Rotorcraft Noise Abatement Procedure Development

Project 38

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Project manager: Rick Riley, FAA

October 22-23, 2019
Alexandria, VA

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 38 through FAA Award Number 13-C-AJFE-PSU-041 under the supervision of Rick Riley. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

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Motivation

- Rotorcraft noise increasingly becoming a larger issue with general public
  - HAI's "Fly Neighborly Guide" is helpful for community noise
    - Since publication, new rotorcraft and operations have been developed
  - Need for more detailed data and information about noise produced from the operation of rotorcraft
  - Need for detailed and specific noise abatement procedures
- This project investigates noise abatement flight procedures of rotorcraft through modeling
  - Physics based modeling of noise leveraging previous research performed for NASA and DoD
  - Comprehensive modeling of the many sources of rotor noise
  - Complete vehicle modeling during example flight procedures
    - Flyover
    - Approach, departure
    - Turn maneuvers, etc.

Objectives

- **Utilize computational and analytical modeling to develop noise abatement procedures for various helicopters and various phases of flight.**
  - **2017 flight test data will be used to determine the effectiveness of the procedures**
- **Support analysis of 2017 flight test data**
- **Determine if it is feasible to develop noise abatement procedures for categories of helicopters.**

Outcomes and Practical Applications

- Outcomes
  - Assess noise abatements procedure flown in the FAA/NASA flight test in August/October 2017.
    - 6 different aircraft
    - Different technology levels, manufacturers, etc.
  - Evaluation of noise abatement procedure strategy
    - Determine weaknesses in noise prediction system
    - Validate the noise abatement procedures and the predictions
    - Develop strategies for more effective noise abatement procedure development by understanding the real flight effects
  - Assessment of effectiveness of noise abatement procedures used in the flight tests

Outcomes and Practical Applications

- Practical applications
  - Demonstrate the value and ability of physics-based tools for the development of flight procedures
    - For rotorcraft manufacturers
    - For Government (FAA)
  - Evaluate noise abatement procedures based on the operating parameters rather than design parameters
    - Noise abatement procedures will be used for different helicopters
    - Goal is that procedures will have wide range of application

Approach

- **Validate** noise prediction system for **noise abatement procedures/maneuvers**
  - Model helicopters for noise prediction
  - Compare predicted noise with flight test data
  - Investigate refinements relevant to noise abatement
- **Model noise abatement procedures** to demonstrate advantages
  - Detailed analysis of abatement procedures
  - Investigate the role of various noise sources
- Evaluate whether **unique** noise abatement procedures should be developed for each helicopter category
  - Determine effectiveness of abatement procedures for different helicopters
  - Consider if a category is really representative of individual helicopters in the category
- Analyze noise abatement procedures in **support of the flight test**
  - Assist the flight test by providing evaluating noise abatement procedures and different maneuvers

Schedule and Status

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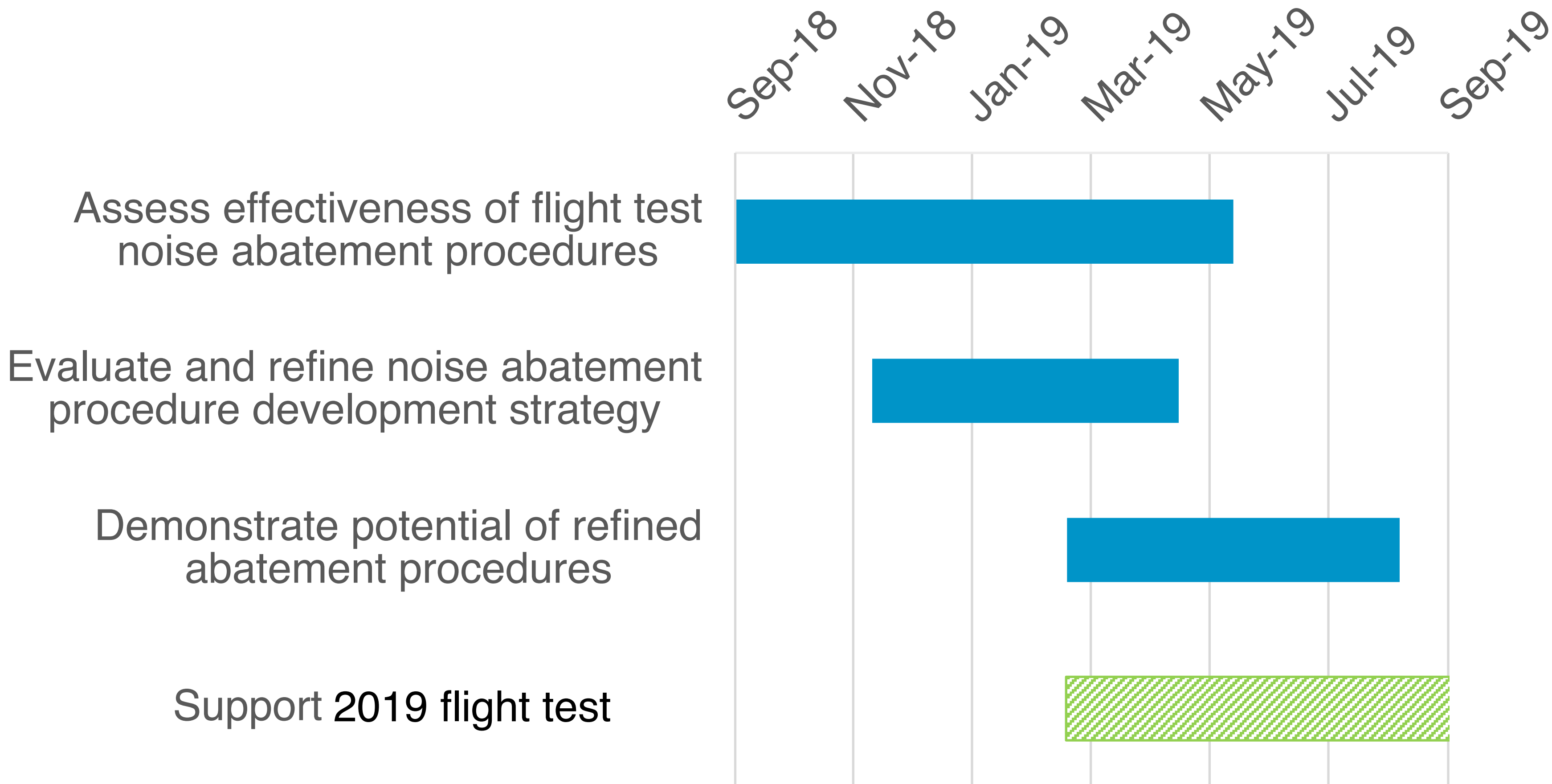


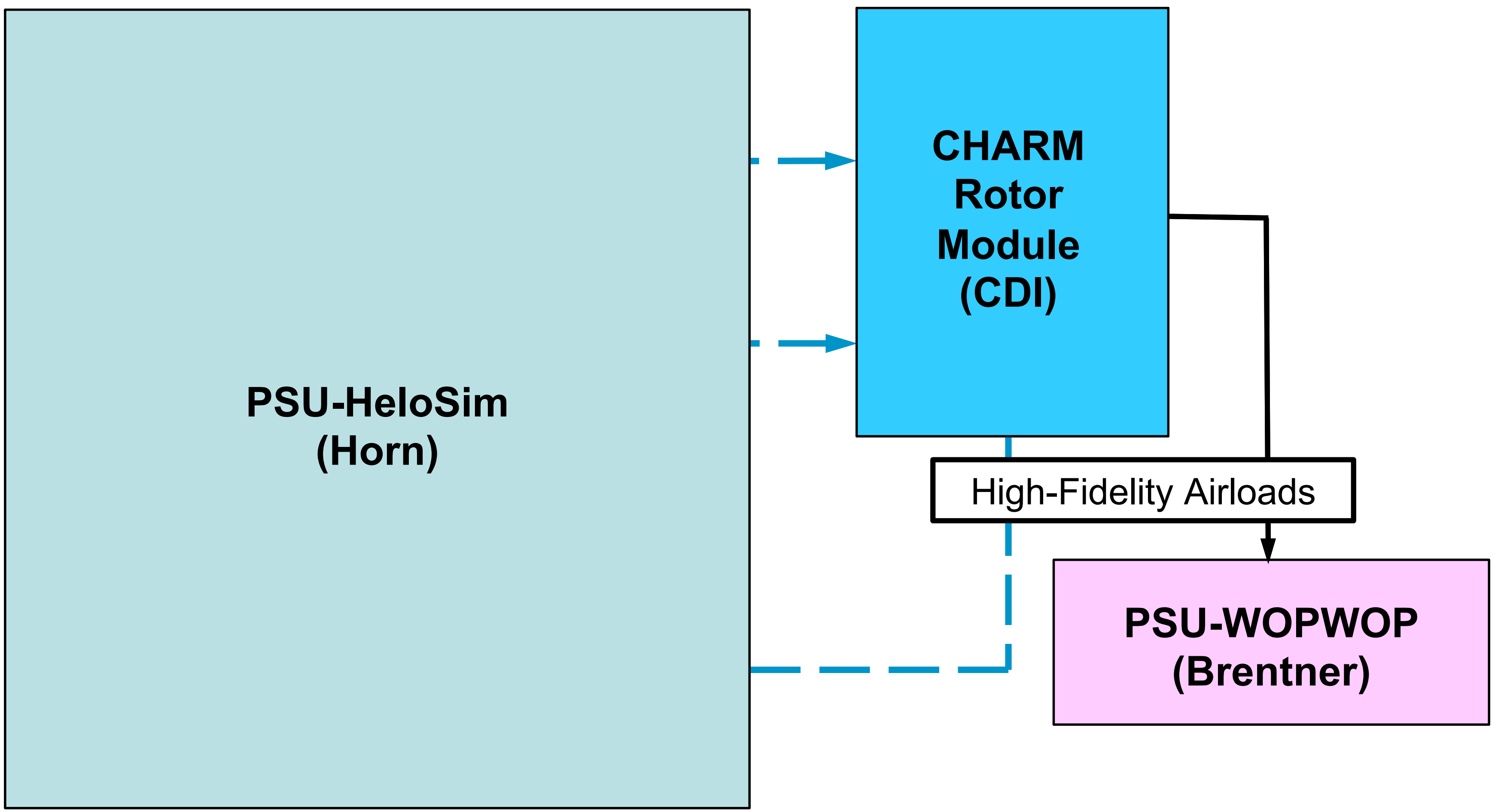
Status and Accomplishments

- **Administration**
  - Original end date was August 31, 2019. No cost extension in place, but funds are limited.
  - New student started working on the project.
  - Mrunali Botre started working for Continuum Dynamics, Inc.

- **Technical Status**
  - **A comprehensive noise prediction system is developed for generating noise abatement procedures**
    - Paper describing updates to noise prediction system was presented at AIAA/CEAS 2019 Aeroacoustics Conference
    - Paper of validation results was presented at the VFS 2019 Forum, May 2019
  - **Analysis of the noise components provides unique outlook for developing noise abatement procedures**
    - Recent work has focused on more detailed analysis for predictions and comparison to flight test data
    - Predicted results help explain what is happening in various maneuvers

Comprehensive noise prediction system development

Components of FAA Noise Prediction System



Validation with flight test data

Helicopters Flown in 2017 FAA/NASA Flight Test and in Simulation

- R44

Selected due to different engine power and size

- R66

- AS350

Selected due to different tail rotor technology
(Fenestron on EC130)

- EC130

- Bell 407

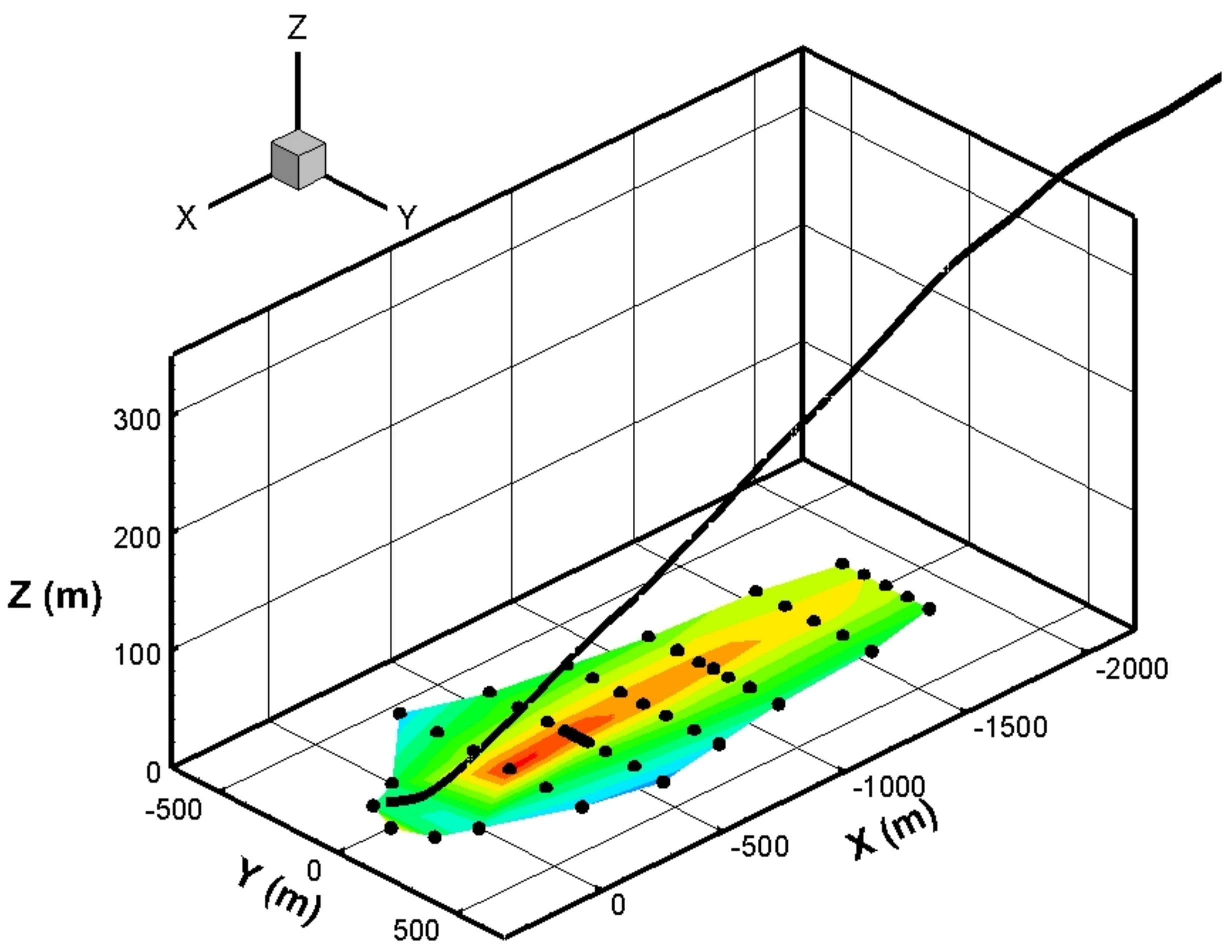
Selected due to different number of MR blades

- Bell 206L

Comparison between prediction and flight test data

- Comparison between the flight test data and prediction – R44, R66, B206, B407, AS350
- Validation of noise prediction system with flight test data
  - Flight Test Data Processing:
    - Measured acoustic pressure processed by PSU-WOPWOP to compute the SEL levels on the ground plane
    - Microphones that did not capture the pressure signal are excluded in prediction too
  - Noise Prediction:
    - Flight tracking data used to direct flight simulation controller
    - Simulation controller **approximates** the actual flight path
    - Discovered blade motions for thickness noise are not updated – periodic motions from first 0.5 sec used throughout maneuver

80 kts, 6º descent



Bell 407

80 kts, 6 deg descent

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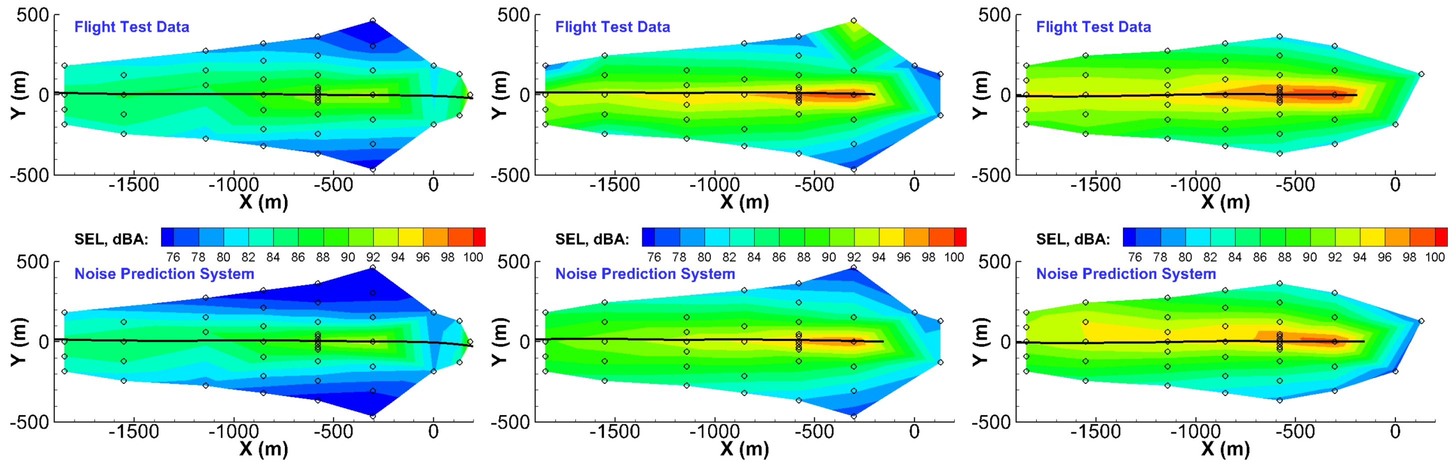
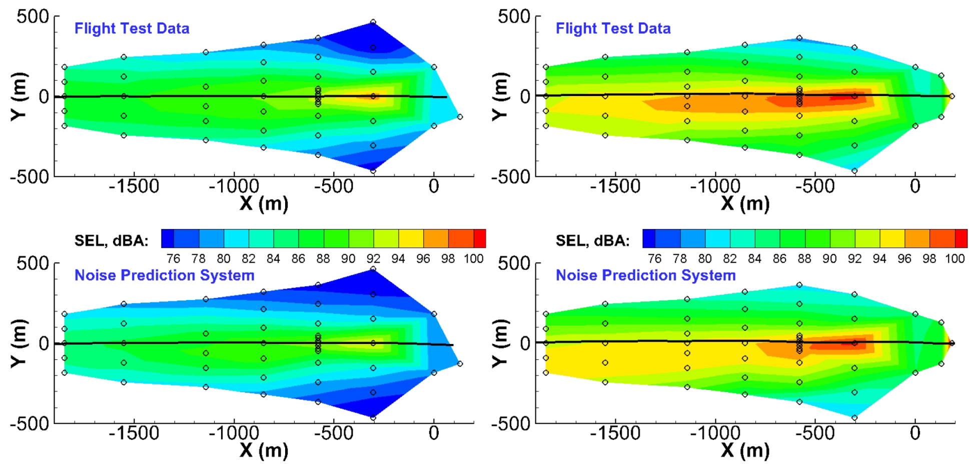


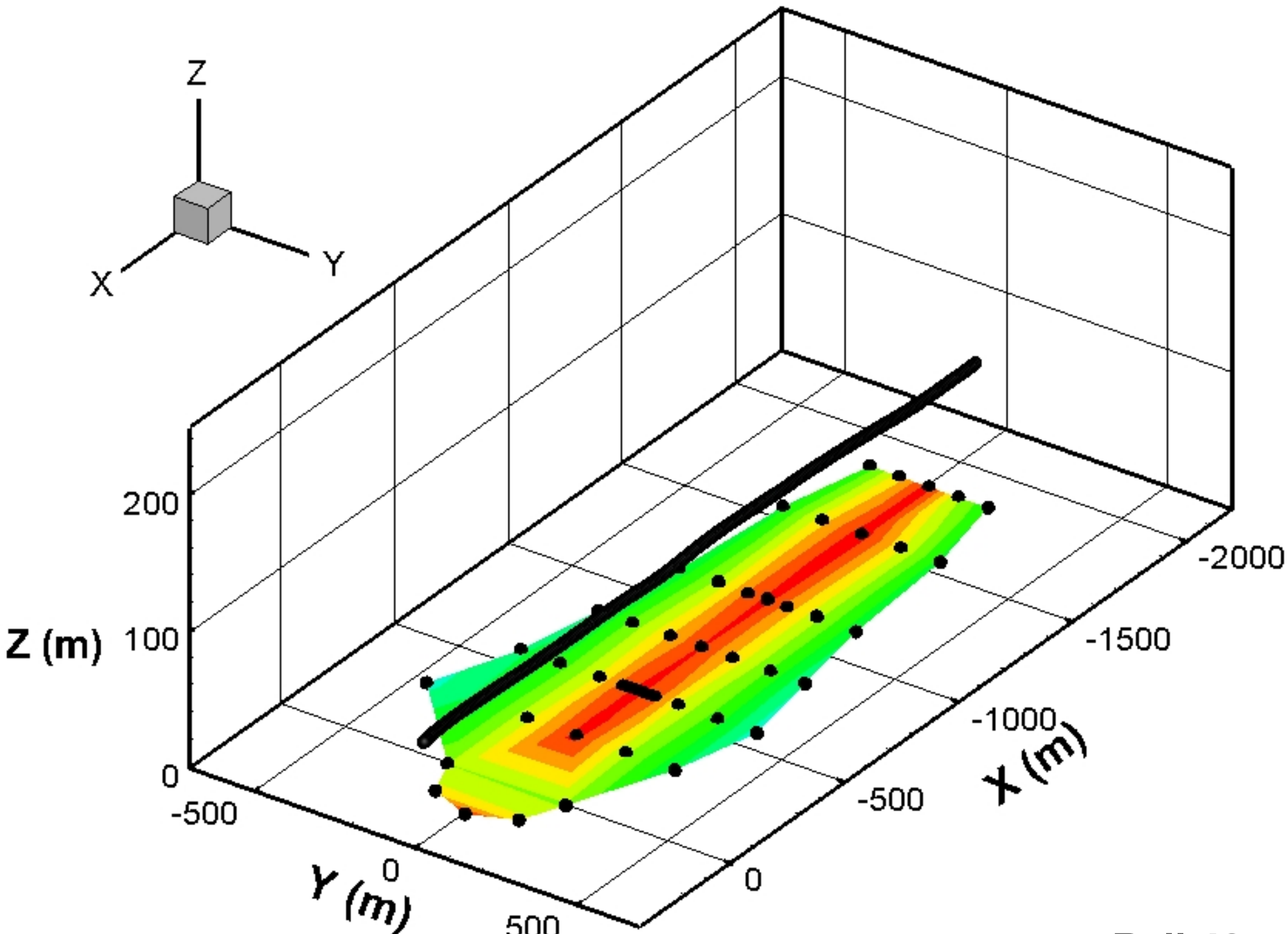
(a) Robinson R44 (b) Bell 206L (c) Airbus AS350



(d) Robinson R66 (e) Bell 407

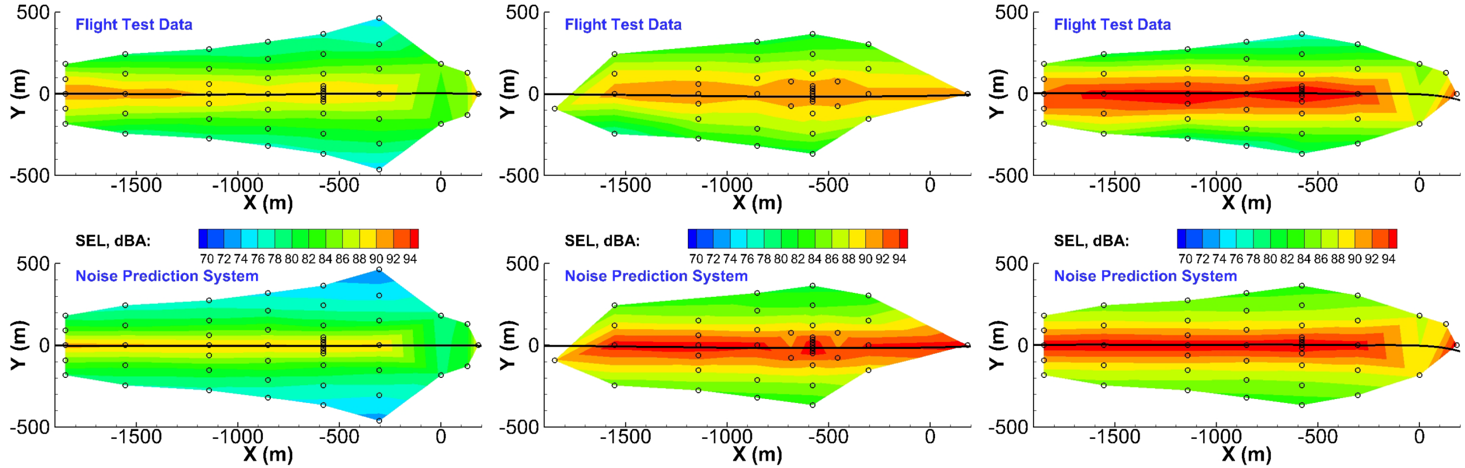
- Agreement quite good for all cases
- Slight underprediction in several cases (more for Bell 407 and Airbus AS350)
- Airbus EC130 not included because Fenestron not modeled

80 kts, level flight

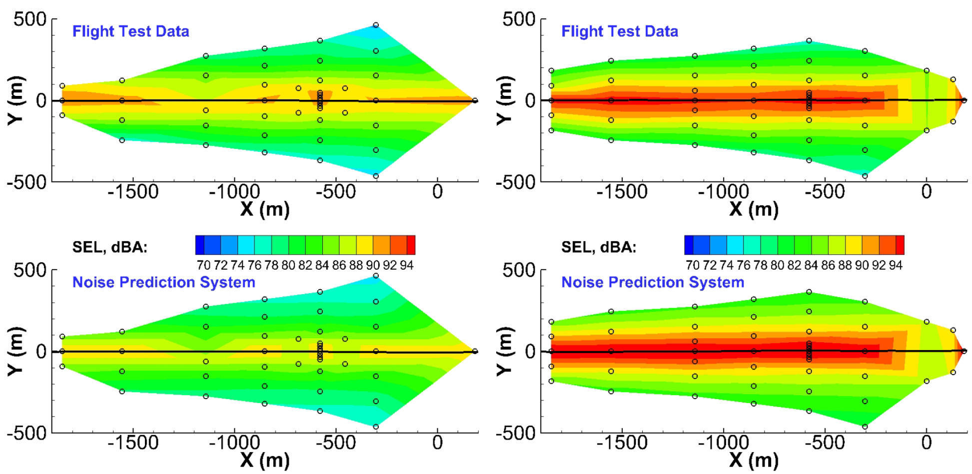


Bell 407

80 kts level flight



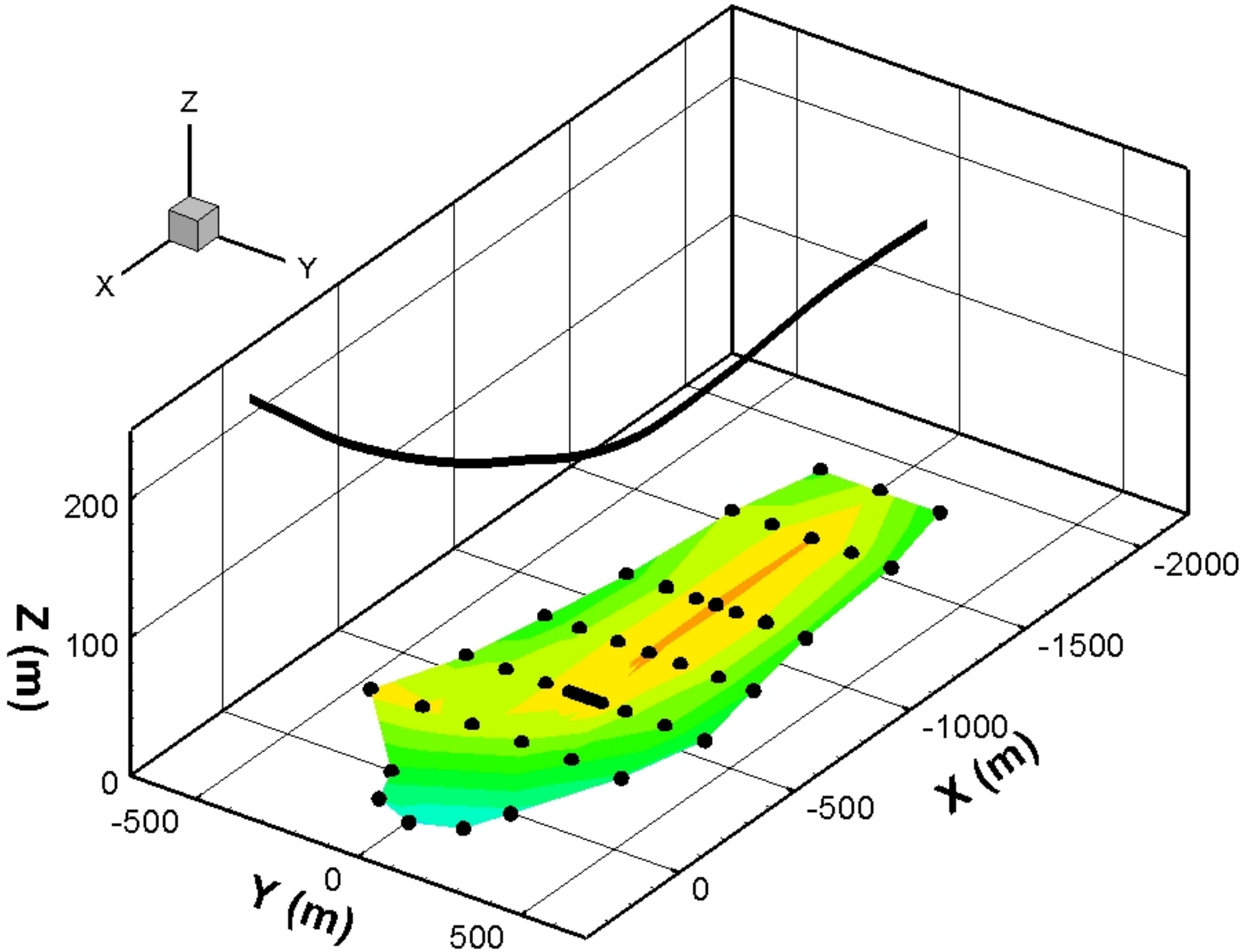
(a) Robinson R44 (b) Bell 206L (c) Airbus AS350



(d) Robinson R66 (e) Bell 407

- Agreement quite good for all cases
- Slightly more overprediction for Bell 206L (broadband noise dominant)

80 kts, level turn



80 kts, level turn

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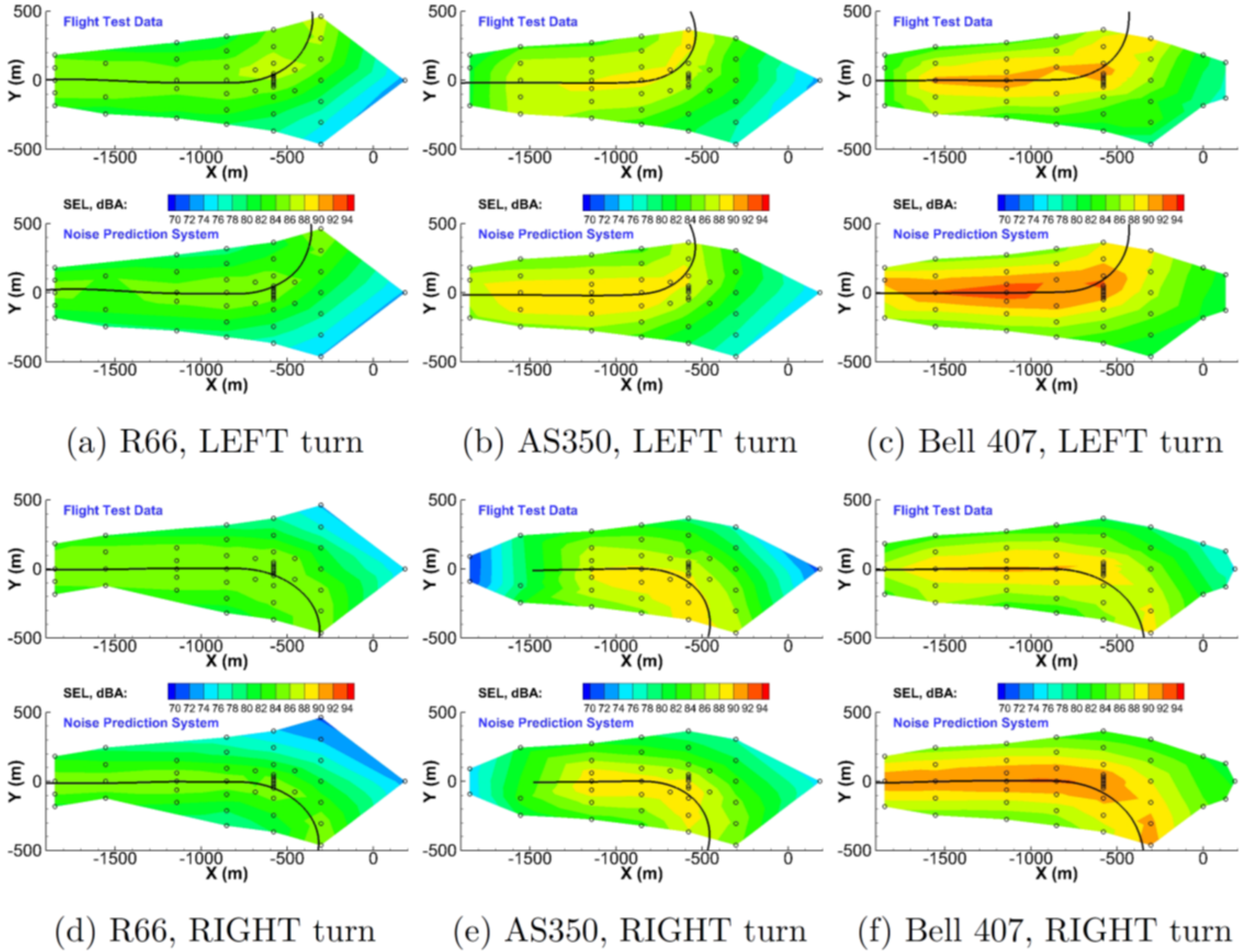
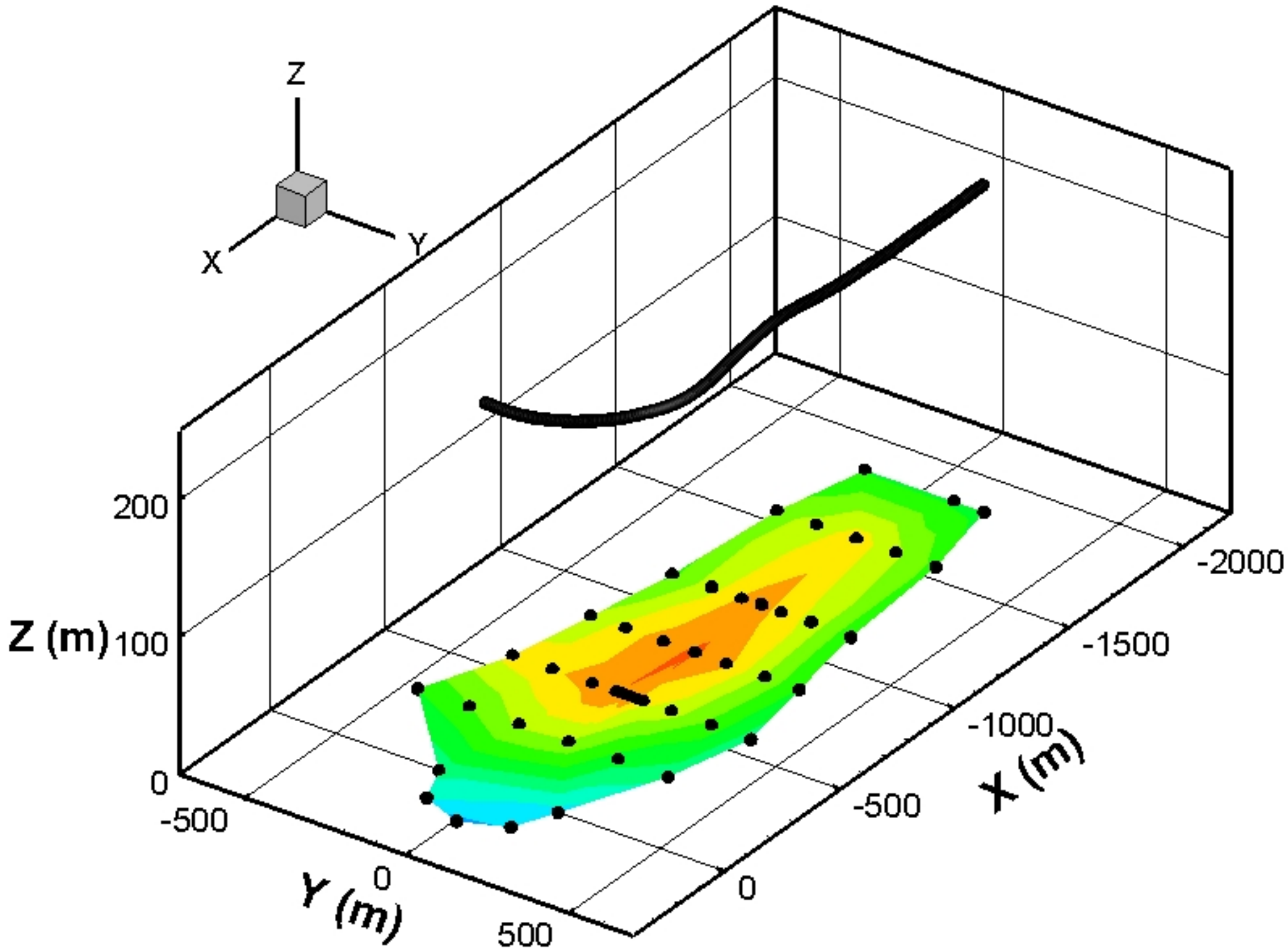


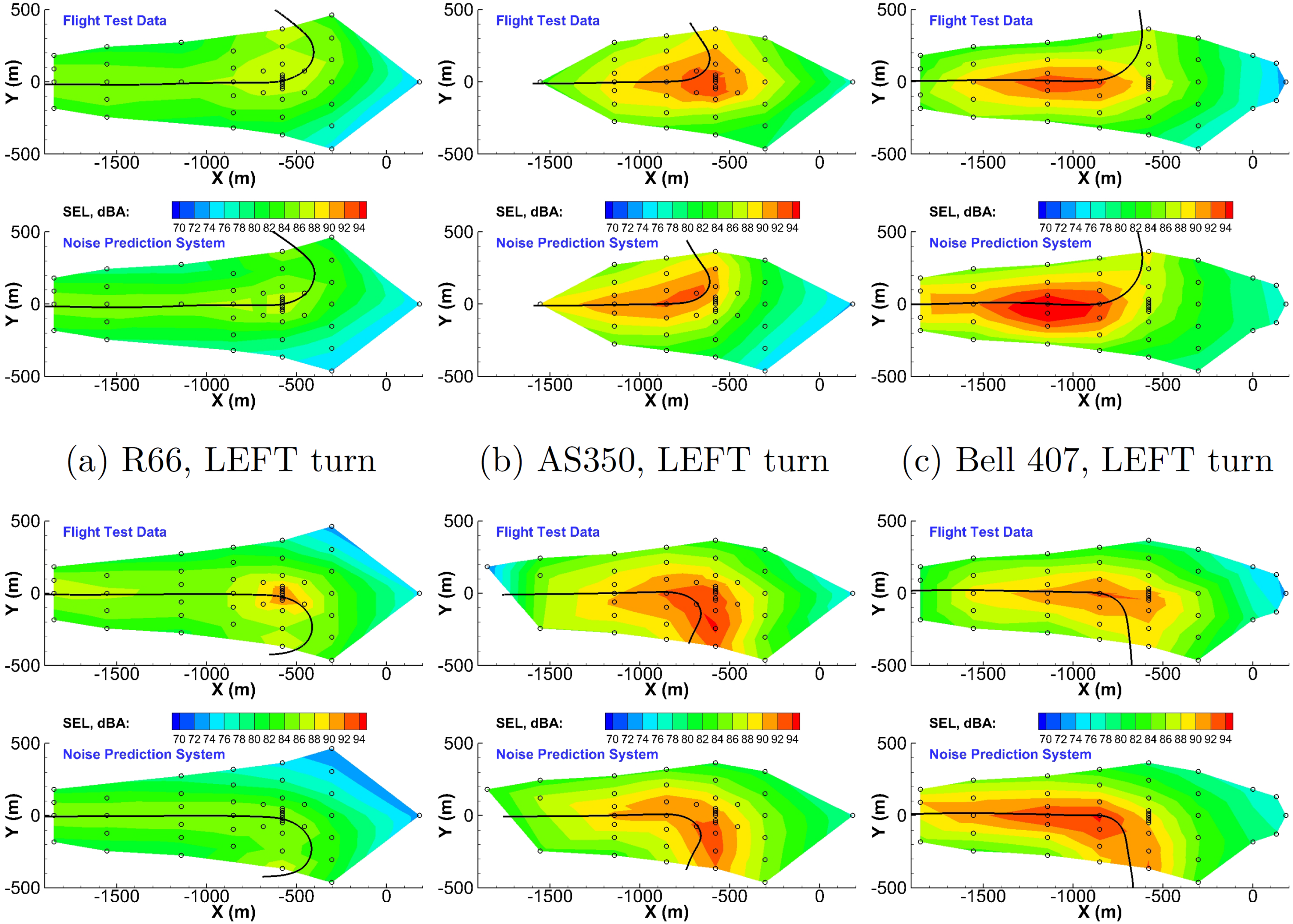
80 kts, level turn with 25 deg roll angle

80 – 60 kts, decelerating level turn



Bell 407

80 kts, decelerating, level turn

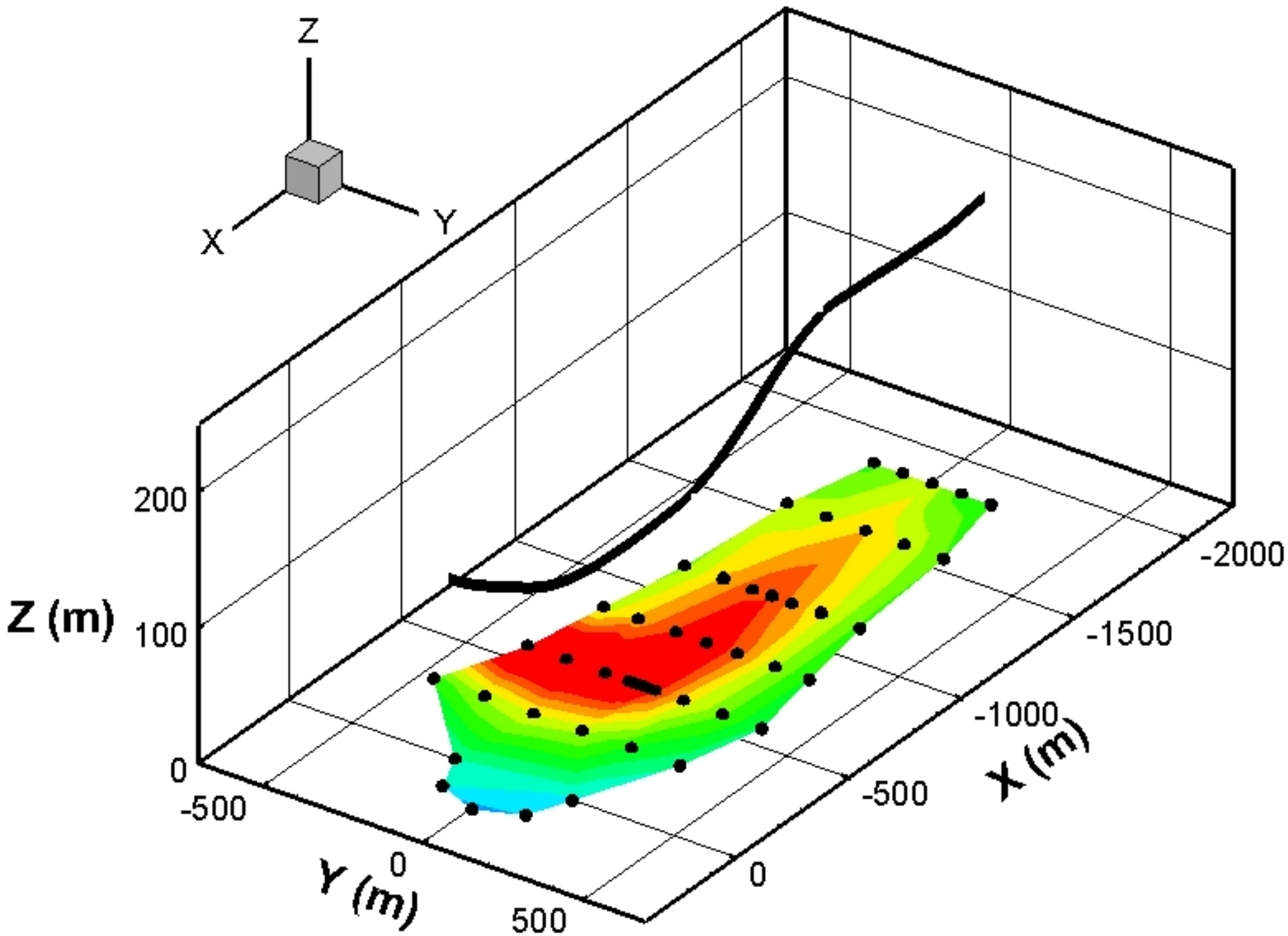


(a) R66, LEFT turn (b) AS350, LEFT turn (c) Bell 407, LEFT turn

(d) R66, RIGHT turn (e) AS350, RIGHT turn (f) Bell 407, RIGHT turn

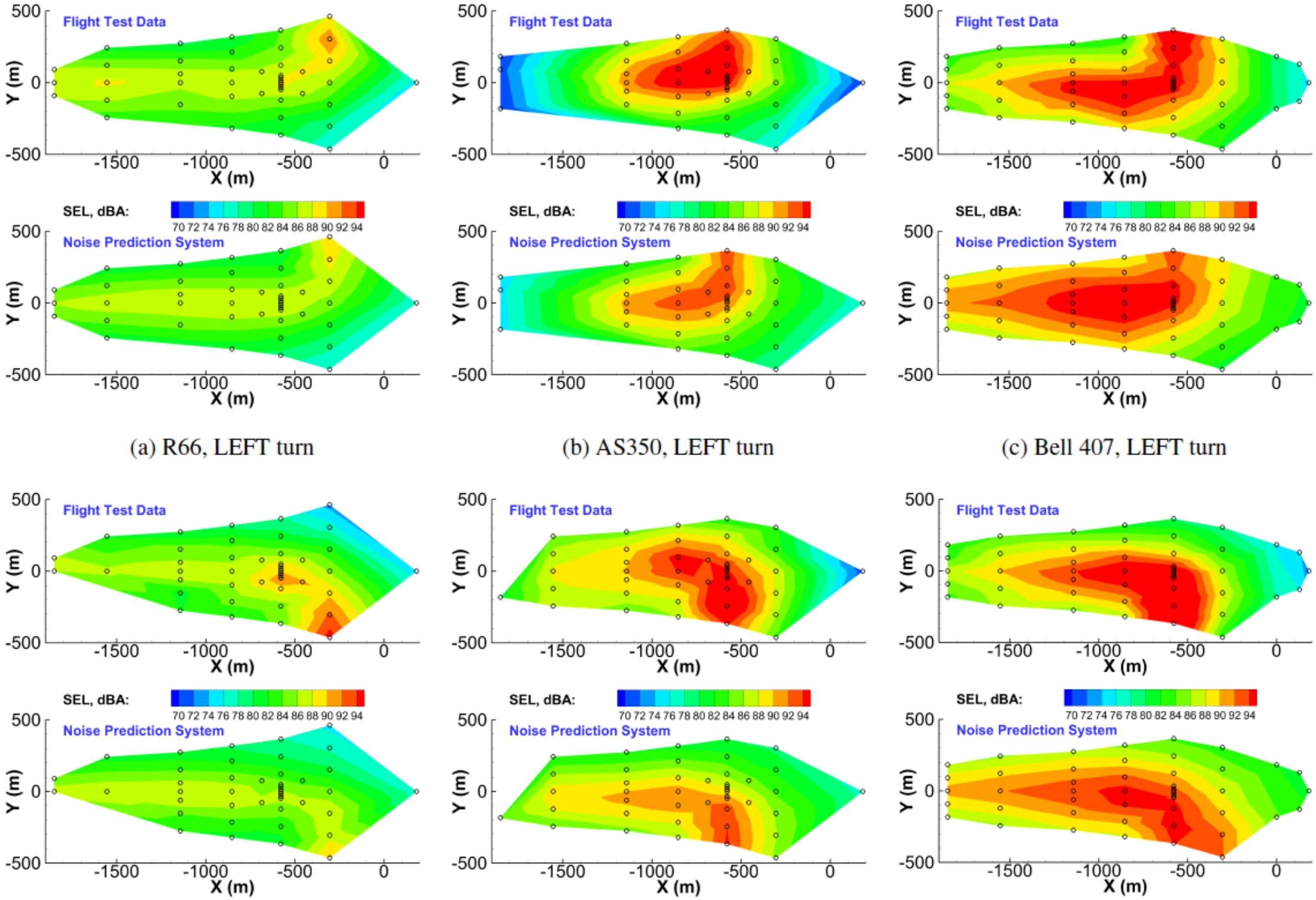
80 kts, level, decelerating turn, final roll angle 35 deg, decelerating from 80 to 60 kts

80 kts, 6º descending turn



Bell 407

80 kts, descending turn



(a) R66, LEFT turn

(b) AS350, LEFT turn

(c) Bell 407, LEFT turn

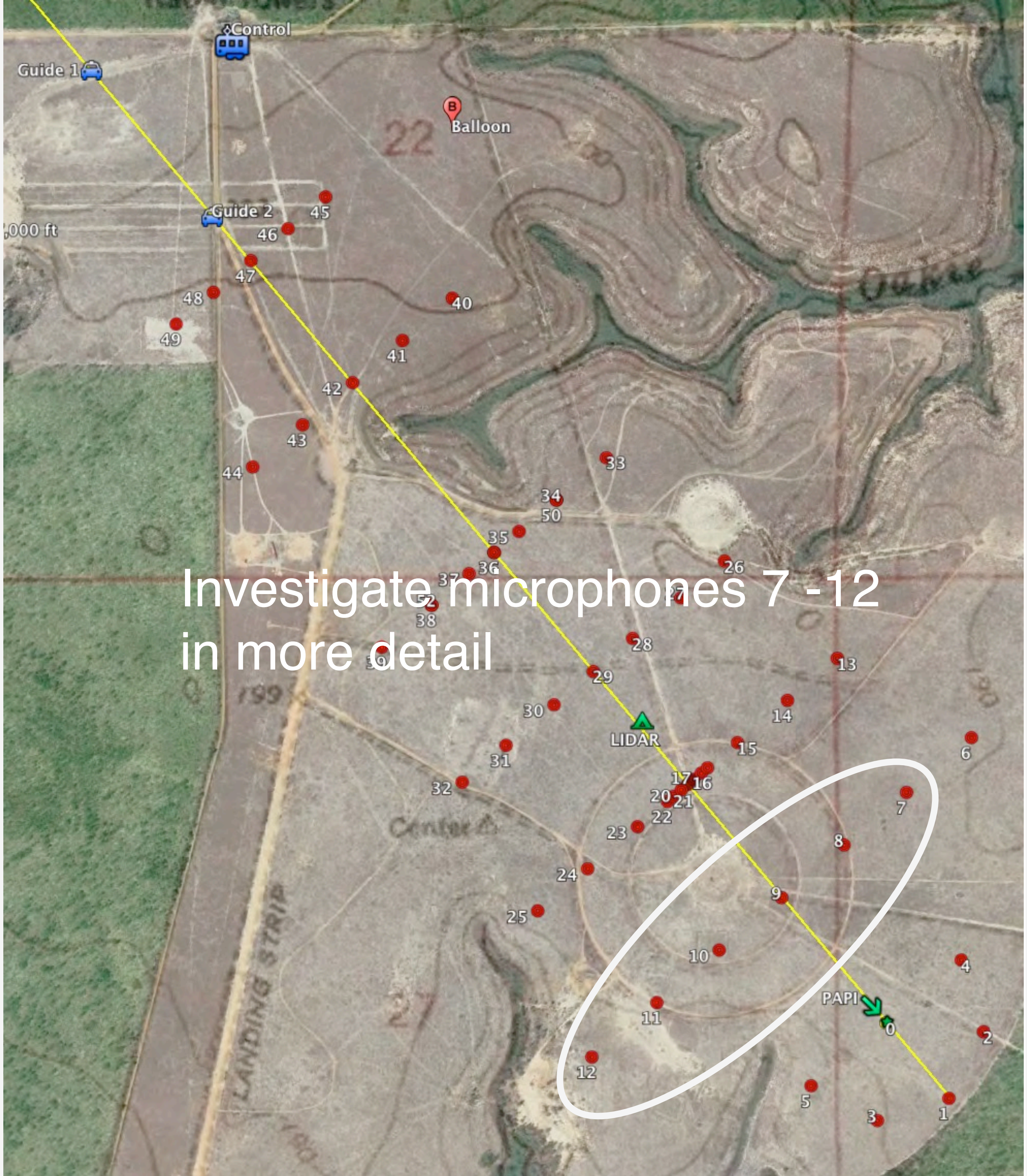
(d) R66, RIGHT turn

(e) AS350, RIGHT turn

(f) Bell 407, RIGHT turn

80 kts, descending turn, 6 deg decent angle, final roll angle 35 deg

Analyzing Bell 407 80 kts level flight


Control
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LANDING STRIP
Investigate microphones 7 -12
in more detail

Analyzing OASPL time history

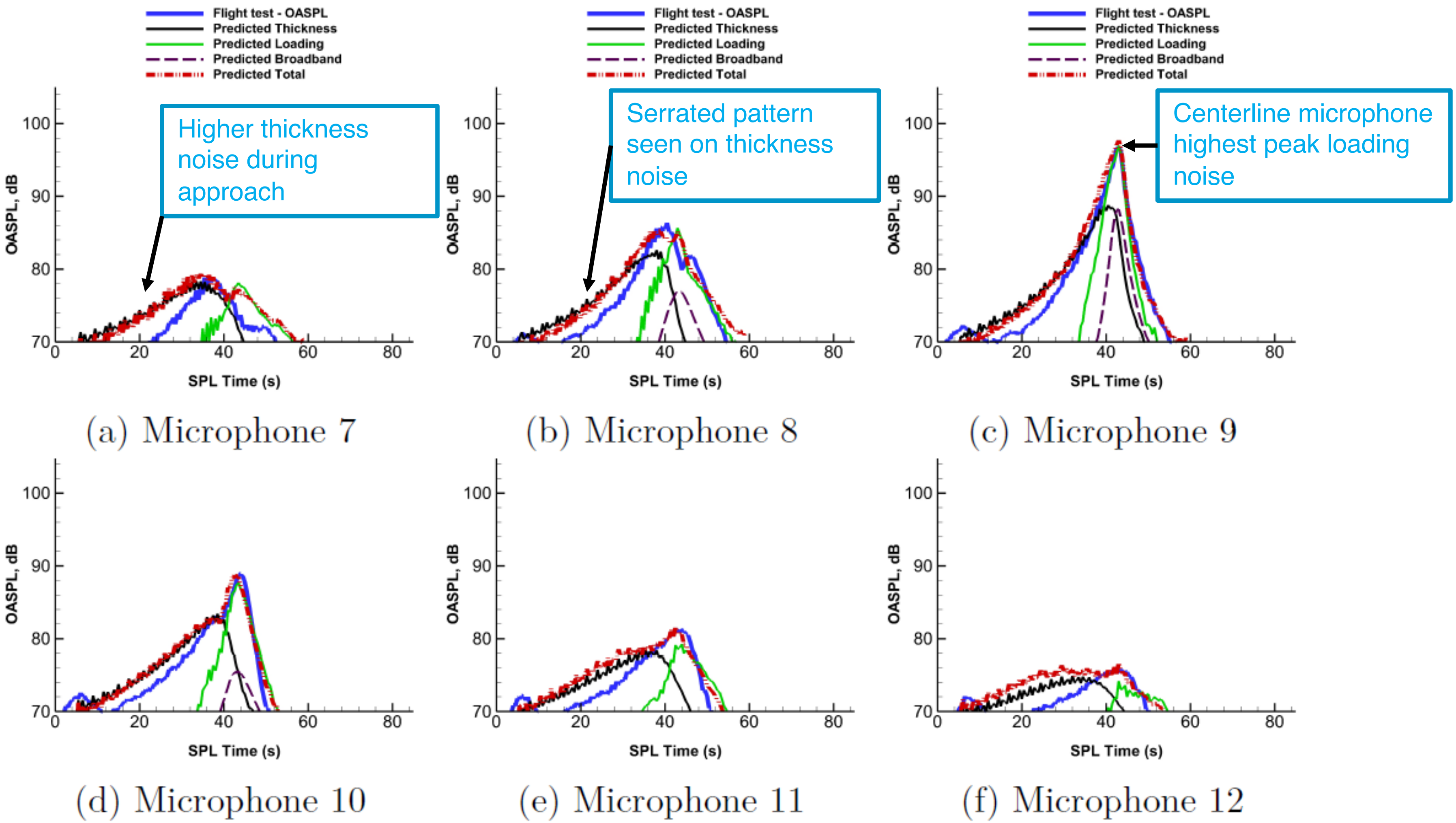
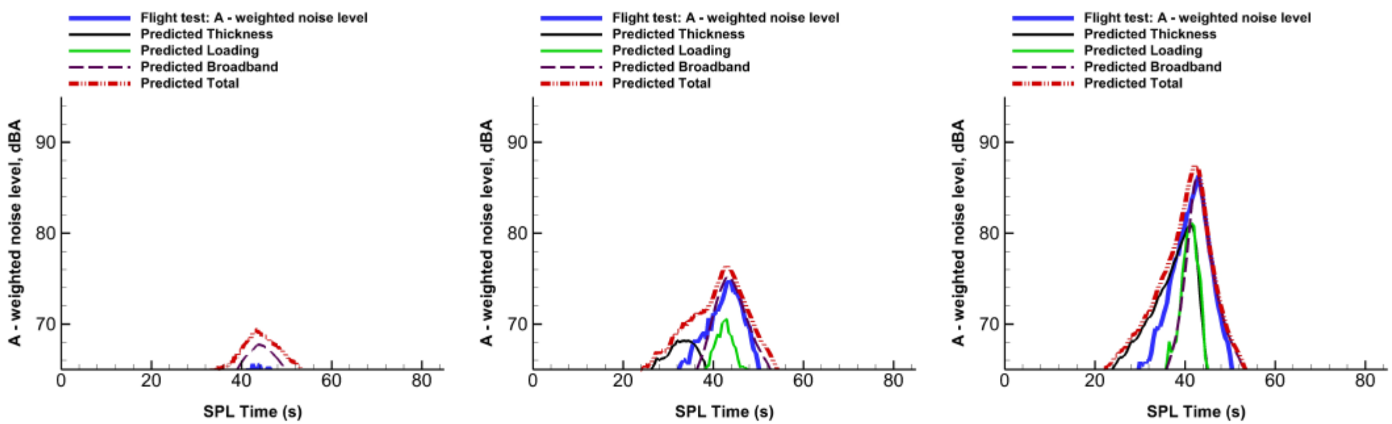
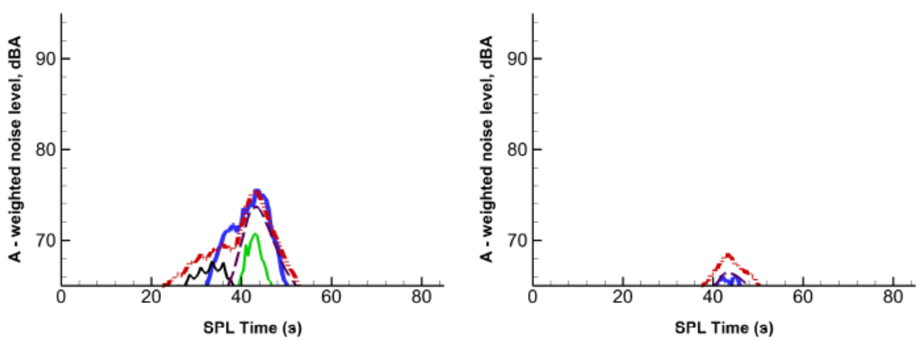


Figure 4.12: Overall sound pressure level along x = -304.8 m for Bell 407 operating at 80 kts level flight.

Analyzing A – weighted time history



(a) Microphone 7 (b) Microphone 8

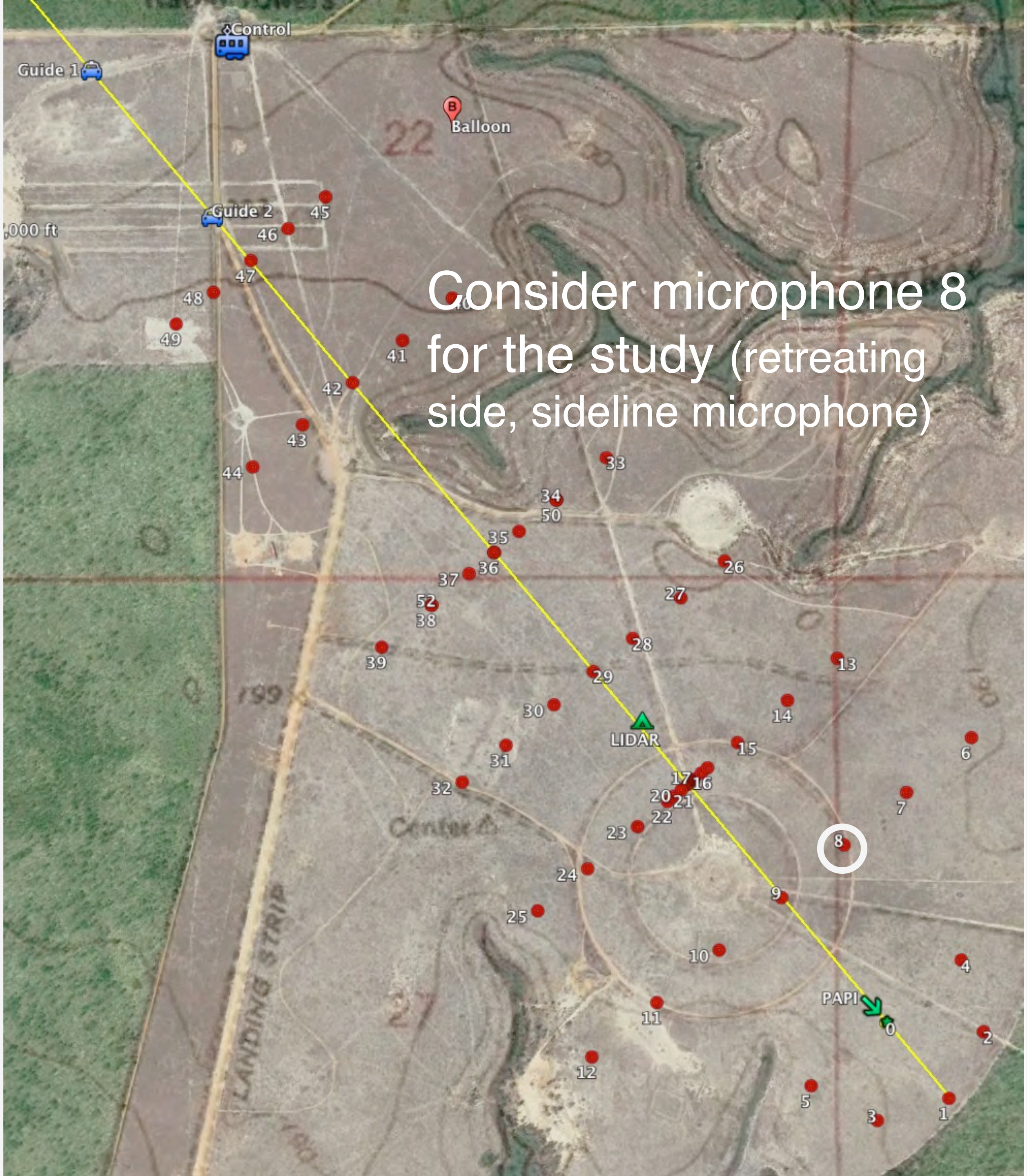


(d) Microphone 10 (e) Microphone 11

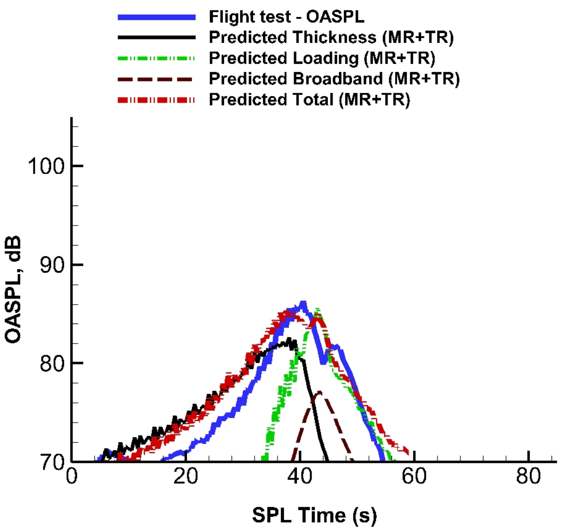
Figure 4.13: A - weighted noise level along x = -304.8 m for Bell 407 operating at 80 kts level flight.

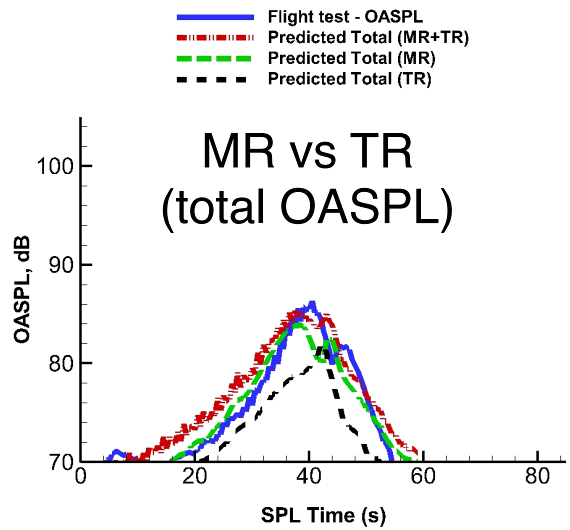
- Broadband noise (– –) is dominant in the A-weighted spectra
- Thickness noise (—) responsible for overprediction as aircraft approaches
- Thickness noise overprediction has small impact on SEL values

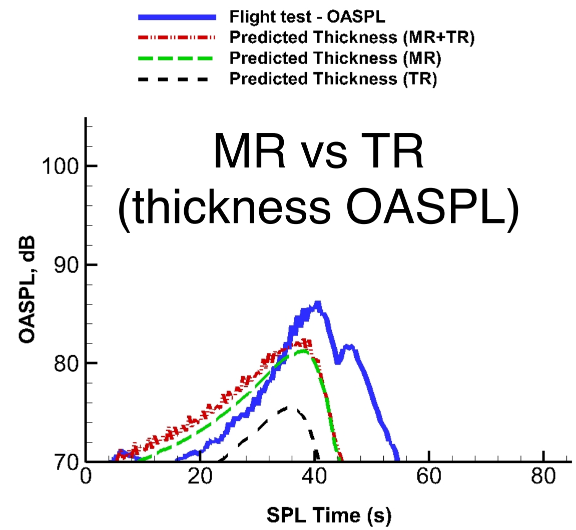
Consider microphone 8 for the study (retreating side, sideline microphone)

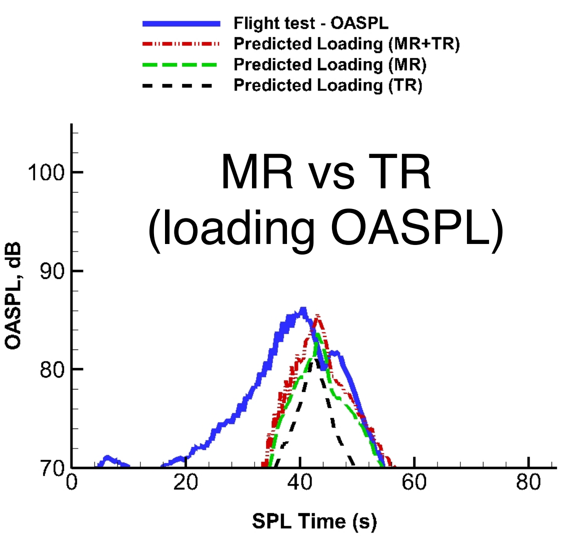


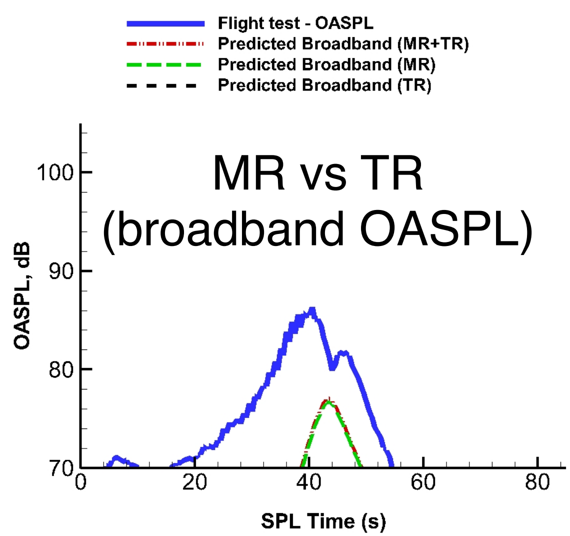
OASPL – Main Rotor vs Tail Rotor





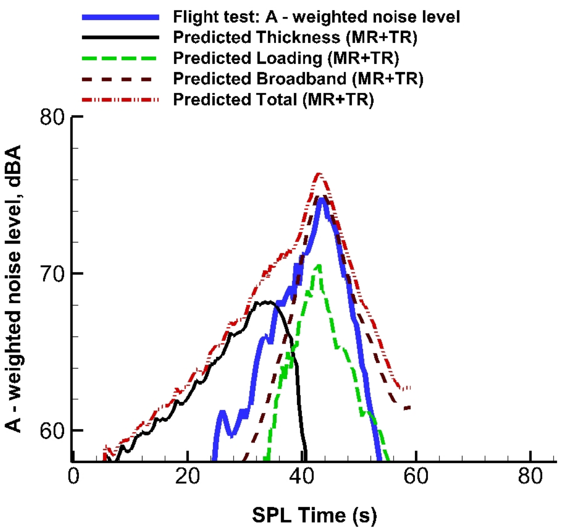


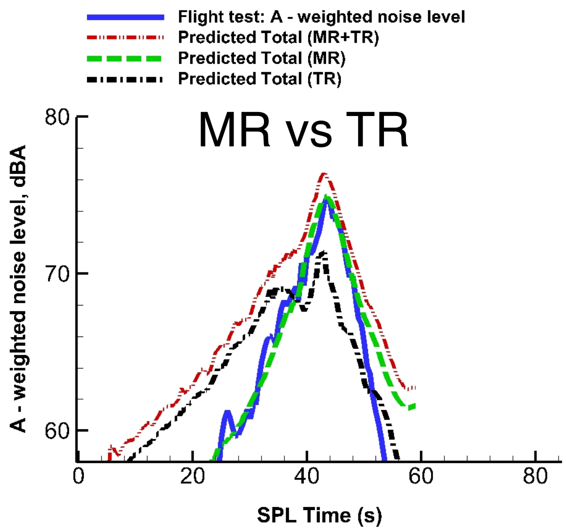


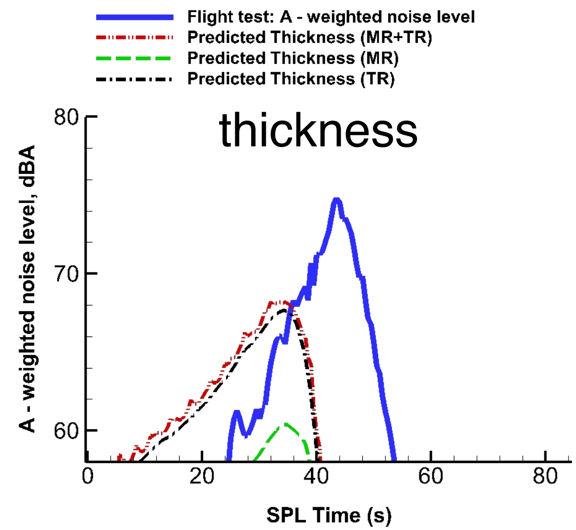


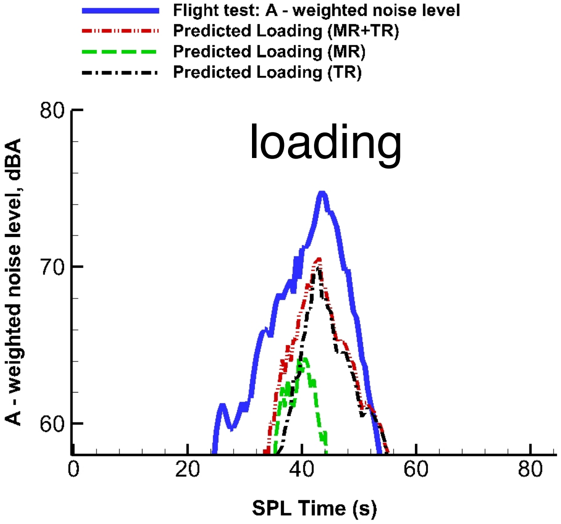
- Main rotor thickness noise dominant as aircraft approaches microphone
- Thickness noise responsible for overprediction as aircraft approaches
- Thickness noise overprediction has small impact on SEL values

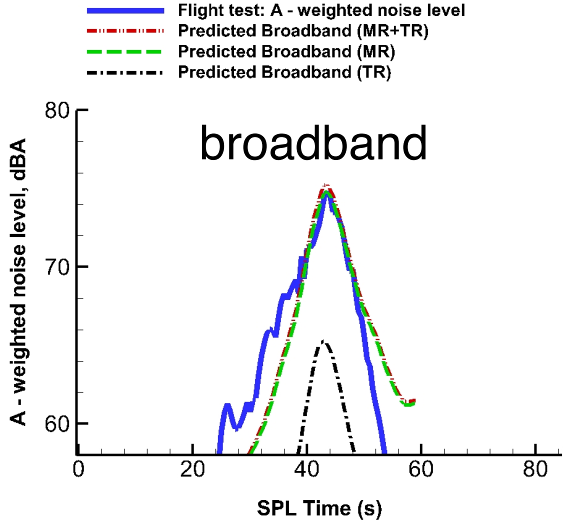
A-weighted SPL – Main Rotor vs Tail Rotor







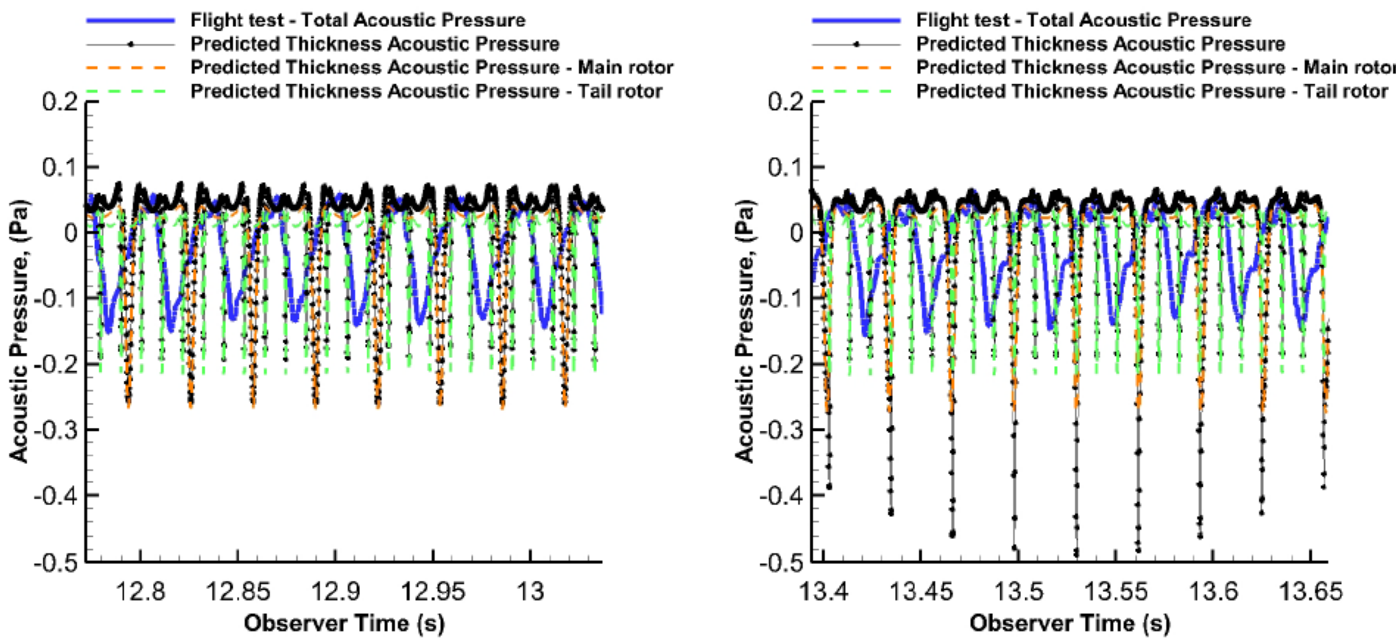




- Tail rotor thickness noise dominates A-weighted SPL as aircraft approaches
- Tail rotor loading noise higher than Main rotor loading noise
- Main rotor broadband noise is dominant for A-weighted SPL

Analyzing serrated pattern seen on thickness noise

time history when aircraft approaching – far uprange

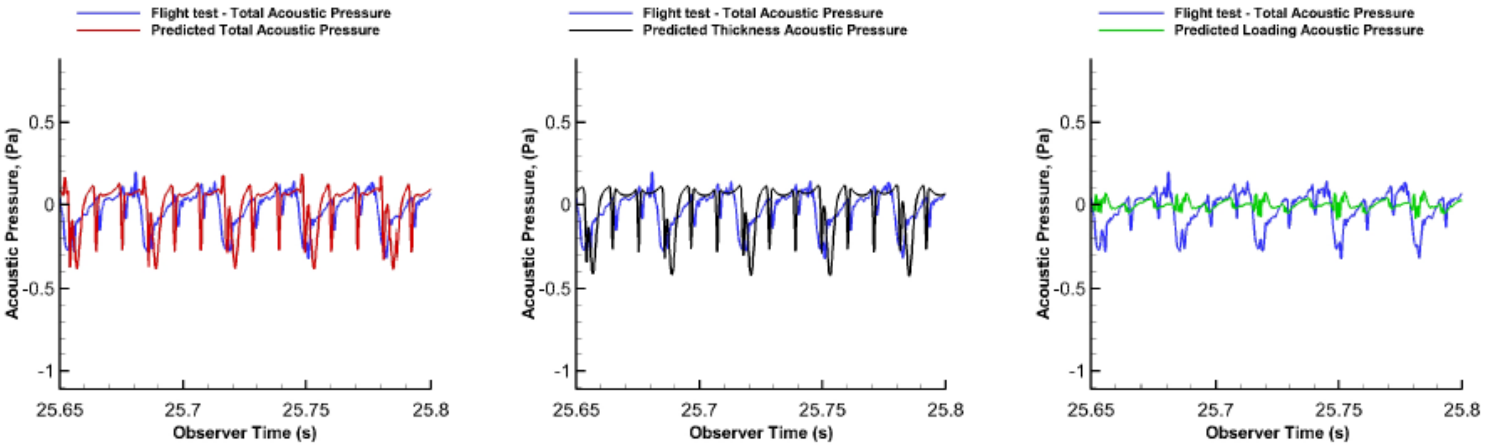


(a) Out of phase

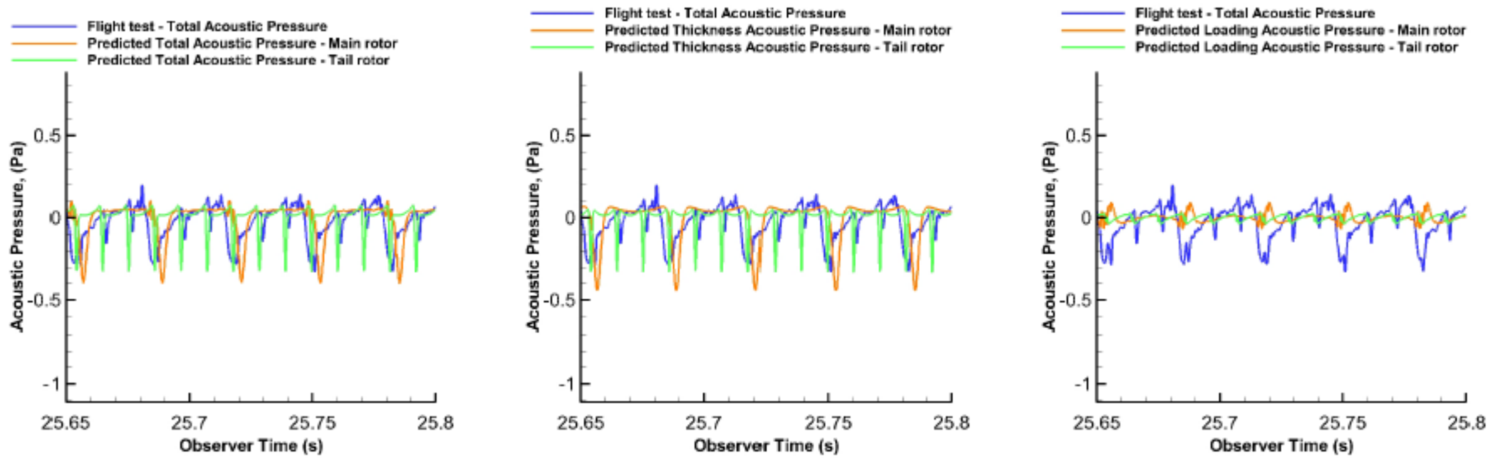
(b) In phase

- Serrated pattern in thickness OASPL time histories is a result of the tail rotor coming in and out of phase with the main rotor

Acoustic pressure – during approach



(a) Total p' (b) Thickness p' (c) Loading p'



(d) Total p' (e) Thickness p' (f) Loading p'

Tail rotor thickness noise (–) overpredicted

Acoustic pressure – at peak noise levels

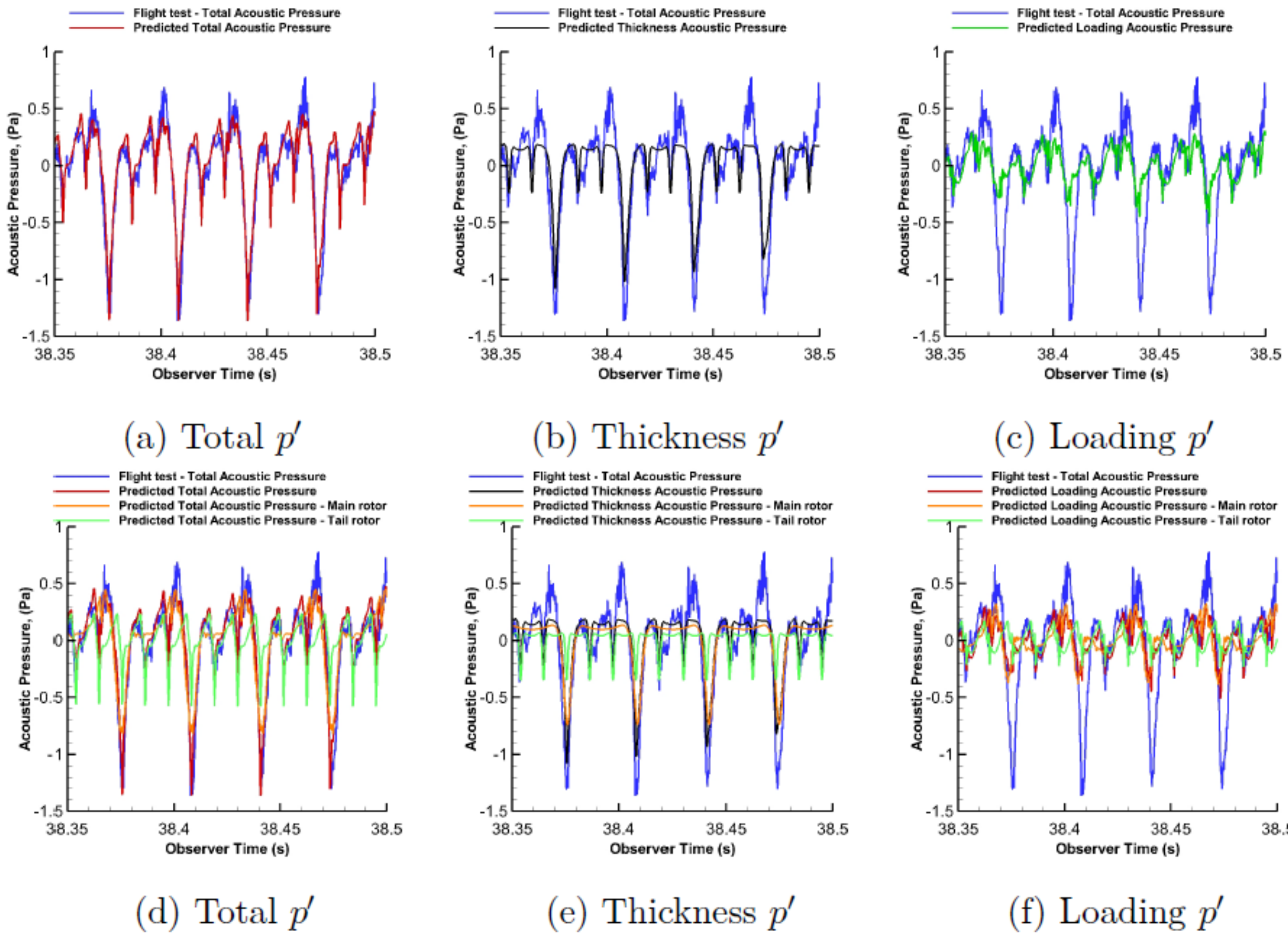


Figure 4.16: Comparison of the acoustic pressure time history for 1 rotor revolution around the peak noise levels at the microphone 8, for Bell 407 operating at 80 kts level flight.

Recent Accomplishments and Contributions

- Detailed analysis and validation of noise predictions
  - Time history of OASPL and A-weighted SPL
  - Thickness noise causes overprediction as aircraft approaches
  - Main rotor broadband noise dominates A-weighted spectrum
  - Acoustic pressure time histories agree quite well too

- Examination of noise components helps explain what is happening in complex maneuvers

- Representative results shown here; much more details in Mrunali Botre's PhD dissertation

Publications

1. M. Botre, K. S. Brentner, J. F. Horn, D. Wachspress, "Validation of Helicopter Noise Prediction System with Flight Test Data," Presented at the Vertical Flight Society 75th Annual Forum and Technology Display, Philadelphia, PA, May 13-16, 2019.

2. M. Botre, K. S. Brentner, J. F. Horn, D. Wachspress, "Developing a comprehensive noise prediction system for generating noise abatement procedures," Presented at the 25th AIAA/CEAS Aeroacoustics Conference, Delft, Netherlands, May 20-23, 2019.

Summary

- Summary statement
  - Physics-based noise prediction system has been formed from previously existing tools
  - Noise prediction system agrees quite well with flight test data for multiple aircraft, even for complex maneuvers
- Next steps
  - Focus on abatement procedure development and comparison between flight test data prediction system
- Key challenges/barriers
  - Starting with a new student – it will take some time to bring her up to speed
  - Lot's of data from the 2017 and 2019 flight tests to sort through – we must be selective to learn what we can
  - Using the system to develop noise abatement procedures – this is challenging to do in new and general ways

Participants

- PI: Kenneth S. Brentner, The Pennsylvania State University (PSU)
- Co-PIs: Daniel Wachspress (CDI); Joseph F. Horn (PSU)
- Graduate Research Assistant: Mrunali Botre (now working at CDI)
- Industrial Partners:
    - Continuum Dynamics, Inc. (CDI)

Acknowledgements

The R-44 and R-66 helicopter data was collected in Phase I of the NASA/FAA/Army joint test conducted in September 2017 at Eglin AFB, and the Airbus AS350B3, Airbus EC130B4, Bell 206L3, and Bell 407 helicopter data was collected in Phase II of the NASA/FAA/Army joint test conducted in October 2017 at Amedee AAF.