Noise Mitigation of a Supersonic Jet Using Shear Layer Swirl

WP19-1288

PI: Z.J. Wang
University of Kansas

02/18/2020

SERDP
DOD ▪ EPA ▪ DOE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*
18/02/2018

2. REPORT TYPE
SERDP Project Outbrief

3. DATES COVERED *(From - To)*
1/15/2019 - 1/14/2020

4. TITLE AND SUBTITLE
Noise Mitigation of a Supersonic Jet Using Shear Layer Swirl

5a. CONTRACT NUMBER
19-P-0006

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER
WP19-1288

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Z.J. Wang
Saeed Farokhi, Ray Taghavi, Huixuan Wu, Charlie Zheng
PhD students: Mohamad Alhawwary, Salman Rahmani, Meihua Zhang
MS students: Cody Hill, Justin Phommachanh
BS students: Bradley Collicott, Blake Hartwell, Josiah Swim
Consultant: Robert Dougherty (OptiNav)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Kansas Center for Research, Inc.
University of Kansas
2120 Learned Hall
Lawrence, KS 66045

8. PERFORMING ORGANIZATION REPORT NUMBER
WP19-1288

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research and Development Program (SERDP)
4800 Mark Center Drive, Suite 16F16
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
WP19-1288

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

•Explore a promising technology of using swirl inducing vanes to achieve significant engine noise reduction levels (3+ dB) for legacy engines.
- Test influence of vane location, swirl angle, and blockage effect on jet flow-field and acoustic signature.
- Validate and verify computational and experimental testing procedures to ensure high confidence in results.
- Establish thrust differentials for the vaned nozzle configurations.

•The ultimate objective is to achieve “substantial” noise reduction at full-scale, at full power.

15. SUBJECT TERMS
Noise Mitigation, Supersonic Jet , Shear Layer Swirl, Twin-Engine Military Aircraft

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Z.J. Wang
UNCLASS	UNCLASS	UNCLASS	UNCLASS	36	19b. TELEPHONE NUMBER *(Include area code)* 785-864-2440

Project Team

- PI: Z.J. Wang
- Co-PIs: Saeed Farokhi, Ray Taghavi, Huixuan Wu, Charlie Zheng
- PhD students: Mohamad Alhawwary, Salman Rahmani, Meihua Zhang
- MS students: Cody Hill, Justin Phommachanh
- BS students: Bradley Collicott, Blake Hartwell, Josiah Swim
- Consultant: Robert Dougherty (OptiNav)

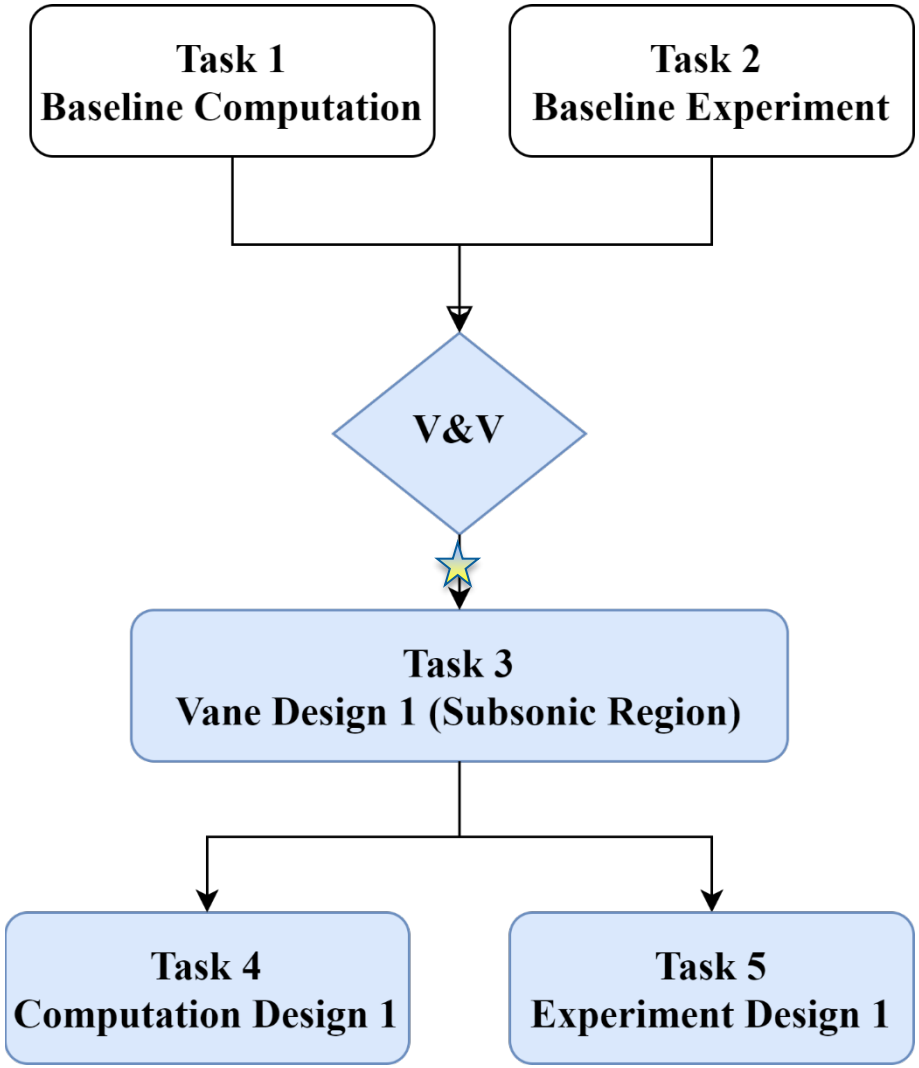
Background

- The project was initiated on January 15, 2019 and completed on January 14, 2020.
- Statement of Need: WPSON-19-C1, Aircraft Engine Noise Reduction Technology

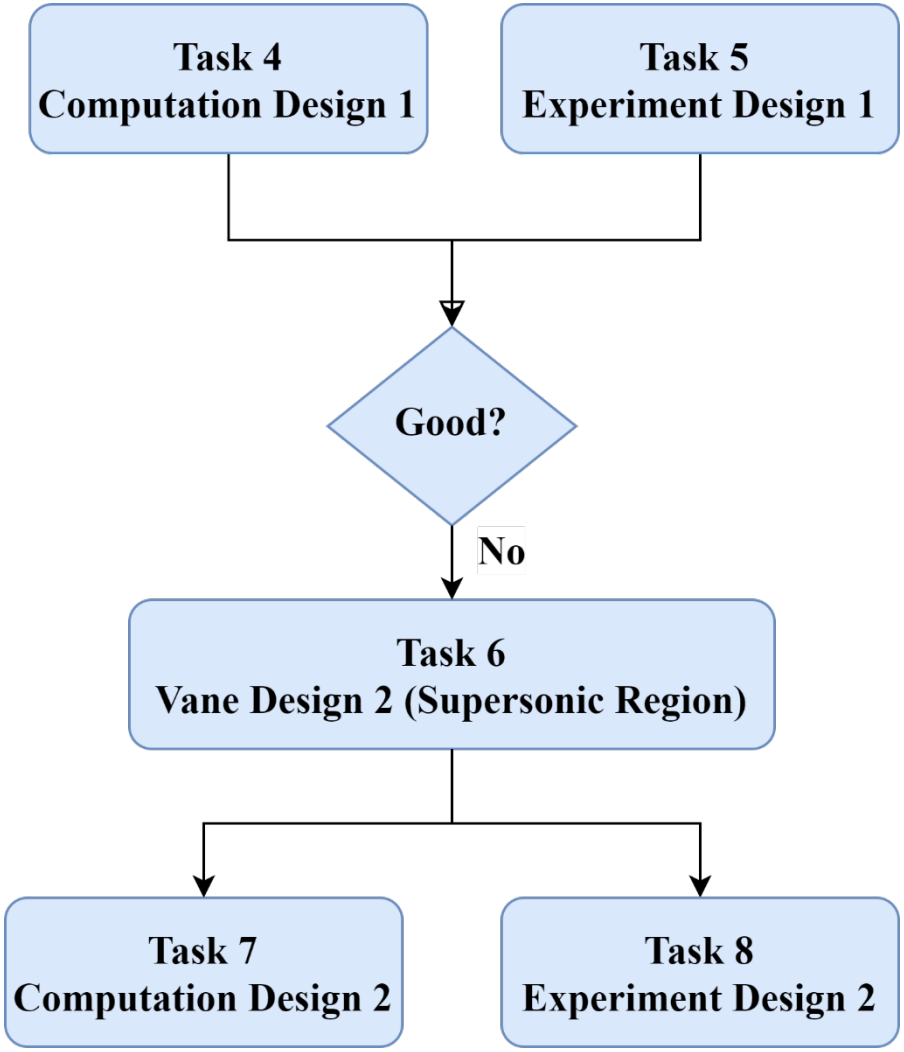
Technical Objectives

- Explore a promising technology of using swirl inducing vanes to achieve significant engine noise reduction levels (3+ dB) for legacy engines.
  - Test influence of vane location, swirl angle, and blockage effect on jet flow-field and acoustic signature
  - Validate and verify computational and experimental testing procedures to ensure high confidence in results
  - Establish thrust differentials for the vaned nozzle configurations
- The ultimate objective is to achieve “substantial” noise reduction at full-scale, at full power.

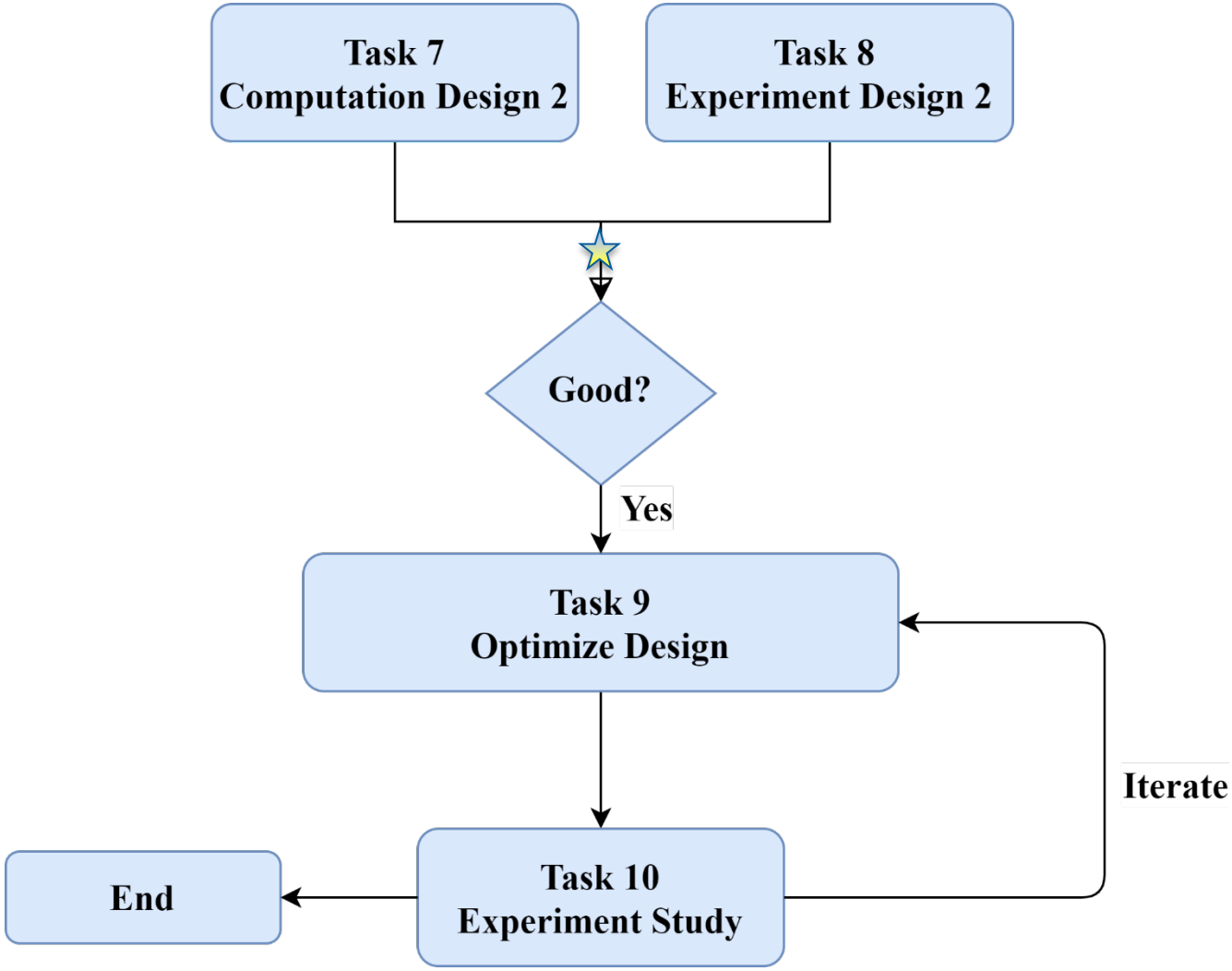
Technical Approach



Technical Approach

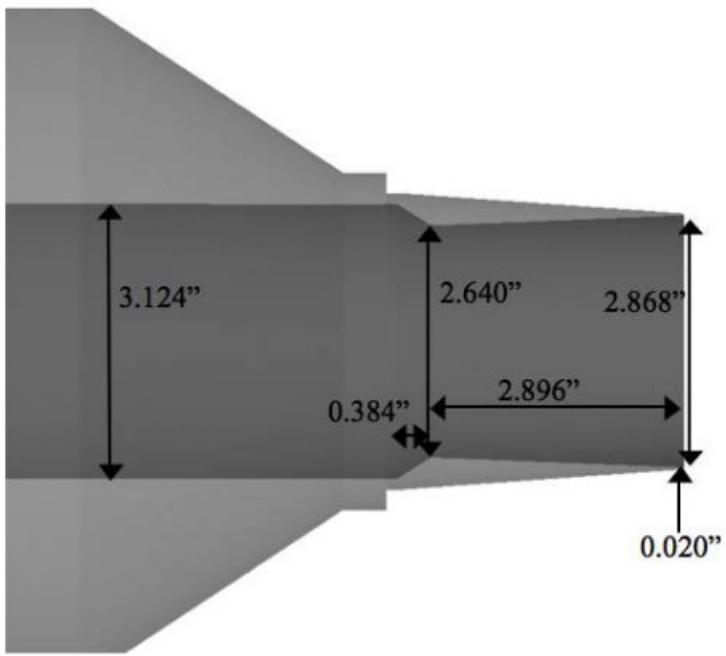


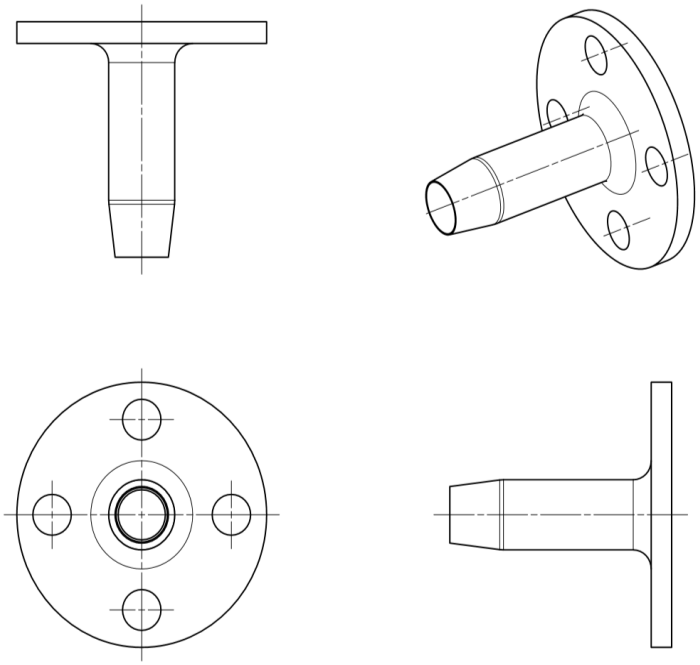
Technical Approach



Results – Task 1 and Task 2

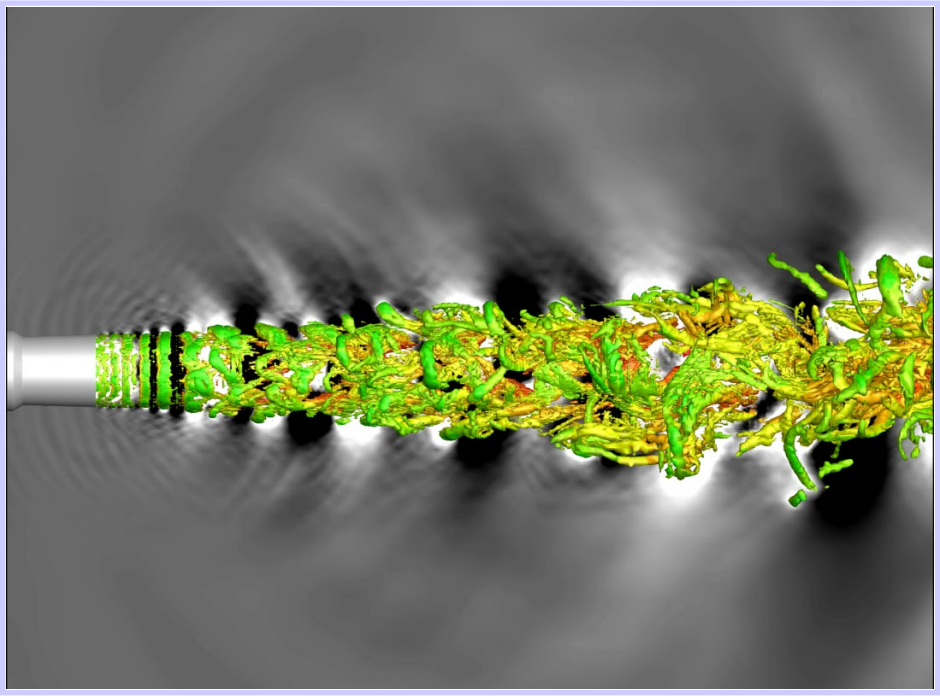
- Verification and validation study using a selected baseline supersonic nozzle (U. of Cincinnati)



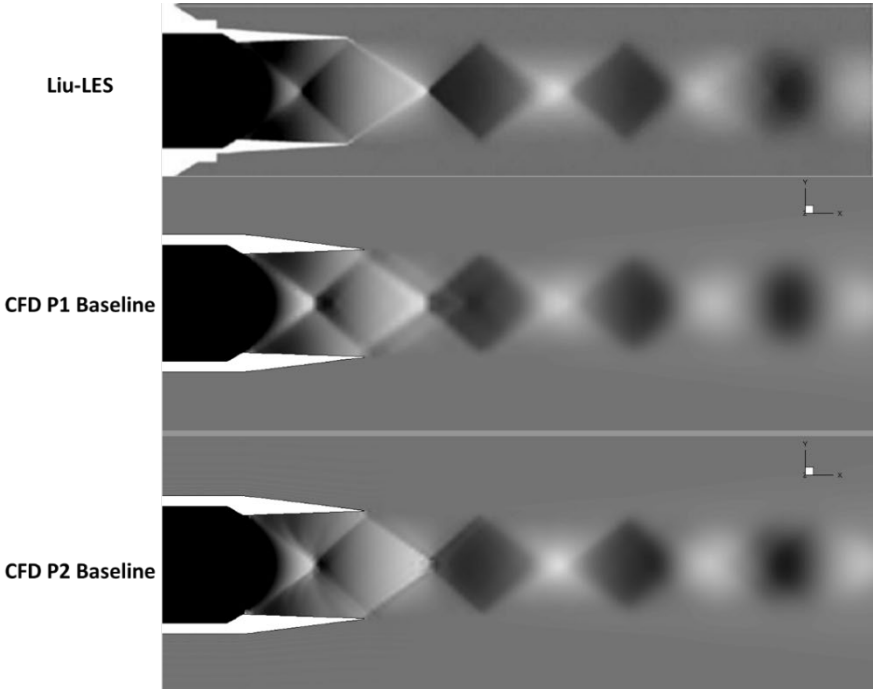


M_d	NPR	M_j	U_j(m/s)	D_j(mm)	TTR
1.5	3.515	1.47	425.8	72.05	1.0

V&V

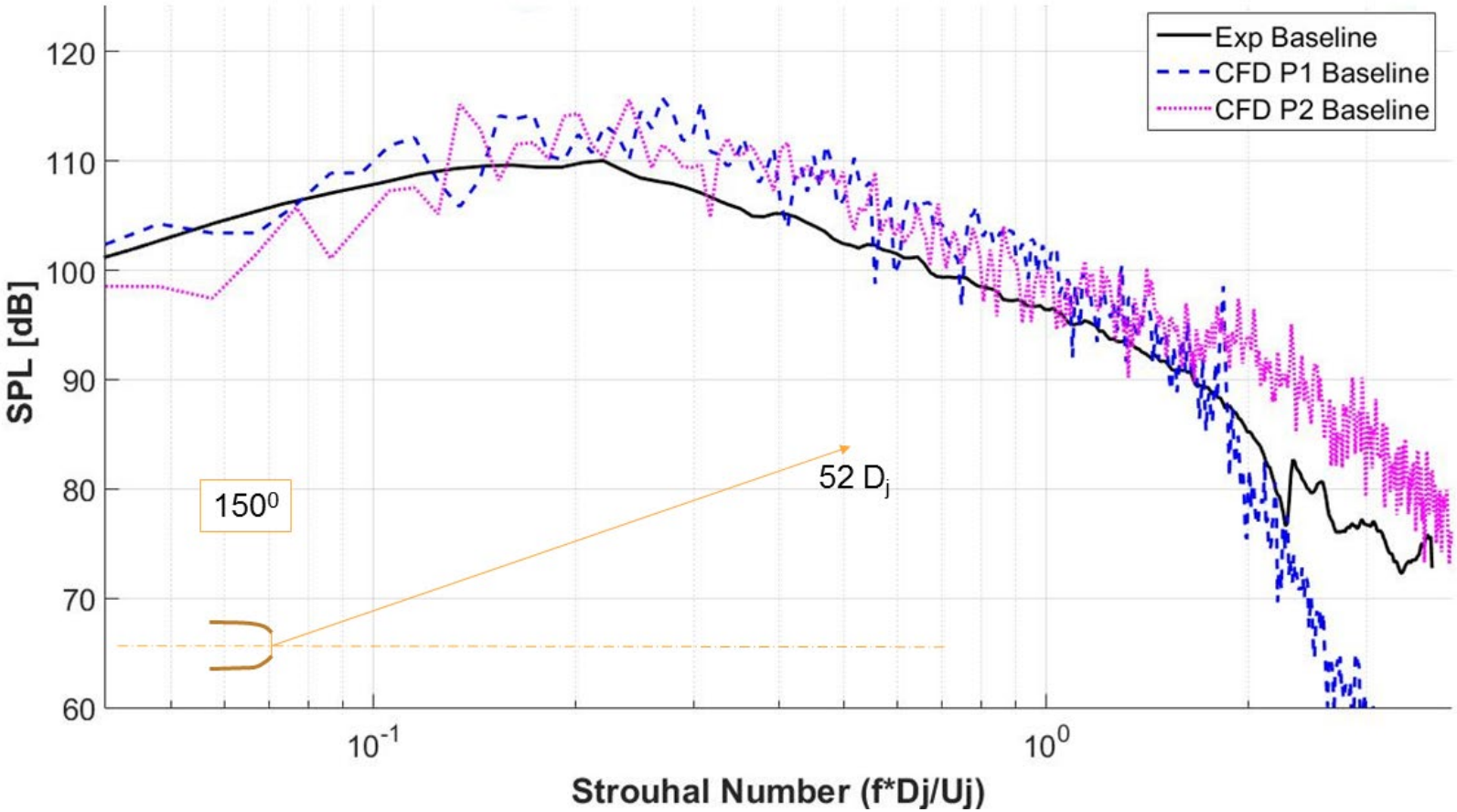


Iso-surfaces of the Q-criterion colored by the streamwise velocity with the pressure distribution in the background (gray)



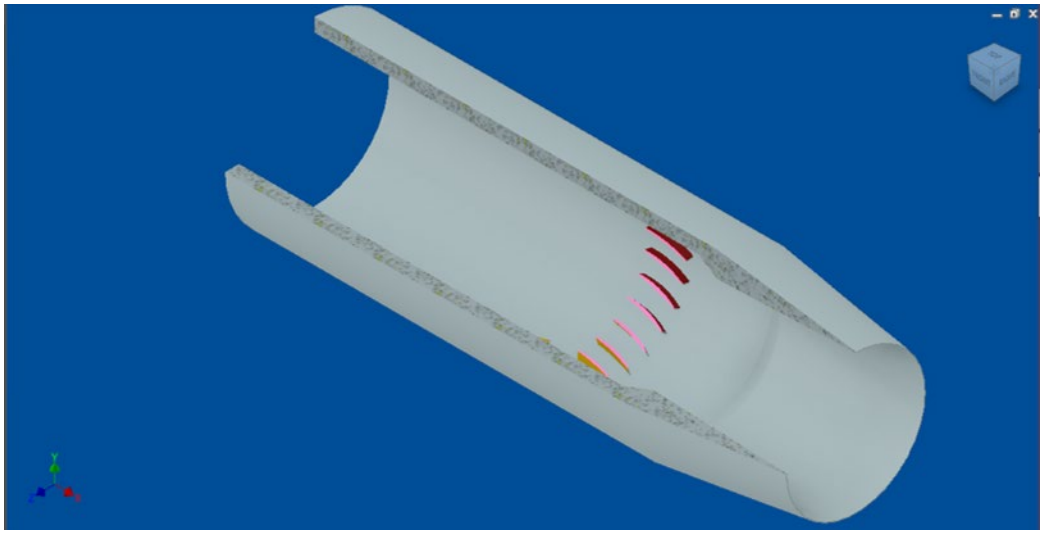
Comparison of the mean pressure between the present simulations and the literature

Far-field Noise Comparison



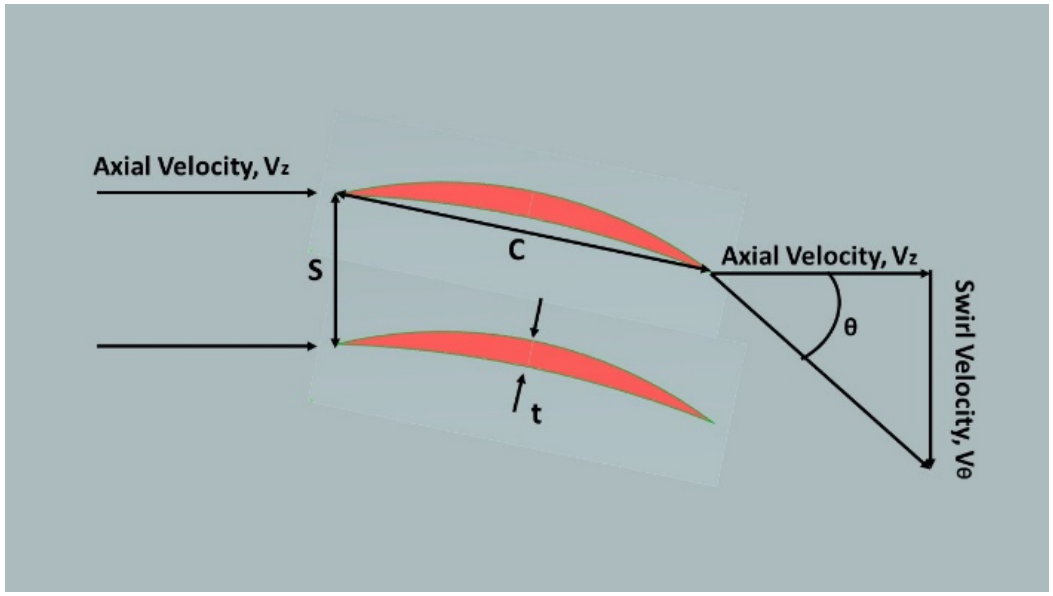
Vane Design 1

- Vanes are located at the upstream of the throat
- Both computational and experimental studies conducted. Noise reduction not obtained



Vane Design 2

- Vanes are located at the supersonic region near the nozzle exit
- Vanes have sharp leading an trailing edges
- Significant noise reduction observed



Parametric Study Conducted

- Swirl Angle (SA): 25°, 60° and 75°
- Solidity (σ): 2.0 and 4.0
- Location: offset and no offset

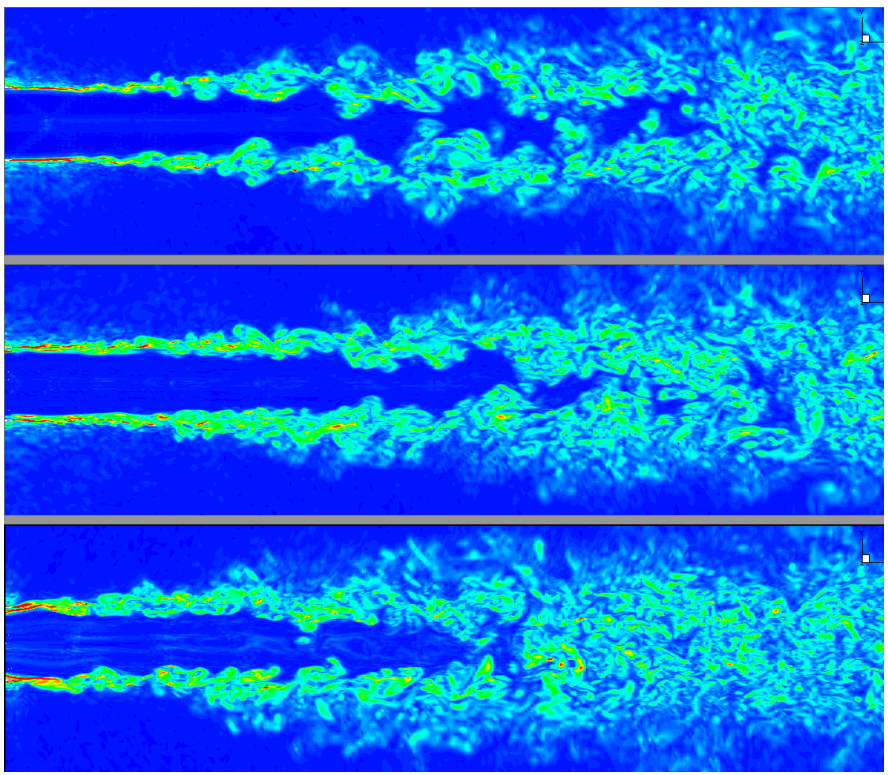
Configuration	X_{LE}/D_e	Solidity (σ)	Swirl Angle (SA)
CDB (Baseline)	N/A	N/A	N/A
Configuration 1	-0.325	2.000	25°
Configuration 2	-0.325	4.000	60°

Significant Mixing Revealed (Computation)

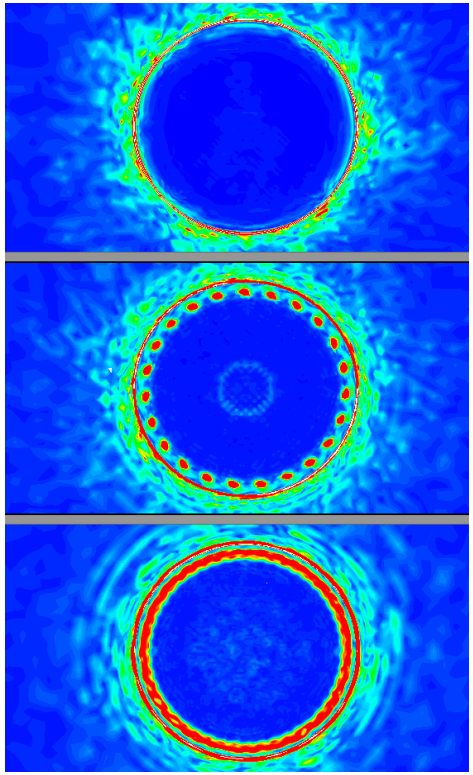
CFD Baseline

CFD Configuration 1

CFD Configuration 2



Midplane vorticity magnitude



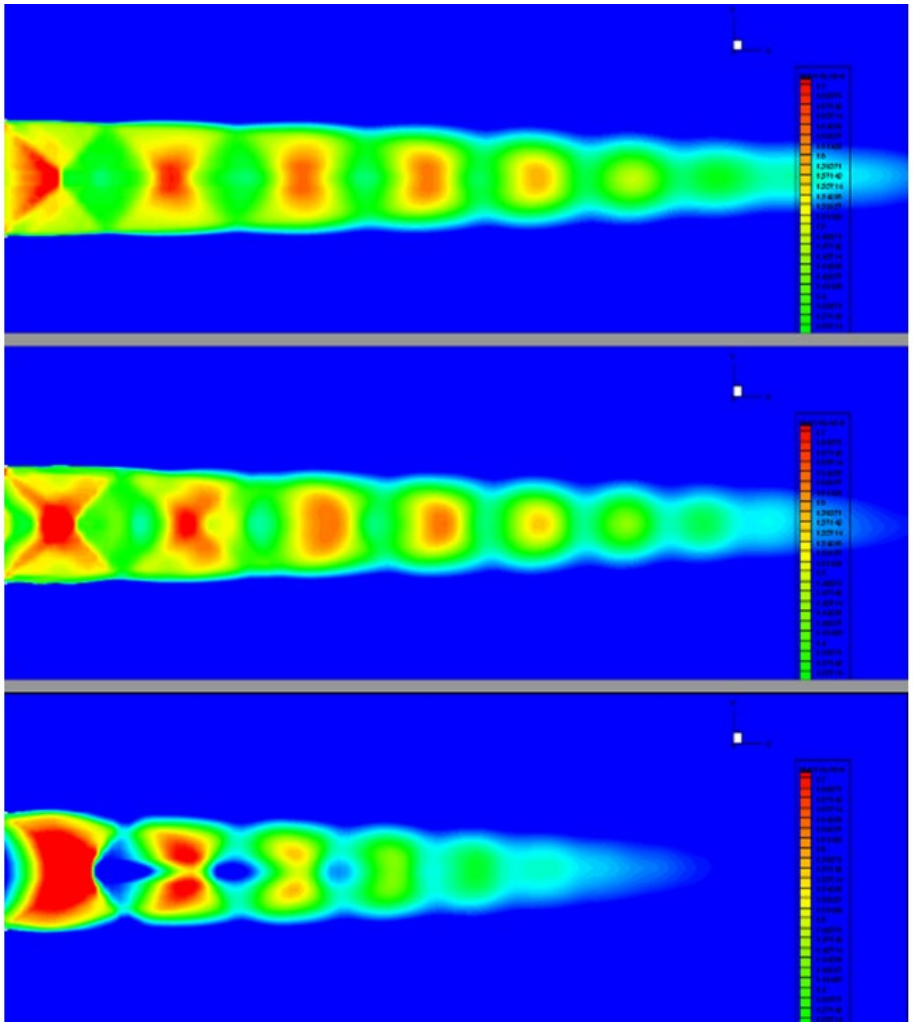
Vorticity magnitude at x = 0D

Shock Cells Altered Significantly

CFD
Baseline

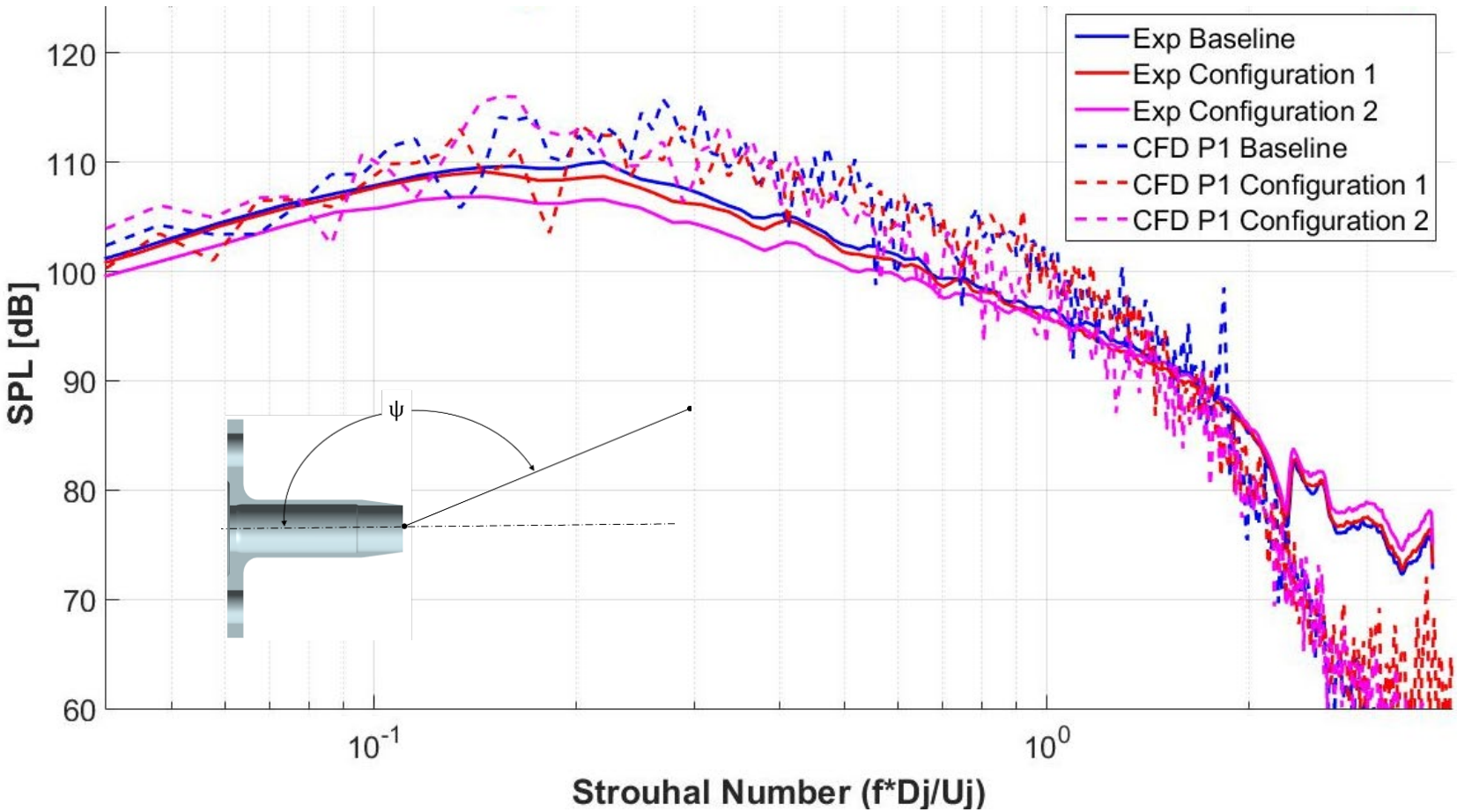
CFD
Configuration 1

CFD
Configuration 2



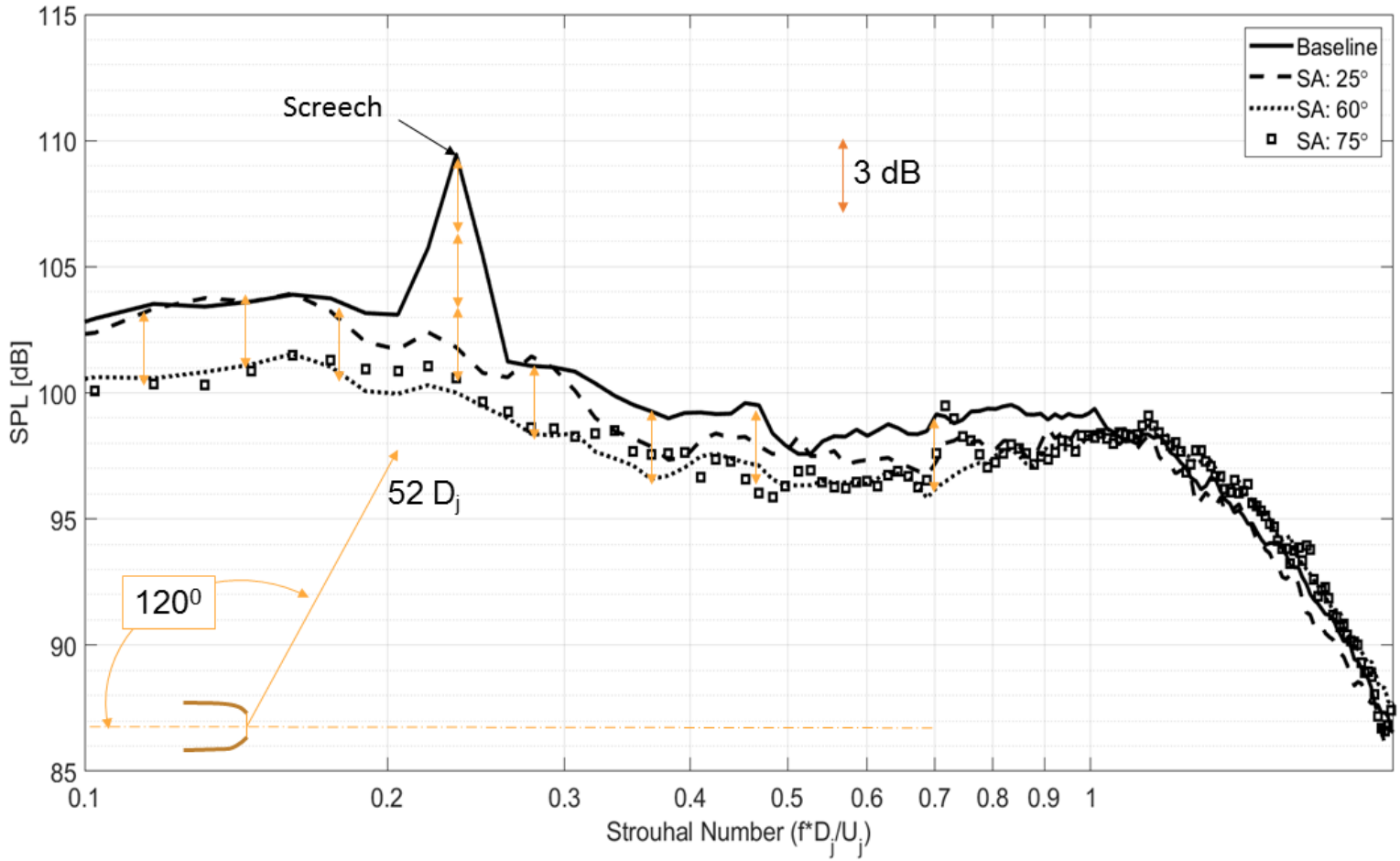
Mach number

Far-field Noise

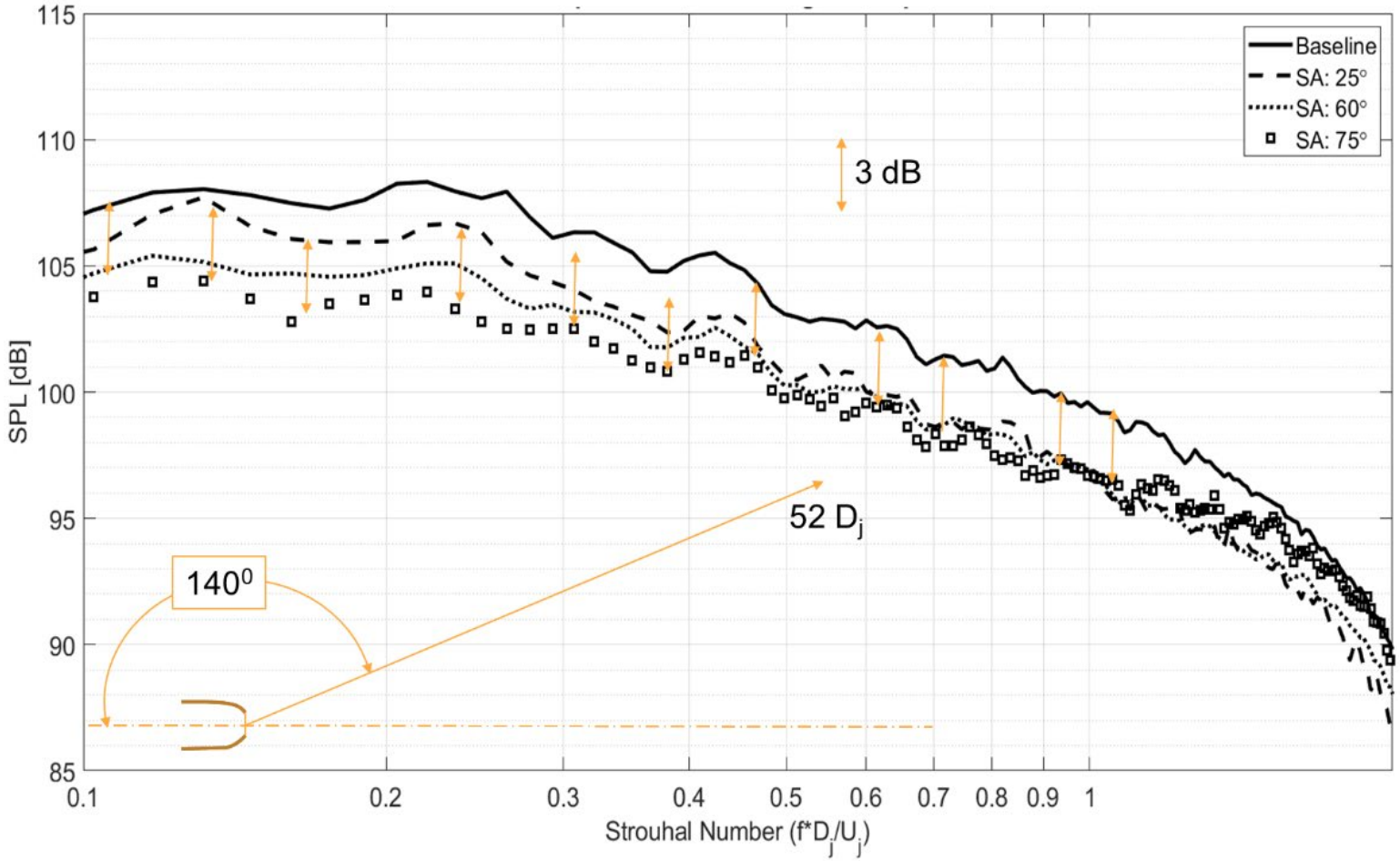


SPL at ψ = 150°

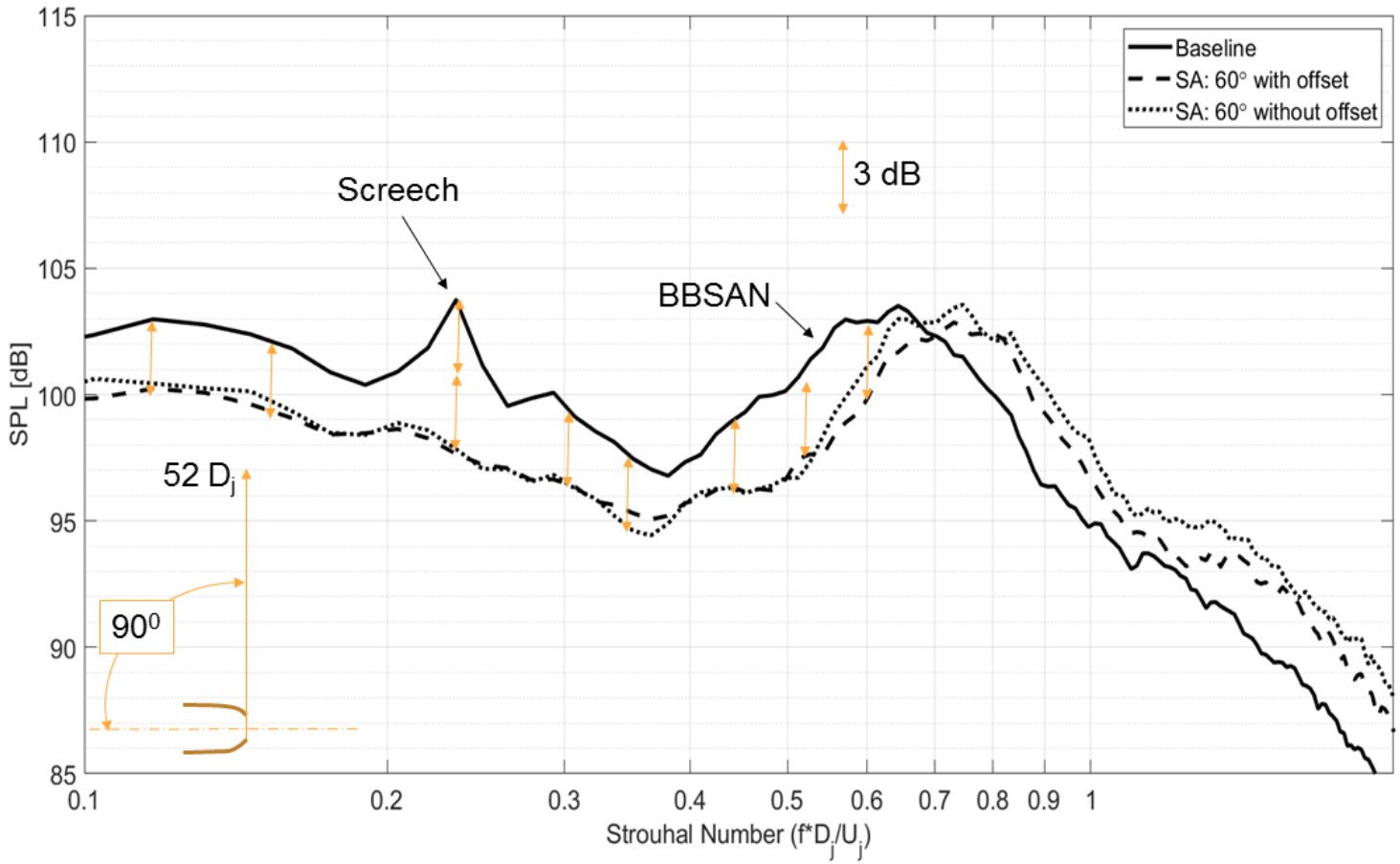
Far-field Noise – Swirl Angle Influence



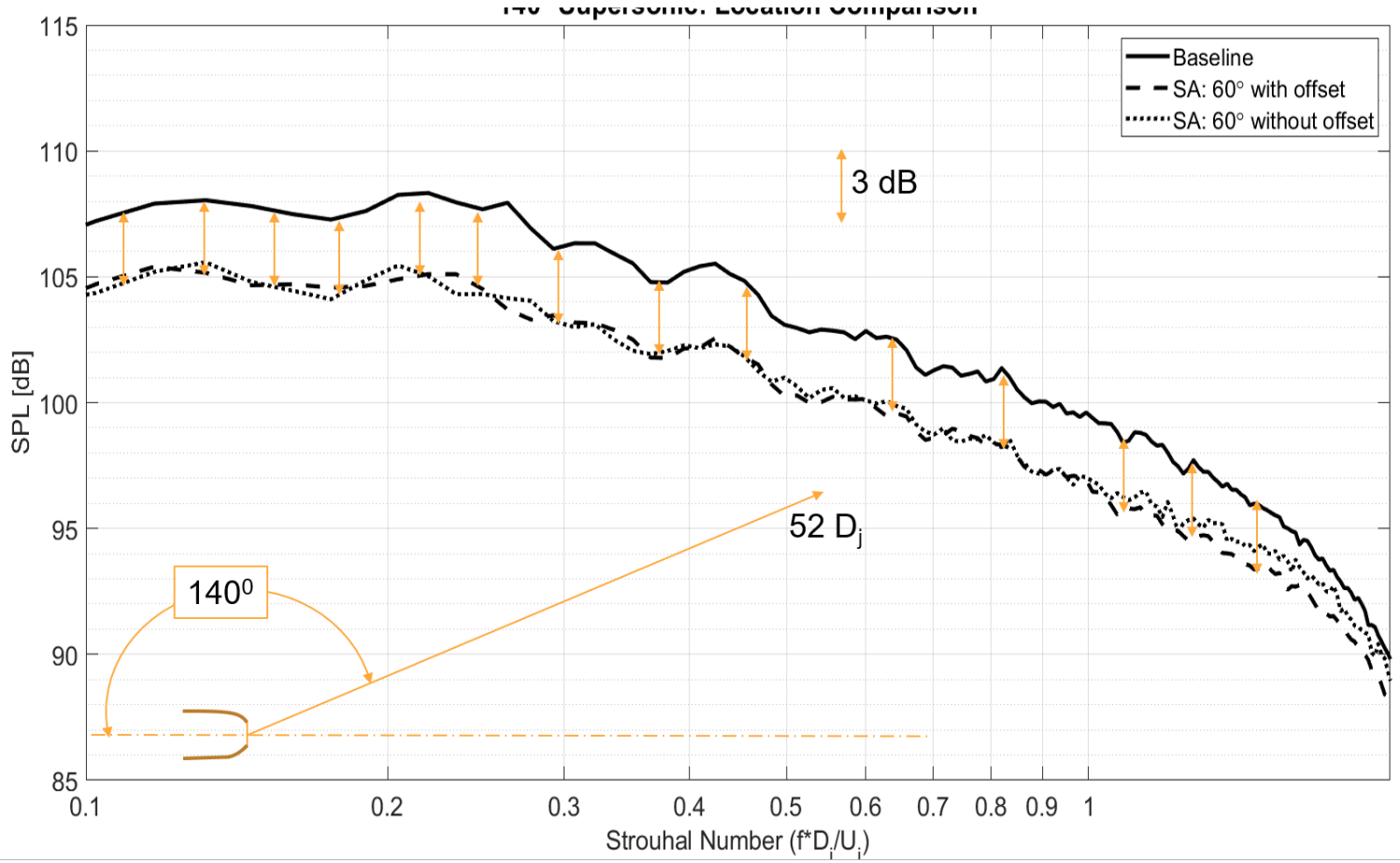
Far-field Noise – Swirl Angle Influence



Far-field Noise – Offset Influence



Far-field Noise – Offset Influence



Next Steps

- Further optimize the vane design
  - So far, variations in the swirl angle, solidity and vane locations are explored
  - Next we will explore three important parameters
    - Chord length of the vanes
    - Height of the vanes
    - Sweep angle of the vanes
- Verify the present results in another facility
  - University or government labs
- Test the vane design for another flow condition
  - Change the exit Mach number and nozzle pressure ratio

Next Steps (cont.)

- Submit a Phase II proposal with a team including GE and the Navy
  - Verify the design in a GE facility
  - Optimize the design
  - Test the design for hot jets
  - Test the design in the actual hardware scale for noise reduction capability
  - Investigate aeroacoustics of twin jets with co- and counter-swirl
  - If the results are positive, implement the design for an actual aircraft engine

Technology Transfer

- Presented a poster in the SERDP/ESTCP Symposium in December 2019
- Published a paper in the AIAA SciTech Conference in January 2020
- Made a presentation in the AIAA SciTech Conference in January 2020
- Filed a patent application titled Methods and Systems of Mitigating Jet Nozzle Noise
- Will present a poster in the 17th Annual Capitol Graduate Research Summit on 2/26/2020 at Topeka, Kansas

Key Points

- The swirl vanes located in the supersonic region of the nozzle reduce jet noise significant over all angles
- The swirl vanes significantly enhance mixing and alter the shock structures
- Preliminary computations put the thrust penalty between 1-3%

Future Research – Option 1

- 1 Year follow-on funding ($200k)
  - Further optimize the vane design
    - Chord length, height and sweep angle of vanes
  - Verify the present results in another facility
    - University or government lab
  - Test the vane design for another flow condition
    - Different jet Mach number and nozzle pressure ratio

Future Research – Option 2

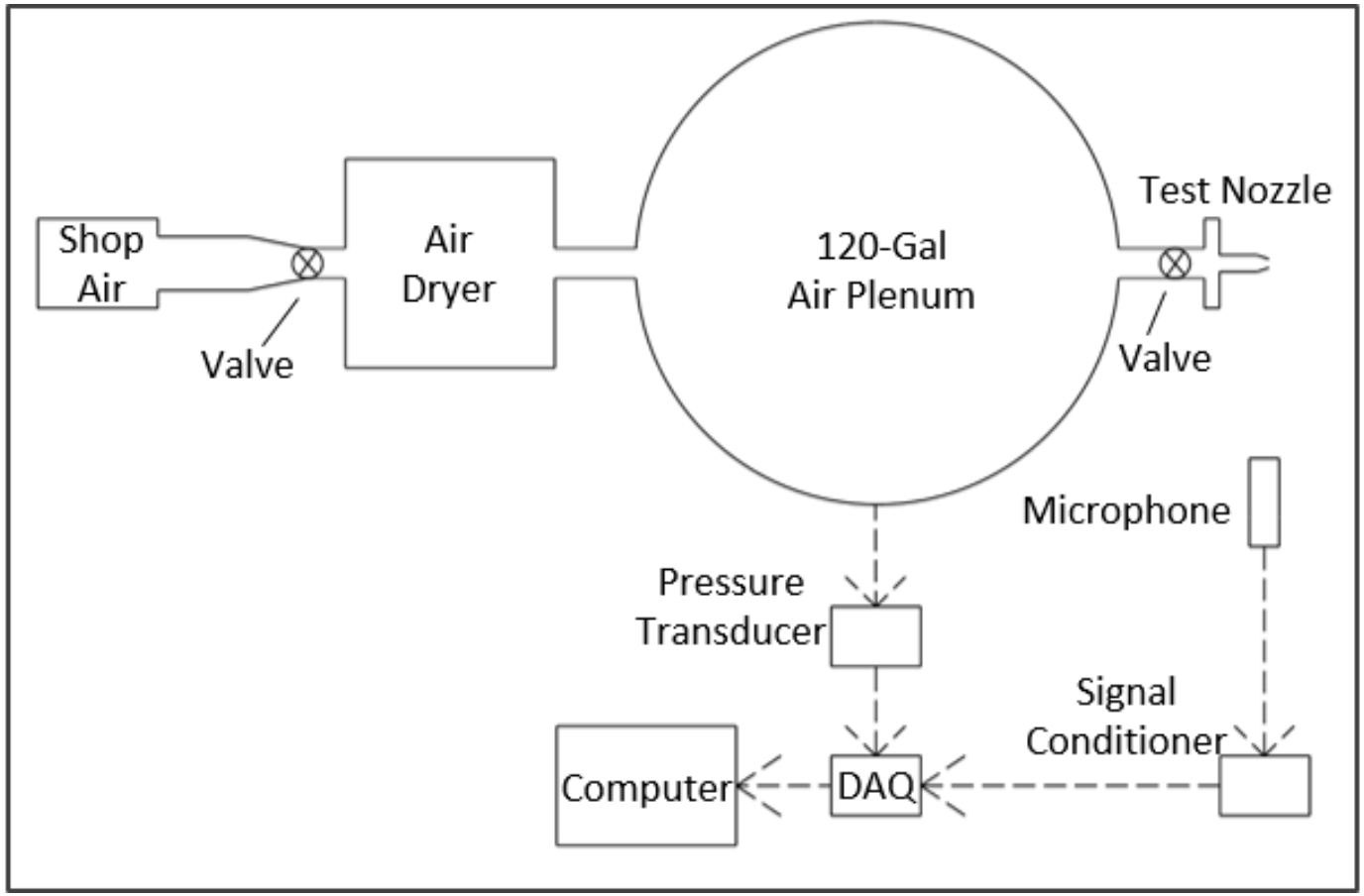
- Phase II funding ($5-10M over 5 years)
  - Team up with GE and the Navy
  - Verify the noise reduction capability at a GE facility
  - Optimize the design
  - Test the design for different flow configurations
  - Test the design for hot jets
  - Test the design in the actual hardware scale for noise reduction capability and verification at a Navy facility
  - Investigate aeroacoustics of twin jets with co- and counter-swirl
  - If the results are positive, implement the design for an actual aircraft engine

BACKUP SLIDES

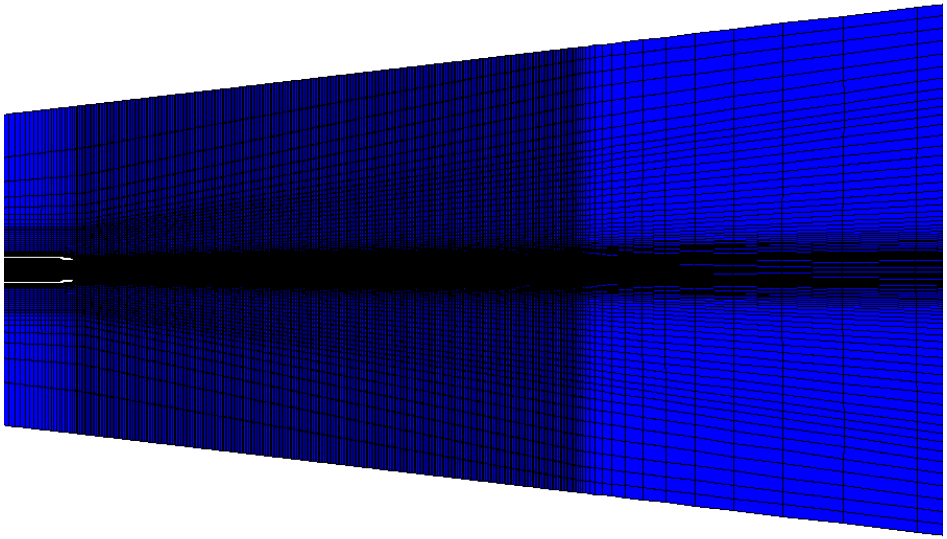
Publications

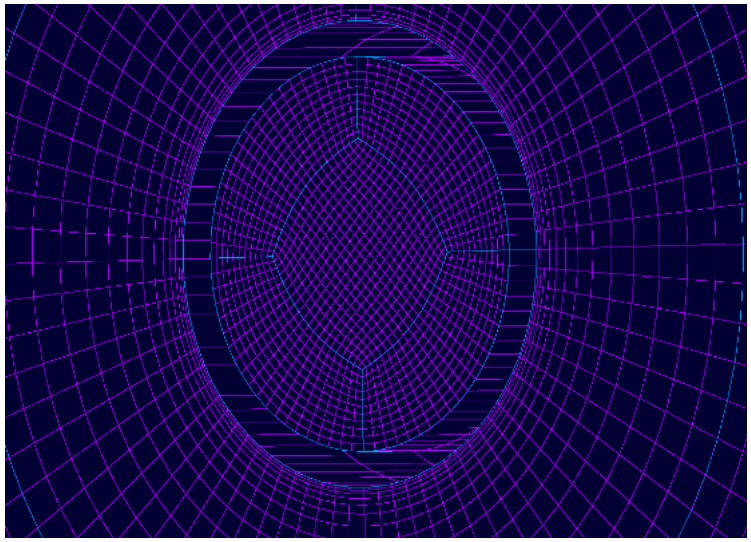
- S. Rahmani, M. Alhawwary, Z.J. Wang, J. Phommachanh, C. Hill, B. Hartwell, B. Collicott, J. Swim, S. Farokhi, R. Taghavi, H. Wu, M. Zhang, Z. Zheng, ”Noise Mitigation of a Supersonic Jet Using Shear Layer Swirl,” AIAA SciTech 2020 Forum, AIAA-2020-0499.
- S. Farokhi, R. Taghavi, Z.J. Wang, H. Wu, Z. Zheng, Methods and Systems of Mitigating Jet Nozzle Noise, Patent Application Docket Number: 20KU022-L01

Experimental Setup



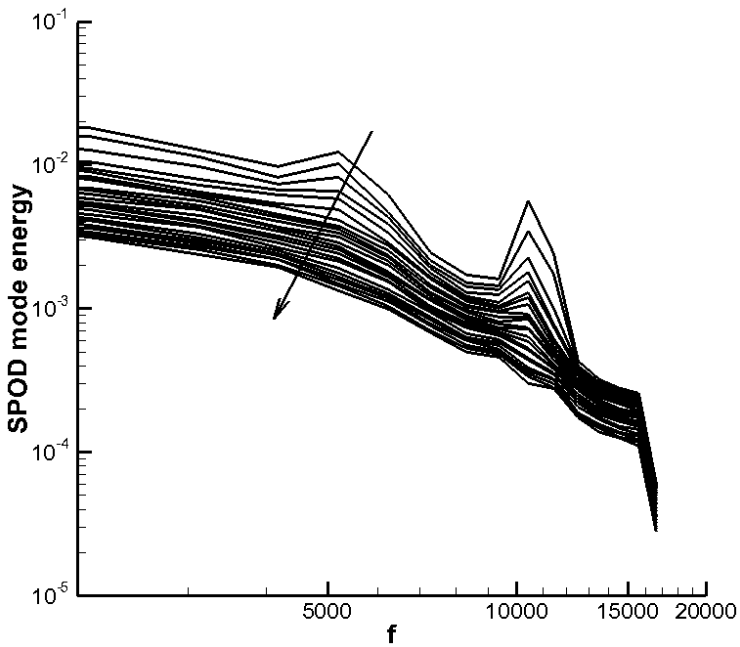
CFD Meshes



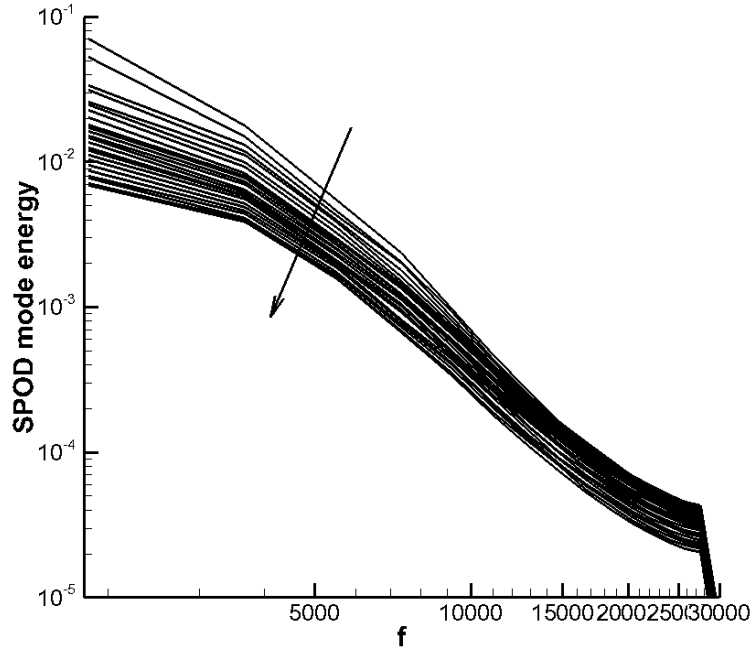


Data Analysis

- SPOD energy distribution with frequency



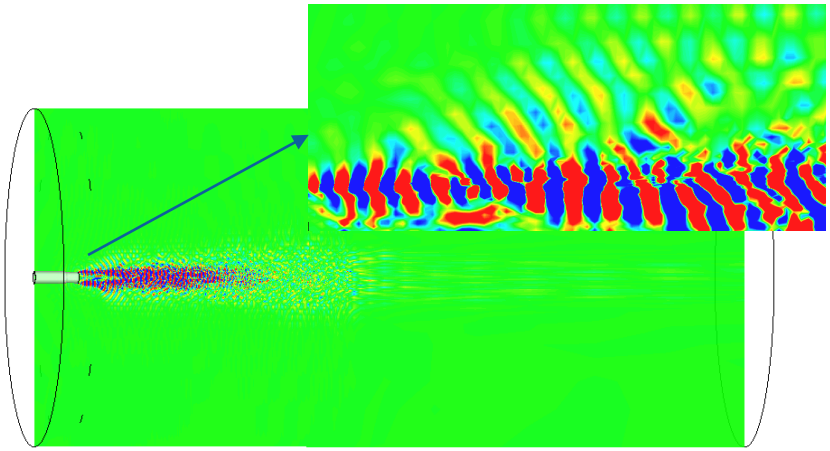
Baseline Nozzle



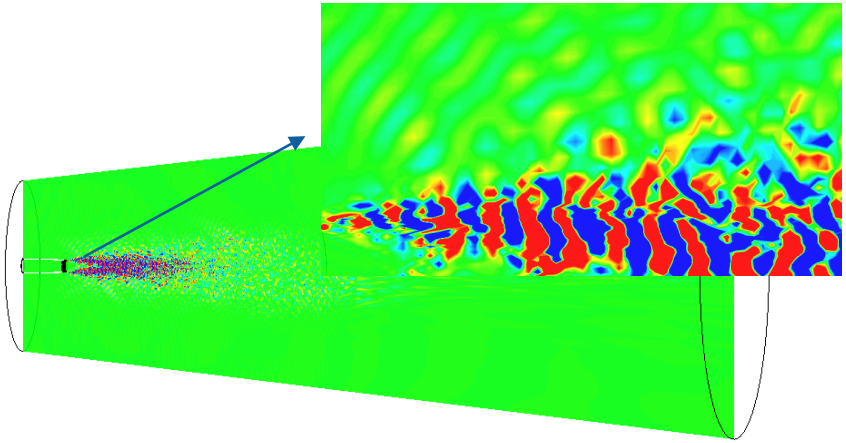
Configuration 2

Data Analysis

- SPOD mode 1 at f=11,029



Baseline Nozzle



Configuration 2

Project Funding

	FY2019-2020
Funds received to date ($K)	$200k
% Expended	~$200k
Funds Remaining ($K)	~0

Status of Funds for Federal Performers

- Report on the status of funds for each MIPR received by a directly funded Federal performer. Provide information on each fiscal year for which there has not been 100% expenditure of funds.

FY2014 Funds			
Directly Funded Federal Performer(s)	**Funds Received**	**Funds Obligated***	**Percent Funding Obligated**
Federal Performer A - Direct Cite MIPR			
Federal Performer A - Reimbursable MIPR			
Federal Performer B - Direct Cite MIPR			
Federal Performer B - Reimbursable MIPR			

* Funds put on contracts and/or purchase orders that have been issued, and funds associated with internal labor or travel expenses that have been incurred.

XX-XXXX: Project Title

Performers:

Technology Focus

- *Summarize technology or methodology being studied or developed*

Research Objectives

- *Summarize research objectives and criteria for success*

Project Progress and Results

- *Describe significant progress, results, and/or concerns to date*

Technology Transition

- *Identify the next steps in the development of the technology following the conclusion of the project. Include any planned outreach efforts to potential end-users*

NOTE: This slide may used by the Program Office in future presentations to provide a brief overview of the project.

Representative graphics and logos.