C-20A Precision Autopilot Development in Support of NASA's UAVSAR Program

Ethan Baumann
DFRC UAVSAR Principle Investigator

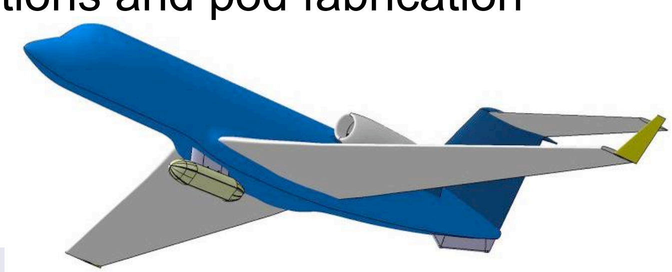
NASA Dryden Flight Research Center

UAVSAR Program

- The primary objective of the UAVSAR Project is to:
  - Develop a miniaturized polarimetric L-band synthetic aperture radar (SAR) for use on an unmanned aerial vehicle (UAV) or minimally piloted vehicle

- Roles & Responsibilities
  - JPL
    - Lead center that will design, fabricate, install and operate the radar instrument, develop processing algorithms and conduct data analysis
  - Dryden Flight Research Center (DFRC)
    - Manage the development of pod design, fabrication and delivery to JPL
    - Deliver RPI interim platform and long term operational platform
      - NASA's C-20A selected as the interim platform
    - Lead the platform modification effort and head up flight operations of the platform
    - Develop Platform Precision Autopilot (PPA) capability
  - Total Aircraft Services, Inc. (TAS)
    - Under contract to perform C-20A modifications and pod fabrication

- First Flight of SAR on C-20A expected Fall '06



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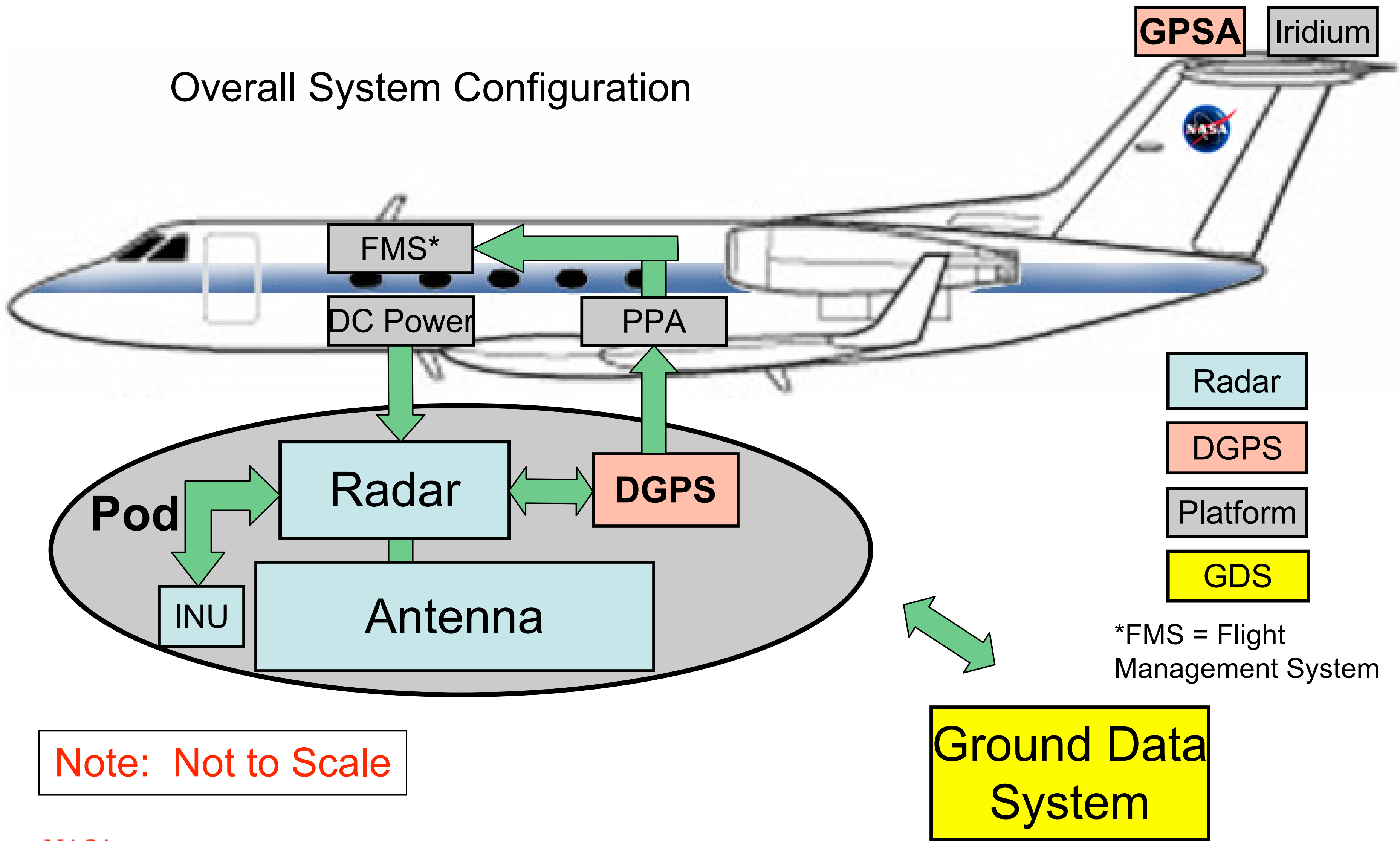
NASA DFRC's C-20A / G-III Aircraft

- Aircraft Goal
  - Provide a research test-bed for NASA, the Air Force, and other government agencies with a long-term capability for efficient test of subsonic flight experiments.
    - “Shirt sleeve” environment
    - Research Infrastructure
- G-III first flight in December 1979
  - Derived from G-II which first flew in 1966
- DFRC's G-III manufactured in early '80s
- Aircraft Dimensions
  - Wing: span 77 ft 10 in; area 934.6 ft^2
  - Fuselage and tail: length 83 ft 1 in; height 24 ft 4.5 in
- Aircraft Performance
  - Max Mach - 0.85
  - Max Operating altitude - 45Kft
  - Normal cruise – 459 kts
  - Range – 3400 nautical miles (full passengers)
  - Climb – 4,049 fpm
  - Large Internal Volume (1500 cu. Ft.)

UAVSAR System High Level Architecture



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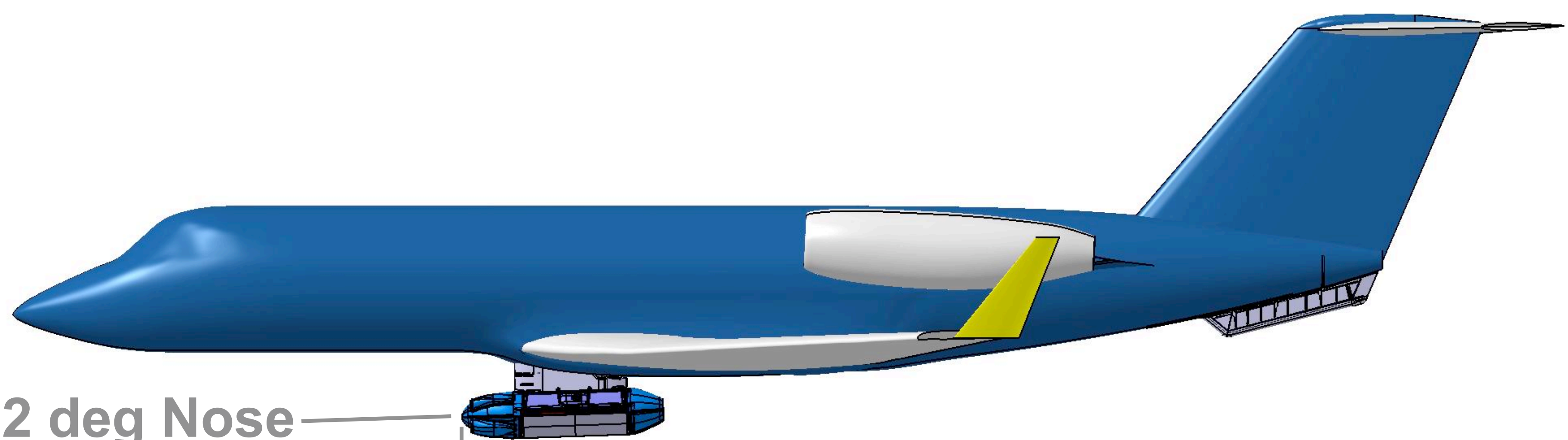
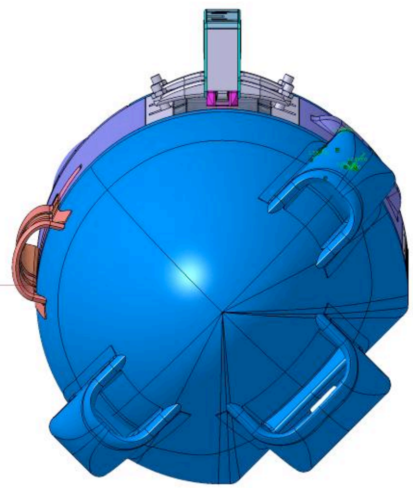
Pod Design
Location on C-20A

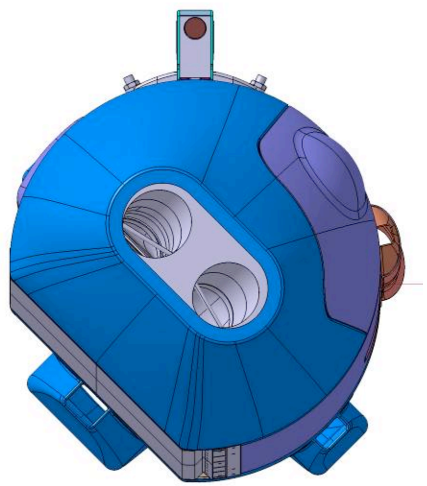


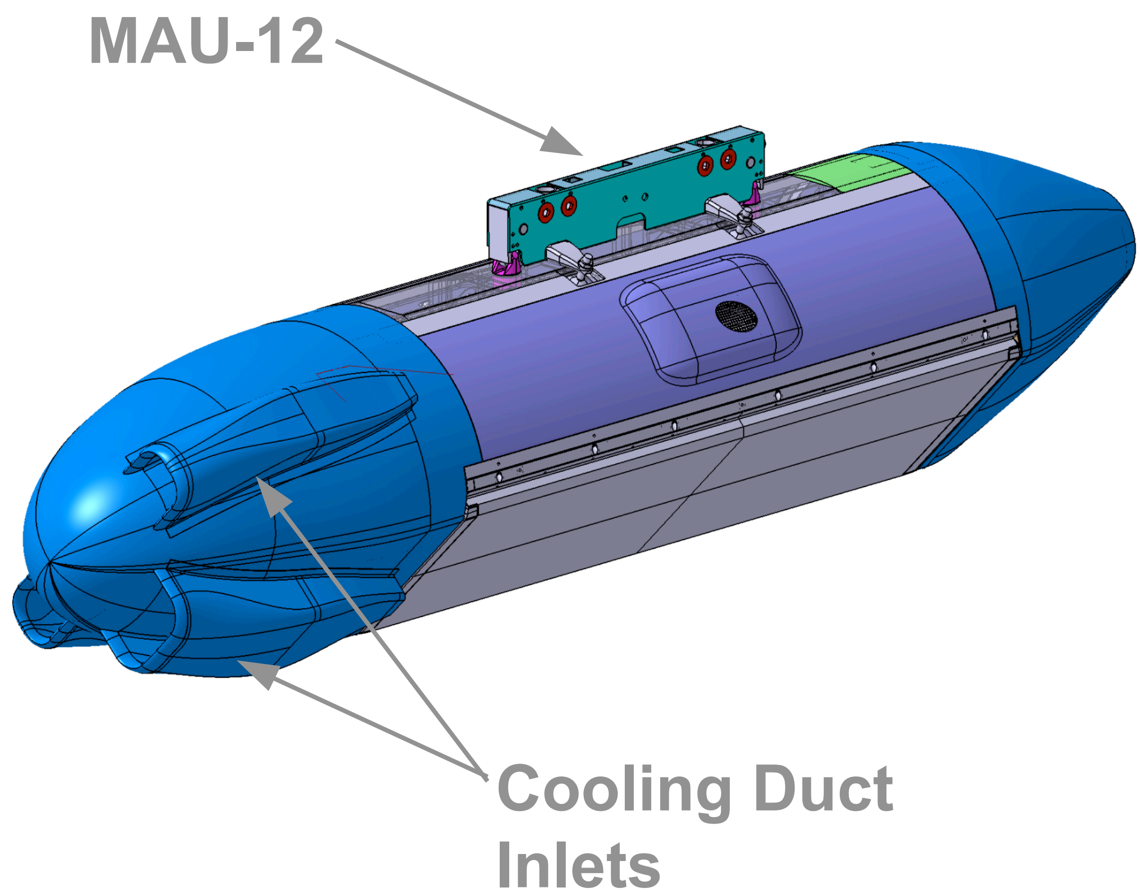
Pod Design
External Views

Front View



Rear View





Platform Precision Autopilot (PPA) Tasks

- Develop C-20A Platform Precision Autopilot (PPA) to support UAVSAR project.
  - Hardware & Software Development
  - Final product is a “care-free” precision autopilot for operation by end users

- Develop C-20A Simulation to support PPA development

PPA Development Plan

- **Overall Approach**
  - Develop the hardware and initial software to work out the kinks in the system and demonstrate feasibility of the approach
    - Initial software is designed to be flexible with uploadable parameters
      - Algorithms are all in Matlab/Simulink and auto-coded with embedded coder
    - Much of the initial software development effort is geared towards developing tools to allow for rapid software updates.
      - Goal of qualifying flight software in under 1 week.
  - Refine the controller and navigation algorithm performance based on flight testing
    - Update simulation and linear models as appropriate
  - Final Product is software suitable for operation by end users
    - Gain tables part of controller
    - Enhanced software restrictions
    - Additional enhancements

PPA Development Flight Test Plan

- PPA Cycle I Controller Test Flights (2-3 flights)
  - Description: Initial flight test of closed-loop PPA
  - Objective: Demonstrate closed-loop operation of PPA
    - Secondary Objective of demonstrating 10 m tube performance

- Cycle II Controller Test Flights (3-5 flights)
  - Description: Flight test of revised PPA applying lessons learned from previous flights.
  - Objective: Demonstrate 10 m (32.8 ft) tube performance. Demonstrate PPA performance at an expanded set of test points

- Cycle III Controller Test Flights (2-3 flights)
  - Description: Flight test of revised PPA
  - Objective: Demonstrate “care-free” operation for UAVSAR RPI application. Expanded set of test points.

Platform Precision Autopilot (PPA) Primary Project Level Requirements

- **Maintain flight within a 10 m (32.8ft) tube in light to calm turbulence levels.**
  - The PPA shall fly the C-20A within a 10 m (32.8 ft) diameter tube for at least 90% of each data take in conditions of light to calm atmospheric disturbances as defined in Section 4.9 of reference 3. The PPA should be able to meet the 10 m (32.8ft) diameter tube requirement in the presence of light to moderate atmospherics disturbances, as defined in Section 4.9 of reference 3, but not at the expense of performance in conditions of light to calm atmospheric disturbances.
    - *Parent*: This requirement is derived from P3 of Reference 1 which states "The UAVSAR Platform shall be capable of flying 80% of all desired tracks to within a 10 m tube for at least 90% of the track".
    - Reference 3 is MIL-STD-1797 Appendix A Flying Qualities of Piloted Vehicles Handbook For

- **Minimize motion during data collection.**
  - The PPA shall minimize motion during SAR data runs.
    - Parent: Self-Imposed
    - Rationale: It is critical to operate the UAVSAR System on a steady platform. This requirement will be further defined and addressed through cooperation with JPL as the PPA is developed.

PPA Design Flow

Interface to C-20A autopilot through Instrument Landing System (ILS)*

IMPLEMENTATION

GOALS

- Achieve required trajectory performance
- Meet UAVSAR schedule requirements
- Facilitate software development and deployment
- Minimize impact to C-20A Flight Management System (FMS)
- Provide for safe and simple operation
- Facilitate migration to UAV platform

JUSTIFICATION

- Makes use of inherent accuracy in ILS
- Simple modification to insert RF switches between ILS signals and PPA, isolating PPA from C-20A FMS
- PPA control is easily disabled by disengaging autopilot
- PPA control algorithms relatively simple

*Approach used by Danish Center for Remote Sensing (DCRS) for a similar application

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Instrument Landing System

- ILS consists of two radio transmitters each with a signal at 90 Hz and 150 Hz
  - VHF transmitter for Localizer
  - UHF transmitter for Glideslope
- Localizer and Glideslope receivers on aircraft measure Difference in Depth Modulation (DDM) of the 90Hz and 150 Hz signals.
  - DDM of localizer signal indicates if aircraft is left or right of centerline
  - DDM of glideslope signal indicates if aircraft is above or below glideslope
  - DDM of zero indicates aircraft is along centerline or glideslope

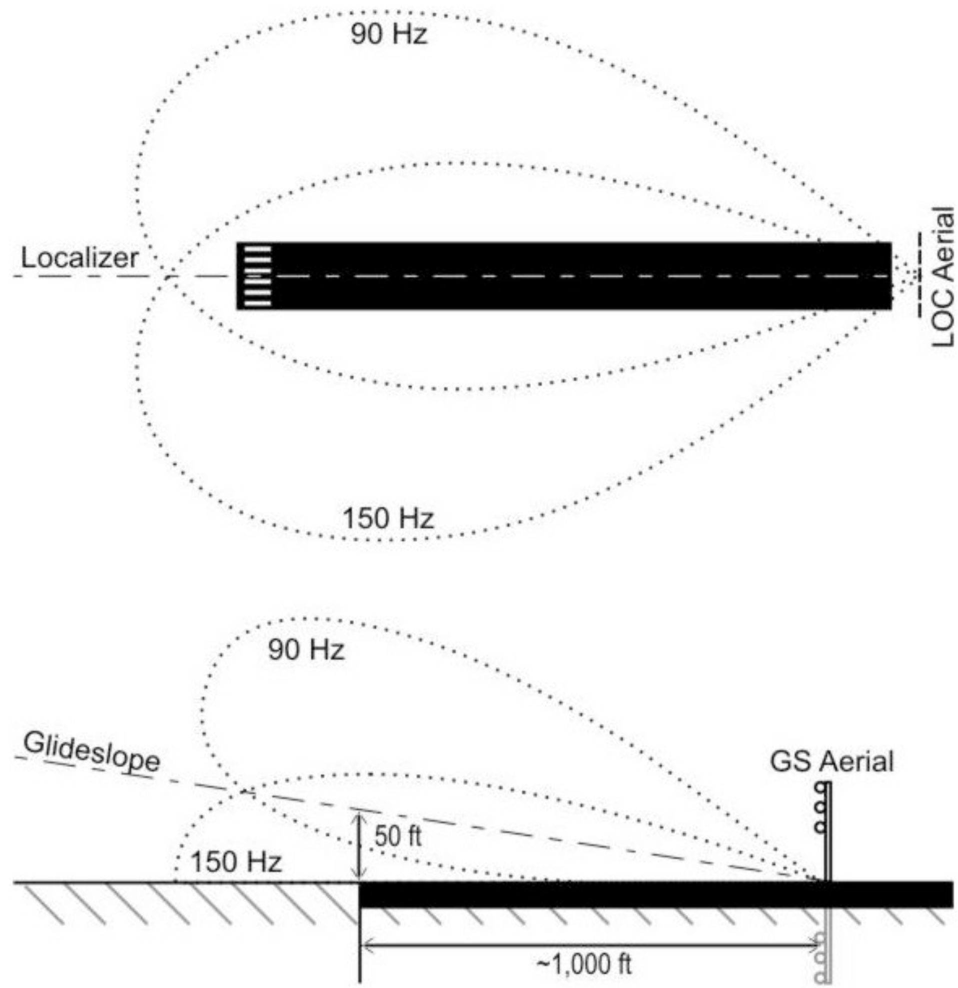

Illustration Source: Wikipedia.org

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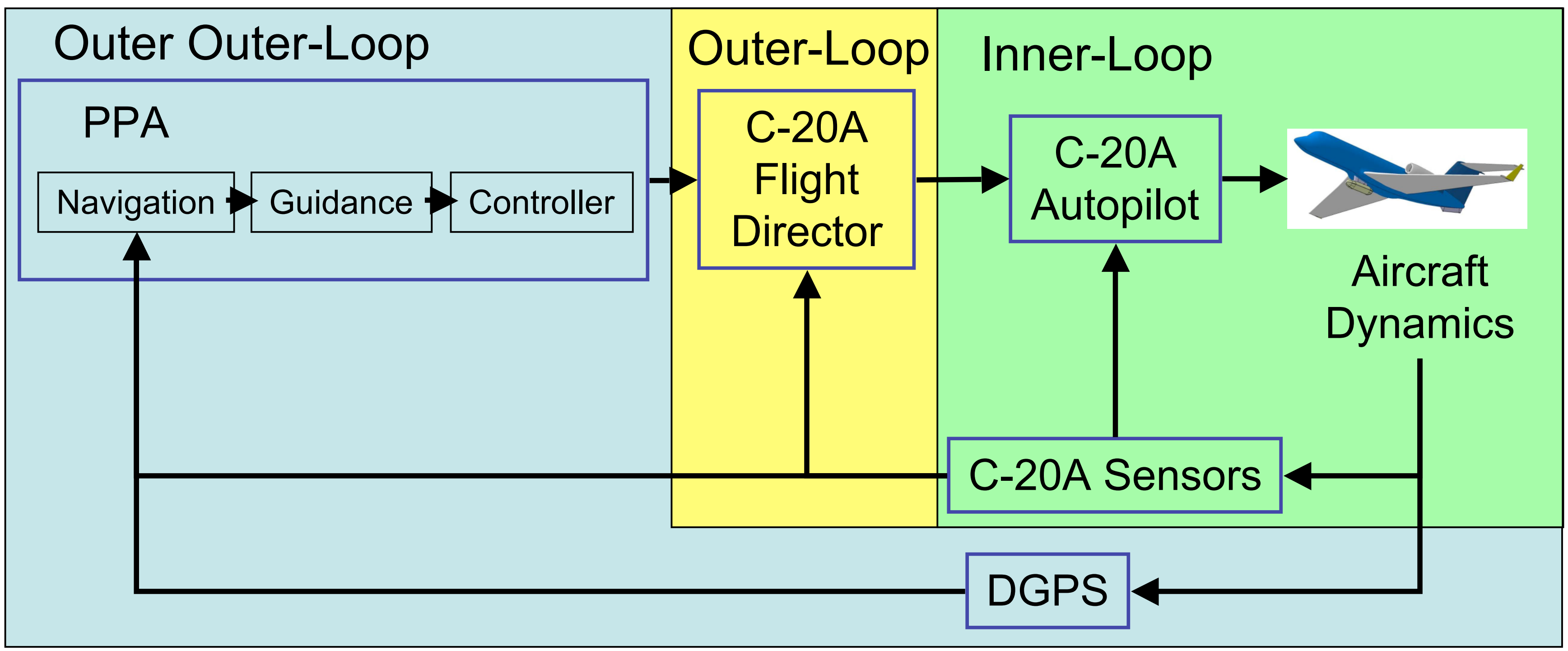
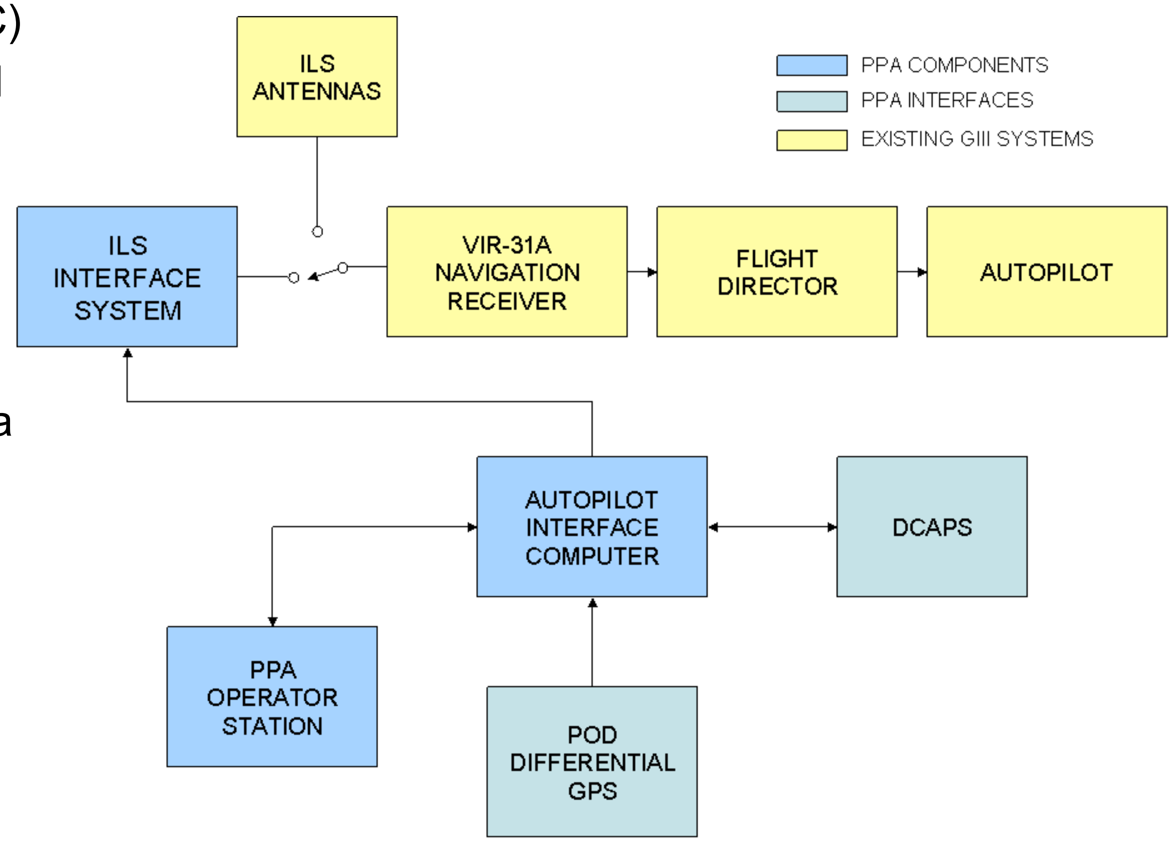
PPA Control Loop Visualization

- Aircraft Inner-Loop dynamics stabilized by C-20A Autopilot
- Aircraft Outer Loop controlled by C-20A Flight Director
- PPA provides Outer Outer-Loop Control
    - Stability & performance metrics are well-defined only for Inner-Loop control
    - No rigorous design criteria exists for Outer-Loop, let alone Outer Outer-Loop control

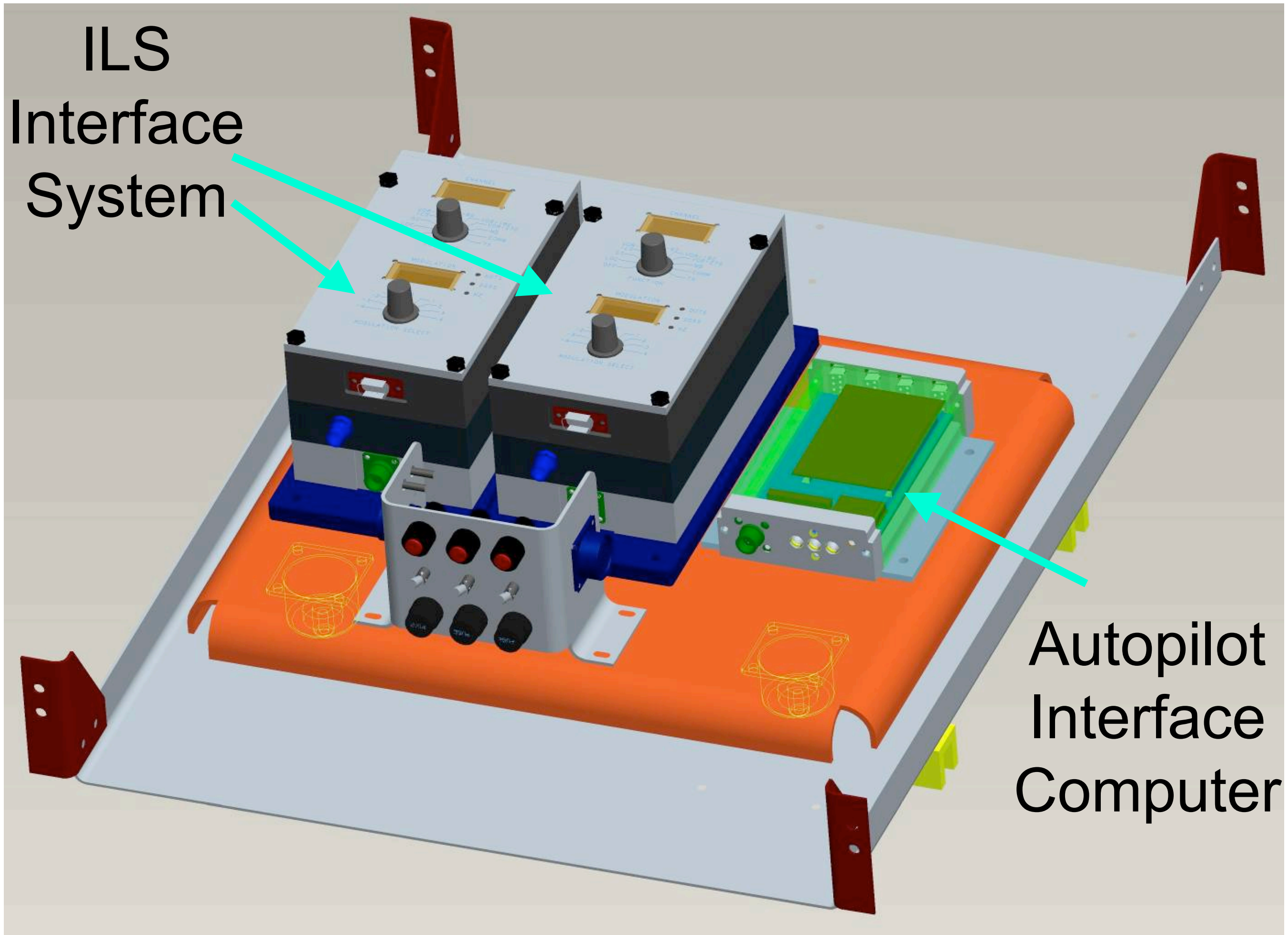


PPA Hardware Interfaces

- Autopilot Interface Computer (AIC)
  - Provide interfaces to external data sources
  - Host the control algorithm
  - Drive the ILS tester
  - Provide interface to operator station of C-20A for waypoint upload, gain control, and data archive
- ILS Interface System (I2S)
  - Modulate the ILS signal based on input from AIC
  - Provide the ILS glideslope and localizer RF signals
- DCAPS (Data Collection and Processing System)
  - Provides C-20A Sensor Data



PPA Pallet on Experiment Rack

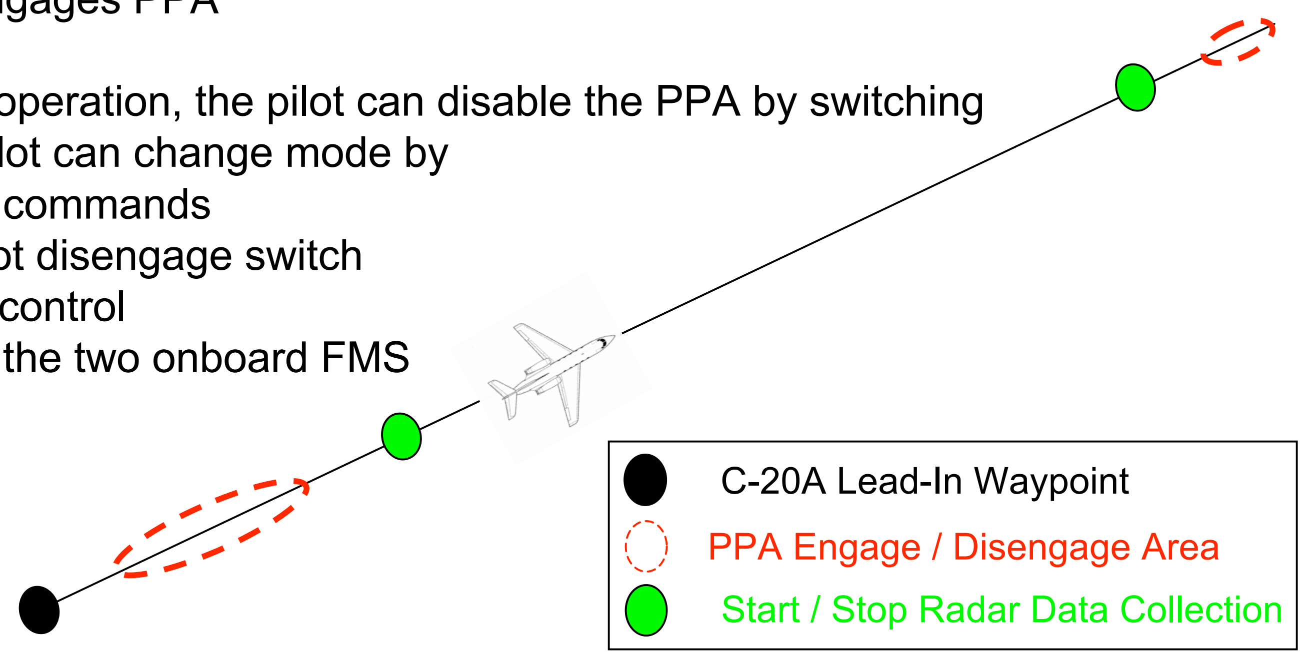


Concept of Operations

- C-20A pilots / autopilot will fly the aircraft to the lead-in waypoint.

- Once the aircraft is stabilized, the PPA will be engaged.
  - Nav receiver source switched to receive from PPA
  - Pilots configure C-20A to fly ILS approach
  - Pilots indicate ready for PPA operation
  - PPA operator engages PPA
  - PPA flies C-20A along desired trajectory
  - PPA operator informs pilots when last waypoint reached
  - Pilots take control of the aircraft (disengage ILS mode)
  - PPA operator disengages PPA

- At any time during PPA operation, the pilot can disable the PPA by switching out of ILS mode. The pilot can change mode by
  - Changing autopilot commands
  - Depressing autopilot disengage switch
  - Moving the aircraft control
  - Switching between the two onboard FMS

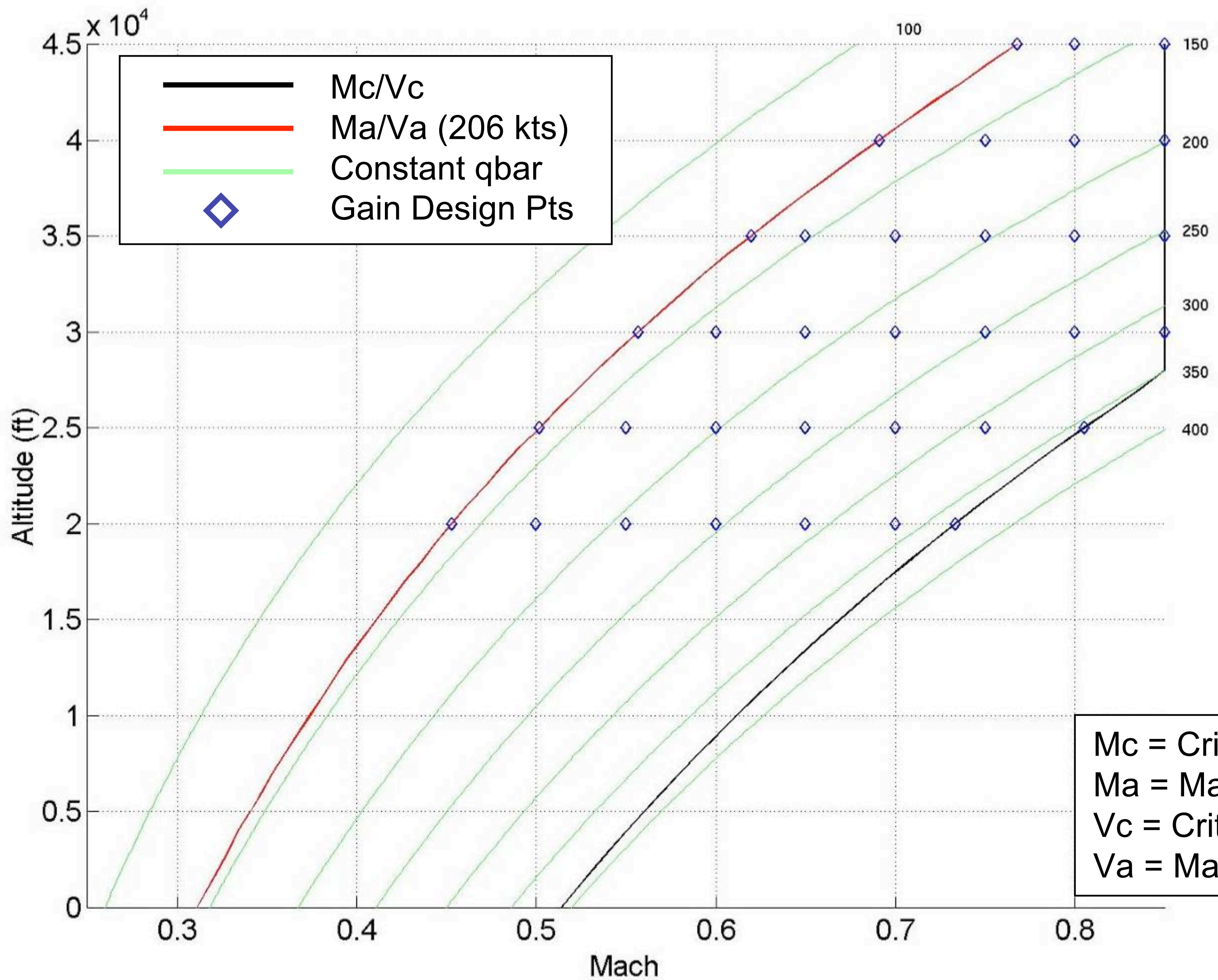


Pilot RF Switch Interface

- Analog switch to control 28 VDC to RF switches
  - One cockpit switch to control both glideslope and localizer RF switches
  - LED indication of switch status
- Output of switch monitored by DCAPS as input discrete and time-stamped

Switch Location

PPA Planned Flight Envelope



Mc = Critical Mach
Ma = Maneuvering Mach
Vc = Critical Speed
Va = Maneuvering Speed

PPA Design Strategy

- Recently finished first cut at full envelope controller design

- This summer, closely examine a handful of flight conditions for flight testing.
  - 2 – 4 sets of gains will be selected for testing at each flight condition
    - Gains will likely be set by matching performance with varying levels of system delay
    - Possibly have high and low performing gain sets for varying levels of system delay

Representative Flight Conditions & Gains for Initial Flight Testing

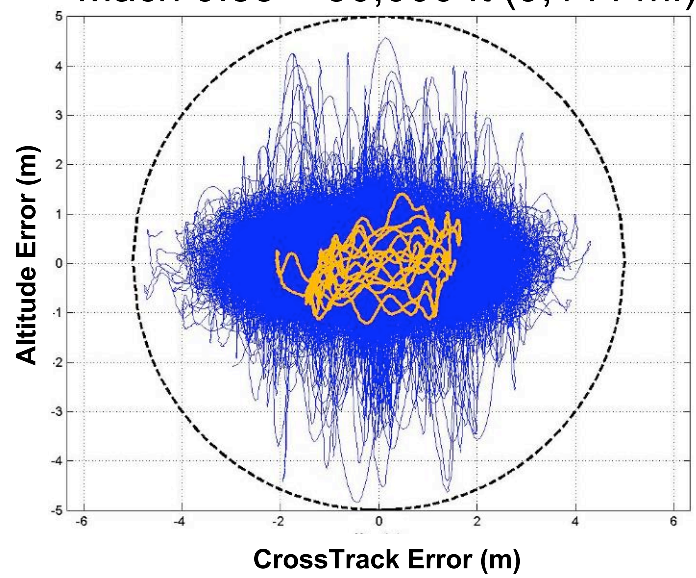
		High System Delay Performance		Low System Delay Performance	
Altitude	Mach	Low	High	Low	High
40,000	0.8				
30,000	0.6				
25,000	0.8				
20,000	0.6				

- *Initially, Flight Test will be focused on controller point designs.*
  - *A refined, full envelope controller will be developed and flight-tested as part of the Cycle II & III Controller updates*

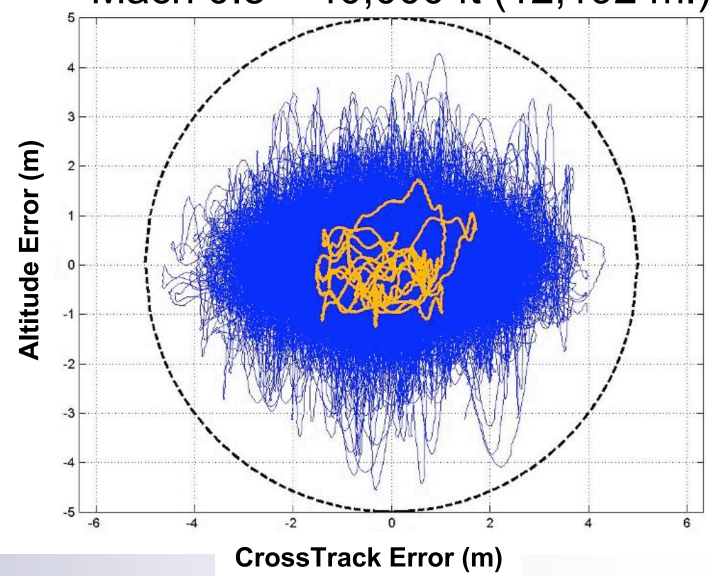
Monte Carlo Simulation Results
10 m. Tube Performance

- Monte Carlo analysis conducted with C-20A simulation
  - Consists of randomly perturbing simulation parameters within specified bounds.
    - 44 simulation parameters perturbed including: aerodynamics, mass properties, system timing, winds.
    - 500 simulation runs were conducted at specific flight conditions.

Mach 0.85 – 30,000 ft (9,144 m.)



Mach 0.8 – 40,000 ft (12,192 m.)



Nominal Run	Monte Carlo Run

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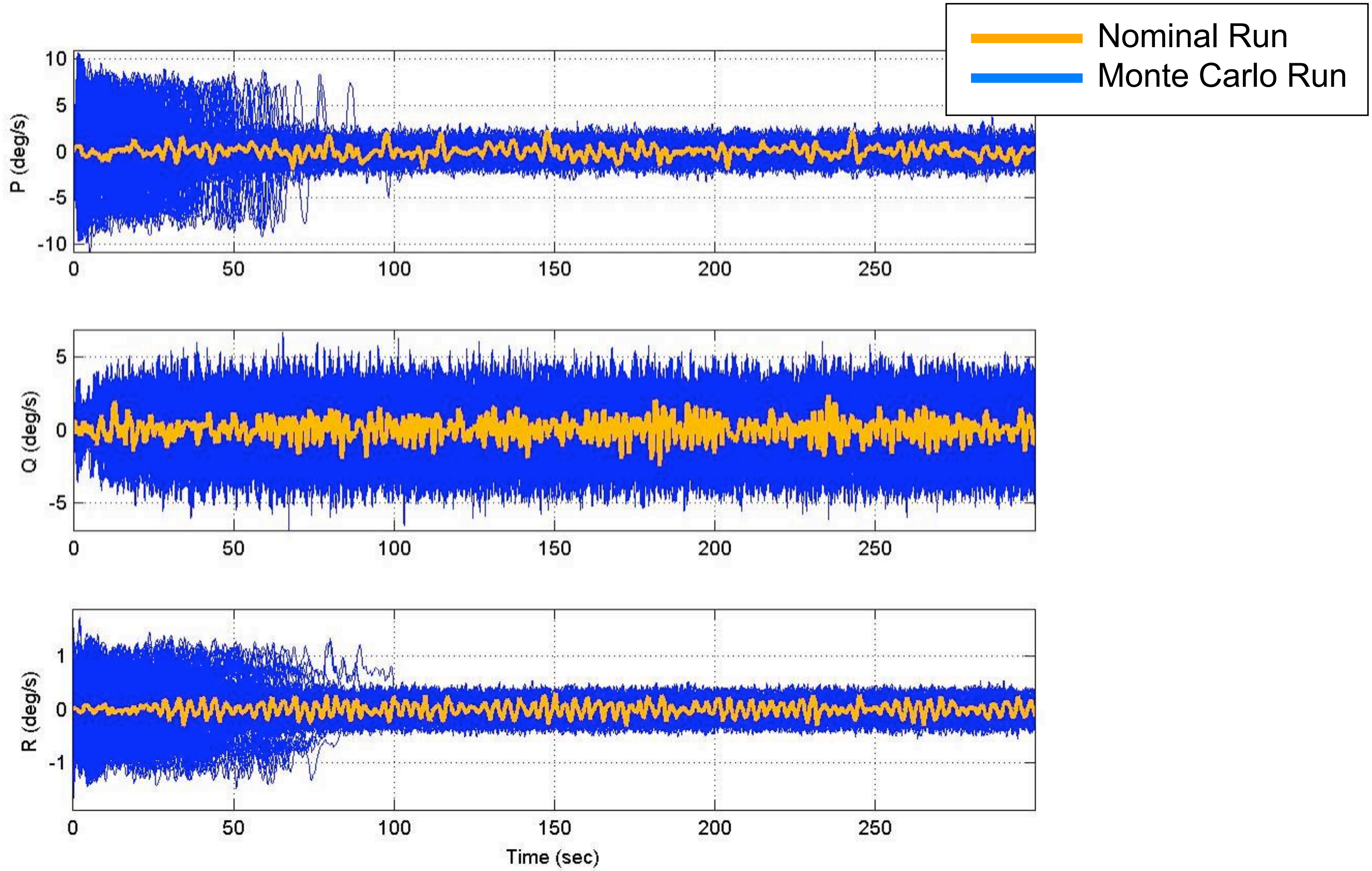
Monte Carlo Results
Mach 0.8 – 40,000 ft (12,192 m)



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Precision Autopilot Status

- Flight hardware buildup ongoing
- Development version of flight code running in Hardware in the Loop Simulation
- Flight code development nearing completion
- Flight code Verification & Validation testing later this summer
- Ground testing in September
- First precision autopilot flight late September / October

Upcoming UAVSAR Milestones

- Recently finished all Critical Design Reviews (CDR)
- C-20A transported to Van Nuys, CA for airframe modifications
- Construction of SAR pods is in progress
- JPL continuing with SAR buildup
- First flight of modified C-20A in early August
- First flight with a “dummy” pod in mid-late August
- First flight with precision autopilot in September
- First flight with JPL’s SAR in October / November

Questions?