FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Rotorcraft Noise Abatement Procedure Development

ASCENT 38

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AVIATION SUSTAINABILITY CENTER

Motivation

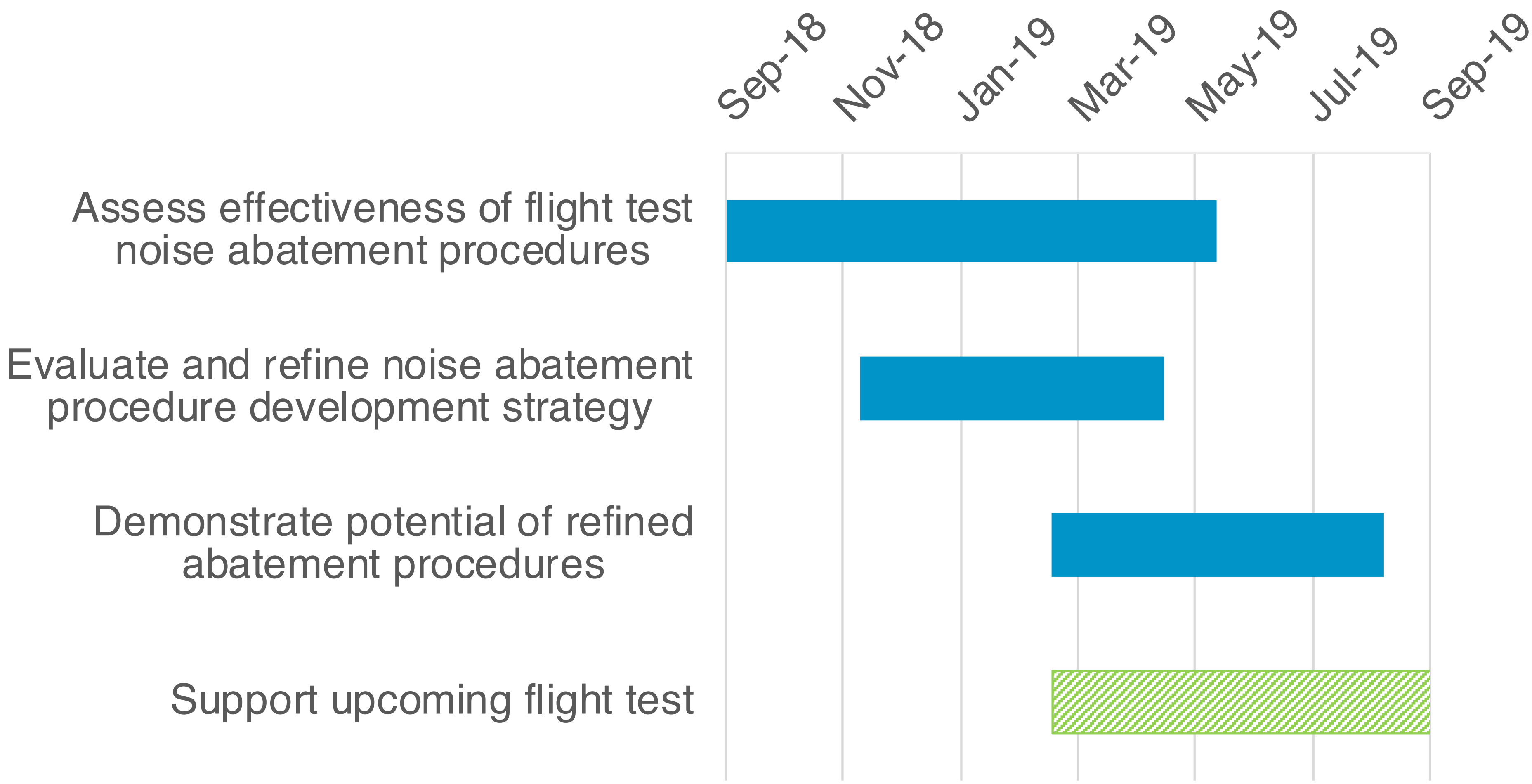
- Rotorcraft noise increasingly becoming a larger issue with general public
  - HAI’s “Fly Neighborly Guide” is helpful for community noise
    - Since publication, new rotorcraft and operations have been developed
  - Need for more detailed data and information about noise produced from the operation 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.
  - Flight test data will be used to determine the effectiveness of the procedures
- Support the upcoming flight test
- Determine if it is feasible to develop noise abatement procedures for categories of helicopters.

Schedule and Status



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

Status and Accomplishments

- **Administration**
  - Nothing at this time
- **Technical Status**
  - **A comprehensive noise prediction system is developed for generating noise abatement procedures**
    - Includes time dependent flight path and attitude information
    - Includes quasi-periodic blade loads
    - Includes time dependent broadband noise prediction
    - Paper describing updates to noise prediction system will be presented at AIAA/CEAS 2019 Aeroacoustics Conference
  - **Validation of the noise prediction system is ongoing**
    - Various flight conditions are compared with flight test data and will be presented during the VFS 2019 Forum
  - **Analysis of the noise components provides unique outlook for developing noise abatement procedures**

Noise Abatement Example (Bell 430)

Segment (a)

- Constant speed (100 kts) descent and increasing flight path angle

Procedure 1

Segment (b): Decelerating at constant flight path angle (-10 deg)

Segment (c): Decreasing descent rate at constant speed

Procedure 2

Segment (b): Decelerating at constant descent rate (1400 fpm)

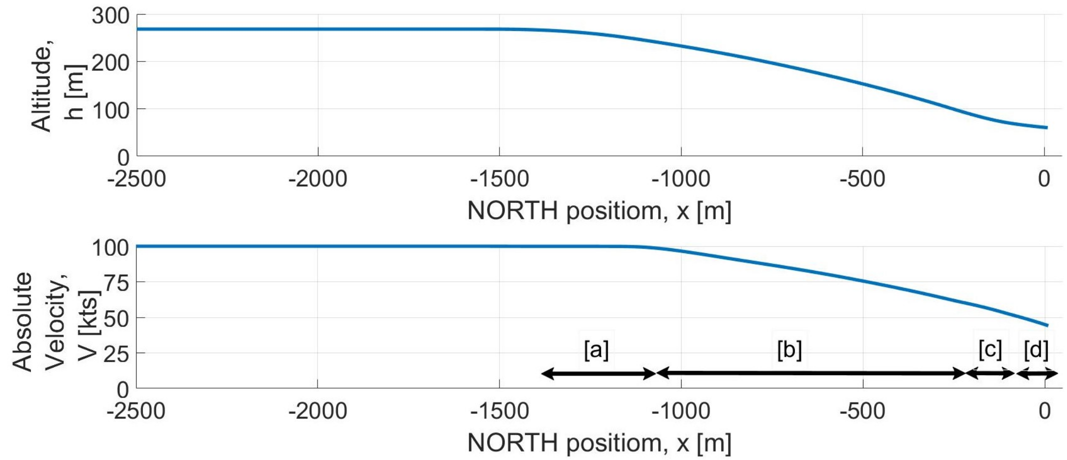
Segment (c): Decreasing the flight path angle and descent rate

Segment (d)

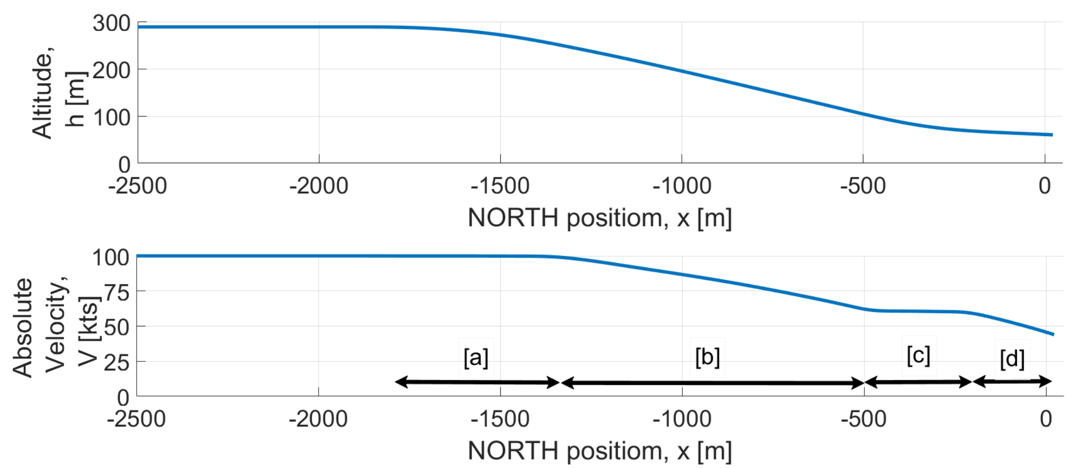
- Decreasing the flight speed at lower descent rate before landing

Notice that segments (a) – (d) are not the same for the two procedures

Noise abatement procedure 1

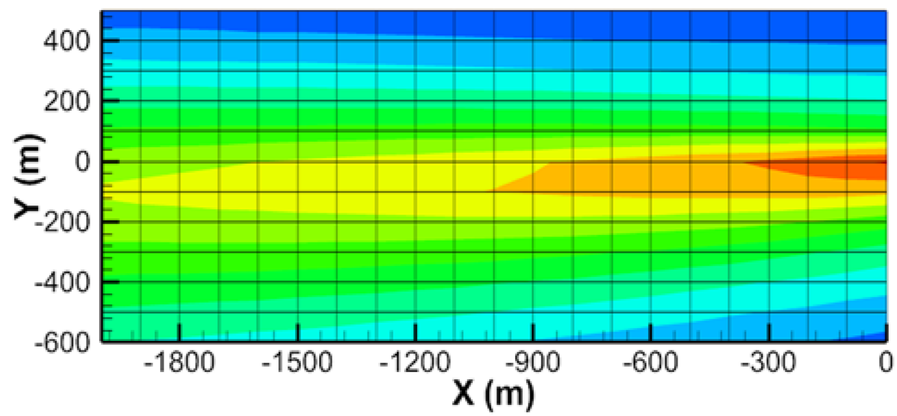


Noise abatement procedure 2

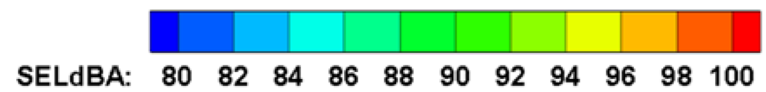


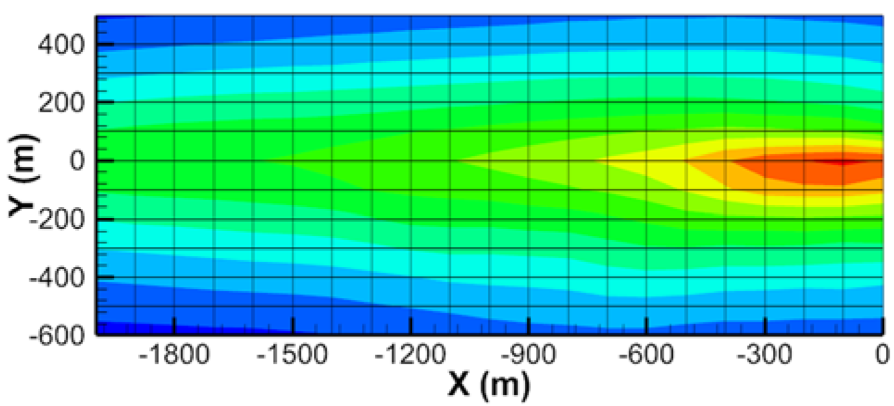
Noise Abatement Example (Bell 430)

- Both procedures make less noise than baseline
- Procedure 2 is significantly better than procedure 1
- These example procedures did not considered “flyability”

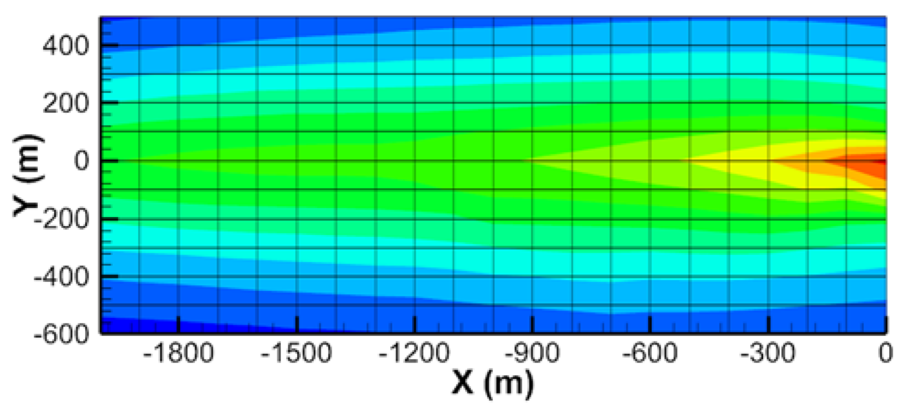


(a) 80 kt 6 deg descent





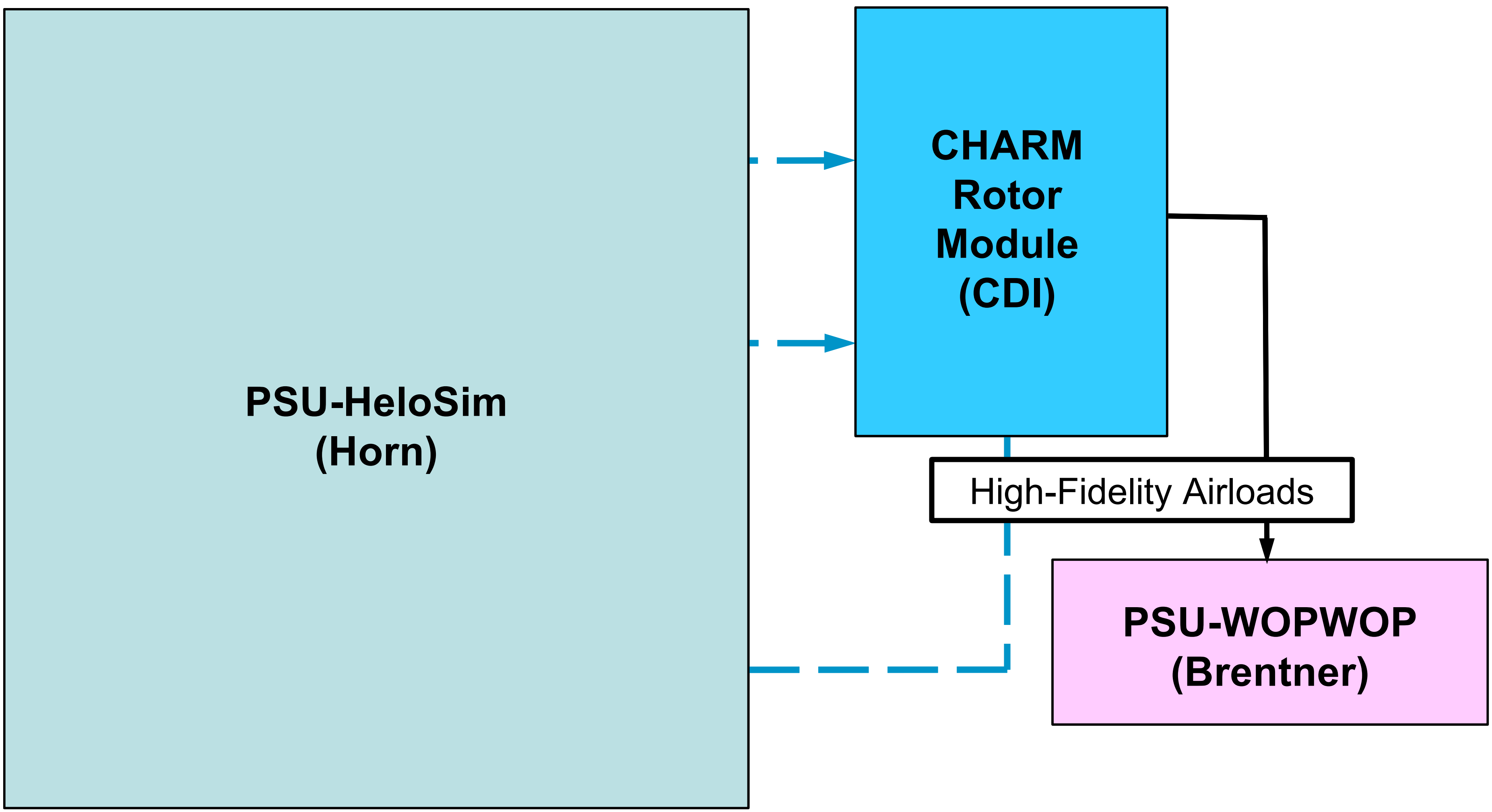
(b) Noise abatement procedure 1



(c) Noise abatement procedure 2

Comprehensive noise prediction system development

Components of FAA Noise Prediction System



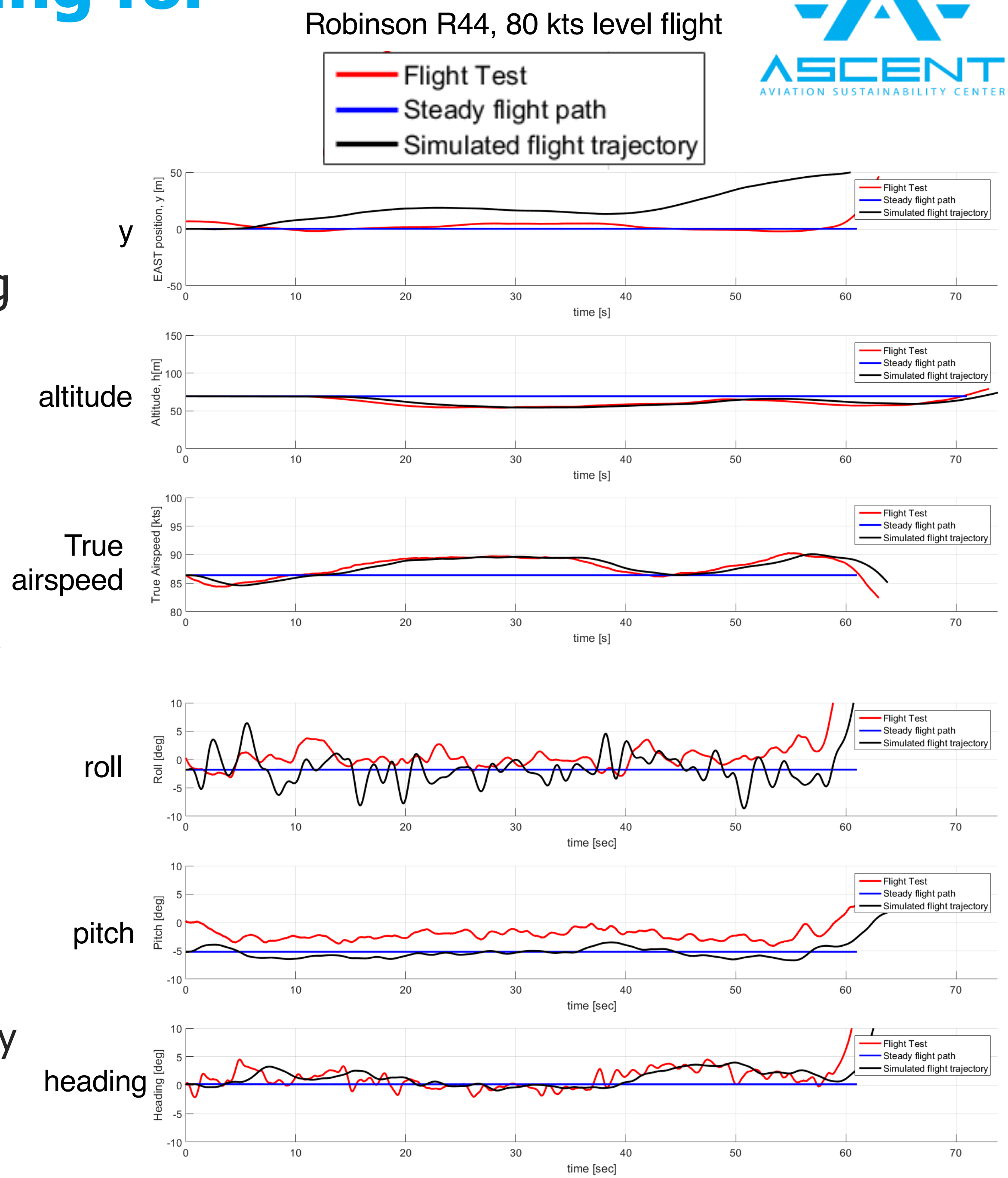
Updates to Noise Prediction System

- Fully implemented time dependent information
  - Aircraft position: (x,y,z)
  - Aircraft attitude: (pitch, yaw and roll)
  - Blade loads
    - Quasi-periodic assumption used
      - One rotor revolution of data – from each rotor – is used for a 0.5 sec time window
      - After 0.5 sec, a new periodic loading from each rotor is used
  - Flapping dynamics for thickness noise calculation
  - Rotor thrust for broadband noise calculation using Pegg's empirical model
- Added wall reflection model for broadband noise

Flight Path Modeling for Validation

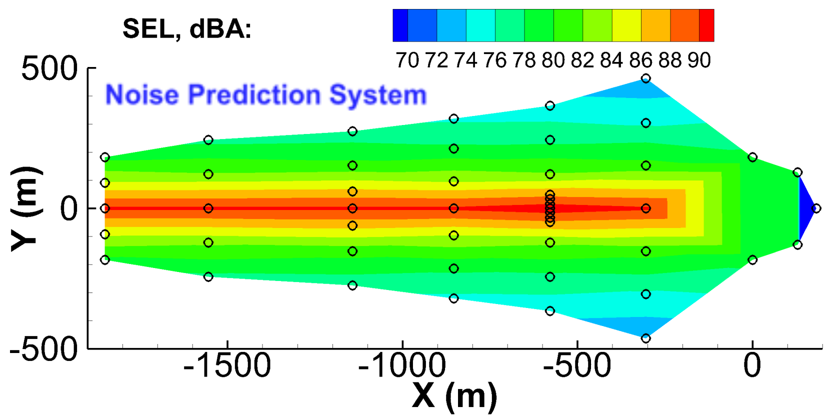
Subtle example showing importance of representing all aircraft motion

- A/C flight motion modeled with current controller
- A/C – position, velocity, and heading modeled
- These figures show a comparison of:
  - Flight test
  - desired (steady flight path)
  - Simulated flight trajectory

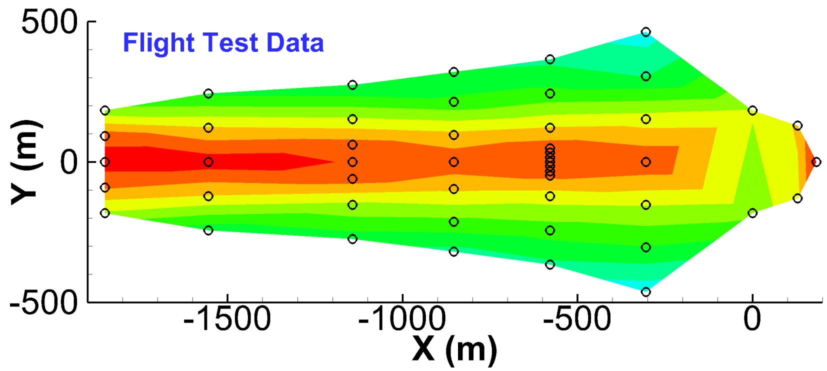


Flight Path Modeling for Validation

Steady flight path

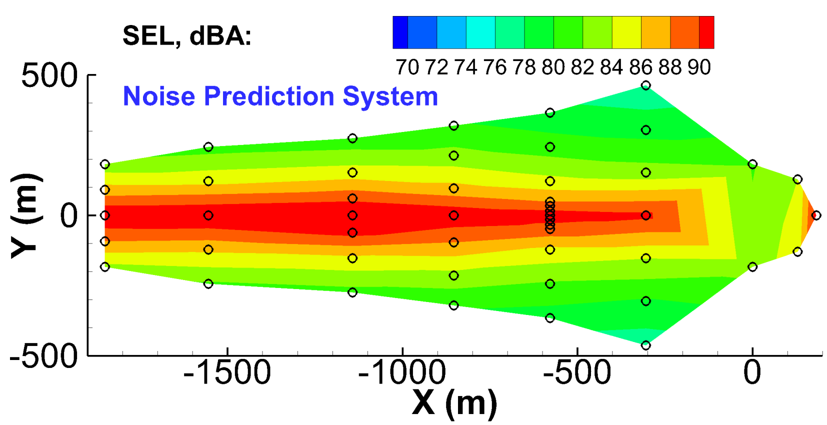


Flight test data



Robinson R44,
80 kts level flight

Simulated flight path



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

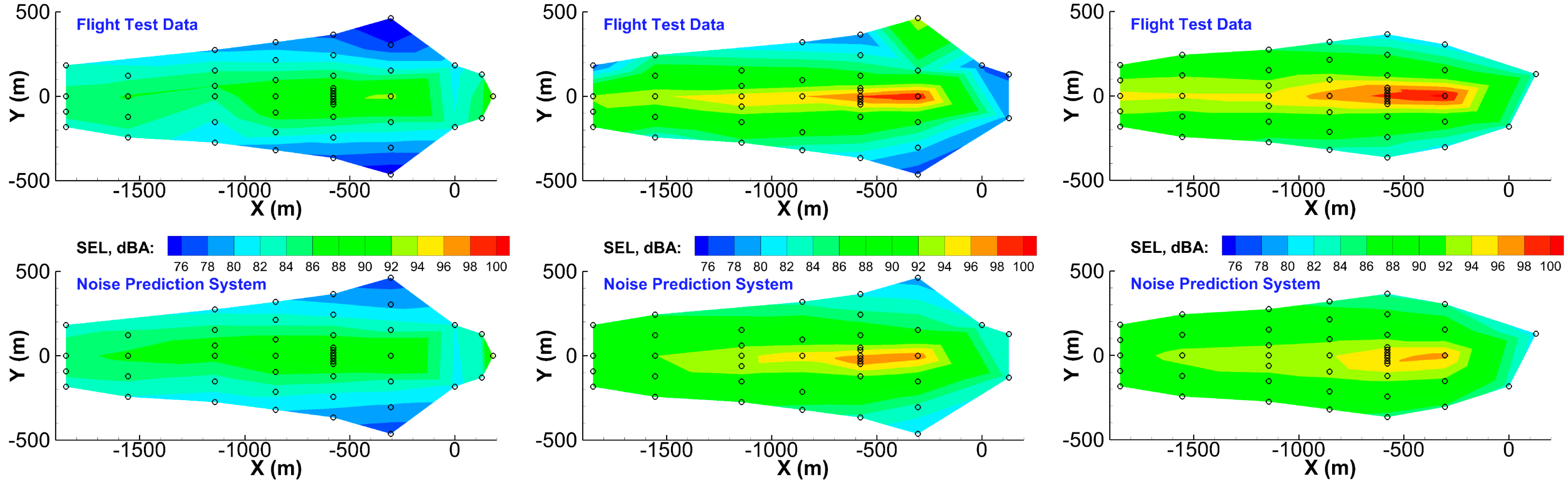
Selected due to different number of MR blades

- Bell 206L

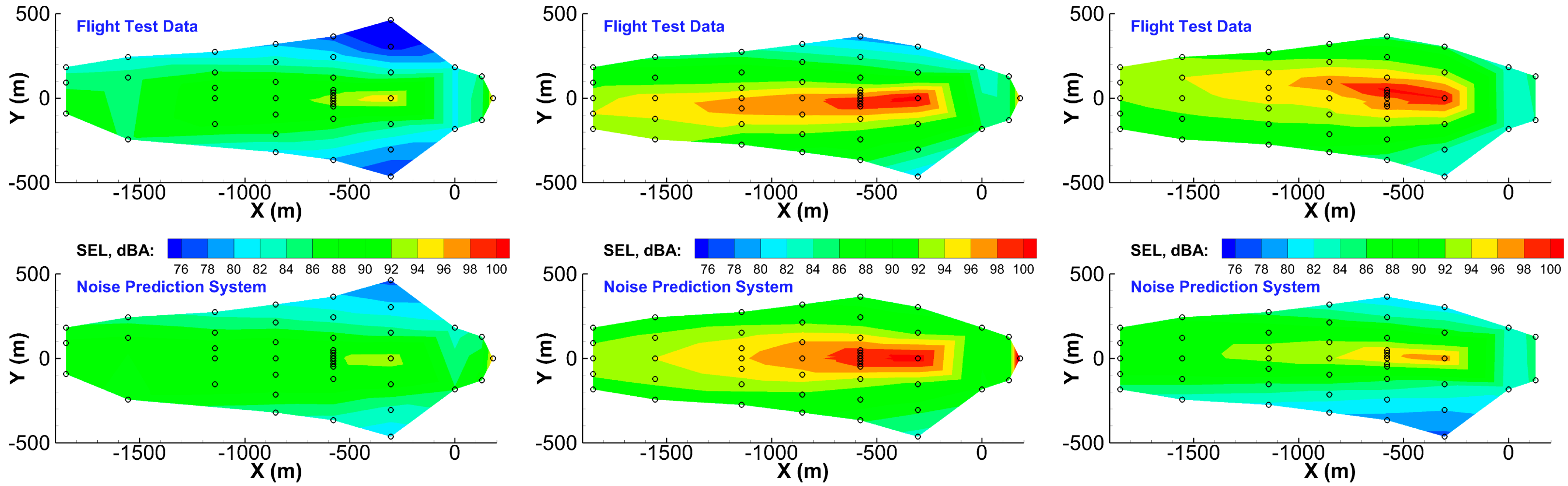
Comparison between prediction and flight test data

- 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, 6 deg descent

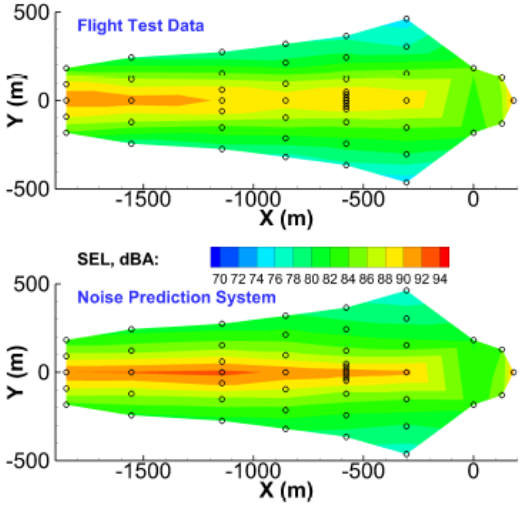


(a) Robinson R44 (b) Bell 206L (c) Airbus AS350

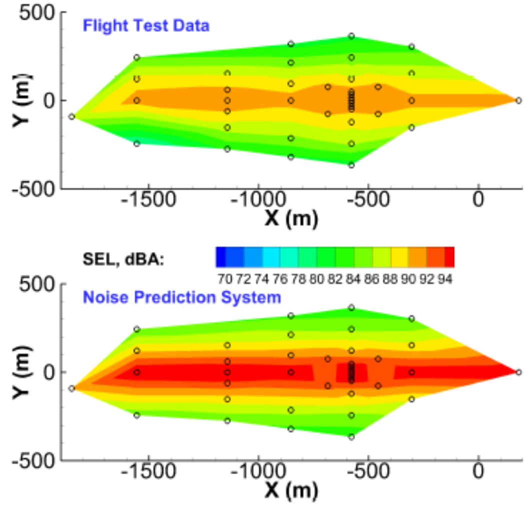


(d) Robinson R66 (e) Bell 407 (f) Airbus EC130

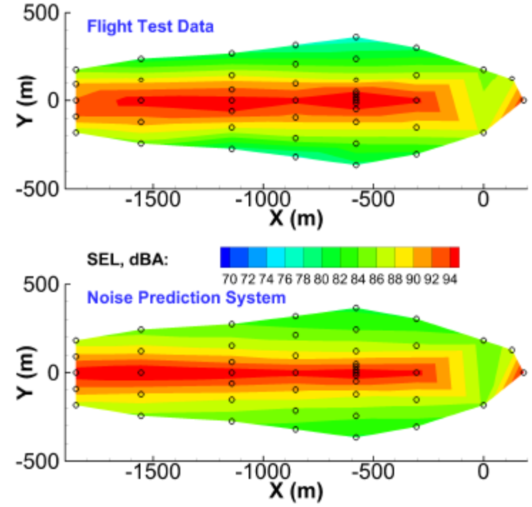
80 kts level flight



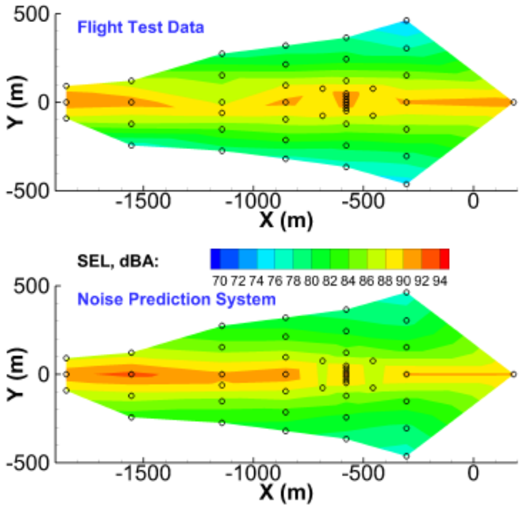
(a) Robinson R44



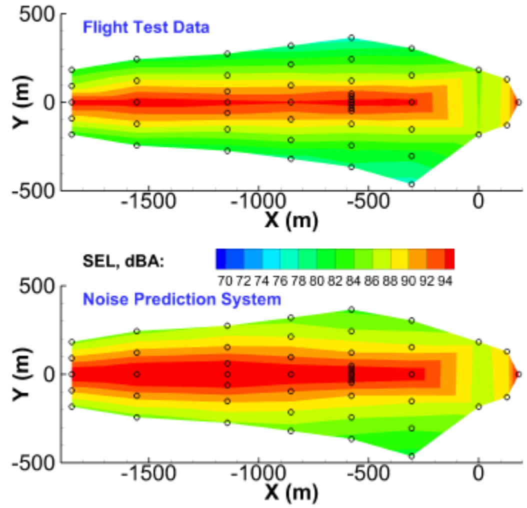
(b) Bell 206L



(c) Airbus AS350



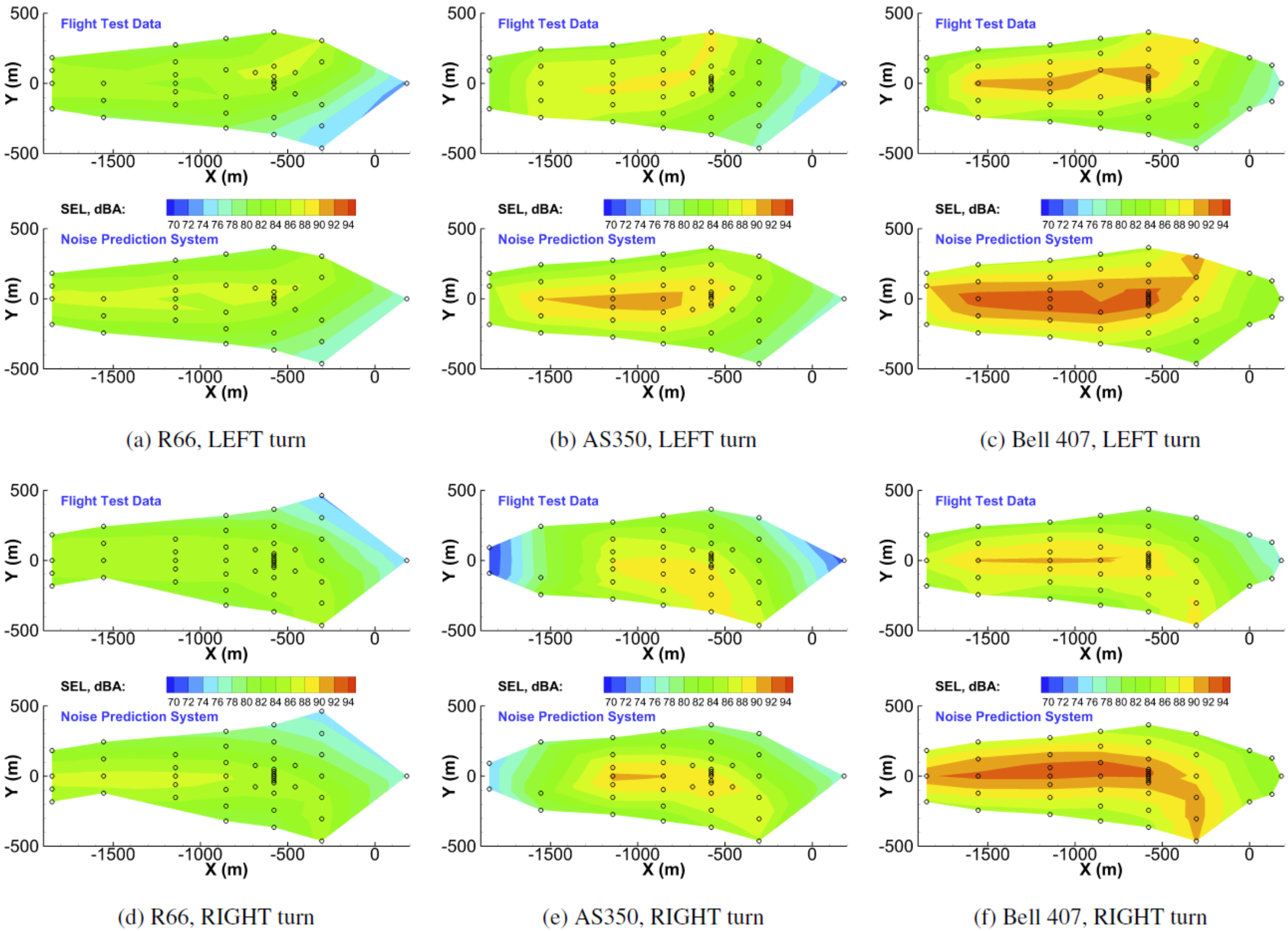
(d) Robinson R66



(e) Bell 407

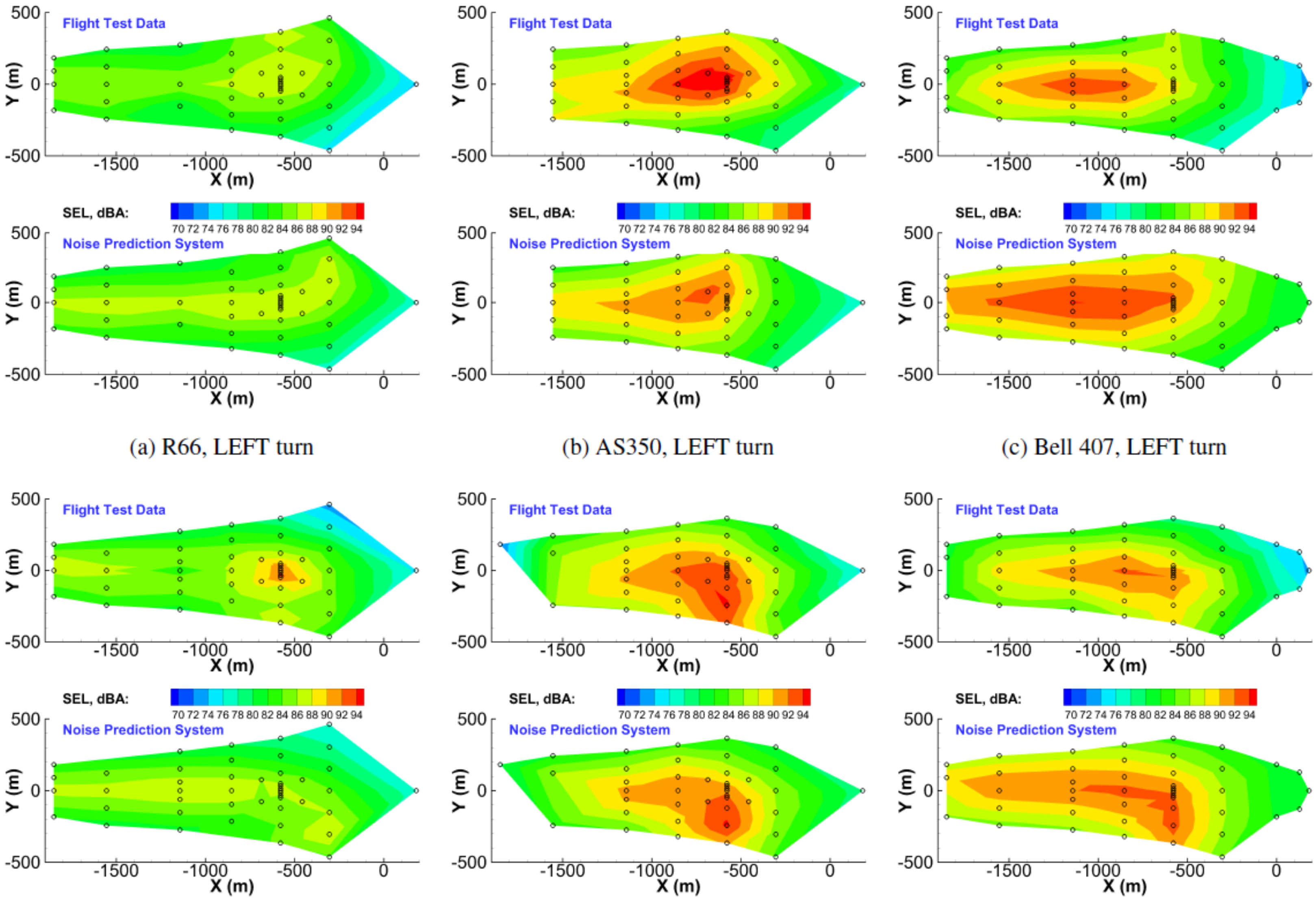
- Agreement quite good for all cases
- Slightly more overprediction for Bell 206L (broadband noise dominant)
- Airbus EC130 not included because Fenestron duct not modeled in predictions

80 kts, level turn



80 kts, level turn with 25 deg roll angle

80 kts, decelerating, level turn

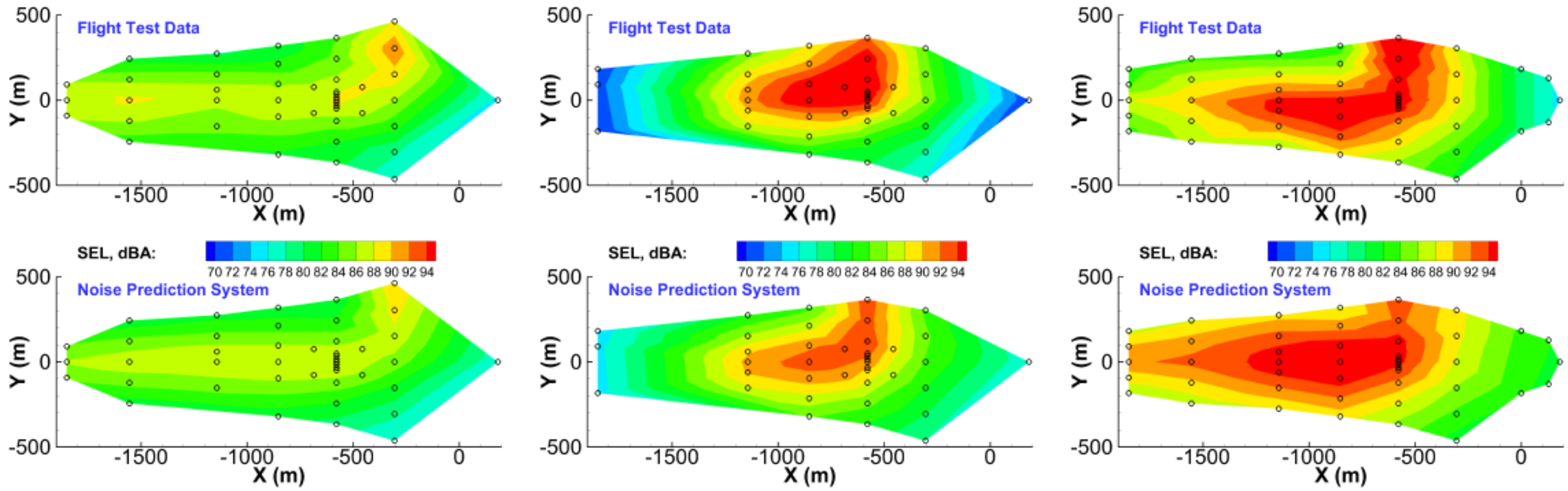


(a) R66, LEFT turn (b) AS350, LEFT turn (c) Bell 407, LEFT turn

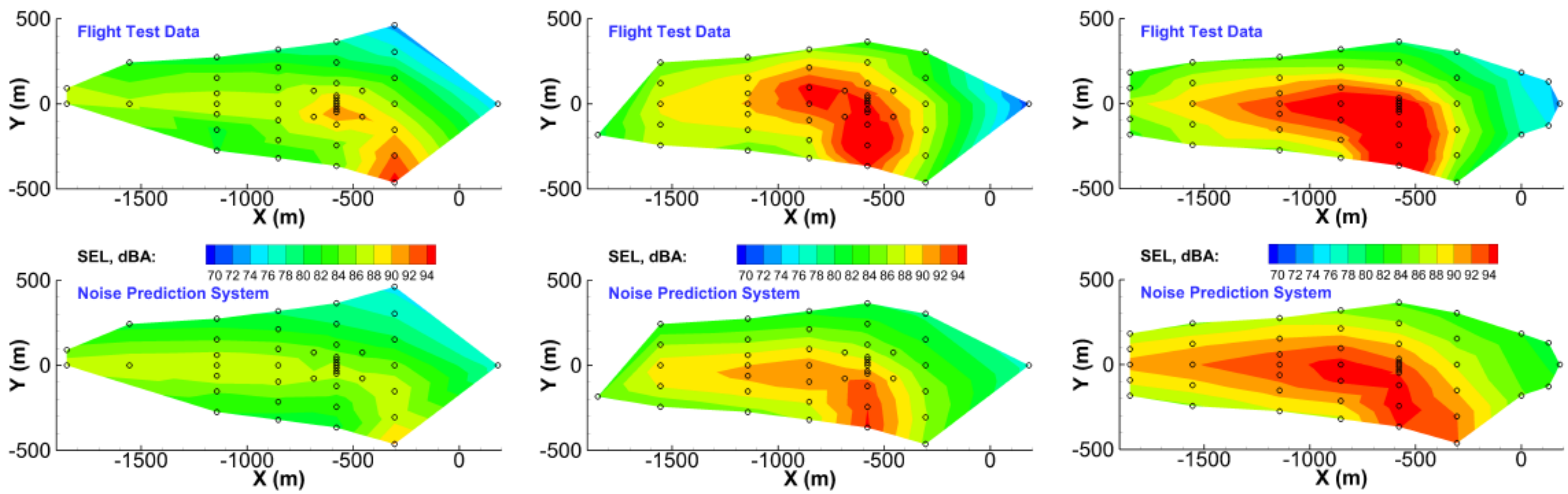
(d) R66, RIGHT turn (e) AS350, RIGHT turn (f) Bell 407, RIGHT turn

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

80 kts, descending turn



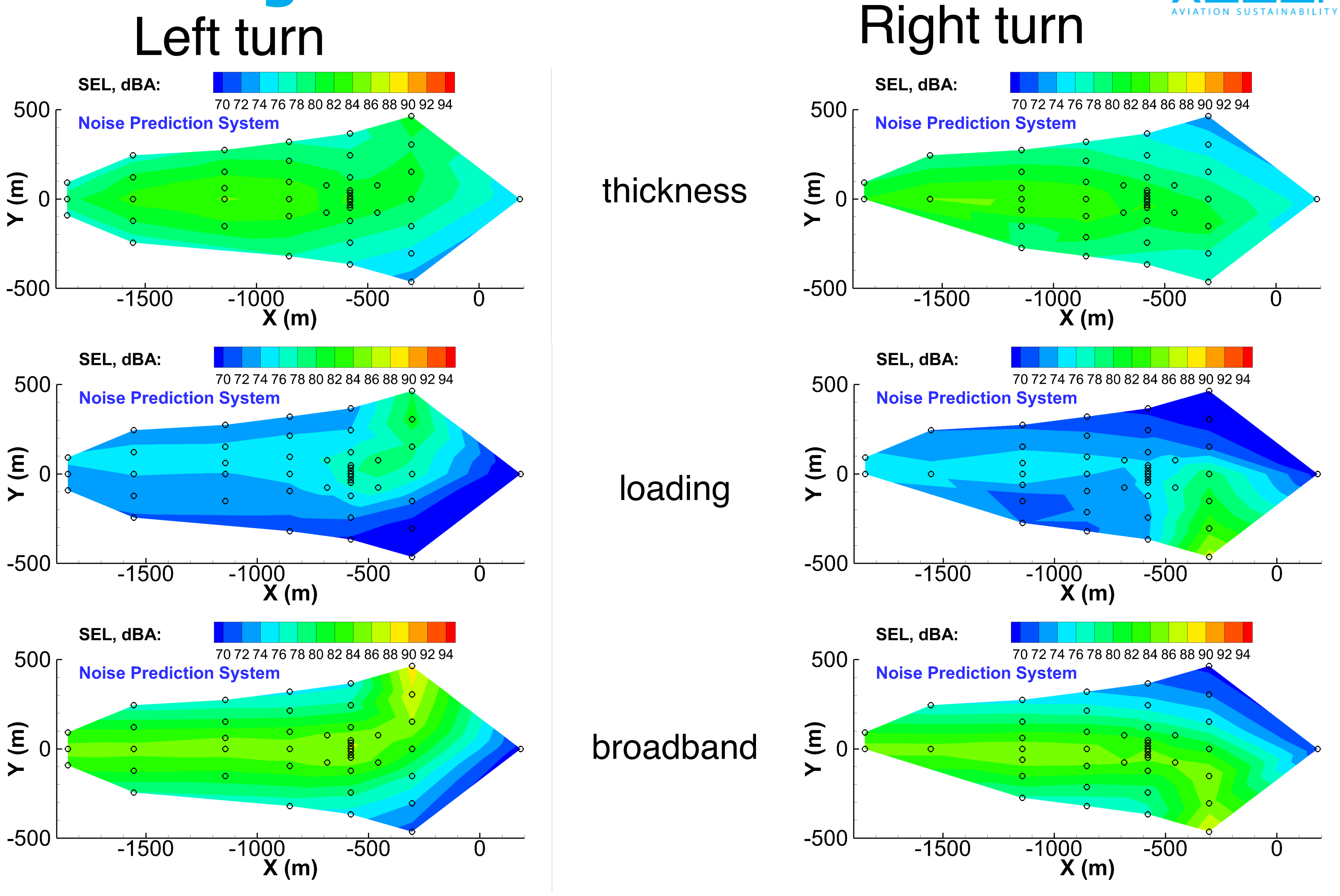
(a) R66, LEFT turn (b) AS350, LEFT turn (c) Bell 407, LEFT turn



(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

R66 – Noise Components, Descending Turn

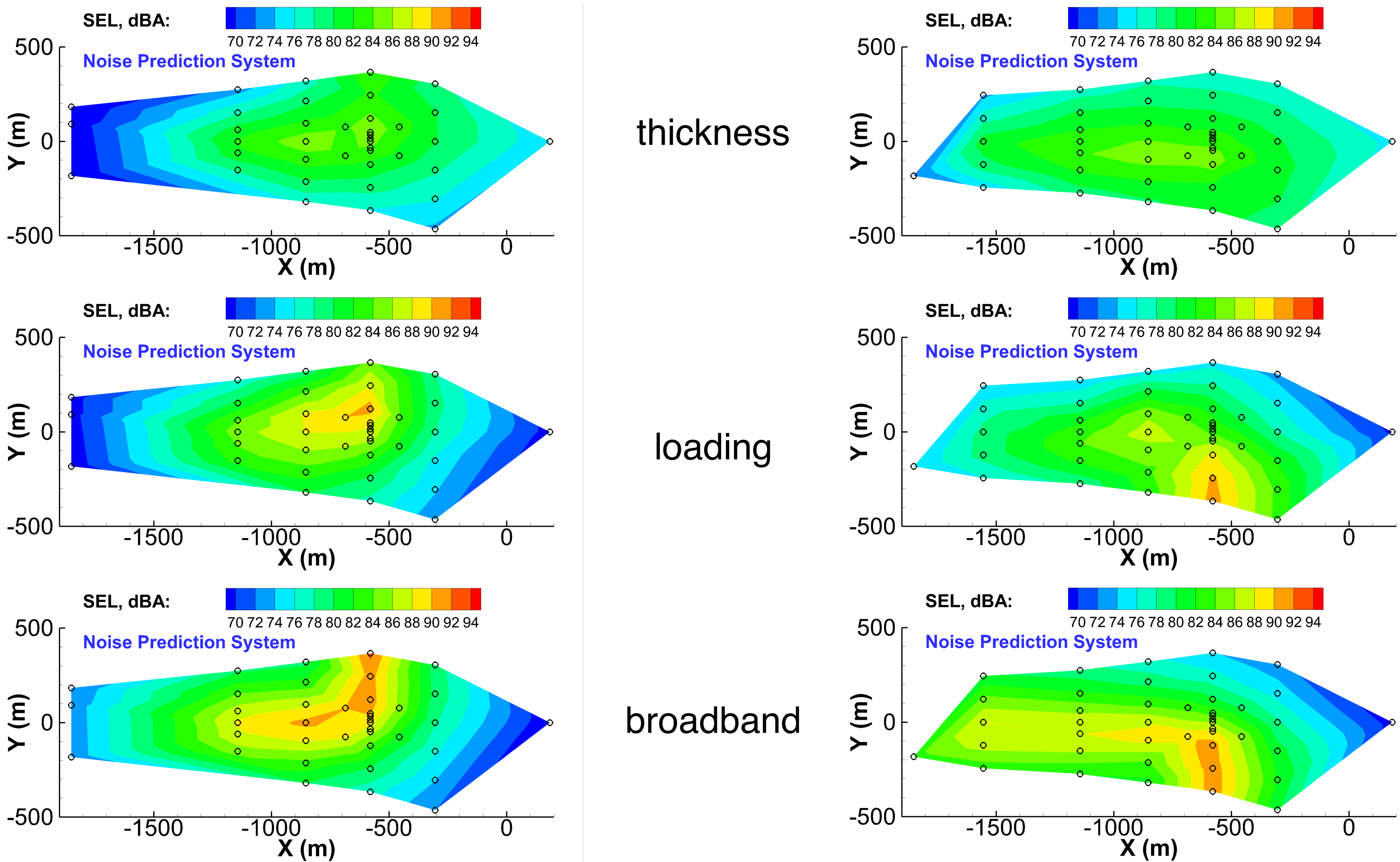


Current flight controller lets the aircraft drift to the side; this should be fixed in future version

AS350 – Noise Components, Descending Turn

Left turn

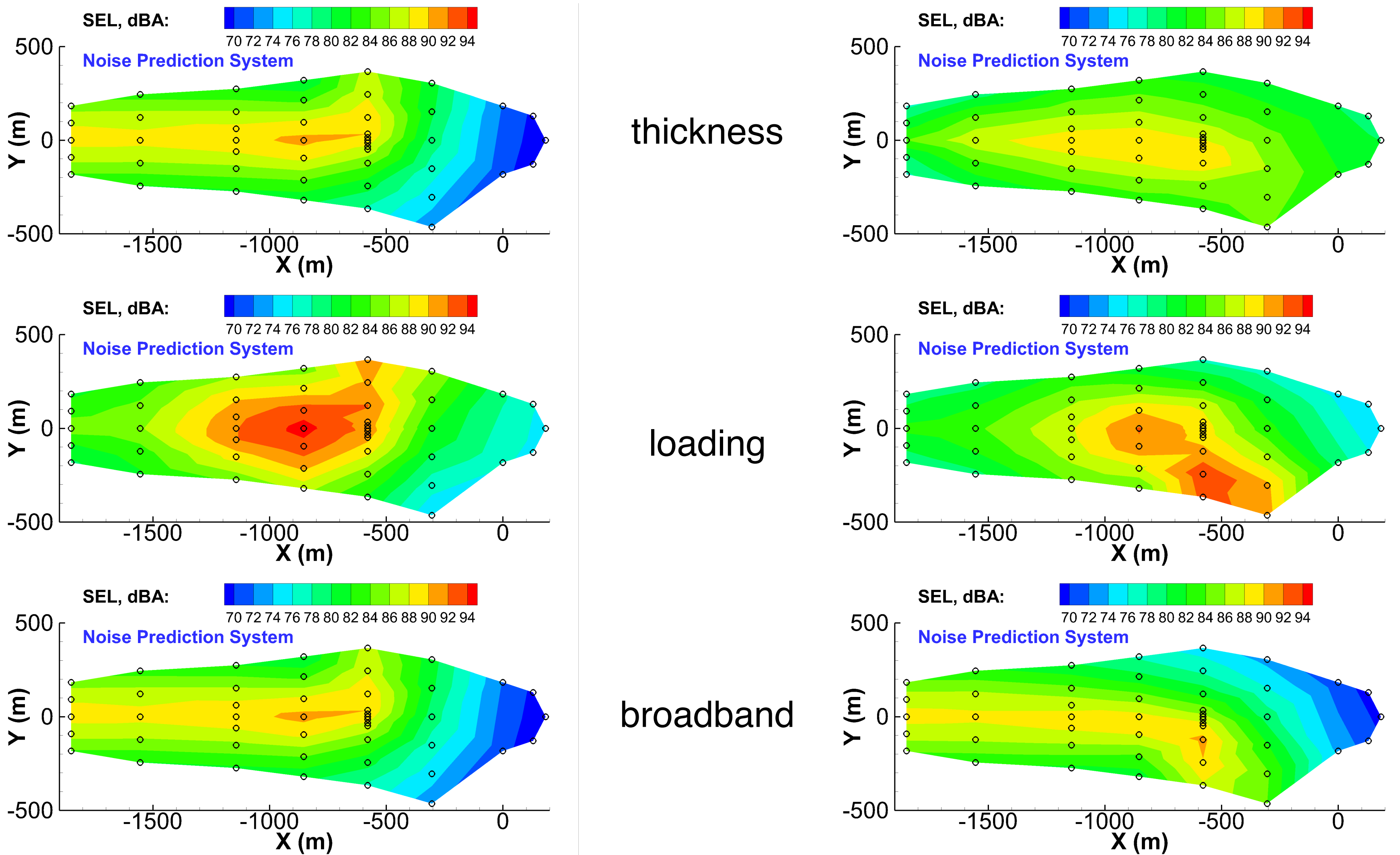
Right turn



Compare AS350 left turn with Bell 407 right turn
(CW vs CCW main rotor rotation)

Bell 407 – Noise Components, Descending Turn

Left turn | Right turn



Left turn: strong BVI noise occurs at the beginning of the turn
Right turn: strong BVI noise occurs at the end of the turn

Recent Accomplishments and Contributions

- Comparison between 6 maneuvering cases is completed
  - Transient flight test results in additional complication in analyzing any maneuver case
  - Most of the cases shows higher loading noise at the region of turn, with highest level seen if the aircraft turns on advancing side
  - Thickness noise computation needs to be modifies to account for changes in blade flapping
- Overall the noise trends are well captured with the level difference of 2-4 SELdB
- Examination of noise components helps explain what is happening in complex maneuvers

Summary

- Summary statement
  - Physics-based noise prediction system has been formed from previously existing tools
  - Noise prediction system agrees quite well with flight flight test data for multiple aircraft, even for complex manuevers
- Next steps?
  - Focus on abatement procedure development and comparison between flight test data prediction system

Contributors

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  - Sikorsky Aircraft Corporation: Eric Jacobs
  - NASA Langley Research Center: Eric Greenwood, James Stephenson, Mike Watts