Flight and Ground Operations in Support of Airframe Noise Reduction Tests

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Airframe Noise Reduction Tests

- **Armstrong Flight Research Center referred to the Airframe Noise Reduction Tests as the Acoustics Research Measurements (ARM) Flights**
- **Flights Conducted with two of NASA's GIII Aircraft**
    - SubsoniC Research Aircraft Testbed (SCRAT)
    - NASA 808
- **ARM's Goal was to examine the acoustic benefits of LAGER and ACTE technologies**
    - Also explored synergistic benefits of the two technologies
- **All flights took place at Edwards AFB**
- **AFRC developed the LAGER hardware with LaRC input**

LAnding Gear noisE Reduction (LAGER)

- Examine acoustic benefits of main landing gear fairing and main landing gear cavity treatments
- PI – Mehdi Khorrami LaRC

Seamless Trailing Edge ACTE Acoustics Measurements (STEAAM)

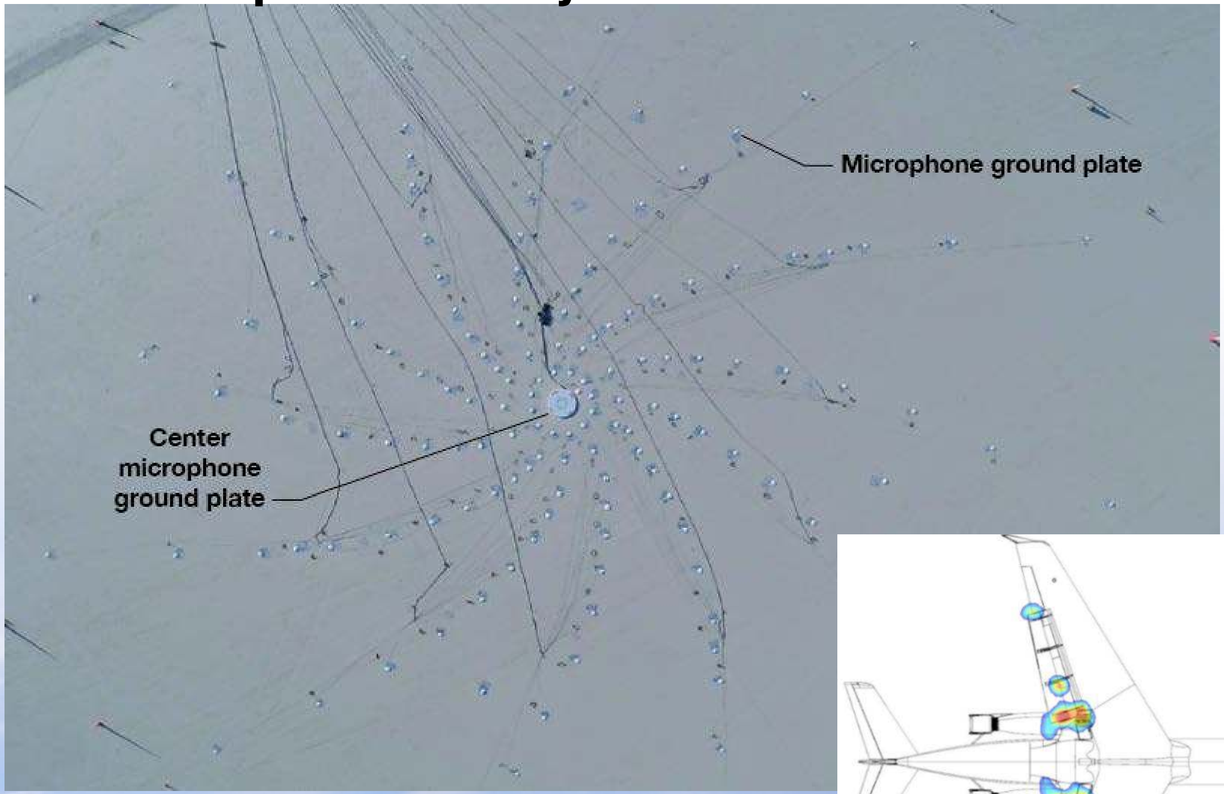
- Examine acoustic benefits ACTE technology
- PI – Steve Cumming, AFRC

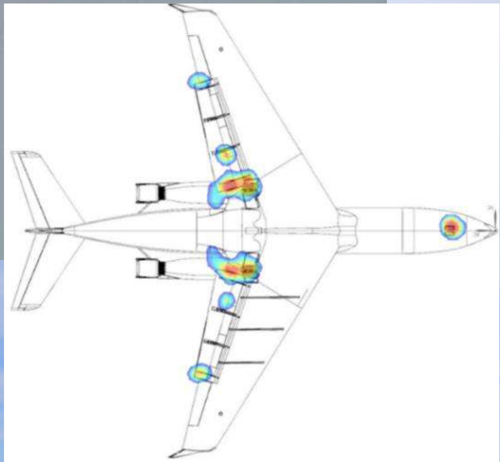
ARM Flight Campaigns

- **The ARM data was collected over three separate flight campaigns.**
  - Aircraft availability and favorable weather conditions drove the timing of the flight campaigns to be in the fall or the spring.
- **ARM I flights - August 24, 2016 and October 5, 2016**.
  - Quantification of the in-situ microphone array performance.
  - Gathered acoustic baseline data for SCRAT and NASA 808
  - Allowed for a preliminary assessment of the acoustic benefits of the ACTE flaps.
  - 16 flights total – 3 practice and 13 where acoustic data was acquired.
- **ARM II flights - August 10, 2017 and October 12, 2017.**
  - Quantification of the acoustic benefits of LAGER MLG fairings, chevron cavity treatment, and mesh cavity treatment in conjunction with the ACTE technology.
  - 17 flights total - 2 LAGER hardware envelope expansion and 16 where acoustic data was gathered.
- **ARM III flights - March 20, 2018 and May 3, 2018.**
  - Flights with both NASA 808 and the SCRAT after the removal of the ACTE flaps, which allowed for a direct assessment of the acoustic benefits of the ACTE flap.
  - Gathered further data with the LAGER hardware.
  - 17 flights total

Beam-Forming Acoustic Array

- **NASA Langley Research Center (LaRC) provided beam-forming acoustic array for noise measurements**
- **Beamforming Array developed by LaRC to measure aircraft noise level and develop noise contour maps to identify noise sources.**
  - 185 Array Microphones
    - 1 Center plate with 49 microphones
  - 136 Ground plates
  - 5 Certification microphones
  - 8 Ground Calibration Speakers
  - Array can also be calibrated via a microphone off of a sUAS.





SubsoniC Research Aircraft Testbed (SCRAT)

- GIII acquired and developed into a SubsoniC Research Aircraft Testbed
- Flight Research quality Instrumentation System developed and installed on SCRAT.
- Telemetry System installed on SCRAT.
- SCRAT Power System modified.
- Aircraft cabin modified to be reconfigurable and allows for researchers to fly along with their experiments
- Extensive data collected to characterize aircraft.
- Aircraft currently available for new work.

Benefits:
- ✓ GIII is capable of supporting a wide range of aeronautics related research.

Benefits:
- ✓ Instrumentation System and Sensors will provide high quality flight data suitable for conducting flight research

Benefits:
- ✓ Allows for control room monitoring during envelope expansion for additional researchers to monitor research flights.

Benefits:
- ✓ Power System flexible enough to allow for future research experiments

Benefits:
- ✓ Cabin can be configured to accommodate a wide range of flight experiments.
- ✓ Researchers can fly along with their experiments and monitor progress real-time without the need for a control room.

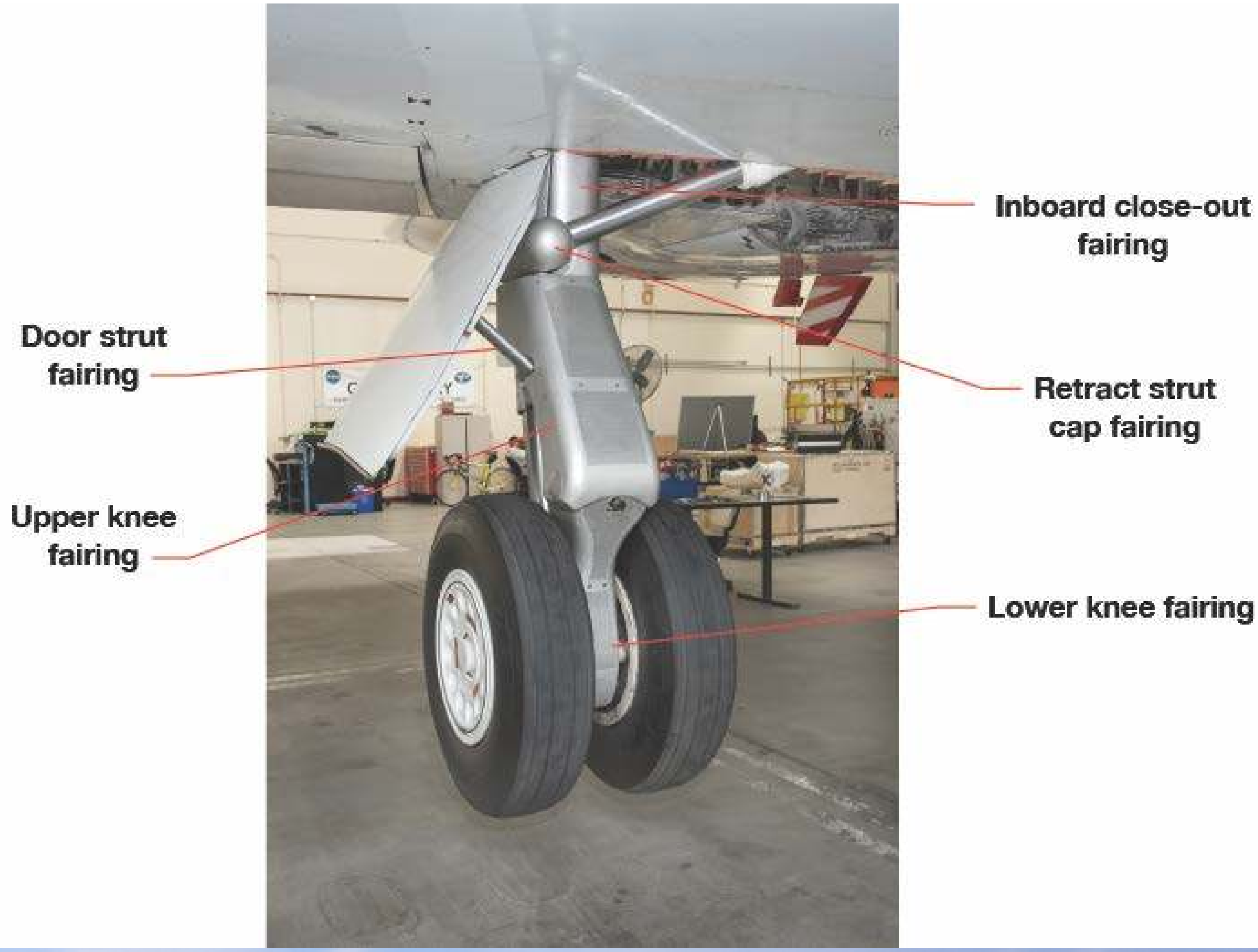
Benefits:
- ✓ Verifies & Validates SCRAT's usefulness as a testbed for aeronautics experiments.
- ✓ Gathers flight data that will be used by follow-on flight research experiments.
- ✓ NASA has a transport class testbed aircraft for developing aeronautics technologies.

Adaptive Compliant Trailing Edge

- AFRL and NASA's Environmentally Responsible Aviation (ERA) Program developed the Adaptive Compliant Trailing Edge (ACTE) flaps as a technology demonstration, which was not meant to be representative of a production system.
- FlexSys, Inc. designed and manufactured the ACTE flaps
- Compliant flap replaced both SCRAT fowler flaps
  - Flap geometry was approximately 19ft in span for each surface
- ACTE flap provided a seamless trailing edge.
- ACTE flown at various flap settings ranging from 0° to 30°.
- ACTE Flaps removed from SCRAT Fall 2017.

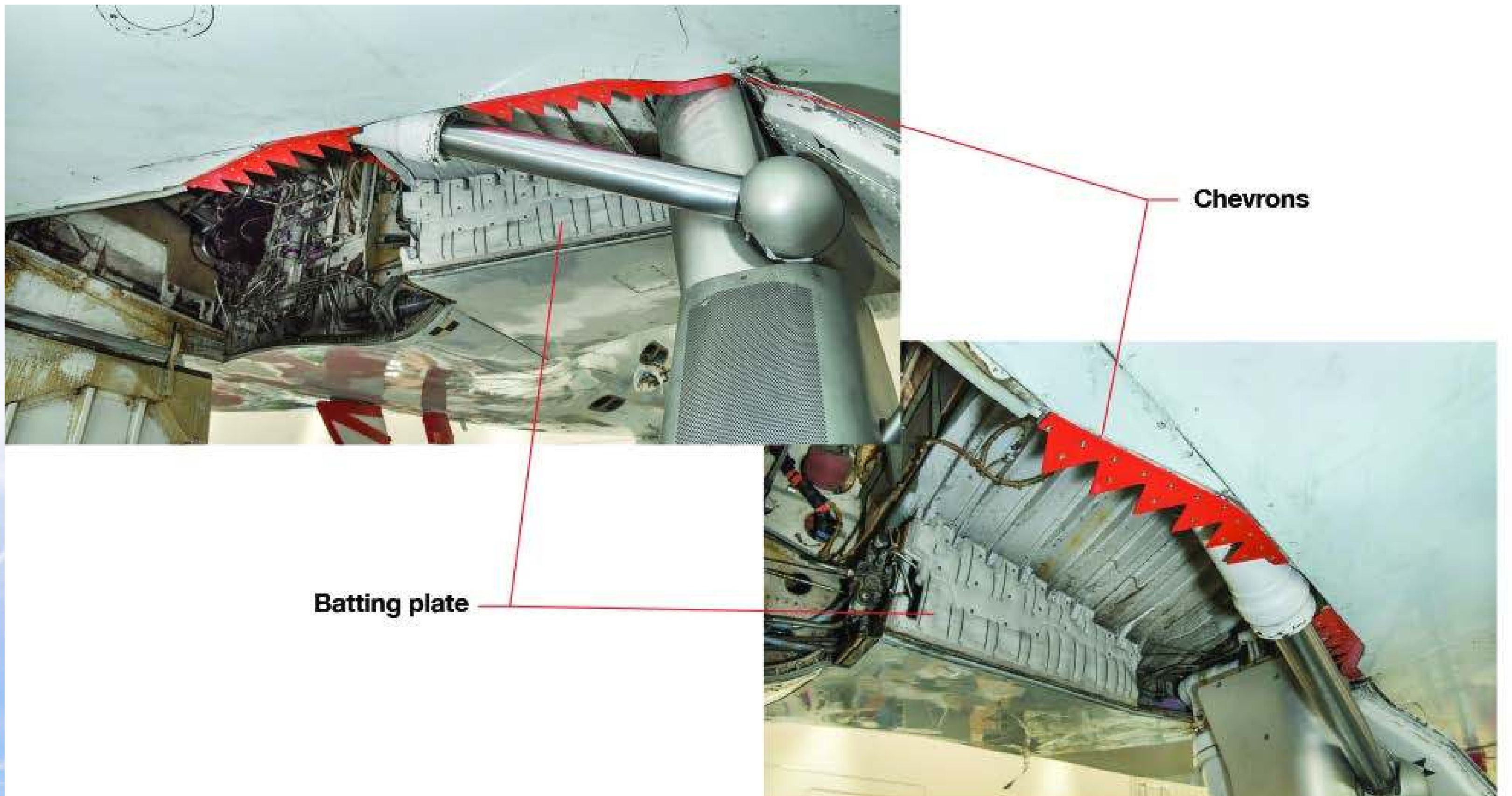
LAGER Main Landing Gear (MLG) Fairings

- MLG Fairings developed as a technology demonstration; they are not representative of a production system.
- MLG Fairings did not allow for landing gear retraction
- MLG fairings manufactured out of aluminum.
- Total weight of left and right MLG fairings is 90 lb.



Chevron & Batting Plate Cavity Treatment

- Chevron & batting plate cavity treatment not representative of a production configuration.
- Chevron & batting plate cavity treatment did not allow for landing gear retraction.
- Total weight of left and right chevron & batting plate cavity treatments is 8 lb.



Mesh Cavity Treatment

- Mesh cavity treatment not representative of a production configuration.
- Mesh cavity treatment did not allow for landing gear retraction.
- Total weight of left and right mesh cavity treatments is 7 lb.

LAGER MLG Fairing Tire Clearance

- **MLG Fairing Tire Clearance proved to be a challenge**
  - Team initially mis-calculated the manufacturer's tire clearance requirements.
  - Tire Clearance was not checked with the 3-D printed prototypes used to verify fit-up on the MLG.
  - MLG fairings had to be trimmed in order to fit on SCRAT.
  - Minor differences in fit-up and tires and positioning between SCRAT and NASA 808 required even further trimming.
- **AFRC's Fabrication Shop proved to be invaluable in modifying the MLG fairings for flight.**

	Required clearance, in.
Radial clearance	1.24
Lateral clearance	0.60
Clearance from tire rim	0.25
Shoulder clearance	0.64

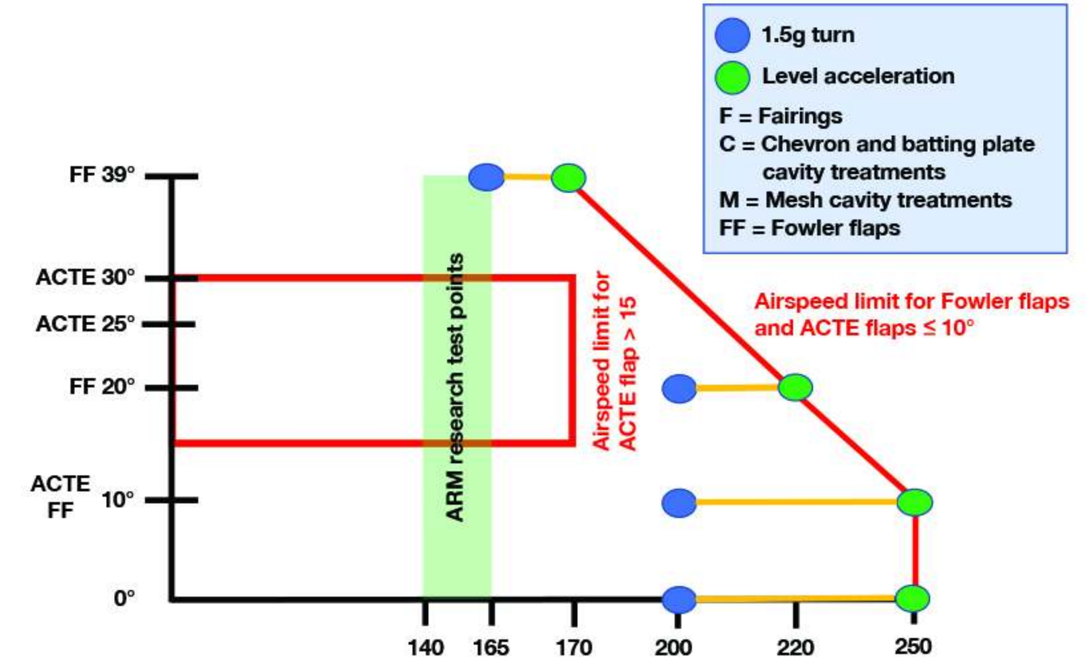
LAGER Hardware Airworthiness Approach

- **Due to AFRC's ability to self-certify aircraft modifications and operate both SCRAT and NASA 808 as public use aircraft, a tailored approach was developed to demonstrate LAGER hardware airworthiness for the ARM flights.**
  - ARM team's approach to qualifying the LAGER hardware would not be an acceptable certification approach for a production system, which would require further testing.
- **LAGER hardware conservatively designed.**
  - Factor of Safety of 2.25
  - Aerodynamic loads conservatively estimated.
- **Two taxi tests performed to demonstrate the MLG fairing hardware did not significantly increase brake temperatures.**

LAGER Hardware Airworthiness Approach

- **Three envelope expansion flights flown to demonstrate LAGER hardware in-flight.**
  - 1 flight each to clear the MLG fairings with the two cavity treatments on SCRAT with the ACTE flaps.
  - 1 flight to clear the MLG fairing and one of the cavity treatments with the GIII production fowler flaps.
- **Envelope Expansion flights flew the LAGER hardware to higher airspeeds, higher dynamic pressure, higher g-load, and lower temperatures than would be required for the ARM flights.**

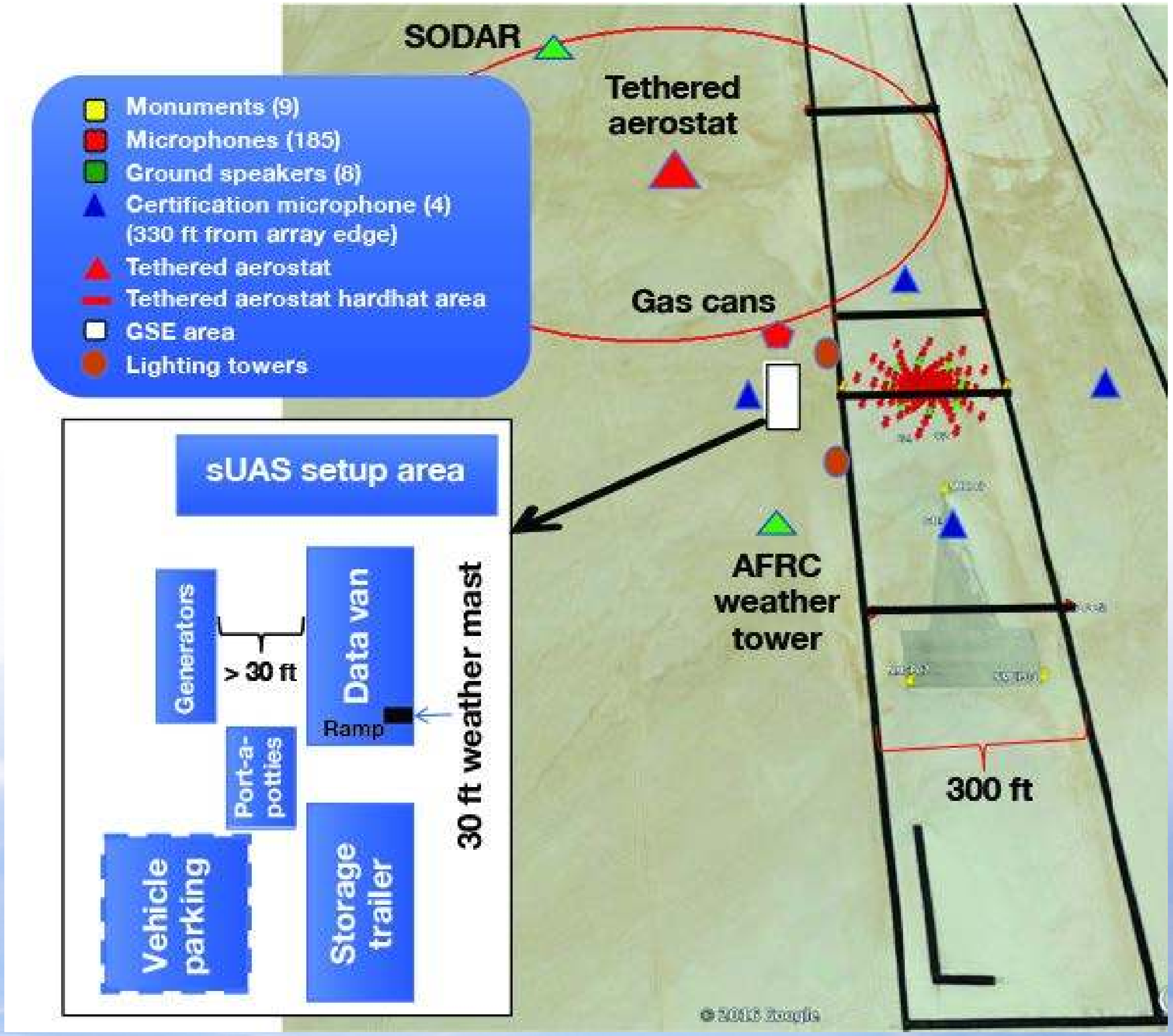
Takeoff
10,000 foot test points -Controllability check -Sideslip to bank check
20,000 foot test points -Wind-up turn to ~1.5g (in reality ~50° bank turn) at 200 KIAS -Level acceleration to the maximum airspeed
10,000 foot test points -Wind-up turn to ~1.5g (in reality ~50° bank turn) at 200 or 170 KIAS -Level acceleration to the maximum airspeed -Controllability check -Sideslip to bank check
Landing



Ground Operations Were Challenging

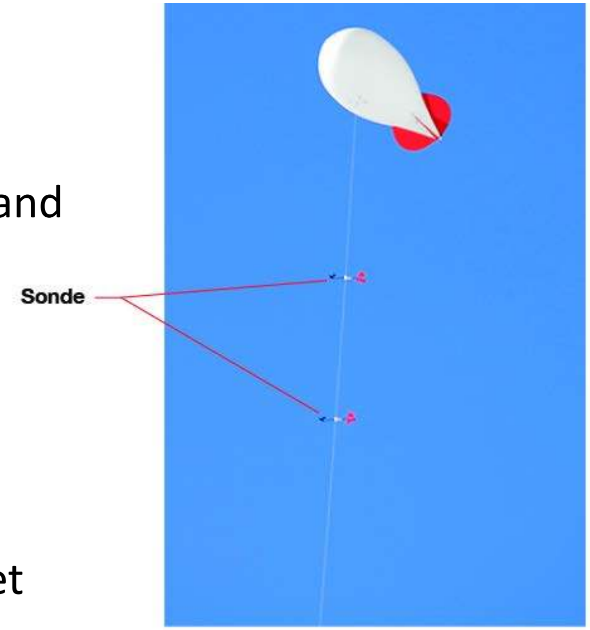
- **Ground operations required extensive coordination with various organizations due to the test locations.**
  - EAFB Airfield Management, Civil Engineering Group, Environmental, Airspace Management, Operations Group Commander, and Frequency Management
  - EAFB office of the National Geospatial-intelligence Agency for all survey work
- **Regular coordination occurred to de-conflict the airspace or frequencies with other EAFB operations on a daily basis during the tests**
- **Ground operations required a large (8-12) daily contingent**
- **Remote location required:**
  - Level III Flight Line Driver's License to drive and operate within the controlled space
  - Special heat stress and wildlife training
  - Significant GSE to support regular operations and for emergencies e.g. waste management, first aid, and emergency response situations were given significant considerations; emergency plans were formed, porta-potties were rented, fire extinguishers, eye wash stations, a spill kit, a first aid kit, and large amounts of water were purchased.
- **Future testers should note that a significant amount of coordination, complicated logistics, and planning is to be expected for any type of field operation and requires a substantial amount of time and labor; readers are directed to "An Overview of Lessons Learned from Sonic Boom Flight Research Projects Conducted by NASA Armstrong Flight Research Center" for a detailed explanation of coordination and logistical planning for similar efforts.**

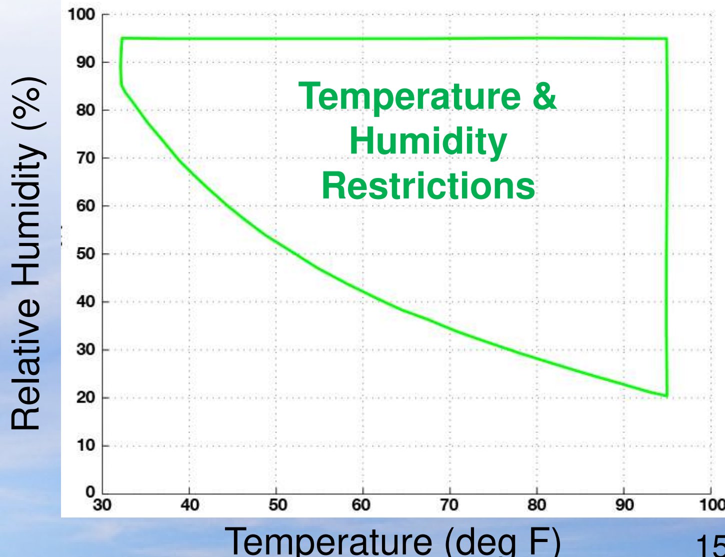
Equipment Layout on Lakebed



Weather Equipment & Restrictions

- **LaRC Data Van Weather Tower – Primary source of ground weather data**
  - Placed near the edge of the microphone array
  - Temperature, Pressure, Relative Humidity, Wind Speed and Direction
- **AFRC Weather Tower – Additional source of weather data**
- **Tethered Aerostat**
  - Inflated Dimensions: 15’ x 6’8” diameter
  - Used to determine the weather profile between 550 feet AGL and the ground before, during, and after the test
- **Mini-SoDAR**
  - Augmented tethered aerostat data by providing wind profile up to 550 feet AGL
- **Temperature and Relative Humidity restrictions in place to maximize data quality**
  - **Wind Restrictions**
    - Maximum Wind Speed < 13 knots
    - Average Wind Speed < 10 knots
    - Maximum Crosswind < 9 knots
    - Average Crosswinds < 6 knots





sUAS for Array Calibration

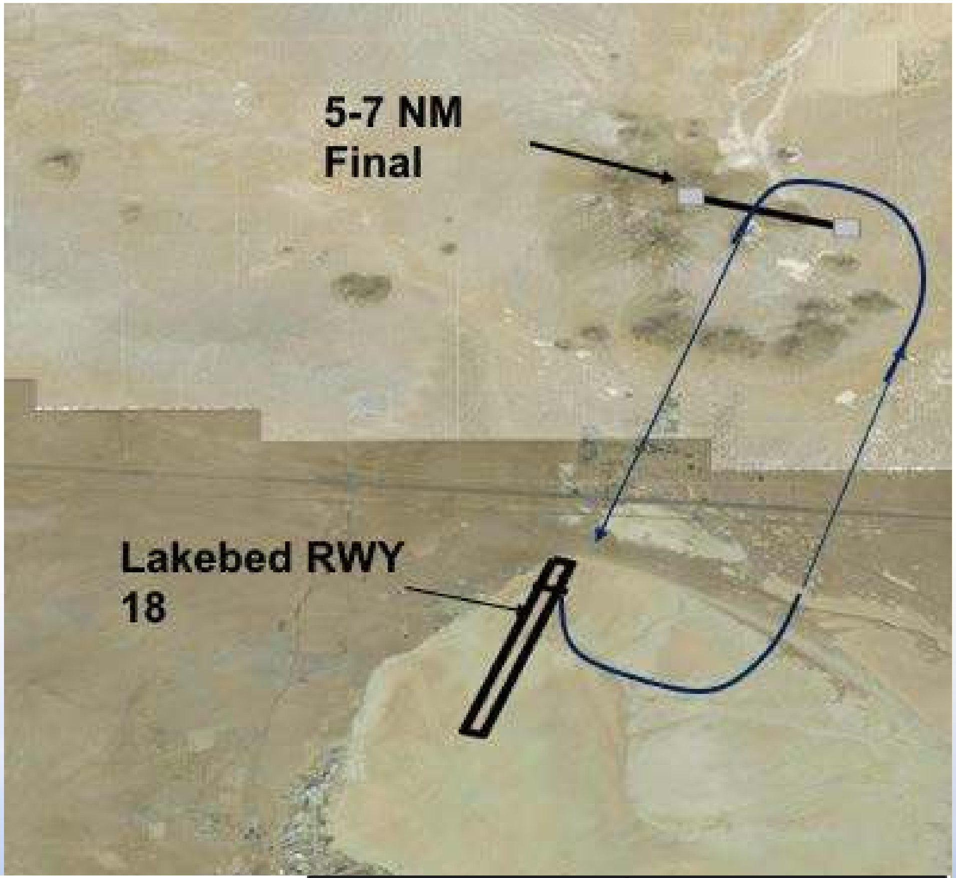
- **DJI Spreading Wing S1000 used for array calibration**
- **sUAS carried a small speaker to play a pure tone.**
- **sUAS dwelled at several altitudes ranging from 100 ft to 350 ft long enough for each pure tone to be played through the speaker.**
- **sUAS equipped with a GPS receiver to provide accurate array calibration**
- **sUAS operations restricted to daylight hours and 26 kt. winds**

Ground & Flight Operations

- Takeoff occurred as close to sunrise as possible in order to maximize favorable weather.
- The ground operations crew would typically arrive at the array site 2-3 hours prior to aircraft take off to begin preparing and calibrating the array for data collection
- The tethered aerostat, mini-SODAR, and a weather mast on the data van were used to evaluate weather throughout the test window.
- sUAS and ground speakers used to calibrate the array throughout the test window.
- AFRC Operations Engineer monitored flights from a control room at AFRC.
- Senior AFRC Representative served as Lakebed Controller, whose responsibilities included overall ground operations and test flow, as well as all test communication with the aircraft.
- Testing halted once an hour for ground speaker calibration and to gather aerostat weather data to 550'.
- Testing continued until aircraft reached a pre-determined minimum fuel state.

ARM I & II Test Point Racetrack Pattern

- **Basic Pattern**
  - 5-7 NM final between 3,300'-7,000' MSL
  - ~6 mins per pattern
  - Throttle to ground idle at ~1 min on final until a few seconds past array center point
- **Practiced approach on downwind leg prior to first pass in a new configuration.**
- **Racetrack Pattern for ARM III modified slightly when acoustic array re-located off of the lakebed to a nearby runway.**



	Nominal	Tolerance
Altitude	350 ft	+/- 50 ft
Offset	0 ft	+/- 35 ft
Airspeed, KIAS	140, 150, 165	+/- 5 kn
Throttle setting	Ground idle	N/A

ARM Test Point Planning

- Prior to each ARM flight campaign, the test team would agree on the aircraft configurations and test points to be flown.
- Each test point would then be prioritized in order to ensure STEAAM and LAGER research objectives were met.
- A flight-test plan document was written for each flight campaign to document the objectives for the flight campaign, the planned aircraft configurations, the planned test points, and the planned detailed flight and ground operations.
- Upfront flight-test planning proved useful as the team experienced maintenance and weather related delays
- Planning provided an invaluable reference to confirm the team was acquiring the required data.
- This information also served as a tool to communicate to team members and management the plans for each ARM flight campaign along with the progress.

Airplane	LAGER MLG fairings installed	LAGER cavity treatment installed	ACTE flap setting	Gear position	KIAS	Number of passes	Flights	Total passes	Priority
SCRAT	No	No	0	Up	140	2	1	2	4
				Up	150	3	1	3	2
				Up	165	3	1	3	4
				Down	140	2	1	2	4
				Down	150	3	1	3	2
				Down	165	2	1	2	4
SCRAT	No	No	25	Up	140	2	1	2	4
				Up	150	3	1	3	1
				Up	165	2	1	2	4
				Down	140	2	1	2	2
				Down	150	3	1	3	1
				Down	165	2	1	2	2
SCRAT	No	Mesh	25	Down	140	3	1	3	2
				Down	150	3	1	3	1
				Down	165	3	1	3	2
SCRAT	No	Chevron and batting plate	25	Down	140	3	1	3	2
				Down	150	3	1	3	1
				Down	165	3	1	3	2
SCRAT	Yes	No	25	Down	140	3	2	6	2
				Down	150	3	2	6	1
				Down	165	3	2	6	2
SCRAT	Yes	Mesh	25	Down	140	3	2	6	2
				Down	150	3	2	6	1
				Down	165	3	2	6	2
SCRAT	Yes	Chevron and batting plate	25	Down	140	3	2	6	2
				Down	150	3	2	6	1
				Down	165	3	2	6	2

ARM Flights & Flight Hours

- **Overall, the ARM flights were accomplished in a safe and successful manner.**
- **Acoustic data acquired for over 1,000 passes.**
- **Researchers were able to quantify the potential of the ACTE and LAGER technologies to reduce airframe noise.**
  - ACTE technology has the potential to reduce airframe noise by approximately 30%

	Flights		
	SCRAT flights	NASA 808	Total
ARM I	12	4	16
ARM II	13	4	17
ARM III	15	2	17
Total	25	8	33

	Total flight hours
ARM I	38.7
ARM II	42.1
ARM III	49.7
Total	80.8

	Research passes		
	Number of passes within altitude and offset required	Total number of passes	Percentage of good passes
ARM I	234	279	84%
ARM II	277	307	90%
ARM III	419	465	90%
Total	930	1051	88%

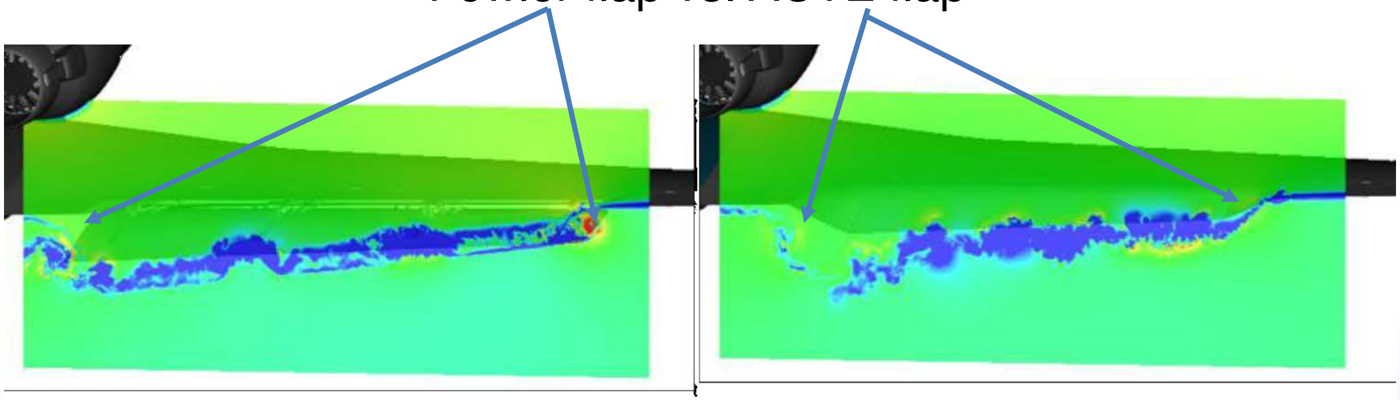
Additional Challenges

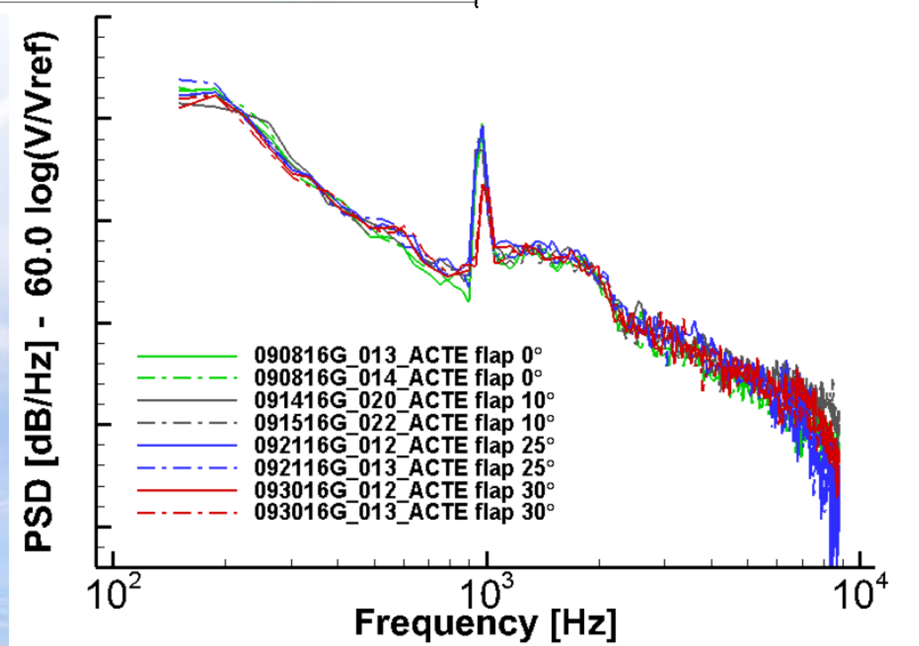
- **The actual number of flights flown was less than desired but determined to be adequate in terms of collecting the minimum required dataset.**
- **Temperature, humidity, and especially winds were oftentimes outside of the restrictions, thereby limiting the allowable flight days.**
- **Array location required significant coordination and occurred the risk of being denied access if significant rainfall realized.**
  - Array was relocated to a nearby runway off of the lakebed for ARM III to minimize the potential impact of seasonal rains on the test location.
- **For the ARM flights, the ACTE flaps were flown far more and for longer times at higher flap deflections than they had been originally intended to be flown.**
  - Resulted in additional inspections
  - ACTE flaps were manually actuated, which required a full day to perform.
- **SCRAT and NASA 808 experienced a number of unplanned maintenance issues, which resulted in lost flight opportunities.**

Flight Test Results

- **The continuous OML enabled by the ACTE flaps significantly decreased the noise signature (>3dB) over the conventional Fowler flaps.**
- **Deflected flaps did not significantly increase noise signature**

Fowler flap vs. ACTE flap

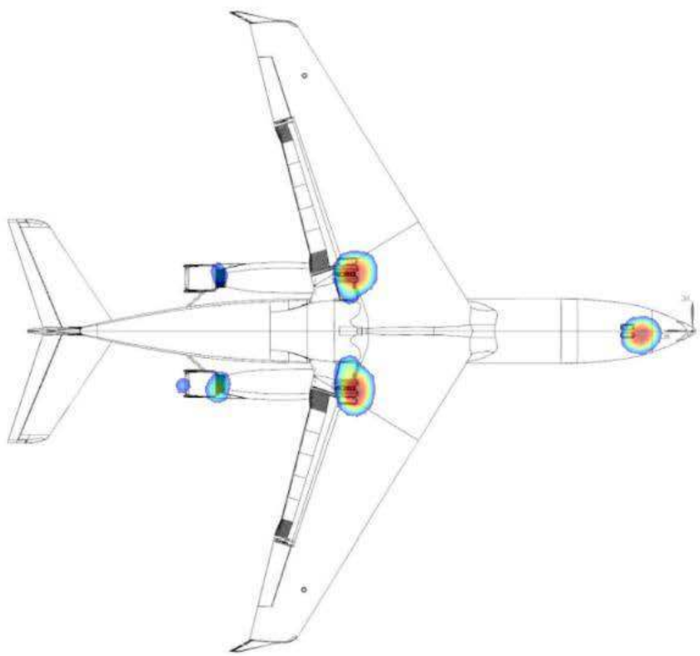




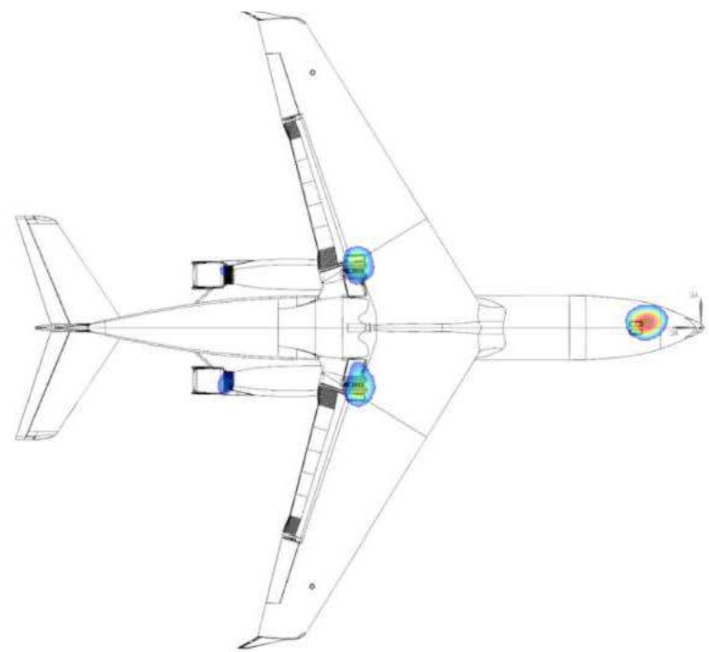
Flight Test Results

- **The noise reduction provided by ACTE allowed for a more accurate evaluation of the LAGER noise reduction effects**
- **With ACTE deflected to 25 degs, a comparison with and without the LAGER hardware installed showed a reduction of about 4dB**

GIII with ACTE at 25 degs, without LAGER hardware



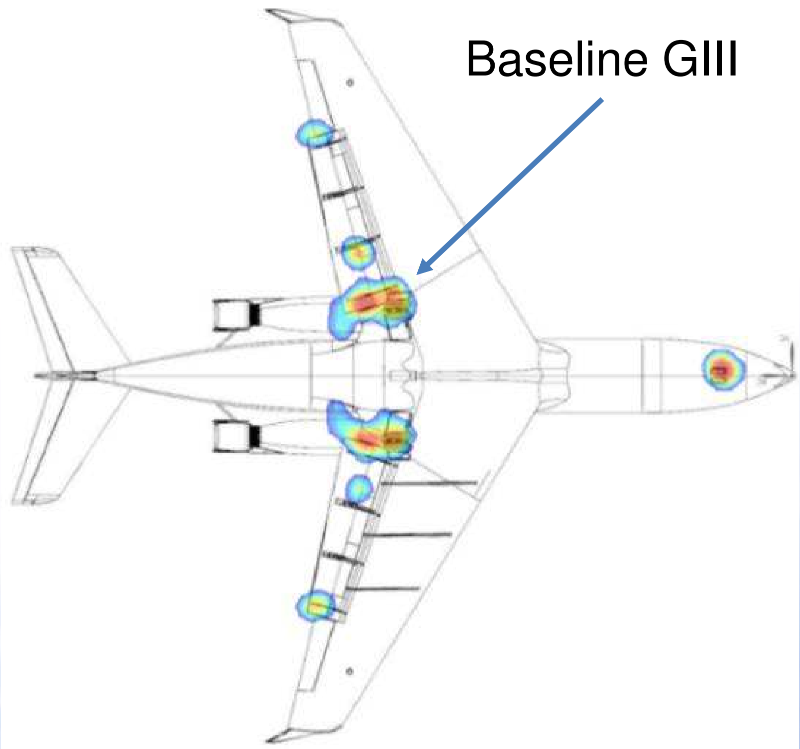
GIII with ACTE at 25 degs, with MLG fairings, chevron, and batting



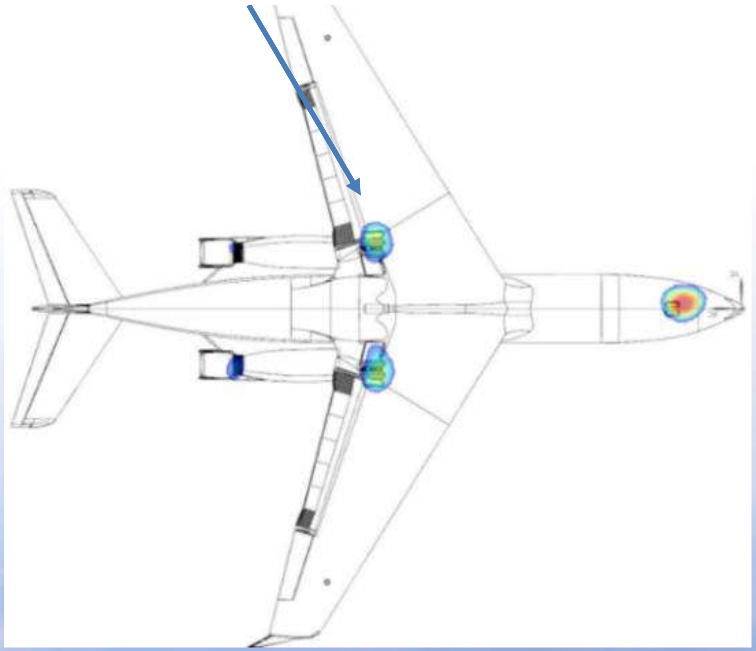
Flight Test Results

- **The combination of ACTE at 25 degs, MLG fairings, cavity chevrons, and batting reduced low-frequency noise levels by 4 – 5 dB (70% reduction in airframe noise)**

Baseline GIII



GIII with ACTE 25 degs, Gear Fairings, Chevrons and Batting



Conclusion

- **The ARM flight and ground operations were accomplished in a safe and successful manner.**
  - The test team was in constant communication and was able to adjust flight plans on very short notice. This flexibility and communication proved key to maximizing the number of ARM flights
- **Data acquired demonstrates the noise reduction benefits of the Adaptive Compliant Trailing Edge (ACTE) flaps, the LAnding Gear noisE Reduction (LAGER) main landing gear fairings, and the LAGER main landing gear cavity treatments.**
- **Preliminary analysis data collected showed the ACTE technology has the potential to reduce airframe noise by ~30%.**
- **The ARM flights gathered over 1,000 over passes of data for numerous aircraft configurations.**
  - This extensive dataset will be used to definitively quantify the acoustic benefits of the ACTE and LAGER technologies.

Questions???