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Review of Supersonic Intake buzz, problems associated and possible solutions

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***Abstract*— Supersonic intake buzz is a type of shock oscillation that could occur at any supersonic inlet of an aircraft and which can alter the mass flow and pressure at inlet. It may lead to combustion instability also. A lot of experiments have been performed to understand the buzz characteristics while visualizing the flow characteristics through flow visualization techniques. Also, there have been a great effort and research to understand the supersonic buzz phenomenon through numerical simulation with the help of computational software packages. There could be different parameters affecting the buzz. Some of them was discovered by the researchers all over the world. Intake buzz distortion get substantially affected by change in angle of attack. Decrease in throttle area was also found to produce prominent effect on buzz by increasing its dominant frequency. The suppression of buzz has become a topic of active research. The suppression of buzz can help in increasing the efficiency of supersonic inlet and efficient compression, so can result in benefit of increasing the economic output and reducing the fuel consumption. Intake performance was found to be increased with small cowl deflection and by the use of buzz predictor and margin controller. Buzz could be controlled by deflecting the air in an advantageous way and generating a weaker gradient at inlet lip.**

***Keywords*—** Supersonic, inlet, buzz, shock, aircraft, experiment, numerical simulations, ramjet

I. Introduction

The people desire to fly at high speed has resulted in realization of a large number of supersonic aircrafts. To that aspect, integration of propulsion system to a supersonic aircraft becomes a concern to fly smoothly and efficiently. Inlet of an aircraft engine plays a significant role in maximizing the power output of the engine. Also, the inlet should be able to provide optimum performance for a large range of Mach numbers. Subsequently, the rapid growth in supersonic flight of aircraft has given an impetus to active research in the field of design for a better supersonic inlet of the aircraft engine. Figure 1 shows a typical flow field occurring at supersonic inlet **[1].**

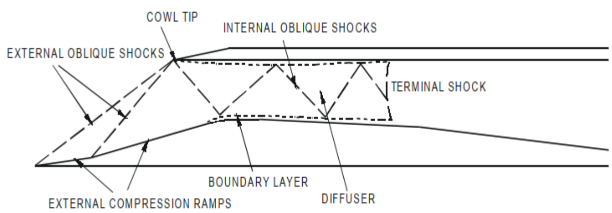

Figure 1. Schematic of flow field over intake [Das et al]

Here, the reduction of velocity was obtained by use of shock waves by providing ramps at inlet lip. A single normal shock could lead to a large pressure loss, so the required compression was obtained by a series of external

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and internal compression oblique shocks followed by a terminal normal shock.

These types of inlets are called mixed compression inlets. For Mach numbers less than 1.6, the deceleration is obtained by a single normal shock as its design is simple and total pressure loss is not high. For Mach numbers ranging from 1.6 to 2.5, oblique shocks followed by normal shock occurring at inlet cowl lip can give satisfactory performance while for Mach numbers greater than 2.5 up to 5, mixed compression inlet design is required for better performance**,** which involves internal reflections also **[2].**

One of the common problems associated with supersonic inlet is intake buzz which is a self-sustained shock oscillation which can decrease the efficiency of inlet and lead to disturbed mass flow and pressure variation to the following parts of engine like compressor and so to combustion chamber.

So, the stability of flow is a massive requirement in designing the supersonic inlet. Theoretically, pulsation free flow at inlet can be achieved at design condition. But, the instability at aircraft engine intake can occur due to change in condition of engine operation and flight condition, which may lead to surge and buzz at inlet of the engine, respectively. In surge, there occurs a condition where mass flow exceeds than that of optimum mass condition where mass flow exceeds than that of optimum mass flow required by the engine while the reverse happens in buzz and so mass flow reduces as required by the engine. So, there are ongoing researches around the world to prevent buzz. So, it is necessary to understand the buzz phenomena and the reasons which cause the buzz and subsequently find the ways to avoid it.

Figure 2, taken from Seddon and Goldsmith **[3]**, illustrates the non-stationary shock pattern of the inlet buzz. The oscillating cycle is started when subcritical shock moves quickly forward and results in reduction of mass flow.

The resulting lower pressure inside the inlet cause the shock to move back. The shock movement overshoots its equilibrium condition and leads to a condition in which entering mass flow is higher than exit flow. Increasing pressure then causes the shock to retreat back and the cycle repeats again and again.

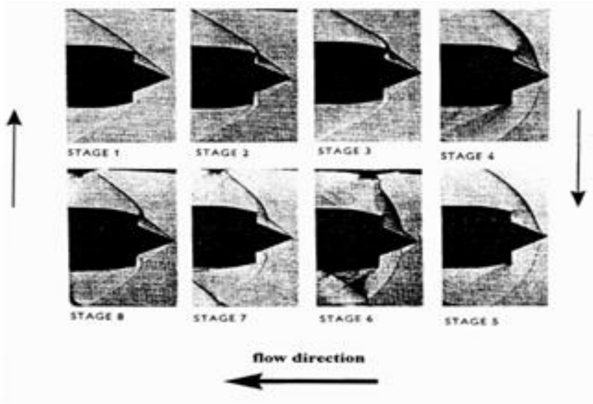

Figure 2. Typical oscillations of inlet buzz taken from Seddon and Goldsmith **[3]**

The buzz can occur on an isolated supersonic inlet but it can also cause and combine with other instabilities like combustion unsteadiness and compressor surge. The buzz can pose restrictions on limit of high supersonic flow. Therefore, it is very necessary to understand the buzz phenomenon and find the ways to avoid it without losing performance. Understanding the buzz phenomena can help to design better intake for engines of supersonic aircraft. Also, understanding the buzz phenomenon can be helpful to design intake of ramjet engines, which are usually used for power generation at supersonic speeds and usually used in missiles having few applications in aircrafts due to its inability to generate thrust in static condition. To understand and reduce the buzz characteristics both experiments and software simulations were performed for different design of supersonic inlets, around the world. The present study is a review of available literatures on experimental analysis and numerical analysis of supersonic intake buzz and proposed solutions to overcome the problems.

II. LITERATURE REVIEW OF EXPERIMENTAL ANALYSIS OF SUPERSONIC INTAKE BUZZ

The nature of buzz occurring at the inlet could differ for different design of intakes. To understand the buzz characteristics, study has been performed both experimentally and numerically. As per the experiment performed on mixed compression rectangular inlet model by Trapier et al **[4]**, two different types of buzzes were studied, the first was “little buzz”, which was found to occur as a result of shear layer beneath the cowl leading face, while another kind of buzz was “big buzz” which occurred due to separation of boundary layer on the compression slopes. Fisher et al **[5]** also observed two forms of instability like ‘big’ and ‘little’ buzz which were found to be of same frequency but different amplitude. Also, they analysed the flow instability at the intake of supersonic passenger aircraft Concorde and subsequently they suggested the design technique for minimizing the pre-entry drag for the engine. They suggested that a weak gradient at the inlet lip could be in contact with the lip without causing instability. For the purpose, they suggested to reduce the pressure difference across the shear zone.

In another experiment, performed on low boom supersonic inlet **[6]**, the inlet buzz occurred at mass flow well below that required for its optimum operation. They used computational fluid dynamics (CFD) along with experimental analysis to understand the physics of buzz cycle. They found that the buzz cycle consisted of spike buzz and choked flow which resulted in reduction of pressure and increase of pressure respectively. Figure 3 shows the interesting shock oscillations from interior to tip of the spike of the inlet **[6]**. The particular buzz cycle took place for 15 times per second. Their analysis examined the performance of inlet for design engine operating regime. They captured the buzz cycle phenomena through the technique of Schlieren photography.

The experiments by Soltani et al **[7]** were performed on an axisymmetric supersonic inlet. They studied inlet buzz for different design & off-design conditions. The experiments had also been performed on a generic, axisymmetric, external-compression inlet with a single-surface center-body [**8]**.

Dailey **[9]** performed the experiment for maximum mass flow of supersonic inlet to determine nature and cause of instability. The mass flow was found to be greatly affected by the buzz. He found that, buzz also affected the combustion process in adverse way. It may also lead to blowout after first cycle of buzz but maintaining the burning during cycle was found to produce no qualitative effect on buzz.

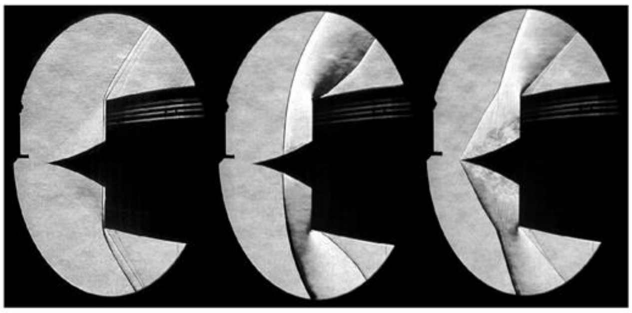

Figure 3. Schlieren photography of buzz cycle taken from Chima RV [6]. The shock travels from inlet interior (left) to the spike tip (right)

In NACA report by Ferri and Nucci **[10]**, buzz called as aerodynamic instability was analyzed for external compression at supersonic inlet. They told that buzz is a velocity discontinuity across a vortex sheet at the shock intersection. They found the origin of this instability at the lip of the inlet cowling. They analyzed the inlet for a range of Mach numbers up to 2.7 and suggested to use inlet design as suitable for application of a particular aircraft. Tanaka et al **[11]** visualized the shock waves at supersonic intake in a shock tunnel at Mach 2.5 and data from PSP (pressure-sensitive paint) measurements & computations were presented.

In another paper by Suryanarayan et al **[12]** of experimental analysis, image analysis of supersonic intake buzz was done and buzz was controlled by natural ventilation. Suryanarayan **[13]** had also shown the application of natural ventilation to reduce the aerodynamic drag of bluff bodies. Patent has also been filed of design of device for preventing buzz in supersonic intake by Jungclaus et al **[14],** which was having application in ramjet engine or guided missiles as claimed by inventors. It was semi-rotationally symmetrical intake cross-section. It was including one air outlet port which deflected the air to give advantage.

III. LITERATURE REVIEW OF NUMERICAL ANALYSIS OF SUPERSONIC INTAKE BUZZ

A lot of numerical analysis along with experiments have also been performed and being performed around the world to understand the behaviour of supersonic intake buzz and to work for getting possible solutions. Also, the numerical and mathematical analysis gives a benefit of economic advantage by saving expenditures on creating actual models and creating set-up for experiments.

Numerical simulation for different cowl deflection angles for supersonic intake was performed by Das et al **[1]**, which was performed for mixed compression by considering two-dimensional flow. They found improvement in performance with small cowl deflection. In numerical simulation by Sivakumar et al **[15]**, for the flow in intake at high supersonic Mach numbers, simulation of non-reacting flow at engine inlet have been performed to compare the performance of intake at various angles of attack and disturbed flow at intake for different angles of attack has been compared and the numerical model was validated with experimental data. In another paper on numerical simulation by Yeom et al, the analysis of supersonic intake buzz was performed on an axisymmetric ramjet engine **[16]**. The numerical simulation by Zhu et al **[17]** was done using acoustic modelling and associated vibration characteristics of buzz was analyzed. Another interesting numerical analysis was done by James et al **[18],** in their analysis they analyzed the buzz characteristics and subsequently separation bubble dynamics at supersonic inlet. They numerically solved the flow field in an axisymmetric supersonic inlet for mixed compression at different Mach numbers. They used two-dimensional Navier Stokes equations for calculation of two-dimensional compressible flow. Sekar et al **[19]** has done the study of unsteady throttling dynamics through numerical simulation for the flow field in a hypersonic inlet at Mach number of 5 for mixed compression. They simulated the throttling conditions by varying the exit area of isolator in the form of plug insets. In yet another literature, numerical simulation was performed on mixed compression intake buzz **[20]**. They performed the simulation at Mach 2. They showed that during buzz, the intake duct is loaded and unloaded. Yamamoto et al **[21]** performed the computational fluid dynamics (CFD) to predict the onset of supersonic inlet buzz. They showed that onset was closely associated with the mass flux through the diffuser. Namkoung et al **[22]** did the numerical simulation for knowing the effects of angles of attack and throttling conditions on supersonic inlet buzz. They found the increase in dominant frequency of the inlet buzz with decrease in throttle area. Also, it was found that distortion was substantially got affected with change in angle of attack, but frequency of inlet buzz producing prominent effect was least affected with angle of attack. Lu et al **[23]** has analyzed the inlet buzz flow problem to minimize the generation of buzz for effective operation. They found that buzz phenomenon may occur and unavoidable in some conditions. Although, the effects could be reduced by proper design of inlet.

Park et al **[24]** developed a theoretical dynamic model to analyse the phenomenon of buzz cycle, which was a low order model and analysed both the intake and combustor with nonlinear equations. They analysed the phenomenon at the intake of a ramjet engine. Trapier et al. **[25]** showed accurate prediction of buzz through simulation of delayed & detached eddy.

Shi et al **[26]** designed the supersonic inlet buzz margin control for ducted rockets and performed numerical simulation to study the effect. The supersonic inlet performance can be increased while operating near the buzz boundary **[26]**. They demonstrated this benefit by design of margin predictor and controller, which predicted the buzz margin and could maintain it at desired value by taking necessary measures.

IV. CONCLUSIONS

As can be seen from Figure 2 and Figure 3, for different design of supersonic spike intakes, the shock oscillations of inlet buzz follow the same pattern. Buzz can affect the mass flow and pressure at inlet in adverse way. Buzz can also affect the combustion stability of combustion chamber in adverse way. Intake buzz distortion get substantially affected by change in angle of attack. Decrease in throttle area was found to enhance the dominant frequency of inlet buzz.

Performance was found to be increased with small cowl deflection of supersonic intake. Also, the buzz problem can be handled by designing a buzz margin predictor and controller, which can increase the efficiency of supersonic intake. The buzz can also be controlled by deflecting the air flow in a beneficial way and natural ventilation. Buzz could be avoided by weak gradient at inlet lip without causing instability. Also, buzz could be avoided by designing inlet suitable for the application.

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References

[1] Das S, Prasad JK. Cowl Deflection Angle in a Supersonic Air Intake. *Defence Science Journal*, Vol. **59**, No. 2, March 2009, pp. 99-105

[2] Farokhi S. Aircraft propulsion, (2014)

[3] Seddon J, Goldsmith EL. Intake Aerodynamics. AIAA education series. *Blackwell Science*, 1999

[4] Trapier S, Duveau P, Deck S. Experimental Study of Supersonic Inlet Buzz. *AIAA Journal*. Vol **44**, No. 10, October 2006. DOI: 10.2514/1.20451.

[5] Fisher SA, Neale MC, Brooks AJ. On the sub-critical of variable ramp intakes at Mach numbers around 2. *ARCR* & RM. (1951) **3711**

[6] Chima RV. Analysis of Buzz in a Supersonic Inlet. *NASA/TM*—2012-217612.

[7] Soltani MR, Farahani M, Kaji MH Asgari. An experimental study of buzz instability in an axisymmetric supersonic inlet. Scientia Iranica B (2011) **18** (2), 241–249.

[8] Lee HJ, Park TH, Jeung IS, Choi JY. Study on the Buzz Characteristics of Supersonic Air Intake at Mach 2.5. *Journal of the Korean Society for Aeronautical & Space Sciences*. May 2007. DOI: 10.5139/JKSAS.2007.35.5.426.

[9] Dailey CL. Supersonic Diffuser Instability. *Journal of the Aeronautical Sciences*, Vol. **22**, No. 11, 1955, pp. 733 – 749

[10] Ferri A, Nucci RM . The origin of aerodynamic instability of supersonic inlets at subcritical conditions.(1951) *NACA* RM-L50K30.

[11] Tanaka N, Mizukaki T. Visualization of unsteady behavior of shock waves around supersonic intake installed in shock tunnel. In: *28th International congress of the aeronautical sciences (ICAS)* (2012)

[12] Suryanarayana GK, Dubey R.Image analyses of supersonic air-intake buzz and control by natural ventilation. *Journal of Visualization*. (2017) **20**:711–727. DOI 10.1007/s12650-017-0420-z

[13] Suryanarayana GK. Aerodynamic drag reduction of bluff bodies - application of natural ventilation. *Lambert Academic Publishers, Cologne* (2009). ISBN **978**-3-8383-1103-6

[14] Jungclaus G, Krohn EO. DEVICE PREVENTING BUZZ IN SUPERSONIC INTAKES OF AIR-BREATHING REACTION ENGINES, PARTICULARLY, RAMJET ENGINES. *United States patent*, Patent no-4502651

[15] Sivakumar R, Babu V. Numerical Simulations of Flow in a 3-D Supersonic Intake at High Mach Numbers. *Defence Science Journal*, Vol. **56**, No. 4, October 2006, pp. 465-476

[16] Yeom HW, Sung HG, Yang V. A Numerical Analysis of Supersonic Intake Buzz in an Axisymmetric Ramjet Engine. *Int'l J. of Aeronautical & Space Sci.* **16**(2), 165–176 (2015). DOI: 10.5139/IJASS.2015.16.2.165.

[17] Zhu J, Luo W, Wei Y, Yan C, You Y. Acoustic Modeling and Vibration Characteristics of Supersonic Inlet Buzz. *Energies* 2020, **13(8), 2048;** DOI: 10.3390/en13082048

[18] James JK, Suryan A, Kim HD. Buzz characteristics and separation bubble dynamics in supersonic intake. *Aerospace Science and Technology* **115** (2021) 106795. DOI:10.1016/j.ast.2021.106795

[19] Sekar KR, Karthick SK, Jegadheeswaran S, Kannan R. On the unsteady throttling dynamics and scaling analysis in a typical hypersonic inlet-isolator flow. *Phys. Fluids* (2020)

[20] Soltani MR, Abedi M, Askari R. Numerical Simulation of Mixed Compression Intake Buzz. *Proceedings of the ASME 2017 International Mechanical Engineering Congress and Exposition.* IMECE2017-71680

[21] Yamamoto J, Kojima Y, Kameda M, Watanabe Y, Hashimoto A, Aoyama T. Prediction of the onset of supersonic inlet buzz. *Aerospace Science and Technology* (2019).

[22] Namkoung H-J, Hong W, Kim J-M, Yi J, Kim C. Effects of Angles of Attack and Throttling Conditions on Supersonic Inlet Buzz. *Int'l J. of Aeronautical & Space Sci.* 13(3), 296–306 (2012).

[23] Lu P-J, Jain L-T. Numerical Investigation of Inlet Buzz Flow. *Journal of Propulsion and Power*, Vol **14**(1), Jan-Feb (1998). DOI: 10.2514/2.5254

[24] Park I-S, Ananthkrishnan N, Tahk MJ, Vineeth CS, Gupta NK.Low-order model for buzz oscillations in the intake of a ramjet engine. *J Propulsion Power* **27**(2):503–506

[25] Trapier S, Deck S, Duveau P. Delayed detached simulation and analysis of supersonic intake buzz. *AIAA J* **46** (1):118-131

[26] Shi X, Chang J-T, Bao W, Yu D, Li B. Supersonic inlet buzz margin control of ducted rockets. *J. Aerospace Engineering* Proc. IMechE Vol. **224**