Department of Aerospace Engineering

JGI Global Campus, Jakkasandra Post, Kanakapura Taluk, Ramanagara District, Pin Code: 562 112

2023 – 2024

Technical Seminar on Emerging / Modern Technologies in the Aerospace Industry

Report on

HYPERSONIC VEHICLES

Submitted in partial fulfilment for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

AEROSPACE/AERONAUTICAL ENGINEERING

SUBMITTED BY

NAME: PANTALEO PROSPER KIRUWA

USN: 20BTRAS057

Department of Aerospace Engineering

Faculty of Engineering

JAIN (Deemed to be **UNIVERSITY)**

TABLE OF CONTENTS

ABSTRACT.

The aviation field is growing increasingly interested in hypersonic speed for passenger transportation, which requires careful study of enabling technologies for optimal vehicle design. The design of hypersonic vehicles is a complex and interdisciplinary problem, with key sub-systems such as aerodynamics, propulsion, structures, and control impacting the vehicle's flight dynamics. Hypersonic vehicles present unique challenges for designers and engineers due to the extreme speeds and high altitudes they operate at. This paper is aimed at describing the dynamics and control of these vehicles taking into account some of the recent experimental models.

Keywords: Aerodynamics; Control systems; Hypersonic; Scramjets; X-43A.

1. INTRODUCTION.

Hypersonic transportation systems are being researched by NASA as a potential solution for affordable space access. While significant work has been done on air-breathing hypersonic technology, there remain critical technological gaps that need to be filled before hypersonic transport systems can be a reality. Today's projects by NASA and other boards aim at conducting research, analysis, and improvement in the flight vehicles for space exploration, and even civil transportation as well as military purposes. Hypersonic flight has long been a goal of aerospace engineers, as it promises to revolutionize air and space travel by dramatically reducing travel times and enabling access to space at a lower cost. There have been developments in the design of hypersonic vehicles, like the recent X-43A vehicle. The X-43A was an experimental hypersonic vehicle designed to test the feasibility of using scramjet engines for high-speed flight. Its slender, streamlined design and highly swept wings optimized the vehicle for high-speed flight, while its scramjet engine provided high thrust and efficient combustion. The X-43A's control systems, which combined onboard sensors with ground-based operators, allowed for precise control of the vehicle during flight. Consider its configuration below;

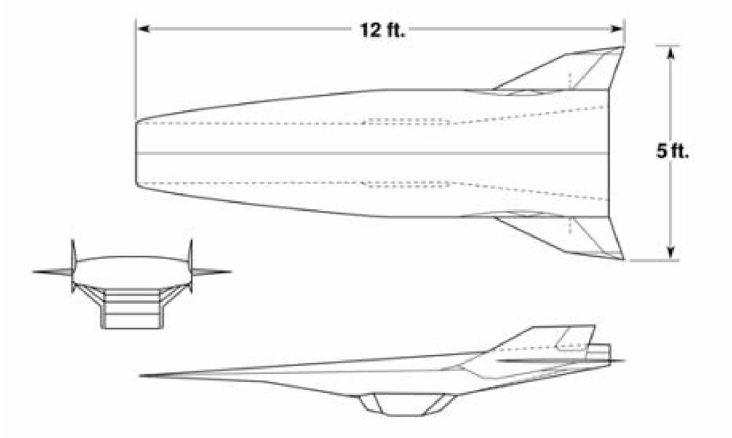

Fig 1: Configurations of X-43A

This report provides a detailed analysis of the aerodynamics and control of hypersonic vehicles. The insights gained from the X-43A's flight tests have been used to improve the design and operation of hypersonic vehicles. The successful flight of the X-43A has demonstrated the potential of scramjet engines for high-speed flight and provided valuable insights into the aerodynamics and control of hypersonic vehicles.

Overall, this report highlights the importance of understanding the aerodynamics and control of hypersonic vehicles for the successful development and operation of these advanced aerospace technologies.

2. AERODYNAMICS OF HYPERSONIC VEHICLES.

The aerodynamics of hypersonic vehicles refers to the study of how these vehicles interact with the air at extremely high speeds, typically above Mach 5 (five times the speed of sound). At these speeds, the aerodynamic forces acting on the vehicle are significantly different from those experienced by subsonic and supersonic vehicles.

One of the primary challenges in hypersonic aerodynamics is dealing with the high temperatures generated by the friction between the vehicle and the air. The air surrounding the vehicle can reach temperatures of thousands of degrees, which can cause thermal stresses and structural damage to the vehicle. To combat this, hypersonic vehicles are often designed with heat-resistant materials and special cooling systems.

Another challenge in hypersonic aerodynamics is the development of shock waves. As the vehicle moves through the air, it creates shock waves that can cause a loss of stability and control. Hypersonic vehicles are designed with special aerodynamic shapes to minimize these shock waves and maintain stable flight.

Consider the flow features of an Airbreathing Hypersonic Flight Vehicle (AHFV) below;

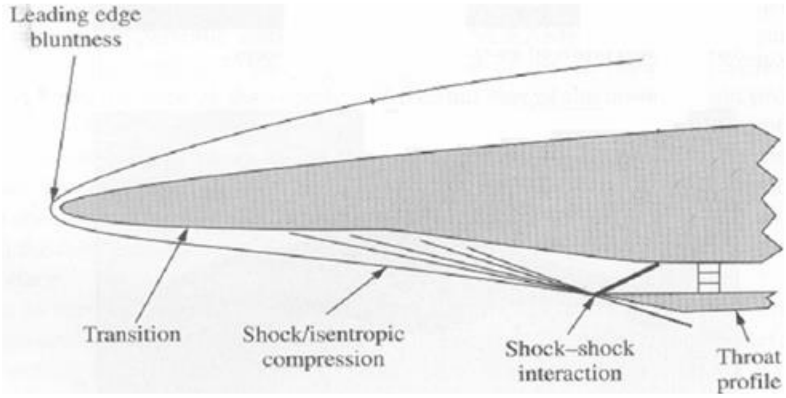

Fig 2: Flow features of a Hypersonic vehicle.

The control of hypersonic vehicles is also challenging due to the high speeds and complex aerodynamic forces. These vehicles require advanced control systems that can quickly and accurately adjust the vehicle's attitude and trajectory to maintain stability and control.

In addition to these challenges, hypersonic vehicles also experience other unique aerodynamic phenomena, such as boundary layer transition and rarefied gas effects. Boundary layer transition refers to the transition of the air flow near the surface of the vehicle from laminar to turbulent, which can affect the aerodynamic forces acting on the vehicle. Rarefied gas effects refer to the behaviour of the air at extremely low pressures, which can cause unexpected changes in the vehicle's flight dynamics.

Overall, the aerodynamics of hypersonic vehicles is a complex and challenging field that requires a thorough understanding of the physics and engineering principles involved. By studying and developing advanced hypersonic aerodynamic designs, engineers can create safer, more efficient, and more reliable hypersonic vehicles.

3. PROPULSION OF HYPERSONIC VEHICLES.

The propulsion of hypersonic vehicles is a critical aspect of their design, as these vehicles require advanced and efficient propulsion systems to achieve and maintain high speeds. There are several different types of propulsion systems that are used in hypersonic vehicles, including scramjets, rocket engines, and hybrid engines.

Scramjets (supersonic combustion ramjets) are a type of air-breathing engine that are specifically designed to operate at hypersonic speeds. Scramjets use the air around the vehicle as the oxidizer for combustion, which eliminates the need to carry an oxidizer on board, making scramjets more lightweight and efficient than traditional rocket engines. However, scramjets are typically limited to speeds of Mach 10 or below.

Rocket engines, on the other hand, are not limited by the speed of the air around the vehicle and can operate at higher speeds than scramjets. Rocket engines work by carrying both fuel and oxidizer on board and burning them together to generate thrust. Rocket engines can produce extremely high levels of thrust, making them ideal for launching hypersonic vehicles into space or for reaching speeds beyond the capabilities of scramjets.

Hybrid engines combine the advantages of both scramjets and rocket engines. These engines use both air and onboard oxidizer to generate thrust, making them more fuel-efficient than traditional rocket engines. Hybrid engines also have the ability to operate over a wide range of speeds, making them well-suited for a variety of hypersonic applications.

The development of advanced propulsion systems is critical for the advancement of hypersonic technologies, as the speed and efficiency of these systems will directly impact the capabilities of hypersonic vehicles. The development of new and innovative propulsion systems, as well as the optimization of existing systems, will play a key role in the future of hypersonic travel and exploration.

4. CONTROL SYSTEM OF HYPERSONIC VEHICLES.

The control system of hypersonic vehicles is a critical aspect of their design and operation, as these vehicles require advanced and precise control to maintain stability and manoeuvrability at extremely high speeds. Hypersonic vehicles experience complex aerodynamic forces, thermal stresses, and other unique phenomena that require advanced control systems to maintain stability and control.

One of the primary components of the control system of hypersonic vehicles is the flight control system. This system uses a combination of sensors, actuators, and control algorithms to monitor the vehicle's attitude, trajectory, and other flight parameters and make the necessary adjustments to maintain stability and control. The flight control system must be capable of making rapid adjustments to compensate for changes in the vehicle's flight conditions and respond to unexpected events or disturbances.

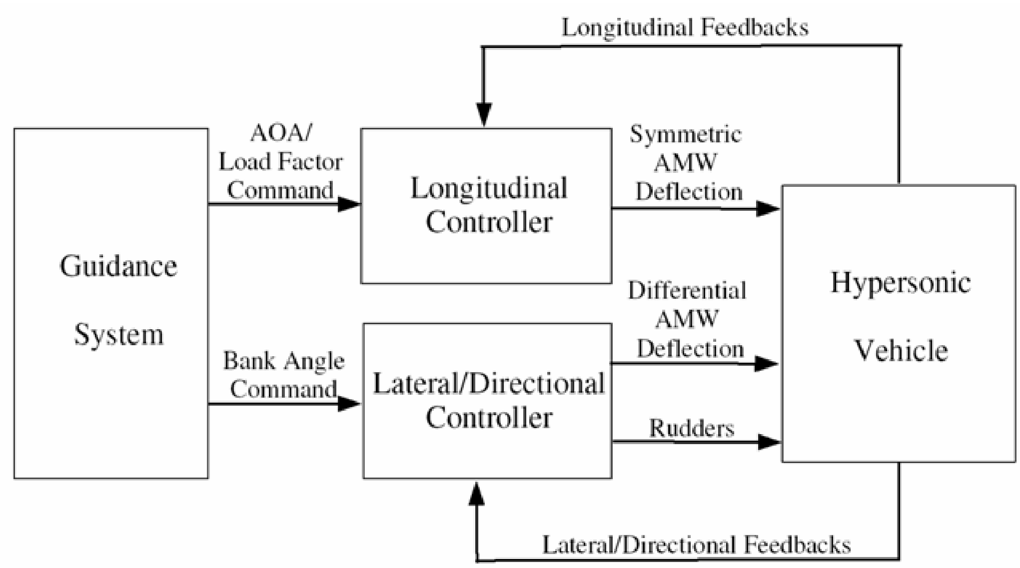

Fig 3: Control scheme of X-43A

The control system of hypersonic vehicles also includes a propulsion control system, which regulates the output of the vehicle's engines and ensures that they are functioning properly. The propulsion control system must be capable of responding to changes in the vehicle's flight conditions and making adjustments to the engine output to maintain stability and control.

In addition to these primary control systems, hypersonic vehicles also require advanced avionics, guidance, and navigation systems to ensure that the vehicle stays on course and reaches its intended destination. These systems use a combination of sensors, GPS, and other technologies to provide accurate positioning and guidance information to the flight control system.

The development of advanced control systems for hypersonic vehicles is critical for the advancement of hypersonic technologies and their applications. These systems must be capable of operating at extremely high speeds and under extreme thermal and aerodynamic conditions, making their development and optimization a significant challenge. However, the successful development of advanced control systems will enable the safe and efficient operation of hypersonic vehicles and open up new opportunities for high-speed travel, space exploration, and other applications.

5. AIRFRAME – PROPULSION – STRUCTURAL DYNAMIC INTERACTIONS.

The interactions between the airframe, propulsion system, and structural dynamics of hypersonic vehicles are critical to their performance and safety. These interactions can have a significant impact on the aerodynamics, stability, and control of the vehicle, as well as the reliability and efficiency of the propulsion system.

The airframe of a hypersonic vehicle must be designed to withstand the extreme thermal and aerodynamic conditions that it will experience during flight. The high speeds and temperatures of hypersonic flight can cause significant thermal stresses on the vehicle, which must be managed through the use of advanced materials and cooling systems.

The propulsion system of a hypersonic vehicle must be designed to provide the necessary thrust to achieve and maintain high speeds, while also being lightweight and efficient. The design of the propulsion system must take into account the aerodynamic characteristics of the vehicle, as well as the structural dynamics of the vehicle, to ensure that it operates reliably and efficiently.

The structural dynamics of a hypersonic vehicle are also critical to its performance and safety. The high speeds and aerodynamic forces experienced during flight can cause significant structural vibrations and deformations, which must be carefully managed through the use of advanced structural analysis and control systems.

The interactions between the airframe, propulsion system, and structural dynamics of hypersonic vehicles are complex and interdependent. Changes in one aspect of the vehicle can have significant impacts on the others, requiring a holistic and integrated approach to vehicle design and optimization.

Consider the interactions among the flight dynamics, the engine, and the structural dynamics by the figure below;

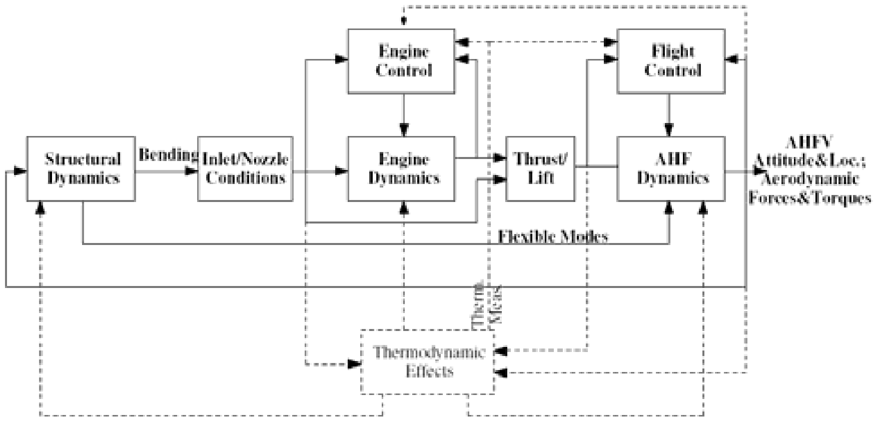

Fig 4: Dynamic interactions of a Hypersonic Vehicle.

The successful design and operation of hypersonic vehicles requires the development of advanced and integrated systems that can manage the interactions between the airframe, propulsion system, and structural dynamics. This requires the use of advanced materials, sensors, control systems, and other technologies to ensure that the vehicle operates safely and efficiently under the extreme conditions of hypersonic flight.

6. MODELLING FOR CONTROL AND DYNAMIC ANALYSIS.

Modelling for dynamics and control analysis is a critical component of the design and development of hypersonic vehicles. Hypersonic vehicles experience complex and highly dynamic aerodynamic phenomena, thermal stresses, and other unique phenomena that require advanced modelling techniques to accurately predict and understand their behaviour.

Dynamics and control modelling involves creating mathematical models that describe the behaviour of the vehicle and its components under different flight conditions. These models incorporate physical principles such as fluid dynamics, thermodynamics, and structural mechanics, as well as control theory and other mathematical techniques.

The use of advanced modelling techniques allows engineers to simulate and predict the behaviour of the vehicle under a wide range of flight conditions and control inputs. This information can be used to optimize the design of the vehicle and its control systems, as well as to develop and test control algorithms and strategies.

Modelling for dynamics and control analysis requires advanced computational tools and techniques, including numerical methods, optimization algorithms, and simulation software. These tools allow engineers to simulate and analyse the behaviour of the vehicle in a virtual environment, providing insights into the vehicle's performance and behaviour that would be difficult or impossible to obtain through physical testing alone.

The development of accurate and comprehensive models for hypersonic vehicles is critical for their safe and efficient operation. These models can be used to optimize the design of the vehicle and its control systems, as well as to identify and mitigate potential issues before they arise. The use of advanced modelling techniques is therefore an essential part of the design and development of hypersonic vehicles, enabling their safe and successful operation in a wide range of applications.

7. CONCLUSION.

the design and development of hypersonic vehicles require a thorough understanding of their complex and dynamic behaviour under extreme conditions. The aerodynamics, propulsion, structural dynamics, and control systems of hypersonic vehicles are all critical aspects that must be carefully designed and integrated to ensure the safe and efficient operation of the vehicle.

Modelling for dynamics and control analysis is a key tool in the design and development of hypersonic vehicles. The use of advanced computational tools and techniques allows engineers to simulate and analyse the behaviour of the vehicle in a virtual environment, providing insights into its performance and behaviour that would be difficult or impossible to obtain through physical testing alone.

The development of accurate and comprehensive models for hypersonic vehicles is essential for their safe and efficient operation. These models can be used to optimize the design of the vehicle and its control systems, as well as to identify and mitigate potential issues before they arise.

Overall, the design and development of hypersonic vehicles require a multidisciplinary and integrated approach that combines advanced materials, sensors, control systems, and other technologies. The use of advanced modelling techniques is a critical component of this approach, enabling the development of safe and efficient hypersonic vehicles that can operate in a wide range of applications.

8. REFERENCES.

M. A. Bolender, "An overview on dynamics and controls modelling of hypersonic vehicles," 2009 American Control Conference, St. Louis, MO, USA, 2009, pp. 2507-2512, doi: 10.1109/ACC.2009.5159864.

Mirmirani, Maj & Wu, Chivey & Clark, Andrew & Choi, Sangbum & Fidan, Baris. (2005). Airbreathing hypersonic flight vehicle modeling and control, review, challenges, and a CFD-based example.

SCHMIDT, DAVID, Harvey Mamich, and Frank Chavez. "Dynamics and control of hypersonic vehicles-the integration challenge for the 1990's." In 3rd International Aerospace Planes Conference, p. 5057. 2012.

S. D. Giorgio, D. Quagliarella, G. Pezzella, S. Pirozzoli. “An aerothermodynamic design optimization framework for hypersonic vehicles”.

Vogel, J. M., A. G. Kelkar, G. Inger, C. Whitmer, A. Sidlinger, and A. Rodriguez. “Control-Relevant Modeling of Hypersonic Vehicles.” 2009 American Control Conference, 2009. doi:10.1109/ACC.2009.5160682.