Thesis Outline

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Abstract

Over the last 20 years, there has been an increase in computational fluid dynamic codes that have made numerical analysis more and more readily available, allowing turbomachine designers to create more novel designs. However, as airport noise limi- tations become more restrictive over time, reducing aircraft takeoff and landing noise remains a prominent issue in the aviation community. One popular method to re- duce aircraft noise is using acoustic liners placed on the walls of the engine inlet and exhaust ducts. These liners are designed to reduce the amplitude of acoustic modes emanating from the bypass fan as they propagate through the engine. The SWIRL code is a frequency-domain linearized Euler equation solver that is designed to predict the effect of acoustic liners on acoustic modes propagating in realistic sheared and swirling mean flows, guiding the design of more efficient liner configurations. The pur- pose of this study is to validate SWIRL using the Method Of Manufactured Solutions (MMS). This study also investigated the effect of the integration and spatial differenc- ing methods on the convergence for a given Manufactured Solution. In addition, the effect of boundary condition implementation was tested. The improved MMS con- vergence rates shown for these tests suggest that the revised SWIRL code provides more accurate solutions with less computational effort than the original formulation.

1. Introduction : What is the reason for me to write this thesis? What has prompted me to select this topic?

   (a) Basic Explaination of the topic and the main problem (What?) During the 1960s, the increased demand for commercialized aircraft transport in- troduced jet engines to support large cargo and passengers. Consequently, this rise in innovation resulted in high volume engine noise.

   (b) Statement of the research questions (Why?)

   (c) The goal and significance of the investigation; (How?)

   (d) Definitions of the terms (if needed);

   (e) Organization of the research (Structure)

2. Literature Review:

a] The problem to be addressed and its significance

b] The theoretical foundation or conceptual framework

c] The research questions, hypotheses, foreshadowed problems, or conjectures

d] The research paradigm and the methodology

   (a) Intro - Topics, Purposes, and Methods of the Literature Review.

      i. Following the discovery of the acoustic impact of swirling flow in 1977, there has been a concerted effort to model sound propagation under such conditions (Cooper, A.J. and Peake N., Kousen, Posson).

   (b) Description and Critique of Scholarly Literature

      i. Sound propagation in ducted flows can be modeled with the Linearized Euler Equations (LEE] though an initial value problem and normal mode analysis. The two normal mode analysis' have been studied by Golubev and Kousen where the flow is assumed to be isentropic, however Tam & Auriault used a non isentropic mean flow with constant density. For isentropic flows, the normal mode analysis requires the perturbation variables to take the form of a linear equation. The components of the perturbation variables has been split into its mean and fluctuating parts in Kousen's study while Golubev , and Atassi splits the pertubation into a vortical and potential part. This study will use Kousen's definition for the perturbation variables

         A. While validation is apart of existing literature, there is currently no literature where the code verification technique of the method of manufactured solutions (MMS) is used for the problem of sound propagation is a ducted flow. Although various code verification methods exist, the MMS is considered to be a gold-standard by experts in computational modeling and simulation (Oberkampf, W. L., and Roy, C.

J., 2010. Verification and validation in scientific computing.) (Roache, P. J., 2009. Fundamentals of verification and validation). The MMS provides a mathematical technique to verify that the LEE simulation solves the equations correctly and that the spatial grid refinement reduces the numerical error at an expected rate based on the numerical scheme used (Roache, P. J., 2002. "Code verification by the method of manufactured solutions".)

(c) Inferences for Forthcoming study

  i. The problem to be addressed in your research and its significance

    A. The code verification presented in Maldando's work will be improved by providing an observed order of accuracy

    B. One key question that remains, is how well do unsteady linearized equations cap- ture the mechanisms of noise generation within realistic turbomachinery flow? The numerical simulations for more complex (axial shear + swirl) flows do not have analytical solutions and contain different categories for the axial wavenumbers.

  ii. possible research questions, hypotheses, foreshadowed problems, or conjectures

    A. What combination of spatial grid resolution and numerical scheme aid the final result? The use of dissipation is apparent in literature, but the amount is not reported.

    B. Can the use of a desired damping rate help aid the sorting of axial wavenumbers

  iii. possible theoretical or conceptual framework to be used and possible research paradigms and methodologies used

    A. MMS study

      - Additional MMS framework will be explored (tanhSummation) and utilized to find MS' that meet the guidelines in Roaches work

      - The use of MMS to test matrix construction for eigenvalue problem

    B. MES study

      - the analytical solution is known for uniform flow and is used for MES

    C. Literature test case studies (some are shared with Maldonado)

      - Kousen's Test Cases

        Cylinder, Uniform Flow with Liner (Table 4.3)

$$
\begin{aligned}
m &= 2 \\
k &= \frac{\omega r_T}{A_T} = -1 \\
M_x &= 0.5 \\
\eta_T &= 0.72 + 0.42i
\end{aligned}
$$

        Confirm if 32 grid points is enough

Cylinder, Shear Flow without Liner (Table 4.4)

$$m = 0$$
$$kb = \left(\frac{\omega r_T}{A_T}\right) b = 20$$
$$b = r_{max} - r_{min}$$
$$\tilde{r} = \frac{r}{b}$$
$$M_x = 0.3(1-\tilde{r})^{\frac{1}{7}}$$
$$\eta_T = 0$$

Confirm if 32 grid points is enough

Annulus, Shear Flow without Liner (Table 4.5)

$$m = 0$$
$$kb = \left(\frac{\omega r_T}{A_T}\right) b = 10$$
$$b = r_{max} - r_{min} = \frac{1}{7}$$
$$k = 70$$
$$\tilde{r} = \frac{r}{b} = 6.0$$
$$M_x = 0.3\left(1 - 2\left|\frac{r_{max} - r}{b} + 0.5\right|\right)^{\frac{1}{7}}$$
$$\eta_T = 0$$

Confirm if 32 grid points is enough

Annulus, Shear Flow with Liner (Table 4.6)

$$m = 0$$
$$kb = \left(\frac{\omega r_T}{A_T}\right) b = 10$$
$$b = r_{max} - r_{min} = \frac{1}{3}$$
$$k = 30$$
$$\tilde{r} = \frac{r}{b} = 2.0$$
$$M_x = 0.3\left(1 - 2\left|\frac{r_{max} - r}{b} + 0.5\right|\right)^{\frac{1}{7}}$$
$$\eta_T = 0.3 + 0.1i$$

Confirm if 32 grid points is enough

- Kousen's test cases which were compared to P.N. Shankar's work and then expanded for cases where data is needed . Maldonado has compared the same tests

(d) Theoretical/Conceptual Framework for Forthcoming Study (May appear in methods chapter)

3. Research Methodology

   (a) Conjectures, or Exploratory Questions:

      - What is the observed order of accuracy for SWIRL's second order and fourth order solutions (MMS/MES)? How many grid points are needed for each scheme

   (b) Research Procedures - Describe in detail how the inquiry was undertaken.

      i. Introduce the epistemology that will guide the inquiry/ Indicate the methodology used and why it was selected.

         A. The steady and unsteady aerodynamic models are presented here.

         B. The MMS and tanh summation method will be used to define a sufficient test case for the second/fourth order differencing schemes for the radial derivatives and for the approximated speed of sound obtained through numerical integration. To account for acoustic liners as boundary conditons, fairing functions were used to impose boundary values for the radial velocity perturbation and for the radial derivative of pressure.

      ii. Explain the theoretical perspective that will drive the research, and why it was selected.

         A. The need for a code verification study prompted the use of MMS and MES to investigate if SWIRL was coded correctly. In addition, the findings from these studies inform the user how the numerical scheme is effecting the final solution which will offer insight for the more complicated flows.

      iii. Indicate the specific methods used and the justification for them. How were sites, cases, and informants selected? Why? What access did you unsuccessfully seek? Which people perhaps tried to minimize contact with you and which repeatedly sought it out? How did you collect your data? Why?

      iv. Indicate how you managed your qualitative data. Did you take notes or make audio/video recordings? Was any data not analyzed? Why?

      v. Indicate how you analyzed and interpreted your data, making sure the analysis was consistent with the selected methodology. If you inferred themes, explain how. If you coded the transcripts, explain the coding system and checks for coding reliability and validity. How did you analyze the data from the coding? How did you triangulate or otherwise verify findings? How did you interpret the full set of data?

4. Results of the Study

   (a) statement of the received results and their analysis

      i. Results for MMS/MES/set of test cases will be presented. The MMS and MES will have errors and convergence rates associated with the schemes that are available in SWIRL.

(b) Comparison of the obtained results and the initial goals/questions

5. Summmary
   (a) Discussion of the research results;
      i. Discuss the convergence rates and make the case for fourth order schemes.
      ii. Discuss the effect on axial wavenumber categorization.
   (b) Comparison of the obtained results with the findings of prior researchers
      i. Discuss the appearance of nearly convected wavenumbers as the tests get more complex.
   (c) Suggestions regarding the use of the obtained findings for the further development of the topic and future investigation
      i. The use of GCI could give a grid which is closer to convergence
      ii. Limitations of the eigensolver
      iii. The use of a desired damping rate can be correlated to the length of a Nacelle
      iv. Comparison against experimental data
6. Appendices