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THEORETICAL REVIEW ON HYPERSONIC CRUISE AND ACCELERATION VEHICLE’S FOREBODY CONFIGURATION

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Original Article

ABSTRACT

Hypersonic Cruise and Acceleration Vehicles have different type of forebody configuration. The forebody not only helps the vehicle to stabilize, but also helps to decelerate the speed of air by which the pressure will be increasing. The external deceleration varies with different shapes and sizes of forebody section. Increase in external deceleration will leads to achieving of the required inlet pressure for the ramjet or scramjet engine. This review summarizes the conceptual design and computational analysis of various forebody configurations of hypersonic aircraft and its performance. Comparative study will be taken with aerodynamic coefficients and other important factors. The vehicle stability and the external deceleration for various configurations are also focused to cover in this article. This article also summarizes the different methods to optimize the shape of hypersonic vehicle forebody with respect to theoretical, numerical, computational and experimental analysis. The engine inlet, aerothermodynamic effects, aerodynamic and propulsion integration, structural parameters are also discussed in this article.

KEYWORDS: Hypersonic Flight, CAV, Forebody, External Deceleration, Airframe & Propulsion Integration

INTRODUCTION

The hypersonic motion in the past decades has seen accelerative research and development enthusiast by the aerospace engineering groups due to its potentiality in the defense as close as progressively at civil advantages. Air-breathing hypersonic propulsion vehicles in future will be a replacement to the current generation subsonic aircraft of passenger flight. The flight of hypersonic aircrafts which is having with high endurance and efficient way of flying for large range is still under development only. But, because of the broad range of hypersonic flight velocities which is concerned with Mach number greater than 5 having a combination of structural and vehicle propulsion system are need to be developed with different types of air breathing turbines engines, ramjets engines, scramjets engines and engines of the rockets. Thinking about this concept of work, a concentrated fore body configuration need to be developed, focusing on the scramjet pre-compression method design perspective [1]. The drag force needs to be reduced as much as possible in air breathing hypersonic aircrafts, which is similar to other subsonic and supersonic aircrafts. The smaller the aerodynamic drag force, the engine performance increased with respect to fuel consumption rate. The aerodynamic drag force of a vehicle belongs to the various types of drag forces like form, skin friction, and the drag due to the lift induced. At flight vehicle velocity preceding the Mach with critical value, wave drag is formed which also involved with the size, represent and the angle of attack (α) which representing the angle between chord and flow field of the hypersonic flight [2].

To decrease the aerodynamic wave drag in Cruise and Acceleration Vehicle’s (CAV) and Ascent and

Reentry Vehicle's (ARV) during its climb operation, the hypersonic vehicle should have to be precisely slender in shapes and have the flight at small angle of attack. Drawings of the hypersonic air breathing vehicle and the bow shock configurations in are illustrated in figure 1a which is compared with winged re-entry vehicle configuration.

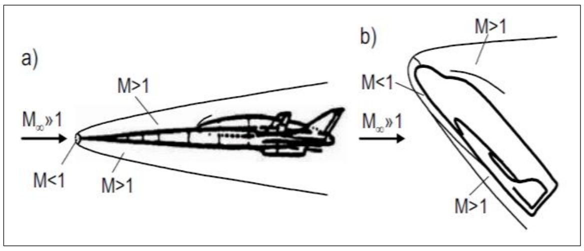

Figure 1: Schematic Drawing of Configurations of a) CAV, and b) W-RV [2].

At Mach number greater than 5 flights, the CAV's and ARV's should have the slenderness ratio less than 0.3 [3]. Small numerical values could not be chased, because then the low-velocity parameters go deficient. Low-velocity properties in hypersonic vehicle typically can be improved by flared wings as shown in figure 2.

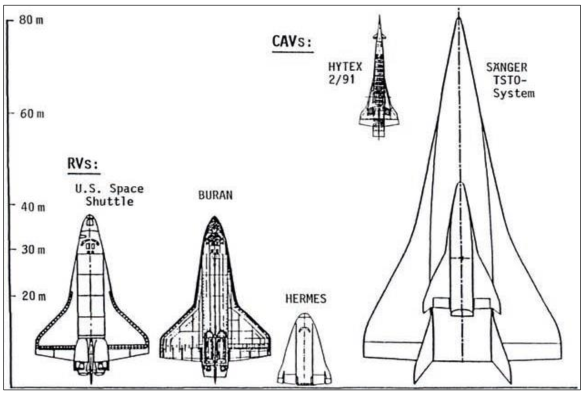

Figure 2: Plan-Form and Size of Example Various Hypersonic Flight Aircrafts and Vehicles [4, 5].

The propulsive system group has an ample role to play with respect to the hypersonic vehicle slenderness. The bigger the group, the much it essential is aft-positioned in bid to restrict the bow shock interference, which will lead to increase in wave drag. Figure 3 represents the design of an aircraft with scramjet powered CAV configuration [6]. The dimensions of the propulsion system group are introductory of all concerned with the essential acquiring engine inlet area. If the forebody pre-compression is designed in the way of decreasing the inlet pressure, so this concept of forebody can be implemented for hypersonic cruise and acceleration aircrafts.

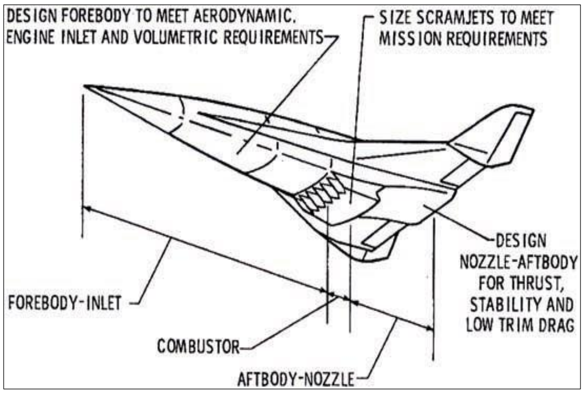

Figure 3: Schematic Drawing of Merged Aerodynamic and Thrust Power System.

The size and shape of the thrust power system is also concerned by that of the nozzle exit. An ample area ratio is demanded because of the sizable ratio of pressure, particularly because of the depressed pressure at higher altitudes. The bell nozzle which is used in the rocket engine's will not be engaged because of theirs outlet which would be too big plane diameter.

The single expansion ramp nozzle (SERN) is used in hypersonic vehicle. The thrust vectoring in the direction and magnitude along the hypersonic vehicle trajectory which is represented in figure 4 is one of the disadvantage of such type of nozzle. The peculiarly critical transonic zone by an achievable correction in the secondary air insertion during the engine nozzle flow [7].

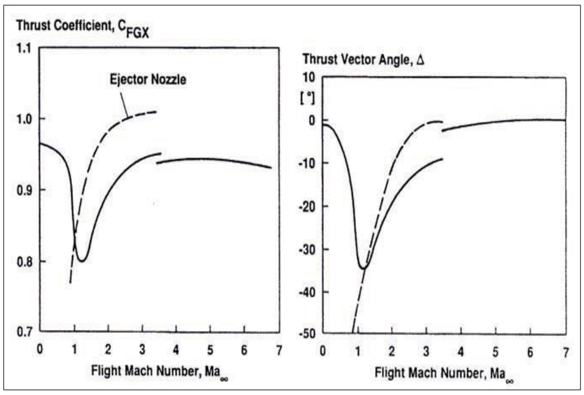

Figure 4: (a) Shows the C_{FGX} and (b) Represents the Δvs. Mach [8].

By considering the above factors the best suitable option for ARV and CAV vehicle, is developing a highly integrated aerodynamic and propulsive systems. Crucial section of outer and inner flow ways of the hypersonic vehicle is at the bottom section as shown in figure 3. The notable size of outer part of thrust power configuration which also includes forebody of the vehicle, inlet and also the area of external nozzle of hypersonic air breathing aircrafts develop with accelerative cruise Mach M_∞ which is shown in figure 5.

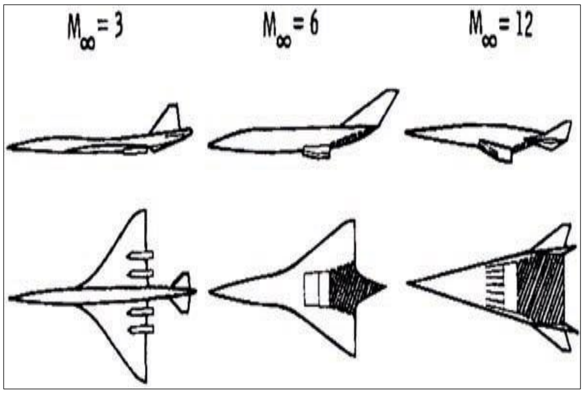

Figure 5: Development of the Dimension of the Outer Part of the Thrust Power System [6].

The concept of hypersonic vehicle design was starts with the sizing of the vehicle forebody along with the engine inlet configuration and the structure of the core scramjet engine, and also the configuration of SERN. The location of centre of gravity, shown in figure 6, helps the hypersonic vehicle to trim, control and to maintain the vehicle stability. The hypersonic aircraft has to be trimmed in steady level even when the engine thrust vectoring is not present. In the end part the article discusses the problems of aero thermodynamic frame structure and thrust power united systems.

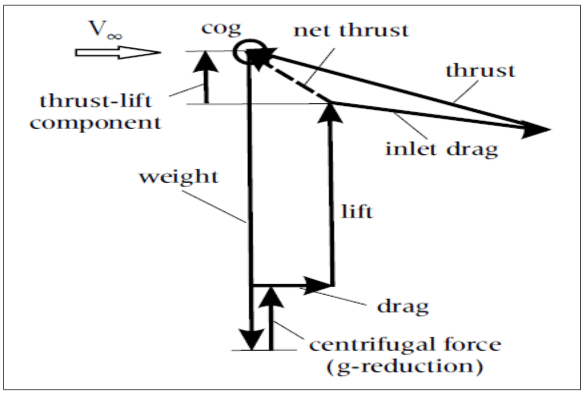

Figure 6: Schematic Diagram of Force at Steady Level CAV Flight [9].

AEROTHERMODYNAMIC AND PROPULSION SYSTEM FORCES

With the reference taken from previous research articles, the forces of aerodynamics recovered in the testing of model placed in wind tunnel and the forces generated by propulsion system are integrated to get the total aerodynamic moments and forces.

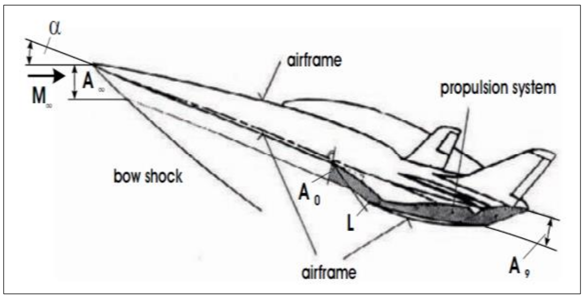

Figure 7: Schematic Drawing of Moment along the Longitudinal in a Hypersonic Vehicle [10].

The scramjet control volume represented with red color indication in figure 8, which includes the whole bottom side of the hypersonic vehicle by not considering the aircraft wings, which contributes to aerodynamic forces and moments. In the front view and also the view of rearward shaded with white color, to indicate the contribution of surface for engine. Here, there is an important point which have to be noted about the vehicle fore-body's bottom side is represented as ramp surfaces.

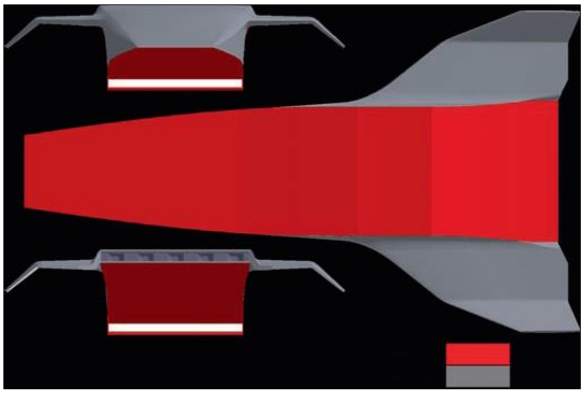

Figure 8: Airbreathing Hypersonic Orbiter Study: Design and Accounting the Surfaces [11].

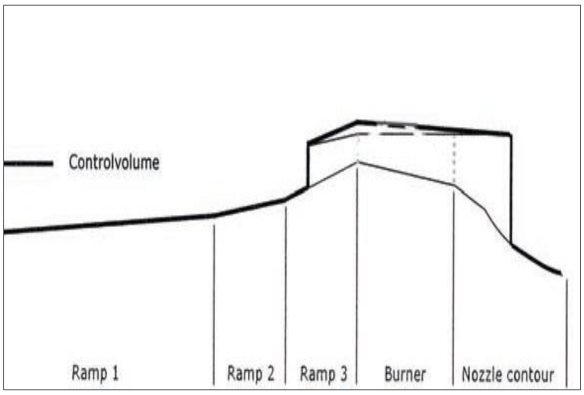

Figure 9: Shows the Air breathing Hypersonic Orbiter Study: Bottom Structures [11].

In figure 10, the positions of the aerodynamic force acting lines in representation to the center of-gravity are described.

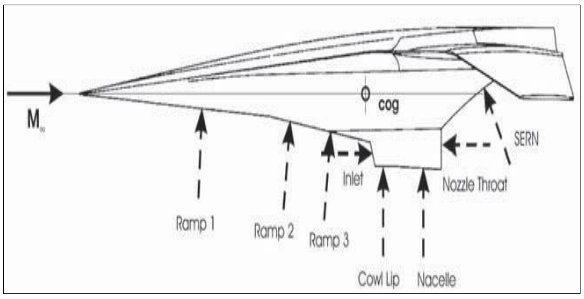

Figure 10: Represents the Air Breathing Hypersonic Vehicle Orbiter Study: The Schematic Diagram of Positions of the Force.

Problems of aero thermodynamic airframe and propulsion combination is reviewed and discussed here. Figures 11 represent the pitching moment contributions, which brings the indi vidual vehicle structures of the scramjet. When the flow is hypersonic with M>5 the lower surface ramp 1 exclusively with its position yield a large aerodynamic pitch up moment, the pitch up moment contributed by element ramp 2 is smaller comparing to pitching moment generated by ramp 1, and the pitching moment of element ramp 3 and the pitching moment of cowl lip are very small. The bottom structure of the engine nacelle with its little angles of inclination yields a small aerodynamic pitch down moment share.

In order to overcome the pitch up moment generated by the ramp surfaces an opposite pitch-down moment will be provided by SERN and Inlet.

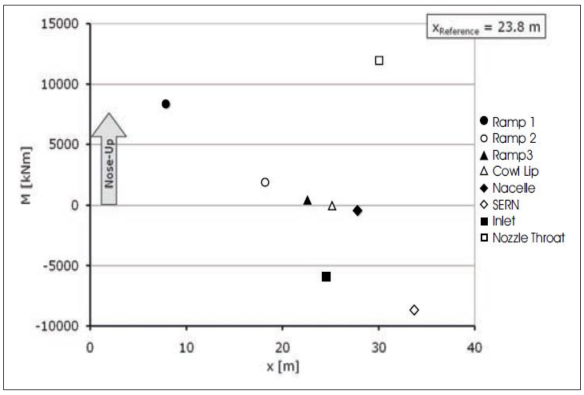

Figure 11: Air Breathing Orbiter Vehicle study: Aerodynamic Pitching Moment M [kNm] [11]

EFFECT OF FOREBODY

Configuration of the hypersonic vehicle forebody is contributing not only to the aerodynamic force needs, but also powerfully to total flight configuration needs for the center of gravity position, internal volume, and also with contributing to thermal and mechanical loads.

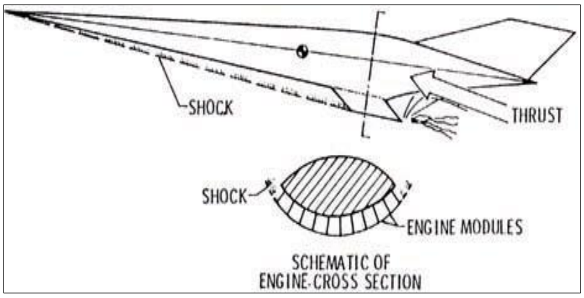

Figure 12: Schematic Diagram of Conical and Circular Vehicle Forebody [12].

If the bow shock which formed due to nose may intersect along with the inlet of engine shock which may cause damage the engine inlet and also in this case the overall engine parameters and its performance will be very low. The bow shock wave needs to be deflected far away and it will be formulated with statement of condition of flows as represented in figure 12 reciprocally in two ways:

- With change in the position of the forebody structure: larger the cross sectional area of it, larger the essential opening angle of bow shock.
- The far rearward placement of engine position.

CONICAL VERSUS FLAT LOWER SIDE OF FOREBODY

The semicircular and semiconical vehicle's forebody is shown in figure 12, or a full conical vehicle's forebody represented in the figure 13. The full conical forebody is configured with circular scramjet inlet and engine setup. On the other hand, the flat lower side of vehicle forebody having a 2D inlet flow and inlet scramjet engine configuration is also reviewed in this section.

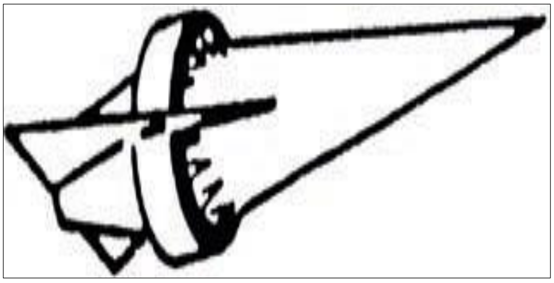

Figure 13: Schematic Diagram of a Hypersonic Aircraft with Circular Engine and Conical Forebody [12].

Nevertheless, at α, aeroelastic vehicle forebody properties, will alter the oncoming flow shape on prejudicial mode as represented in the image 14 represents this schematic diagram for a positive α.

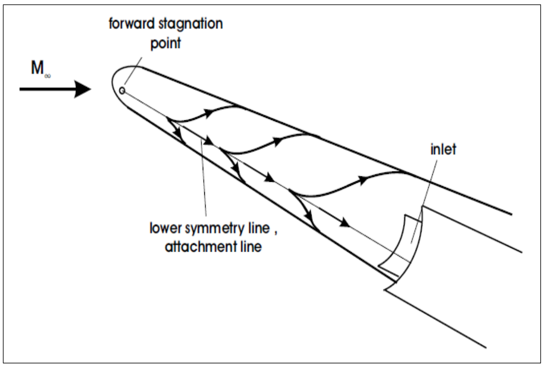

Figure 14: Schematic Diagram of Line of Skin Friction Pattern of Conical Hypersonic Vehicle Forebody with Positive α.

The flat lower portion of a hypersonic vehicle forebody issues the 2D onset flow at first ramp structure of the engine inlet. Between those attachment and lower symmetry lines as shown in figure 15, which means a definite limitation for the flow over the structure? Yet, an alteration in angle of attack will change the pre-compression.

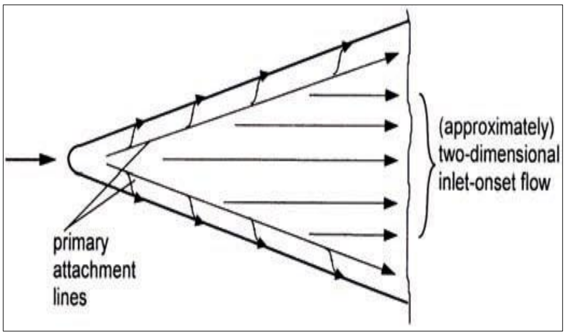

Figure 15: Schematic Represents the Skin Friction Pattern at Bottom Side of the Flat Vehicle Forebody.

During German Hypersonic Technology Programme [GHTP], the details of hypersonic vehicle forebody configurations are studied [13, 14]. Blunt, pointed or narrow vehicle forebody structure with the some structure of concave bottom side cross sectional are noted for getting good inlet of engine and the hypersonic vehicle parallel axis motion and its aerodynamic parameters and its performance needs.

FOREBODY PRE-COMPRESSION

Principle

Generalization for pre-compression developed on a vehicle forebody structure with the flat bottom side can be easily described, irrespective of vehicle forebody structure which has a pointed blunt or broad nose. Bottom side of hypersonic vehicle forebody is always inclined with angle θ to flow free-stream. Angle of inclination is given by $\theta = \theta_0 + \alpha$

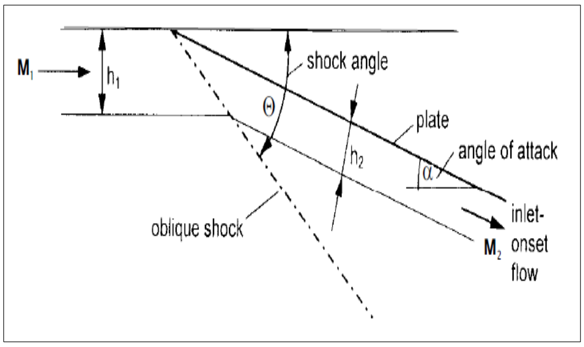

Figure 16: Schematic Diagram of Stream-tube Compression at α.

Considering $\alpha \approx \theta$, the figure 16 represents that the resultant stream tube contraction which regulates the cross sectional area of the propulsion system.

The SANGER hypersonic aircraft with scramjet engine system is represented in figure 17. By considering the primary modifications of flow parametric quantities, aerodynamic performance parameters and net thrust, modifications of $\Delta\theta$ in the hypersonic vehicle forebody structure, the pre-compression can be increased.

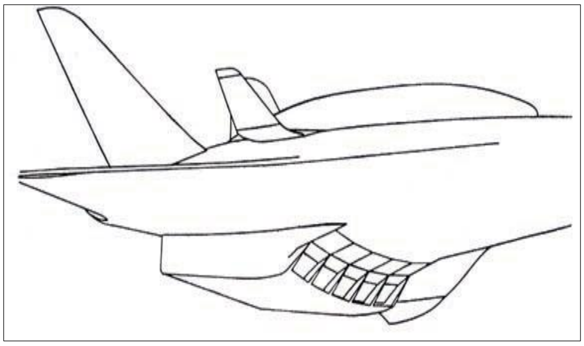

Figure 17: The Thrust Power Scramjet Engine System of Hypersonic Aircrafts [8].

Engine Inlet Ramp Flow

Needed pre-compression with Mach of turbojet and ramjet engines combustion chamber of aircraft Mach, were in the order of $0.4<M<0.6$, whereas the Mach of scramjet engines combustion chamber were in the range of $2<M<3$. The retardation of hypersonic vehicle velocity of freestream is either full or partly these Mach numbers earned by assist of the shock waves [2].

The rate of flow and its simulation difficulties are involved in a practical three ramp structure inlet design [22, 23] as represented in figure 18 [21]. The three ramps design of the inlet has different angles. Figure 18 displaysa pressure failure that can be seen in lower location of forebody. P_0 refers to free stream total pressure, and P_p represents to pilot pressure.

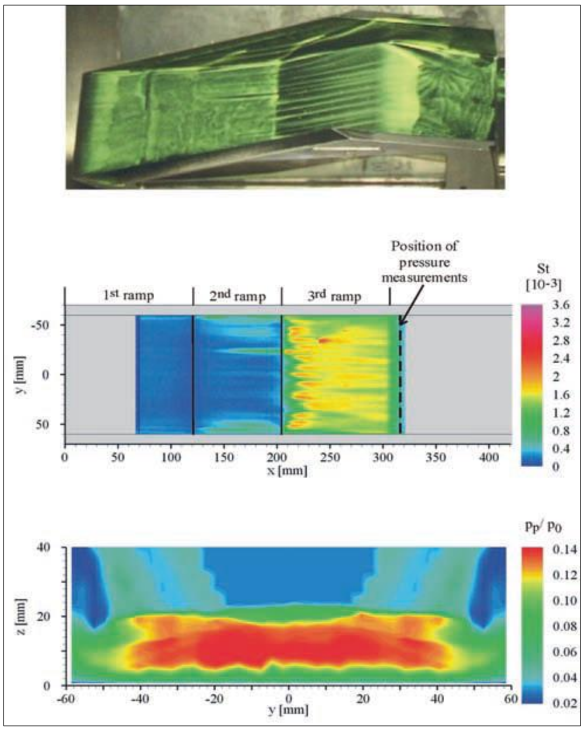

Figure 18: Three Ramp Inlet Structure Flow Configuration and Flow Visualization [21].

CONCLUSIONS

In summary, the article explains about the problem of aerodynamics and propulsion system involved in hypersonic cruise and acceleration vehicle. In order to overcome the above said problem, a forebody configuration, which will integrate the propulsion and aerodynamic system together is reviewed in the article. The various types of forebody, forebody configuration with ramps and their contribution to integrated structure and propulsion system are also discussed in this article. As a future work, analysis will be carried out with various ramp types, which includes change of ramp angle, change of ramp length, adding or subtracting the ramps.

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