LINKÖPING UNIVERSITY

EXPERT CONFERENCE: Sonic Boom Reduction of Supersonic Aircrafts

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1 Supersonic Flows and Shock Waves

With the ever increasing urge to travel faster and faster we move from subsonic to supersonic speeds. When an aircraft flies at the speed of sound it is said to fly in the supersonic speed regime. Once it flies beyond Mach 1 the fluid which comes in contact is no longer incompressible, hence we see disturbances in the form shock waves, expansion waves. These compressibility effects are caused due to abrupt changes in pressure, density and temperature of the medium. The airflow behind the shock wave breaks up into a turbulent wake creating a drag called wave drag which severely impacts the performance of an aircraft. [1].

A sonic boom as seen in Figure 1 is a sound that

Fig. 1 . F-22 Raptor undergoing Sonic Boom.

is created due to shock waves whenever an object travels through the air faster than the speed of sound. A larger amount of energy is contained in a sonic boom. Sonic booms of an aircraft can cause structural damages and cause discomfort to living creatures. Neither is the sonic boom omnidirectional nor does it occur at the moment the object crosses Mach 1. Sonic boom is rather a 3-Dimensional cone that is formed behind the aircraft, which grows proportionally and dies out gradually.
Usually when an aircraft flies in a subsonic speed regime, the aircraft produces pressure waves in front of the wing, similar to waves in water when a stone is thrown into it. These waves become tightly packed ahead of the aircraft than at the rare side. Until the aircraft travels slower than the speed of sound, these waves are nested within each other, .i.e., one pressure wave within another pressure wave. These pressure waves do not intersect each other in subsonic regime. But when the aircraft travels faster than the speed of sound things change. When a pressure wave generated intersects another pressure wave already present, they are forced together forming a Mach cone [1]. The pressure rises at the nose and steadily decreases to a negative pressure as the wave approaches the tail, after which it again sharply increases to its normal pressure. This pressure profile is plotted is called the N-wave. So therefore, the N-wave causes two booms- first when the pressure rises and the other when the pressure returns to normal as seen in Figure 2.

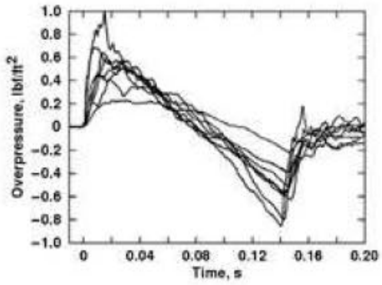

Fig. 2 . N wave representing the pressure distribution across the aircraft body.

2 Environmental Issues and Regulations

The greatest barrier for supersonic flight is the environmental restrictions because of the sonic boom generated when aircraft speeds exceed speed of sound.
The noise generated when the aircraft is traveling at supersonic speed, has a wide range of distance, approximately 80 Km around the aircraft. Such a large range of noise can cause many problems for the environment.
After the development of the Concorde aircraft, was when the sonic boom generated by it was taken into consideration. In 1968 the Aircraft Noise Abatement Act was created in order to establish standards regarding supersonic flight. *FAA* [2].

3 Methods of Reducing Sonic Boom

3.1 Past Developments

To reduce the effects of sonic boom, it becomes necessary to reduce the pressure change effectively so that the loud noise is reduced to a quieter sound. Following are the examples of developments that have taken place to reduce the intensity of sonic boom:

1. F-5 E: The nose of the F5 was replaced with a longer version. NASA took 1300 sonic-boom measurements from various ground sensors. "The results showed that there was an 18 percent reduction in the initial impulse pressure. This resulted in the reduction of larger pressure variation. The noise levels measured were found to be 4.7 decibels lesser than the regular F5", as taken from *NASA* [3].
2. SR-71: The Blackbird had a diffuser at the engine. "The shock waves hitting the main body would flatten out against the diffuser, resulting in a quieter sonic boom due to smoother movement of airwaves" , as taken from *Lockheed Martin* [4].

3.2 Experiments

In the past, NASA's Dryden Flight Research Centre came up with the concept of introducing a long nose on an existing F-15B aircraft. This modification consisted of a 24 ft long nose which was intended to breakdown the shock waves into 3 smaller ones before it reached the main body. This project known as the Quiet Spike Testing aims to induce Laminar Flow Control which reduces the turbulent cross flow on the wing which causes shocks. The underlying principle is the conversion of the traditional N shaped shock waves to a less intense S shaped waves as described by *NASA's Dryden Research Centre* [5].
"Currently, NASA continues to research by creating "superbooms" which are generated when aircraft accelerate or decelerate but can be heard at only one place. If the locations are planned correctly these "superbooms" can be heard only over places with minimum disturbance such as a desert or a water body. This project is currently being tested with microphone arrays over land. The tests are being performed by F18 aircraft to create sonic booms over Florida in USA. They are also researching a way so that shock waves produced such that only a general pressure rise is developed instead of a loud boom. The data collected from these tests will aid in designing future supersonic aircraft"- *NASA's Dryden Research Centre* [5].

4 Future Concepts

1) Spike S 512: This is a future aircraft that is designed to produce noise levels less than 70 db. The sweep of the wing is designed in a way to reduce the shock waves. "The S-512's sonic boom signature on the ground is further reduced by careful optimization of the shape of the airplane. Extensive use of advanced Computational Fluid Dynamics (CFD) software was made to optimize the shape parameters of the wing and fuselage to minimize shock wave strength. Interactions between shock waves and flow expansion regions located on the surface of the airplane were analyzed, and design of the flow expansion regions was refined to mitigate the strength of the waves" as quoted by *Spike Aerospace* [6].

2) Lockheed are developing a Quiet supersonic X- plane which believes in streamlining the aircraft to eliminate the sonic boom. "The idea is to create a sleeker shape that distributes the shock waves over a broader area, and add lifting surfaces like a canard, stabilator, and T-tail to further minimize impact points between the airframe and the air, creating fewer shock waves. Ditching the cockpit canopy in favor of an electronic vision system eliminates another boom point", as seen in Figure 3 which is taken from *X-59 QueSST* [7].

Fig. 3 . Main Design Features of QueSST.

5 Conclusion

Summarizing the above discussed methods and concepts we can say that there have been considerable developments in the research towards decreasing intensity of the sonic boom. It can be concluded that in future we can expect supersonic flights without sonic boom.

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