

Measurement Accuracy and Uncertainty Analysis of the X-59 Air Data Probe Calibration Test Entry One

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Outline

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- Test Setup
- Calibrated Test Section Analysis
- Air Data Probe Pressure Analysis
- Air Data Probe Orientation Analysis
- Conclusions





Introduction: Air Data Probe Calibration Tests

- The NASA commissioned the development of the X-59 to demonstrate quiet sonic boom technology.
- In support of the aircraft development, two theoretically identical air data probes were tested at the NASA Glenn Research Center's 8- by 6-Foot Supersonic Wind Tunnel.
- One probe would become the **installed flight hardware** nose probe responsible for the X-59's computed airspeed, pressure altitude, angle of attack, and angle of sideslip while the other would be a backup.
- Testing was required in order to generate the air data probe calibration curves and spanned two test entries (Spring 2021 and Winter 2022).
- This presentation will focus only on data acquired during the Spring 2021 test entry.



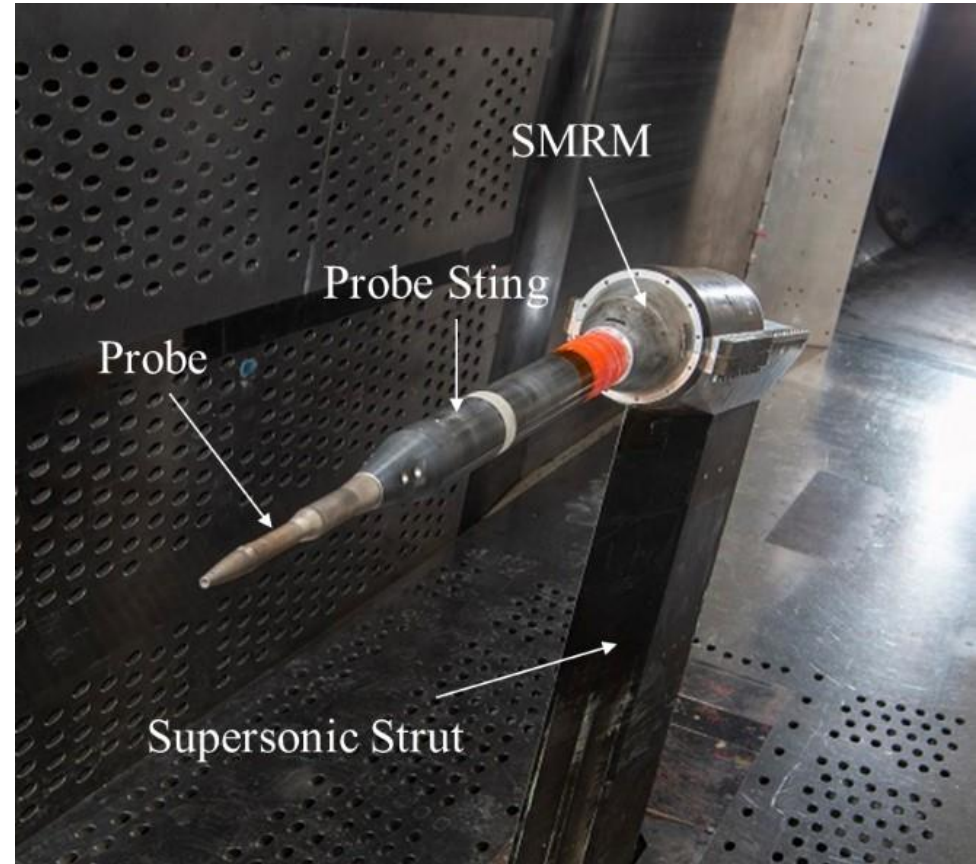
Introduction: Measurement Accuracy and Uncertainty Analysis

- A measurement accuracy and uncertainty analysis was performed to better understand the uncertainties in the calibration curves quantities of interest.
- This is important to demonstrate confidence in the air data system for safety of flight.
- All uncertainties are quoted at 95% confidence level (i.e., two sigma)
- For brevity, only select results will be presented as additional information can be found in the paper.

Test Setup



- Setup included:
 - A Multi-Function Air Data Probe
 - Probe Sting
 - Small Model Roll Mechanism (SMRM)
 - Supersonic Strut



Multi-Function Air Data Probe



- Pressure Ports:
 - One total pressure (p_t)
 - Four-manifolded static pressure (p)
 - Two angle of attack pressures (p_{AoA})
 - Two angle of sideslip pressures (p_{AoS})

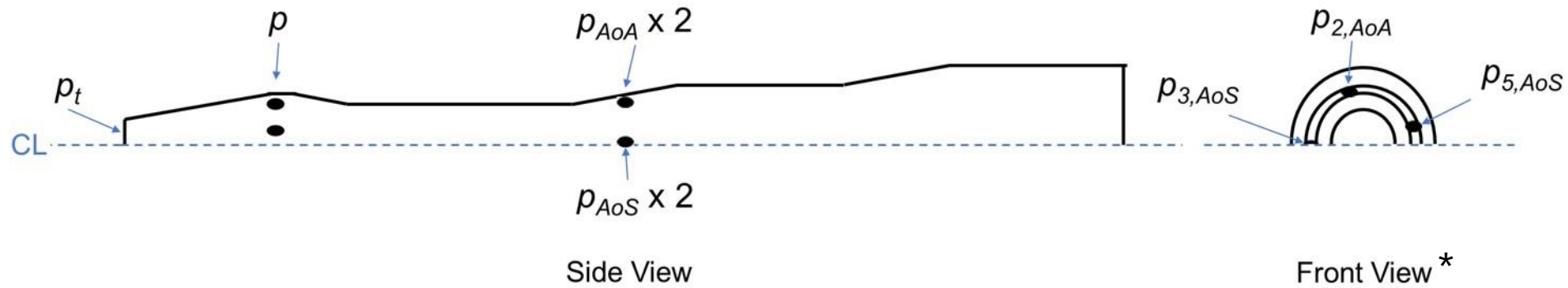


Diagram not to scale

* Omits static and total pressure ports for clarity

Calibrated Test Section Analysis: Overview



- Calibration of the wind tunnel test section was performed in 2019
- The calibration included obtaining measurements of:
 - Static Pressure
 - Total Pressure
 - Total Temperature
- Pressures were measured using ± 15 psid Electronically Scanned Pressure (ESP) modules.
- Temperatures were measured using K-type and E-type thermocouples.

Device	Accuracy	Uncertainty
ESP Module	± 0.0075 psi	0.0092 psi*
K-type Thermocouple	-	$\pm 1.98^{\circ}$ R
E-type Thermocouple	-	$\pm 1.80^{\circ}$ R

*accounts from thermal effects

Calibrated Test Section Analysis: Results



- Uncertainties in the test section Mach number, static pressure, and total pressure increased when the flow was supersonic.
- Min test section total temperature uncertainty was 1.01° R.
- Max test section total temperature uncertainty was 1.17° R.
 - Max uncertainty corresponds to calibrated test section Mach 0.90 condition

Calibrated Test Section Mach 0.25 – 0.95

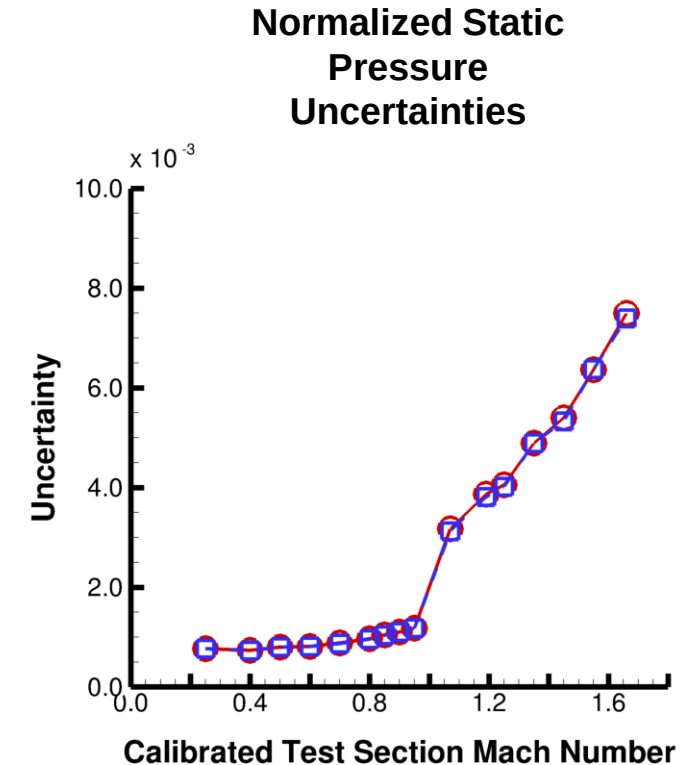
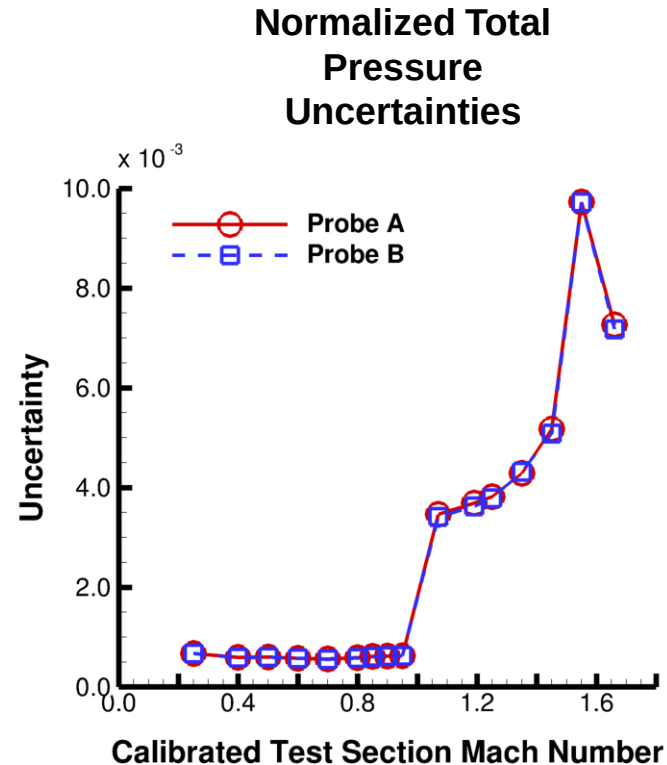
Uncertain Parameter	Min	Max
Test Section Mach Number	0.0006	0.0013
Test Section Static Pressure	0.0062 psi	0.0067 psi
Test Section Total Pressure	0.0034 psi	0.0051 psi

Calibrated Test Section Mach 1.07 – 1.66

Uncertain Parameter	Min	Max
Test Section Mach Number	0.0039	0.0077
Test Section Static Pressure	0.0267 psi	0.0322 psi
Test Section Total Pressure	0.0590 psi	0.1764 psi

Air Data Probe Pressures Analysis - 1

- Air data probe pressures normalized by respective test section pressures
- Quoted uncertainty values are for when the air data probes were level at 0° roll
- Uncertainties jump when the flow goes supersonic



Air Data Probe Pressures Analysis - 2



- Average differences in the uncertainties between the two probes are nearly identical.
- Max probe uncertainties are nearly two orders of magnitude higher than the average differences.
- Probe A and Probe B can be considered statistically the same.

	Normalized Total Pressure Uncertainties	Normalized Static Pressure Uncertainties
Average Difference ($\times 10^{-5}$)	2.51	2.88
Maximum ($\times 10^{-5}$)	973	998

Air Data Probe Orientation Analysis



- Air data probe roll angle measured using an Avago Technologies (AT) HEDL-5540 encoder installed inside the SMRM.
- Air data probe pitch angle measured using a Q-FLEX QA-2000 accelerometer.

Device	Accuracy	Uncertainty
AT HEDL-5540	0.007°	0.2°*
Q-FLEX QA-2000	0.005°	0.005°

*measured slop as installed in the SMRM

Uncertain Parameter	Uncertainty
Yaw Angle	0.00034°
Pitch Angle	0.01416°

Conclusions



- A measurement accuracy and uncertainty analysis was performed from data obtained during the first test entry.
- All uncertainties were small and within the acceptable ranges.
- The two air data probes were shown to be statistically identical.
 - Important as it implies that the backup probe will give data consistent with the primary installed flight hardware nose probe.
- All of the above leads to more confidence in the flight air data system.

Acknowledgements

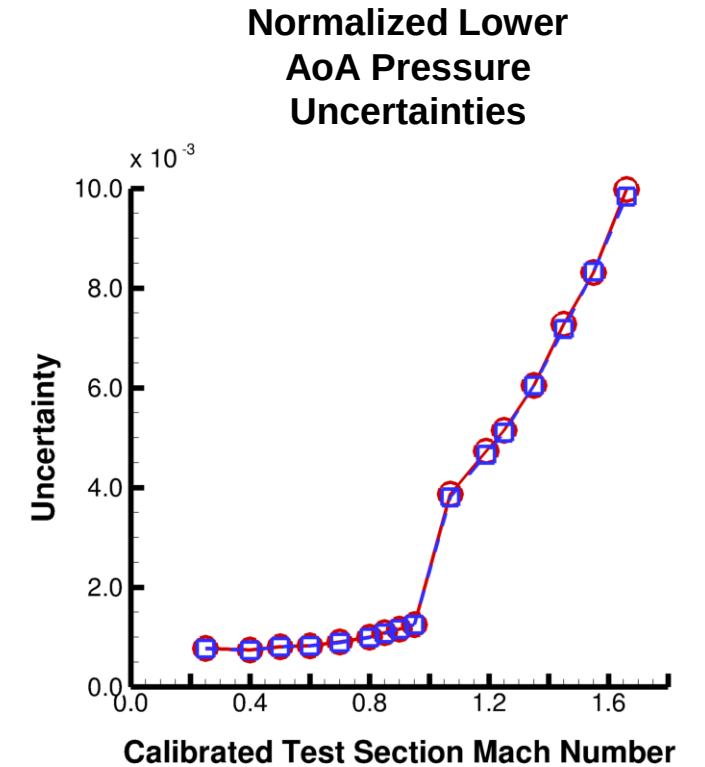
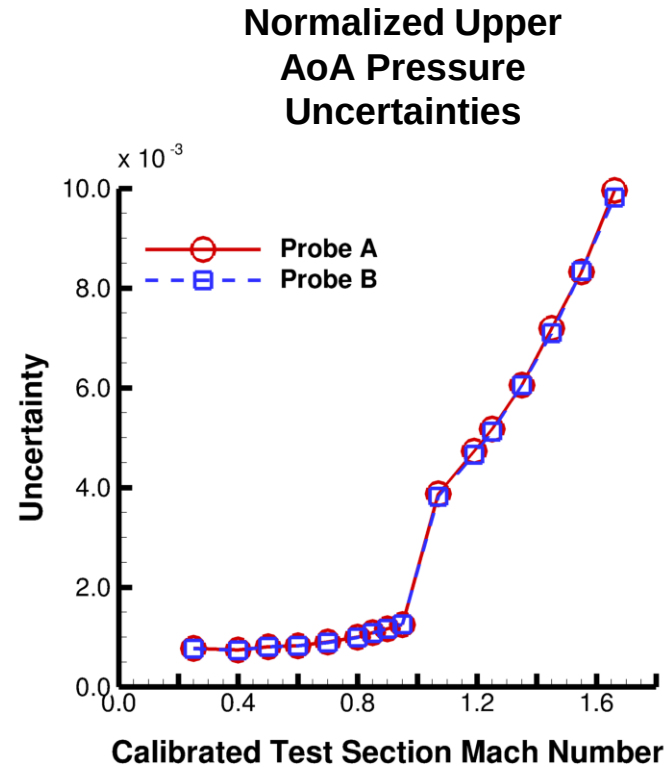


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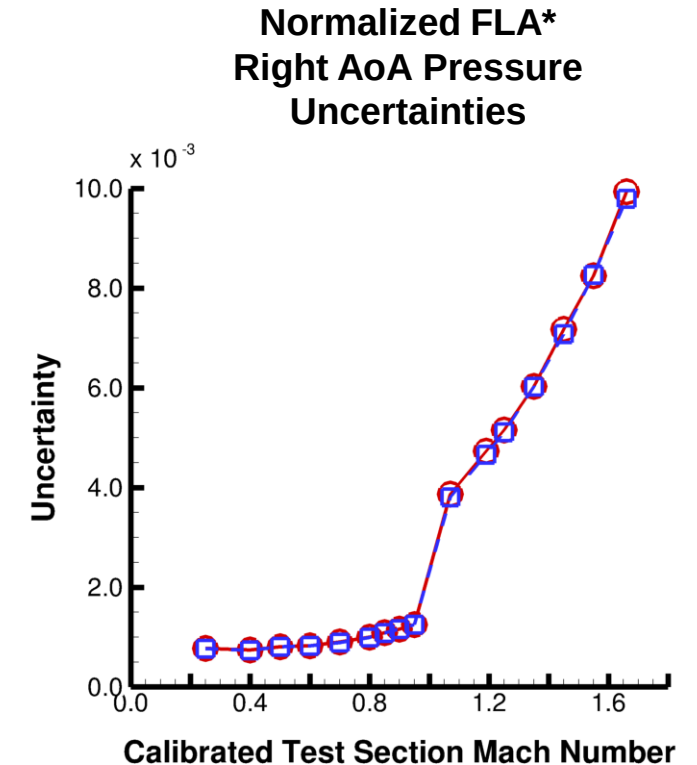
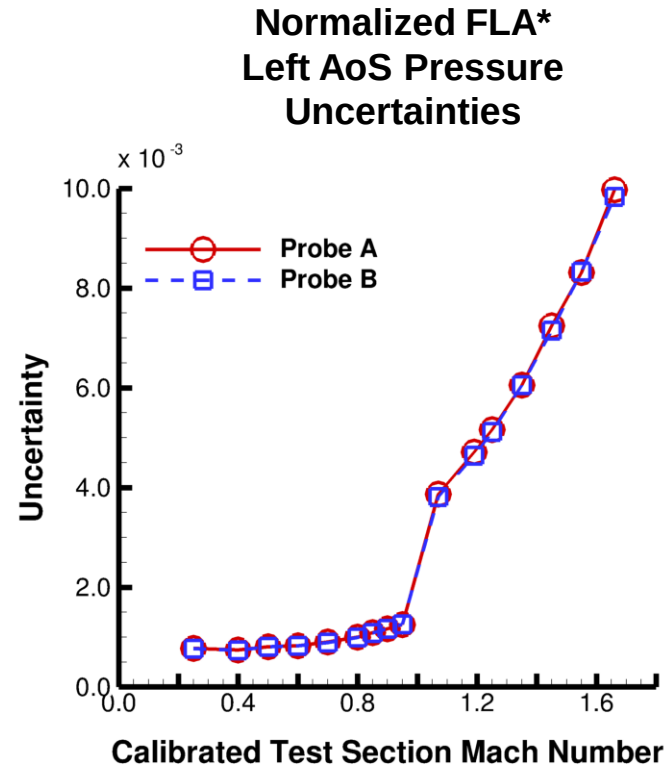
Air Data Probe Pressures Analysis – Angle of Attack (AoA)

- Normalized AoA pressure uncertainties show similar trends to the normalized static pressure uncertainties.



Air Data Probe Pressures Analysis – Angle of Sideslip (AoS)

- Normalized AoS pressure uncertainties show similar trends to the normalized static pressure uncertainties.



* FLA: Forward Looking Aft