Rotorcraft Noise Abatement Procedure Development Project 38

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Project 38

Rotorcraft Noise Abatement Procedure Development

The Pennsylvania State University

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Cost Share Partner(s): Continuum Dynamics, Inc. and Supernal

CoPIs: PSU: J. Horn, E. Greenwood;

CDI: D. Wachspress, M. Botre

RA: Rupak Chaudhary, UG: S. Ibnoukhaiber

Objective:

- Compare effectiveness of procedures by class of helicopters (light versus medium)
- Develop coupling with FAA noise prediction tools
- Develop noise abatement flight maneuvers for medium-size aircraft and compare with light vehicles
- Investigate the modeling of shrouded rotor noise

Project Benefits:

Quick and accurate models of various untested flight maneuvers will allow for optimized model-specific noise abatement guidance for pilots.

Research Approach:

- Develop and Validate PSU noise prediction system (PSU-NPS) for noise abatement procedures
- Analyze noise abatement procedures
- Model noise to demonstrate noise reduction advantages of certain flight maneuvers
- Evaluate noise abatement procedures against each helicopter category
  - Determine effectiveness of abatement procedures
  - Consider if a category is representative of a helicopter's classification

Major Accomplishments (since Spring meeting):

- New version of noise prediction system documented
- Compatibility issues of input files fixed for: AS350, Bell 407
- Trajectory controller improved to simulate sharp turns
- Investigated decay of SEL with altitude from spherical spreading
- Several updates to user manual, tutorials

Future Work / Schedule:

- Version compatibility issues for input files: test other helicopter models
- Refine user manual, get feedback from users at Penn State
- Improve broadband noise predicting retuning Pegg models with flight test data (collaboration with Project 49)

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Presentation Outline

- Introduction
- Recent Updates:
  - Penn State Noise Prediction System (PSU-NPS)
  - PSU-NPS User Manual
- Summary

Motivation

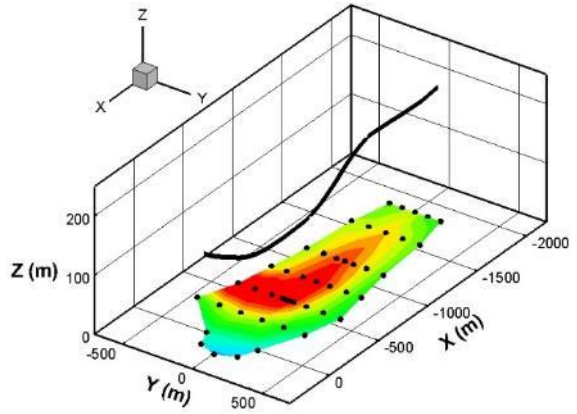
- Rotorcraft noise increasingly important
  - VAI's "Fly Neighborly Guide" is helpful for community noise
  - Need for more detailed data and information about noise produced from the operation of rotorcraft
  - Need for detailed noise abatement procedures specific to area of operation
- This project 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.

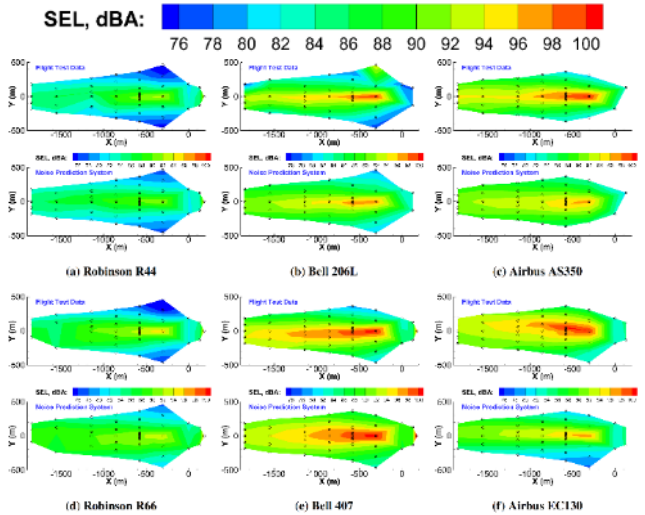
Bell 407

Sikorsky S-76D

Research Approach (Review)

- Validate PSU-NPS for noise abatement procedures/maneuvers
- Analyze noise abatement procedures
- Model noise to demonstrate noise reduction advantages of certain flight maneuvers
- Evaluate noise abatement procedures against each helicopter category
  - Determine effectiveness of abatement procedures
  - Consider if a category is representative of a helicopter's classification





Botre et al. 2019

Objectives and Potential Benefit

Objectives: (This year)

- Complete switch to DEPSim for helicopter noise predictions (Helosim has been superseded by DEPSim)
- Develop model for shrouded rotor noise prediction to support additional helicopter models
- Update PSU-NPS documentation and sample cases for users like FAA and DOT Volpe
- Enhance broadband noise predictions
- Apply enhanced PSU-NPS to noise abatement procedure analysis for various helicopters, such as the Airbus AS350 and Bell 407

Project Benefits:

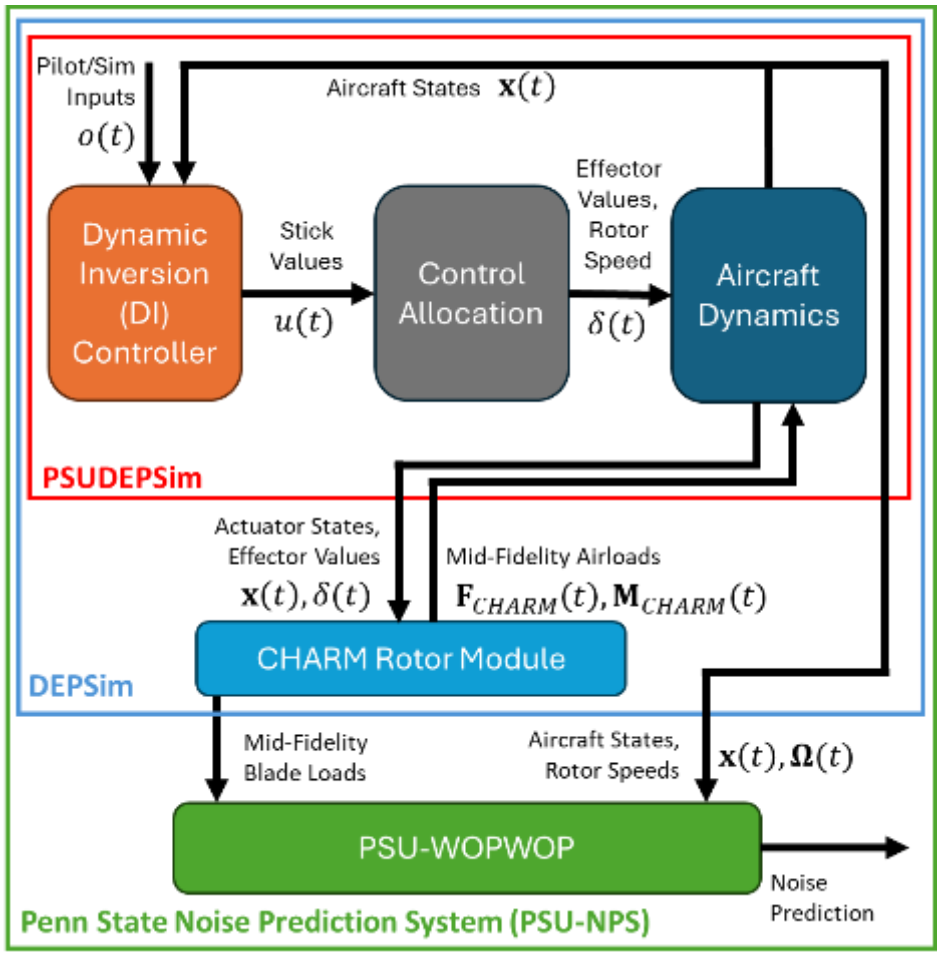
- Tool to test noise abatement guidance for:
  - pilots
  - manufacturers
  - government
  - researchers

UPDATES TO THE PENN STATE NOISE PREDICTION SYSTEM (PSU – NPS)

PSU-NPS: Review

Software constituents:

- PSUDEPSim: Flight simulation code for DEP aircraft
- CHARM: Aeromechanics modeling code by CDI
- PSU-WOPWOP: Acoustic propagation solver



Chaudhary et al. 2024

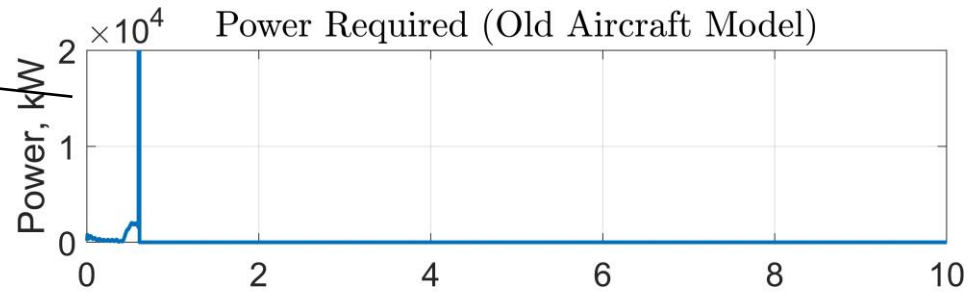
Latest Update: PSUDEPSim

- Updated to support new version of CHARM
  - Updated build configuration to support new CHARM 8 library
  - Blade wake interaction data are now provided for enhanced noise prediction models being developed in Project 49
- Ongoing bug fixes and controller improvements for broader aircraft support
- Improved trajectory tracking
- Can now be built with new versions of MATLAB

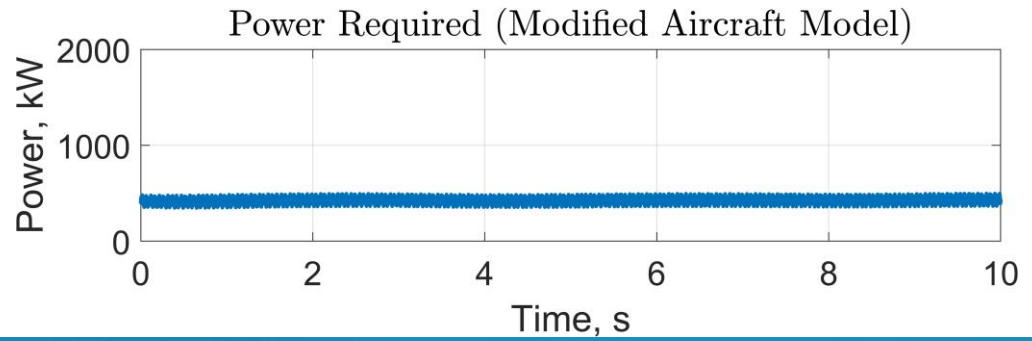
Updates to Helicopter Models

- Helicopter model definitions updated to support DEPSim
- Updates: modified C_T (used in trim), gear ratio, maximum collective, input engine speed, velocity and collective trim schedules and control constants
- Helicopters updated to support DEPSim : AS350, Bell 407

Not Physical

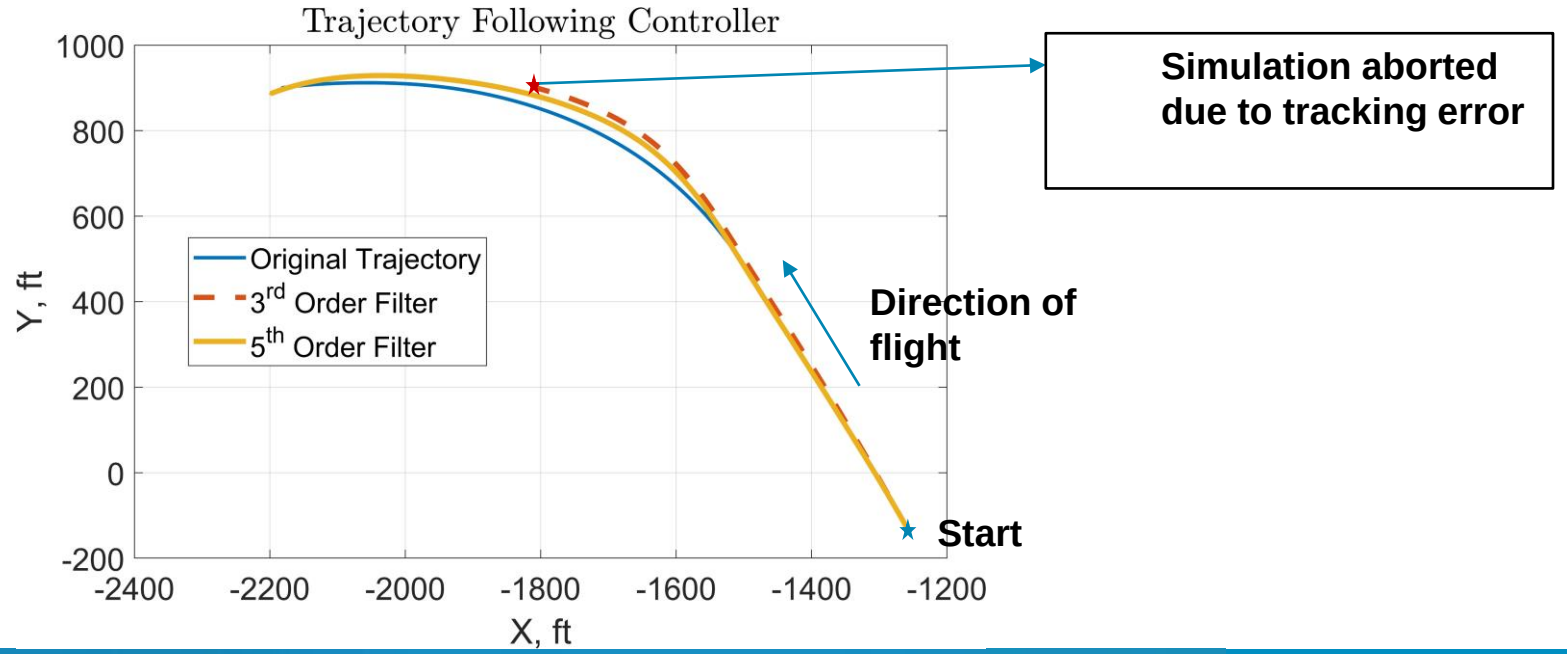


Note: Different Y-axis range



Trajectory Following: Updates For Sharp Turn

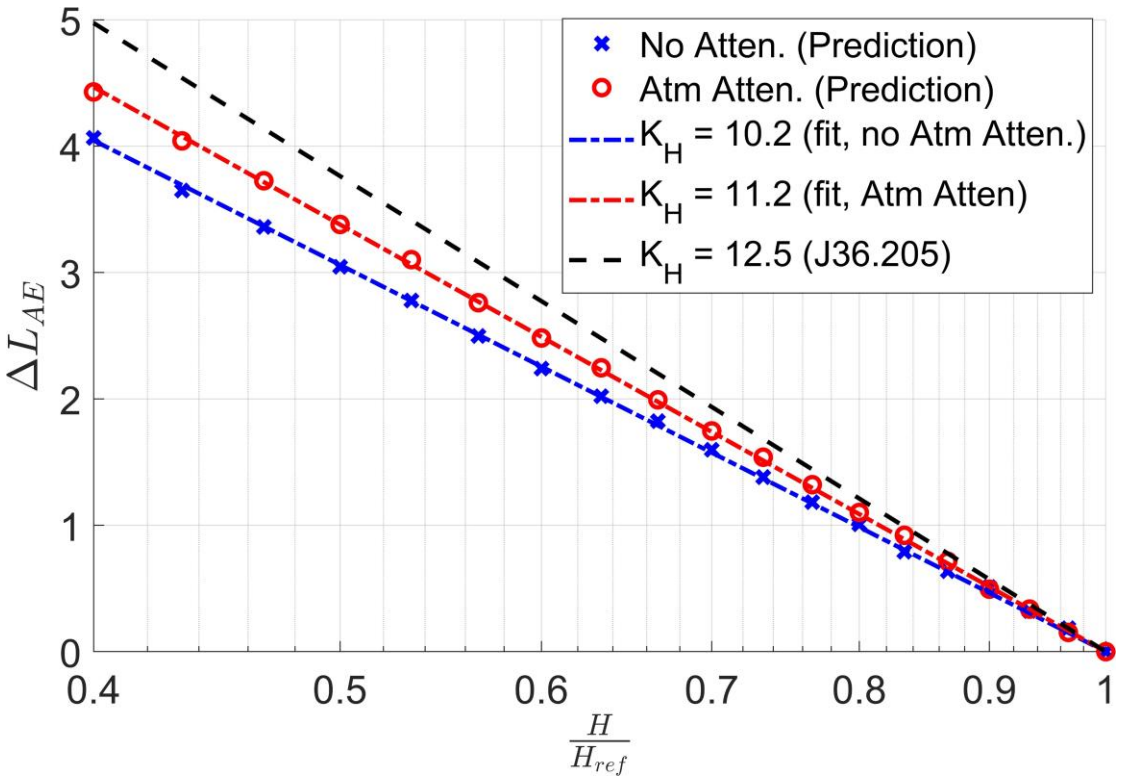
- Modification required in controller coefficients for aggressive turn maneuver
- 3rd order filter $[(S+3)^4]$ unable to track trajectory
- 5th order filter $[(S+5)^4]$ able to track trajectory with some deviation



Example PSU-NPS Application

- Validate 14 CFR Part 36, Section J36.205 Data Correction Procedures
- Assess effect of atmospheric absorption on K_H (ISO 9613-1:1993)
- Case Definition:
  - AS350 helicopter
  - 121 kts level flight
  - $T = 60°F,\ R_H = 70\%$
  - Observer directly below flight path
- Results:
  - $K_H = 10.2$ without absorption
  - $K_H = 11.2$ with absorption
  - $K_H = 12.5$ from J36.205

$$\Delta L_{AE} = K_H \log_{10}(H/H_{ref})$$



UPDATES TO THE PENN STATE NOISE PREDICTION SYSTEM USER MANUAL

PSU-NPS: Overview

- Currently a loose collection of codes
  - Not user-friendly, steep learning curve
  - Examples and "best practices" will be helpful to all users
- Current focus: development of user manual and refining user interface
  - Develop tutorials and document best practices
  - Target users: partners in FAA, VOLPE, and industry
- Goal: Share system with complete manual with FAA and DOT Volpe for feedback

PSU-NPS Manual: New Additions

I. Introduction

II. PSU-NPS Description

1. PSUDEPSim
2. CHARM
3. Simulation Modes
   a) Coupled vs Uncoupled Flight Simulation
   b) Aperiodic vs Quasi-periodic Data
4. PSU-WOPWOP

→ 1. Background on helicopter noise theory
2. Definition of AS350 maneuver example

→
- Overview of PSU-NPS components
- Examples of how simulation setup influences noise prediction accuracy

PSU-NPS Manual: New Additions

I. Introduction
II. PSU-NPS Description
III. Installation and Setup
1. PSUDEPSim
2. CHARM
3. PSU-WOPWOP

IV. PSU-NPS File Structure
1. DEPSim Root File Listing
2. *Include* and *DEPSim_cpp_V2*
3. *AircraftModels*
4. *PSUDEPSim*
5. *Binary2CSV*

→
- PSUDEPSim build instructions
- CDI provides CHARM
- PSU-WOPWOP provided with PSU-NPS

→
- Description of the DEPSim/CHARM file organization and directory structure

PSU-NPS Manual: New Additions

I. Introduction
II. PSU-NPS Description
III. Installation and Setup
IV. PSU-NPS File Structure
V. PSU-NPS Input Files
1. DEPSim
2. CHARM
3. PSU-WOPWOP

VI. PSU-NPS Output Files
1. DEPSim
2. CHARM
3. PSU-WOPWOP

- Details the structure and formatting of input files required to operate the system

- DEPSim simulation results
- CHARM output and wake visualization
- PSU-WOPWOP output files:
  - Acoustic pressure time history
  - Narrowband and 1/3 octave spectra
  - Integrated metrics (SEL, EPNL)
  - Sigma surfaces for debugging & visualization

PSU-NPS Manual: New Additions

I. Introduction
II. PSU-NPS Description
III. Installation and Setup
IV. PSU-NPS File Structure
V. PSU-NPS Input Files
VI. PSU-NPS Output Files
VII. Utility Programs

1. *Plot_results.m*
2. *GenFlightTestCaseCmd.m*
3. *FlightTestComparisonPlot.m*
4. *ProcessForWOPWOP.m*
5. *read_nc_files_amedee.m*

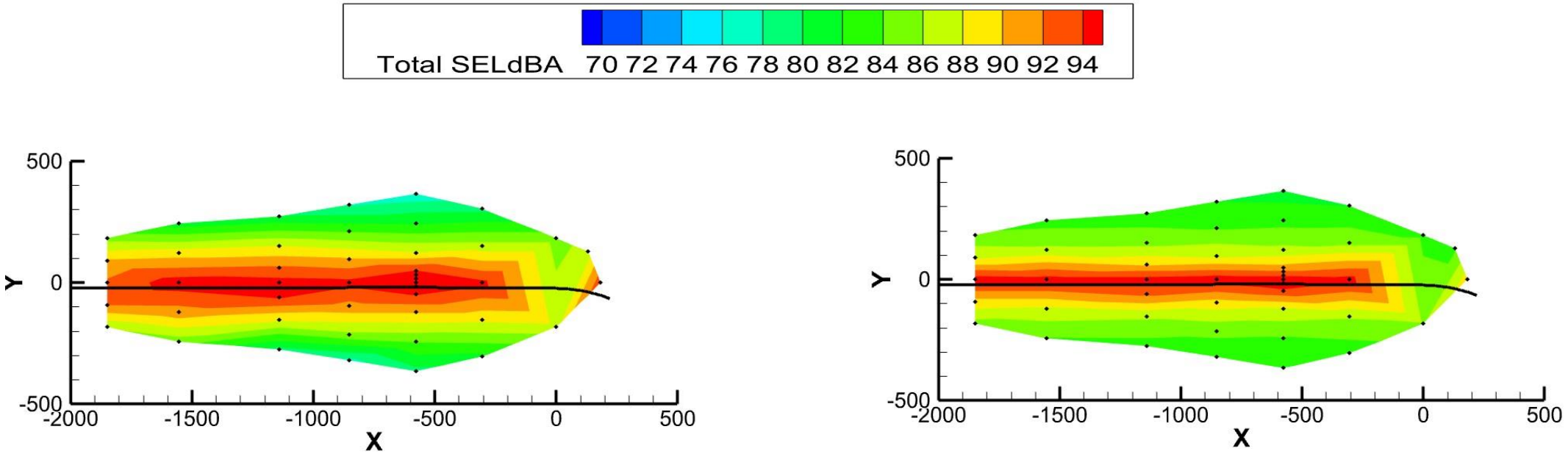
- MATLAB scripts to visualize & analyze results
  - *Plot_results.m:* Allows visualization of states, state derivatives, control inputs, etc.
  - *GenFlightTestCaseCmd.m:* Uses 2017 NASA/FAA flight test datafiles to generate a DEPSim input files to simulate desired maneuvers
  - *FlightTestComparisonPlot.m:* Simulation vs flight state comparison of aircraft states
  - *ProcessForWOPWOP.m:* Manages the input files to run PSU-WOPWOP

PSU-NPS Manual: Table of Contents (Updated)

- Examples based on 2017 FAA/NASA flight tests
  - AS350 helicopter in level flight
  - R44 helicopter in maneuvering flight
- Detailed instructions provided:
  - Case setup
  - Analysis of predicted data

PSU-NPS AS350 Tutorial: Comparing With Flight Test Data

- AS350 helicopter at 80 knots level flight
- Analysis of SEL noise levels shows good match with flight test data



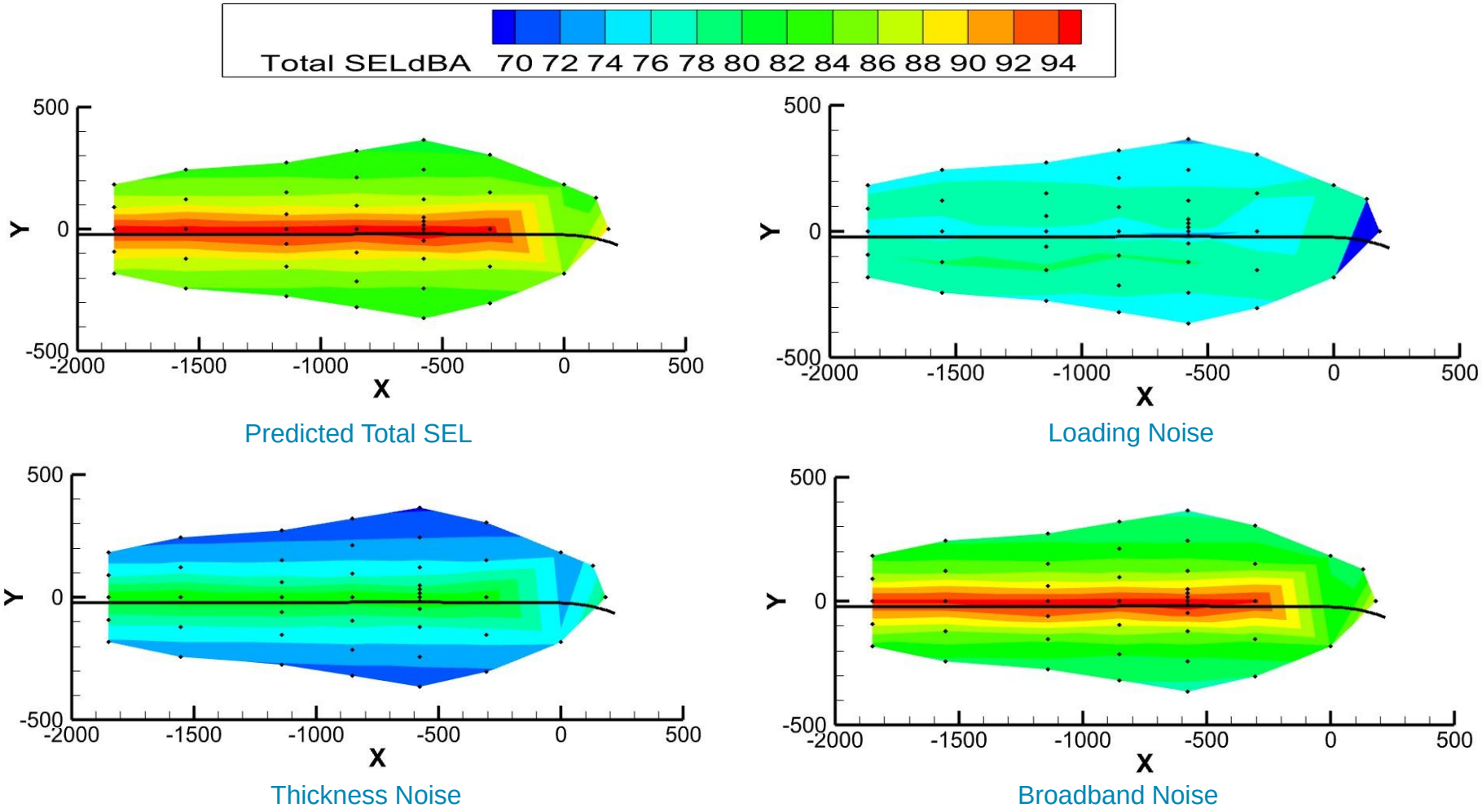
Flight Test Data

Predicted Total SEL

AS350 80 Knots Level Flight: Test Data vs Prediction

PSU-NPS AS350 Tutorial: Demonstration Of Analysis

- PSU-WOPWOP calculations allow analysis of noise components
- Here broadband noise is the dominant source of noise



Predicted Total SEL | Loading Noise

Thickness Noise | Broadband Noise

Predicted SEL Noise Components

Summary

- ***Major Accomplishments:***
  - Updates to noise prediction system:
    - New version of CHARM that can provide input to predict wake interaction broadband noise
    - Fixes to input files for AS350 and Bell 407 helicopters: compatibility issues with new version
    - Improved trajectory following controller for more aggressive manuevers
    - Investigate data correction procedures for altitude (14 CFR Part 36, Section J36.205)
  - User manual:
    - Updates to new version documented and sections updated
    - Added new results and analysis of maneuvers used in tutorial
- ***Future Work:***
  - Test remaining helicopter models that worked with previous version of DEPSim and Helosim
  - Continue refinement of user manual
  - Improve broadband noise predicting retuning Pegg models with flight test data (collaboration with Project 49)

References

1. M. C. Botre, K. S. Brentner, J. Horn, and D. A. Wachspress, "Developing a comprehensive noise prediction system for generating noise abatement procedures," in 25th AIAA/CEAS Aeroacoustics Conference, Delft, The Netherlands: American Institute of Aeronautics and Astronautics, May 2019, p. 20. doi: 10.2514/6.2019-2617.
2. R. Chaudhary, V. Valente, B. Mukherjee, A. Jue, K. Brentner, and E. Greenwood, "Understanding Takeoff and Landing Noise for Small Multirotor Vehicles," in Proceedings of the Vertical Flight Society 80th Annual Forum, Montreal, Canada: The Vertical Flight Society, May 2024, pp. 1–22. doi: 10.4050/F-0080-2024-1157.

Participants

1. PI: Kenneth S. Brentner, Penn State University (PSU)
2. Co-PIs: Eric Greenwood & Joseph Horn (PSU); Daniel Wachspress & Mrunali Botre (CDI)
3. Graduate Research Assistants: Bhaskar Mukherjee
4. Industrial Partners: CDI, BRRC, Sikorsky, Supernal

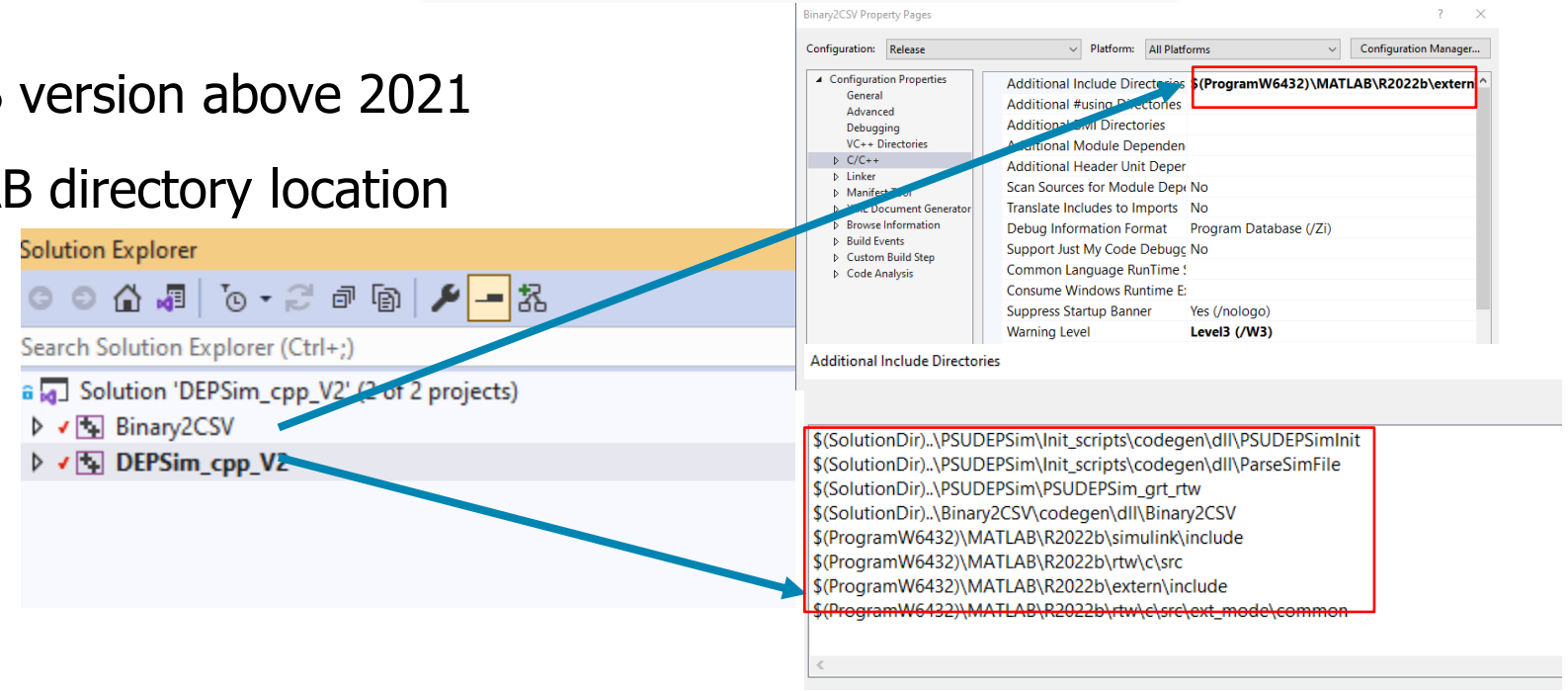
BACKUP MATERIAL

Build Latest DEPSim

- Modification in user manual of Penn State Noise Prediction System (in progress)
- Change in DEPSim solution dependency
- Modify linker library dependency

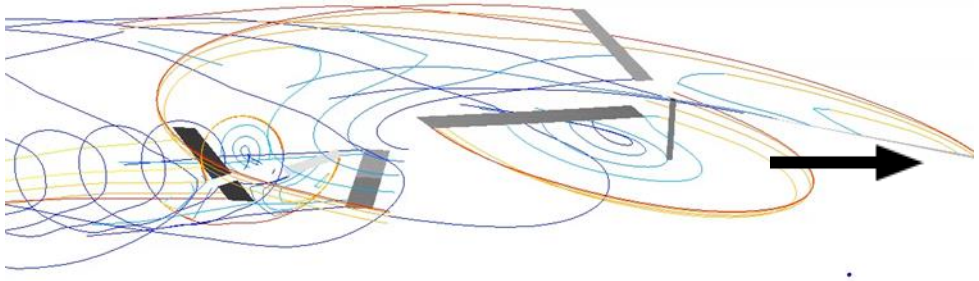
```
$(SolutionDir)..\Binary2CSV\codegen\dll\Binary2CSV
$(SolutionDir)..\PSUDEPSim\Init_scripts\codegen\dll\ParseSimFile
$(SolutionDir)..\Include\CHARM\lib\64
$(SolutionDir)..\Include\XPcomms_Lib\x64
$(SolutionDir)..\PSUDEPSim\Init_scripts\codegen\dll\PSUDEPSimInit
<different options>
```

- Can be built in MATLAB version above 2021
- Need to change MATLAB directory location

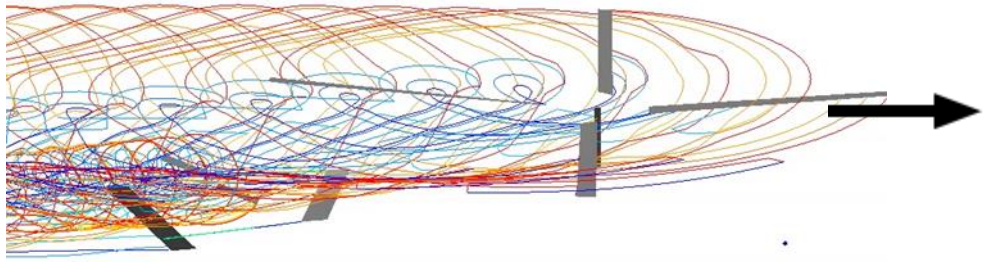


Helicopter Models (Prepared)

AS350



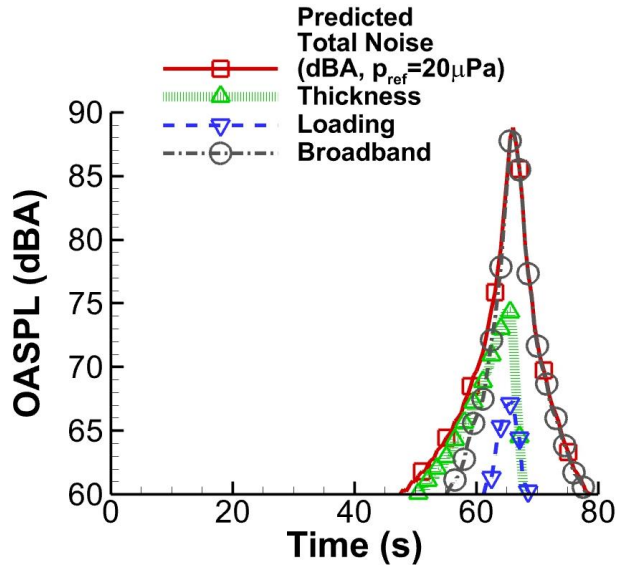
Bell407



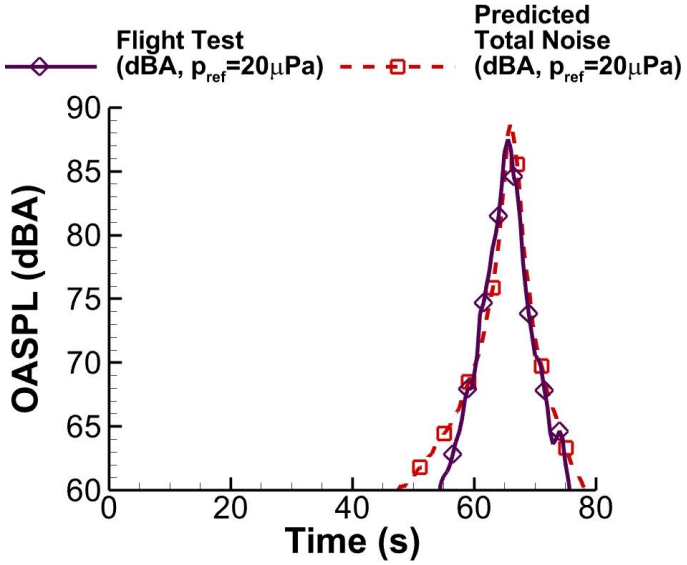
- Two helicopter model updated for latest DEPSim : to be included in new PSU-NPS distribution
- Works with trajectory following and default pilot (cyclic, pedal and collective input) controller
  - Easier to switch
  - Switching requires to run design_controller command

PSU-NPS AS350 Tutorial Results (Review)

- AS350 helicopter at 80 knots level flight (Run No. 289154)
  - Analysis of A-weighted noise levels help reveal component of noise potentially important for estimating community annoyance
  - Broadband noise has been found to be dominant source of noise in absence of events such as BVI
  - Pegg model currently used for estimating broadband noise: improvements planned



Predicted OASPL (dBA) for AS350:
80 knots level flight, mic below flight trajectory



Flight test vs Predicted: A-weighted