



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 9, September 2022

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 8.118



9940 572 462



6381 907 438



ijirset@gmail.com



www.ijirset.com



# Influence of Several Techniques on Hypersonic Vehicles subjected to various Aerodynamics Forces: Theoretical Overview

Sheetal Prajapati<sup>1,\*</sup>, Tushar Pundir<sup>1</sup>, Bhartendra Mahor<sup>1</sup>, Himanshi Vij<sup>1</sup>

<sup>1</sup>Department of Research and Development, ASTROEX RESEARCH ASSOCIATION, Deoria, India

\*Corresponding Author

**ABSTRACT:** For Mach 6 wind tunnel, the structure of a hypersonic boundary layer and its impact on aerodynamic heating is studied. We looked at the rates of heat generation brought on by the dilatation and shear processes. To evaluate the temperature distribution brought on by aerodynamic heating, a theoretical study is offered. Each sort of hypersonic facility has certain benefits and drawbacks. Testing in a range of various locations would be necessary for experimental hypersonic to be successful. The use of shock tubes for testing is not discussed in this work since such tests are more appropriate for studying the basics of shock relaxation than for evaluating in-depth wind tunnel model simulations for aerodynamic heating and drag reduction.

**KEYWORDS:** Aerodynamic, Drag, Energy, Measurement, Technique

## I. INTRODUCTION

One of the challenges for hypersonic vehicle (HSV) design and analysis is the requirement of considering aerodynamics, aerodynamic heating, thermal transfer, and structural dynamic response. Many effective numerical techniques have been used to solve thermal problems. These methods present a significant computational burden, which is impractical for control system design and optimization. A significant portion of research in hypersonic involves reproducing flows past actual aircraft and spacecraft for engineering purposes. Ground test facilities generally cannot test a full-scale flight vehicle over a complete range of flight conditions. Consequently, it is necessary to discuss the methodologies to simulate hypersonic flows over flight vehicles using ground test facilities. Due to its critical importance to the safety of ultra-high-speed flight, aerodynamic heating is a major topic in hypersonic flow research. Everyone agrees that the development of flow disturbances and the beginning of turbulence, which alters skin friction, are associated with increased heat transmission. In tests and numerical simulations, the area with a sharp rise in skin friction and heat transfer (HT) is frequently designated as the beginning of the turbulent state.

There are many ways to reduce the order of thermal problems, such as the Guyan reduction, augmentation of the eigenvector basis, and modal identification method. The eigen mode basis may not be optimal for approximating the dominant physics of a system while containing the fewest number of modes.

The sorts of modes involved appear to have an impact on how hypersonic aerodynamic heating behaves. At  $Ma = 6$  planar hypersonic boundary layer's transition processes were studied by Franko & Lele (2013). After the transitional region, HT, for the first mode-oblique interaction processes mechanism, a clear overshoot of heat transfer was seen. This was explained by the creation of stream-wise vortices and the resulting rise in wall shear stress. Where the second mode reached its height, a further peak of heat release, HS, occurred. While the corresponding skin friction of the former is just marginally greater than that of the latter, the temperature readings at HS are somewhat higher than those at HT.

## II. LITERATURE REVIEW

Dan Xie et.al (2020) studied for air-breathing hypersonic vehicles, the Thermal Protection System (TPS) is intended to allay worries about aerodynamic heating. TPS size design also incorporates aerothermoelastic stability. According to recent research, the TPS size used in Culler's groundbreaking work is not the ideal design for either a higher flutter boundary or less weight [1].

Xiaoxuan Yan et.al(2020) studied that hypersonic vehicle aerothermoelastic analysis is a challenging multidisciplinary coupling problem. For the purpose of resolving the radiative thermal transfer problem, this work developed a tractable approach-based reduced-order modeling technology. Case studies were done to verify and rate the methodology's sturdiness [2].

Mohammad Sadegh Karimi et.al (2018) studied that It is suggested to look at novel techniques for thermal protection and drag reduction for hypersonic velocity. Techniques such as geometry, mass injection, energy deposition, and magneto aerodynamics are presented. It is demonstrated how each technique affects the lowering of aerodynamic heating and drag waves [3].

Yiding Zhu et.al (2018) studied that Rayleigh-scattering flow visualization; fast-response pressure sensors, fluorescent temperature-sensitive paint (TSP), and particle image velocimetry are all used in experiments carried out in a Mach 6 wind tunnel. Additionally, calculations are carried out using both direct numerical simulations and parabolized stability equations (PSE) (DNS). While strengthening local aerodynamic heating at HS, increasing the unit Reynolds number favors second-mode dissipation. The second mode's associated high-frequency fluid compression and expansion was the primary cause of the aerodynamic heating in HS [4].

Rui Ding et.al (2020) studied that A novel double layer combined cooling conception is suggested in this paper. An improved design with a semi-through slot in the high temperature region is suggested. This work aims to provide the designers of future hypersonic vehicles with an active thermal management approach [5].

## III.DRAG AND AERODYNAMIC HEATING REDUCTION TECHNIQUES

It is crucial to look into the philosophy of development and technology because philosophy is more than just physics. Thought experiments are the whims of the mind; they offer glimpses into the essence of things. A philosophical thought experiment is a fictitious scenario created in the "laboratory of the mind" that often defies the laws of physics or is even technologically impossible, but which is intended to show something philosophically significant or basic about the subject under discussion. Thought experiments can be used to explain a point, amuse, solve a mystery, expose a conflict in our thinking, and prompt us to offer further explanation. Thought experiments have a prestigious intellectual history, in fact. Thought experiments are crucial to both the formulation of relatively and the interpretation of quantum physics. The approaches in this article have been categorised into four main groups. Approaches based on geometry, mass injection, energy deposition, and magneto aerodynamics. Each approach is described here, along with a thorough overview of the development process. Later, the group's unique physics and the method's efficacy are examined.

### Mechanism of drag reduction, the effective body approach

The extent of the recirculation zone, which screens a sizeable section of the forebody, is a typical explanation for the drag decrease seen by spiked blunt bodies [4-6]. This theory was largely accepted since it was shown to be adequate for explaining how spiky bodies function. This hypothesis, however, leaves out some events connected to sharp-pointed spikes. This is due to two factors: First off, lengthening the spike lowers flow pressure all around, not only at the reattachment point. Second, the little change in the reattachment point doesn't seem to be enough to account for the sharp decline in peak pressure. To more precisely understand the mechanism of drag reduction in spiky bodies, the idea of the effective body is used. Some studies used an imprecise shear layer to determine the effective body. The explanation of the drag reduction process in models with aero disks uses the effective body hypothesis based on the dividing streamline. The separation point, which is situated at the aero disk shoulder, may be demonstrated to move farther from the forebody axis as the aero disk size increases.

According to Chapman et al., the dividing streamline is the streamline that divides the "escaping" and "reversing" streamlines. The only streamline in the shear layer that entirely stagnates on the body surface at the reattachment point is the dividing streamline. When compared to experimental research, this approach is more accurate at defining the effective body's outer profile. The inclinations of the separation shock and the flow expansion prior to separation are two ways in which the shape of the effective body controls the pressure field. The pressure over the whole-body surface, including the reattachment point, is further reduced by lengthening the spikes. The current explanation and the prior research up until this point do not make obvious the methods of drag reduction employing aero disks, their relative superiority, or the further drag reduction produced by increasing their diameters.

### **Cavity**

Aerodynamic heating is a major factor when an aircraft is moving quickly. The initiation of ablation in unstable hypersonic flow around nose tips with a forward-facing cavity was investigated numerically and experimentally. Higher Mach numbers and lower angles of attack were often where the unstable flows exhibited occasional bow-shock activity and no axisymmetric. A hemisphere-cylinder body with a cylindrical hollow served as the study's geometry for both parts. The ideal cavity length is four times as long as there are noses. The cavity diameter that most significantly prolonged the ablation start time was half the nose diameter. By slightly reducing the diameter of the nose tip, the addition of a forward-facing cavity can be employed to postpone the commencement of ablation without increasing drag.

### **Mass Injection Technique Aerodynamic Drag reduction and Heating**

By injecting fluid from the blunt body forward, one can reduce drag on blunt bodies in hypersonic flow. Typically, the injection is focused at or near the body surface's stagnation point. A non-structural spike made up of the forward penetrating jet should theoretically take the place of the structural spike. If the mass injection approach is done correctly, it would prevent the heating and ablation problems that arise from a physical spike.

### **Mass injection mechanism of drag variation and heat transfer**

The opposite jet approach can virtually have the same impact on heat reduction in the nose region as the spiking technique when used as a fully reusable thermal protection. The shock wave caused by the jet moves away from the nose and forms a recirculation area. The governing variables that control the flow field are the total pressure ratio, total temperature, free stream, and jet Mach values, blunt body diameter, and nozzle exit. With a drop in the temperature at the stagnation point, the temperature of the recirculation zone and the surface heat flow will also drop. Heat flux is substantially impacted by the jet's overall temperature. The low temperature in the recirculation zone is caused by a large cool supersonic jet layer. The flow of surface heat decreases as a result. The decrease in heat capacity of the jet layer is to blame for the temperature increase. Additionally, density increases somewhat as nozzle exit diameter grows, and temperature rise then decreases as nozzle exit diameter increases. With a high exit Mach number, the cool supersonic jet layer expands. Surface pressure forces are primarily responsible for creating the aerodynamic forces and moments. In comparison to pressure-based forces, skin friction is insignificant. There will be a change in the general aerodynamic properties if the fluid injection might modify the pressure distribution. If the fluid is injected with a lot of force, it can drive the bow shock ahead and reconnect on the surface far from the stagnation point, creating a tolerable dead air zone with extremely low pressure. This reduces drag, albeit in certain situations the powerful reattachment is followed by a reattachment shock that increases pressure and heat transfer. However, there is no appreciable change in shock standoff distance when the mass is injected with a relatively modest momentum. It is reasonable to anticipate that the overall aerodynamic properties won't change significantly because the dead air zone is likewise extremely tiny.

### **The effectiveness of the injection techniques**

The main purposes of injection techniques are to modify the boundary layer or to improve the flow near surfaces by establishing a more controlled condition. It's mostly used for cooling in high-speed applications. A single jet or a group of jets may be used for injection, as was previously mentioned. However, because there are no significant changes in the aerodynamic aspects of the flow, such as drag, an array of jets has no effect on the stability of the body and can



lower surface heat transfer rates by up to 50%. A single jet's cooling performance is inferior to an array of jets' cooling performance due to the single jet's narrower field of impact.

#### IV. LASER AND PLASMA ENERGY TECHNIQUES

After establishing methods for aerodynamic heating and drag in mass injection and geometrical approaches, new techniques like laser and plasma energy methods are employed. We categorize energy techniques into two main groups. the use of laser and laser-plasma energy methods. These methods are used to reduce drag and achieve aerodynamic heating; the first technique used is energy deposition using a laser or other technology that has significant benefits for reducing drag. With the advancement of this plasma-based technique, our capacity to reduce heat and drag in flow fields has increased. This section will introduce the physics and philosophy behind these strategies.

varying drag using energy processes Energy deposition upstream of the body causes separation and creates a low-pressure area in front of the body, which reduces wave drag. Through a means of energy transfer, the air is informed of the body's impending arrival in this procedure. The placement of the energy addition, the size of the energy source, and the power of the energy source are three criteria that have a significant impact on drag reduction. The interaction between the bow shock over the body and the blast wave caused by the deposition of energy creates the recirculation zone, and a virtual spike supported by an axisymmetric recirculation is created in front of the cylinder.

One possible method for lowering wave drag is localized energy deposition upstream of the configuration of interest. This creates an area of low pressure in front of the vehicle, which reduces drag. Due to the versatility, it provides in terms of application, this unique approach is promising and drawing attention. For flow control via energy deposition, any acceptable energy source may be employed.

The use of focused energy deposition to reduce drag has been extensively discussed in previous research. According to Kremeyer's research on Lines of Energy Deposition for Supersonic/Hypersonic Temperature/Drag Reduction and Vehicle Control, deposition of the energy along the stagnation line frequently results in a 90% reduction in drag and a 40–50% decrease in surface temperatures.

Adding energy in front of a supersonic or hypersonic vehicle is a well-known method for reducing drag and heat transmission. This may be accomplished by concentrating the radiation that high-power lasers generate. Be aware that any decrease in pressure at the body's nose may be cancelled out by shocks originating from the energy deposition, which might result in an increase in total drag.

#### Heat addition method

A very real and significant issue is reducing aircraft drag. Fuel currently accounts for half of an aircraft's total weight and much more for rockets. The payload or range of an aeroplane increases by around 10% for every 1% reduction in drag. To fly higher and faster has been the aviation industry's catchphrase for many years, and it has come to the point where funding ideal designs to reduce drag has almost reached its limit. Consequently, we present a novel technology for aerodynamic heating and drag reduction in this part. The exothermic interaction between the atomic oxygen behind the shock wave and the chromium atoms ablated from the stagnation area of the chromium-coated blunt cone produces the heat addition. The tests reveals a about 47% reduction in drag for a blunt cone with a 60° apex angle. Installing a needle or injecting a gas jet at the end of the aircraft's nose can both minimise hypersonic aerodynamic drag. Both a significant redistribution of surface pressure and a decrease in drag coefficient are made possible by controlling the needle location or the pressure of the injected gas. The effect is produced by the development of flow separation zones in front of the body, where the pressure is lower than behind the separated shocks in front of similar bodies without a needle or gas injection.

#### V. COMBINATION TECHNIQUE

When the stagnation pressure of the counterflowing jet is high enough, the combinatorial configuration of a counter flowing jet and a forward-facing cavity is more advantageous than that with the counter flowing jet alone. When the total pressure ratio is high, the cavity behaves exactly like a speed-up nozzle for the counter flowing jet. The reduction of heat release and performance enhancement of the drag is both benefited by the high total pressure ratio, and the recirculation zone is crucial to heat release reduction. However, if the overall pressure ratio is low, the cavity will squander the counter-flowing jet's energy, which might lead to an unstable situation. The unstable oscillation in the



supersonic cavity flow is a drawback that may be avoided by a combinatorial arrangement with a low total pressure ratio, and the heat release reduction is more sensitive to variations in cavity diameter than to variations in cavity length. In comparison to the individual techniques of energy deposition and a counter-flowing jet, this combinatorial arrangement exhibits greater reductions in total drag and heat release. The combinatorial arrangement also significantly lessens the counter-flowing jet's instability issue. It has been demonstrated that the upstream energy deposition greatly improves the stability and penetration of the counterflowing jet. The annular ring injection stabilizes the jet; centered forward injection without upstream energy deposition would experience considerable instability.

For reducing drag and aerodynamic heating, a combinatorial technique combining both lateral jets and aerospikes is both feasible and efficient. To displace the leading shock wave's conical shape from the blunt body, lateral jets are employed. In addition to a significant temperature drop at the blunt body's shoulder, this can effectively cool the aerospoke tip. The findings indicate that even with a 4° angle of attack by the lateral jet, the peak pressure at the reattachment zone may be reduced by 65%, and its potential for use in engineering is rather high.

## VI. CONCLUSION

In this paper, we examine innovative techniques for reducing drag and heating aerodynamically. Hypersonic vehicles are heated and their drag is decreased using geometrical, mass injection, energy deposition, and magneto aerodynamic approaches. The method of energy deposition promotes heat transport to the body while reducing large drag. Aerospoke or aero disk connections to the body minimize the peak reattachment heat flow, which may result in a drop in surface temperature. The technique of injecting energy into a fluid alters the boundary layer or produces a flow that is easier to manage. A single jet or a group of jets may be used for injection, which greatly minimizes surface heat transfer while having no effect on the stability of the body.

The features and abilities of the various hypersonic wind tunnels were then covered. These facilities were divided into three categories according to their typical flow regimes, which ranged from low to very high total enthalpies or flow velocities. These facilities' strengths and weaknesses were quantitatively evaluated. Several diverse test facilities, each with its own special capabilities and limits, are used in experimental hypersonic research. Even at low and medium enthalpy circumstances, expansion tunnels may occasionally be preferred over reflected shock tunnels because they provide test flows with less thermochemical excitation. For instance, the LENS XX facility enables the testing of models with realistic dimensions at moderate total enthalpies leading to long enough testing times.

## Acknowledgment

We would like to express our gratitude towards Mr. Ankit Kumar Mishra, Executive Director and Research Advisor at ASTROEX RESEARCH ASSOCIATION, DEORIA for helping us throughout the research work and providing his sincere guidance and support for successful completion of the project.

## REFERENCES

- [1]. AXie, D., Dong, B., & Jing, X. (2020). Effect of thermal protection system size on aerothermoelastic stability of the hypersonic panel. *Aerospace Science and Technology*, 106. <https://doi.org/10.1016/j.ast.2020.106170>.
- [2]. Gu, S., & Olivier, H. (2020). Capabilities and limitations of existing hypersonic facilities. In *Progress in Aerospace Sciences* (Vol. 113). Elsevier Ltd. <https://doi.org/10.1016/j.paerosci.2020.100607>
- [3]. Zhu, Y., Lee, C., Chen, X., Wu, J., Chen, S., & Gad-El-Hak, M. (2018). Newly identified principle for aerodynamic heating in hypersonic flows. *Journal of Fluid Mechanics*, 855, 152–180. <https://doi.org/10.1017/jfm.2018.646>
- [4]. Karimi, M. S., & Oboodi, M. J. (2019). Investigation and recent developments in aerodynamic heating and drag reduction for hypersonic flows. In *Heat and Mass Transfer/Waerme- und Stoffuebertragung* (Vol. 55, Issue 2, pp. 547–569). Springer Verlag. <https://doi.org/10.1007/s00231-018-2416-1>
- [5]. Ding, R., Wang, J., He, F., Wang, M., Luan, Y., Dong, G., & Tang, L. (2020). Numerical investigation on a double layer combined cooling structure for aerodynamic heat control of hypersonic vehicle leading edge. *Applied Thermal Engineering*, 169. <https://doi.org/10.1016/j.applthermaleng.2020.114949>



- [6]. Chang, C.-L. & Malik, M. R. 1994 Oblique-mode breakdown and secondary instability in supersonic boundary layers. *J. Fluid Mech.* 273, 323–360.
- [7]. Pruett, C. D. & Chang, C.-L. 1998 Direct numerical simulation of hypersonic boundary-layer flow on a flared cone. *Theor. Comput. Fluid Dyn.* 11, 40– 67.
- [8]. Malik, M. R. & Spall, R. E. 1991 On the stability of compressible flow past axisymmetric bodies. *J. Fluid Mech.* 228, 443–463.
- [9]. Li, X., Fu, D. & Ma, Y. 2008 Direct numerical simulation of hypersonic boundary-layer transition over a blunt cone. *AIAA J.* 46 (11), 2899–2913.
- [10]. Menezes V, Saravanan S, Jagadeesh G, Reddy KPJ (2003) Experimental investigations of hypersonic flow over highly blunted cones with Aerospikes. *AIAA J* 41(10):1955–1966.
- [11]. Kalimuthu R, Mehta RC, Rathakrishnan E (2008) Experimental investigation on spiked body in hypersonic flow. *Aeronaut J* 112(1136):593–598.
- [12]. Yamauchi M, Fujii K, Higashino F (1995) Numerical investigation of supersonic flows around a spiked blunt body. *J Spacecr Rocket* 32(1):32–42.
- [13]. Sifton SI, Goldstein DB (2000) Ablation onset in unsteady hypersonic flow about nose tip with cavity. *J Thermophys Heat Transf* 14(3):421–434.
- [14]. Sifton si, goldstein db (2005) Use of an axial nose-tip cavity for delaying ablation onset in hypersonic flow. *J Fluid Mech* 528:297–321.



**INNO SPACE**  
SJIF Scientific Journal Impact Factor  
**Impact Factor: 8.118**



**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
**INDIA**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



[www.ijirset.com](http://www.ijirset.com)

Scan to save the contact details