HYPERSONIC GLIDE VEHICLE

AIRCRAFT DESIGN PROJECT REPORT

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(Under Section 3 of UGC Act, 1956)

BONAFIDE CERTIFICATE

Certified that this project report titled **"Hypersonic Glide Vehicle"** is the Bonafide work of "**Namya Padasala, Krisha Kotian, Riddhi Joshi, Dharani Pavanan",** who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form any other project report or dissertation based on which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

This project focuses on the design and performance analysis of a Hypersonic Glide Vehicle (HGV) for atmospheric re-entry and descent missions. Key aerodynamic parameters, including airfoil and wing design, were optimized to enhance stability and performance during hypersonic flight. The NACA 4 series airfoil was selected for its low pitching moment and stability at high speeds, while the wing design ensures efficient lift generation and drag minimization.

The SOYUZ-2 rocket was chosen based on its payload capacity and performance characteristics. Performance analysis during re-entry, glide, and landing phases was conducted to optimize lift-to-drag ratios and glide angles for efficient descent. Stability considerations, including center of gravity calculations, are vital for designing the tail and fuselage.

Aerodynamic control surfaces, such as elevons and body flaps, were analyzed for maneuvering during glide, with fuel validation focusing on the reliance on aerodynamic forces rather than engine thrust. The project highlights a design approach that balances aerodynamic efficiency, stability, and thermal protection for future atmospheric re-entry and descent missions.

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1. INTRODUCTION

Hypersonic Glide Vehicles (HGVs) represent a new frontier in aerospace technology, offering the potential for high-speed, long-range, and efficient atmospheric re-entry capabilities. HGVs are designed to glide through the Earth's atmosphere at hypersonic speeds, utilizing aerodynamic forces for maneuvering and control rather than relying on conventional propulsion systems. These vehicles are critical for applications ranging from space exploration and planetary re-entry to military reconnaissance and weapon systems.

The main objective of this project is to design and optimize the key elements of a Hypersonic Glide Vehicle (HGV), focusing on its aerodynamics, performance during atmospheric re-entry, and the selection of suitable propulsion systems. The design process integrates detailed analyses of aerodynamic parameters, including airfoil and wing characteristics, to ensure the vehicle can maintain stability and maneuverability under extreme conditions. The selected airfoil, NACA 0012, is ideal for hypersonic speeds due to its symmetric shape, which ensures minimal pitching moments and maintains a stable glide.

An essential part of the design involves the selection of an optimal wing configuration, as this directly influences the vehicle's lift, drag, and overall stability during flight. The wing geometry is carefully chosen to maximize aerodynamic efficiency, balancing high lift-to-drag ratios with stable glide performance. The choice of the SOYUZ-2 rocket as the propulsion system is based on its payload capacity and thrust-to-weight ratios, making it a suitable candidate for launching the spacecraft (HGV) into the desired trajectory.

The HGV's performance is analyzed during three key phases of atmospheric flight: re-entry, glide, and landing. Each phase requires different aerodynamic considerations, including lift and drag optimization, as well as effective control surfaces to manage the vehicle's orientation and stability. Throughout these phases, the vehicle's aerodynamic design ensures it can achieve controlled descent and smooth landing, minimized thermal stress and maximized safety.

A significant challenge in this project is the accurate estimation of the lift and drag forces, which are crucial for determining the vehicle's glide path and descent angle. These forces are influenced by various factors such as the vehicle's velocity, atmospheric conditions, and the angle of attack, which is carefully controlled to maintain stability and reduce drag.

In addition to aerodynamic analysis, the project emphasizes the importance of stability calculations and the design of the vehicle's tail and control surfaces. These components play a vital role in maintaining the vehicle's trajectory and ensuring it remains controllable during its high-speed glide. The analysis also includes considerations for the center of gravity (CG), which must be accurately determined to ensure that the tail and fuselage are appropriately sized.

Overall, this project aims to provide a comprehensive design for a Hypersonic Glide Vehicle that can efficiently navigate the Earth's atmosphere during re-entry, glide smoothly to its designated landing site, and ensure the safe delivery of its payload. Through careful selection of aerodynamic parameters, propulsion systems, and control surfaces, the project seeks to optimize the vehicle's performance and stability while accounting for the unique challenges posed by hypersonic flight.

2. METHODOLOGY

The design and analysis of the Hypersonic Glide Vehicle (HGV) involves several stages, each of which integrates various engineering principles, computational tools, and analytical methods to achieve a robust and efficient design. This section outlines the methodology used to develop the HGV, focusing on key aspects such as aerodynamic analysis, performance estimation, and propulsion system selection. The following steps describe the approach taken:

2. 1. Litrature survey:-

2.1.1. lists of HGVs considered :-

- **Space craft lander:-**

  i. Space Shuttle :-
     1. Enterprise
     2. Columbia
     3. Challenger
     4. Discovery
     5. Atlantis

  ii. Buran

  iii. X-37B

  iv. Drea
  m Chaser

  v. Space
  Rider

  vi. Starship

- **Hyper-sonic Glide missile :-**

  i. Avangard

  ii. DF-ZF

  iii. HTV-2

  iv. C-HGB

  v. Lockheed D-21

  vi. Yu-71

  vii. HSTDV

  viii. X-15

  ix. Tupolev Tu-2000

2.1.2. Multiple of same Space Shuttle model :-

The data collected from the space shuttle has been averaged as all 5 space Shuttle models as they showed similar trends in their properties. The average of 5 different Space Shuttle models are considered as Space Shuttle in later use.

Orbiter	Wing Type	Chord	Span	Aspect Ratio	Taper Ratio	Sweep Angle
Enterprise	Delta	10 m	23.79 m	2.4	0.15	81°
Columbia	Delta	10 m	23.79 m	2.4	0.15	81°
Challenger	Delta	10 m	23.79 m	2.4	0.15	81°
Discovery	Delta	10 m	23.79 m	2.4	0.15	81°
Atlantis	Delta	10 m	23.79 m	2.4	0.15	81°

Table 2.1.1:- Different Space shuttle configurations

Orbiter	Wing Angle	Mach No	Altitude (km)	Length	Dry Mass (kg)
Enterprise	15°	25	200–650	37.24 m	68,000
Columbia	15°	25	200–650	37.24 m	68,585
Challenger	15°	25	200–650	37.24 m	68,000
Discovery	15°	25	200–650	37.24 m	68,000
Atlantis	15°	25	200–650	37.24 m	68,000

2.1.3. Starship:-

Starship is not considered majorly for this survey as it is not a glider with wings but a rocket which uses its rocket engine to manoeuvre and control using small fins.

2.1.4. Missing Data:-

Most of the data was available but some of it was classified or not available for public view, due to this reason there is Data missing in the Table 2.1.2.

(exception:- starship which does not have the wing data as it does not possess a wing)

2.1.5. Data not applicable to HGVs :-

1. Maximum Mach Number: During re-entry, the maximum Mach number for a spacecraft is 25.
2. Rate of Climb and Cruise Speed: Not applicable for most hypersonic vehicles as they primarily glide.
3. Thrust and Propellant Mass: Not explicitly mentioned as these vehicles rely on initialization speeds provided by boosters or launch vehicles.

2.1.6. Parameters :-

a) Aspect Ratio:- In aircraft design, aspect ratio is the ratio of the wingspan to the mean chord length, representing the slenderness of the wing and its aerodynamic efficiency

b) Length:- Length refers to the distance from the nose (front) to the tail (rear) of the aircraft, typically measured along its longitudinal axis.

c) Height:- Height refers to the vertical distance from the lowest point of the aircraft (such as the bottom of the wheels) to the highest point (such as the top of the tail or fin) when the aircraft is on the ground.

d) Service Ceiling:- The service ceiling of an aircraft is the maximum altitude at which it can sustain a specified minimum rate of climb, typically 100 feet per minute, under standard atmospheric conditions.

e) Span:- span refers to the total distance from one wingtip to the other, measured along the wingspan.

f) Sweep Angle:- The sweep angle of an aircraft wing is the angle between the wing's quarter-chord line (or leading edge) and a line perpendicular to the aircraft's longitudinal axis, affecting aerodynamic performance at high speeds.

g) Chord:- Chord refers to the straight-line distance between the leading edge and the trailing edge of the wing, measured along the wing's cross section. Mach Number:- Mach number is the ratio of an object's speed to the speed of sound in the surrounding medium, indicating whether the object is traveling at subsonic, transonic, supersonic, or hypersonic speeds.

h) Dry Mass (kg):- Dry mass refers to the mass of an object or vehicle, such as an aircraft or spacecraft, excluding any fuel, water, or other consumables. It represents the mass of the structure and equipment alone.

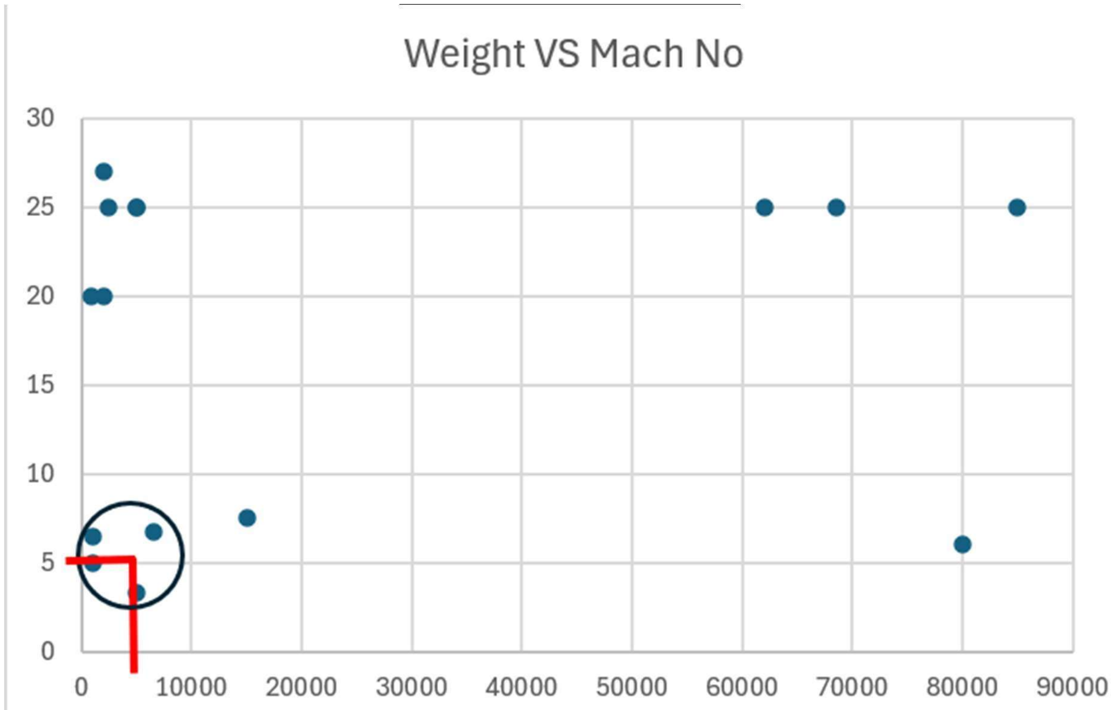
Vehicle	Aspect Ratio	Length	Height	Service Ceiling	Span	Sweep Angle	Root Chord	Tip Chord
Space Shuttle	2.4	37.24 m	17.27 m	304 Km	23.79 m	45°	10 m	1.5 m
Buran	2.5	36.37 m	16.35 m	306 Km	23.92 m	45°	10 m	2.0 m
X-37B	1.5	8.92 m	2.90 m	800 Km	4.55 m	35°	2 m	0.5 m
Dream Chaser	2.0	9 m	2.2 m	400 Km	7 m	40°	3 m	1.0 m
Space Rider	1.0	4.5 m	2.2 m	400 Km	4.5 m	45°	1 m	0.8 m
Starship		50 m	9 m	700 Km				
Avangar d	1.5	5.4 m	2 m	100 Km	4 m	60°	2 m	1.0 m
DF-ZF	2.0	6 m	2.5 m	100 Km	5 m	55°	3 m	1.5 m
HTV-2	1.2	5.4 m	2 m	60 Km	4 m	65°	2 m	1.0 m
C-HGB	2.0	6 m	2.5 m	80 Km	5 m	60°	2.5 m	1.2 m
Lockhee d D-21		13.06 m	2.1 m	29 Km	5.8 m		13.06 m	0
Yu-71	2.0	6 m	2.5 m	100 Km	5 m	60°	2.5 m	1.2 m
HSTDV	1.5	5.4 m	2 m	60 Km	4 m	55°	2 m	1.0 m
X-15		15.24 m	4.12 m	108 Km	6.8 m			
Tupolev Tu-2000		46 m	13 m	30 Km	28 m	70°		

Table 2.1.2:- parameters for HGVs							
Vehicle	Wing Area (m^2)	Mach No	Cruise Speed (Km/h)	Range	Altitude (km)	Dry Mass (kg)	Engine
Space Shuttle	136.7925	25			200–650	68,000	3 × RS-25 SSME
Buran	143.52	25			200–650	62,000	4 × RD-0120
X-37B	5.6875	25			200–500	4,990	AR2-3 engine (hydrogen peroxide/JP-8)
Dream Chaser	14	25			400.00	5,000	
Space Rider	4.05	25			400.00	2,500	
Starship		25			200–700	85,000	6 × Raptor engines
Avangard	6	20	11,000	18,000 Km	50–100	2,000	R-37M2
DF-ZF	11.25	7.5	10,000		50–100	15,000	DF-17
HTV-2	6	20			30–60	900	
C-HGB	9.25	5			40–80	1,000	
Lockheed D-21	37.874	3.3	4,062	5,600 Km		4,990	1 × Marquardt RJ43-MA-20S4 ramjet
Yu-71	9.25	27			50–100	2,000	
HSTDV	6	6.5	8,026		40–60	1,000	
X-15	19	6.7	7,270	450 Km		6,622	1 × Reaction Motors XLR99-RM-2

Tupolev Tu-2000		6	2,700	10,000 Km		80,000	2 × turbofan, 2 × scramjet

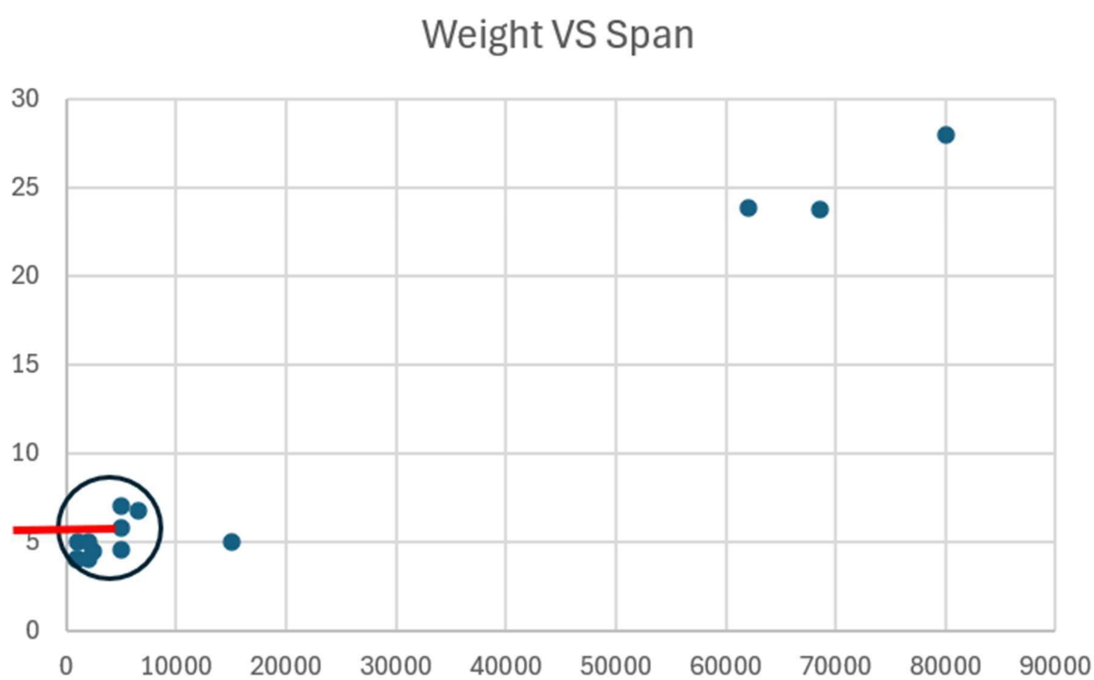
2.1.7. Plots for average parameters

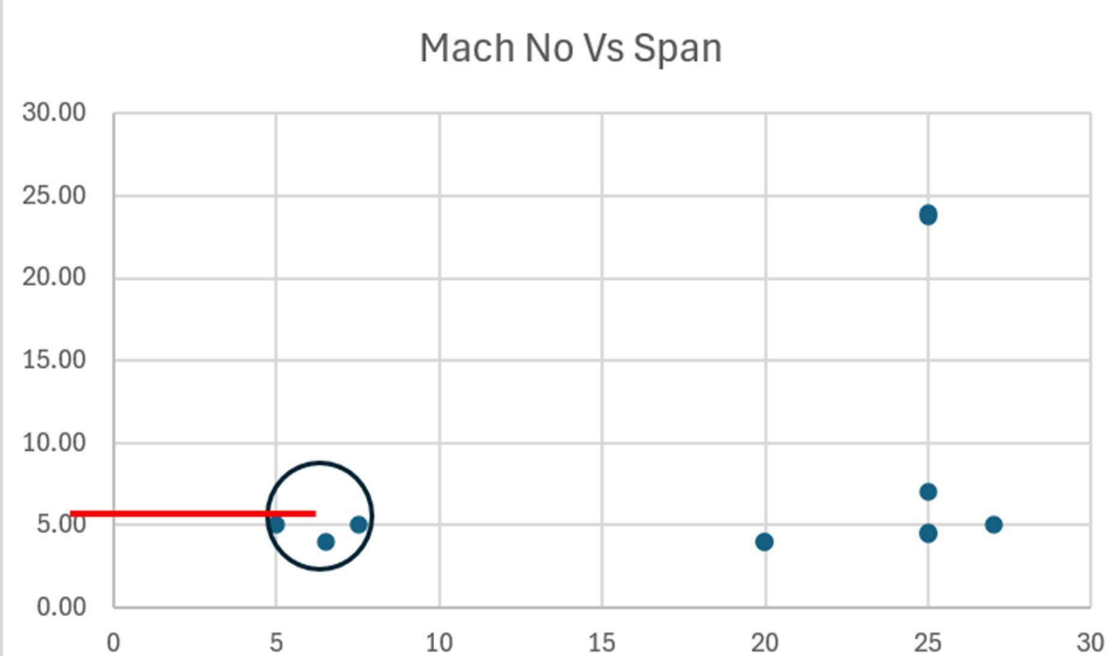
2.1.7.1. Weight Vs Mach No.



2.1.7.2 a. Weight Vs Span

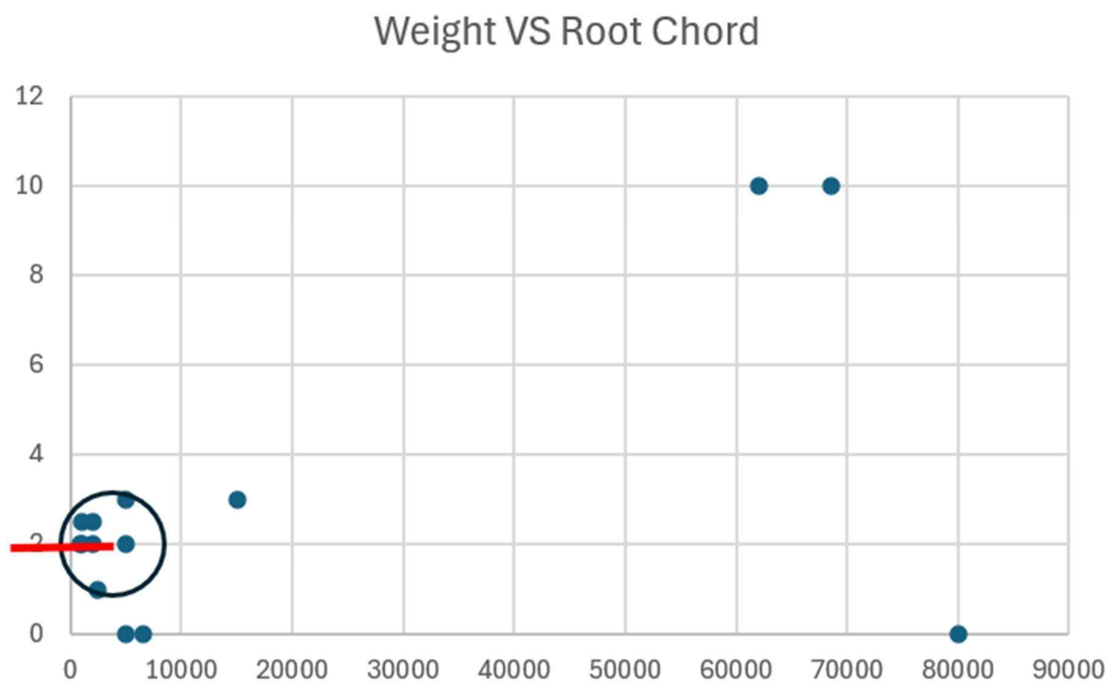
b. Mach No. Vs Span

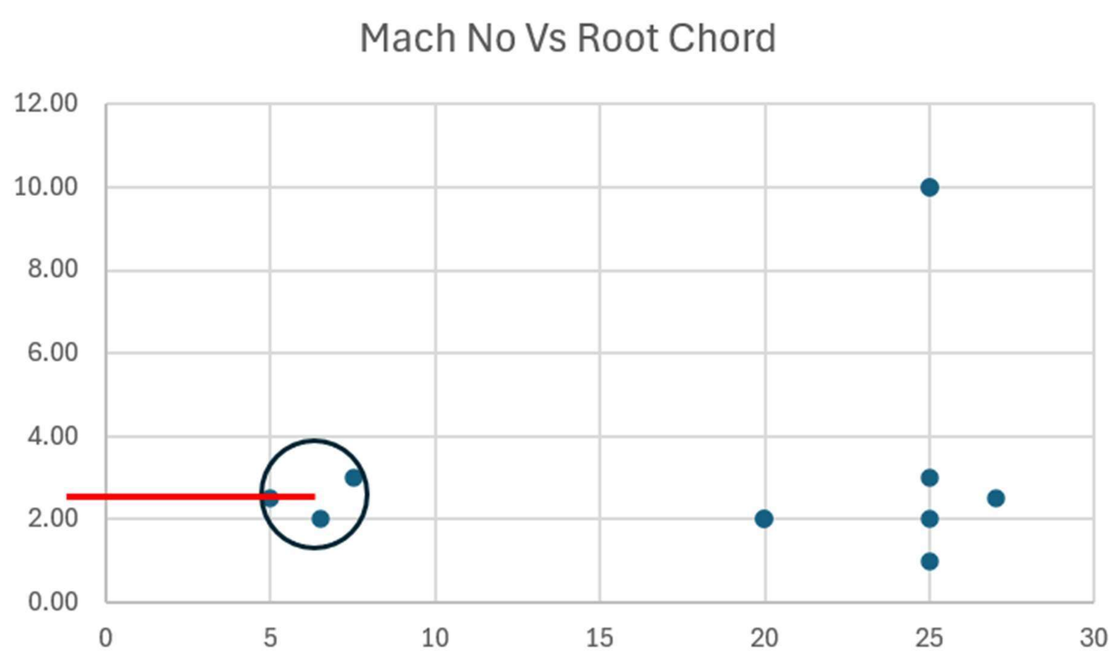




2.1.7.3 a. Weight Vs Root Chord

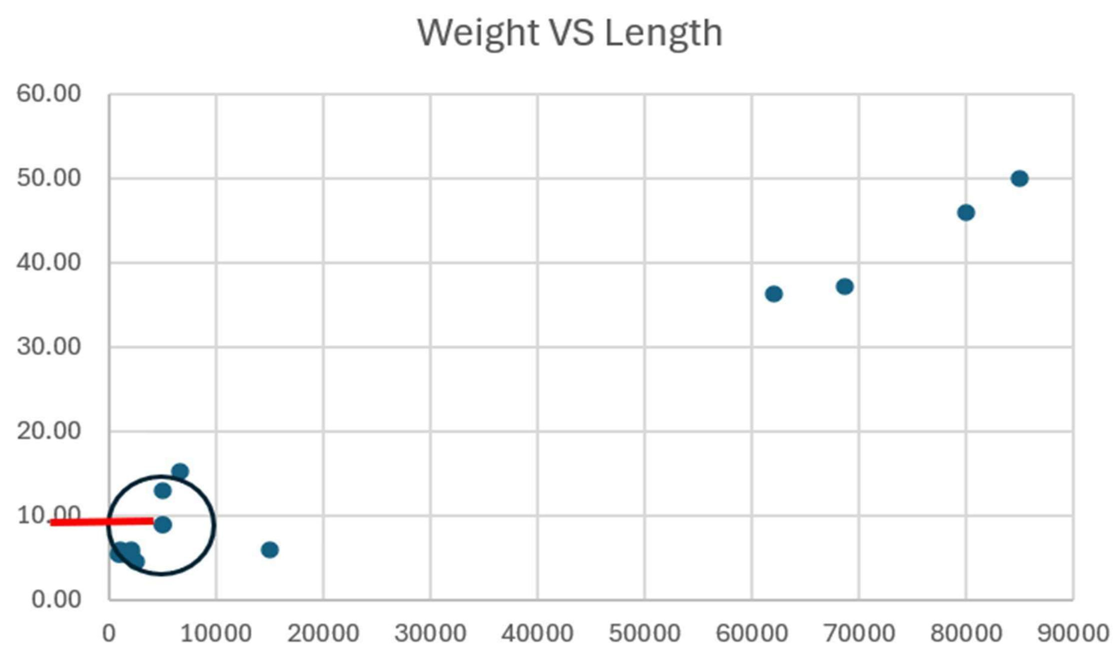
b. Mach No. Vs Root Chord

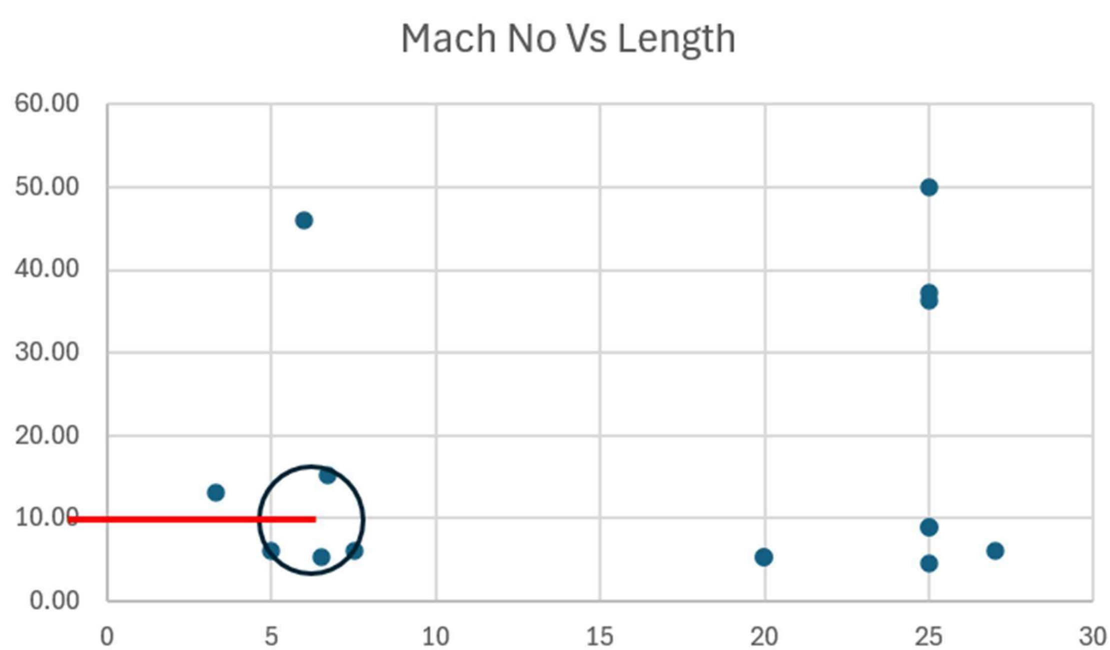




2.1.7.4 a. Weight Vs Length

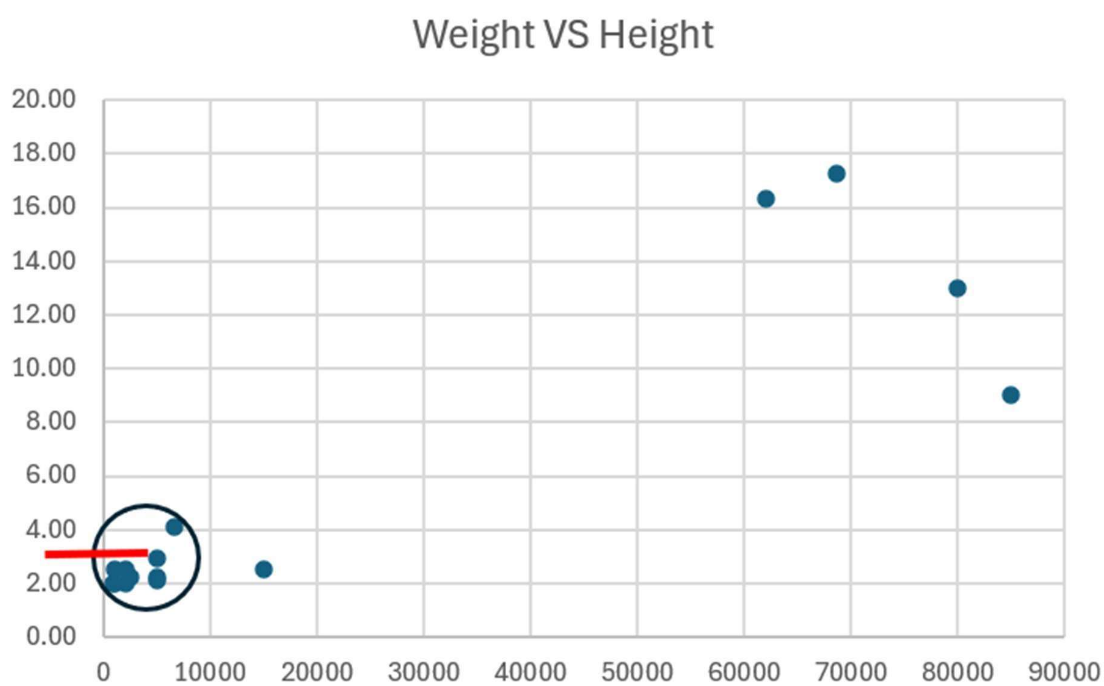
b. Mach No. Vs Length

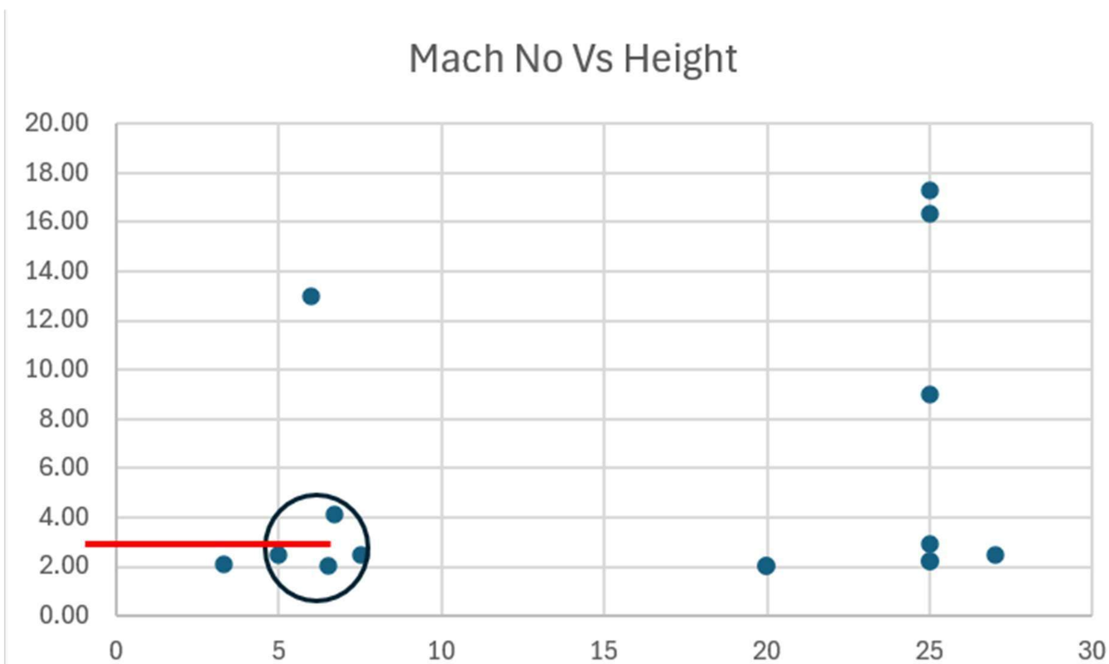




2.1.7.5a. Weight Vs Height

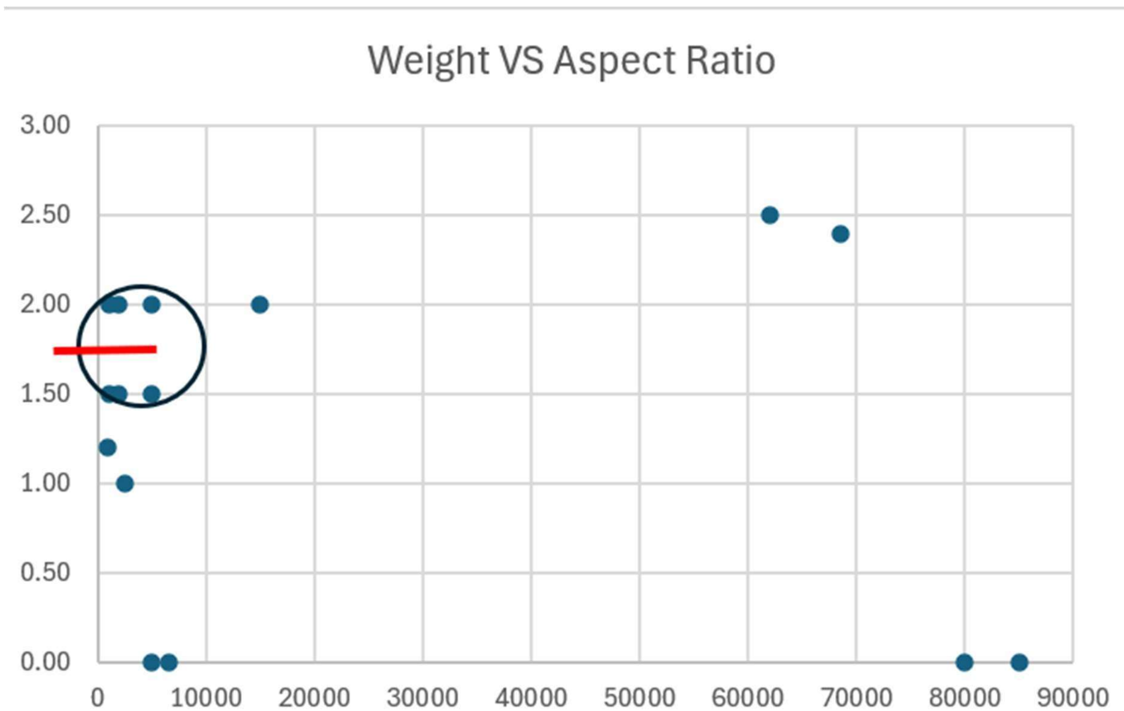
b. Mach No. Vs Height





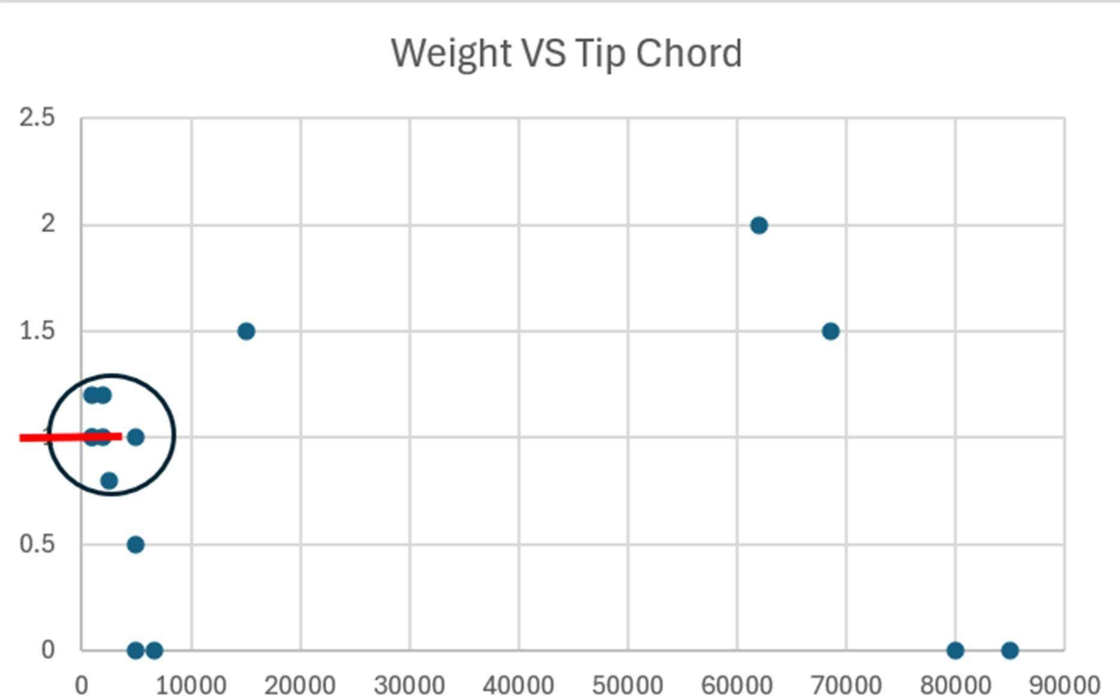
2.1.7.6 a. Weight Vs Aspect Ratio

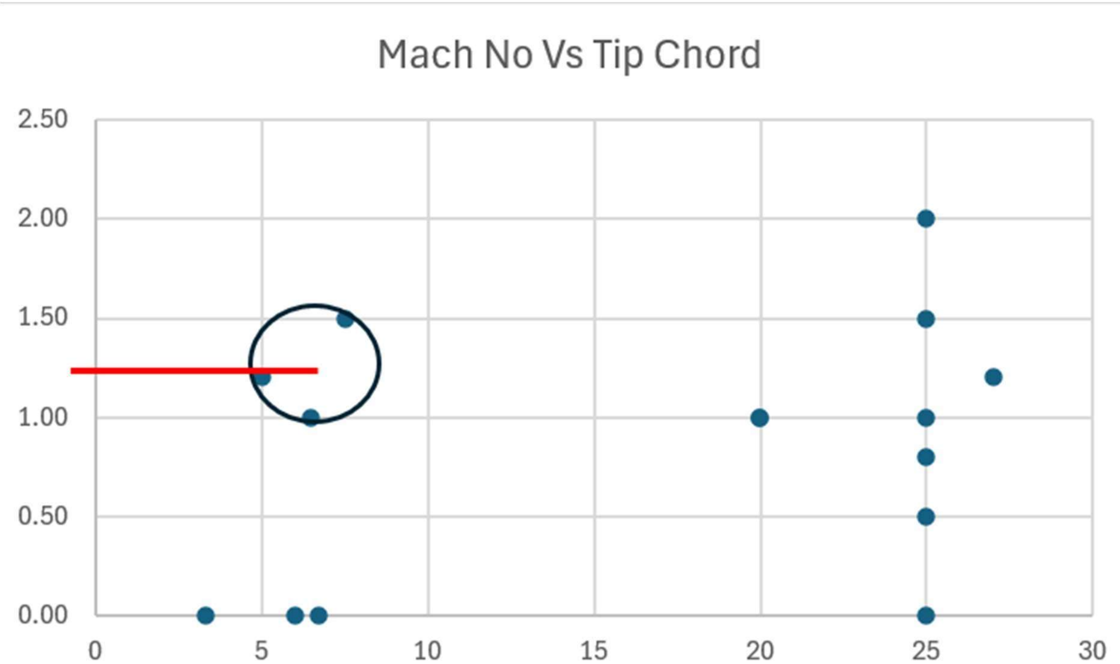
b. Mach No. Vs Aspect Ratio



2.1.7.7 a. Weight Vs Tip Chord

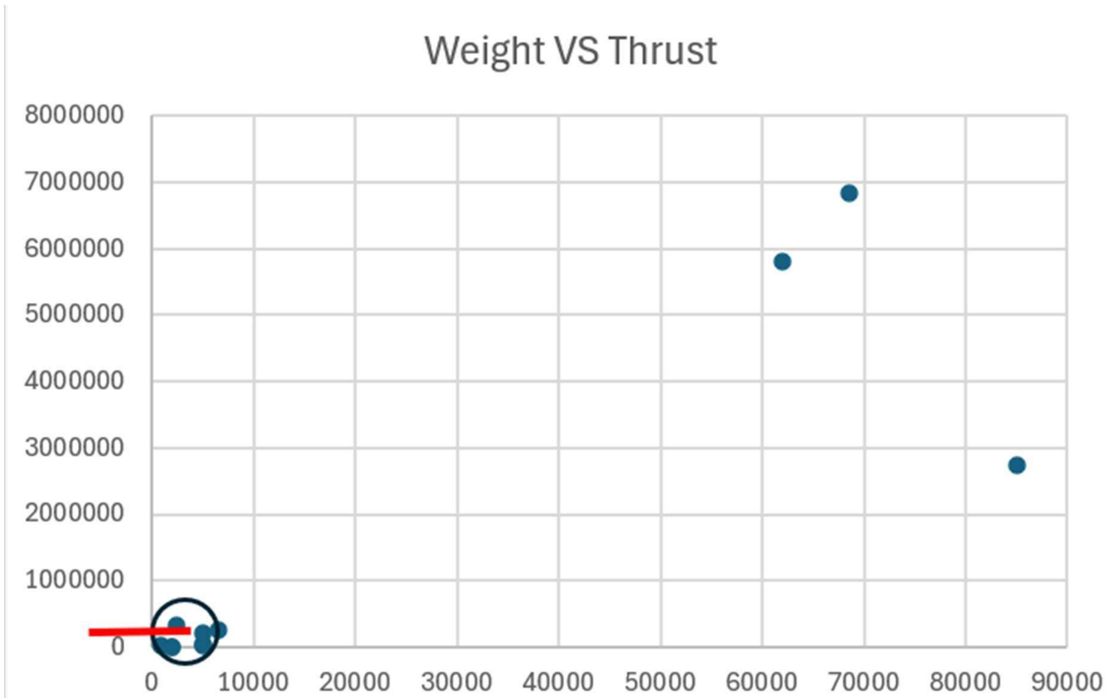
b. Mach No. Vs Tip Chord

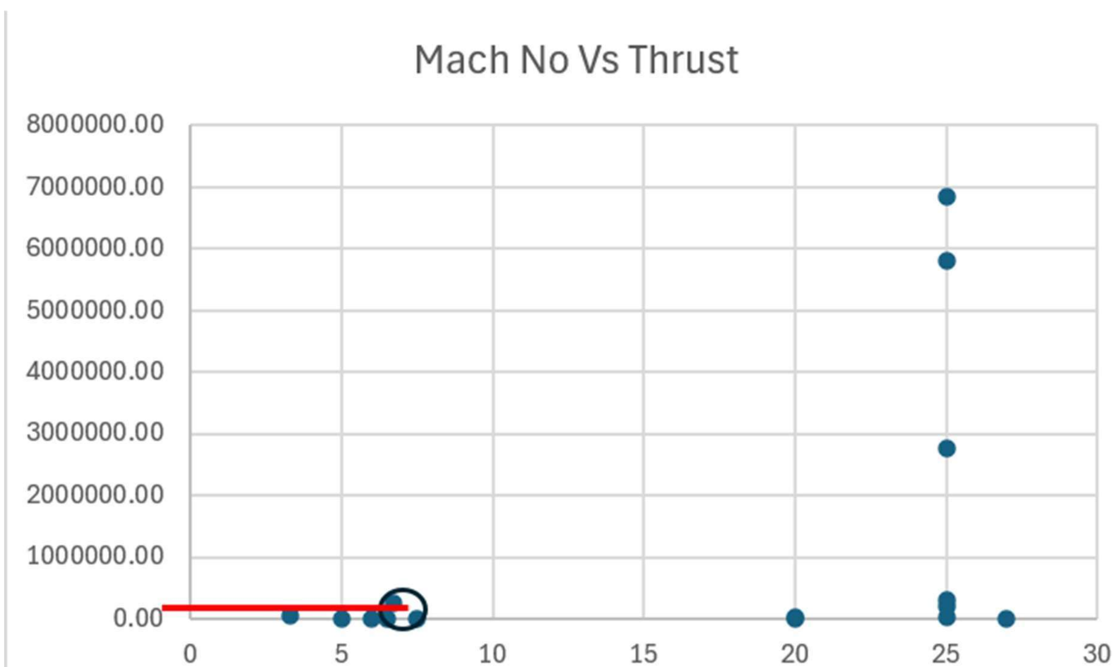




2.1.7.8 a. Weight Vs Thrust

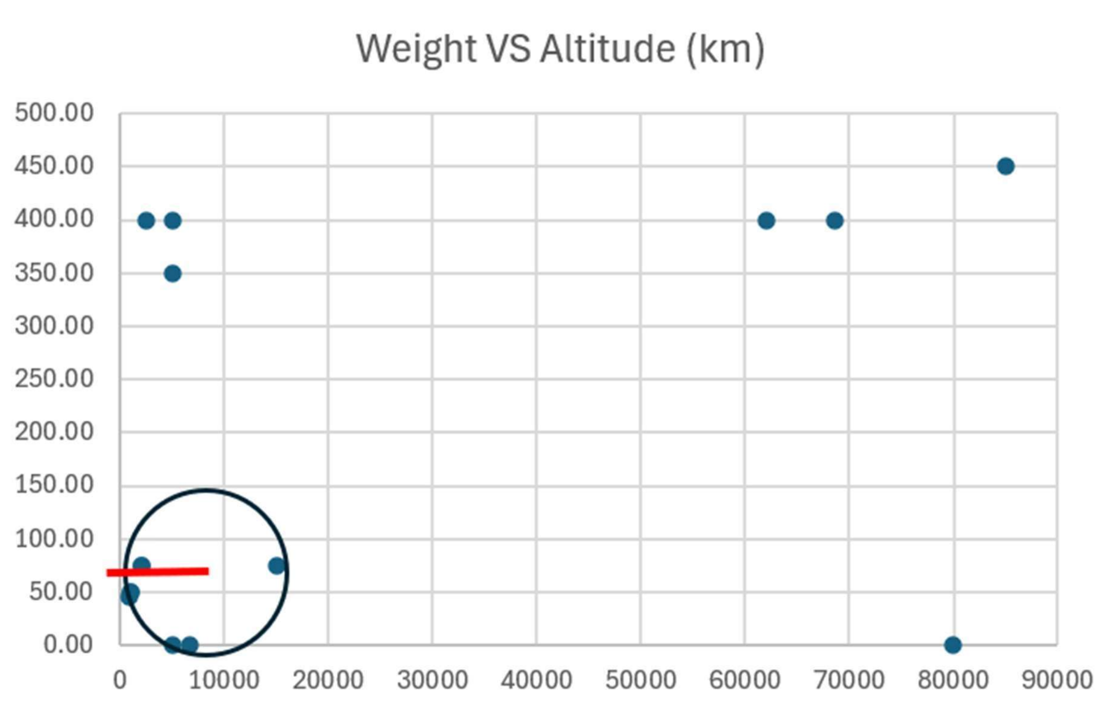
b. Mach No. Vs Thrust

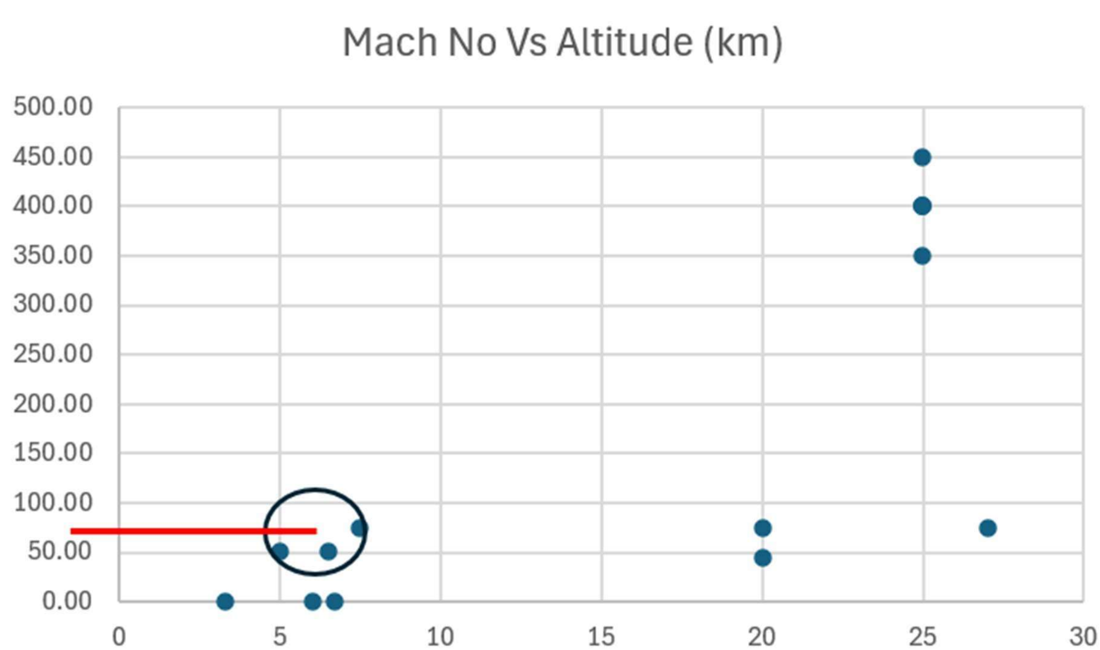




2.1.7.9 a. Weight Vs Altitude

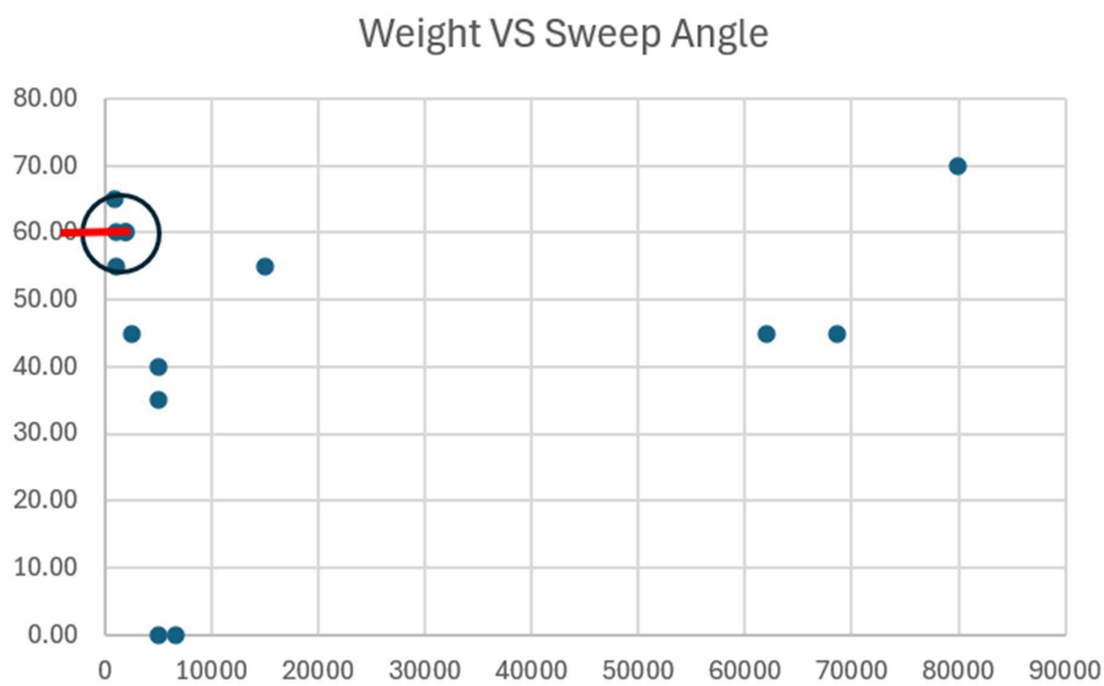
b. Mach No. Vs Altitude

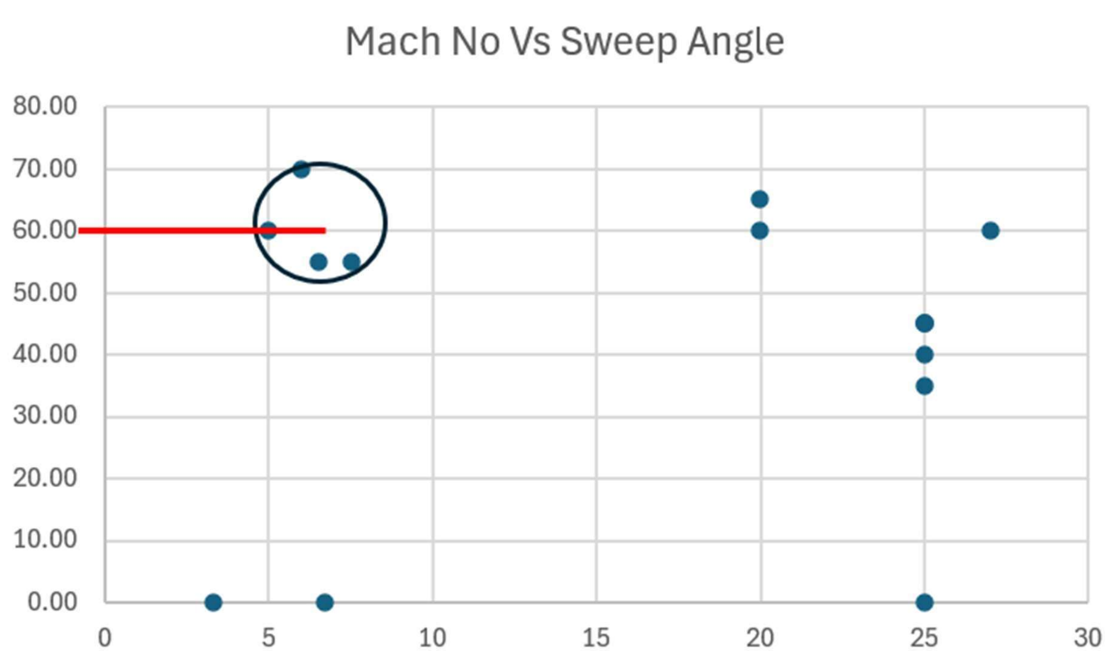




2.1.7.10 a. Weight Vs Sweep Angle

b. Mach No. Vs Sweep Angle





2.1.8 Wing Area

Wing area is product of average chord and wing span. We can find the average chord by averaging tip chord and root chord.

2.1.9 Extracted data set from the Plots

Wing Area:-

VS Weight

$6 * (2+1)/2 = 9$ m^2

Vs Mach no

$6 * (2.25 + 1.25)/2 = 10.5$ m^2

Parameter	Weight	Mach.no
Vs	5000Kg	5
WingArea	9 m^2	10.5 m^2
Wingspan	6 m	6 m
Chord	2 m	2.25 m
Length	10 m	10 m
Height	3 m	3 m
Aspect Ratio	1.75	1.75
Tip Chord	1 m	1.25 m
Thrust	250000N	
Altitude	75Km	75Km
Sweep	60	60

Table 2.1.3:-Parameter vs Weight and parameter vs Mach. no

2.2. Weight estimation

Weight estimation is a critical component in the preliminary design phase of any aerospace vehicle, including hypersonic glide vehicles (HGVs). The goal is to predict the take-off gross weight, empty weight, and the payload weight to ensure feasibility of the design from structural, propulsion, and performance perspectives.

Base values from assignment 2

Parameter	Weight	Mach.no
Vs	5000Kg	5
Wing Area	9 m^2	10.5 m^2
Wingspan	6 m	6 m
Chord	2 m	2.25 m
Length	10 m	10 m
Height	3 m	3 m
Aspect Ratio	1.75	1.75
Tip Chord	1 m	1.25 m
Thrust	250000N	
Altitude	75Km	75Km
Sweep	60	60

Table 2.2.1: - Extracted data from the Plots

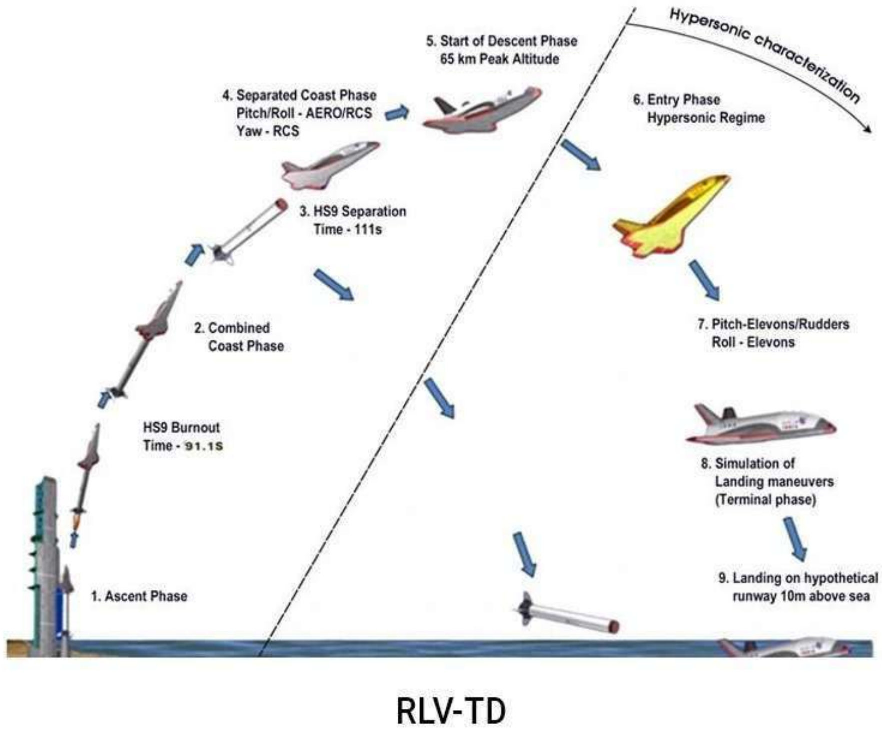


Fig 2.2.1:- Mission profile (6. To 9.)

For HGV we consider there to be no fuel systems after re-entry phase, and we consider the mission profile from re-entry phase, containing (re-entry phase, glide phase, landing phase) (Here we consider HGV from Step 6 to Step 9).

2.2.1 Weight estimation formula :-

- Wo = W.crew + W.payload + W.fuel + W.empty
- W.fuel = 0
- Wo = W.crew + W.payload + W.empty
- Wo – (W.empty * Wo/Wo) = W.crew + W.payload
- Wo (1 - W.empty/Wo) = W.crew + W.payload
- Wo = (W.crew + W.payload) / (1 - W.empty/Wo)
- Wo= (Wc + Wp)/(1 – We/Wo)

Empty Weight Fraction vs W 0

- We/ Wo = A W^c Kvs

As we have fixed sweep Kvs = 0

For HGVs Typical values for A and C

Vehicle Type	Example(s)	W0 (kg)	We/W0	A	C
Orbital Spaceplane (Large, Expendable Fuel Tank)	Space Shuttle Orbiter	99,000	0.05	0.25	-0.25
Small Orbital Spaceplane (Reusable, No Fuel Tank)	Dream Chaser	9,000	0.44–0.53	0.4	-0.18
Autonomous Military Spaceplane	X-37B	4,990	0.60	0.45	-0.14
Mini Orbital Spaceplane	ESA Space Rider	2,500	0.73	0.5	-0.11
Hypersonic Glide Vehicle (HGV, Boost- Glide, No Fuel)	Avangard	2,000	0.6–0.85	0.55	-0.08

Table 2.2.2:- Empty Weight Fraction vs W

For Our case we will be going with the value of

- A = 0.65
- C = -0.1

For weight estimation (parameters)

(L/D)max	5
Payload weight	2500 Kg
Crew	2
Crew weight	180

Table 2.2.3:- Weight estimation (parameters)

2.2.2 Weight estimation

Wo Estimated (kg)	Wc (kg)	Wp (kg)	We (kg)	We/Wo	Wo-calculated (kg)
1500	180	2500	676.3945	0.45093	4880.977
1600	180	2500	719.163	0.449477	4868.097
1700	180	2500	761.798	0.448116	4856.097
1800	180	2500	804.3077	0.446838	4844.87
1900	180	2500	846.6994	0.445631	4834.328
2000	180	2500	888.9797	0.44449	4824.394
2100	180	2500	931.1544	0.443407	4815.007
2200	180	2500	973.2287	0.442377	4806.112
2300	180	2500	1015.207	0.441395	4797.662
2400	180	2500	1057.095	0.440456	4789.617
2500	180	2500	1098.895	0.439558	4781.941
2600	180	2500	1140.612	0.438697	4774.605
2700	180	2500	1182.249	0.43787	4767.58
2800	180	2500	1223.809	0.437074	4760.843

2900	180	2500	1265.294	0.436308	4754.372
3000	180	2500	1306.708	0.435569	4748.147

Table 2.2.4:- Weight estimation (Iterations)

Calc example :-

Wo Estimated = 1500 kg

We/Wo = 0.65 * 1500^-0.1 = 0.45093

We = (We/Wo) * Wo = 676.39 Kg

Wo Calculated = (180 + 2500) / (1 – 0.45093) = 4880.977

2.2.3 Reference value for Sizing

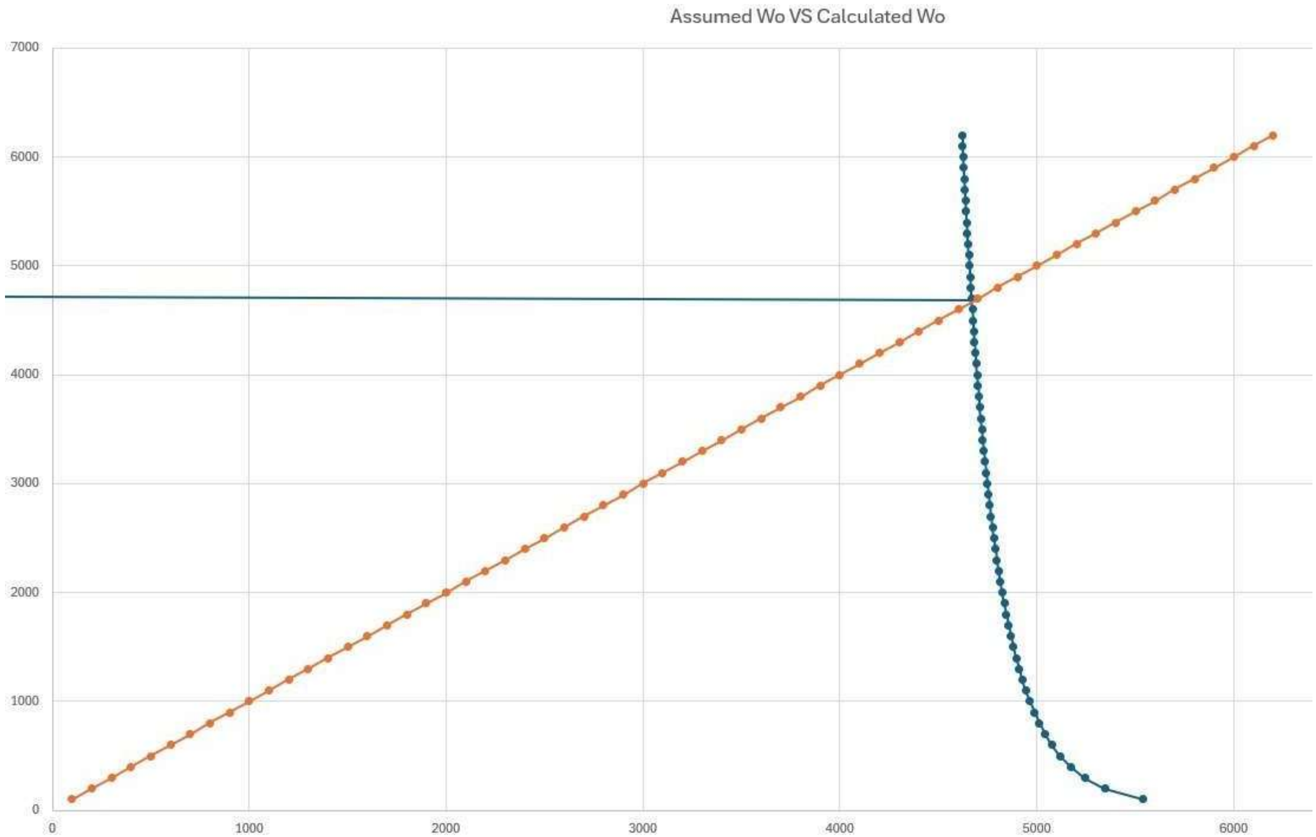


Fig 2.2.2:- Wo Assumed Vs Wo Calculated

Wo = 4670 Kg

Wo	4670 Kg
We	1990 Kg
Wc	180 Kg
Wp	2500 Kg

Table 2.2.5:Weight parameters

2.3 Airfoil Selection

As part of the aerodynamic design methodology, the selection of a suitable airfoil is essential to ensure the HGV achieves stable and efficient glide characteristics during atmospheric re-entry and descent. In this project, the NACA 0012 symmetric airfoil was selected based on its favorable performance under high-speed and hypersonic conditions.

This airfoil was chosen due to the following considerations:

- Symmetric Profile: The symmetric shape ensures zero pitching moment at zero angle of attack, which is advantageous for maintaining controlled glide and stable re-entry orientation.
- High-Speed Suitability: The NACA 0012 performs effectively under high Reynolds number flow, typical during hypersonic re-entry, while providing sufficient lift and maintaining low drag.
- Well-Documented Characteristics: Its extensive documentation and availability of aerodynamic data simplify modeling and integration into simulation tools like XFLR5.
- Balanced Lift-to-Drag Ratio: The airfoil offers a good balance of lift and drag, critical for optimizing the glide path and energy management during descent.
- Structural Simplicity: Its moderate thickness and lack of camber aid in easier structural design and manufacturing, which is suitable for re-entry vehicles that undergo high thermal and pressure loads.

2.3.1 AIRFOILS USED

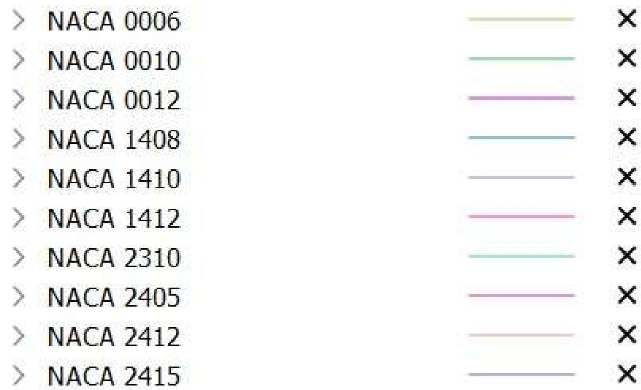


Fig 2.3.1: NACA 0006

Fig 2.3.2: NACA 0010

Fig 2.3.3: NACA 0012

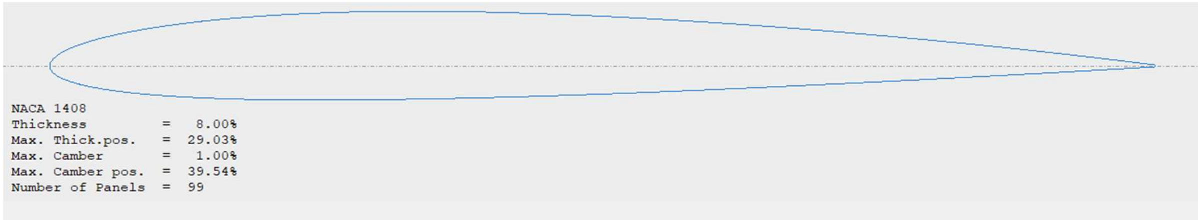


Fig 2.3.4: NACA 1408

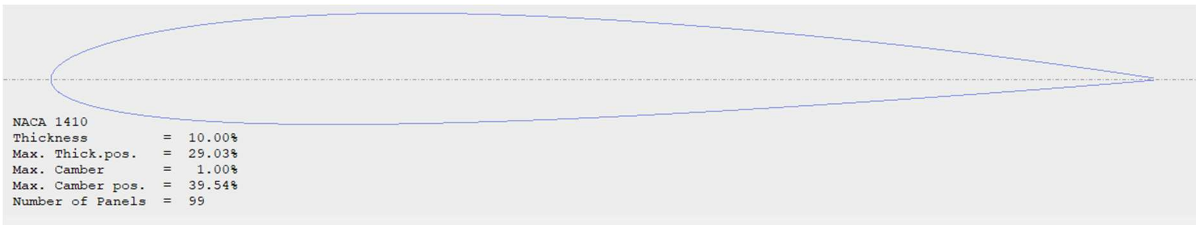


Fig 2.3.5: NACA 1410

Fig 2.3.6: NACA 1412

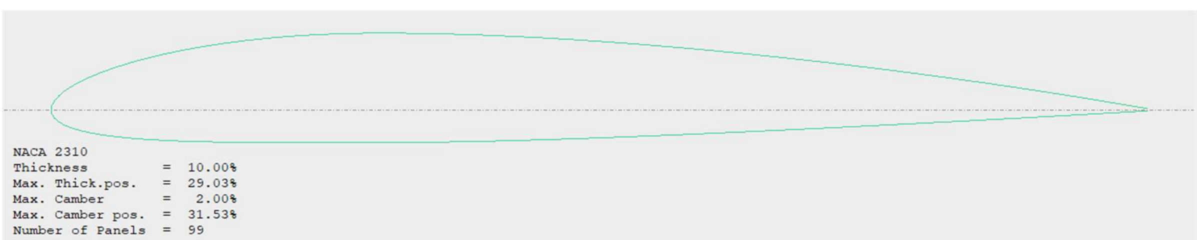


Fig 2.3.7: NACA 2310

Fig 2.3.8: NACA 2405

Fig 2.3.9: NACA 2412

Fig 2.3.10: NACA 2415

2.3.2 GRAPHS USED

2.3.2.1 Cl VS Cd graph

Determining Aerodynamic Efficiency (L/D Ratio) – Higher Cl/Cd means better efficiency, crucial for range and glide performance.
Finding Optimal Cruise Condition – Aircraft operate where Cl/Cd is maximized to minimize drag.
Airfoil Selection – Helps choose airfoils with the best lift and lowest drag for a given mission.
Stall Behavior Analysis – Identifies stall characteristics for stable flight.
Comparing Airfoils – Evaluates different airfoil shapes and their efficiency.

For hypersonic glide vehicle (HGV):

- Minimizing drag for efficient glide.
- Optimizing L/D at high Mach numbers.
- Ensuring smooth control without abrupt stall

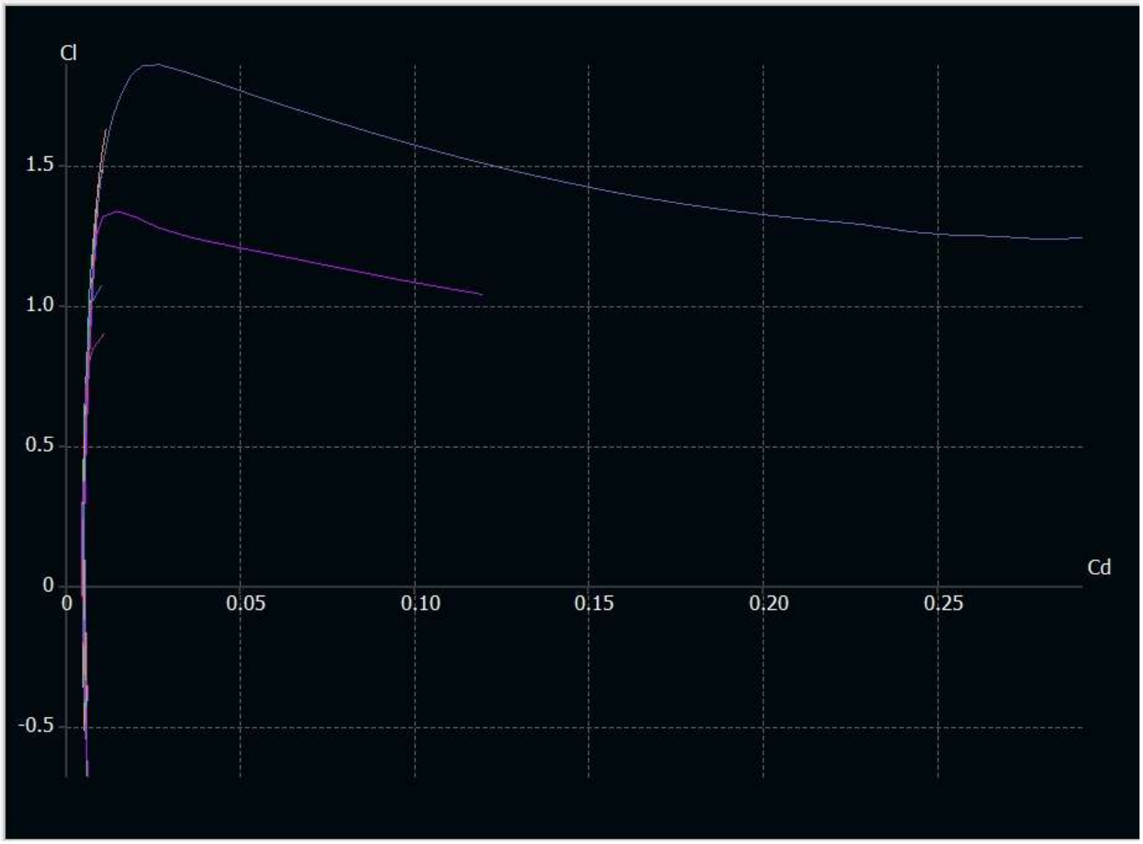


Fig 2.3.11: Cl vs Cd for Different airfoils

2.3.2.2 <u>Cl vs Alpha graph</u>

1. Determining Lift Characteristics – Shows how lift (Cl) changes with angle of attack (α), essential for stability and control.
2. Finding Stall Angle – Identifies the α where Cl stops increasing (stall occurs), crucial for flight safety.
3. Assessing Lift Curve Slope – The slope (ΔCl/Δα) indicates how responsive the airfoil is to angle changes, affecting maneuverability.
4. Comparing Airfoil Performance – Helps select airfoils with the best lift generation for specific applications.
5. Analyzing Hypersonic Glide Stability – Ensures Cl remains predictable in hypersonic flight to avoid instability.

For hypersonic glide vehicle (HGV):

- Find the optimal α for stable glide.
- Avoid excessive α that increases drag or causes instability.
- Ensure a smooth lift response without sharp stall behaviour

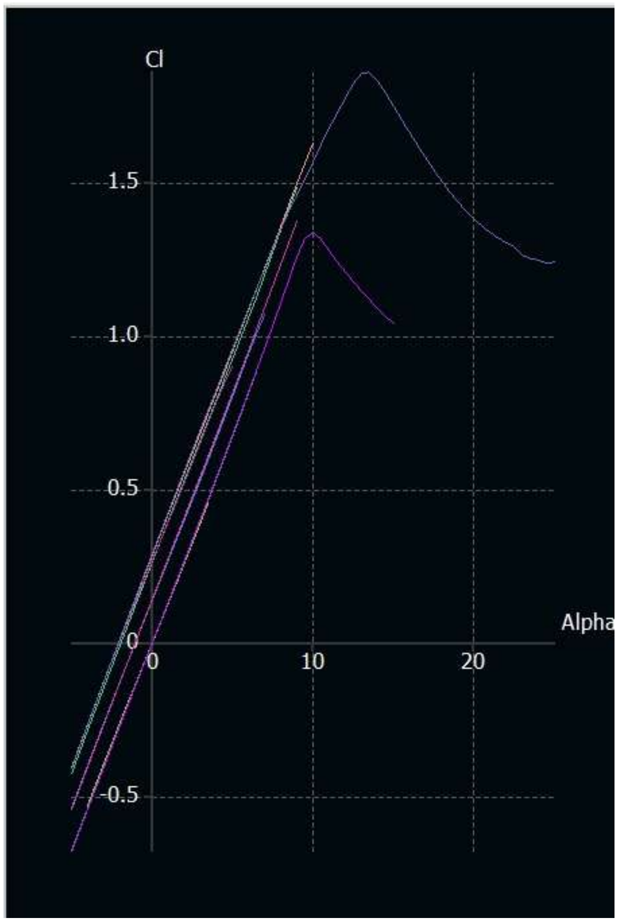


Fig 2.3.12: Cl vs alpha for Different airfoils

2.3.2.3 <u>Cm vs Alpha graph</u>

1. Determining Lift Characteristics – Shows how lift (Cl) changes with angle of attack (α), essential for stability and control.
2. Finding Stall Angle – Identifies the α where Cl stops increasing (stall occurs), crucial for flight safety.

3. Assessing Lift Curve Slope – The slope (ΔCl/Δα) indicates how responsive the airfoil is to angle changes, affecting maneuverability.
4. Comparing Airfoil Performance – Helps select airfoils with the best lift generation for specific applications.
5. Analyzing Hypersonic Glide Stability – Ensures Cl remains predictable in hypersonic flight to avoid instability.

2.3.3 For hypersonic glide vehicle (HGV):

- Find the optimal α for stable glide.
- Avoid excessive α that increases drag or causes instability.
- Ensure a smooth lift response without sharp stall behavior.

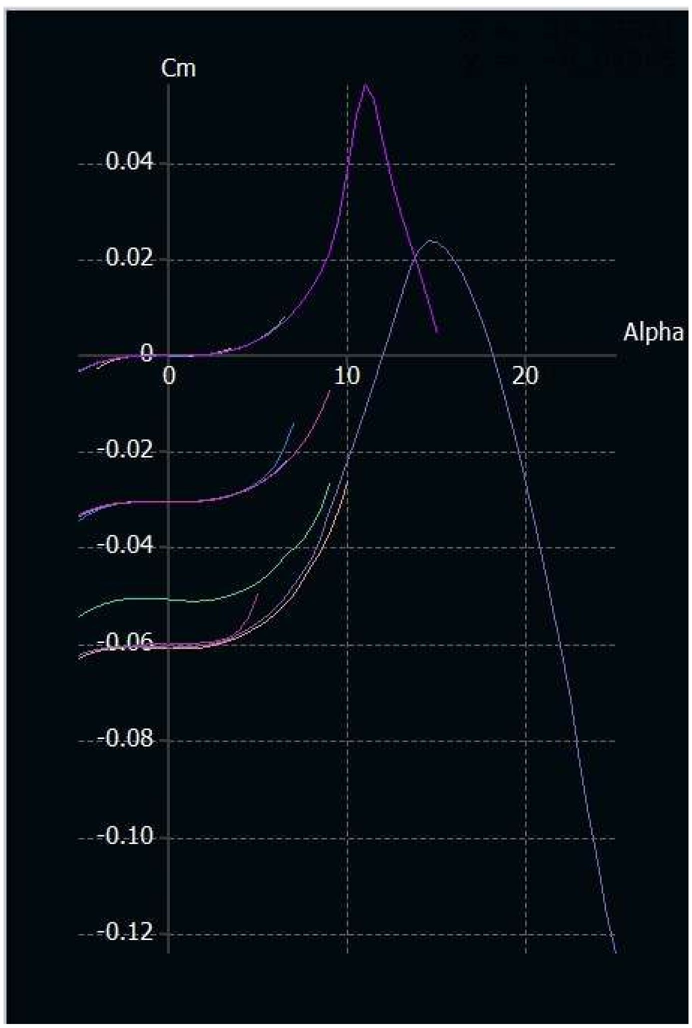
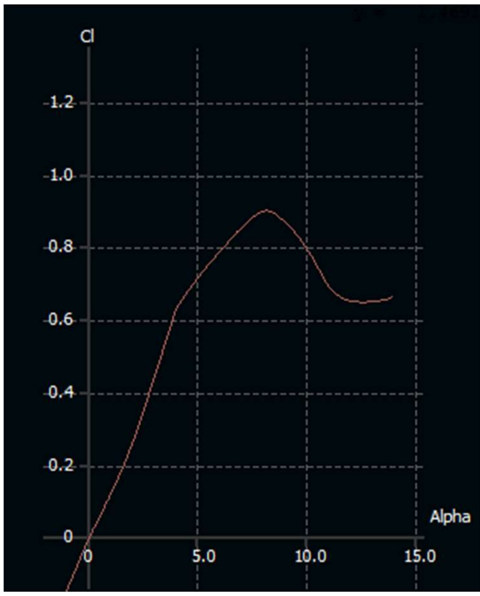
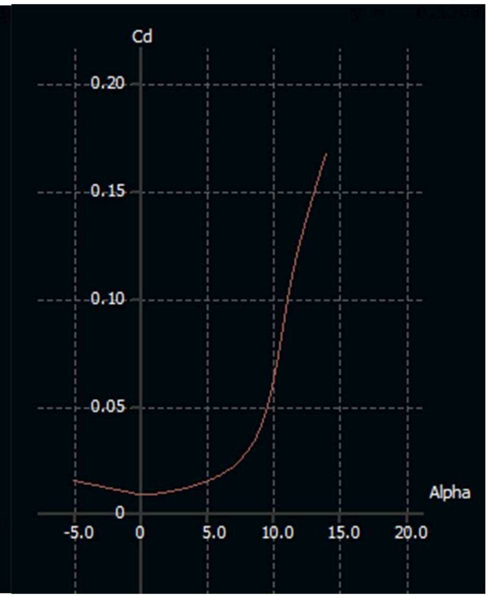
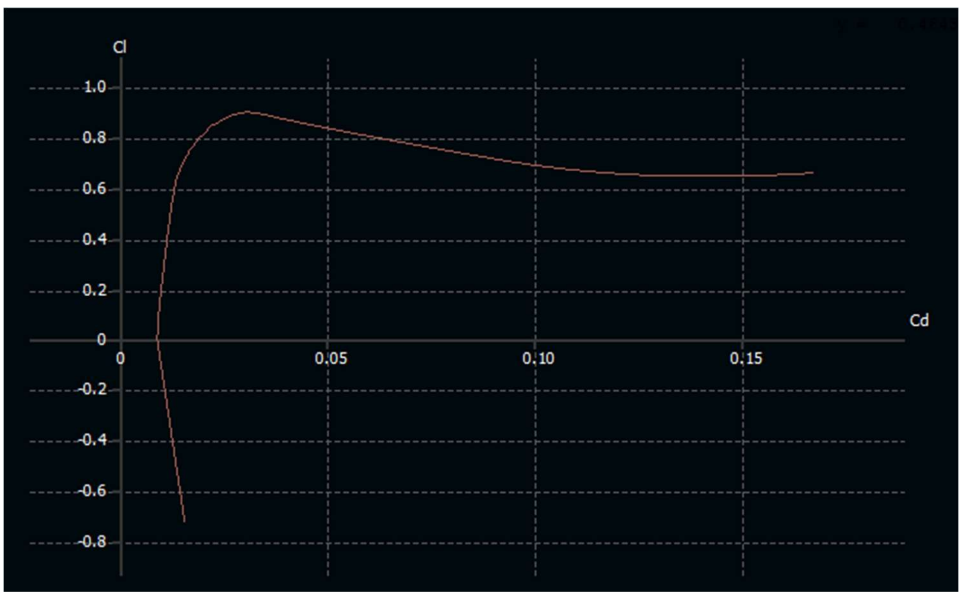


Fig 2.3.13: Cm vs for Different airfoils

2.3.4 NACA 0012







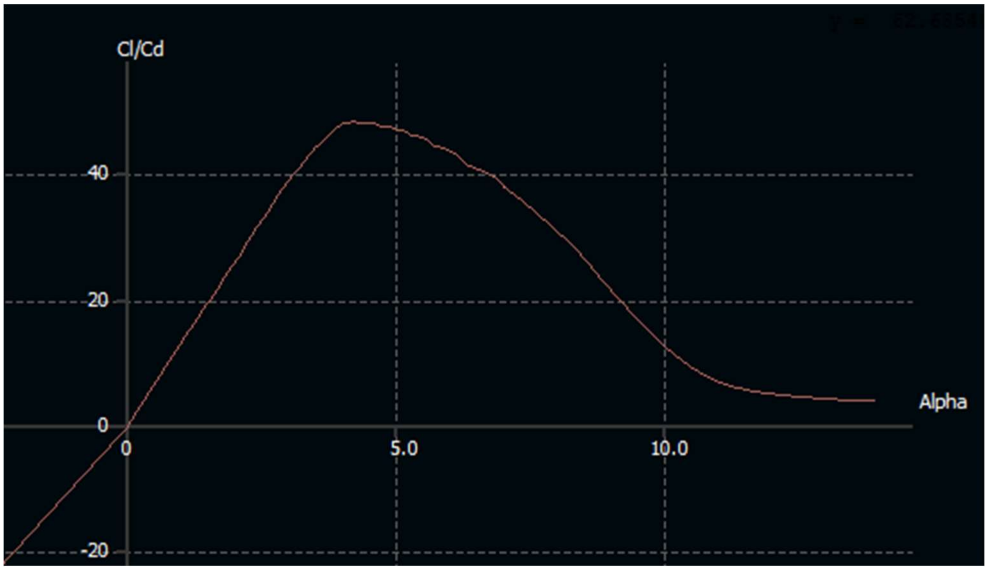


Fig 2.3.14: Graphs for NACA 0012

We chose the NACA 0012 air foil for our hypersonic glide vehicle (HGV) because it provides zero pitching moment (Cm = 0), ensuring better longitudinal stability during glide.

Since the aircraft has no moving parts or control surfaces, a symmetric air foil is the best option to maintain a predictable aerodynamic response.

Cambered airfoils have built in positive Cl at 0 degree angle of attack which can cause unwanted pitching moments at hypersonic speeds and negative CM leading to nose-down instability, requiring larger control deflections

Reduced Pitching Moment (Cm)

Additionally, NACA 0012 offers:

- Lower wave drag at hypersonic speeds, reducing energy loss.
- Uniform heating, simplifying thermal protection system (TPS) design.
- More stable high-speed handling, preventing unwanted pitching.
- Although NACA 0012 has a lower Cl value, stability and low drag are higher priorities for our design,

2.4 Wing Design

The wing design is a critical component in determining the aerodynamic efficiency, stability, and control of the hypersonic glide vehicle (HGV) during its atmospheric phases. A trapezoidal wing configuration using the previously selected NACA 0012 airfoil was modeled in XFLR5 to analyze aerodynamic properties and refine geometric parameters.

Key steps and considerations in the wing design include:

- Wing Configuration: A low-mounted, unswept trapezoidal wing was chosen to provide both structural simplicity and effective lift distribution. The wing has zero twist and no anhedral, aligning with shuttle-like glider behavior.
- Geometric Parameters: The wing has a span of 6 meters, with a root chord of 2.125 m and a tip chord of 1.125 m, leading to a taper ratio of approximately 0.5294. The wing area was determined to be 6.965 m^2 from the XFLR5 model, supporting adequate lift generation for the vehicle's weight.
- Aspect Ratio and Mean Chord: With an aspect ratio of 3.692 and a mean aerodynamic chord of 1.6875 m, the wing is optimized for balance between lift and maneuverability, essential for controlled descent.
- Sweep Angle: A modest leading-edge sweep of 14.04° was implemented to delay shock formation and improve stability at transonic and hypersonic speeds.
- Integration Considerations: The wing is designed in proportion to the fuselage, with a fuselage-width-to-span ratio of 1.714, ensuring minimal interference drag and preserving aerodynamic cleanliness.

2.4.1 Wing Parameters:-

Wing	NACA 0012
Span	6m
Root Chord	2.125m
Aspect Ratio	3.692
Tip Chord	1.125m
Stall angle	17deg
Cl max	1.6
mean chord	1.6875m
Wing area	6.965m2 (from xflr5)
sweep angle	14.04 (for delta)
tapper	0.5294
Twist	0
anhedral	0
location of wing	low wing
fuselage width to span ratio	1.714

Table 2.4.1:Wing Parameters

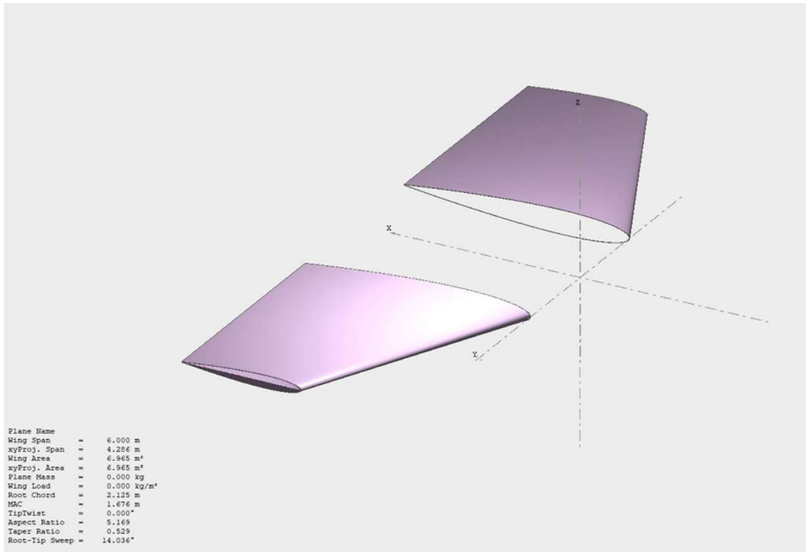


Fig 2.4.1 :- Wing model(sample) in xflr5

2.5 Powerplant Selection

In the case of a hypersonic glide vehicle (HGV), the vehicle does not possess an onboard propulsion system for atmospheric flight. Instead, it relies on an external launch vehicle (rocket) for its ascent into space. Thus, powerplant selection refers specifically to the rocket system used to carry the HGV to the desired altitude and velocity, from which it begins its unpowered glide phase.

The methodology followed for selecting the launch system was based on the following criteria:

- Payload Mass Compatibility: The rocket must be capable of carrying a payload mass of 4670 kg.
- Payload Dimensions: The launch vehicle must accommodate a payload width of 6 m, height of 3 m, and length of 10 m.
- Orbital Capability: The rocket must be capable of placing the vehicle in a suitable suborbital or low Earth orbit trajectory compatible with the HGV's mission profile.
- Launch Vehicle Database: Among several candidate rockets, three systems were considered based on their proven performance:
    - GSLV Mk-III (India)
    - H-IIA (Japan)
    - Soyuz-2 (Russia)

2.5.1 REQUIREMENTS

Payload Mass	4670 kg
Payload height	3 m
Payload width	6 m
Payload Length	10 m

Table 2.5.1 :Payload parameters

2.5.2 ROCKET CHARACTERISTICS

[Table2.5.2(1-3):Rocket Characteristics]

2.5.2.1 GSLV-MK-3

Stages			3		
Thrust					
1	2	3	5,150 kN	1,5G8 kN	186.36 kN
Mass					
1	2	3	236,000 kg	125,000 kg	33,000 kg
Payload			10,000kg		

2.5.2.2 H-II A

Stages		2	
Thrust			
1	2	1,078 kN	121.5 kN
Mass			
1	2	260,000 kg	60,000 kg
Payload		10,060 kg	

2.5.2.3 SOYUZ-2

Stages			3		
Thrust					
1	2	3	838.5 kN	7G2.5 kN	2G8.03 kN
Mass					
1	2	3	44,413 kg	GG,765 kg	27,755 kg

Payload	7,430 kg

Form this details we can say the ideal choice for the HGV is

SOYUZ-2

Flap selection:- Elevons

2.6 Performance and tail selection:-

2.6.1 Vstall

$$Vstall = \sqrt{\frac{2W}{\rho S Cl_{max}}}$$

W=4669.301kg

ρ=1.225kg/m^3

Cl max = .9 for naca 0012

Vstall = 92.039 m/s

2.6.2 WingLoading:-

$$\frac{W}{S} = \frac{Weight}{Area}$$

Weight = 4669.31Kg

Area = 6.965m^2

W/S = 670.39 Kg/m^2

2.6.3 Glide angle For naca 0012 Airfoil:-

(L/D)max = 49 at 4.2deg

Cl=.65

Cd = .0132

$$\sin\theta = \frac{1}{(l/d)_{max}}$$

Glide angle = 1.169^{o}

2.6.4 MTOW

MTOW = $W_{payload} + W_{rocket}$

MTOW = 4669.301+312000

MTOW = 316,669Kg

2.6.5 Total Lift

Total Lift = $L_{wing} + L_{flap}$

= 0.5 * 1.225 * 171.5 ^2 *6.965 * .65 + L_{flap}

= 81,558N + L_{flap}

2.6.6 Total Drag

Total Drag= $D_{Wing} + D_{Fuselage} + D_{Tail} + D_{others}$

= 0.5 * 1.225 * 171.5 ^2 *6.965 * .0132 + $D_{Fuselage} + D_{Tail} + D_{others}$

= 16,562N + $D_{Fuselage} + D_{Tail} + D_{others}$

2.6.7 Take-off Distance

=0 as the rocket does not require a runway to lunch

2.6.8 Landing distance

$$s_g = jN\sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{\max}}} + \frac{j^2(W/S)}{g\rho_\infty(C_L)_{\max}\,[T_{\text{rev}}/W + D/W + \mu_r\,(1 - L/W)]_{0.7V_{\text{TD}}}}$$

j = 1.11

T/w = 0

(1.1 * 92) + (1.1^2* 670)/(9.81 *.65 *((233.54/4669) + (1-11,500/4669))

Sg = 11.2243656688 m

2.6.9 Stability

Longitudinal

wing

$$C_{m_{0_w}} = C_{m_{ac_w}} + C_{L_{0_w}}\left(\frac{X_{cg}}{\bar{c}} - \frac{X_{ac}}{\bar{c}}\right)$$

$$C_{m_{\alpha_w}} = C_{L_{\alpha_w}}\left(\frac{X_{cg}}{\bar{c}} - \frac{X_{ac}}{\bar{c}}\right)$$

Tail

$$C_{m_{0_t}} = \eta V_H C_{L_{\alpha_t}}(\varepsilon_0 + i_w - i_t)$$

$$C_{m_{\alpha_t}} = -\eta V_H C_{L_{\alpha_t}}\left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

[29]

Where

$$\eta = \frac{\frac{1}{2}\rho V_t^2}{\frac{1}{2}\rho V_w^2}$$

$$V_H = l_t S_t / S\bar{c}$$

We can not calculate anything here or move forward without the location of cg to be able to design the tail parameters we require the fuselage sizing and need to calculate the location of cg with regards to the location of wing and tail which is currently impossible without the fuselage parameters

2.6.10 Tail type:-

2.6.10.1 Conventional Tail

Description: The horizontal stabilizer and elevator are mounted at the rear of the fuselage, with the vertical stabilizer (fin) and rudder on top.

Examples: Boeing 737, Cessna 172

Pros: Simple, effective, well-understood

Cons: Can be affected by disturbed airflow from wings and engines

2.6.10.2. T-Tail

Description: Horizontal stabilizer is mounted at the top of the vertical stabilizer, forming a “T” shape.

Examples: McDonnell Douglas MD-80, Bombardier CRJ

Pros: Keeps stabilizer out of wing/engine wake

Cons: Deep stall risk, harder to inspect/maintain

2.6.10.3. Cruciform Tail

Description: Horizontal stabilizer is mounted midway up the vertical fin, forming a cross shape.

Examples: F-4 Phantom, some business jets

Pros: Balances pros/cons of T-tail and conventional tail

Cons: Slightly more complex structurally

2.6.10.4. V-Tail (Butterfly Tail)

Description: Uses two surfaces in a V-shape to provide both pitch and yaw control (ruddervators).

Examples: Beechcraft Bonanza V35, some UAVs

Pros: Less surface area = less drag

Cons: Complex control mixing, less effective control separation

2.6.10.5. H-Tail (Twin Tail or Twin Boom)

Description: Two vertical stabilizers connected by a horizontal stabilizer (usually used in twin-boom aircraft).

Examples: P-38 Lightning, Rutan Voyager

Pros: Redundant vertical surfaces, improved yaw stability

Cons: More drag and complexity

2.6.10.6. Inverted V-Tail

Description: Like a V-tail but upside down, with surfaces pointing downward.

Examples: Some UAVs and drones

Pros: Same as V-tail but better ground clearance

Cons: Same complexity in control mixing

2.6.10.7. Canard (Foreplane)

Description: Control surfaces are placed in front of the main wings.

Examples: Dassault Rafale, Rutan Long-EZ

Pros: Improved maneuverability, natural stall resistance

Cons: Can cause trim drag; stability concerns

For Hgv we will be selecting the conventional tail

For hgv calculation we require stability calculations which are not possible without cg calculation

2.7 Fuel Validation:-

When a spacecraft is gliding, especially during re-entry and descent through an atmosphere (like Earth's), it does not use engines or thrust for maneuvering. Instead, it relies on aerodynamic control surfaces and inertial momentum. Here's how it maneuvers:

2.7.1 Aerodynamic Control Surfaces

In spacecraft that are designed to glide through the atmosphere (like the Space Shuttle or lifting body vehicles), maneuvering is done using:

- Elevons: Combined elevators and ailerons for pitch and roll control.
- Rudder: Mounted on the vertical stabilizer for yaw control.
- Body flap: Used for pitch control at hypersonic speeds.

These surfaces deflect the airflow around the spacecraft, changing its attitude and direction just like an airplane.

2.7.2 Center of Gravity and Lift

- By changing the angle of attack, the spacecraft can generate lift in different directions.
- This allows it to steer left/right or increase/decrease descent rate while gliding.

2.7.3 Reaction Control System (RCS) (in upper atmosphere or space)

Before the atmosphere gets thick enough for aerodynamic control surfaces to work, spacecraft may use small thrusters (RCS) to change orientation or attitude. These are not used during pure gliding but before or after that phase.

- Uses monopropellant (like hydrazine) or bipropellant (fuel + oxidizer) to generate thrust.

- Each RCS thruster produces a small but precise amount of force.
- Arranged in pairs or clusters to provide balanced control.

**Spacecraft uses control surfaces for manoeuvring during gliding phase,and thrusters in space (the fuel differ for different thruster used) so the fuel validation is not applicable for spacecraft design.

2.8 Lift and drag estimation

The lift and drag force estimations for a space shuttle-type hypersonic re-entry vehicle during three critical phases of its atmospheric flight: re-entry, glide, and landing. The estimations are based on the given aerodynamic coefficients, vehicle velocity, atmospheric conditions at sea level, and a specified reference wing area.

The aerodynamic forces were calculated using the standard lift and drag equations:

$L = (1/2) * \rho * V^2 * S * C_L$

$D = (1/2) * \rho * V^2 * S * C_D$

where:
- L = Lift force (N)
- D = Drag force (N)
- ρ = Atmospheric density (1.225 kg/m^3)
- V = Velocity (m/s)
- S = Reference area (6.955 m^2)
- C_L = Lift coefficient
- C_D = Drag coefficient

2.8.1 Flight Conditions and Aerodynamic Parameters

Phase	Angle of Attack (AoA)	C_L	C_D	Velocity (m/s)
Re-entry	25°+	0.5	0.6	411.6
Glide	5°	0.65	0.07	240
Landing	10°	0.9	0.15	164

Table 2.8.1:- Flight conditions

2.8.2 Results

2.8.2.1 Re-entry Phase

L = 251.69 kN

D = 302.03 kN

2..2.2 Glide Phase

L = 110.77 kN

D = 119.29 kN

2..2.3 Landing Phase

L = 724.87 kN

D = 120.81 kN

2.8.3 Summary of Forces

Phase	**Lift (kN)**	**Drag (kN)**
Re-entry	**251.69**	**302.03**
Glide	**110.77**	**119.29**
Landing	**724.87**	**120.81**

Table 2.8.2:- L and D results

- During re-entry, drag is higher than lift, ensuring rapid deceleration and thermal protection through atmospheric braking.
- In the glide phase, lift and drag values become comparable, supporting controlled descent with a high lift-to-drag (L/D) ratio.
- During landing, a significant increase in lift enables a smooth and stable touchdown, while drag remains moderate.

3. CONCLUSION

This report presented a comprehensive preliminary design and performance study of a shuttle-type Hypersonic Glide Vehicle (HGV), aimed at achieving controlled atmospheric re-entry and efficient glide-based landing. Through a structured approach encompassing nine key components, the vehicle's aerodynamic, structural, and mission compatibility aspects were thoroughly evaluated.

Beginning with a defined mission profile, the overall configuration of the HGV was laid out to support hypersonic glide and atmospheric control. The selection of the NACA 0012 airfoil balanced high-speed performance and subsonic landing capability. Detailed wing design was performed using XFLR5, optimizing parameters like sweep, taper, aspect ratio, and surface area to ensure favorable lift-to-drag characteristics across all flight regimes.

Rocket selection was guided by payload dimensions and mass, leading to the Soyuz-2 as the most compatible launcher. Performance calculations covered stall speed, wing loading, and lift/drag efficiency, while also considering the limitations of tail sizing due to CG dependencies. A conventional tail was selected for simplicity and reliability. Fuel validation clarified that no propulsion is needed during the glide phase, relying on aerodynamic control surfaces instead.

Finally, lift and drag were estimated during re-entry, glide, and landing phases, confirming the vehicle’s ability to maintain stability and maneuverability throughout its descent. These results demonstrate that the proposed HGV configuration aligns well with real-world design principles used in vehicles like the Space Shuttle, offering a solid foundation for more advanced stability, structural, and thermal modeling in future stages.

Author's Note:

All research, data collection, and calculations presented in this work were carried out by us. ChatGPT was used solely to help rephrase and structure our findings into a clearer and more readable format. The values and analysis was not done by ChatGPT, and was entirely based on our original work.

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