https://ntrs.nasa.gov/search.jsp?R=20170005548 2019-04-22T01:39:12+00:00Z

Aerodynamics and Performance X-Plane Airworthiness Guidelines and Best Practices

Stephen B. Cumming
Trong Bui
Mark S. Smith
Mike Frederick
Daniel Banks
NASA Armstrong Flight Research Center

Outline

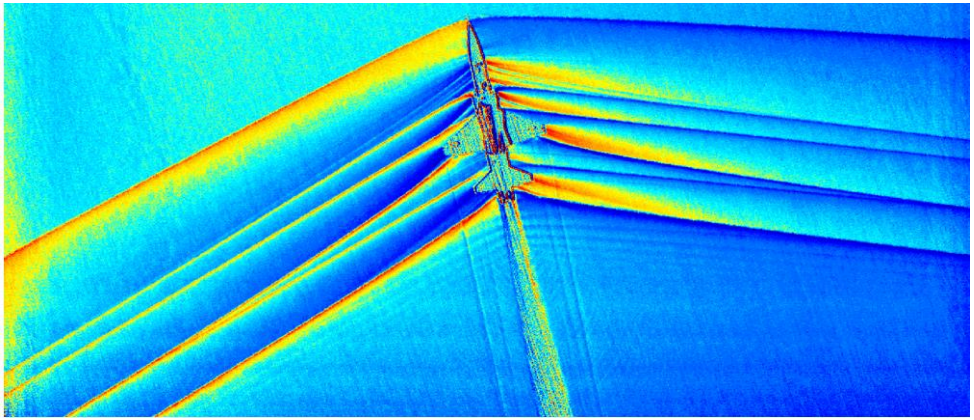
- Introduction
- Background
- Aerodynamic Modeling
- Computational Fluid Dynamics
- Aerodynamics Instrumentation
  - Air Data
  - Research Sensors
- Flight Test
- Flight Data Analysis
  - Aerodynamic Parameter Identification
- Concluding Thoughts

Armstrong Flight Research Center

- Mission: Advancing technology and science through flight
- Vision: To fly what others only imagine
- 70+ years of flight test and flight research history and experience
- Located on Edwards Air Force Base
- Some of the aircraft tested and flown at AFRC:
  - X-15
  - F-8 Digital Fly-By-Wire
  - F-8 Supercritical Wing
  - HL-10 Lifting Body
  - X-29
  - X-31
  - F-18 HARV
  - F-16XL
  - X-43A
  - SOFIA
  - X-56

Aerodynamics and Propulsion Branch

- Competencies include:
  - Aerodynamics
  - Propulsion and Performance
  - Flow Physics
  - Aerospace Meteorology
- Responsibilities include both research and airworthiness support



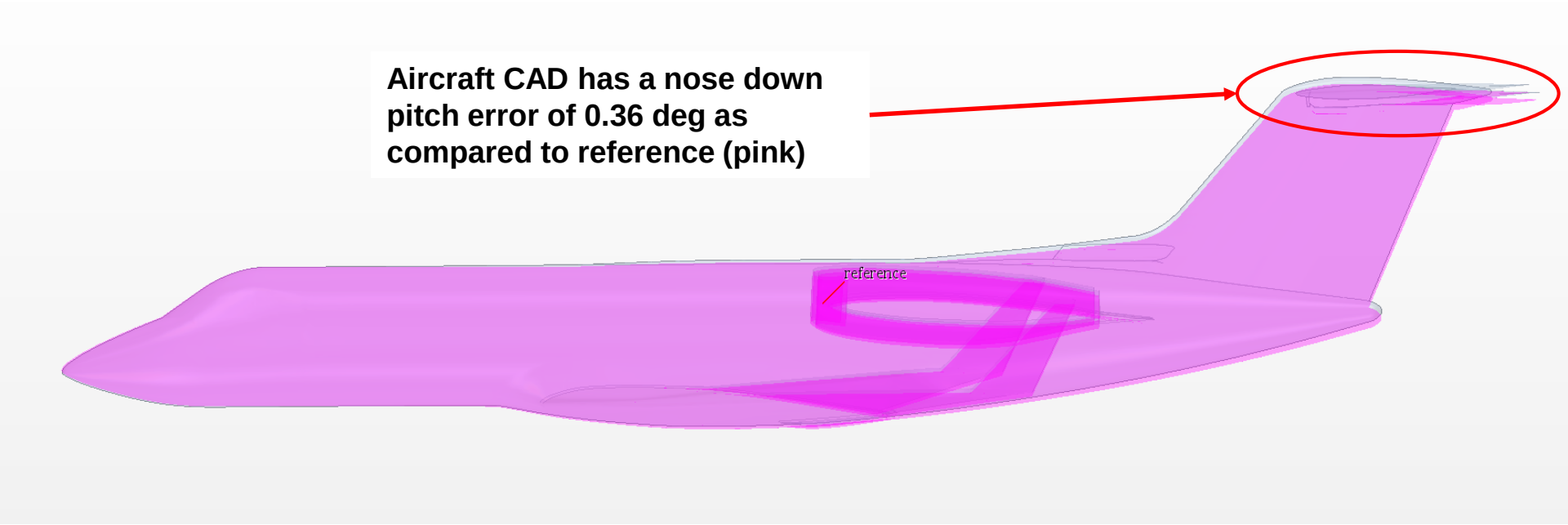
Aerodynamic Modeling

- Create an aerodynamic model with uncertainties for integration into a simulation
  - Comment the code and document the model, including appropriate use and limitations
  - Make note of the model's system of axes (body, stability, etc.)
  - Use version control
- Aerodynamic models can be created using wind tunnel data, CFD analysis, flight data or a combination of all three
  - Understand and document the strengths and weaknesses of the sources for the data
  - Using different tools and techniques to create the data for the model adds value
  - Be aware of potential different conventions for flow angles, reference lengths, etc. when compiling data for the model
  - Stage data generation so that the aerodynamic model can be refined over time
- Plan to validate aerodynamic models and uncertainties with flight data during envelope expansion

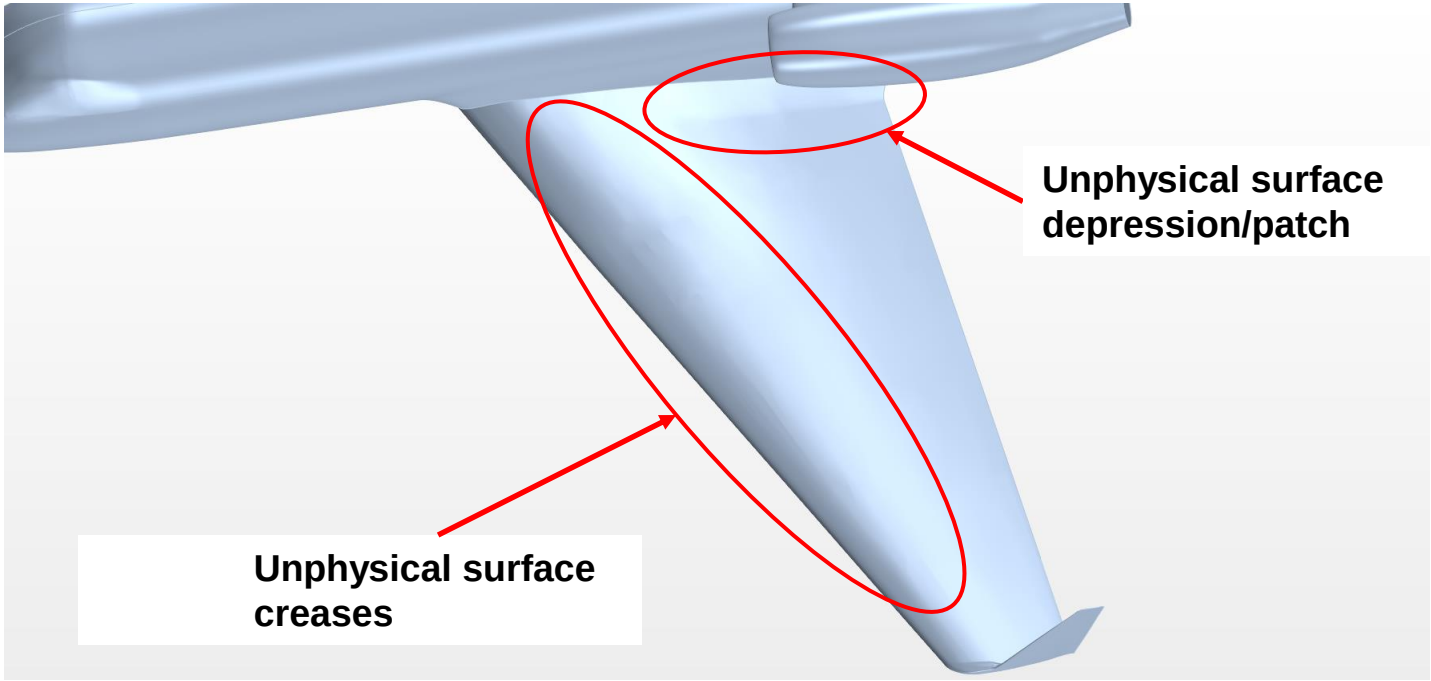
Computational Fluid Dynamics

- Establish known and consistent aircraft reference coordinate system and origin as well as sign conventions for forces and moments, aircraft angles, and control surfaces
- Validate any new CFD codes/tools extensively
  - Simple validation test cases can be very effective in identifying bugs in codes
  - Compare validation results obtained from several different codes and CFD engineers
- Perform grid independence studies on the most complicated geometries and challenging flow physics to quantify CFD solution grid independence
  - Pay attention to both the global mesh as well as any locally complex regions and geometry features
  - Make sure that the grid refinements adequately address global and local complex flow/geometry features
- Archive
  - All of the airplane CAD models, CFD simulation grids, solver inputs/settings, user scripts, and solutions that were used in airworthiness reviews.
  - CFD codes and versions that have been used in support of airworthiness reviews
- Check the airplane CAD models against actual aircraft pictures and/or measurements of the as-built airplane prior to using them in CFD work
- CFD engineers should continue to interface with the project throughout the project lifecycle

Computational Fluid Dynamics



Computational Fluid Dynamics



Aerodynamics Instrumentation

- Start with project and research objectives and requirements
  - Plan for entire flight program
  - Consider the length of the total flight program for reliability and maintainability
- Instrumentation design should start early
  - Sensor requirements can affect airplane design parameters
  - Procurement time for some sensors can be longer than expected
- Request additional margin for your system
  - Modifying a system during a flight campaign is easier than making additions
- Understand the strengths and weakness of your selected sensors
- Calibrate and size sensors for the full flight envelope and the worst-case environment for that sensor location
- Sensor/system owners should understand installation and calibration processes and be present during the actual work
- Thoroughly check and double check instrumentation locations, labels, and calibrations prior to the start of the flight campaign
- Good configuration control is essential
- Invest in processes and tools that make it easier to perform measurements and calibrations

Air Data

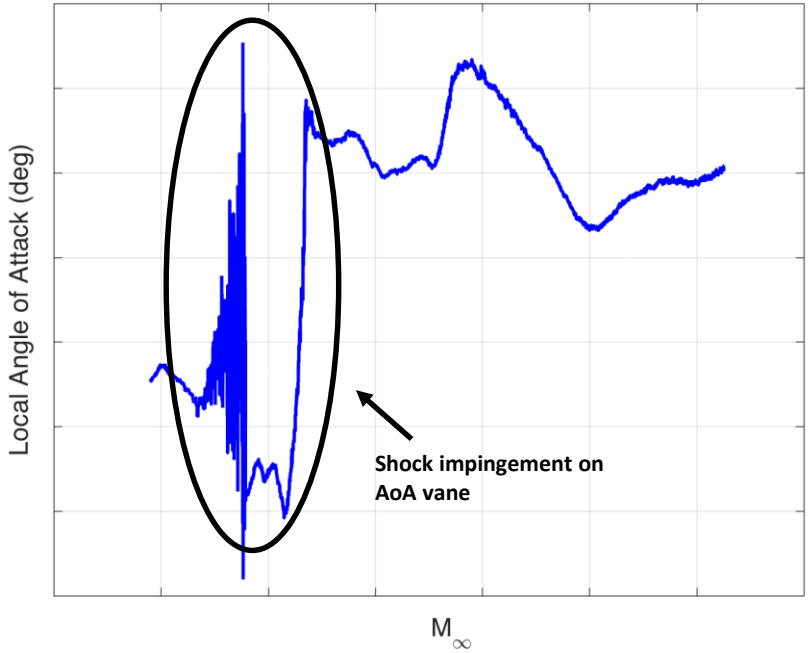
- Many options for research air data systems exist, including nose booms, FADS (Flush Air Data Sensing), production systems, and a variety of custom installations

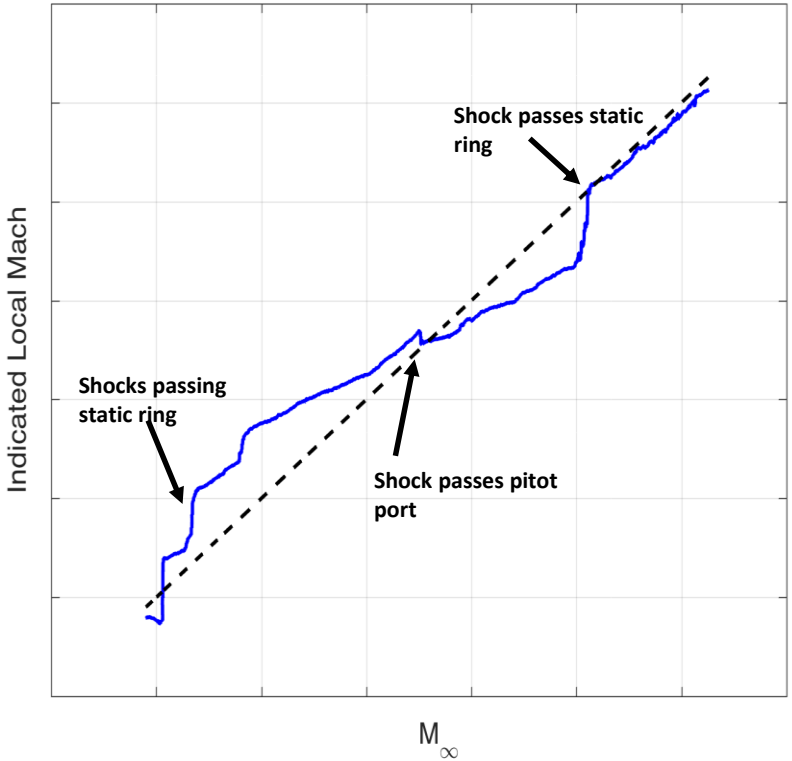
Air Data

- Plan for in-flight air data calibration/validation
- Understand your air data measurement accuracy requirements prior to system design
- Know the strength and weaknesses of your air data system
  - FADS systems don't affect airflow but require extensive calibration
  - NACA boom provides excellent results when mounted on the nose, but can be unreliable when used in flow fields with large spatial gradients because of the large separation distances between pitot and static ports, and flow vanes
  - Production air data systems often need additional calibration from flight data to achieve research-quality accuracy
  - Custom air data installations may not meet desired accuracies, even with extensive calibration

Air Data

NACA boom on CLIP under F-15B

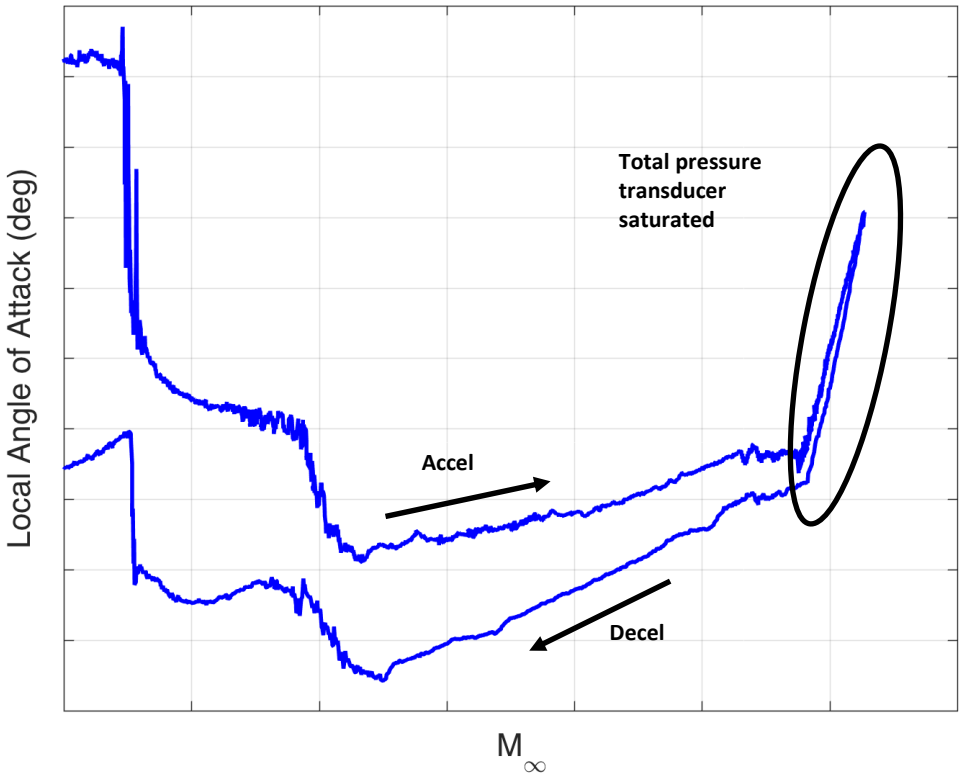




Aerodynamics Research Sensors

- Understand the strengths and weakness of your instrumentation system and selected aerodynamic sensors
  - Be aware of potential sensor affects on the phenomena you're measuring
  - Be wary of temperature effects on instrumentation.
    - Temperature effects can sometimes mimic real phenomena occasionally leading to misinterpretation of data.
    - Temperature sensitivity of some types of instrumentation (e.g. piezoresistive pressure transducers) requires that the sensor be heated to a constant temperature due to the dynamic temperature ranges that can be experienced during flight test
  - Pneumatic effects (lag, attenuation, distortion) from tubing can adversely affect your measurements
- Understand your instrumentation measurement range, accuracy, and resolutions requirements
  - Relatively small errors in pressure measurement for an experimental wedge probe led to intolerable errors in the computed local air data. A subsequent sensitivity analysis after the first flight phase showed that relatively small errors in pressure (on the order of 1%) could give errors in angle of attack of up to 80%.

Aerodynamic Research Sensors



Flight Test

- Plan for the right pilot mix
  - Pilots all have different ways of doing things and having a good mix usually results in everyone learning more
  - Too many pilots can result in each pilot not having enough time to master the machine or maneuvers
- Have a well thought out bail-out plan for envelope expansion, especially at edges and corners of envelope
- Identify cliffs in CFD or WT and look for them in-flight
  - Cliffs may not be where predicted but if they show up in WT or CFD they are likely really out there
- Know that you don't know it all
- Doing something, especially something unorthodox, on the fly without prior discussion and planning, will frequently surprise you with unexpected results
- Even two of the same airplane may behave differently in some situations
- Airplanes grow roots and test teams rust
  - An airplane that sits for a long time usually becomes more difficult to get flying again
  - A test team that has been out of the game/control room for a while, or has not worked together, will take some time to get up to speed
- Use your flight simulation
- Document
  - Discrepancies, flight test results, etc.

Piloted Flight Simulation

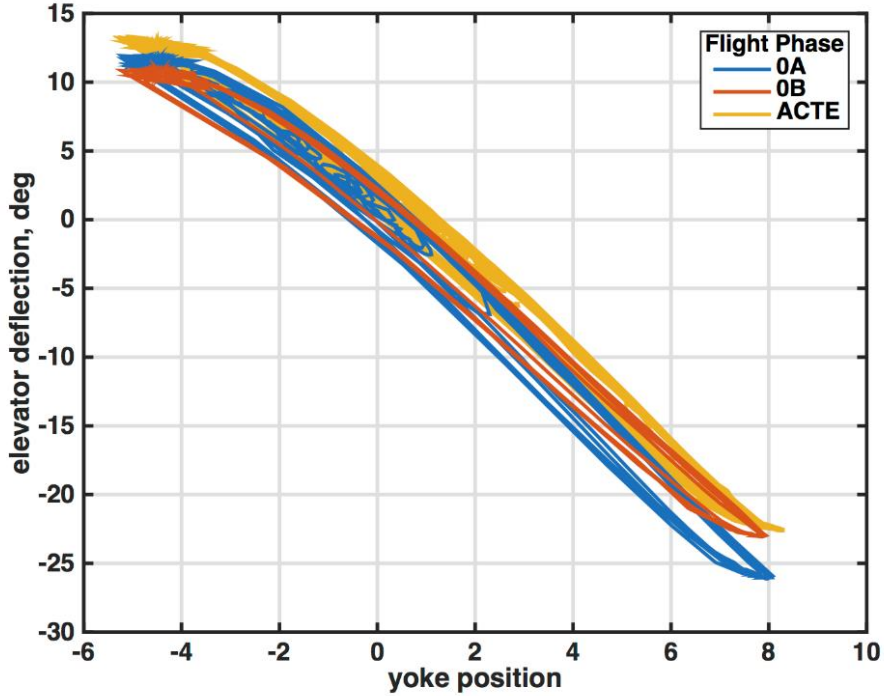
- Piloted and batch simulations are critical tools for flight research and test
- Use piloted and batch simulation to help design and practice flight-test maneuvers, select test conditions, etc.
- A proper flight simulation informs how flight condition and maneuver design can influence the identifiability of the important objectives
- Pilots practicing maneuvers, especially unique maneuvers, in the simulation prior to flight substantially improves flight test efficiency and quality of data from flight

Flight Data Analysis

- Instrumentation can change whenever a plane has been down for a while, even if it officially hasn't changed
  - Recheck time shifts
  - Recheck control surface measurements' calibrations
- Understand how your flight data server modifies data for output
- Scrutinize your flight data early and often
- Actively compare predictions with analyzed flight data
- Be familiar with your analysis tools and scrutinize results carefully
- Careful analysis of early results can allow for effective analysis automation later

Flight Data Analysis

Differences in surface position measurement between flight phases

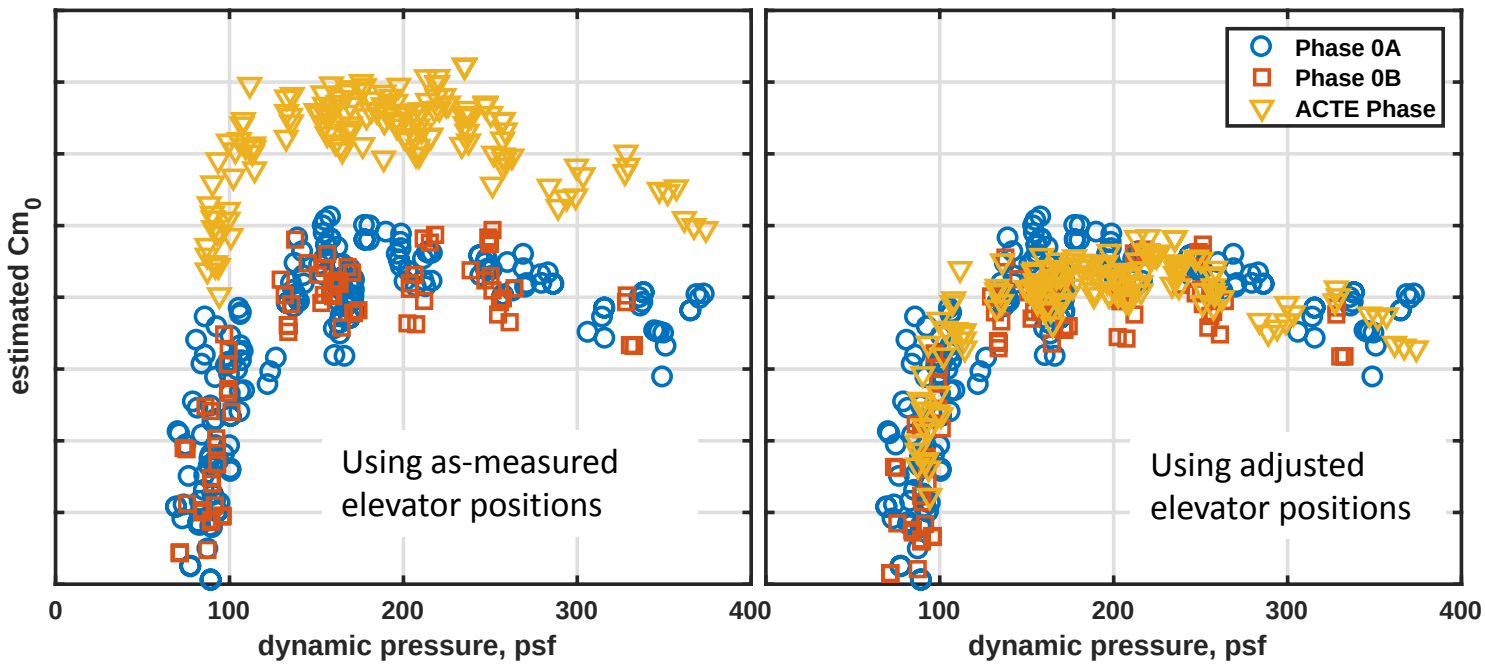


Differences in elevator deflection measurement vs. yoke position, relative to flight phase 0A:

	Scale Difference	Bias Difference
Phase 0A	0	0
Phase 0B	11 %	0.2 deg
ACTE Phase	7 %	2 deg

Flight Data Analysis

Effect of Instrumentation Differences on Analysis Results

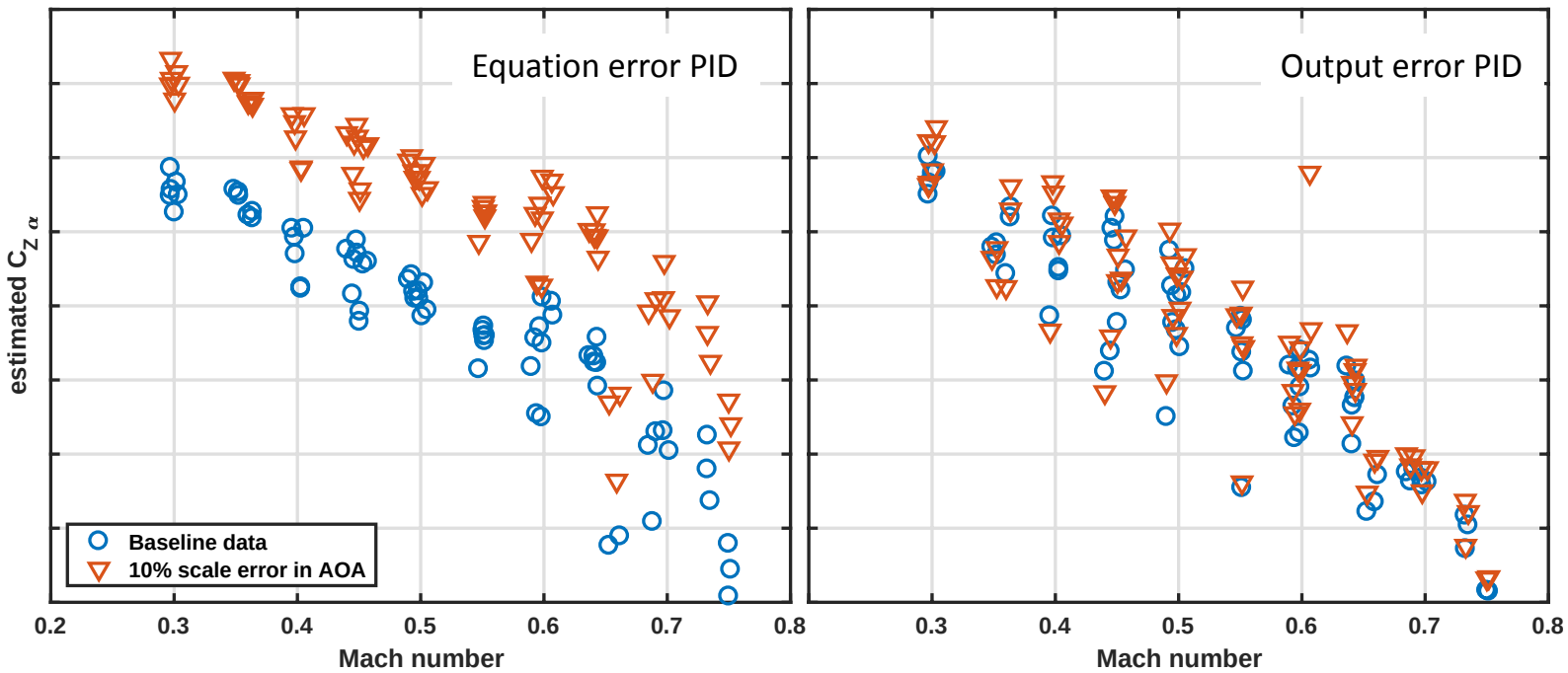


Aerodynamic Parameter Identification

- 90% of PID is data processing; the other half is the parameter identification
- Automate as much of the process as possible
  - Easier to make changes and try again
  - Allows for easy comparisons of signals and settings
- Correct your standard errors for colored residuals/Cramer-Rao bounds
  - Realize that your actual uncertainties are higher
- Use multiple parameter estimation techniques
  - Different techniques respond differently to noise, biases, time shifts, etc.
  - Differences in the parameter estimates can point out the existence of data errors
- Validate your pre-flight aerodynamic models and update them as-needed

Aerodynamic Parameter Identification

Equation error and output error PID can respond differently to measurement errors, such as scale errors in angle of attack



Concluding Thoughts

- Flight research, especially with one-of-a-kind aircraft, is difficult
- Documentation is important
- Lessons are learned (and often re-learned) in every flight program

Questions?

Thanks:

Mark Davis

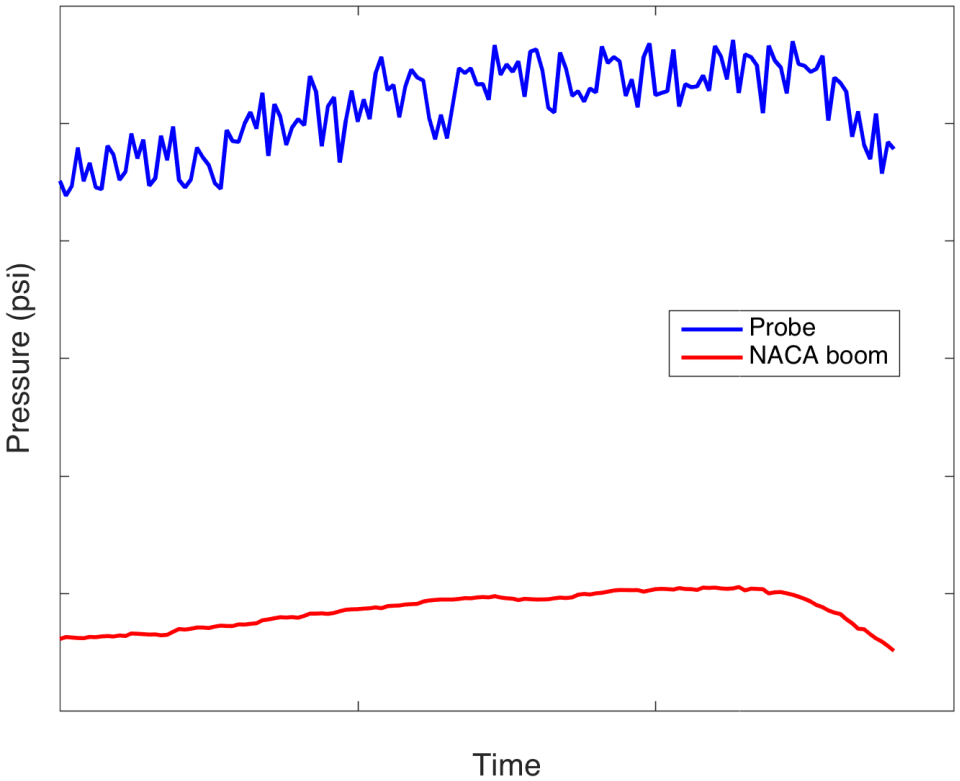
James Murray

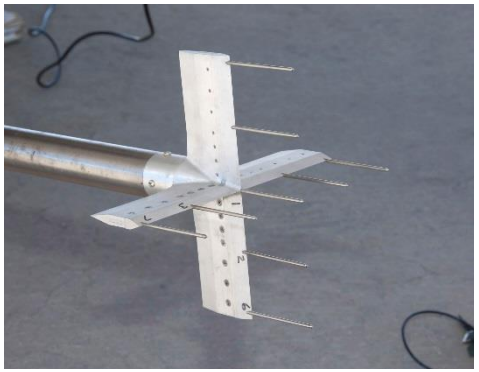
Backup

Introduction

- Combination of airworthiness guidelines and recommendations, best practices, and lessons learned from the Aerodynamics and Propulsion Branch at NASA Armstrong Flight Research Center
- Discussion is applicable to future X-planes or other experimental vehicles as well as aerodynamics flight research in general

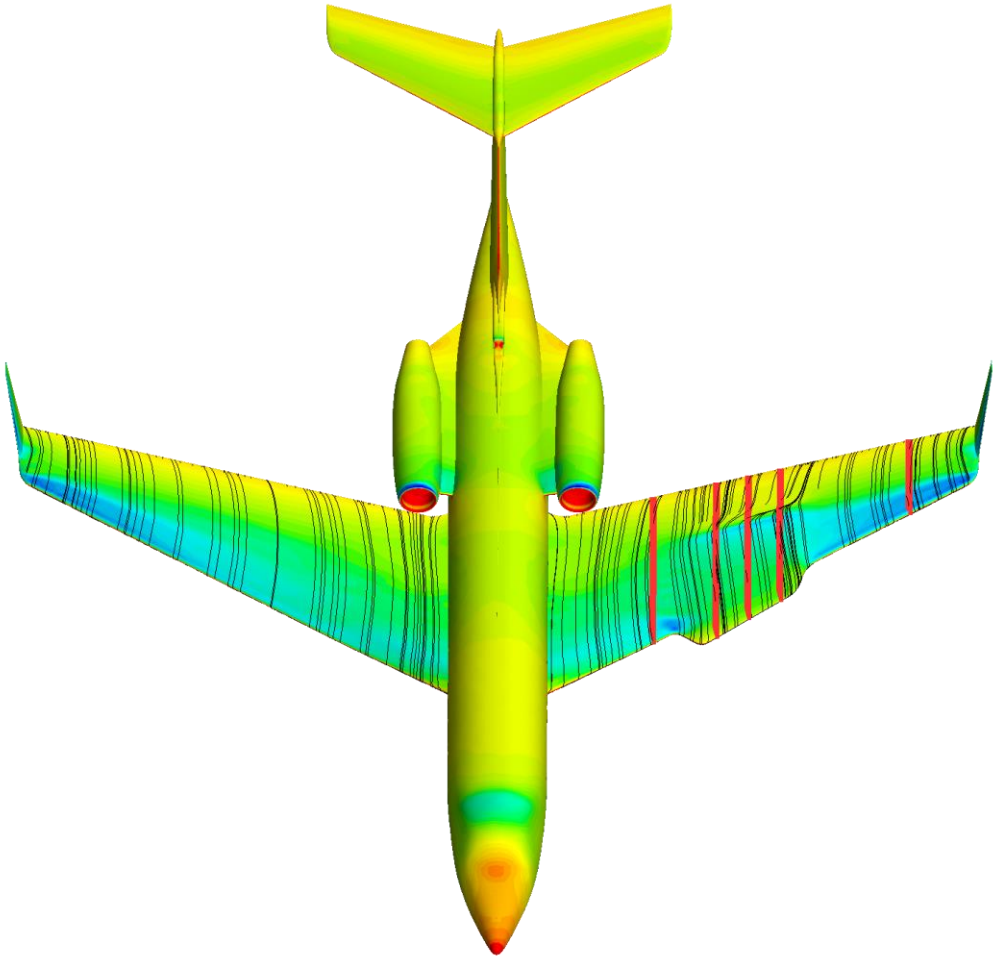
During the first ever flight of RAGE, the signal to noise on the probe pressure measurements was very low because +/-30 psid transducers (with a 12 bit system) were used for total pressure and +/-15 psid were used for the statics





360
45
90
135
180
225
270
315

SOFIA
NASA
DLR

SOFIA
NASA
DLR
N747NA
NASA
843

ARMSTRONG FLIGHT RESEARCH CENTER
N804NA
NASA
804