Learjet Acoustics Flight Test

An Initial Look

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NASA Advanced Air Vehicles Program
Commercial Supersonic Technology Project

Airport Noise Prediction Uncertainty Reduction Tech Challenge

Objective

– Reduce uncertainty of system studies of commercial supersonic aircraft.

– Extend empirical models to cover supersonic **fan** and **jet** propulsion configurations.

Approach

– Validate physics-based simulations against rig tests of conventional configurations.

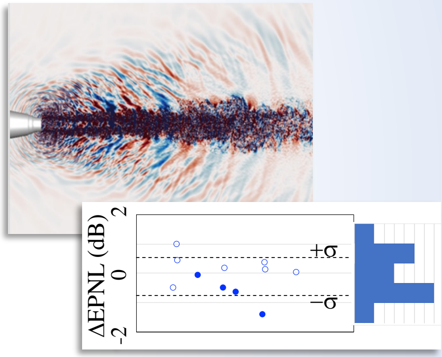
– Simulate noise of supersonic configurations to create extended noise database.

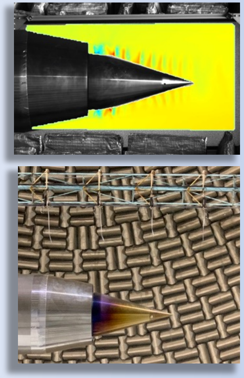
– Improve empirical models using extended database.

Key tasks highlighted at Spring 2023 ATWG:

– Establish and validate best practices for simulations of jet noise.

– Establish connection between jet noise measured in rig and flight tests.





NASA TEAM

Flight Test: Learjet 25 at Niagara Falls International Airport (KIAG)

NASA Glenn – Acoustics, GPS Positioning, Instrument Review & LiDAR (Langley)
Brenda Henderson (PI), Lennart Hultgren (co-PI), Devin Boyle, Jordan Cluts, Alexander Svetgoff

NASA Glenn – Airworthiness (CDR/FRR), GPS Trial Flights (T-34C)
Jeff Polack, Matt Fakler, Kurt Blankenship, Mark Russel, Stephen Plaskon

NASA Langley – Drone Weather Measurements
Jacob Revesz, Jennifer Fowler, Mark Motter, Mark Frye, Scott Sims

Scale-Model Test Data, Overall Data Processing & Analysis

NASA Glenn AAPL/NATR
Brenda Henderson

NASA Glenn Data Processing and Analysis
Brenda Henderson, Lennart Hultgren

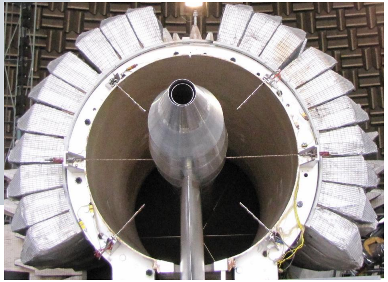
INTRODUCTION

Motivation/Objective/Significance

- Improve ability to predict takeoff noise of future supersonic aircraft
- Validate/Improve application of semi-empirical jet-noise prediction to flight noise
- Expect improvement in noise prediction methods for system studies of future commercial supersonic aircraft

Approach

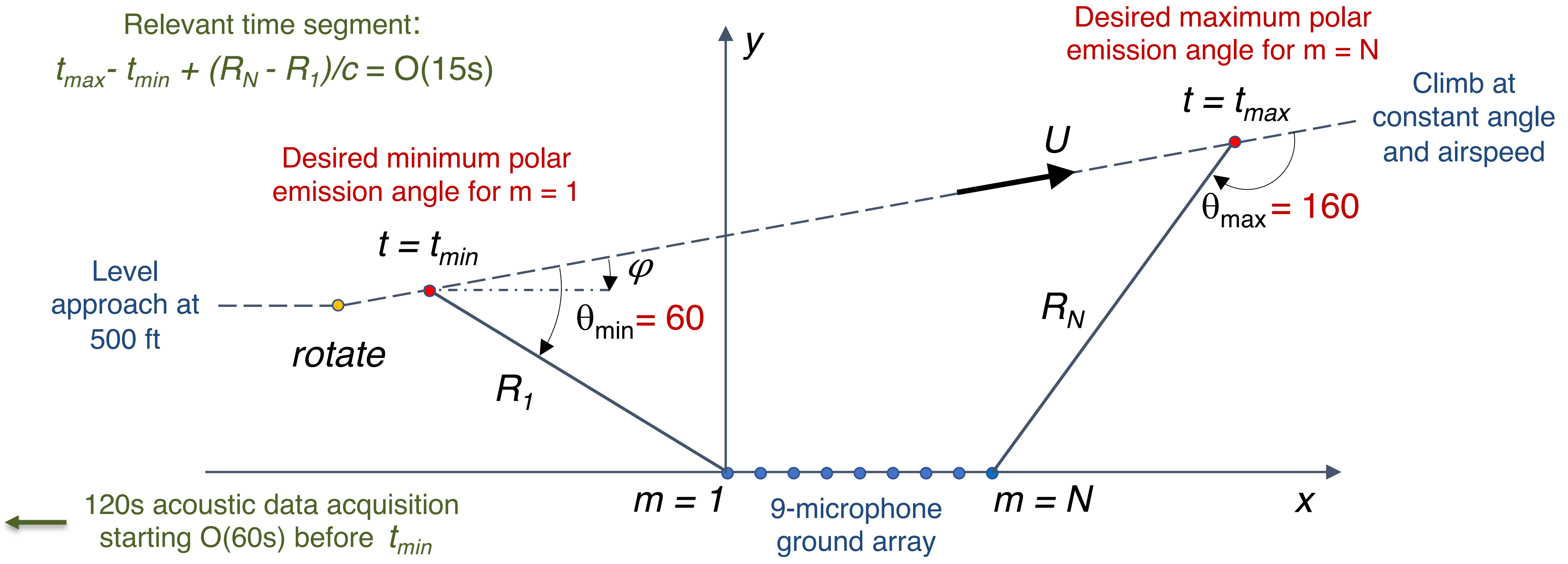
- Fully process and document flyover data
- Compare facility and flight acoustic data
- Develop flight correction model as needed



FLIGHT TEST – KIAG, September 1 & 8, 2022

- Learjet 25/CJ610 aircraft selected to ensure jet-noise dominated source
- Aircraft owned and operated by Calspan Corporation (under NASA Contract)
- Research instrumentation on aircraft for continuous recording of position (NASA) and select engine/aircraft data (Calspan; EPR, EGT, RPM, static & dynamic P_{pitot})
- 9-microphone linear array on the ground
- LiDAR for wind measurements
- Langley drone for atmospheric measurements
- 4 sorties over 2 days – total of 73 flyovers
- Aircraft flown at constant climb angles
- No flaps or landing gear deployed
- One engine at idle
- All data timestamped based on GPS

FLIGHT PROFILE



- Level-flight approach, one engine idle -> then rotate
- Climb at constant angle to keep airspeed constant for flyover throttle setting

AIRCRAFT POSITION PROCESSING – NASA GLENN

NASA GNSS/IMU
Unit on Learjet

Satellite Data

RTKLIB
Post-Processing
O(10 mm) accuracy

NYLP Base Station Data

LLA Position

Coordinate Transformation
LLA -> ENU -> RPY

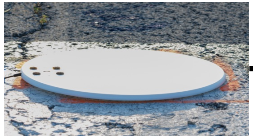
Microphone 1 LLA Position (High Accuracy)

Source-to-microphone distance and travel time

Langley Drone atmospheric data

- Post-processing => high-precision Latitude, Longitude, Altitude data (WGS84)
- LLA turned into local coordinates (East, North, Up), with origin at microphone 1
- ENU turned into aircraft-based spherical coordinates, with zenith direction = roll axis and reference plane defined by pitch and yaw axes
- Microphone 1–9 : distance and reception time for each emission polar angle

ACOUSTIC DATA PROCESSING – NASA GLENN



GRAS 67AX ground array microphone kit
Pre/Post Sensitivity

NI PXIe-4499
24-bit 40kHz

Frequency Response Correction

Microphone Response (Cal Lab)

PSD

Ground & Background Subtraction

First 30s of flyover for each microphone

PSD

Langley Drone
atmospheric data

De-Propagation to Source
spherical spreading and atmospheric attenuation
Average over Microphones

Microphone-averaged PSD

De-Doppler Shift
ground-observer frequency
moving-source frequency

PSD

In Progress

Compare to AAPL/NATR Scaled Data

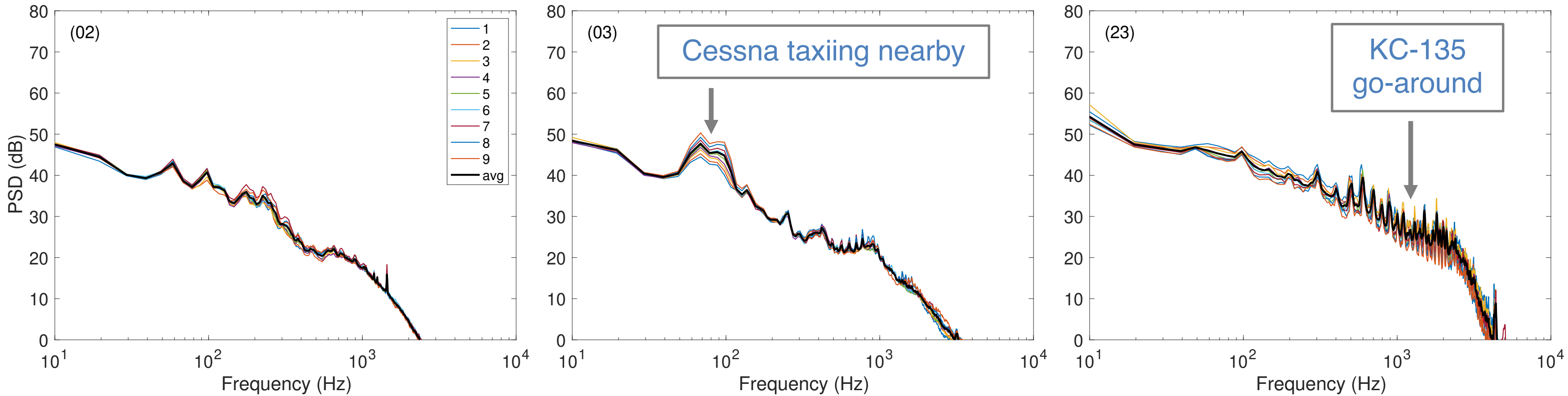
- Spectra computed using 0.512s interval centered about reception time
- $N_{FFT} = 4096$ & pwelch (MATLAB) => 9 averages per microphone & $\Delta f = 9.77$ Hz
- Backgound removal, de-propagation to virtual source sphere, & de-Doppler shift

SOME MIDSTREAM COMMENTS

- One sortie (out of 4), with 19 flyovers, has received due attention so far
- Position and aircraft/engine data continuously recorded during each sortie
  - times, locations, and parameters are known
- Drone flights before, mid, and after sortie
  - drone measurements GPS tagged
  - atmospheric profiles interpolated in time

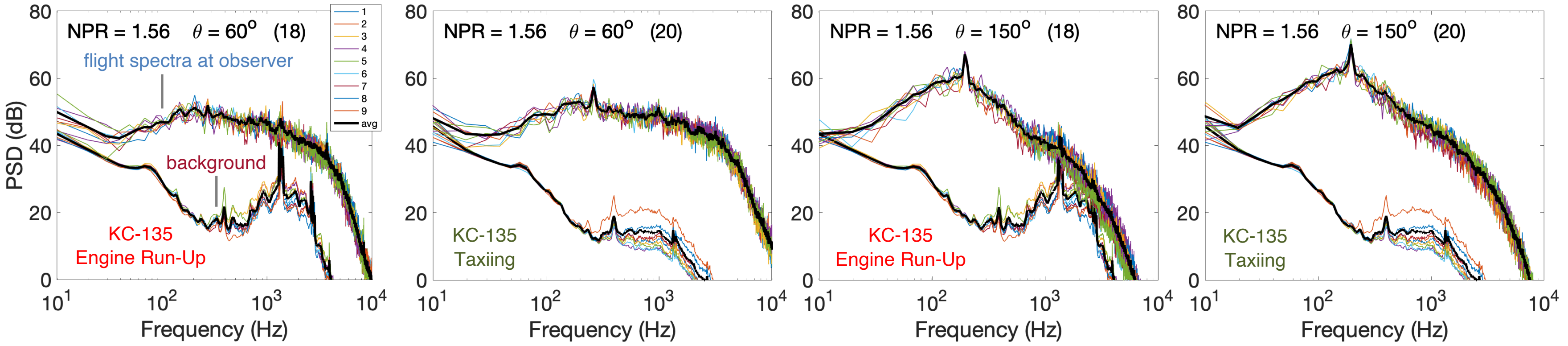
- Microphone array on a decommissioned runway – but the airport is active
- Each sortie ~ 2h duration – determining background-noise levels is crucial issue
- Nominal EPR values 1.5 – 2 range => NPR in 1.55 – 2.1 range
- S/N expected to decrease away from peak emission angle – could be an issue for lower EPR (NPR) settings

BACKGROUND MEASUREMENTS



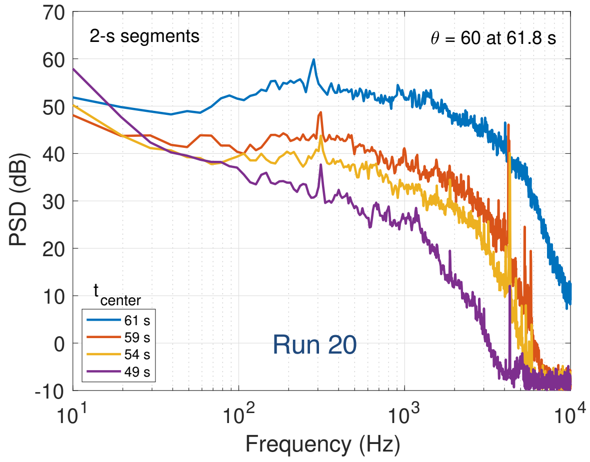
- 120-s backgrounds – (#02) & (#03) before first-sortie flyovers and (#23) after
- Active airport – aircraft could be taxiing during flyovers (no takeoffs/landings)
- Background noise environment is not 'static'
- Procedure: first 30s of each flyover pass determines background levels
  - background noise spectrum unique to each flyover (can reject is S/N is bad)
  - overall data acquisition starts roughly 60s before relevant emission time interval

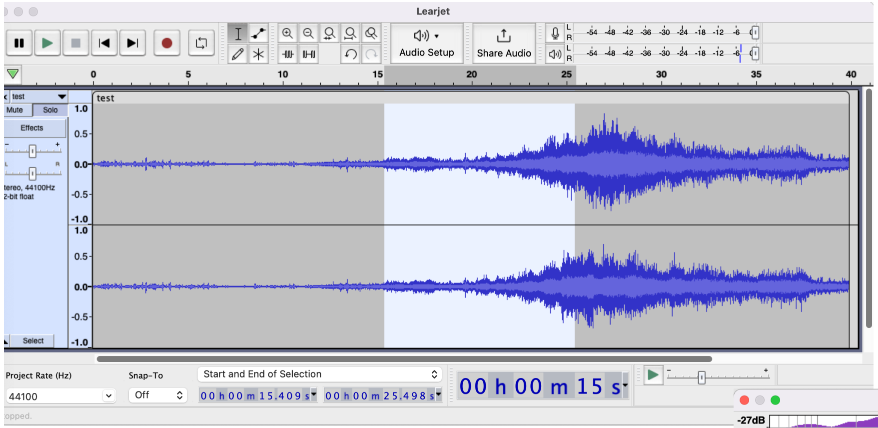
WORST-CASE S/N SCENARIO



- Runs 18 & 20 – level flight – can average 0.512s flight-data over microphones
- 9 x 9 = 81 segments averaged for flight data (top curves)
- Background data – first 30s – 584 segments per microphone (bottom curves)
- Run 18 – KC-135 engine run-up, inlet facing array – S/N is not acceptable
- Run 20 – KC-135 taxiing, inlet parallel to array – S/N is acceptable (except low *f*)

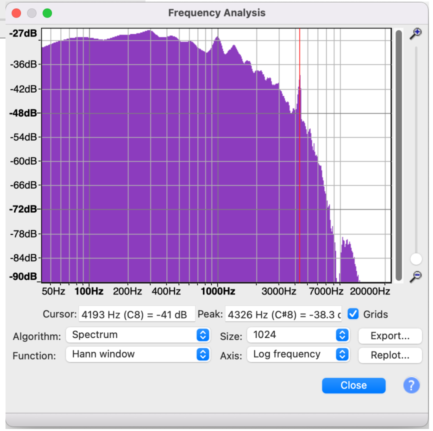
HIGH-FREQUENCY TONE ~ 4 kHz





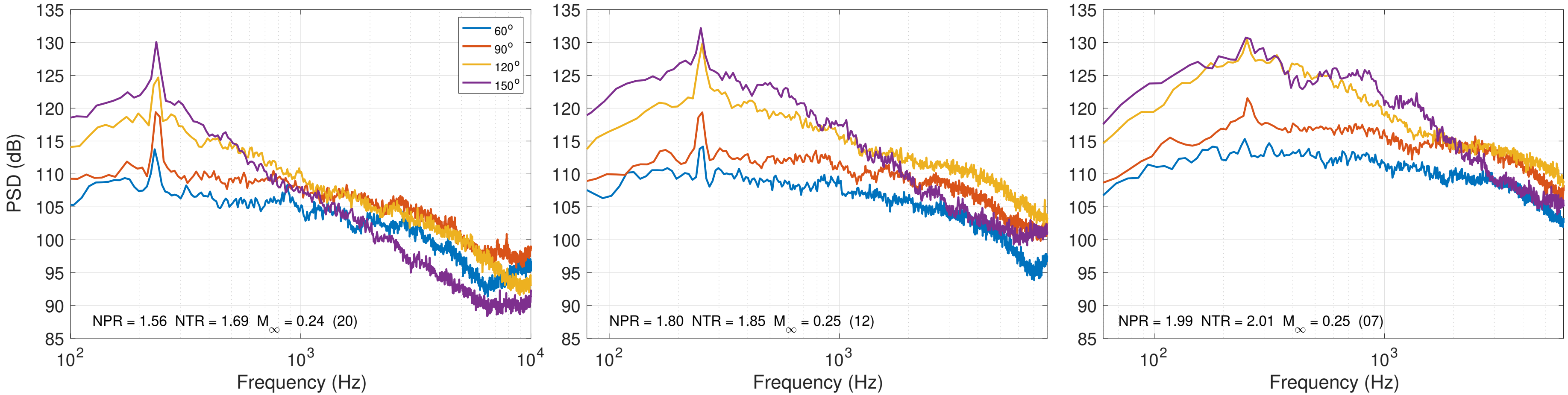
Pre-Test Flight

Devin Boyle's iPhone



- As jet approached a high-frequency tone could be heard
- Origin is not clear – small cavity airframe noise, compressor tone from idle engine, or …
- Becomes insignificant as $\theta_e \geq 60^o$ compared to jet noise

MICROPHONE-AVERAGED SOURCE SPECTRA



- Flight data processed for θ_e = 60, 65, …, 160°
- Examples in figure above

Run	EPR	EGT (K)	M_∞	NPR	T_∞ (K)	NTR	RPM	f_{shaft} (Hz)	f_{tone} (Hz)
20	1.50	764.53	0.24	1.56	290.16	2.64	14,376	239.6	234.4
12	1.72	806.75	0.25	1.80	288.20	2.80	15,135	252.3	253.9
7	1.90	850.30	0.25	1.99	287.37	2.96	15,504	258.4	253.9

Tone determined at θ = 90°

- Shaft frequency f_{shaft} often visible in spectra – unrelated to jet noise
- Comparison with AAPL/NATR scale-model data is in progress

SUMMARY – LEARJET 25/CJ610 FLIGHT TEST

Flyover Acoustics Test (multi-center effort):

- Well-instrumented flight test – acoustics, aircraft position/conditions, atmosphere, wind limits ✓

Test outcome:

- Reference case of flyover acoustic data ✓

Complementary rig data:

- Existing and new AAPL/NATR data ✓

Acoustic data analysis:

- Methods tested and data (partially) processed
- Comparison with scale-model data ongoing

Significance: Ultimate improvement in noise-prediction methods for system studies of future commercial supersonic aircraft

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