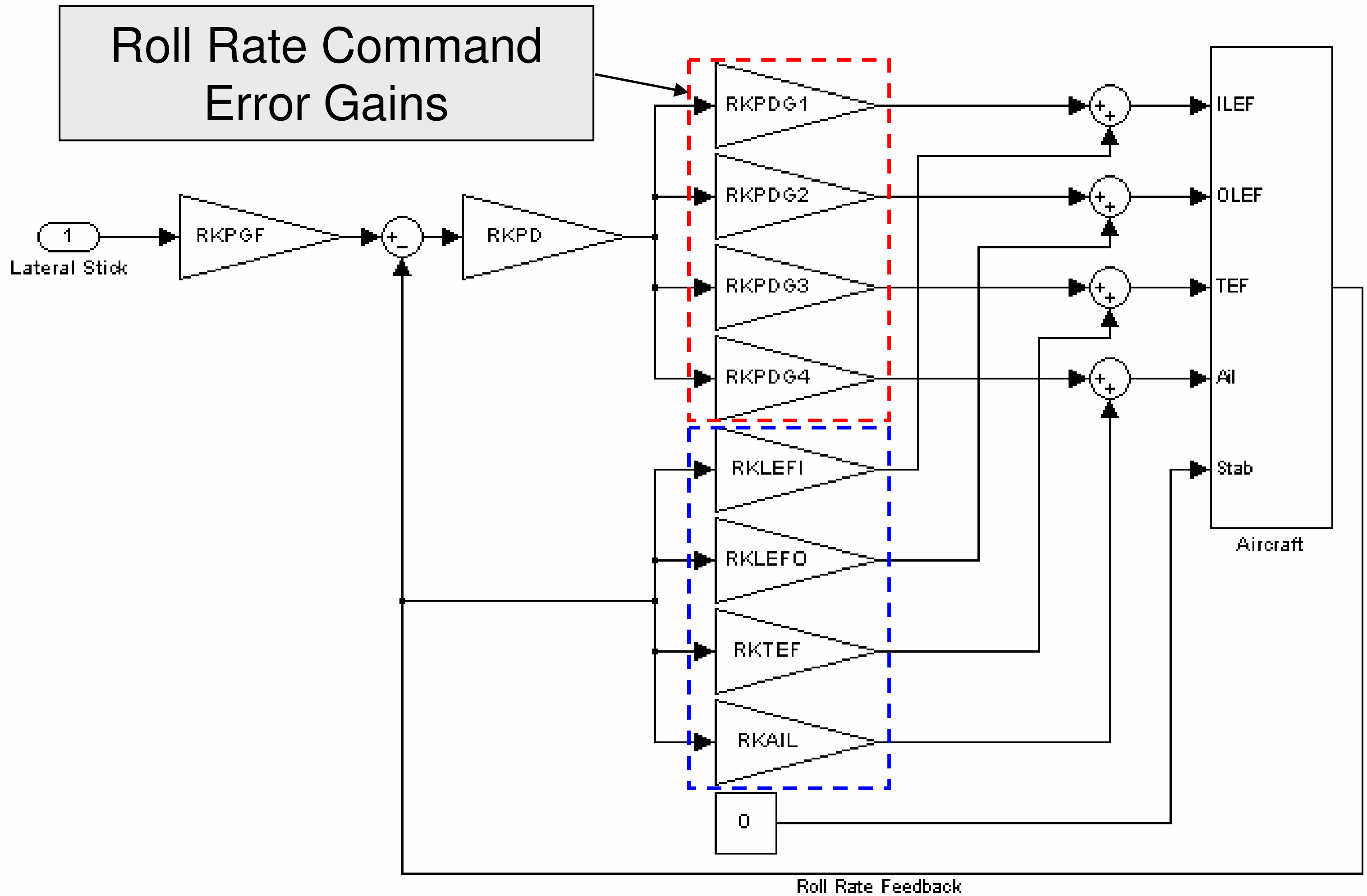
(Green text indicates specifications previously set as Soft constraints)

Lateral Controller Gains



- Inner loop gain reduced to create an open loop system
- Natural aircraft characteristics were good enough not to require closed loop feedback
- Held constant in the CONDUIT optimization

Lateral Controller Gains

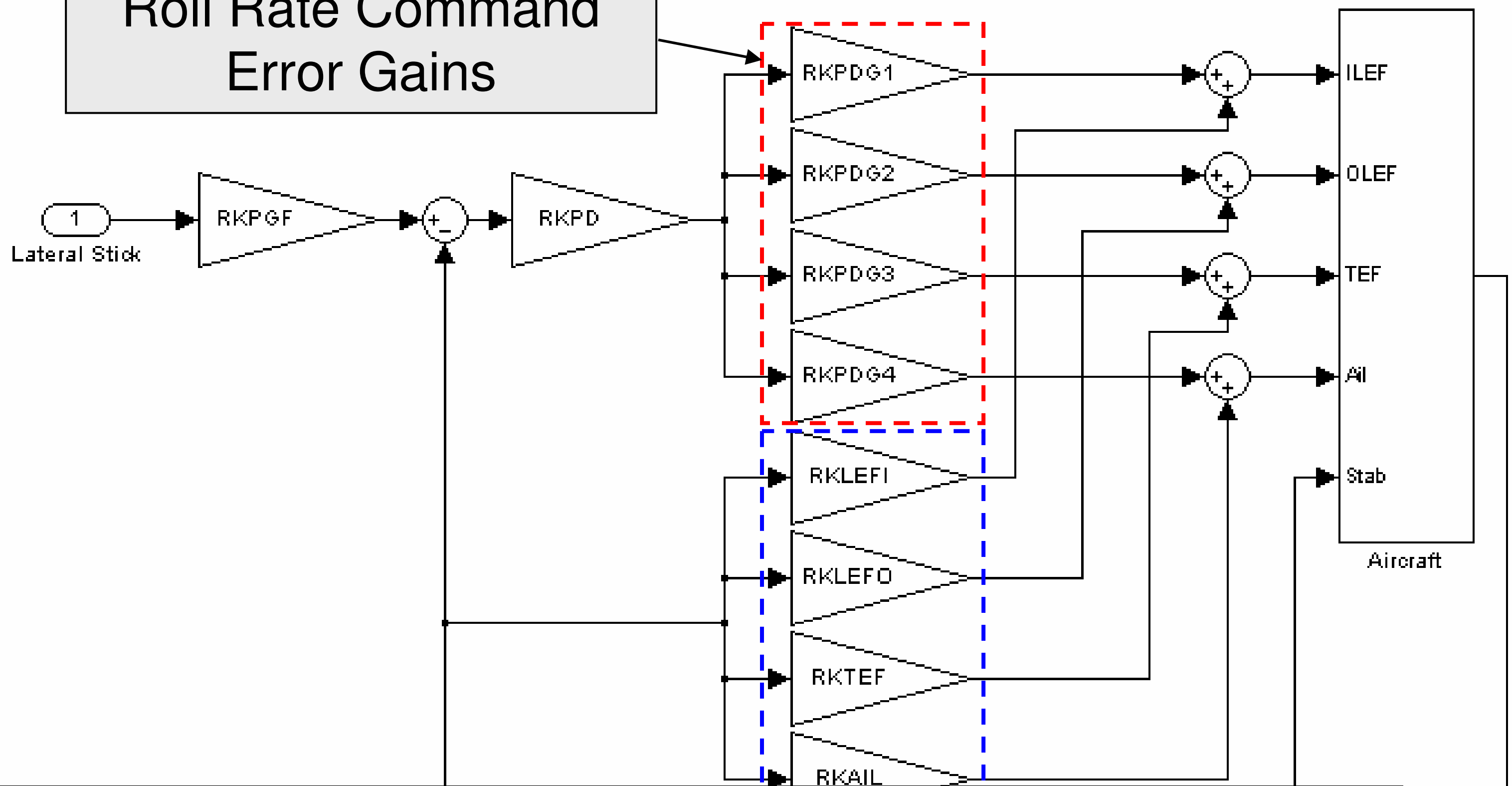


Rol

-
-
- held to zero in the CONDUIT optimization

Lateral Controller Gains

Roll Rate Command Error Gains



- Provided to CONDUIT for optimization
- Design was essentially a control allocation problem

CONDUIT Strategies

- CONDUIT unrestricted
  - CONDUIT optimizes four roll rate command error gains
  - Maximize roll rate
  - Minimize roll mode time constant
  - Loads constrained within design limits
- CONDUIT restricted to twist wing
  - Region II test points
  - Trailing edge surfaces held at zero
  - Artificially create a Region III test point to investigate wing twisting

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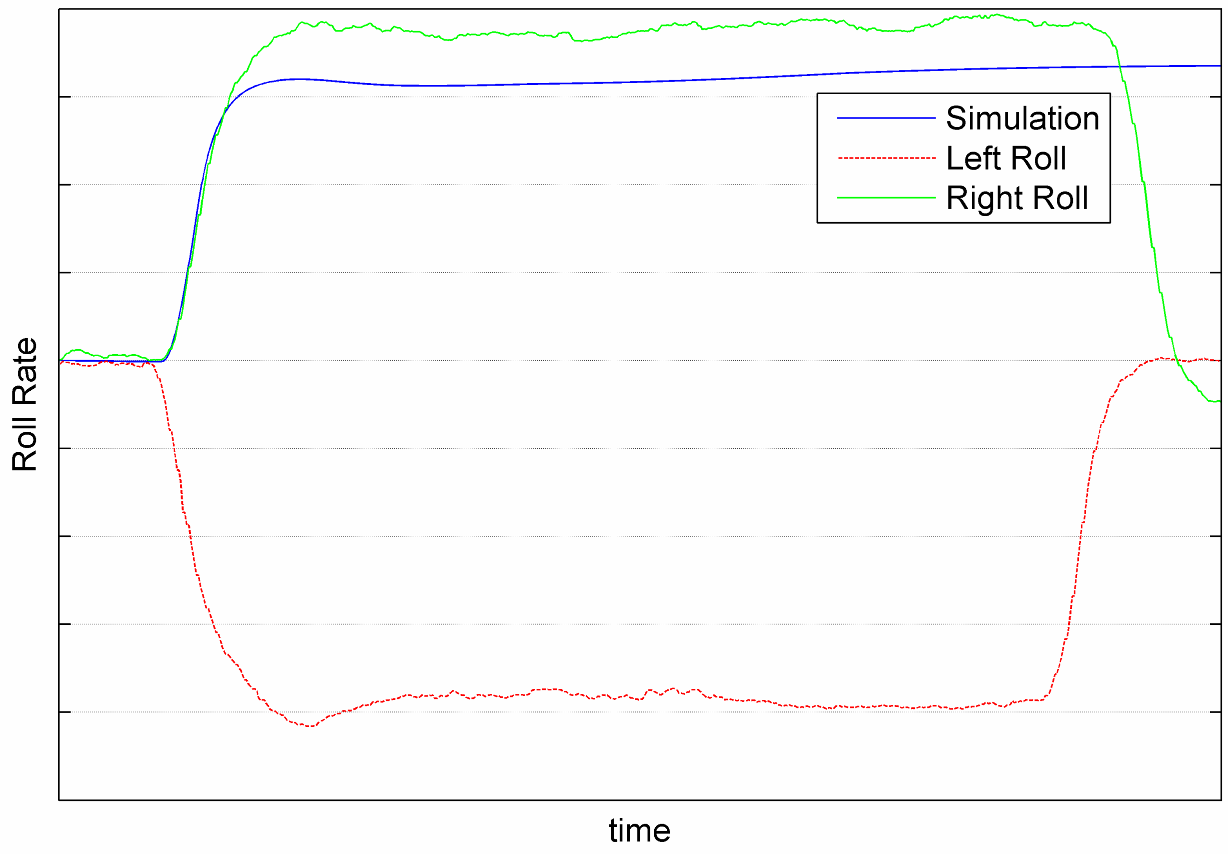
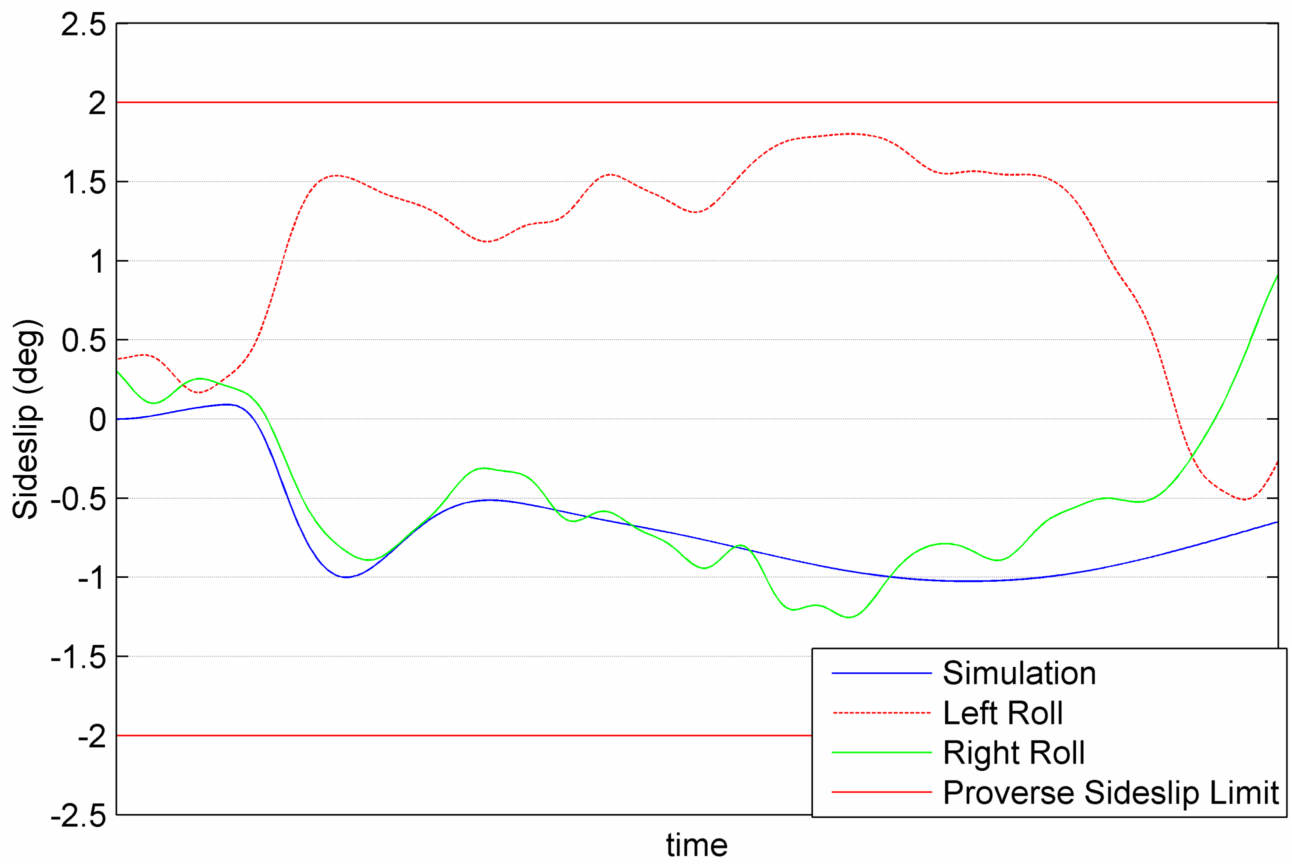
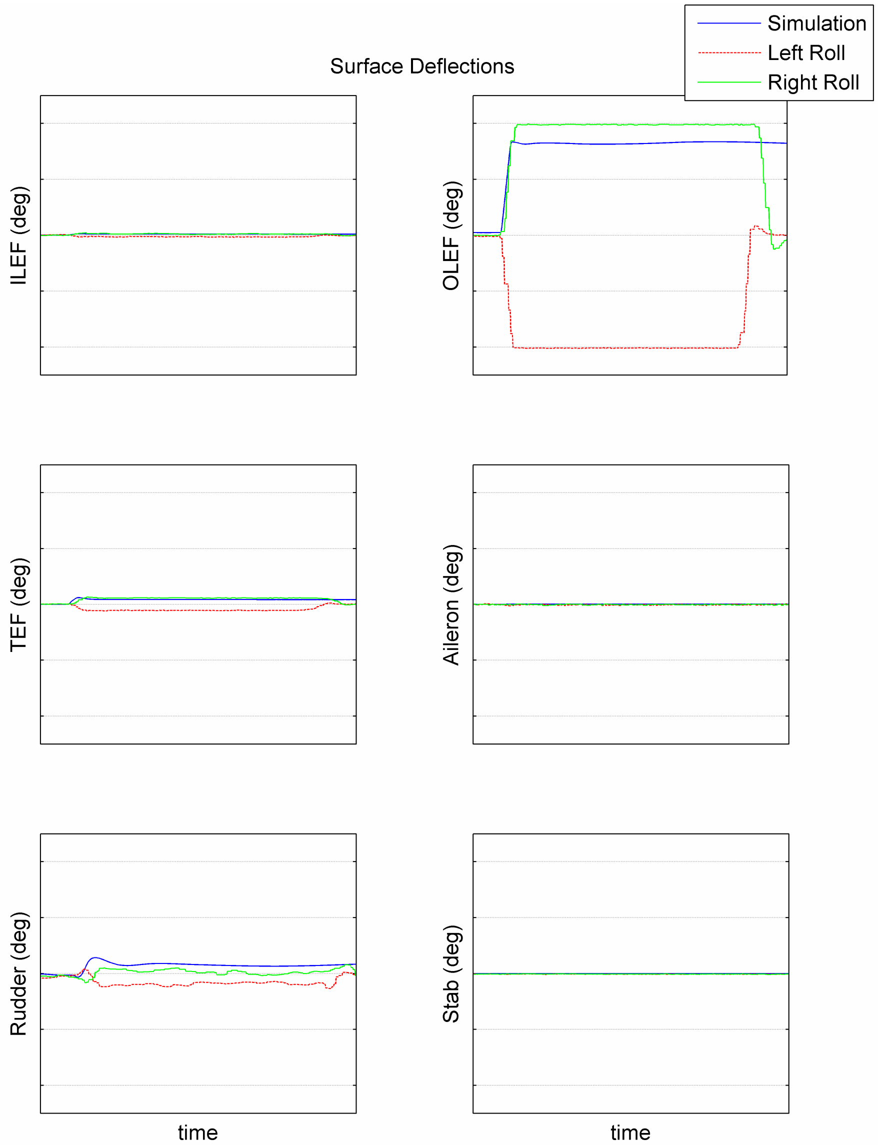
Roll Rate



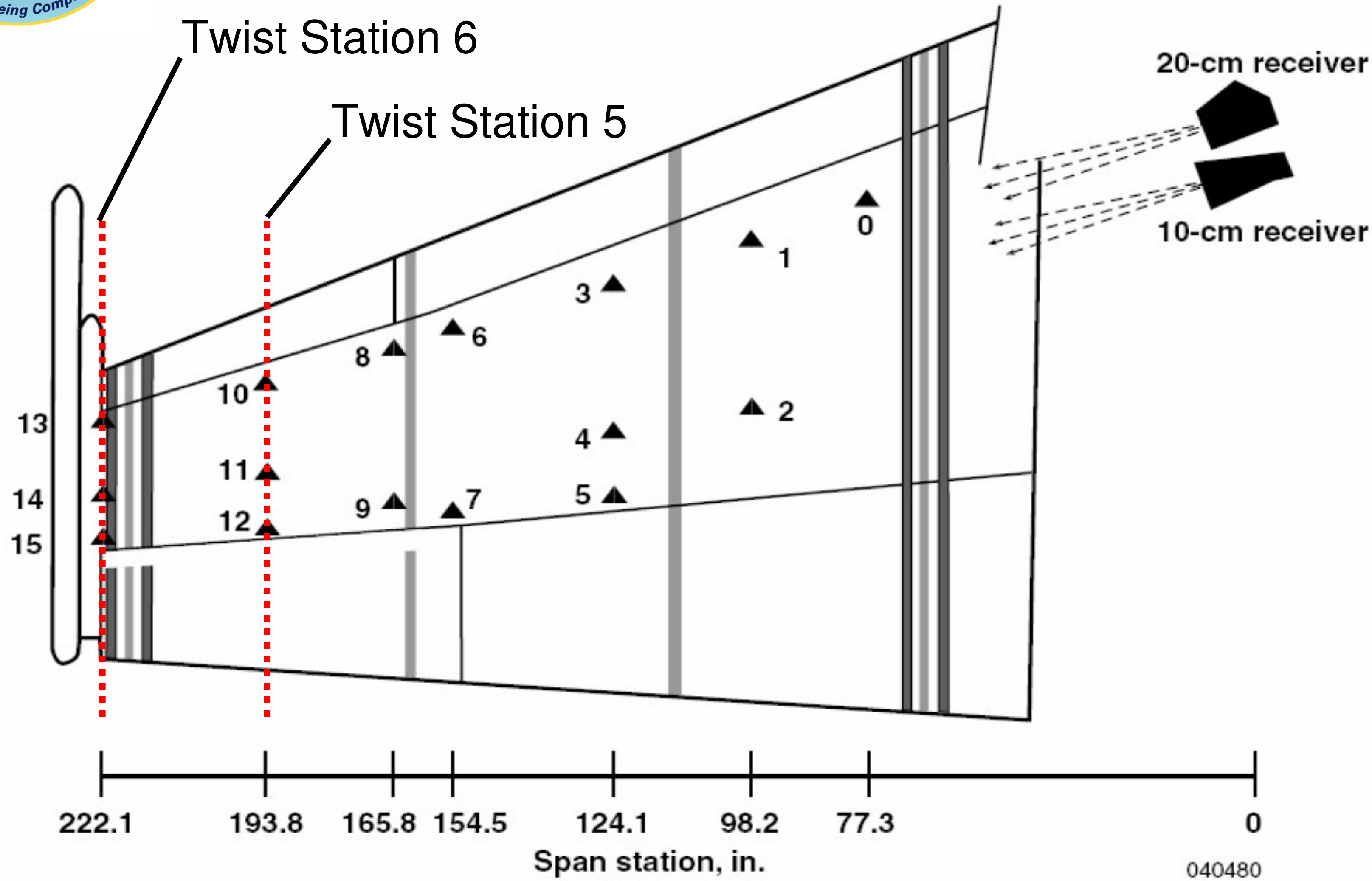
Sideslip


2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Sideslip (deg)
time
Simulation
Left Roll
Right Roll
Proverse Sideslip Limit

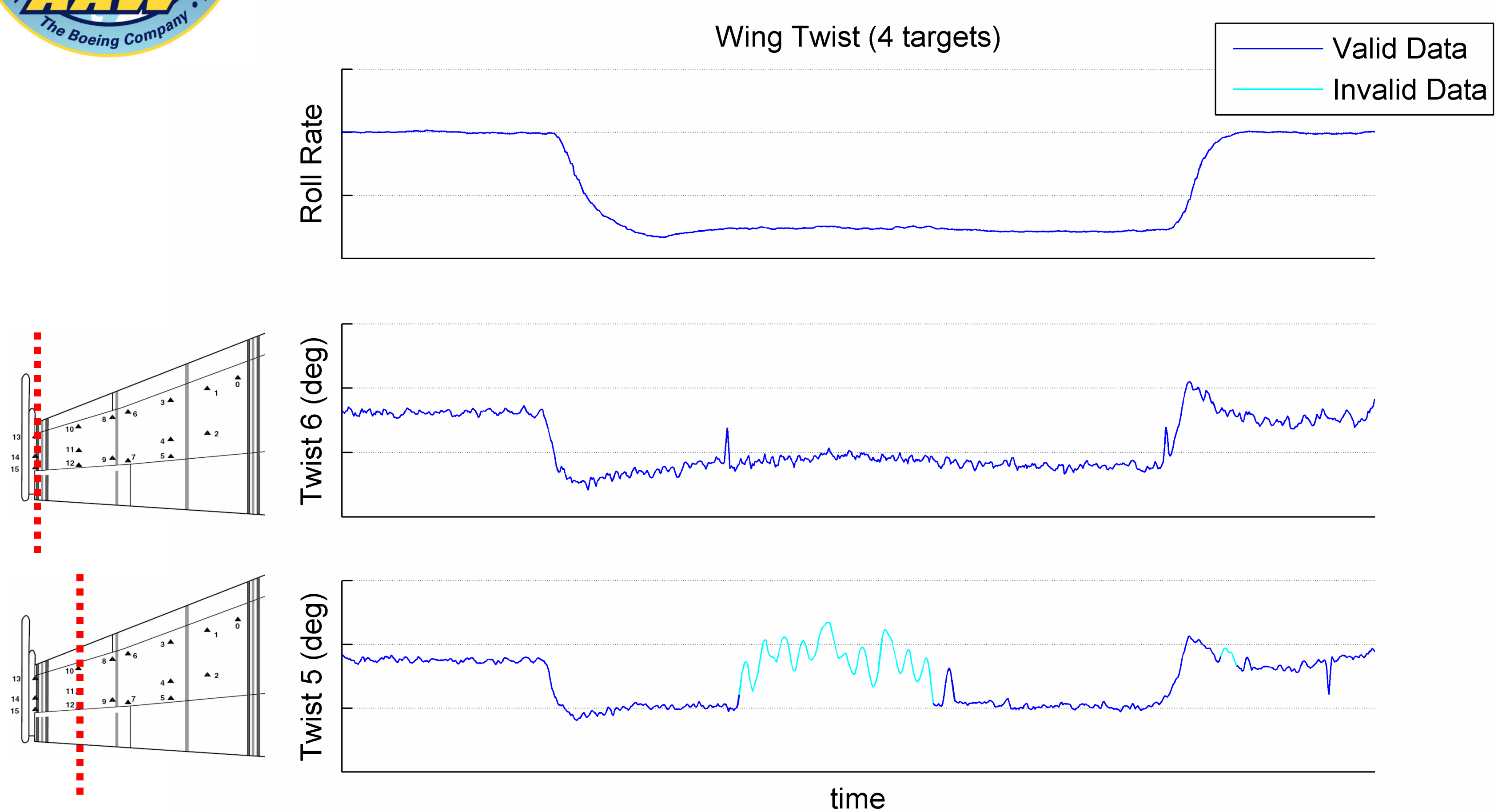
Surface Deflections



FDMS Target and Pressure Sensor Locations

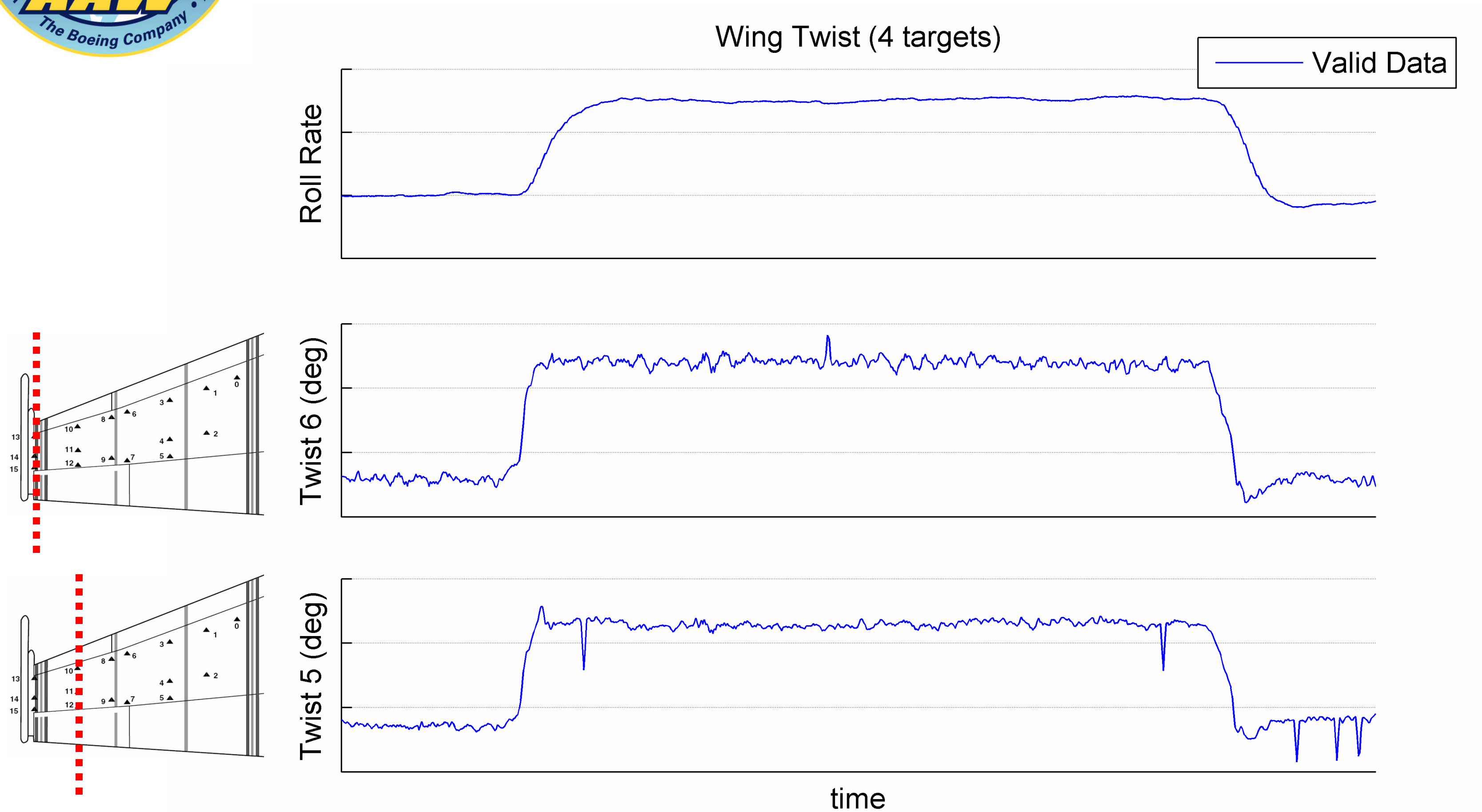


Left Wing Twist, Left Roll



(Positive twist denotes leading edge up)

Left Wing Twist, Right Roll



(Positive twist denotes leading edge up)

Conclusions

- Design Conclusions
  - CONDUIT was an effective tool in optimizing performance while maintaining loads and handling qualities requirements
  - Flexibility of CONDUIT
    - Multidisciplinary optimization was both possible and practical
    - Modification of CONDUIT improved execution time by a factor of 15
    - Incorporation of nonlinear simulation proved to be beneficial
- Flight Conclusions
  - Roll Rate feedback gains were not necessary
  - Wing twist induced roll was demonstrated in flight

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC02-0065-40 Date: March 27, 2002 Photo by: Tom Tschida
A modified F/A-18 in a distinctive red, white and blue paint scheme was showcased during formal rollout ceremonies for the Active Aeroelastic Wing flight research program.