NASA Armstrong Status

Aerospace Control & Guidance Sub-committee
Meeting 113
Englewood, CO
March 2014

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Abstract

The NASA Armstrong (formerly Dryden) Flight Research Center continues it’s legacy of exciting work in the area of dynamics and control of advanced vehicle concepts. This status presentation highlights the research and technology development that Armstrong’s controls and dynamics branch is performing in the areas of “Control of Flexible Structures” and “Automated Cooperative Trajectories.”

Dryden Flight Research Center is now Armstrong Flight Research Center

On March 1, 2014, NASA's Dryden Flight Research Center became the Armstrong Flight Research Center in honor of research pilot and astronaut Neil A. Armstrong. NASA's Western Aeronautical Test Range is now named for NACA director and NASA's first deputy administrator Hugh L. Dryden.

CONTROL OF FLEXIBLE STRUCTURES RESEARCH

NASA ARMD Fixed Wing Objectives (FY19): Optimal Aspect Ratio +50 to +100%, TRL 3

Aero **Struc** Prop Clean Quiet

Objective

Explore and develop aerodynamic, structural, and control technologies to expand the optimal wing system drag vs. weight design trade space for reduced energy consumption

Technical Areas and Approaches

Tailored Load Path Structure

- Passive aeroelastic tailored structures

Active Structural Control

- Distributed control effectors, robust control laws
- Actuator/sensor structural integration

Aerodynamic Shaping

- Low interference external bracing
- Passive wave drag reduction concepts

Active Flow Control

- Transonic drag reduction; mechanically simple high-lift

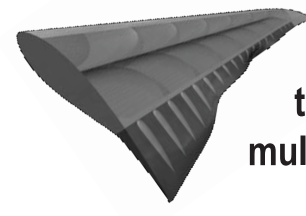
Adaptive Aeroelastic Shape Control

- Continuous control effector(s) for mission-adaptive optimization

Benefit/Pay-off

- 20% wing structural weight reduction
- Wave drag benefits tradable for weight or other parameters
- Concepts to control and exploit structural flexibility
- Optimal AR increase up to 50% for cantilever wings, 100% for braced wings

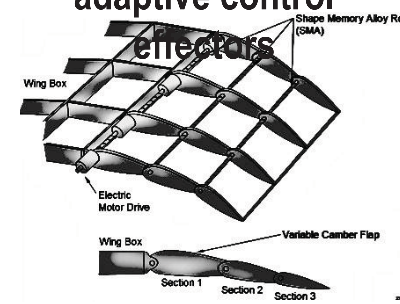
active controls load alleviation

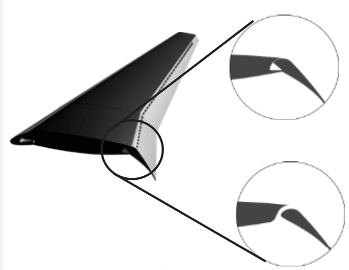


tailored multifunctional

passive/active advanced aerodynamics

adaptive control effectors





AFC-based high-lift

X56A Stiff Wing Envelope Clearance Completion

Problem

The X-56A built by Lockheed Skunkworks with AFRL funding is going through initial airworthiness flights using both stiff and flexible wings. After demonstration is completed the aircraft will be transferred to NASA/FW for research in active control of lightweight flexible structures that can lead to lighter, more efficient, higher aspect ratio wings.

Objective

Demonstrate airworthiness of X-56A vehicle (with stiff and flexible wings) and flight systems; assess vehicle dynamic characteristics and provide validation of the dynamic modeling process.

Approach

Incrementally clear the vehicle through a systematic process of envelope expansion through pilot input response testing and computer programmed control surface movements, and record data with onboard research instrumentation system.

Results

- Eight stiff wing flights July-September
- Vehicle was stable and controllable from takeoff up to 130 knots.
- Good correlation between flight and predicted dynamic responses, with some model adjustments made.
- Nose landing gear dynamics were less damped than predicted, requiring a nose landing gear modification.
- Ship systems checked out well.

Significance

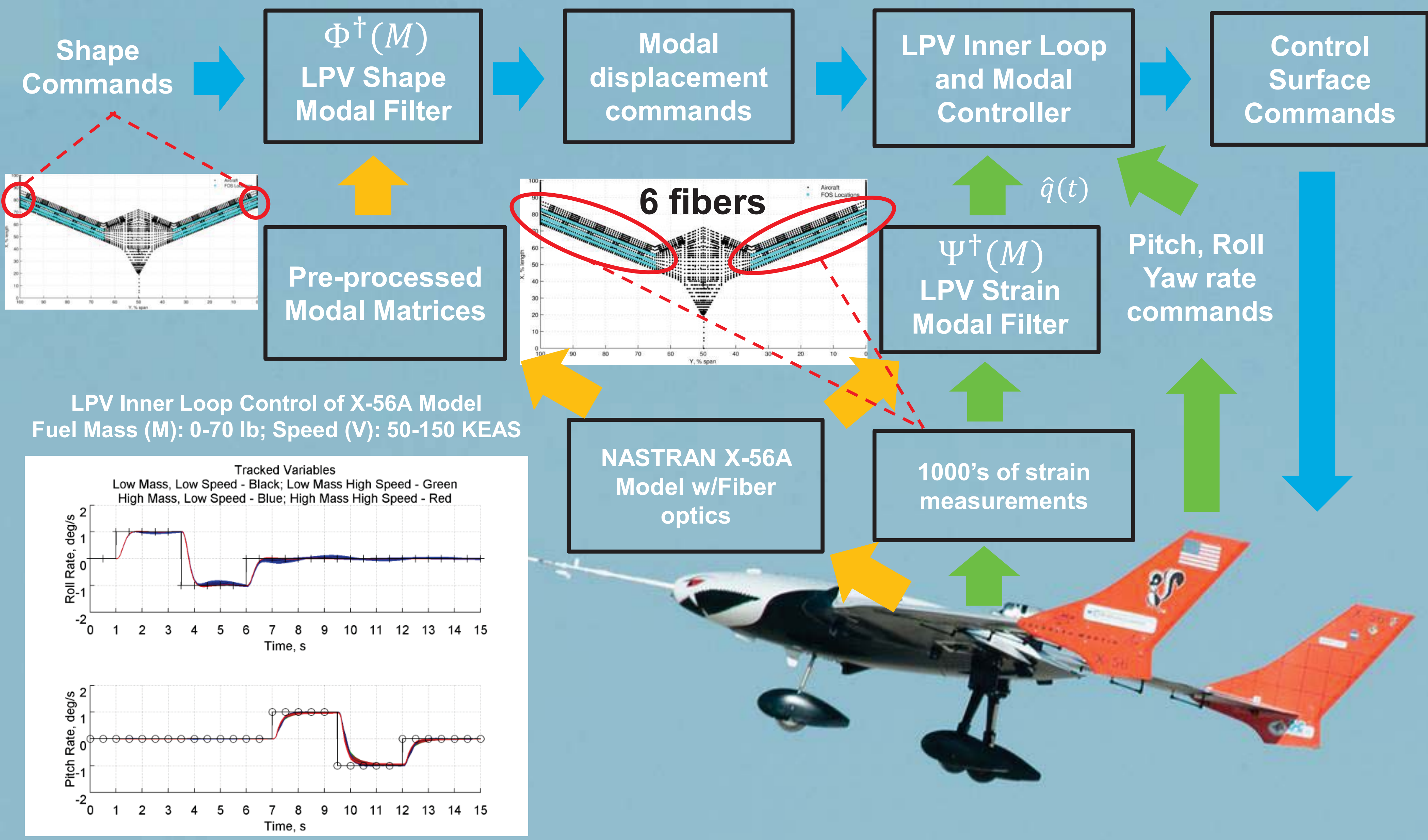
- Completion of X-56A Stiff Wing Envelope Clearance is a significant milestone in the progression towards inflight demonstration of active flutter suppression. The improved dynamic models resulting from this test will provide the ability to finalize the control system gains and proceed to flight with flexible wings. NASA provided range and ground safety and airworthiness advice during this flight phase.

POCs (AFRC): John Bosworth, Gary Martin, Marty Brenner

Advanced Development Programs

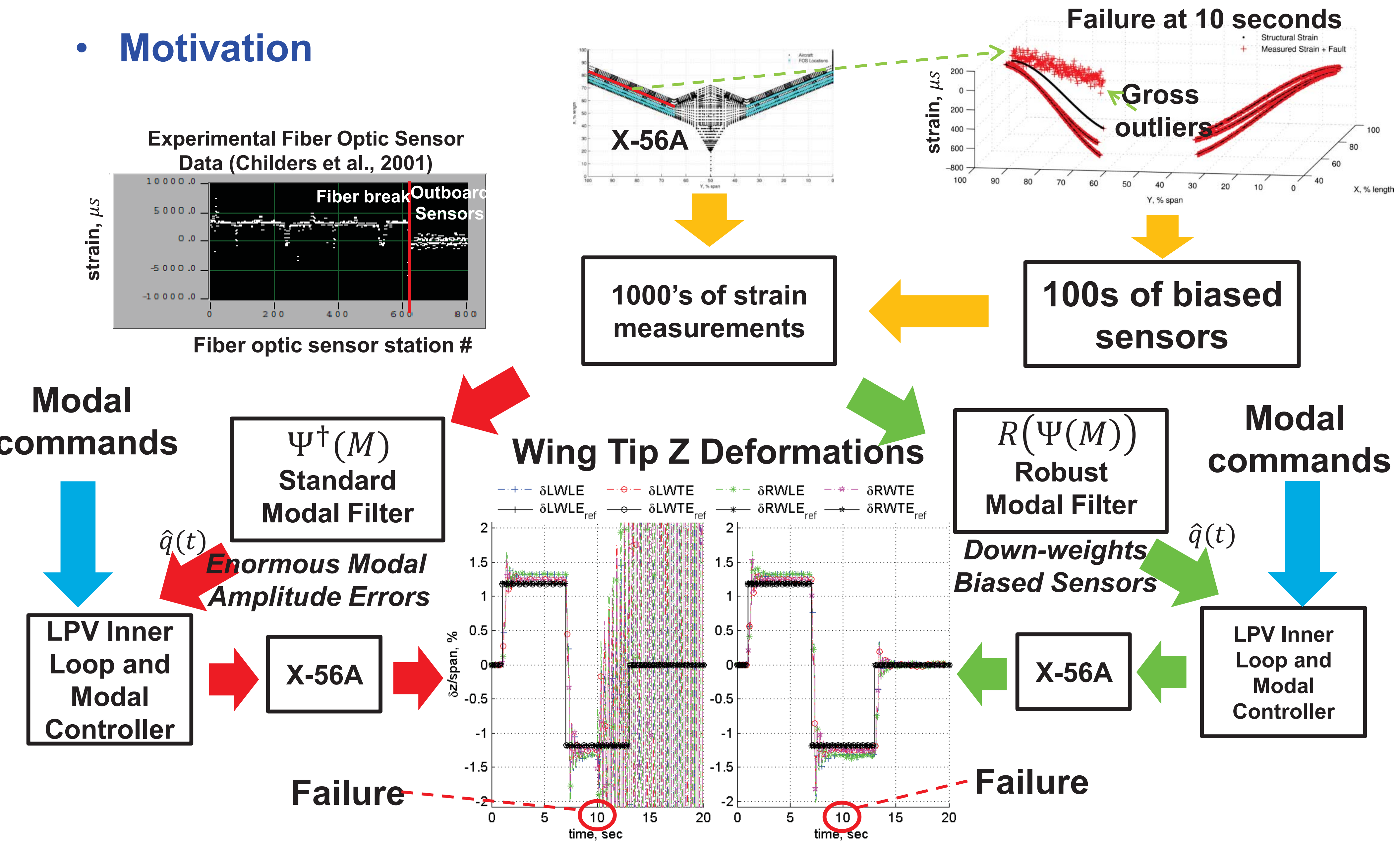
LOCKHEED MARTIN

Linear Parameter Varying (LPV) Virtual Deformation Control



Robust Modal Filtering: Tolerance to Distributed Sensor Failures

- **Motivation**



CFS Research and Development Plans

- Familiarization with Research vehicle (2014)
  - Shadow Lockheed-Martin
  - Develop NASA controller for stiff wing flights
  - Receive the X-56 from Lockheed/AFRL
- Develop models and release them to the community (ITAR restrictions may apply)
  - Aeroelastic models
  - Aerodynamic coefficients (PID)
  - In-flight structural characterization/ mode shapes (PID)
- Develop flutter and aeroelastic shape control technologies (ongoing)
  - Accel and Fiber optic shape sensor based controllers
- Conduct flight research using NASA and external partner developed controllers (2015 and beyond)
  - NASA AFRC Flex Wing controller
  - NASA ARC Aero-efficiency controller (Nhan Nguyen)
- Dissemination of research (ongoing)

Automated, Cooperative Trajectories

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What are Cooperative Trajectories?

Cooperative Trajectory (CT) Concept

- Two or more aircraft using ADS-B data-link communication
- reduced separation (1 – 2 NM)
- Automatic control to maintain relative location and separation
- Probabilistic vortex models to estimate the initial wake location
- Sensor fusion used to refine the wake location

Trail aircraft flies in the upwash region of the lead's wake

Aircraft are separated by 1 to 2 NM

CT is a class of Formation Flight with large separations between aircraft

Results: Efficient Commercial Transports

Sustained, trimmed flight within the upwash portion of the lead aircraft's wake reduces the trailing aircraft's total drag by as much as 10% -15%.

- Lower Cost per Mile
- Reduced Particulate Emissions at Altitude

This is the focus of the current NASA cooperative trajectory research activities

Experimental Validation

German Institute for Fluid Mechanics

1995

10% Power Reduction

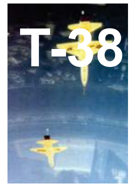
NASA Dryden Flight Research Center

2001

14% Fuel Savings

Air Force Test Pilot School

2001



9% Fuel Savings

Close Formation Flight Research

NASA DFRC / USAF FTC

2010

7-8% Fuel Savings

DARPA / AFRL / Boeing / NASA DFRC

2012-2013

10% Fuel Savings

NASA AFRC

Planned for 2015

Cooperative Trajectory Flight Research

Cooperative Trajectory Flight Research on the G-III SCRAT

Goal: Develop key technologies for commercial CT operations and mature their TRL through demonstration in a relevant flight environment.

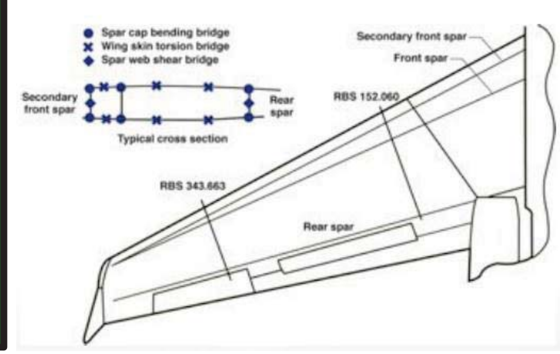
Key Technologies

- An automated CT architecture based on commercial off-the-shelf civilian data-link and autopilot systems
- A robust wake-avoidance algorithm to prevent wake crossings and wake-induced upsets
- An on-line sensor-fusion algorithm to enable robust, accurate estimates of the size and location of the lead aircraft's wake structure

Approach

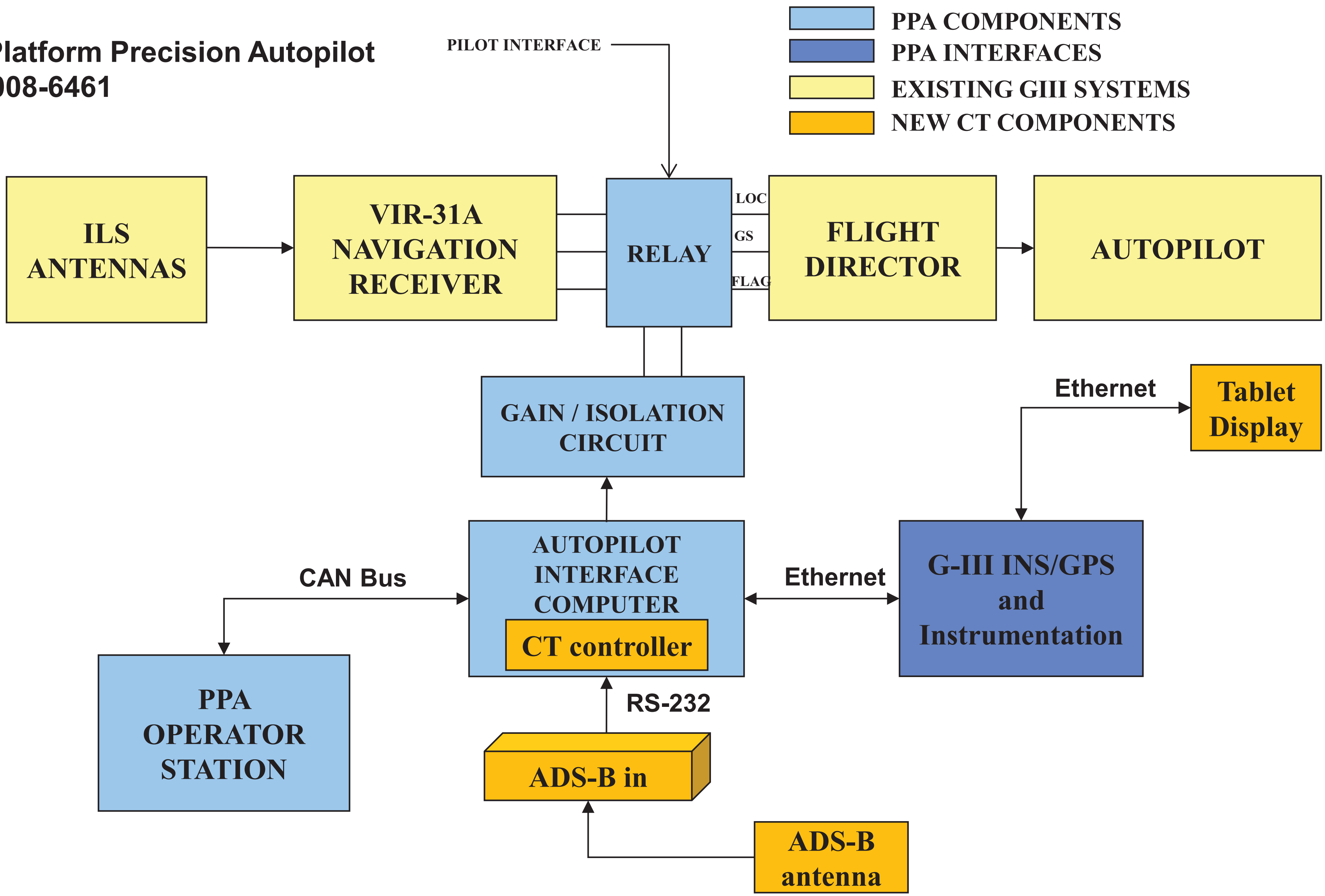
- Outfit the SCRAT G-III with a platform precision autopilot and ADS-B In
- Additional instrumentation on the SCRAT enables exploration of wake characteristics

SCRAT wing structural instrumentation



Proposed GIII CT System Configuration

PPA – Platform Precision Autopilot
AIAA 2008-6461



G-III SCRAT CT Control Development

- Use ADS-B from the lead, estimated winds/vehicle state from the trail, and probabilistic low-order vortex models to estimate the initial wake location region at trail distance (1-2 nm back)
  - Estimate closest distance from trail to vortex system

- Control cross track to vortex, vertical track to vortex, and along track to lead using roll command, altitude command, and speed command
  - Adaptive roll trim gain for steady-state flight within the vortex area of influence
  - NASA G-III lacks an auto-throttle, so PLA commands are displayed to the pilot

- When the trail is within the lead's vortex area of influence, use an on-line sensor fusion approach to refine the estimate of the vortex core locations relative to the trail, and "sweet spot" estimation [in development]

- Use the updated vortex core locations and ADS-B information from the lead in the wake-avoidance algorithm to prevent wake crossings and wake-induced upsets [in development]

Request for Information (RFI) for FAST/853

- **NASA will be releasing an RFI on FAST/853 usage in an effort to understand research community requirements and develop partnerships**
- **Research and flight test capabilities for FAST 853**
  - **Control system research and evaluation in a single string, dual string, or quad redundant environment**
    - » **Inner loop control**
    - » **Outer loop guidance**
    - » **Autonomy**
  - **Piloted flying qualities evaluation**
  - **Pilot interaction with adaptive systems**
  - **In flight sensor development/evaluation including integration into the primary flight control sensor**
- **RFI release spring 2014**

To Fly What Others Imagine …