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### Computational Fluid Dynamics Simulation and Optimization of 69-Degree-Delta Wing Model in Supersonic Flow

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Washington University in St. Louis

SCHOOL OF ENGINEERING & APPLIED SCIENCE

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Mechanical Engineering and Material Science Independent Study  
12/9/2016

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## Computational Fluid Dynamics Simulation and Optimization of 69-Degree-Delta Wing Model in Supersonic Flow

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James Mitchell  
Independent Study Report  
Washington University in St. Louis  
Under the Supervision of Dr. Ramesh Agarwal

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## 1 **ABSTRACT**

The Computational Fluid Dynamics simulation and optimization of a 69-degree-deltawing model in a supersonic flow condition. The steady compressible Reynolds Averaged Navier-Stokes (RANS) equation using the inviscid Euler equations will be solved using the flow solver ANSYS Fluent. The CFD simulations will be compared to experimental and prior results before optimization begins. After simulation results compare well with AIAA sonic boom workshops provided data, a genetic algorithm will be created to optimize the deltawing to minimize the pressure disturbance [1]. The study of temperature effects on the pressure disturbance will also be considered using the sBOOM code provided by NASA Langley Research Center [2].

## 2 **INTRODUCTION**

I participated in the research of a 69-degree-deltawing model in a supersonic flow condition under the supervision of Dr. Ramesh Agarwal in support of a masters in Aerospace Engineering from the School of Engineering and Applied Sciences at Washington University in St. Louis. The end result of the research project is to optimize the deltawing model to minimize the pressure disturbance created in supersonic flight.

When an aircraft enters supersonic flight, Mach Number ( $Ma$ )  $\approx 1.2$ , a fast release of air pressure occurs and creates a pressure disturbance that is propagated from the aircraft outward. If the pressure disturbance is not minimized, it could potentially harm buildings or humans on the ground.

Colleague Junhui Li had been working on this research project as his thesis before it was handed down as my research project. Junhui had successfully created a mesh around the deltawing model, but the computational time for the results to converge in ANSYS Fluent was too long. A rough calculation of time it would have taken to optimize the deltawing with Junhui's mesh would have been around 350 to 400 days.

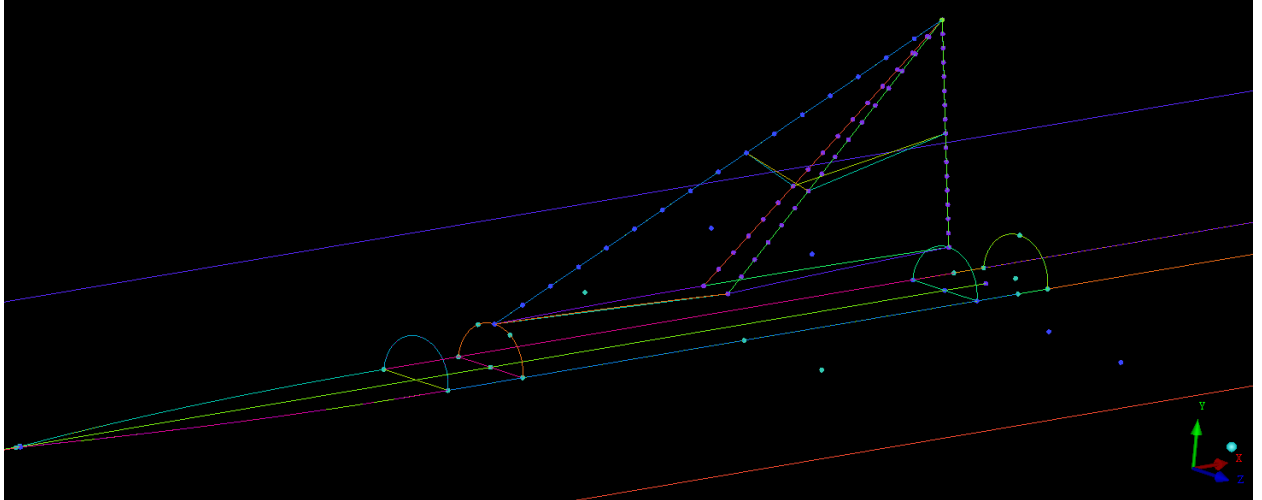
With the help of Dr. Agarwal and Junhui, I have successfully used a hexahedral blocking technique to mesh the deltawing model, cutting the number of nodes and cells in half without compromising the convergence of the results. I have also successfully studied the effects of temperature on the pressure disturbance.

## 3 **69-DEGREE-DELTAWING MODEL**

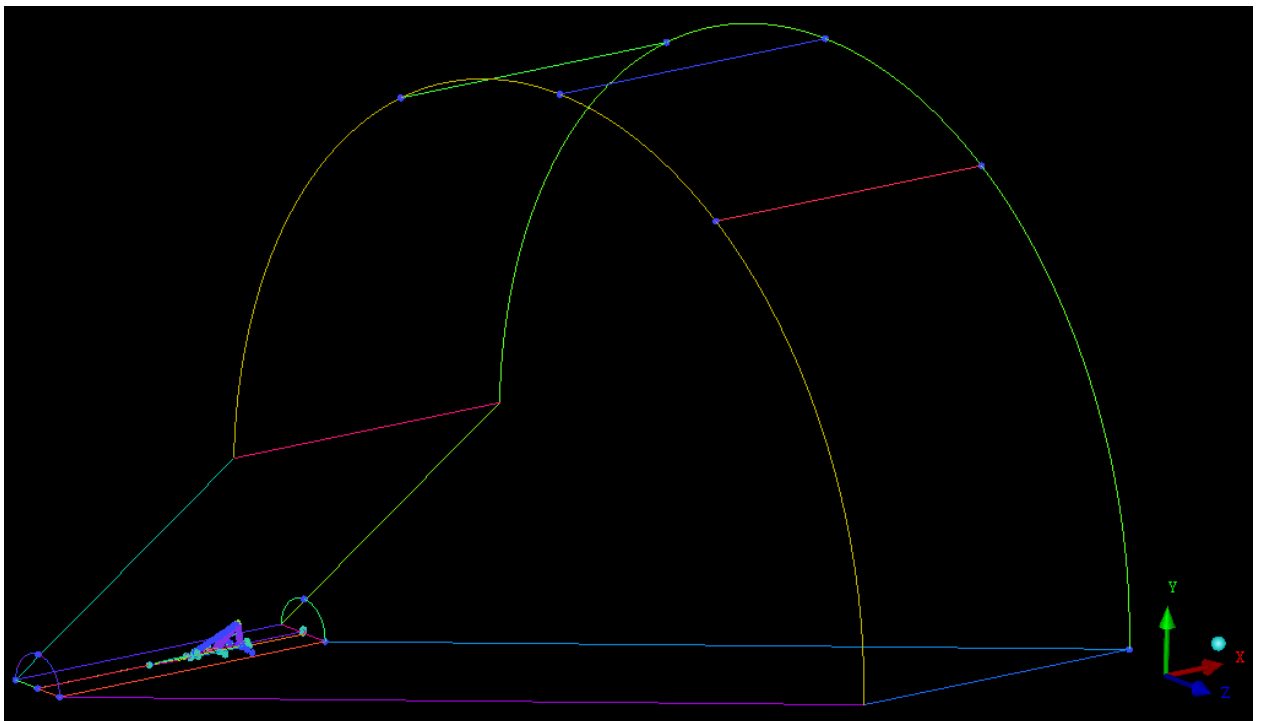
### 3.1 **GEOMETRY AND MESH**

The 69-degree-deltawing model geometry was created within the commercial grid generation software ICEM such as any other model is created within another modeling software. The geometry is shown in Fig. 1 and Fig. 2. Surfaces are then created around the geometry to set up meshing boundary conditions after the mesh is created.





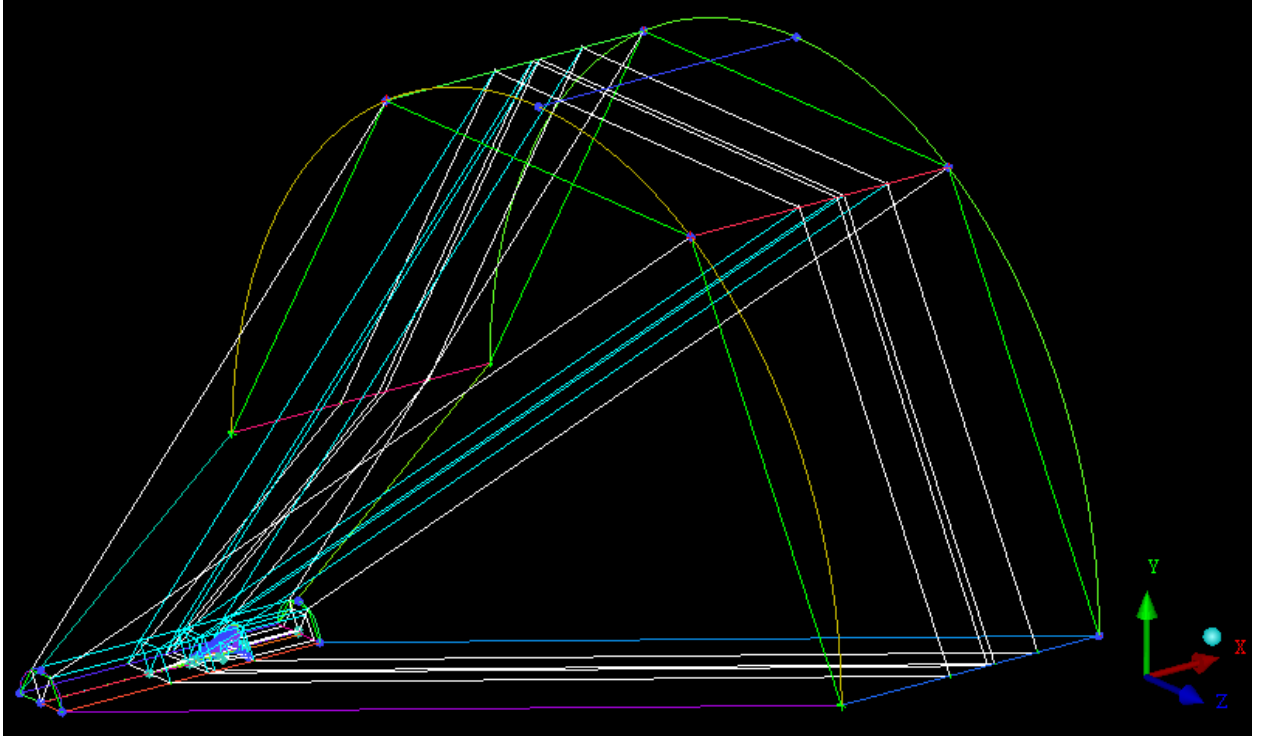
**Fig. 1** 69-Degree-Delta wing Model Geometry Created in the Commercial Grid Generation Software ICEM.



**Fig. 2** Geometry of 69-Degree-Delta wing Model with Boundary Flow Conditions Created in the Commercial Grid Generation Software ICEM.

To mesh the geometry created, a hexahedral blocking technique was used because of its ability to give the user complete control over the mesh. The user is able to define the number of nodes along a blocking line, the spacing ratios from one end of the line to the other, and to apply this to single blocking lines or multiple blocking lines throughout the mesh. The hexahedral blocking technique requires creating blocks around the geometry at the start, then working down from the block to shape the block around the geometry created. This is done by associating geometric lines, points, and faces with the blocking lines, points, and faces. After the correct associations have been applied and the number of nodes and spacing ratios have been set, as shown in Fig. 3, a mesh can be constructed around the geometry. The quality of the mesh then needs to be checked for errors,

mainly errors involving volume orientation, penetrating elements, and overlapping elements of mesh cells. After the quality of the mesh has passed the check, applicable boundary conditions can be applied within ICEM before importing the mesh into CFD Fluent.



**Fig. 3 Hexahedral Blocking of the Geometry of 69-Degree-Deltawing Model and Boundary Flow Conditions Created in the Commercial Grid Generation Software ICEM.**

The mesh created for the 69-degree-deltawing model is shown in Fig. 4 and Fig. 5. The green mesh represents the far-field boundary condition surface, the red mesh represents the pressure outlet boundary condition surface, the blue mesh represents the symmetry plane boundary condition surface, and the purple mesh represents the wall boundary condition surface around the deltawing model geometry. The mesh is made up of 2,090,090 nodes, 113,254 quads, and 2,033,050 hexas. It can be seen in Fig. 5 that the number of nodes and cells increase where blocking lines meet the deltawing geometry. This increases the definition of the mesh around the geometry to ensure Fluent results will converge with accuracy.

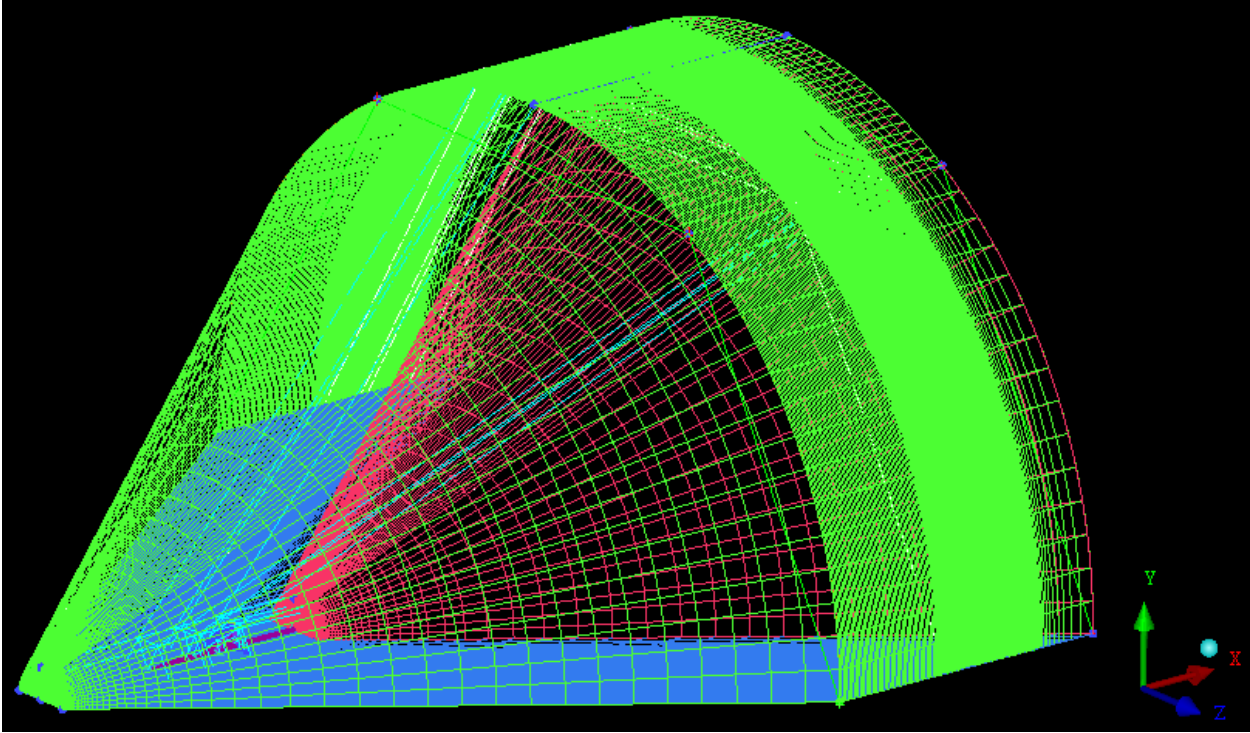


Fig. 4 The Mesh Created Around the Geometry of 69-Degree-Delta wing Model and Boundary Flow Conditions.

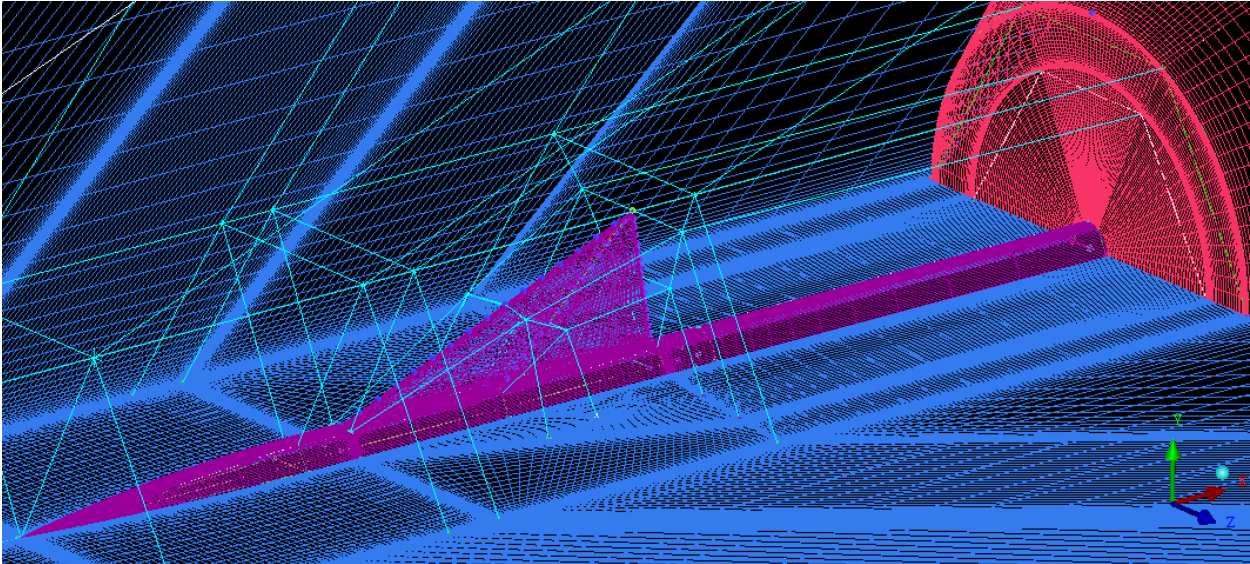


Fig. 5 Zoomed View of the Mesh Created Around the Geometry of 69-Degree-Delta wing Model.

#### 4 FLUENT SETUP

After importing the mesh into ANSYS Fluent, the following setup is required to replicate the flow conditions that the 69-degree-deltawing model would operate in.

The solver type is set as density-based because the delatwing case is a high-speed compressible flow. The density-based solver uses the continuity, momentum, energy, and species equation simultaneously to linearize the governing equations to create a system of equations for the dependent variables. The system is then solved for the flow-field solution. The energy model is applied along with the Spalart-Allmaras viscous model. The fluid material is changed to air with the air properties shown in Table 1.

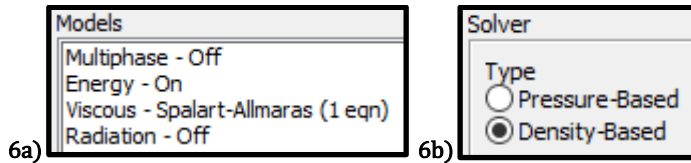


Fig. 6a & 6b The Setup for the Solver Type and the Model Types.

Table 1 The Properties of Air Inputted into Fluent.

Properties of Air	
Density	Ideal-Gas
Specific Heat	$1006.43 \frac{\text{J}}{\text{kg}\cdot\text{K}}$
Thermal Conductivity	$.0242 \frac{\text{W}}{\text{m}\cdot\text{K}}$
Viscosity	$1.789 \frac{\text{kg}}{\text{m}\cdot\text{s}}$

The cell zone condition type was set to fluid to represent air and operating pressure was set to 0Pa. Within boundary conditions, the zone type of the wall surface of the delatwing was set to wall and the zone type of the symmetry surface was set to symmetry. The far-field surface zone was set as pressure-far-field with a gauge pressure of 101325Pa, a  $Ma = 1.7$ , x-component of flow in the x-direction, and a turbulent viscosity ratio of 5. The outlet surface zone was set to pressure-outlet with a turbulent viscosity ratio of 5.

Reference values were computed from the far-field and the reference zone was set to fluid. The courant number was set to 1, coefficient of lift and drag monitors were setup, and the solution was initialized. The number of iterations was set at 30,000 and the CFD simulation was calculated.

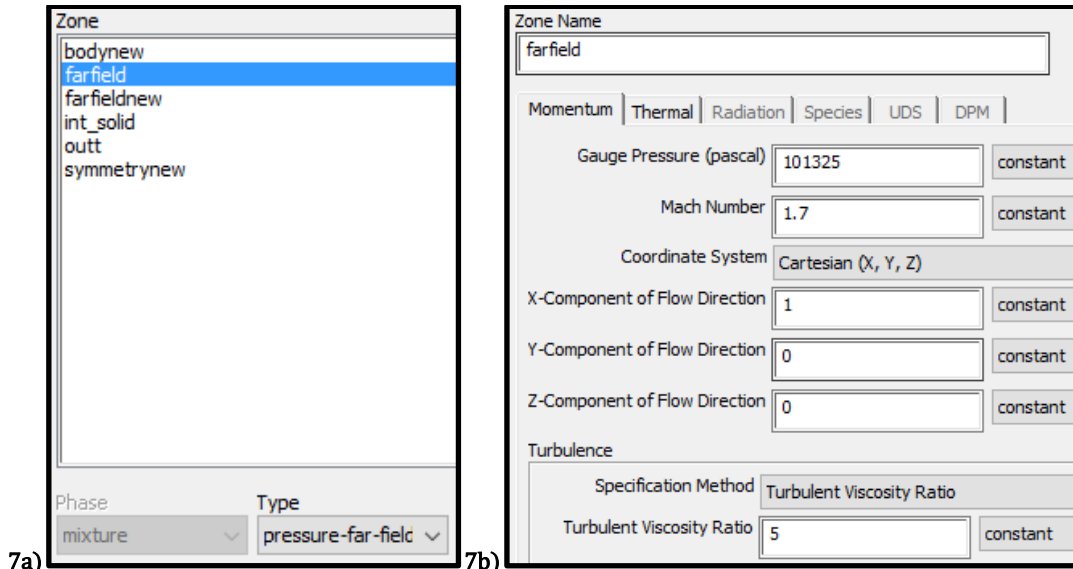


Fig. 7a & 7b The Setup for Boundary Condition Zone Far-field.

## 5 NUMERICAL RESULTS

Three different plots were taken into consideration when analyzing the pressure disturbance of the delatwing model. The first plot is the experimental data obtained from AIAA sonic boom signature workshops that our numerical results would be compared and validated with. The second plot is the pressure disturbance of the created mesh. The third plot is the pressure disturbance of just the body of the delatwing without the delatwing on it. These were plotted for azimuthal angles of 0° and 90° counterclockwise from the ground. The plots are shown in Fig. 8 and Fig. 9.

Figures 8 and 9 present the  $\Delta P/P$  along the x-directions at 25 inches away from the body and display very good accuracy for the mesh created. The two signature peaks are created from the front nozzle of the aircraft and the delatwing. The signature from just the delatwing body can be seen to only produce a peak signature at the front of the aircraft. The CFD simulation has successfully predicted the pressure signature, therefore our mesh is verified and validated to begin optimization of the body of the delatwing model.

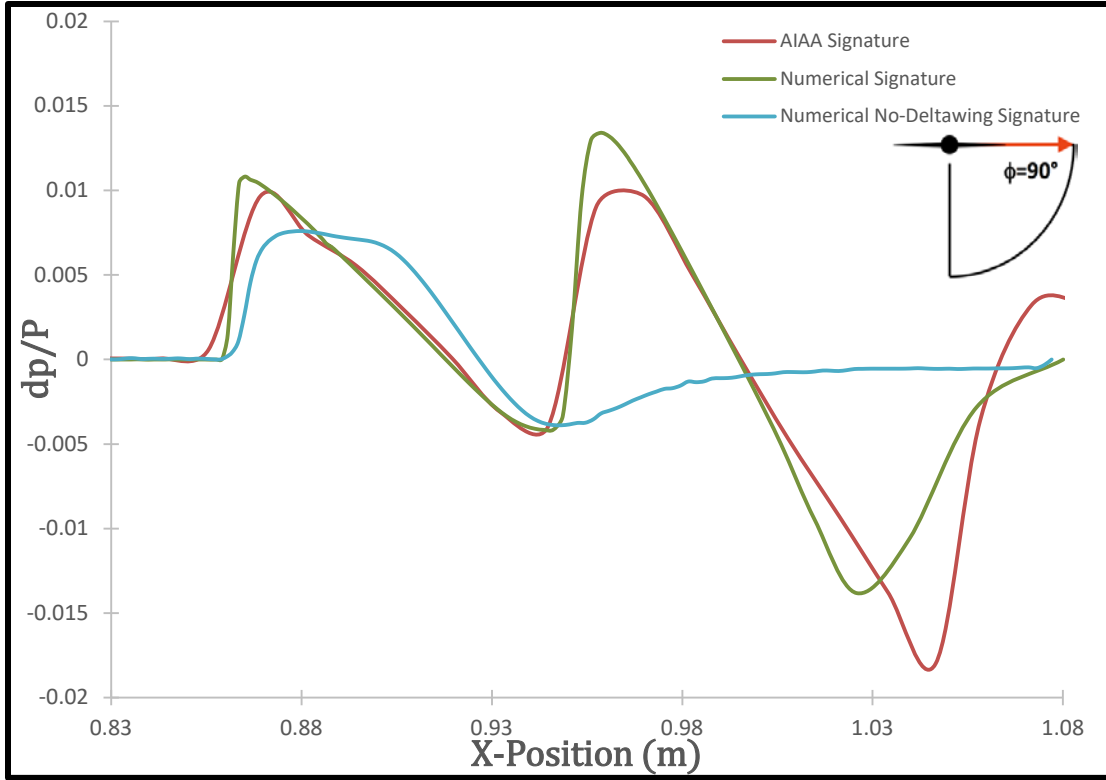


Fig. 8 The Pressure Disturbances at  $\Phi = 90^\circ$  for the 69-Degree-Deltawing Model.

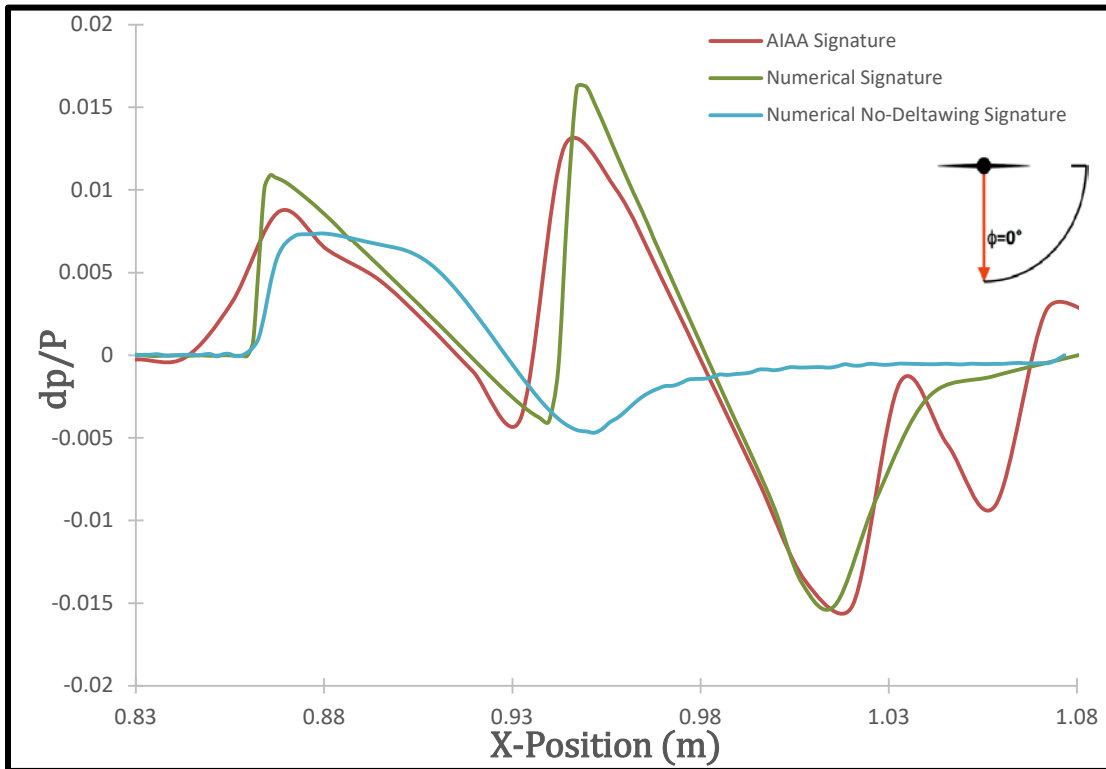


Fig. 9 The Pressure Disturbances at  $\Phi = 0^\circ$  for the 69-Degree-Deltawing Model.



## 6 SBROOM PROPAGATION RESULTS

The results of sonic boom propagation from a height of 45,000 to several heights above the ground are presented for the original SEEB-ALR, optimized SEEB-ALR, and the 69 Degree Delta Wing-Body.

### 6.1 SEEB-ALR MODEL

The propagation signatures for the SEEB-ALR model were propagated from 45,000ft. The sBoom code accurately predicted the waveform of the signature at various altitudes. The results of the propagation are shown in Figure 10 and the results for the optimized SEEB-ALR are shown in Fig. 11.

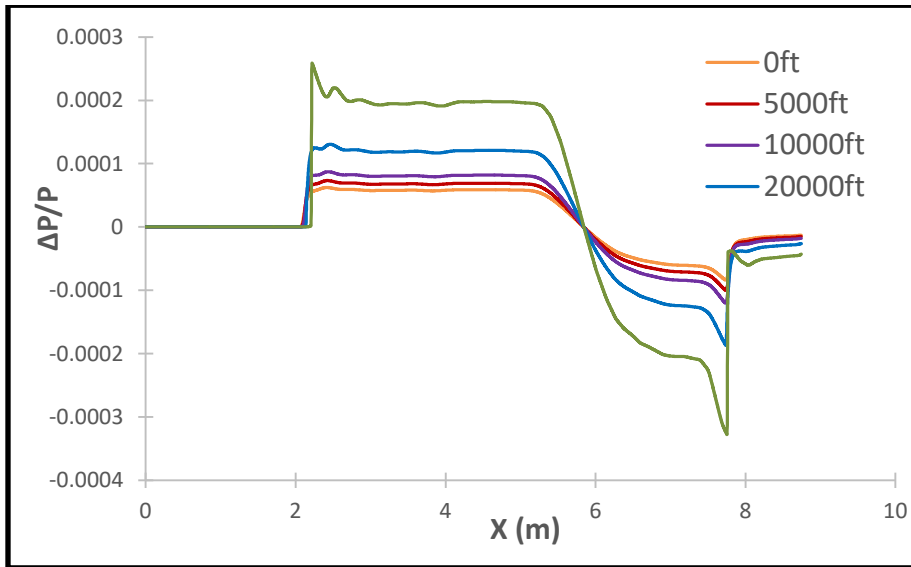


Fig. 10 Pressure signatures propagated from 45K feet for scaled SEEB-ALR model at various altitudes above the ground

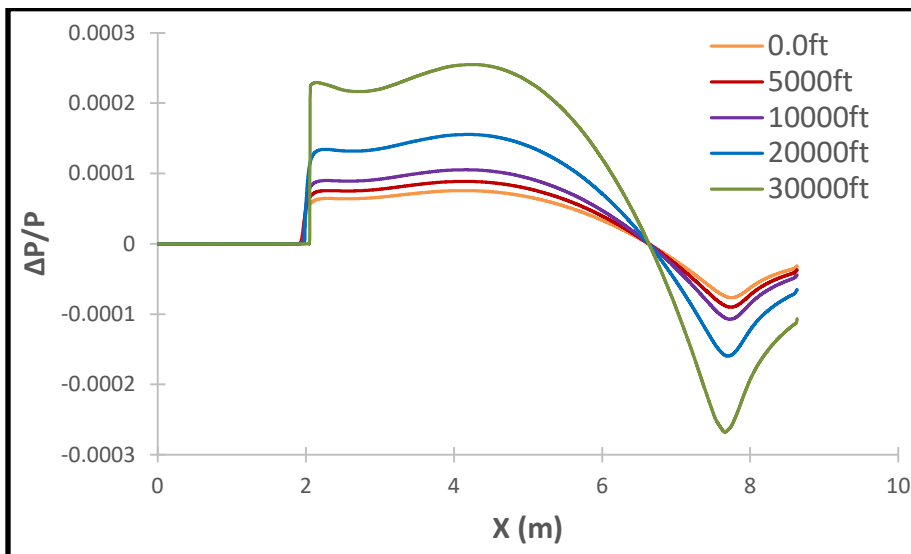
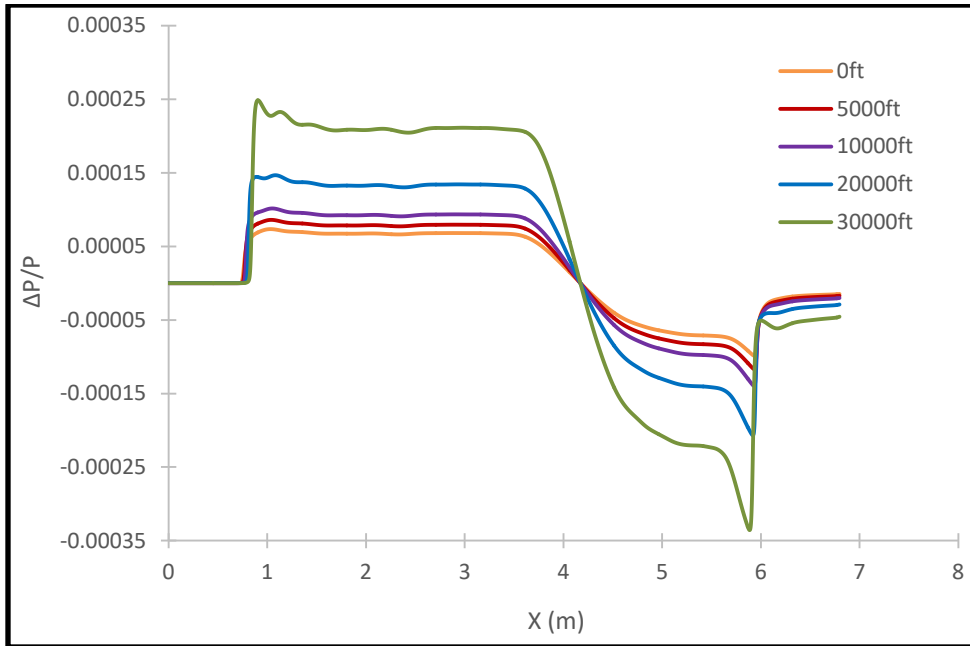


Fig. 11 Pressure signatures propagated from 45K feet for scaled optimized SEEB-ALR model at various altitudes above the ground

The pressure signatures for the SEEB-ALR and the optimized SEEB-ALR were also subjected to different reference atmosphere temperatures for the months of January, April, July, and October at a latitude of 38° N [3]. The results of the propagation for the SEEB-ALR model for January and July are shown in Fig. 12 and Fig. 13. The results of the propagation for the optimized SEEB-ALR model for January and July are shown in Fig. 14 and Fig. 15. The results for April and October fell between the results for January and July and therefore are not shown.



**Fig. 12** Pressure signatures propagated from 45K feet for scaled SEEB-ALR model at various altitudes above the ground subjected to a reference atmosphere temperature profile in January.



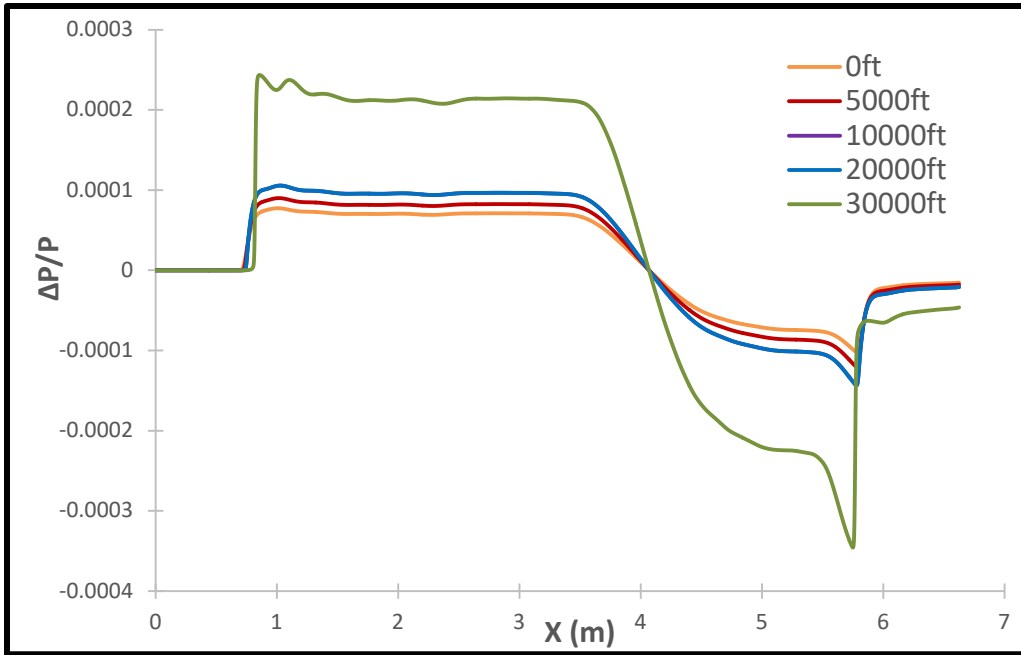


Fig. 13 Pressure signatures propagated from 45K feet for scaled SEEB-ALR model at various altitudes above the ground subjected to a reference atmosphere temperature profile in July.

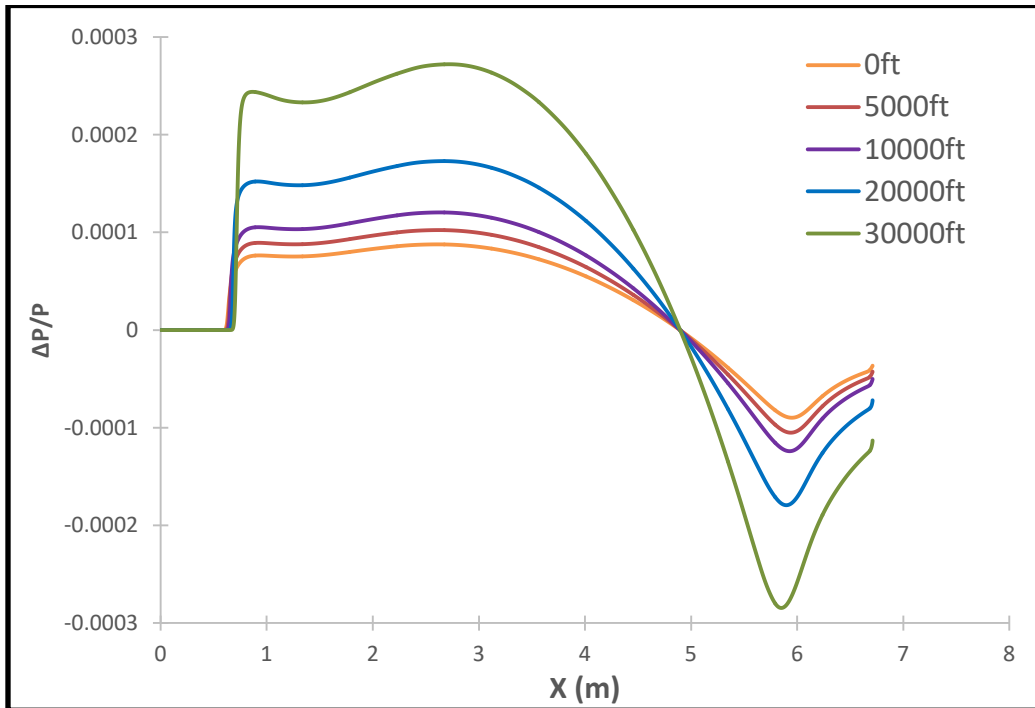


Fig. 14 Pressure signatures propagated from 45K feet for scaled optimized SEEB-ALR model at various altitudes above the ground subjected to a reference atmosphere temperature profile in January.

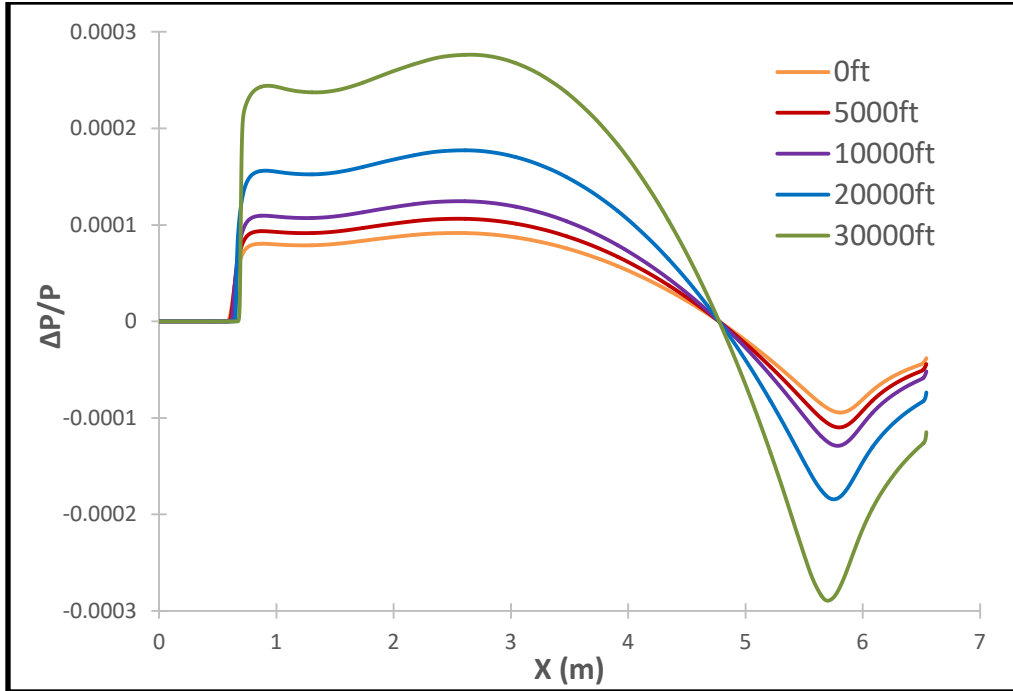


Fig. 15 Pressure signatures propagated from 45K feet for scaled optimized SEEB-ALR model at various altitudes above the ground subjected to a reference atmosphere temperature profile in July.

The pressure signatures for both the SEEB-ALR model and the optimized SEEB-ALR model for reference atmosphere temperature profiles during the months of January and July display minimal change. The resulting C-weighted loudness values from the pressure signatures for each altitude are shown in Fig. 16 for the SEEB-ALR model and Fig. 17 for the optimized SEEB-ALR model.

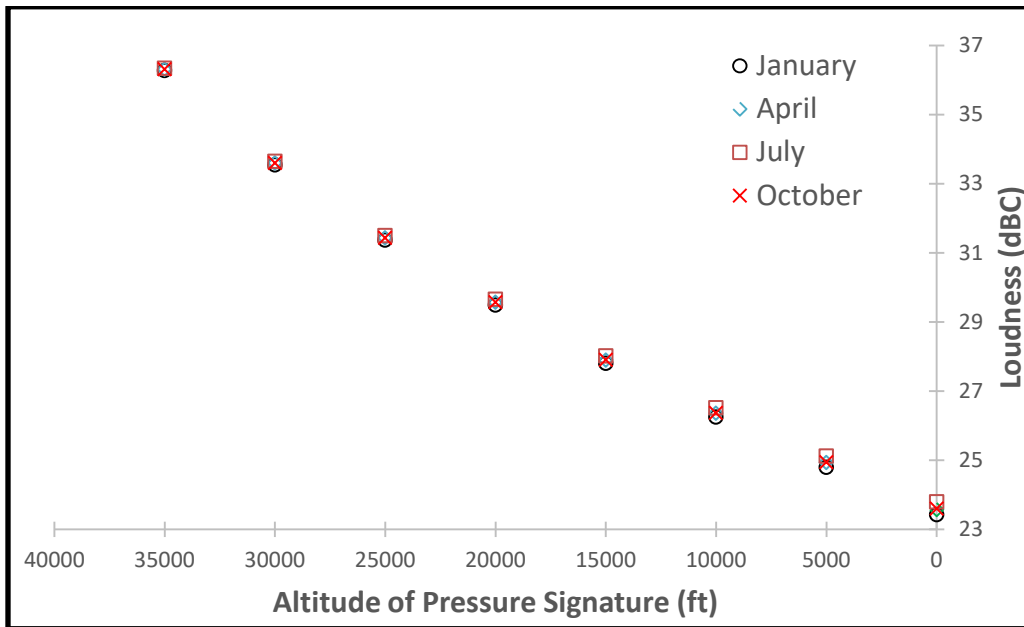


Fig. 16 C-Weighted loudness values from the pressure signatures for the scaled SEEB-ALR model at various altitudes above the ground subjected to reference atmosphere temperature profiles for the months of January, April, July, and October at a latitude of 38° N.

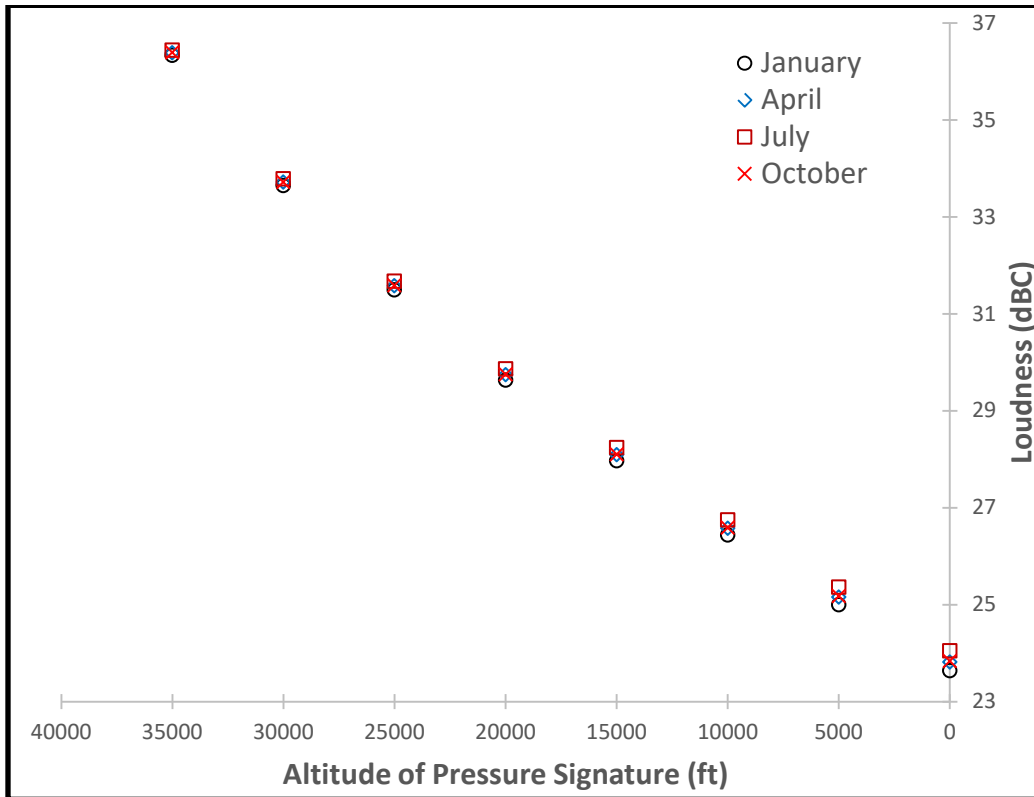


Fig. 17 C-Weighted loudness values from the pressure signatures for the scaled optimized SEEB-ALR model at various altitudes above the ground subjected to reference atmosphere temperature profiles for the months of January, April, July, and October at a latitude of 38° N.

The C-weighted loudness values for the SEEB-ALR model and the optimized SEEB-ALR model display minimal change when subjected to reference atmosphere temperature profiles for the various months. The C-weighted loudness values of most interest are those at ground level that could potentially cause harm to buildings or individuals. These values are shown in Table 2 for the SEEB-ALR model and the optimized SEEB-ALR model.

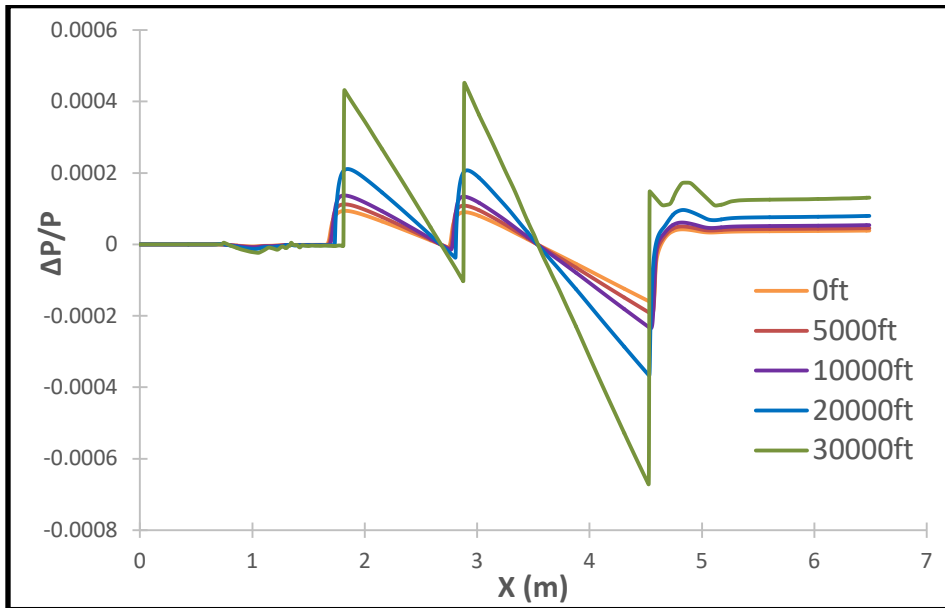
Table 2 C-weighted loudness values at ground level when subjected to reference atmosphere temperature profiles for the months of January, April, July, and October at a latitude of 38° N

	SEEB-ALR C-Weighted Loudness Values (dBC)	Optimized SEEB-ALR C-Weighted Loudness Values (dBC)
January	19.78	20.55
April	19.93	20.67
July	20.14	20.86
October	19.96	20.7

## 6.2 69-DEGREE-DELTAWING MODEL

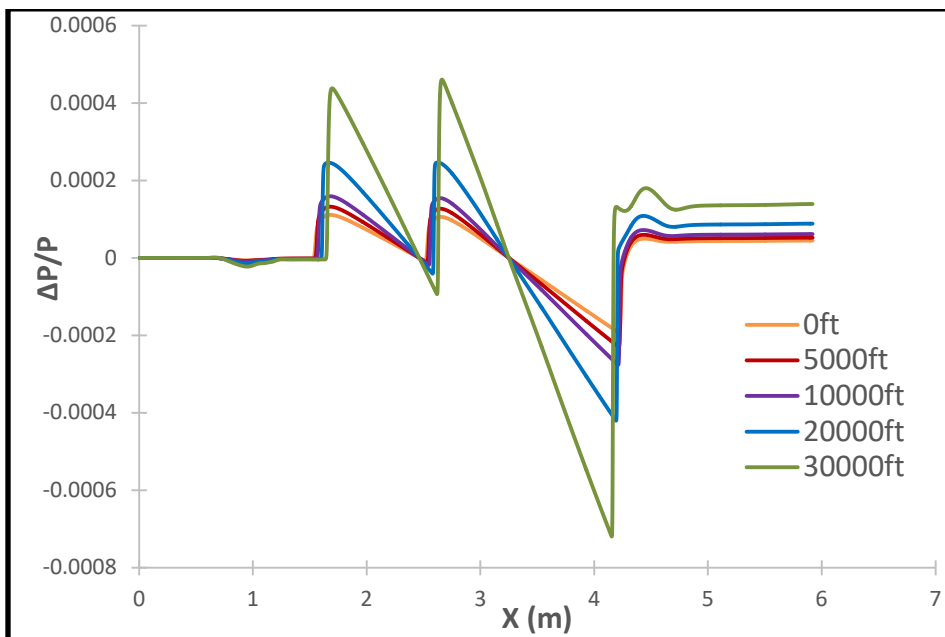
The propagation signatures for the 69-degree-deltawing model are shown in Fig. 18. The sBoom code accurately predicted the waveform of the signature at various altitudes. The

waveform appears to smooth out the smaller disturbances the closer the signature gets to the ground.



**Fig. 18** Pressure signatures propagated from 45K feet for scaled Delta Wing-Body model at various altitudes above the ground.

The pressure signatures for the 69 Degree Delta Wing-Body model were also subjected to different reference atmosphere temperatures for the months of January, April, July, and October at a latitude of 38° N. The results of the propagation for the Delta Wing-Body for January and July are shown in Fig. 19 and Fig. 20. The results for April and October fell between the results for January and July and therefore are not shown.



**Fig. 19** Pressure signatures propagated from 45K feet for scaled Delta Wing-Body at various altitudes above the ground subjected to a reference atmosphere temperature profile in January.

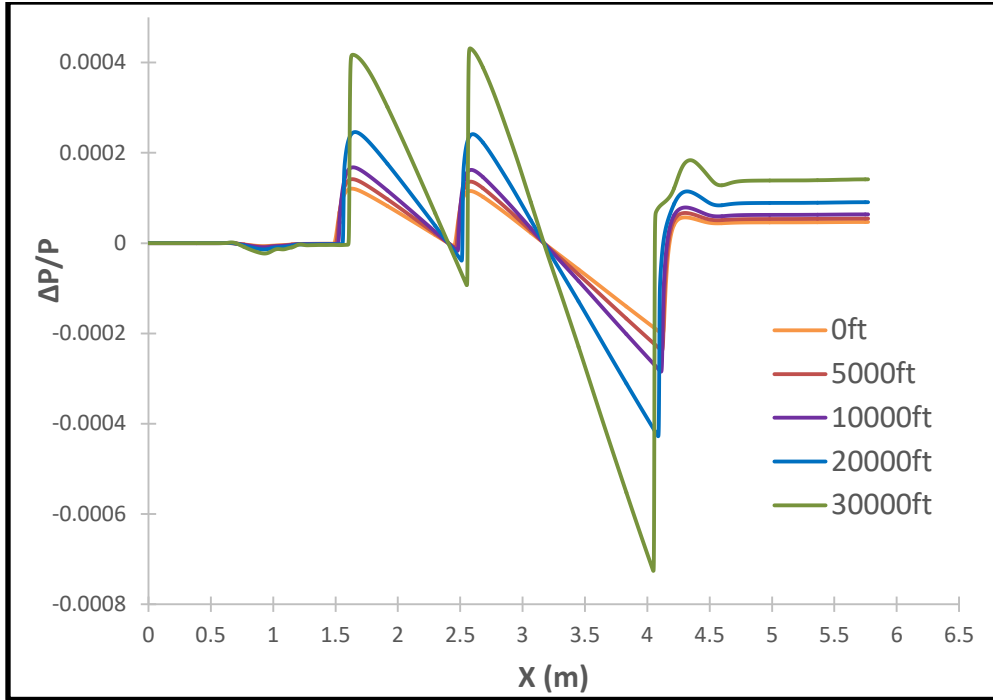


Fig. 20 Pressure signatures propagated from 45K feet for scaled Delta Wing-Body at various altitudes above the ground subjected to a reference atmosphere temperature profile in July.

It appears that as the reference temperature profiles increase the pressure signature peaks begin to smooth out. The overall pressure signatures for the Delta Wing-Body model for reference atmosphere temperature profiles during the months of January and July display minimal change though. The resulting C-weighted loudness values from the pressure signatures for each altitude are shown in Fig. 21.

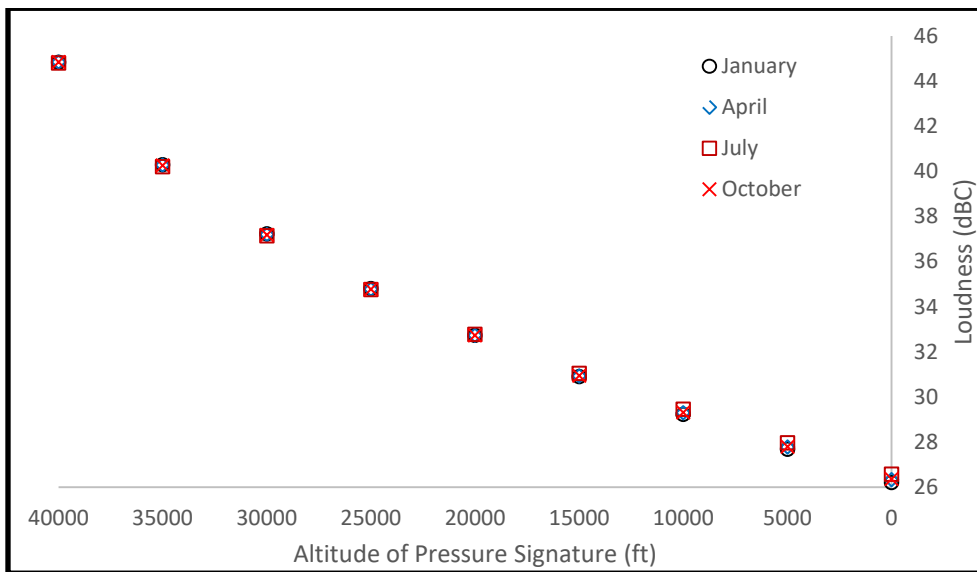


Fig. 21 C-Weighted loudness values from the pressure signatures for the scaled Delta Wing-Body model at various altitudes above the ground subjected to reference atmosphere temperature profiles for the months of January, April, July, and October at a latitude of 38° N.

The C-weighted loudness values for the scaled Delta Wing-Body model display minimal change when subjected to reference atmosphere temperature profiles for the various months. The C-weighted loudness values of most interest are those at ground level that could potentially cause harm to buildings or individuals. These values are shown in Table 3 for the scaled Delta Wing-Body model.

**Table 3 C-weighted loudness values for the scaled Delta Wing-Body model at ground level when subjected to reference atmosphere temperature profiles for the months of January, April, July, and October at a latitude of 38° N**

	<b>Delta Wing-Body C-Weighted Loudness Values (dBC)</b>
<b>January</b>	26.207
<b>April</b>	26.333
<b>July</b>	26.575
<b>October</b>	26.365

## **7 CONCLUSION**

Our numerical results show great agreement with the AIAA Sonic boom workshop data which validates the mesh used during the CFD simulation. This allows us to proceed forward onto optimization of the deltawing. The sBoom code predicted that the pressure waveforms are effected very little by changes in temperature and that the signature diminishes a significant amount when propagated from 45,000ft.

## **8 FUTURE WORK**

The next steps for this research project consist of creating a genetic algorithm that will be able to change the shape parameter of the body of the deltawing. This will be implemented when we run another Fluent simulation and it will optimize the body shape of the deltawing without altering specific flight expectations that a deltawing has. From there it will be considered and determined whether any other shape parameters should be optimized. The optimized deltawing signature will be inputted into sBoom to obtain the pressure disturbance waveform along with the effects of temperature on the waveform.

## **9 ACKNOWLEDGEMENTS**

I would like to extended my thanks to Dr. Agarwal for the opportunity to research such an interesting and important project, Junhui for all his help with learning ANSYS ICEM and Fluent, and Dr. Rallabhandi for providing the sBoom code.

## **10 REFERENCES**

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- <sup>2</sup>Rallabhandi, S.K. "Advanced Sonic Boom Prediction Using the Augmented Burgers Equation." *Journal of Aircraft* (2011): 1245-1253.
- <sup>3</sup>Champion, K. S. W., Cole, A.E., and Kantor, A.J., "Standard and Reference Atmospheres," *Handbook of Geophysics and the Space Environment*, Ch. 14, 1985, pp. 1-12.