T-38 Talon

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Abstract:

Moving at supersonic speeds causes the air around the supersonic vehicle to be disturbed. When discontinuities occur at supersonic speeds, a shockwave is formed. The effect of a shockwave can be seen by change in pressure, temperature, or density. In this paper, the change in pressure is used to determine how changing the Mach number, angle of attack, or afterburner velocity effect the shockwave distribution, strength, and placement. The results showed that as the angle of attack is increased both the strength and distance effected from the leading edge or nose cone of the shockwave is increased. It was also determined that the free stream Mach number directly effects the angle steepness at which the shock wave is formed and the intensity of the shockwave. Further investigation needs to be completed to determine the effects due to afterburner velocity, no real change was shown in the shockwave when velocity exiting the fighter jets was changed.

Introduction:

Nasa in early 2019 took the picture, shown in figure 1, of two supersonic T-38 Talon training fighters' jets, flying at a Mach number of 1.3 at 28000 feet [1]. They were able to visualize the shockwave interaction between the two fighter jets by a third aircraft flying at 30000 feet, using a special imaging equipment that can capture 1400 frames per second [1]. The planes are flying in pattern where the trailing plane is 30 feet to the left of the first plane [1]. The image to the right leads to the questions that is attempted to be understood in this paper, what effects the shock wave disbursement, intensity, and placement from the leading edges of the fighter jets, is it the the Mach number, the angle of attack of the fighter jet, or the velocity exiting the diverging nozzle that thrusts the fighter jet through the air? In this paper, all three of the above possibilities will be examined, to determine the effects on the shockwaves as the angle of attack is changed from 5 to 15, the Mach number is changed from 1.6 to 2.2, and the velocity exiting from the fighter jet is changed from 600 to 1200 meters per second. The T-38 Talon that was used for this analysis was found on the Grab cad website, where the T-38 was modeled in accordance to mechanically correct proportions [2]. The T-38 Talon geometry was meshed, scaled, and boundary conditions were selected using Pointwise software. Ansys fluent was used for all simulations. Pressure counters were used to track the placement, intensity, disbursement of the shock waves. An adaption mesh, with respect to pressure, was conducted within Ansys fluent, so that the highest shock wave visualization

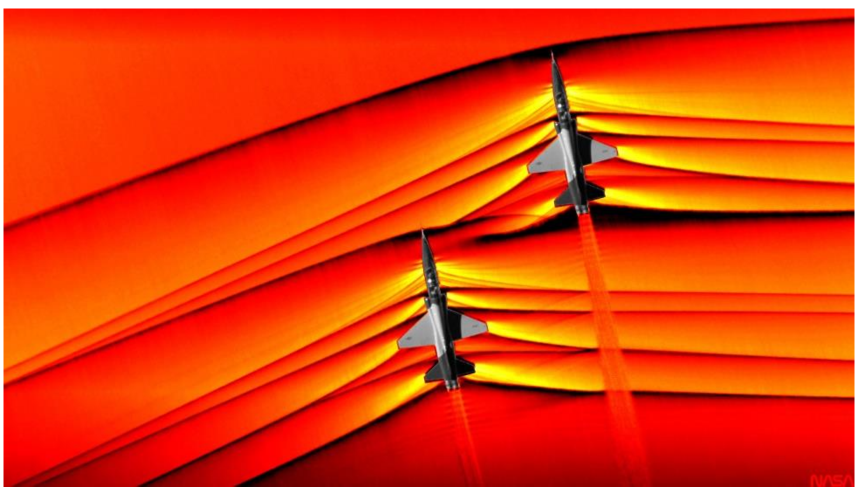

Figure 1 T-38 Talon [1]

could occur as the shock wave moved away from the body of the fighter jets. Computational resources were provided by the University of Tennessee Chattanooga Sim Center.

Mesh:

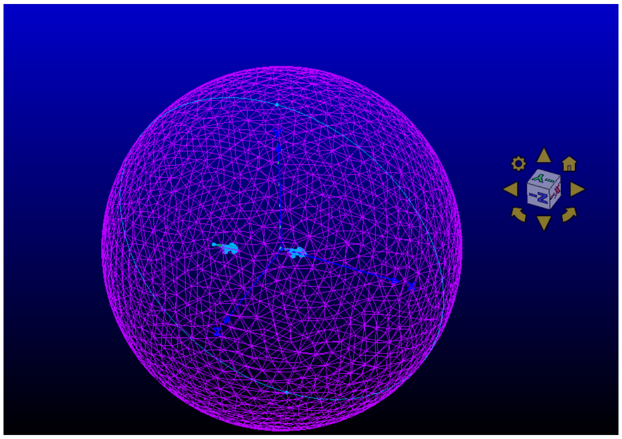

Figure 2 Overview of Mesh

The image, to the right, shows an overview of the mesh that was created within pointwise to capture the pressure forces acting at the surface of the T-38. The mesh shown, is an unstructured mesh that consists of 3.1 million points and 101 computational domains. An unstructured mesh was selected because it does not require equal spacing on all four connectors, which helped in meshing the complicated geometry. The imported geometry from grab cad was also simplified by combining databases and quilts, within pointwise, to allow for model surfaces to be broken into sections such as wing, fuselage, empennage, and afterburners [2]. Layers were added, in pointwise, so that domains, models, and blocks were separated to avoid undesired alteration. Due to the symmetry of the T-38 only one side of one of the fighter jets needed to be meshed fully, this allowed the others 3 sides to be created by translating, orientating and mirroring the first side to the correct positions that were described above. The mesh was not placed at any angle, allowing for all changes in angle of attack to be conducted within Ansys fluent.

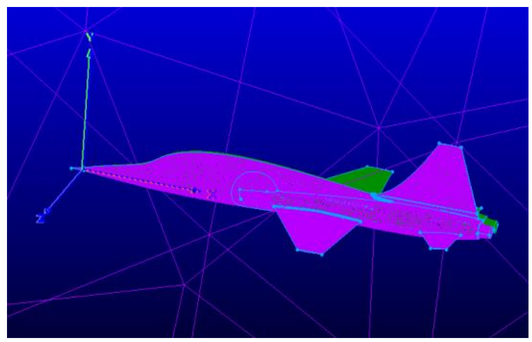

Figure 3 T-38 on Domains

Figure 3 shows the side of the T-38 that was meshed in full. Fine spacing and large point count were placed on the wings, empennage, and fuselage of both T-38's to verify that an accurate pressure forces would be obtained. In contrast, the far field was given very spread out spacing because not much change or interaction was occurring at the boundaries of the mesh. A few interesting adaptions that were made with in this mesh to help keep a low aspect, volume, and area ratio, a patch was placed on the side of the T-38's fuselage between the wall and the intake with the same spacing so the cells could be built in the volume mesh between the two domains. Also, the model from the geometry initially did not have a tipped nose, a nose cone was then designed by using true lengths form the T-38 and geometry tools within Pointwise. The fighter jets were then scaled to the correct size and the planes were placed in the correct positions, which can be seen from figure 4. After the meshing was completed boundary conditions were selected for the mesh, the main body of the T-38's were set

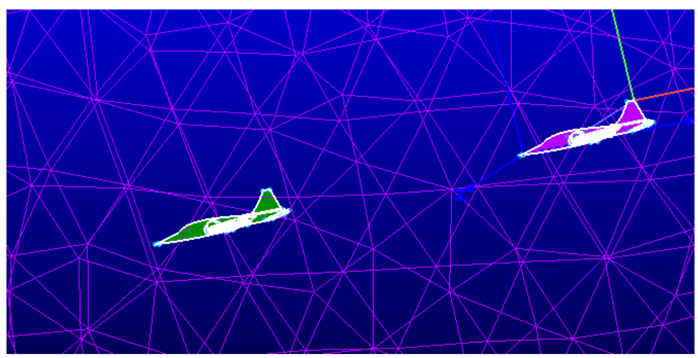

Figure 4 T-38 Positions

too wall boundary conditions so that flow would have to adjust as it made contact with the fighter jets. The back of the diverging nozzle (after burner) was selected to be a velocity inlet so that velocity and temperature exiting the diverging nozzle of the fighter jet could be altered. The front of the intake was set to a pressure outlet boundary condition, this allowed for the flow and pressure entering the intake to be adjusted. The outer spherical surface of the mesh was selected to be a pressure far field, which would allow for the change in Mach number and angle of attack. After all meshing and boundary conditions were selected, the Ansys fluent solver was selected and the mesh was written to a Ansys .cas file. Once in Ansys fluent, free stream Mach number, velocity and temperature of diverging nozzle outlet, angle of attack, and pressure at inlet entrance could all be adjusted to visualize how each change effected the pressure and or shockwave placement, intensity, and distribution. A plane was created that intersected with both fighter jets to allow for shockwave disbursement to be easily seen at the nosecone and leading edges. The far field conditions were set within Ansys fluent to simulate the T-38's flying at an altitude of 28,000 feet at that altitude's standard temperature and pressure. The operating pressure was placed at the pressure related to an altitude of 28000 feet, this made all gage pressure values be set to zero. Far field boundary condition was used for reference frame evaluations in these simulated solutions. Both the lift and drag were plotted at each time step to verify that acceptable flight conditions were occurring that would allow the fighter jets to remain in flight. The conclusions and results that were obtained from this experiment are shown below.

Results:

Changing angle of attack:

Figure 5 AOA 5 Mach number 1.3

Changing the angle of attack of an aircraft directly effects that aircrafts lift and drag values, the changing in aerodynamics forces, at supersonic speeds, then causes a change in shockwave disbursement, intensity and placement, the change in shockwave characteristics then lead to a change in pressure, temperature, and density at the surface of a supersonic vehicle. The two images shown to the right and below show a comparison between the two aircrafts as their angle of attack is changed from 5 degrees (above) to 15 degrees (right). It can be observed from the image above that at a lower angle of attack the change in pressure is less then when the angle of attack is larger, which can be seen in the image to the right. The increase of pressure at the surface of the fighter jet leads to the understanding a larger shock wave is occurring at the leading edge. The figures also show that at a lower angle of attack the pressure change and expansion is quicker, which can be determined by the width of the pressure change extruding from

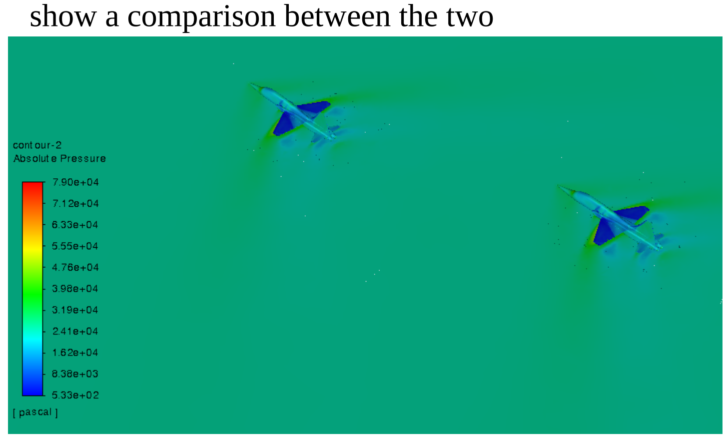

Figure 6 AOA 15 Mach number 1.3

the leading edges of the fighter jet. The larger angle of attack also causes the pressure lines to disburse further form the leading edge of the T-38s. From this observation, the conclusion can be made that as the Mach number is increased the distance away from the leading edges that the shock wave effects also increased. In closing, the increase in the angle of attack causes the pressure force to increase at the surface of fighter jet, the increase in angle of attack causes an increase in pressure disturbances further from the leading edge or nose cone, and the increase in the angle of attack causes more distance to occur before the expansion wave can reset the pressure disturbances caused by the shockwave.

<u>Changing Mach number:</u>

From above, it was shown that as the shockwave increased the pressure acting at the surface of T-38's increased. The study above shows indirectly how changing the angle of attack changes the Mach number which in turn changes the shockwave characteristics, where this comparison is a direct comparison between changing the Mach number and how it effects the pressure acting on the bodies of the fighter jets due to the change in shockwave. It is important to note, as the velocity is increased, at a specified altitude where the speed of sound is not changed, the Mach number also is increases. Where the velocity increase is specified to the velocity in the far field and not an increase in the velocity exiting the afterburner. The two figures on the right show the difference in pressure distribution that occurs at a Mach number of 1.6 and a Mach number of 2.2. Similarly, to the study completed above as the Mach number is increased the pressure force also increases which means a larger shockwave is occurring at the surface of the leading edges. Dissimilarly, it can be observed between the two images that the steepness of the pressure distribution begins to increase as the Mach number increases, where the steepness in pressure distribution directly relates to the steepness of the shockwave. Logically this makes sense, because as the Mach number increases the force intensity at which the plane is contacting the unaware air also increases. This leads to lack of pressure distribution across the surface of fighter jet, where a pressure distribution can be seen in the first image but not in the higher Mach

Figure 7 AOA Mach 1.6

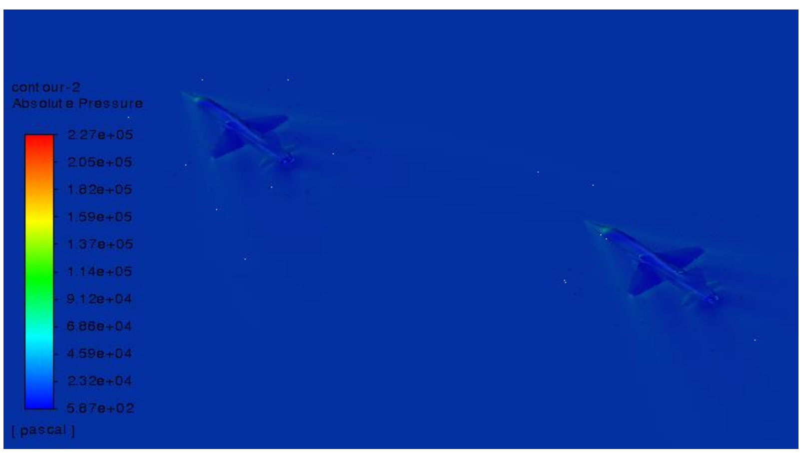

Figure 8 AOA 5 Mach 2.2

number case in the second image. Unlike the angle of attack, the change in Mach number does not appear to cause the distance of pressure disbursement from nose cone or leading edge to increase. In conclusion, of this section, the increase of the free stream Mach number similarly to the change in the angle of attack caused the pressure on the surface of the fighter jets to increase, dissimilarly, from changing the angle of attack, the increase in Mach number directly caused the angle at which pressure is effected to become steeper.

<u>Changing Velocity in Diverging Nozzle:</u>

Where the section above focused on changing the Mach number and therefore the velocity in the free stream, the study below looks at changing the velocity exiting the fighter jet. The study found that changing the velocity of the after burner had no effect on the pressure distribution or pressure forces acting on the fighter jet. This can be related to no change occurring with shock wave distribution, intensity, or placement. These results can be observed by the two images shown below, the image on the right is set to a velocity exiting at 1200 meters per second, where the velocity in the image to the left is exiting at 600 m/s. From the results discussed above, no real change with respect to pressure can be observed from the two images. This leads to the conclusion, that with in the problem set up that the free stream Mach number caused all changes to the pressure force and distributions, meaning the free stream Mach number causes all changes to shockwaves. If the velocity from the afterburner wanted to be evaluated with respect to pressure and or shock wave a different problem setup would need to be conducted with in Ansys fluent. Further research will be conducted to determine effects of changing diverging nozzle velocity, to observe its effects on changing shockwave characteristics.

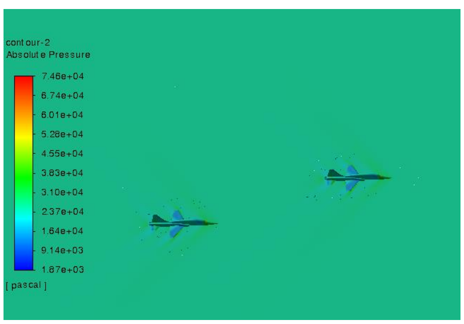

Figure 9 AOA 5 Velocity 600 m/s

Figure 10 AOA 5 Velocity 1200 m/s

<u>Conclusions:</u>

From the information discussed above conclusions can be determined about how the shockwave intensity, placement, and disbursements occur with respect to changing the Mach number, angle of attack, and velocity exiting the afterburner

1) Increasing the angle of attack causes the shockwave intensity to increase, which was observed by a change in pressure, an increase in the angle of attack also causes the distance that that shock wave disburses to increases, but does not cause a large change in the steepness angle of the shock wave.

2) Similarly to increasing the angle of attack, increasing the free stream Mach number also caused the shock wave to increase in strength, dissimilarly ,to increasing the angle of

attack, the increase in the free stream Mach number does cause the steepness of the angle of the shockwave to increase.

3) Changing the velocity exiting the fighter jet had no effect on changing the pressure on the surface of the fighter jet, meaning there was no change in shock wave. Further investigation needs to be conducted to determine if the velocity leaving the fighter jet effects shock wave intensity, placement, or angle.

In conclusion, the understanding of how Mach number, angle of attack, and velocity exiting fighter jets effect shockwaves are crucial to the future of aerospace advancements and improvements.

Conflicts of Interest:
The author declares that there is not a conflict of interest in the paper if it were to be published.

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The author would like to thank Dr. Kidambi Sreenivas for supporting, guiding, and mentoring the student to create a project about the information on shockwave placement, intensity, distribution that was described above. The author also thanks his coworkers for guidance and listening, questioning, and preparing the author for what will hopefully be a successful future.

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