NASA VCLS Demo 2
SDR
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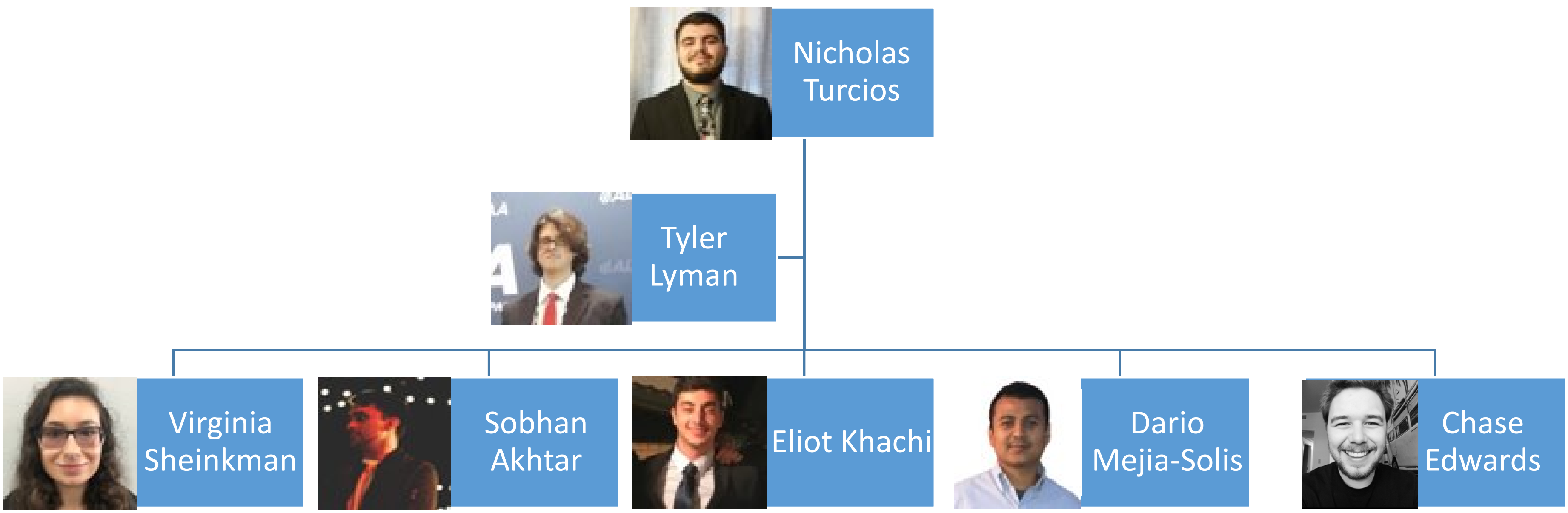
Organizational Chart



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Acronyms

Acronym/Shorthand	Meaning
-X	Mission X
ACS	Attitude Control System
EOM	End of Mission
FS	Factor of Safety
MS	Margin of Safety
LV	Launch Vehicle
OEI	One Engine Inoperative
AP	Ammonium Perchlorate propellant
LCH_4	Liquid Methane fuel
LOX	Liquid Oxygen

RFP-Specified Mission Requirements

Mission 1: A dedicated launch service for CubeSats that will include a single launch with a delivery of 30 kg payload mass to 500 km at inclination of TBP degrees between 40-60°.

Mission 2: A launch service with CubeSats as the primary payload. This includes a single launch for delivery of Constellation A and B. Constellation A is a 75 kg payload mass to a 550 km Sun-Synchronous Orbit (SSO). Constellation B is a second delivery of 20 kg to 550 km SSO with a minimum 10° plane change.

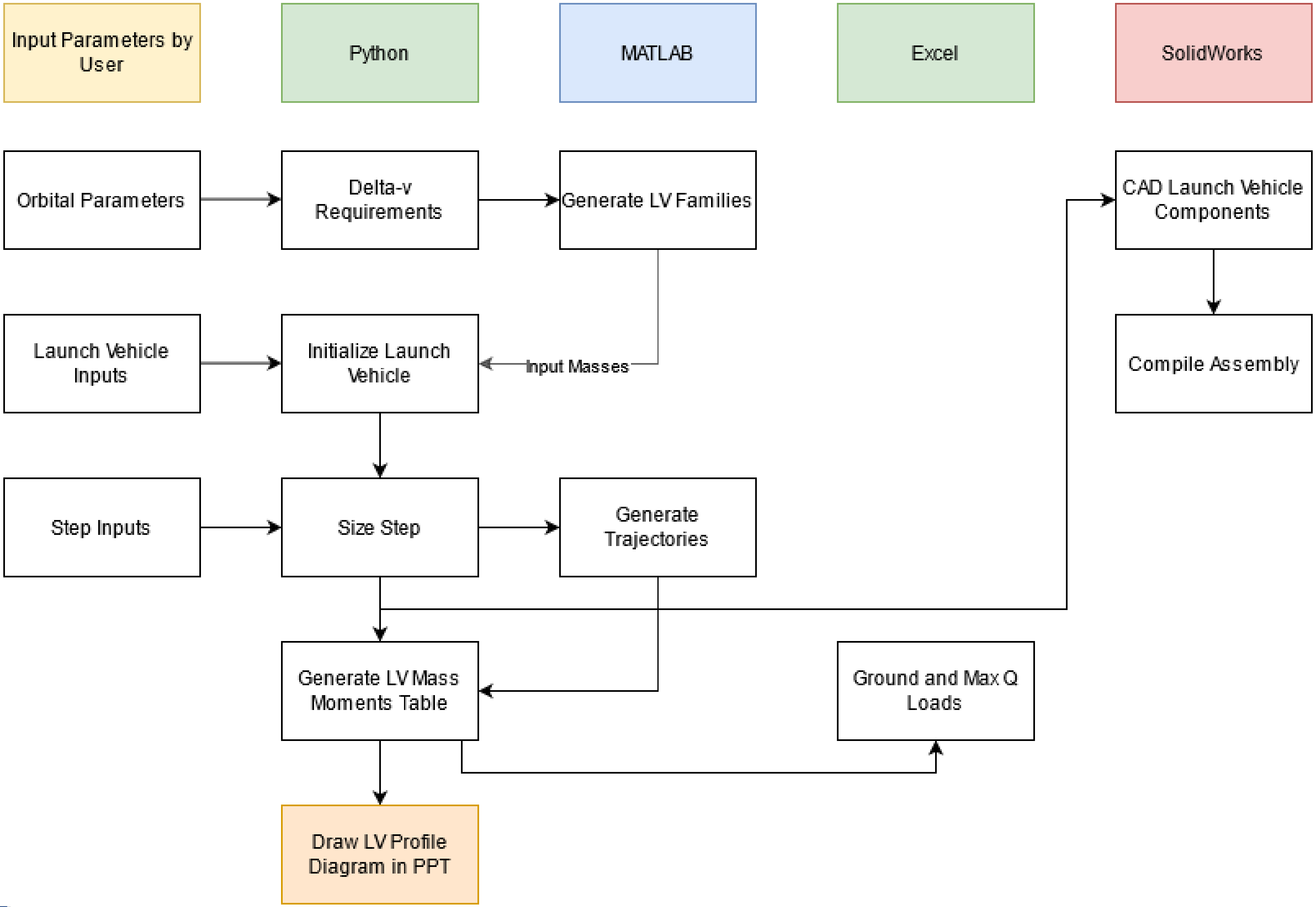
Mission Architecture Considerations

	Mission 1	Mission 2
Payload	30 kg	95 kg
Altitude	500 km	550 km
Inclination	60°	98°
Plane Change	None	10°
Orbit Shape	Circular	Circular
Launch Site	Kennedy Space Center	Vandenberg Air Force Base*
Launch Latitude	28.5°	34.74°
Azimuth Angle	34.48°	189.75°
Design Δv_{req}	9.54 km/s	10.99 km/s**

*Refer to backup slide for Kodiak comparison

** Δv_{req} includes the 10° inclination change.

Launch Vehicle Design Methodology



Architecture 1: Minerva

Staging Possibilities:

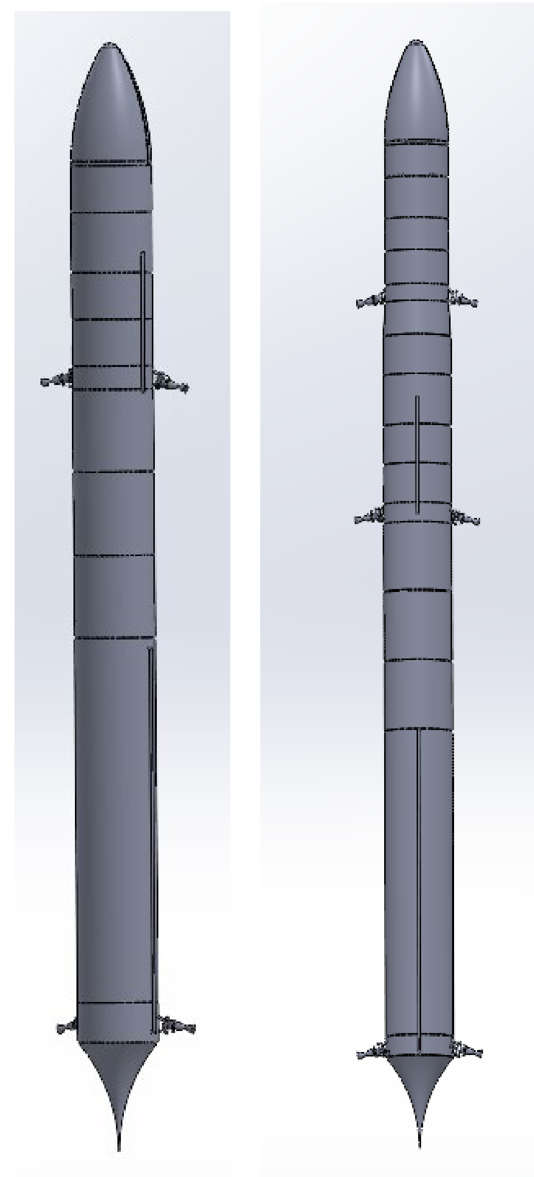
- Modular Launch Vehicle
  - Mission 1 utilizes 2 stages
  - Mission 2 utilizes 3 stages
- 1st stage is recovered and reused

Propellant Choice:

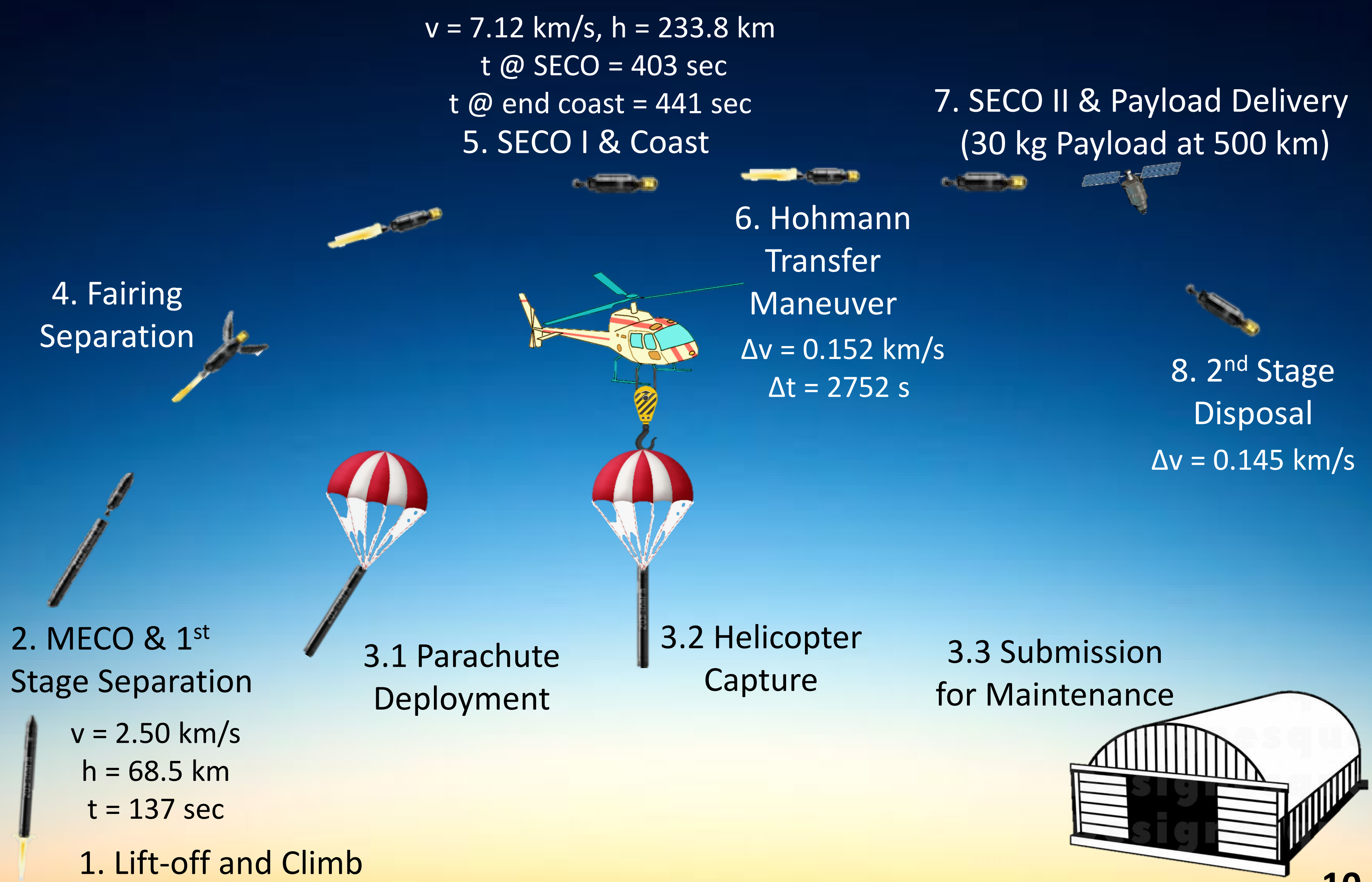
- All stages are liquid propellant (RP-1/LO_2)
  - Adequate performance
  - Non-cryogenic nature makes it easy to handle

Nozzle Choice: aerospike for all stages

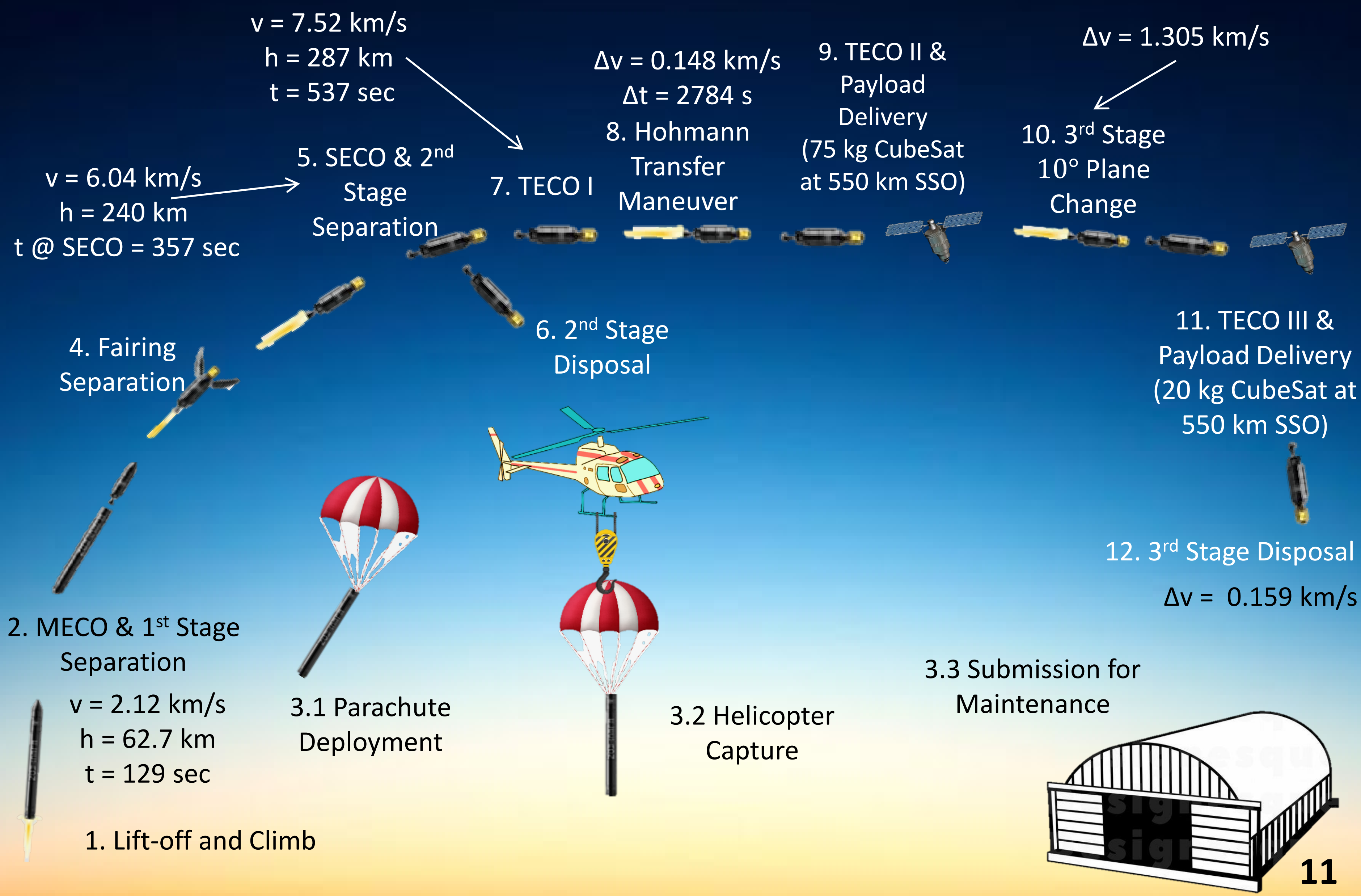
- Compensates for altitude pressurization



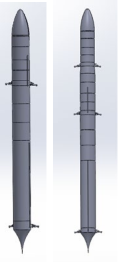
Minerva Mission 1



Minerva Mission 2



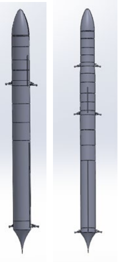
Minerva Design Specifications



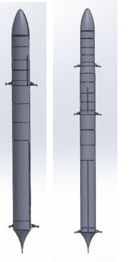
	Mission 1 Thrust (kN)	Mission 2 Thrust (kN)	I_{sp} (sec)	Structural Mass Fraction σ
Minerva Stage 1 (SL)	77.9	83.3	296*	0.11
Minerva Stage 2 (Vacuum)	13.8	17.9	359*	0.11
Minerva Stage 3 (Vacuum)	N/A	3.8	359*	0.11

* Minerva will have all aerospike nozzles (based on the J-2T-250K) attached to Merlin-type engines.

Minerva LV Family Methodology



- Numerically solved for Mission 2 masses
  - %Δv for stage 1 of values from 1% to 49%
  - %Δv for stage 3 of values from 1% to 49%
  - %Δv for stage 2 was the remaining percent
- Used propellant masses of Stage 1 and 2 to solve for capable Δv for Mission 1
- Used if-statements to determine the minimum mass that was still capable of Mission 1

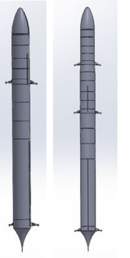


Minerva Lift-Off Mass Estimates

	Mission 1 (kg)	Mission 2 (kg)
Stage 3	N/A	426.8
Stage 2	1336.7	1306.7
Stage 1	4338.2	4338.2
Total	5704.9	6071.4

- Minerva has stage 3 for Mission 2
- Upper-most stage mass includes payload

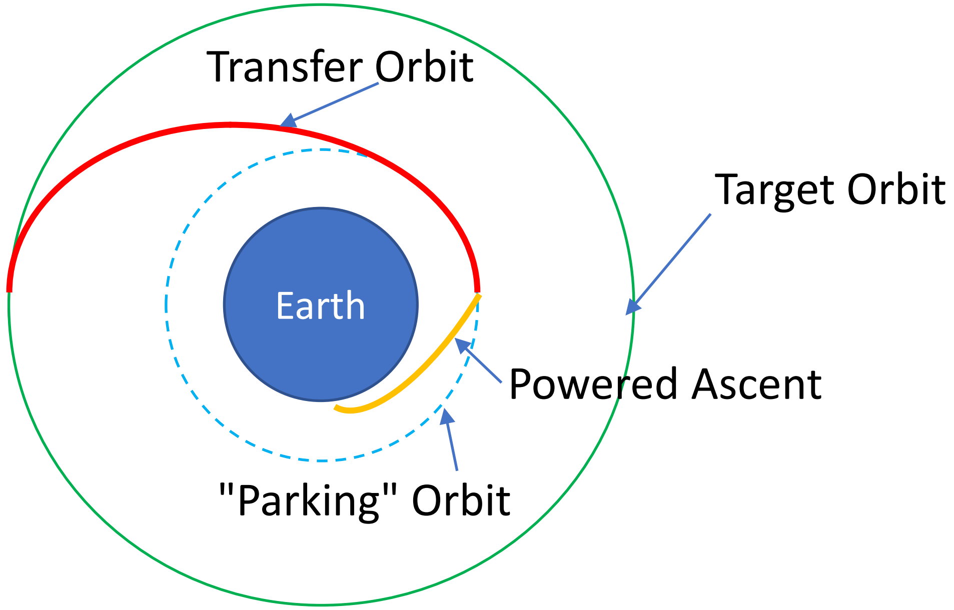
Trajectory Methodology

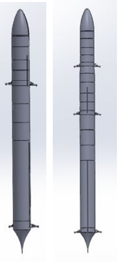


- Used MATLAB to simulate gravity turn and Hohmann transfer
- Program will simulate a large family of trajectories varying in:
  - Stage thrust
  - Initial pitch kick
  - Propellant mass left over per stage
- This method is preferred because it can down select trajectories without needing to 'trial & error' by hand
- Selection Criteria:
  - Powered ascent must leave enough mass to complete a Hohmann transfer to be valid
  - Of valid trajectories, which one requires the least Δv to circularize parking orbit
  - Included extra 'rule-of-thumb' criteria to rule out false positives

Trajectory Simulations – Hohmann Transfer

- The trajectory for both missions includes a Hohmann Transfer from a low altitude orbit to the target orbit to release the payload.





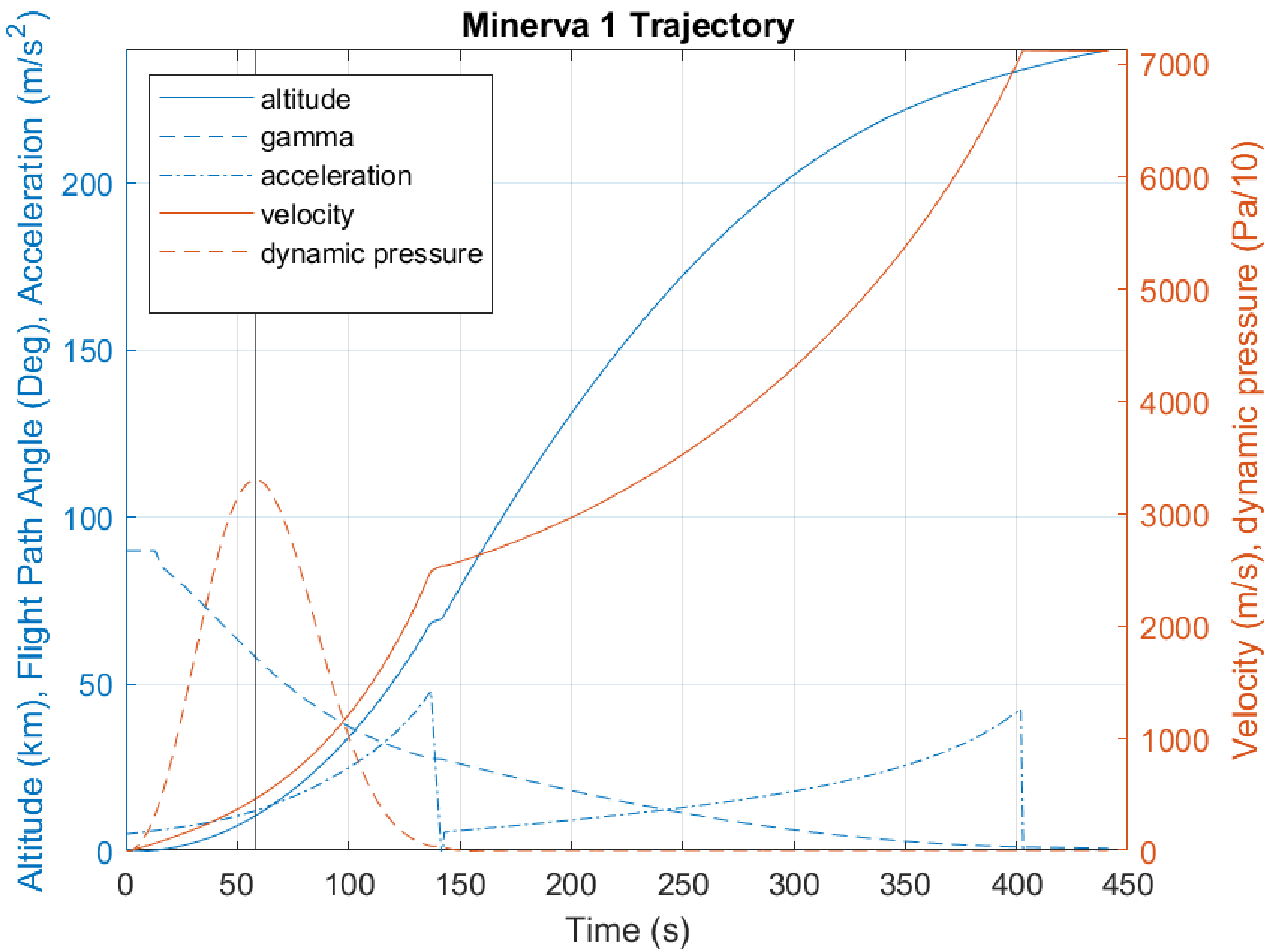
Minerva Transfer Orbit Descriptions

Below are the conditions at end of powered ascent phase:

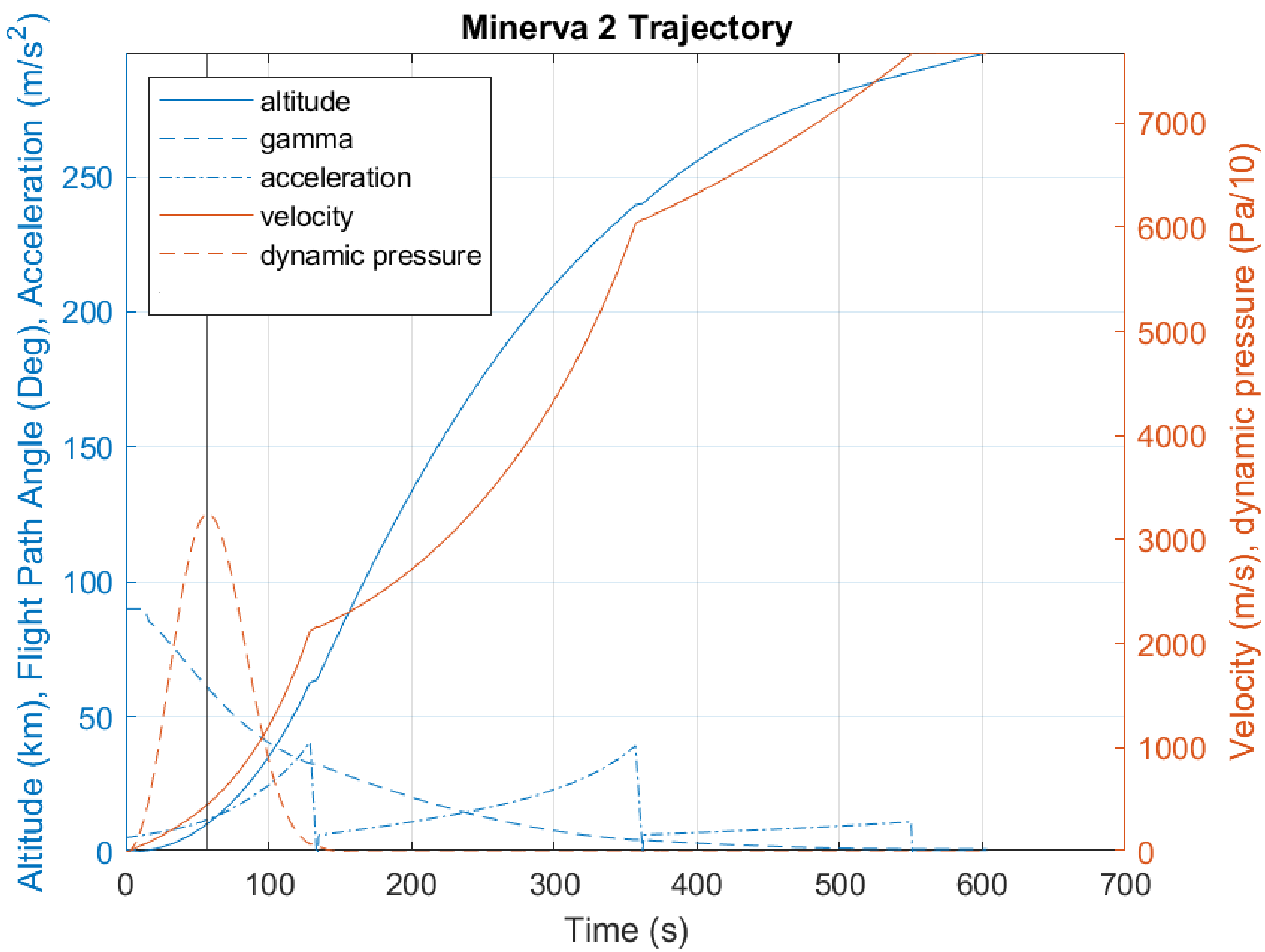
	Mission 1	Mission 2
Altitude (km)	213.5	361.7
Velocity (km/s)	7.31	7.64

Following this, an appropriate kick burn is applied that effectively circularizes and enters the Hohmann Transfer.

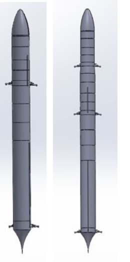
Minerva-1 Trajectory



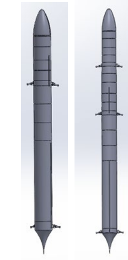
Minerva-2 Trajectory



Launch Vehicle (LV) Sizing Methodology



- Input Parameters Used:
  - MATLAB-Estimated Propellant Masses
  - Propellant Choice & Mixture Ratio
  - Engine Specific Impulse
  - Material of Components
  - Diameter of LV stages
- The diameter of the launch vehicle was selected to fulfill the following requirement
  - Minimize air resistance by being as slender as possible without exceeding an L/D of 17



Minerva-1 Diagram

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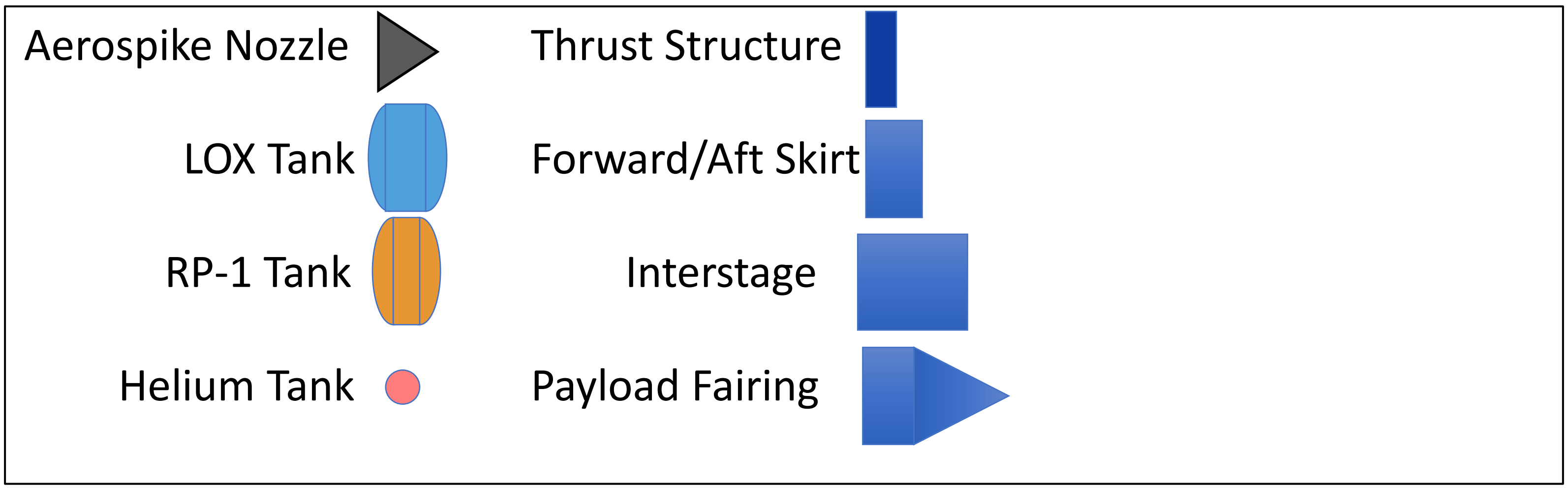
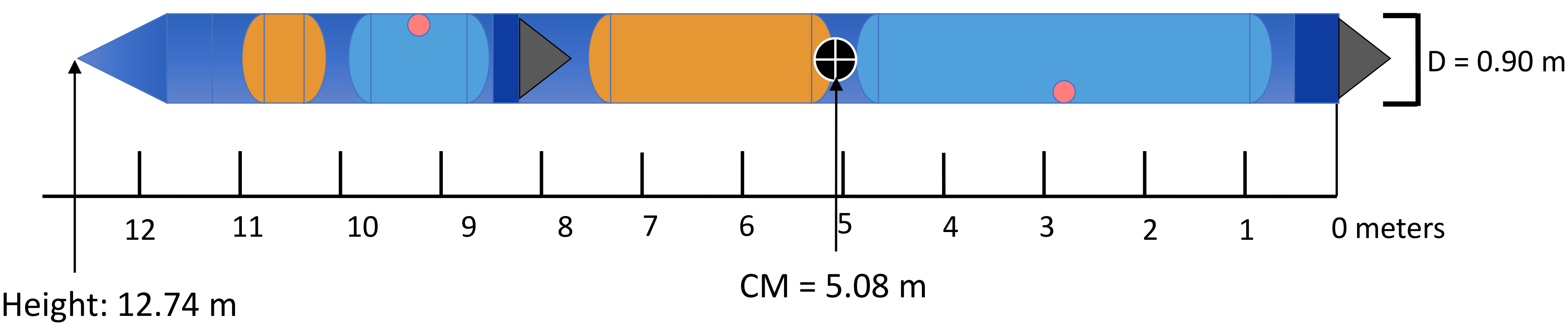
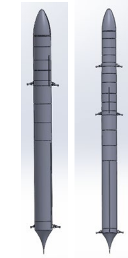




Minerva-2 Diagram



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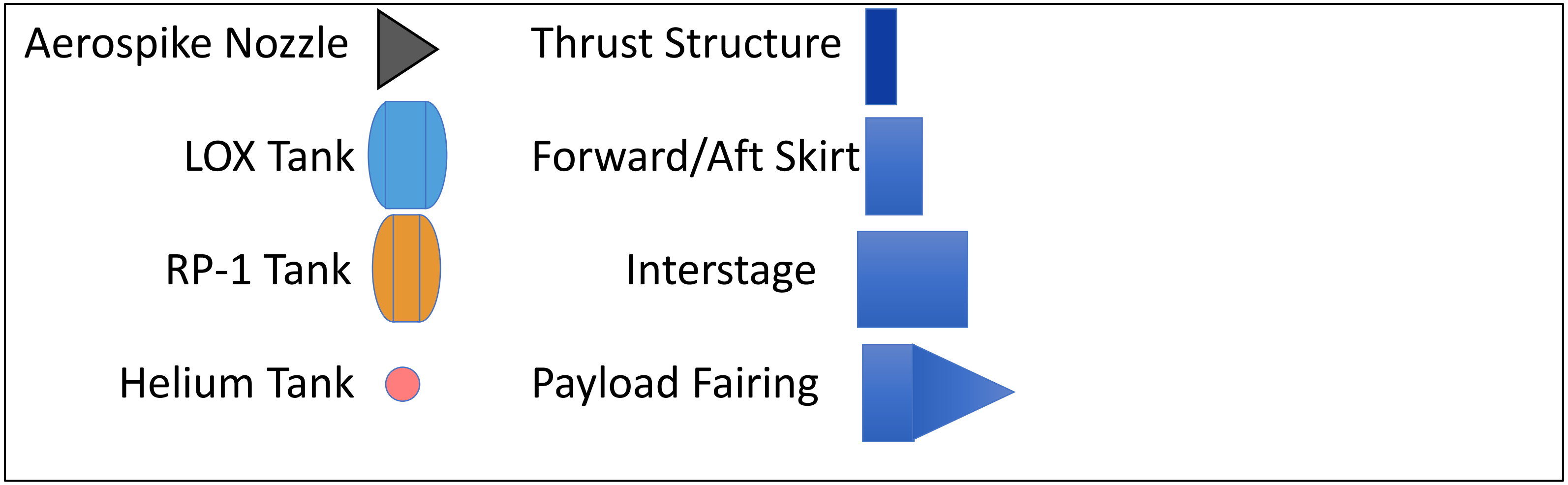
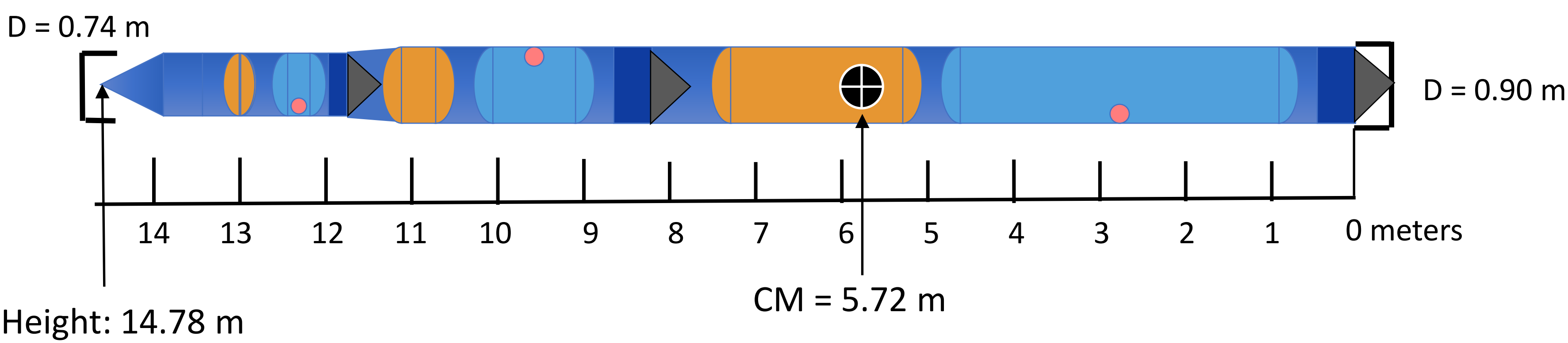
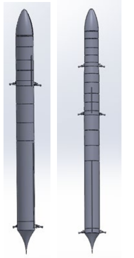
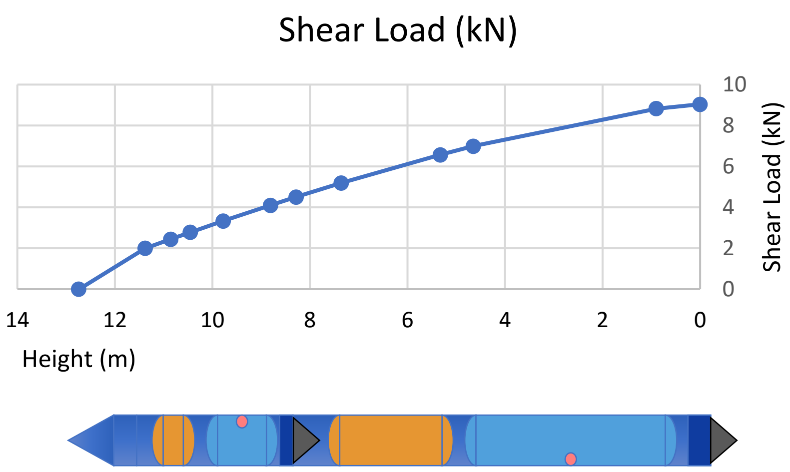
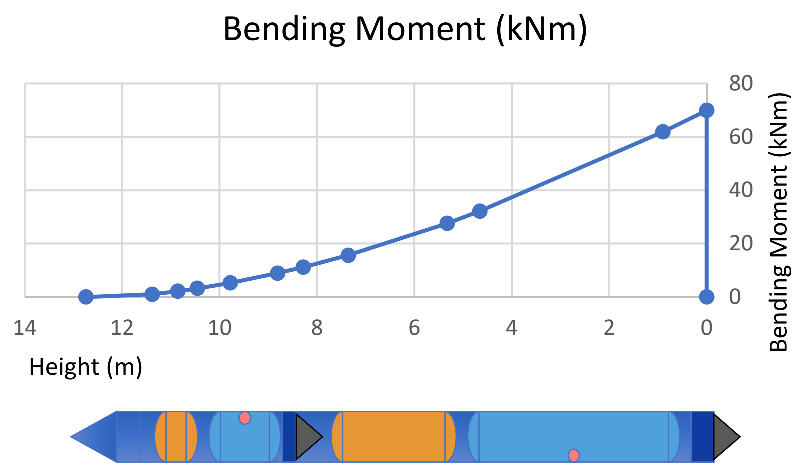


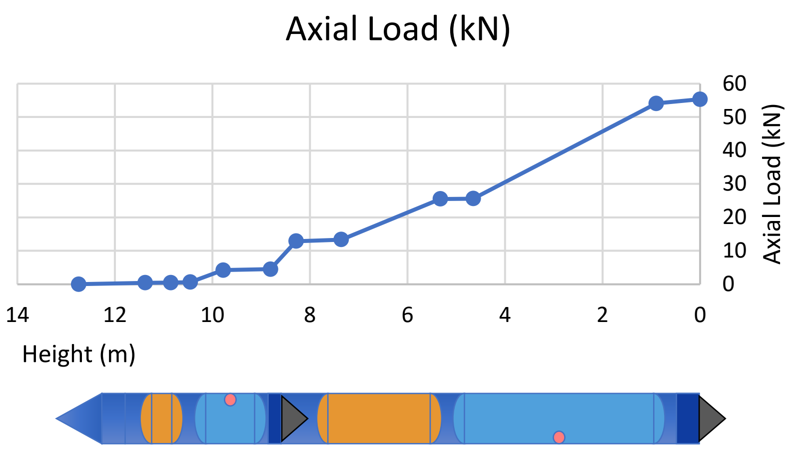


Minerva-1 Ground Loads Analysis



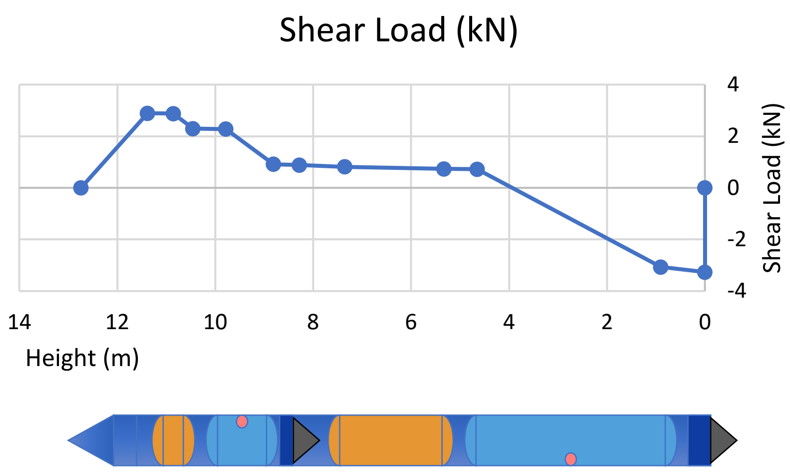


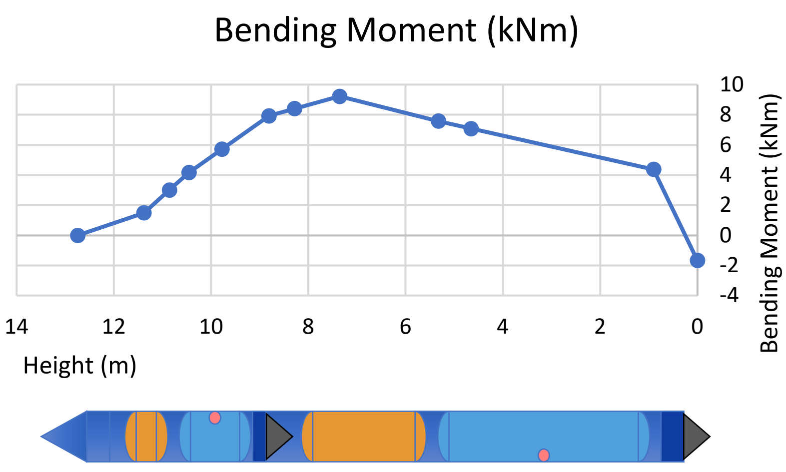


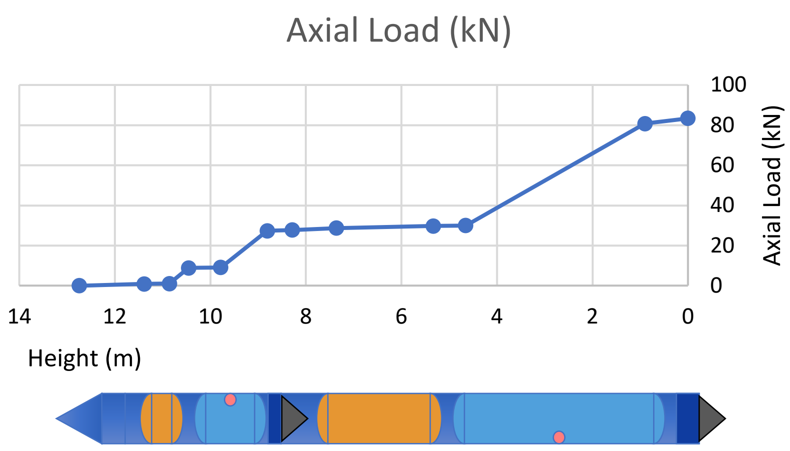


- Max shear is at the aft skirt
  - 9.0 kN
- Max bending moment is at the aft skirt
  - 69.8 kNm
- Max axial load is equal to the weight
  - 55.3 kN

Minerva-1 Max-q Loads Analysis

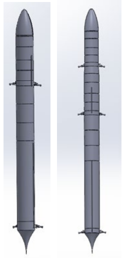


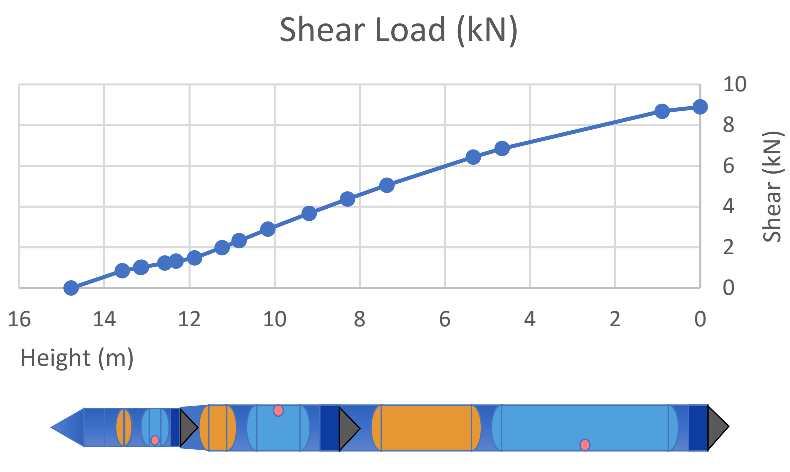


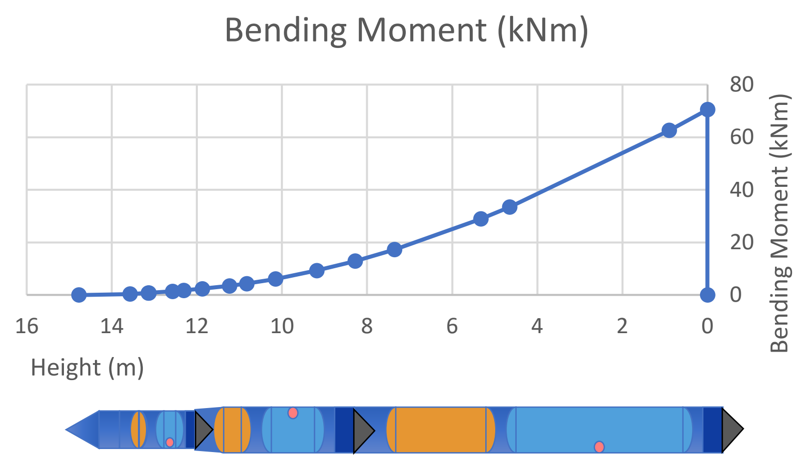


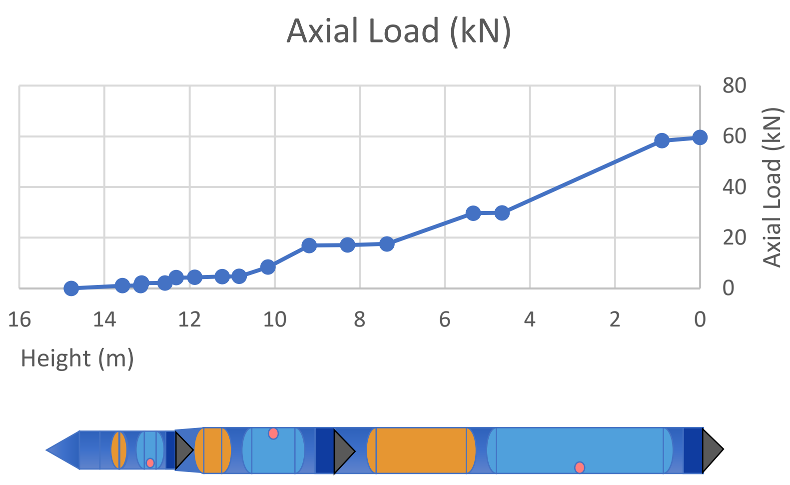
- Max shear ends close to 0
- Max bending moment ends close to 0
- Max axial load is equal to the thrust
  - 83.4 kN

Minerva-2 Ground Loads Analysis

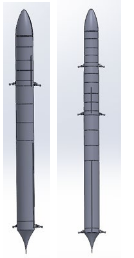




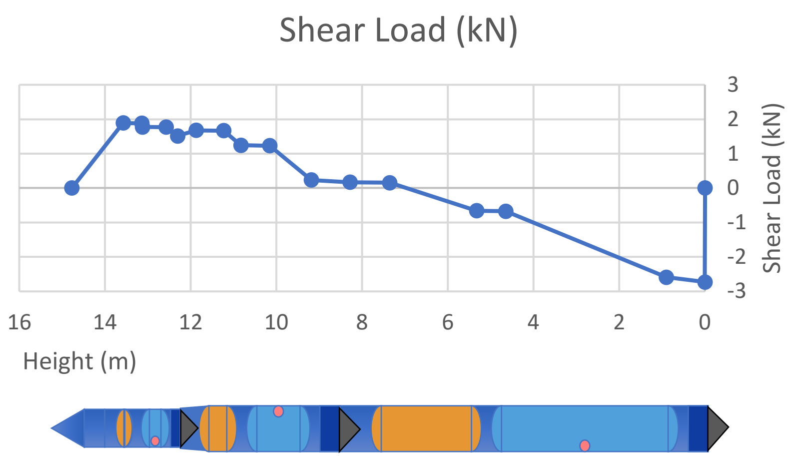


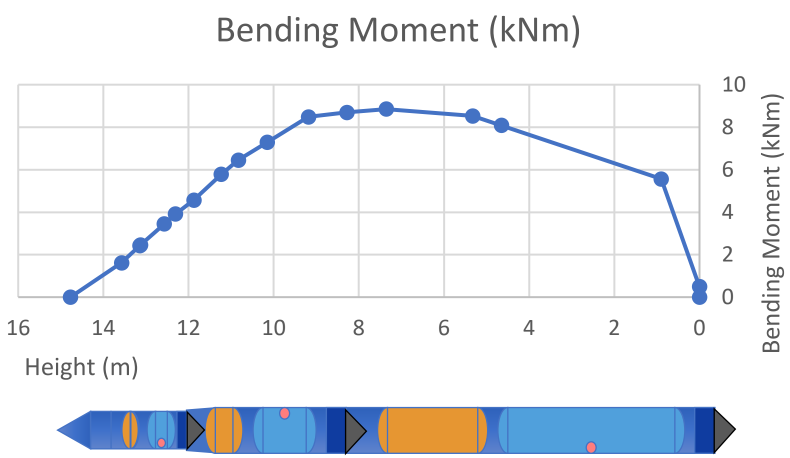


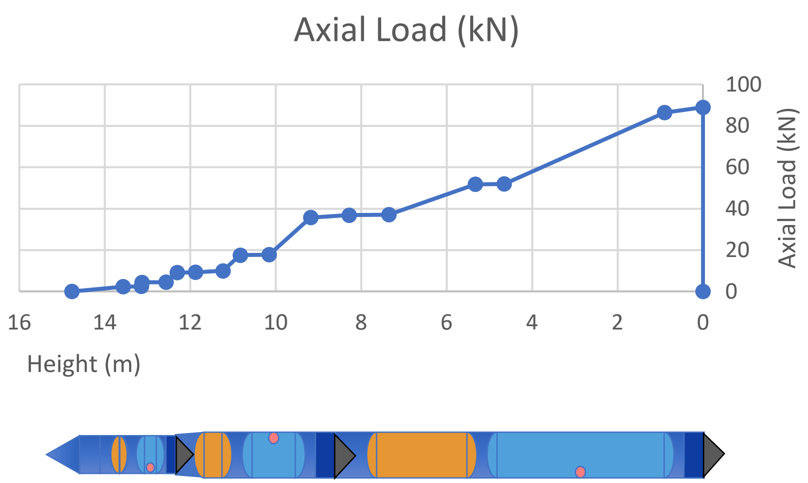
- Max shear is at the aft skirt
  - 8.9 kN
- Max bending moment is at the aft skirt
  - 70.5 kNm
- Max axial load is equal to the weight
  - 59.4 kN



Minerva-2 Max-q Loads Analysis

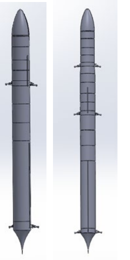






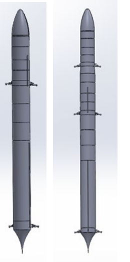
- Shear load ends at 0
- Bending moment ends near 0
- Max axial load is equal to the thrust
    - 88.9 kN

Minerva Manufacturing: Material Selection



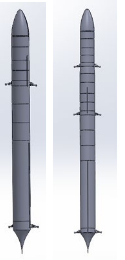
Launch Vehicle Component	Material	Coating
Cryogenic Propellant Tanks	Aluminum 2014-T6	Zinc Chromate
Non-Cryogenic Propellant Tanks	Aluminum 7075-T6	Zinc Chromate
Non-Pressurized Body Components	Aluminum 7075-T6	Zinc Chromate
Payload Fairing	Aluminum 2219-T852	Zinc Chromate

Minerva 1 –Margin of Safety on Ground



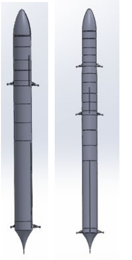
			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal**	**MS (%) Hoop**	**MS (%) Buckling**
1	Forward Skirt	1	18,599	75,404	1,264
2	Stage 2 Fuel Tank	1	5,090	62,979	328
4	Stage 2 Ox Tank	1	2,170	2,479	72
5	Interstage	1	2,083	2,463	**59**
6	Stage 1 Fuel Tank	1.5	3,262	3,490	333
8	Stage 1 Ox Tank	1.5	**1,975**	**1,189**	397
9	Aft Skirt	1.9	2,876	1,523	624

Minerva 1 –Margin of Safety at Max-q



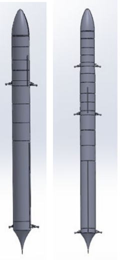
			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal**	**MS (%) Hoop**	**MS (%) Buckling**
1	Forward Skirt	1	31,512	162,485	2,002
2	Stage 2 Fuel Tank	1	9,823	116,154	1,172
4	Stage 2 Ox Tank	1	3,494	15,671	310
5	Interstage 1	1	2,766	5,419	66
6	Stage 1 Fuel Tank	1.5	1,639	4,088	352
8	Stage 1 Ox Tank	1.5	**657**	**1,827**	124
9	Aft Skirt	1.9	770	2,348	**50**

Minerva 2 –Margin of Safety on Ground



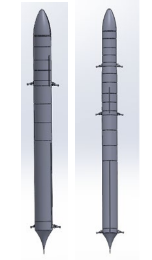
			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal**	**MS (%) Hoop**	**MS (%) Buckling**
1	Forward Skirt	1	14,780	24,612	1,113
2	Stage 3 Fuel Tank	1	9,166	13,217	**6,633**
4	Stage 3 Ox Tank	1	5,259	6,311	653
5	Interstage 2	1	4,705	6,204	275
6	Stage 2 Fuel Tank	1	2,974	3,946	139
8	Stage 2 Ox Tank	1	1,837	1,893	260
9	Interstage 1	1	**1,783**	1,831	**43**
10	Stage 1 Fuel Tank	1.5	2,691	1,964	251
11	Stage 1 Ox Tank	1.5	2,266	**1,106**	330
12	Aft Skirt	1.9	2,863	2,863	526

Minerva 2 –Margin of Safety at Max-Q

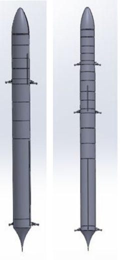


			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal**	**MS (%) Hoop**	**MS (%) Buckling**
1	Forward Skirt	1	95,744	51.950	3,541
2	Stage 3 Fuel Tank	1	45,164	27,968	**181,080**
4	Stage 3 Ox Tank	1	20,401	13,590	1,121
5	Interstage 2	1	14,699	13,359	597
6	Stage 2 Fuel Tank	1	7,253	14,788	842
8	Stage 2 Ox Tank	1	3,339	4,106	415
9	Interstage 1	1	2,376	4,064	**39**
10	Stage 1 Fuel Tank	1.5	1,558	3,497	88
11	Stage 1 Ox Tank	1.5	**648**	**1,688**	112
12	Aft Skirt	1.9	762	2,176	48

Minerva Attitude Control System

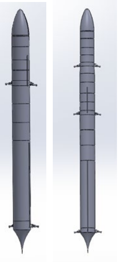


- Minerva will use vernier engines for its ACS
- Minerva-1:
  - 2 Verniers at the bottom of all stages
  - Based on LR101-NA-7
  - Scaled down to produce 1.6 kN of thrust
  - Controllability ratio of 2.00
  - Time to double of 1.19s
- Minerva-2:
  - Will use same verniers as Minerva-1 for all stages
  - Controllability ratio of 2.05
  - Time to double of 1.48s



Minerva End of Mission

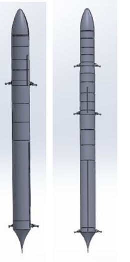
- EOM disposal:
  - Minerva's Stage 1 will be retrieved to be refurbished
  - Subsequent stages will burn up on re-entry
- Recovery operations:
  - Minerva's 1st stage will be recovered by parachute deployment and helicopter capture
  - It will be sent off for cleaning, repair/replacement checks, and testing before being cleared for flight



Minerva Fault Analysis

- Minerva-1 and -2 all have one engine per stage, which means OEI will end mission
- To mitigate this risk, the likelihood of OEI shall be confirmed to be below 1/1000 (based on Merlin 1D reliability statistic)

Minerva Preliminary Cost Estimation

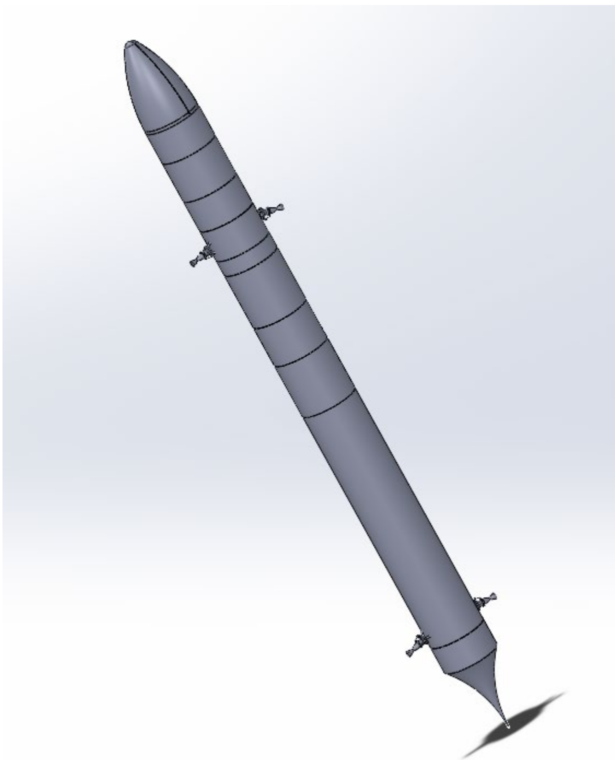


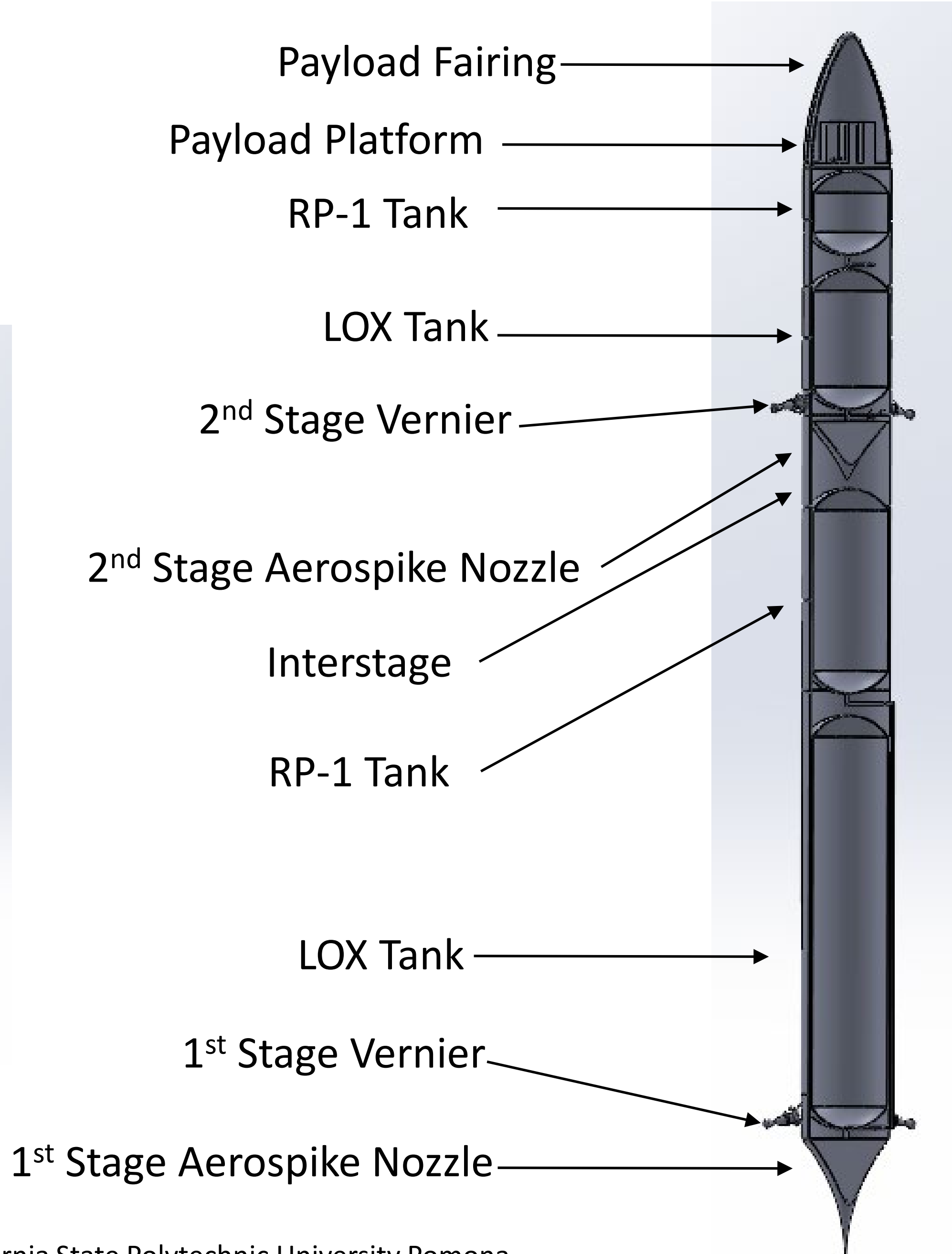
Source: *Handbook of Cost Engineering for Space Transportation Systems* including TRANSCOST 8.1 (2010)

Methodology: Cost Estimating Relationships output Work-Years→ convert to 2010 dollars→ convert to 2021 dollars

Preliminary cost estimation for the Minerva Program: **$21.9 B**

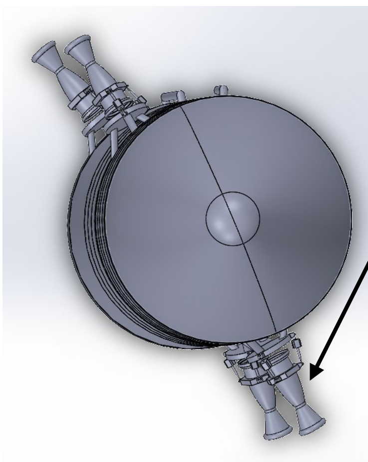
Minerva-1 3D Model





Minerva-1 3-View

Vernier Engine Gimbal

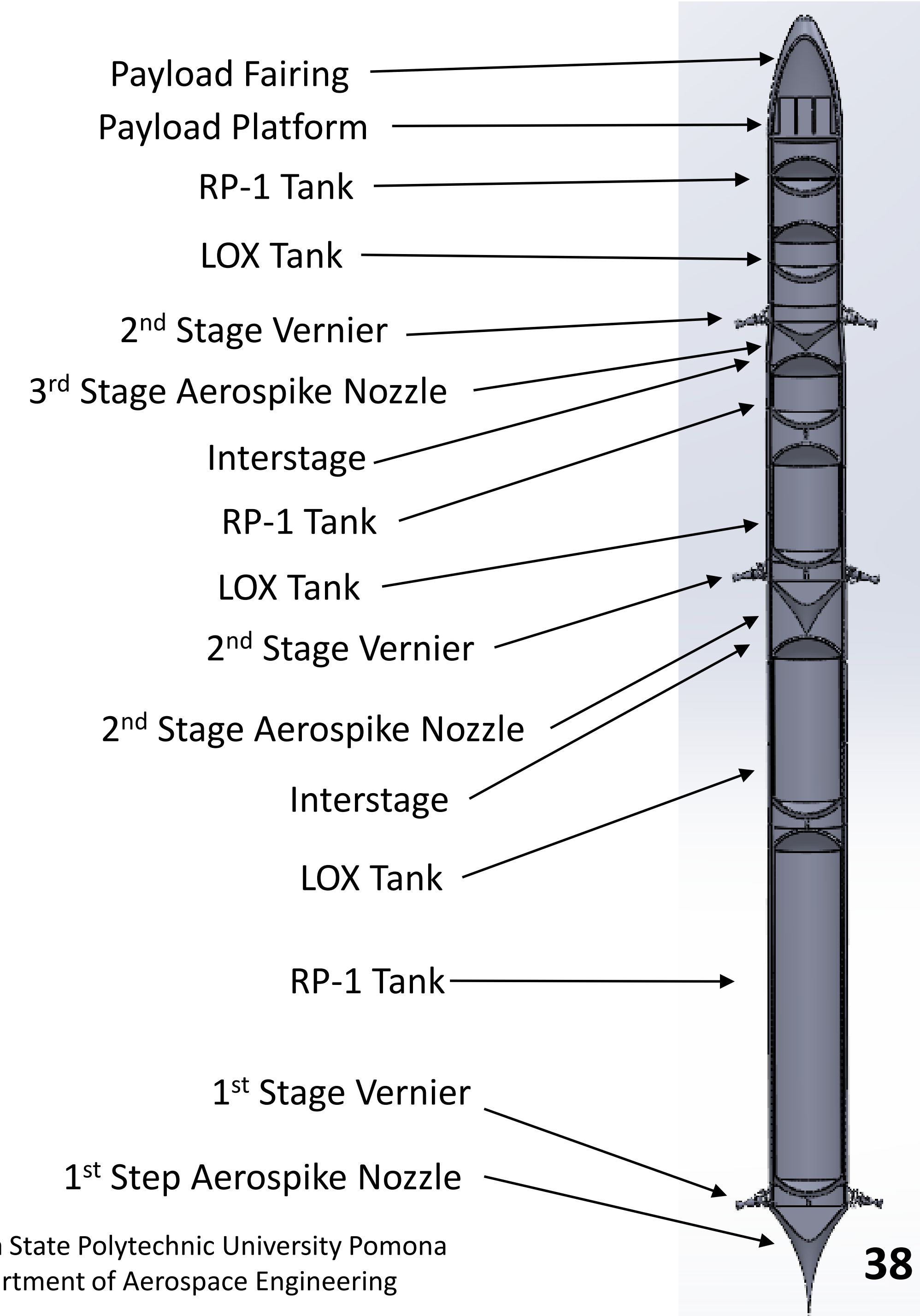


Top View

Bottom View

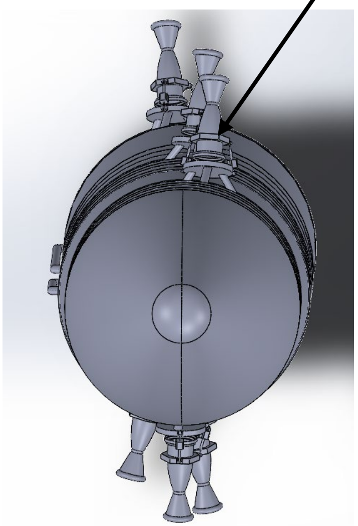
Front View

Minerva-2 3D Model

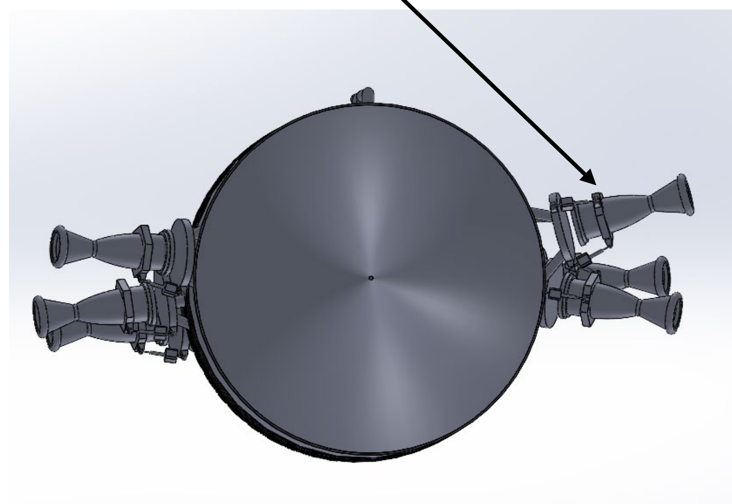


Minerva-2 3-View

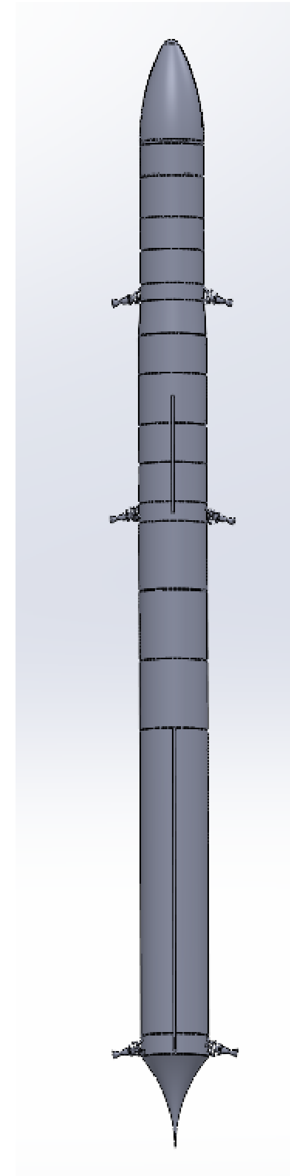
Vernier Engine Gimbal



Top View



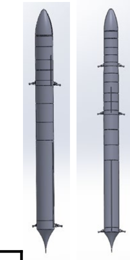
Bottom View



Front View

California State Polytechnic University Pomona
Department of Aerospace Engineering

Minerva Summary



	Stage 1	Stage 2	Stage 3
Diameter (m)	0.9	0.9	0.74
Length (m)	8.28	4.45	2.90
Engine Type	Liquid Propellant Aerospike	Liquid Propellant Aerospike	Liquid Propellant Aerospike
Propellant	RP-1/LOX	RP-1/LOX	RP-1/LOX
I_{sp} (s)	296	359	359
Propellant Mass (kg)	3980	1200	305
Dry Mass (kg)	310	115	60
Structural Ratio	0.11	0.11	0.11
T/W	1.4	1.05	0.9
GLOM (kg)	6075		

Architecture 2: Latona

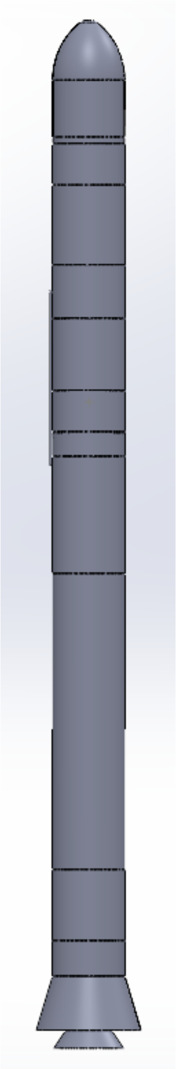
Staging possibilities:

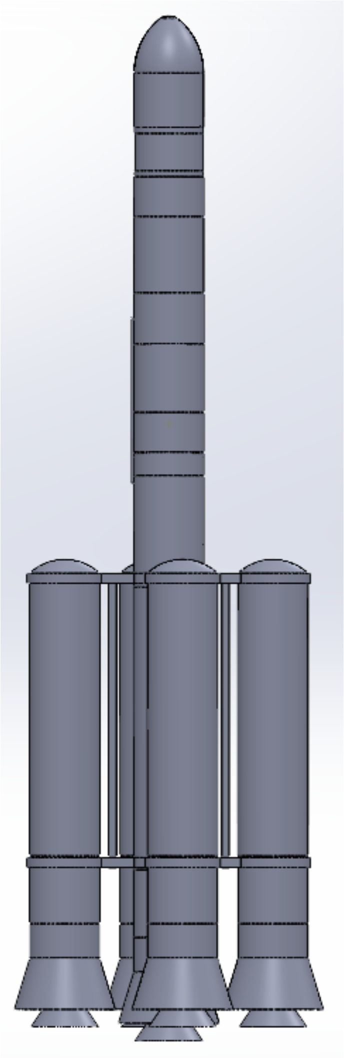
- TSTO to accommodate Mission 1
- 4 Parallel SRBs to accommodate the extra Δv for Mission 2

Propellant Choices:

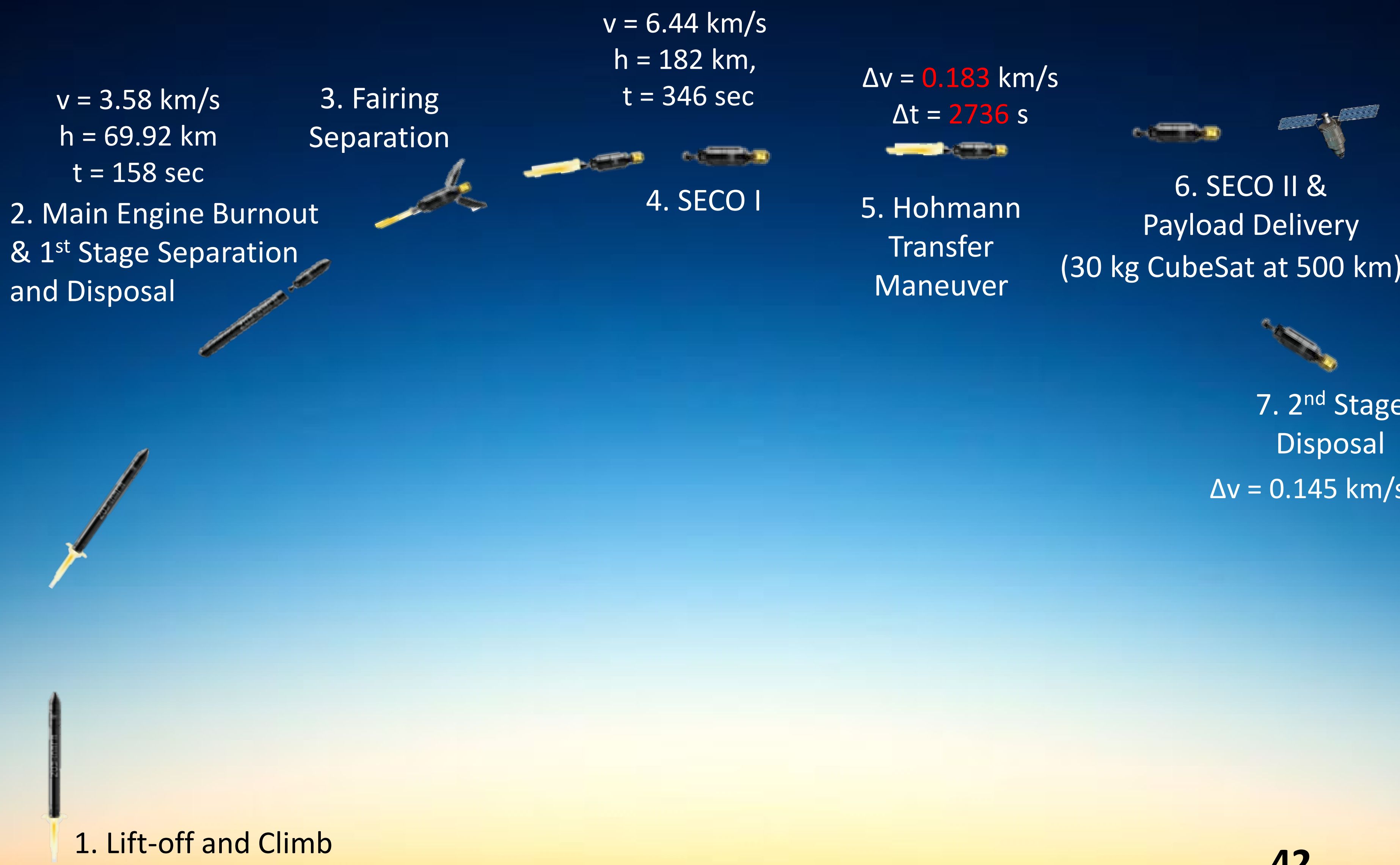
- 1st stage (and SRBs) solid propellant: ammonium perchlorate composite (using AP for oxidizer, Al for fuel, and HTPB for binder)
  - Wide ambient temperature limits, good burn-rate control, good storage stability
- 2nd Stage liquid propellants: LCH_4/LO_2
  - Higher performance/I_{sp} → less quantity of methane required for lift off → smaller tanks →mass savings

Nozzle Choice: bell nozzle for all stages

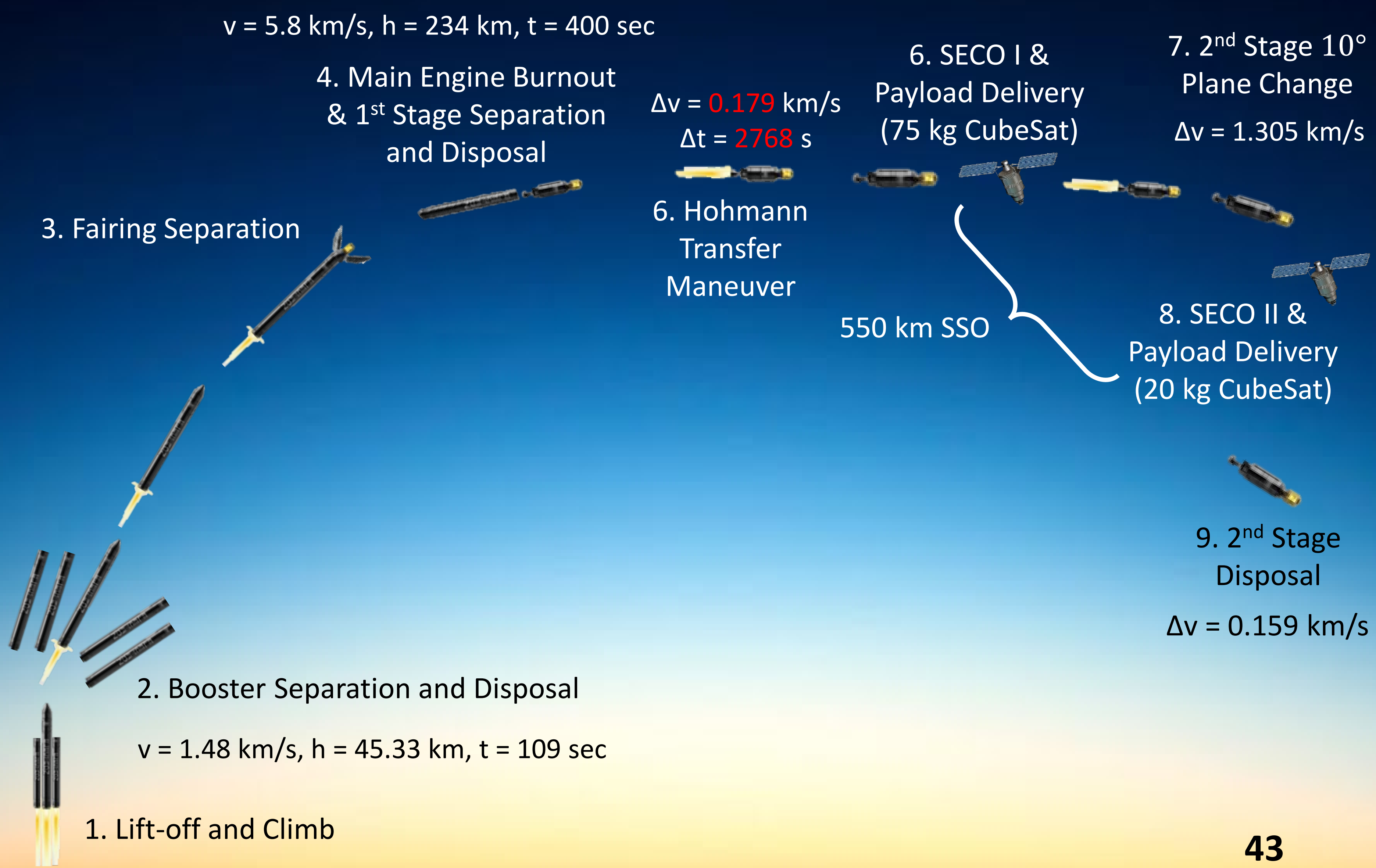




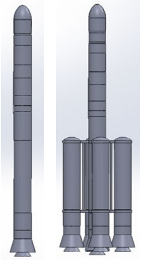
Latona Mission 1



Latona Mission 2



Latona Design Specifications

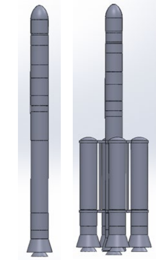


Architecture	Mission 1 Thrust (kN)	Mission 2 Thrust (kN)	I_{sp} (sec)	Structural Mass Fraction σ
Latona Stage 0 (Sea Level)	N/A	81.8	265*	0.08
Latona Stage 1 (Sea Level)	21.1	21.1	265*	0.08
Latona Stage 2 (Vacuum)	2.8	3.0	380**	0.11

* Solid propellant motors for its main engine and 4 strap-on boosters

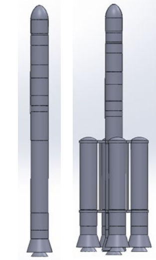
**Latona will have a Raptor-type engine for its 2^{nd} stage

Latona LV Family Methodology



- Solved for the minimum mass of Mission 1
- Used the mass of propellants for Mission 2
- Set up a system of equations based off %Δv for Stage 0 and %Δv for Stage 1 to solve numerically for the values

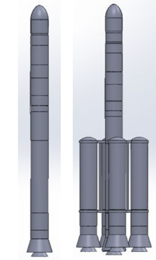
Latona Lift-Off Mass Estimates



	Mission 1 (kg)	Mission 2 (kg)
Stage 2	272.4	337.4
Stage 1	1269.6	1269.6
Stage 0	N/A	4319.6
Total	1542.0	5926.6

- Latona has SRBs for Mission 2
- Upper-most stage mass includes payload

Latona Transfer Orbit Descriptions

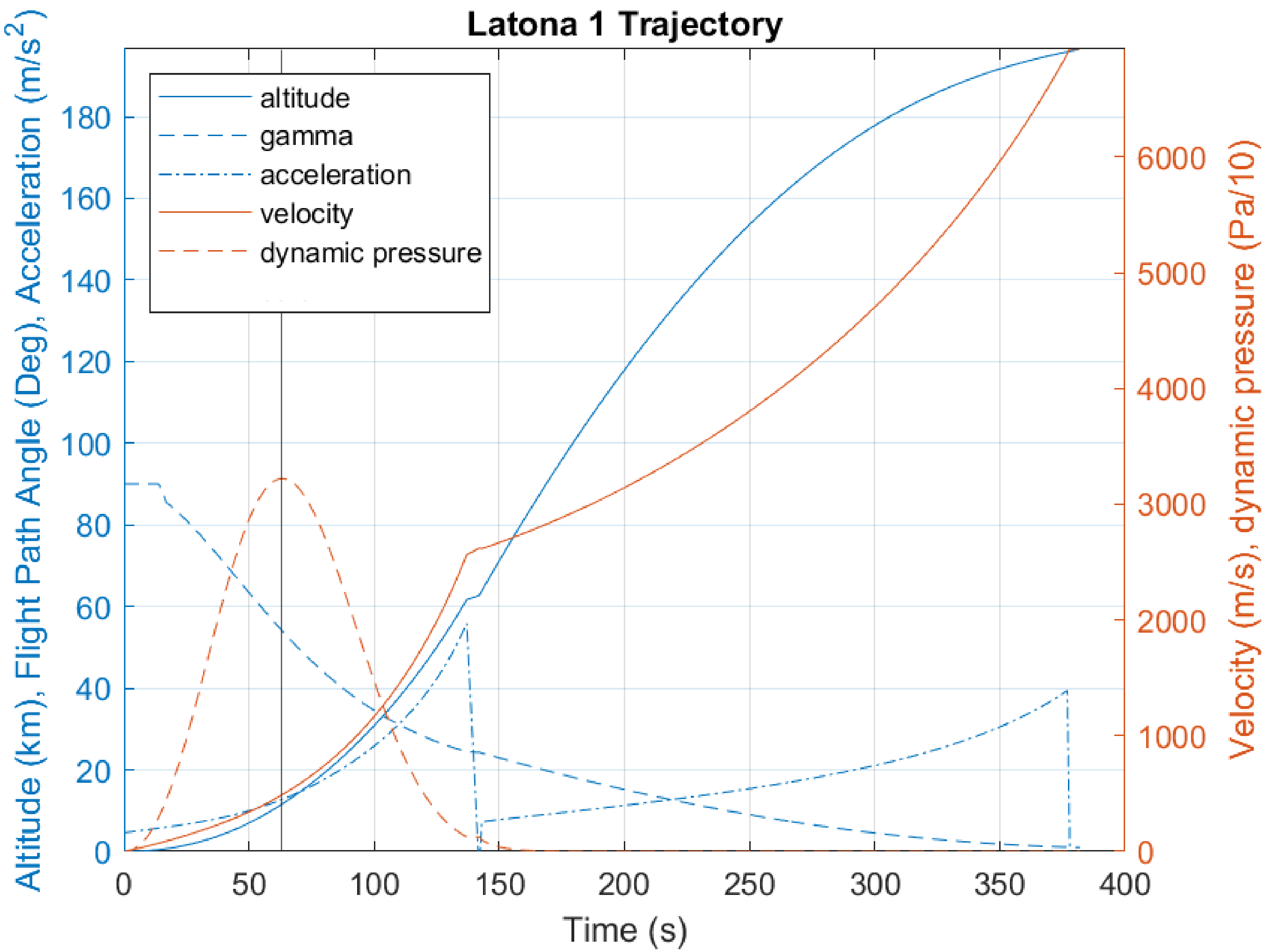


Below are the conditions at end of powered ascent phase.

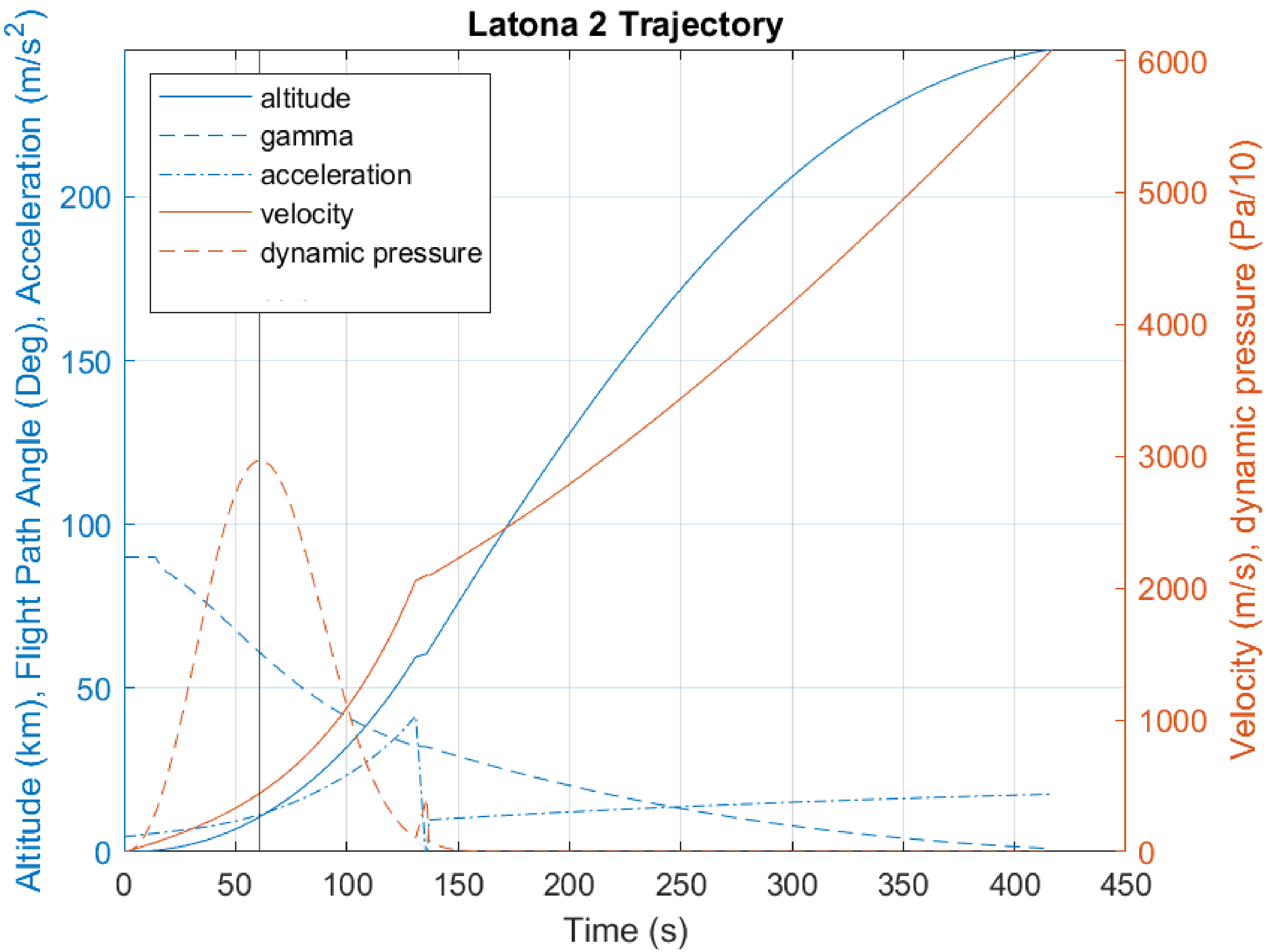
	Latona 1	Latona 2
Altitude (km)	196.5	293.2
Velocity (km/s)	6.93	7.47

Following this, an appropriate kick burn is applied that effectively circularizes and enters the Hohmann Transfer.

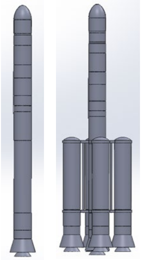
Latona-1 Trajectory

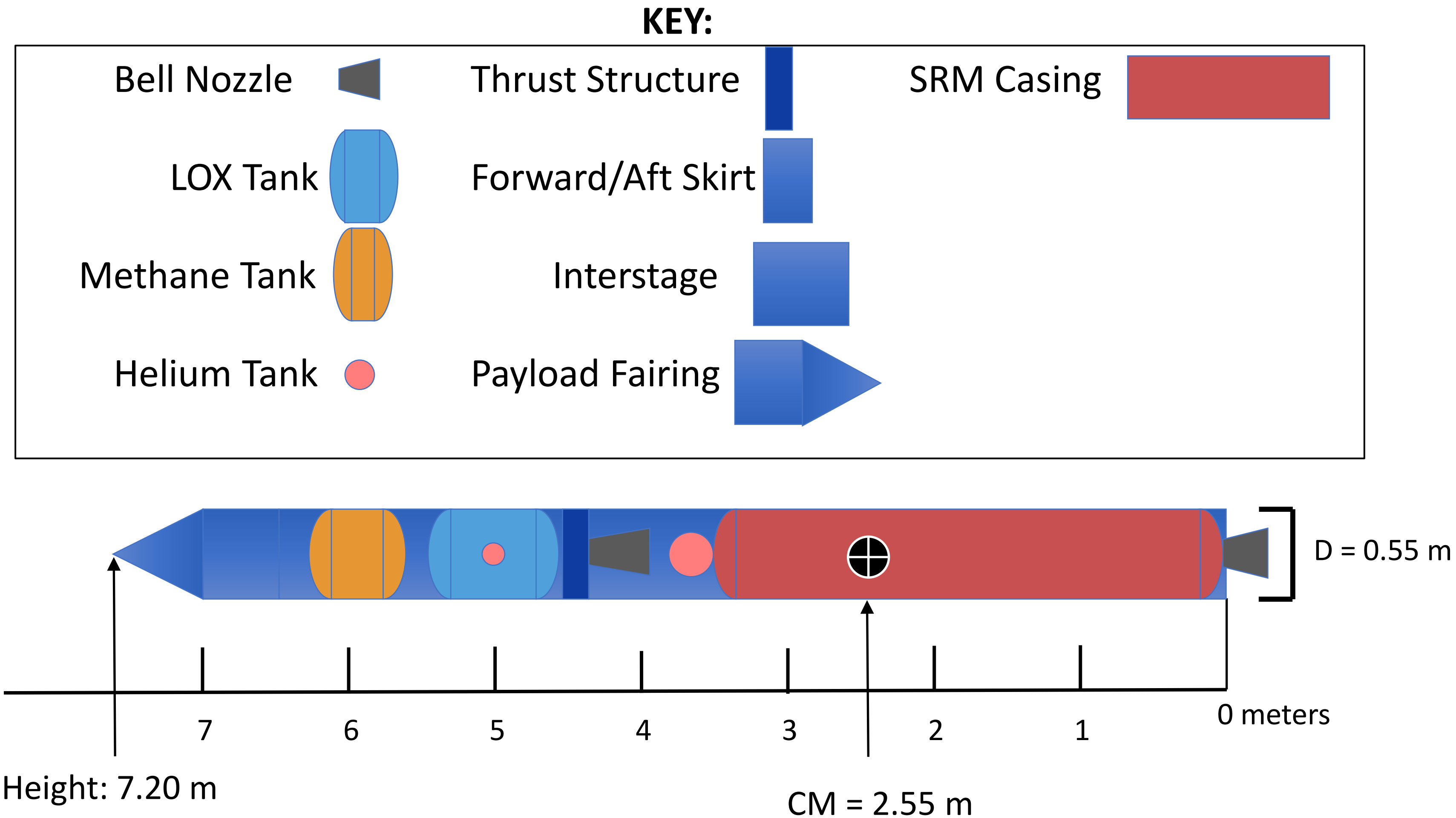


Latona-2 Trajectory

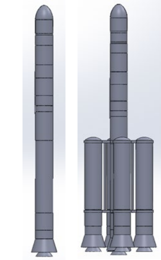


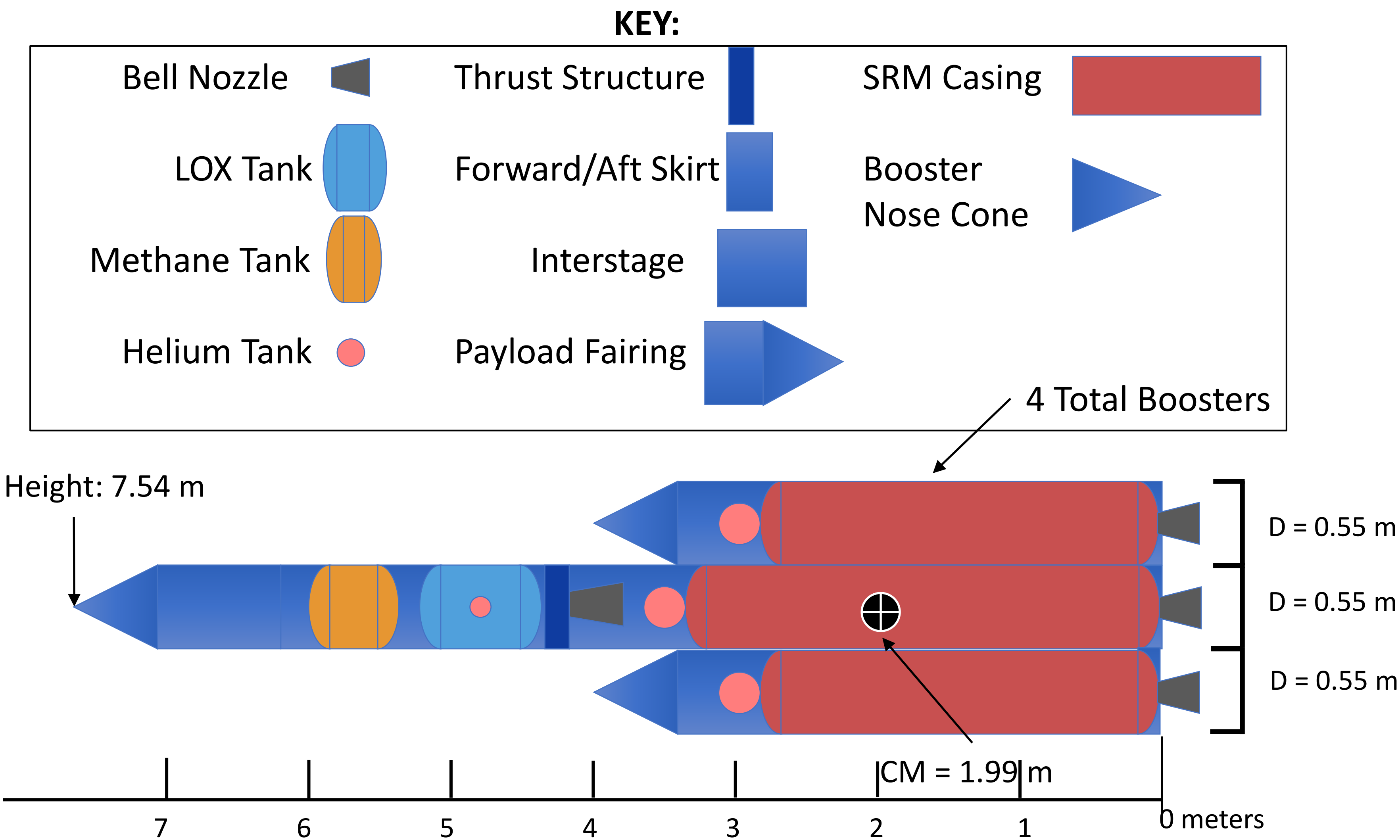
Latona-1 Diagram



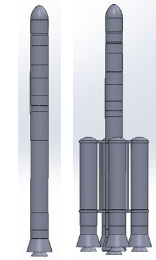


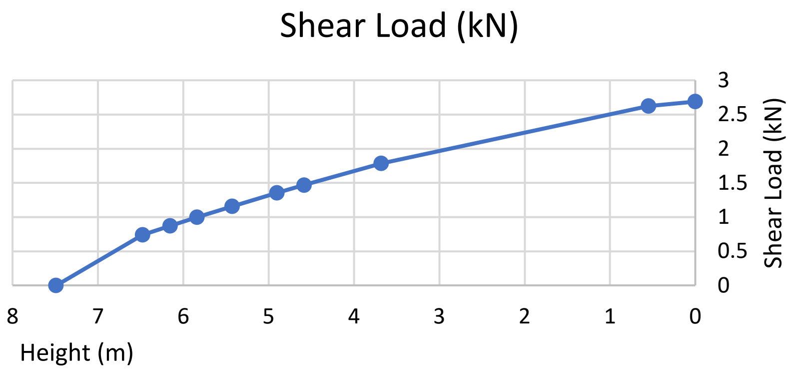
Latona-2 Diagram

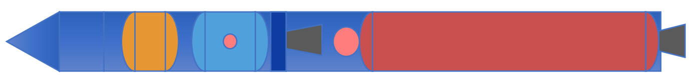


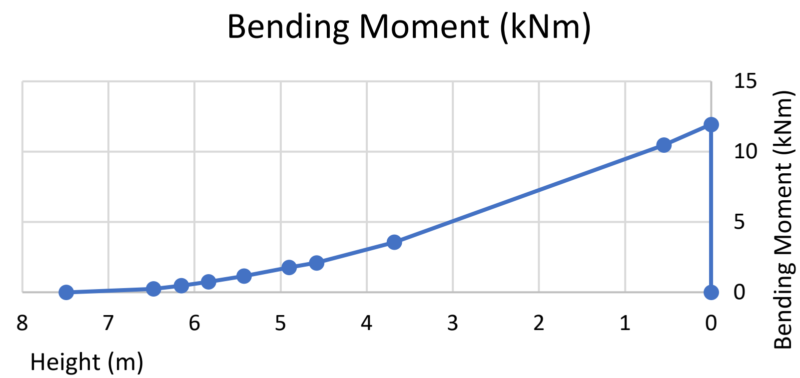


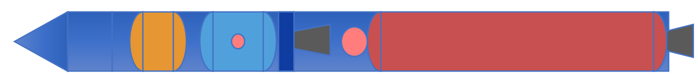
Latona-1 Ground Loads Analysis

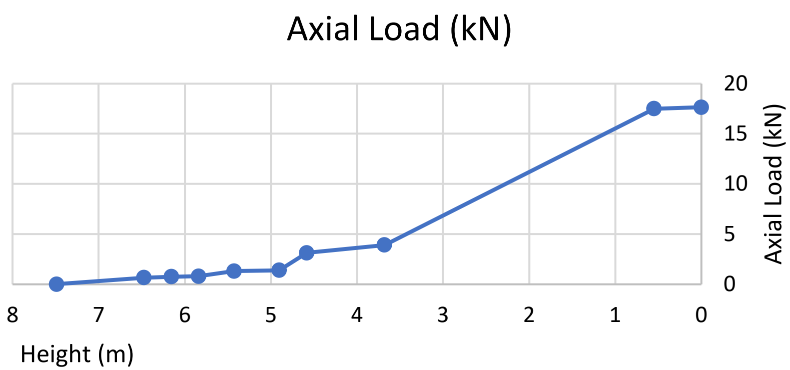


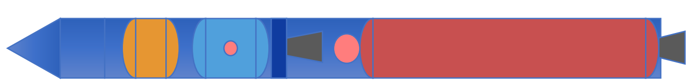




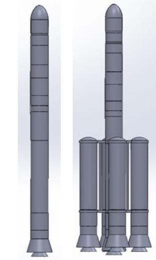




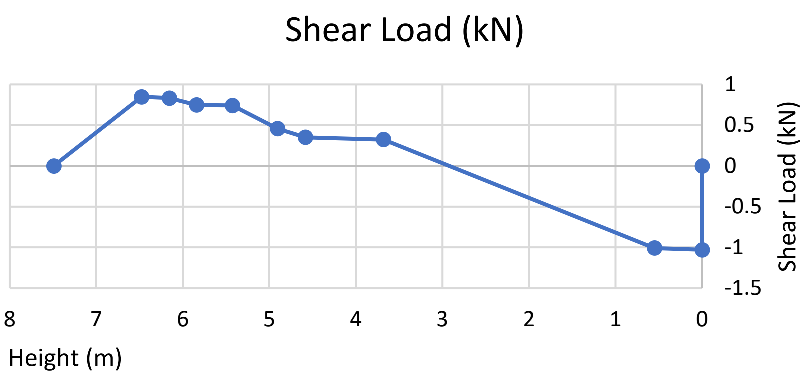


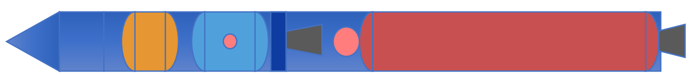


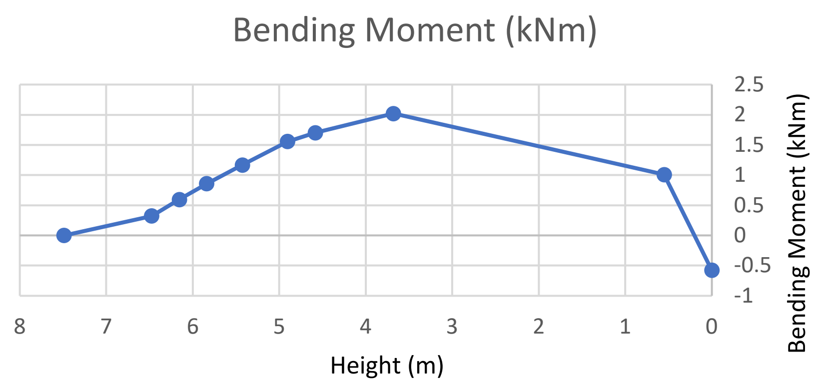
- Max shear is at the aft skirt
  - 2.7 kN
- Max bending moment is at the aft skirt
  - 11.9 kNm
- Max axial load is equal to the weight
  - 17.6 kN

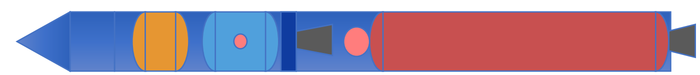


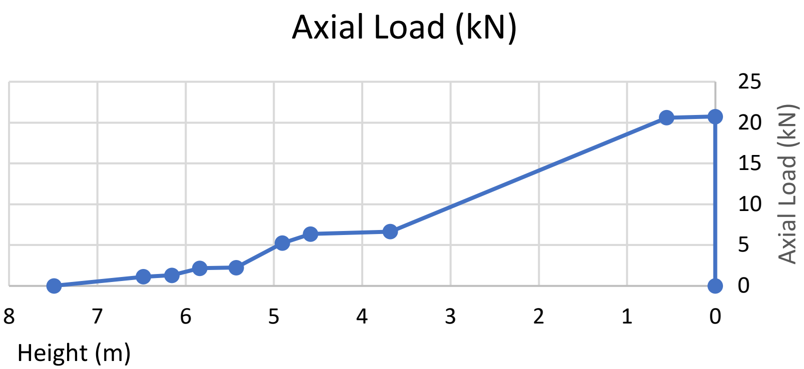
Latona-1 Max-q Loads Analysis

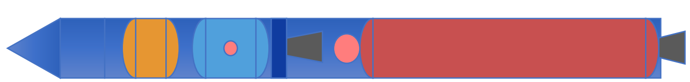




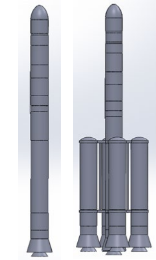




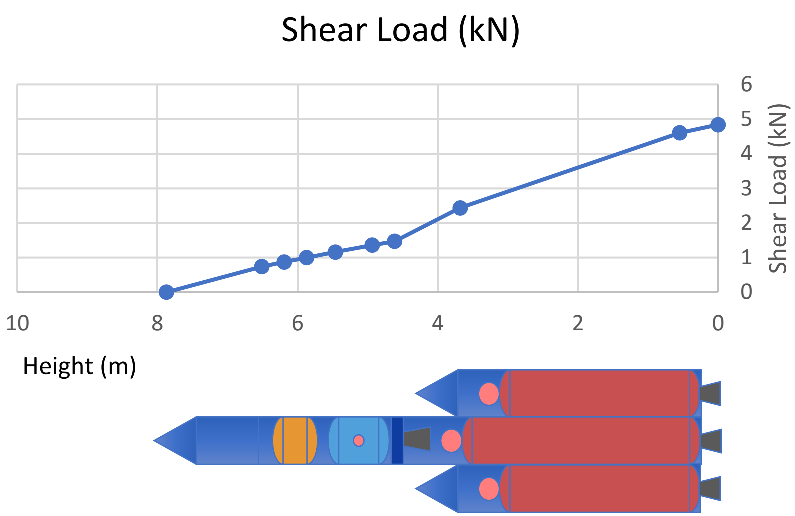


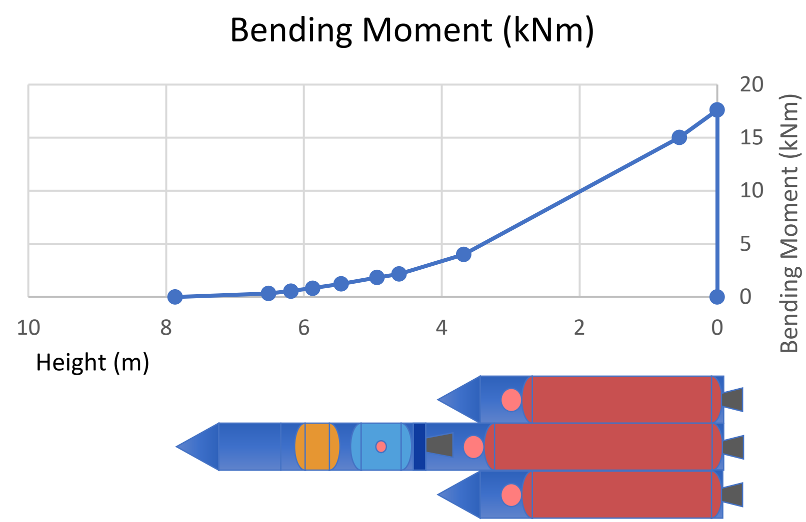


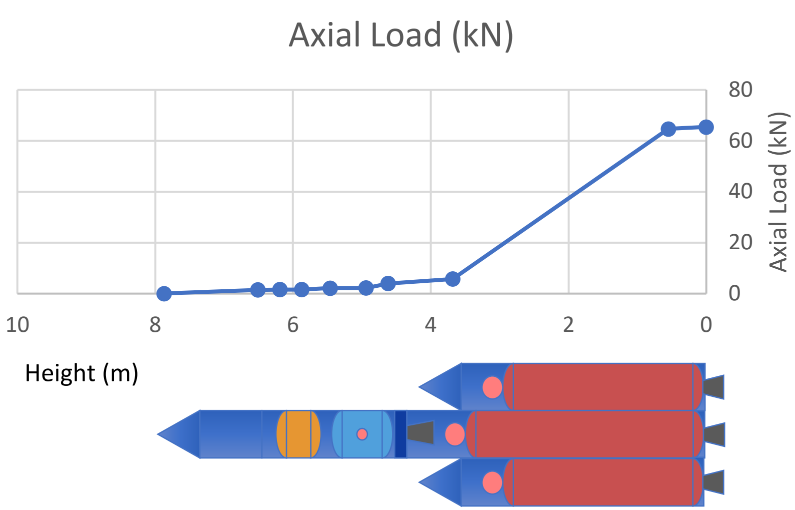
- Max shear ends at 0
- Max bending moment ends close to 0
- Max axial load is equal to the thrust
  - 20.7 kN



Latona-2 Ground Loads Analysis

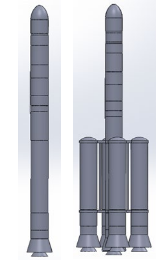




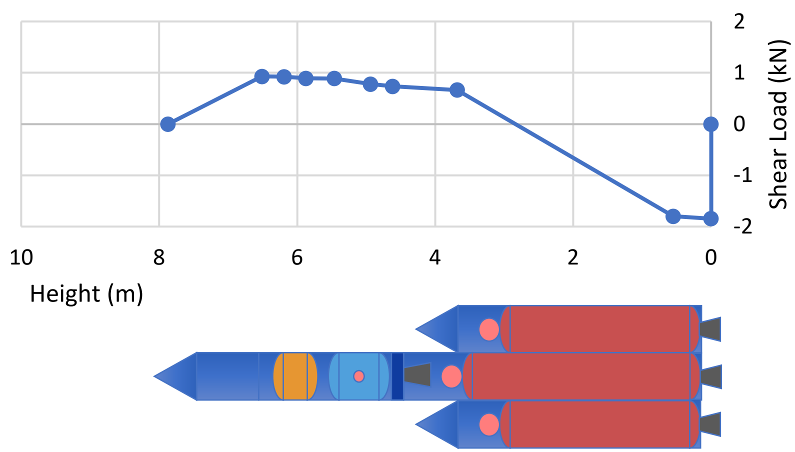


- Max shear is at the aft skirt
  - 4.8 kN
- Max bending moment is at the aft skirt
  - 17.6 kNm
- Max axial load is equal to the weight
  - 65.4 kN

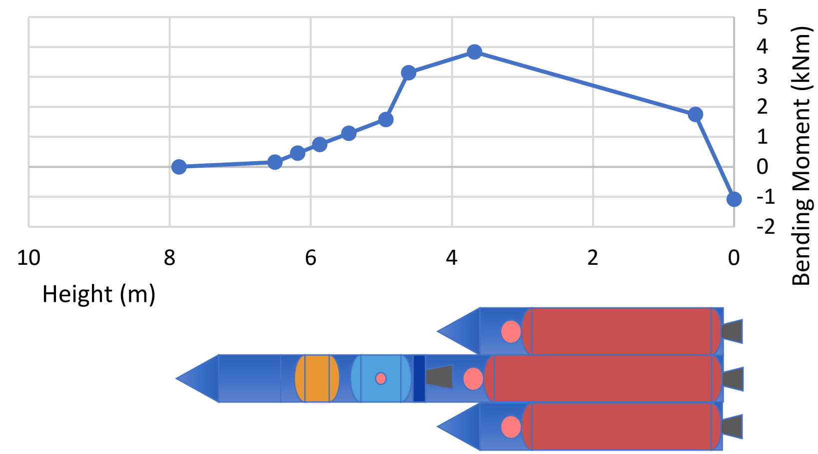
Latona-2 Max-q Loads Analysis



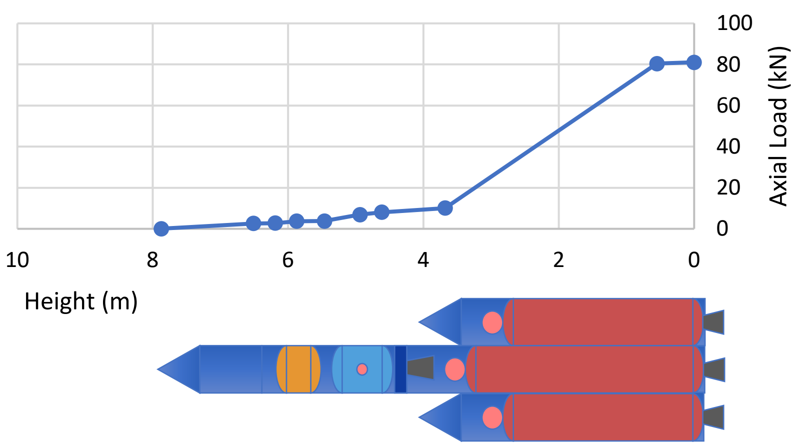
Shear Load (kN)



Bending Moment (kNm)

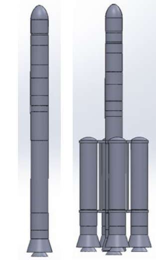


Axial Load (kN)

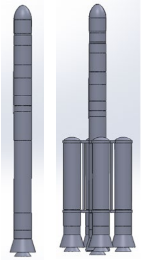


- Max shear ends at 0
- Max bending moment ends close to 0
- Max axial load is equal to the thrust
  - 81.0 kN

Latona Manufacturing: Material Selection



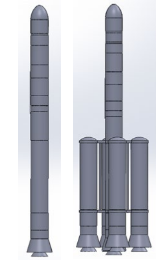
Launch Vehicle Component	Material	Coating
Cryogenic Propellant Tanks	Aluminum 2014-T6	Zinc Chromate
Non-Cryogenic Propellant Tanks	Aluminum 6061-T6	None
Non-Pressurized Body Components	Aluminum 6061-T6	None
Payload Fairing	Aluminum 2219-T852	Zinc Chromate



Latona 1 –Margin of Safety on Ground

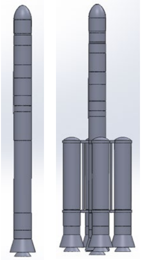
			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal**	**MS (%) Hoop**	**MS (%) Buckling**
1	Forward Skirt	1	13,659	21,254	3,962
2	Stage 2 Fuel Tank	1	9,906	19,402	1,710
3	Stage 2 Ox Tank	1	5,024	8,024	795
4	Interstage	1	2,446	3,665	652
5	Stage 1 SRM Casing	1	**1,607**	1,060	**563**
6	Aft Skirt	1.5	1,813	**1,051**	750

Latona-1 –Margin of Safety at Max-q



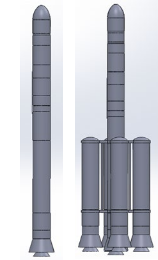
			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal Stress**	**MS (%) Hoop Stress**	**MS (%) Buckling Stress**
1	Forward Skirt	1	26,115	36,135	5,584
2	Stage 2 Fuel Tank	1	23,979	55,512	2,776
3	Stage 2 Ox Tank	1	6,475	30,557	1,128
4	Interstage	1	3,025	7,517	660
5	Stage 1 SRM Casing	1	**526**	**1,266**	465
6	Aft Skirt	1.5	724	1,934	**287**

Latona 2 –Margin of Safety on Ground



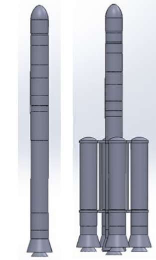
			MS Against Yielding		
Num	**Component**	**Thickness (mm)**	**MS (%) Longitudinal Stress**	**MS (%) Hoop Stress**	**MS (%) Buckling Stress**
1	Forward Skirt	1	12,636	9,131	3,660
2	Stage 2 Fuel Tank	1	9,106	11,346	1,863
3	Stage 2 Ox Tank	1	4,513	6,085	854
4	Interstage	1	1,443	2,871	356
5	Stage 1 SRM Casing	1	**412**	**197**	**344**
6	Aft Skirt	1.5	705	343	452

Latona-2 –Margin of Safety at Max-q

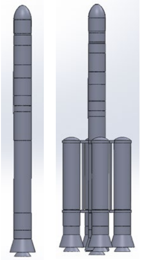


Num	Component	Thickness (mm)	MS Against Yielding: MS (%) Longitudinal Stress	MS Against Yielding: MS (%) Hoop Stress	MS (%) Buckling Stress
1	Forward Skirt	1	19,391	16,148	3,497
2	Stage 2 Fuel Tank	1	13,869	26,023	2,250
3	Stage 2 Ox Tank	1	6,224	19,121	1,023
4	Interstage	1	2,919	5,932	613
5	Stage 1 SRM Casing	1	**336**	**270**	306
6	Aft Skirt	1.5	457	449	**109**

Latona Attitude Control System



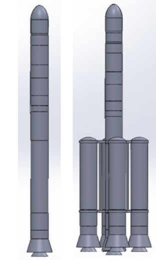
- Latona will use Thrust Vectoring
- Latona 1:
  - Max Gimbal Angle approximately 5.57°
  - Time to Double approximately 0.71 seconds
- Latona 2:
  - Max Gimbal Angle approximately 2.60°
  - Time to Double approximately 0.86 seconds
- Latona is designed for a Controllability Ratio of 2



Latona End of Mission

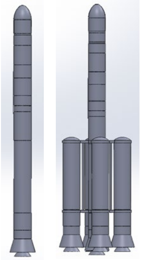
- EoM disposal: Latona will be entirely disposable
  - Stage 0 and Stage 1 will be disposed in the ocean.
  - Stage 2 will be disposed by deorbiting and burn up upon reentry.

Latona Fault Analysis



- Latona-1 has one engine per stage, which means OEI will end mission
- Despite Latona-2 having 4 boosters on its 1st stage, OEI will also end mission because the engines are not redundant (stage 2 has 1 engine)
- To mitigate this risk, the likelihood of OEI shall be confirmed to be below 1/1000 (based on Merlin 1D reliability statistic)

Latona Preliminary Cost Estimation

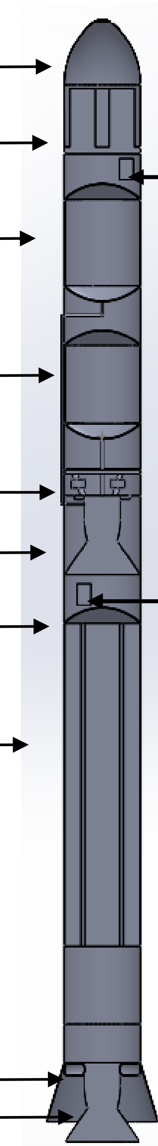


Source: *Handbook of Cost Engineering for Space Transportation Systems* including TRANSCOST 8.1 (2010)

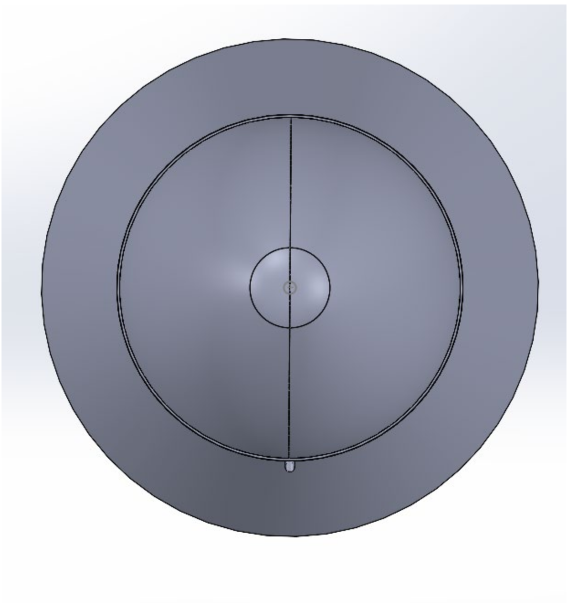
Methodology: Cost Estimating Relationships output Work-Years→ convert to 2010 dollars→ convert to 2021 dollars

Preliminary cost estimation for the Latona Program: **$4.94 B**

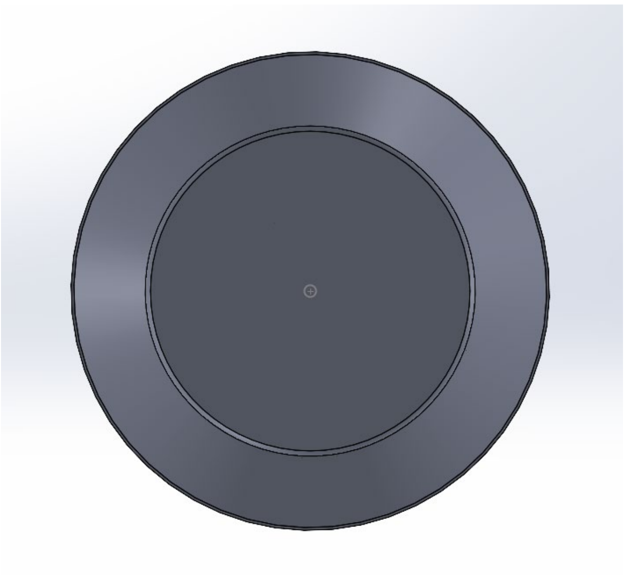
Latona-1 3D Model



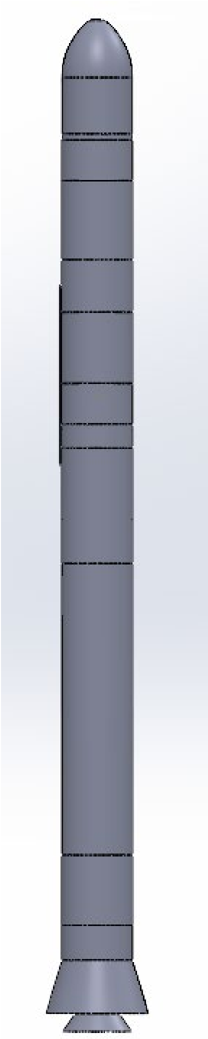
Latona-1 3-View



Top View

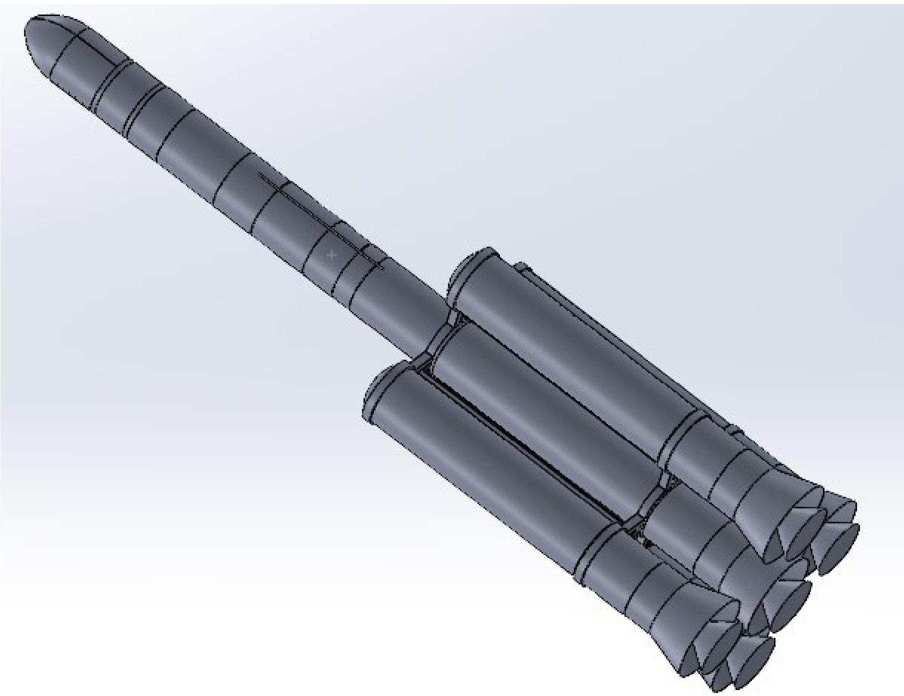


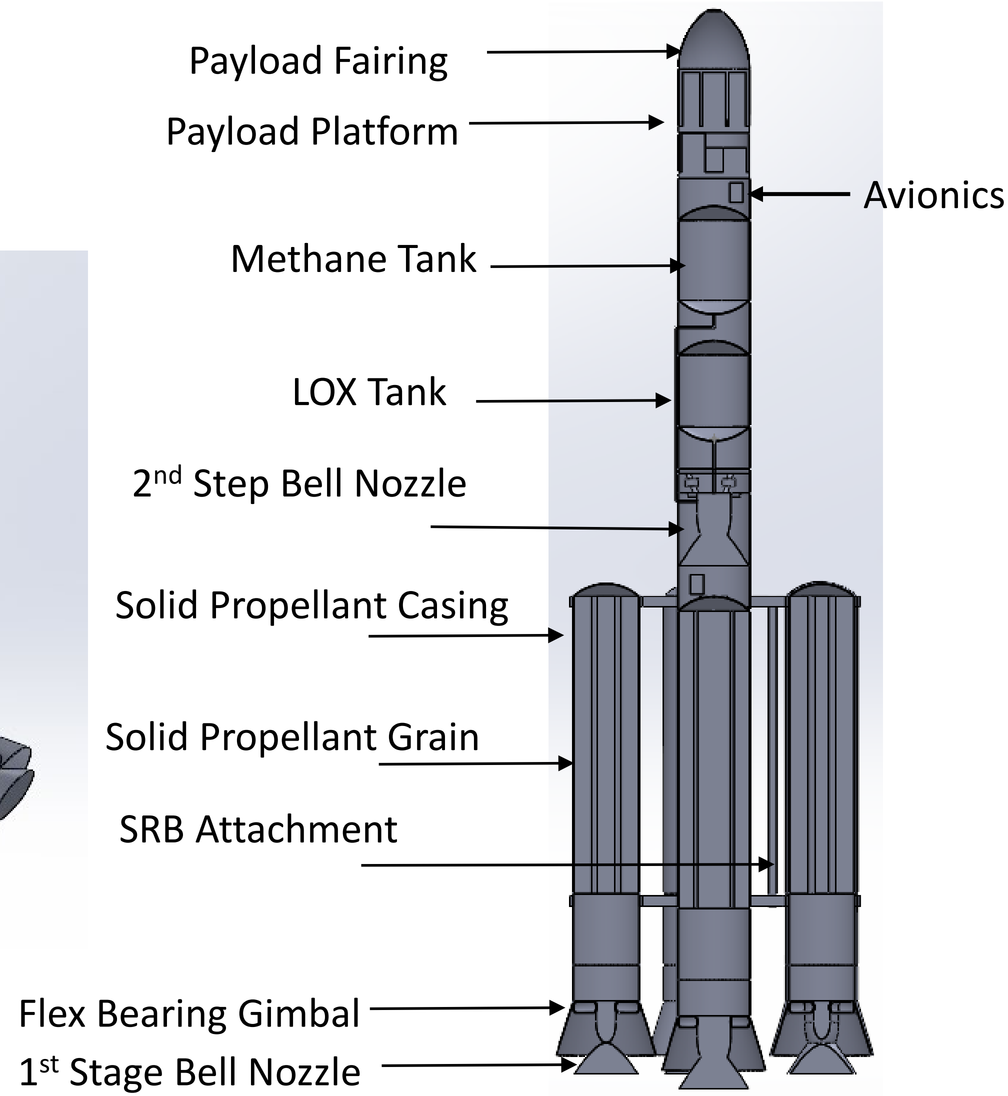
Bottom View



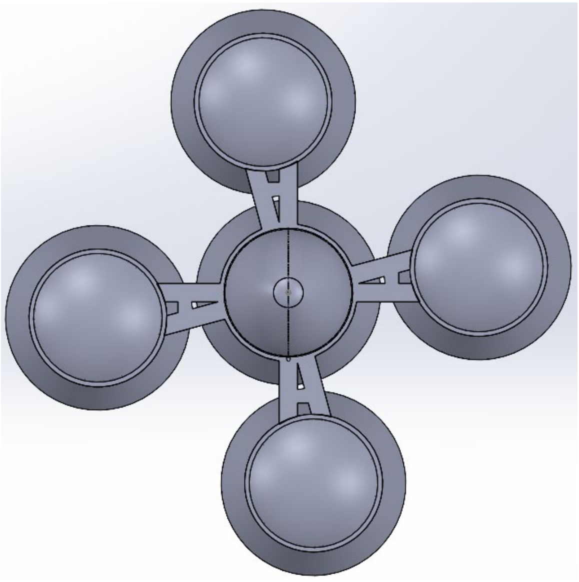
Front View

Latona-2
3D Model

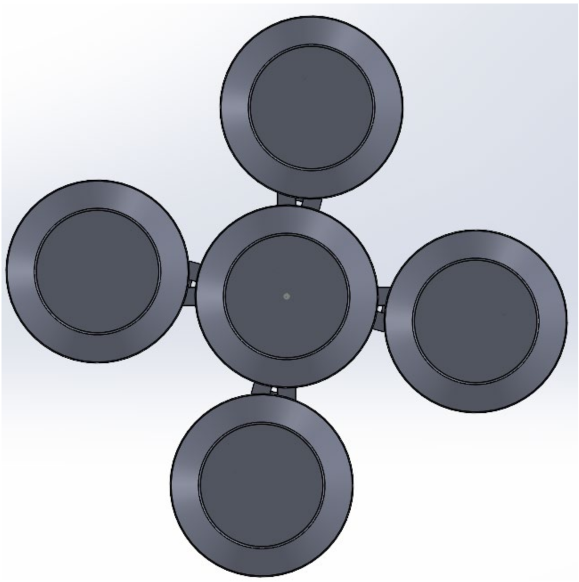




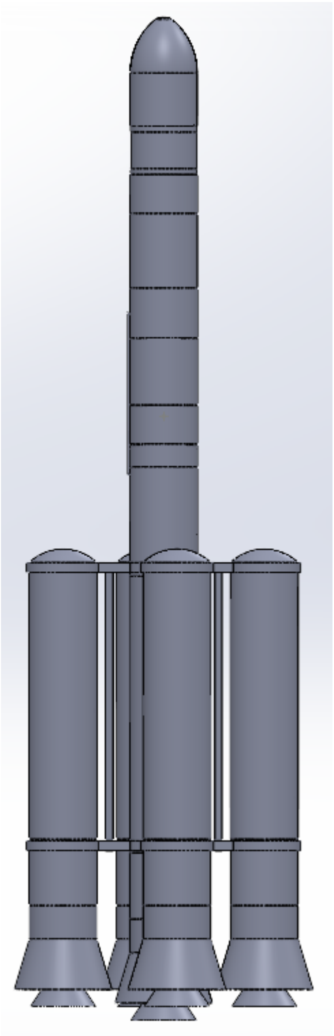
Latona-2 3-View



Top View

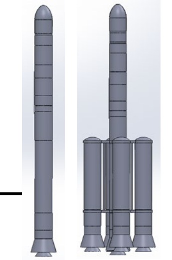


Bottom View



Front View

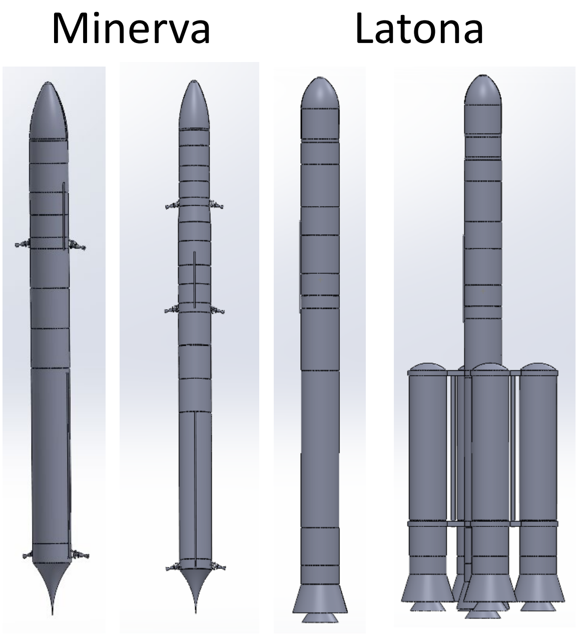
Latona Summary



	Stage 0	Stage 1	Stage 2
Diameter (m)	0.55	0.55	0.55
Length (m)	4.39	4.62	3.25
Engine Type	Solid Propellant Bell Nozzle	Solid Propellant Bell Nozzle	Liquid Propellant Bell Nozzle
Propellant	AP	AP	LCH_4/LOX
I_{sp} (s)	265	265	380
Propellant Mass (kg)	4000	1200	220
Dry Mass (kg)	1900	190	50
Structural Ratio	0.08	0.08	0.11
T/W	1.4	1.4	1.05
GLOM (kg)	7680		

Summary

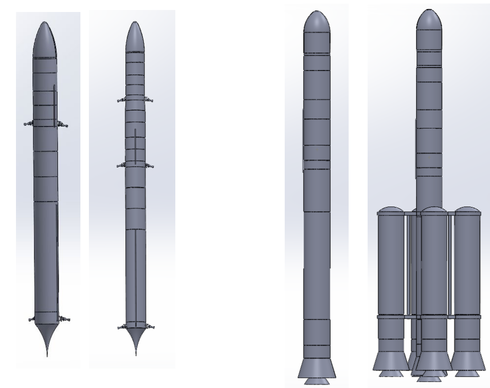
- Goal: Create a launch vehicle system capable of taking 30 kg payload to 500 km orbit and of taking 95 kg payload to 550 km SSO
- Minerva is an innovative, partially-reusable design that features aerospike nozzles and a modular third stage
- Latona is a more traditional design featuring classic bell nozzles and modular SRBs



Selection Criteria

- **Affordability**
  - Low Lifetime Costs
  - Competitive Price per Flight
- **Reliability**
  - Low remanufacturing or refurbishing time to stay on schedule
  - Low chance for mission failure
- **Feasibility**
  - Traditional manufacturing methods (tried-and-true)
  - Research and development time

Minerva Latona

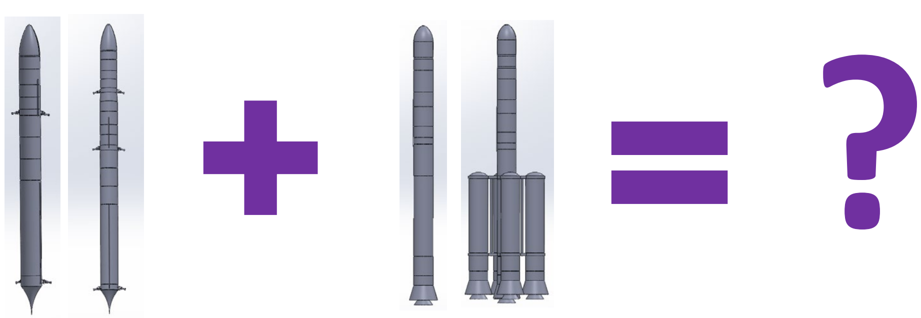


LV Comparison

- **Affordability**
  - Latona has a lower program cost than Minerva ~($4.94 B vs. $21.9 B)
- **Reliability**
  - Latona's parallel staging for Mission 2 has more failure modes compared to Minerva's series staging
- **Feasibility**
  - Minerva's aerospikes are more difficult to manufacture compared to Latona's bell nozzles
  - Minerva features a more experimental design compared to Latona (longer R&D time and cost)

New Architecture: Zephyr

- Will combine the best aspects of Minerva and Latona Architectures
  - Minerva series staging is preferable over Latona parallel staging
  - Latona bell nozzle engines are preferable over Minerva experimental aerospike engines
  - No first stage recovery



References

- [1] *Design of Rockets and Space Launch Vehicles* by Donald Edberg
- [2] *Handbook of Cost Engineering for Space Transportation Systems* (Revision 3a) including TRANSCOST 8.1
- [3] www.astronautix.com
- [4] *Rocket Propulsion Elements* (9^{th} ed.) by Sutton and Biblarz
- [5] https://www.usinflationcalculator.com/

BACK-UP

Minerva-1 Mass, Inertia, Loaded and Dry

Case	Mass (kg)	CM (m)	$J_{pitch/yaw}$ (kg m^2)	J_{roll} (kg m^2)
Empty Vehicle	602.8	5.6	13383	59
Fully Loaded Vehicle	4049.4	6.3	62128	59
Step 1 Dry, Step 2 Loaded	1798.8	8.9	42517	59
Step 2 Loaded Only	1441.5	10.6	35984	30
Step 2 Dry Only	245.3	10.5	6850	30
Step 1 Dry Only	357.3	3.9	6533	29

Minerva-2 Mass, Inertia, Loaded and Dry

Case	Mass (kg)	CM (m)	$J_{pitch/yaw}$ ($kg\ m^2$)	J_{roll} ($kg\ m^2$)
Empty Vehicle	786.0	7.7	27665	68
Fully Loaded Vehicle	4478.8	7.3	101551	68
Step 3 and 2 loaded, Step 1 dry	2288.8	10.28	70924	68
Step 3 and 2 Loaded	1924.0	11.8	62182	39
Step 3 Loaded, Step 2 dry	724.9	13.1	36300	39
Step 3 Loaded	557.0	14.1	33806	25
Step 3 Dry Only	253.3	14.3	16429	25
Step 1 Dry Only	364.7	3.9	39368	29

Latona-1 Mass, Inertia, Loaded and Dry

Case	Mass (kg)	CM (m)	$J_{pitch/yaw}$ (kg m^2)	J_{roll} (kg m^2)
Empty Vehicle	377.1	3.4	1420	22
Fully Loaded Vehicle	1252.0	2.768	3169	22
Step 1 Dry, Step 2 Loaded	598.7	4.1	2659	22
Step 2 Loaded Only	381.3	5.1	2504	7
Step 2 Dry Only	159.7	5.3	1265	7
Step 1 Dry Only	217.4	2.1	153	15

Latona-2 Mass, Inertia, Loaded and Dry

Case	Mass (kg)	CM (m)	$J_{pitch/yaw}$ ($kg\ m^2$)	J_{roll} ($kg\ m^2$)
Empty Vehicle	1246.8	2.7	3949	81
Fully Loaded Vehicle	6667.2	2.1	6293	81
Step 1 and 0 Dry, Step 2 Loaded	1468.7	3.0	5890	81
Step 2 Loaded Only	465.9	5.4	5442	13
Step 2 Dry Only	244.0	5.7	3500	13
Step 1 Dry Only	634.4	1.9	342	53

SLR Prioritization Methodology

Requirements are ranked based on Consequence Statements that state the consequence for having failed a requirement.

Ranking: 1 = Highest Priority 4 = Lowest Priority

Consequence Number	Consequence Statement	Priority P (1-4)
1.0	Disqualified from winning the NASA Launch Services Program VCLS Demo 2 contract.	1
2.0	Launch system fails to perform Mission 1 or 2 as outlined in the Statement of Work (SOW).	2
3.0	The safety of involved personnel or the public is compromised.	3
4.0	The schedule and/or cost-efficiency of the program management plan is compromised.	4

System Level Requirements

REQ #	WBS #	FOM	Requirement Statement	P (1-4)
T4.1	4.0	No	A single launch system must be able to complete both Mission 1 and Mission 2 in the VCLS RFP	2
T3.1	3.0	No	The system must have the payload capacity for a 30 kg payload for Mission 1	2
T4.2	4.0	No	The system must reach a minimum orbit of 500 km and deliver the payload for Mission 1	2
T4.3	4.0	No	The system must achieve an inclination of 40-60 degrees for Mission 1	2
T3.2	3.0	Yes	The system must carry a 75 kg payload and a 20 kg payload for Mission 2	2
T4.4	4.0	Yes	The system must reach a minimum orbit of 550 km sun-synchronous orbit and deliver the 75 kg payload for Mission 2	2
T4.5	4.0	Yes	The system must make a minimum 10-degree plane change with a 20 kg payload for Mission 2	2

System Level Requirements

REQ	WBS #	FOM	Requirement Statement	P (1-4)
P5.1	5.0	No	The team will ensure the safety of the public and personal property and equipment	3
T6.1	6.0	No	The system must launch from Vandenberg and Kennedy Space Center	4
T3.3	3.0	No	The system must be able to deploy payload without causing the CubeSats damage that is detrimental to the completion of either mission	2
T5.2	5.0	Yes	The system must have a reliability of 1 in 1000 for the success of each mission	4
C2.1	2.0	No	The system must abide by adequate price competition as prescribed under FAR15.403-1(C)	1
C2.2	2.0	Yes	The service must be more cost effective than existing launch vehicles that can perform Missions 1 & 2	4

System Level Requirements

REQ #	WBS #	FOM	Requirement Statement	P (1-4)
P2.3	2.0	Yes	The system must be ready for the launch date in the year 2027	4
P1.1	1.0	No	The team will conduct periodic design reviews on dates that are TBP	4
P2.4	2.0	No	The team will develop and maintain a master schedule and sub-tier schedules	4
P2.5	2.0	No	The team will acquire all government permits, licenses, and approvals by the launch date	1
P1.2	1.0	No	The team will provide the recommended payload success criteria prior to the launch, the post-launch supporting data, and the Final Post Flight Report	4
C2.6	2.0	No	The team will acquire insurance to cover any damages to government property	1

System Level Requirements

REQ #	WBS #	FOM	Requirement Statement	P (1-4)
C2.7	2.0	No	The team will pay for all transportation cost and taxes	4
P6.2	6.0	No	The team will acquire a range safety document for Vandenberg and Kennedy Space Station	3
P2.8	2.0	No	The team will obtain NPR 8621.1, NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping	1
P2.9	2.0	No	The team will obtain a Certification Regarding United States Commercial Provider of Space Transportation Services (Public Law 105-303, Title II, Section 201)	1
T4.6	4.0	Yes	The system will utilize sufficient flight instrumentation to establish that the vehicle launch environments meet the requirements of the ICD	4
P6.3	5.0, 6.0	No	The team will provide and make arrangements for all facilities, supplies, and services required for preparation and launch of the vehicle.	4

System Level Requirements

REQ #	WBS #	FOM	Requirement Statement	P (1-4)
P6.4	6.0	No	The team will Identify launch vehicle ground and flight safety launch constraints	3
P6.5	6.0	No	The team will provide and schedule the necessary support services at the launch range that are required for launch preparation of the launch vehicle, integrated testing with the payload, and launch.	1
P6.6	6.0	No	The team will provide access for up to three Government personnel at the launch site for familiarization and communication of launch status	1
P6.7	3.0	No	The team will provide a certified ISO 14644-1 Class 8 or better cleanroom for CubeSat integration	1
P6.8	3.0	No	The team will maintain the contamination environment within the payload fairing such that it meets ISO 14644-1 Class 8 or better	1

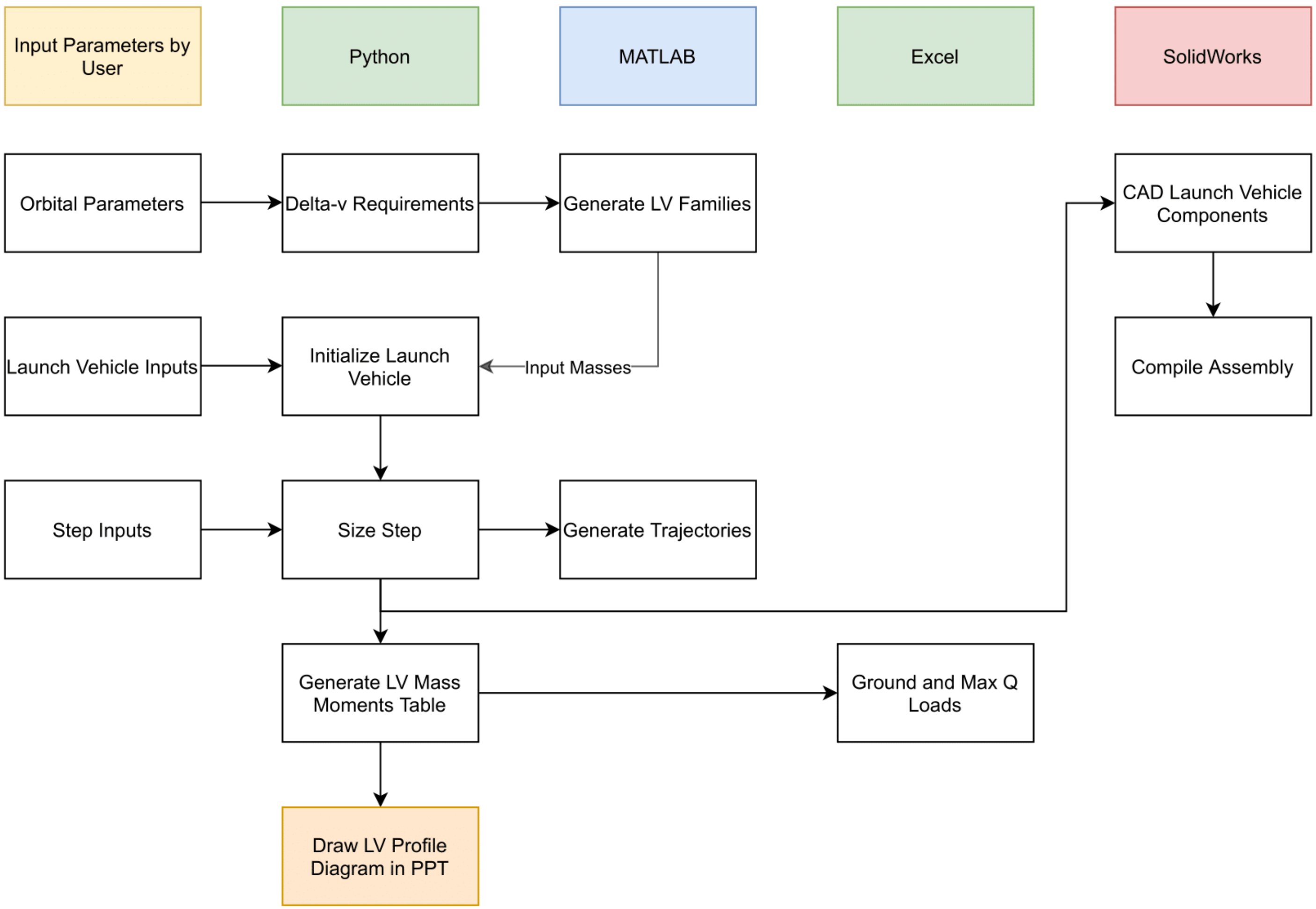
System Level Requirements

REQ #	WBS #	FOM	Requirement Statement	P (1-4)
P2.10	2.0	No	The team will establish, implement, and maintain risk management, safety, reliability, and quality assurance programs with AS9100, Aerospace Quality Management System	4

Kodiak vs Vandenberg

- Vandenberg has more launch windows due to daylight and weather conditions.
- Kodiak would save only approximately 100 m/s from the total mission Δv.
- To ship the Launch Vehicle to Kodiak would cost more than the savings from launching from Kodiak.

Vandenberg is thus more optimal

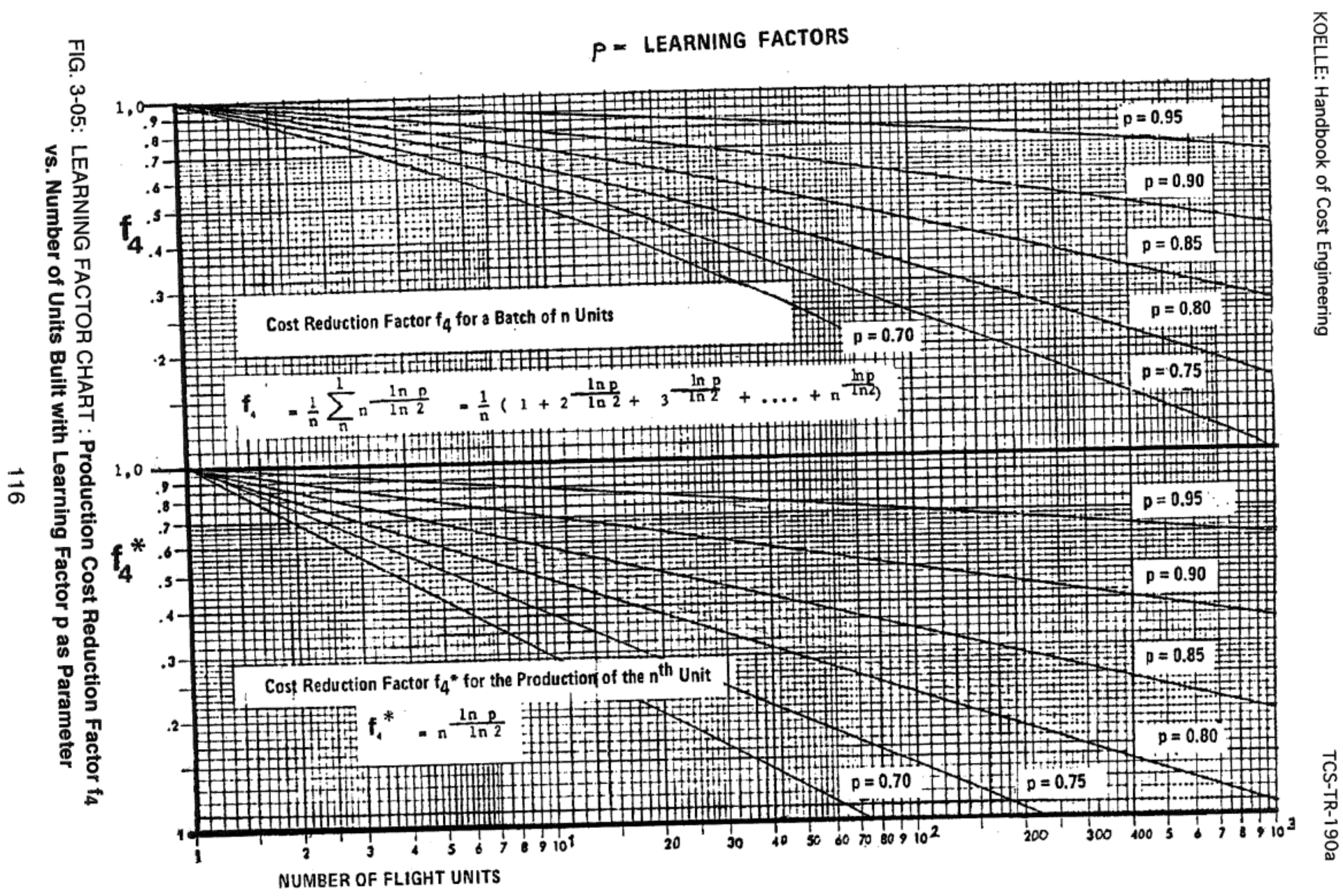


Input Parameters by User
Python
MATLAB
Excel
SolidWorks
Orbital Parameters
Delta-v Requirements
Generate LV Families
CAD Launch Vehicle Components
Launch Vehicle Inputs
Initialize Launch Vehicle
Input Masses
Compile Assembly
Step Inputs
Size Step
Generate Trajectories
Generate LV Mass Moments Table
Ground and Max Q Loads
Draw LV Profile Diagram in PPT

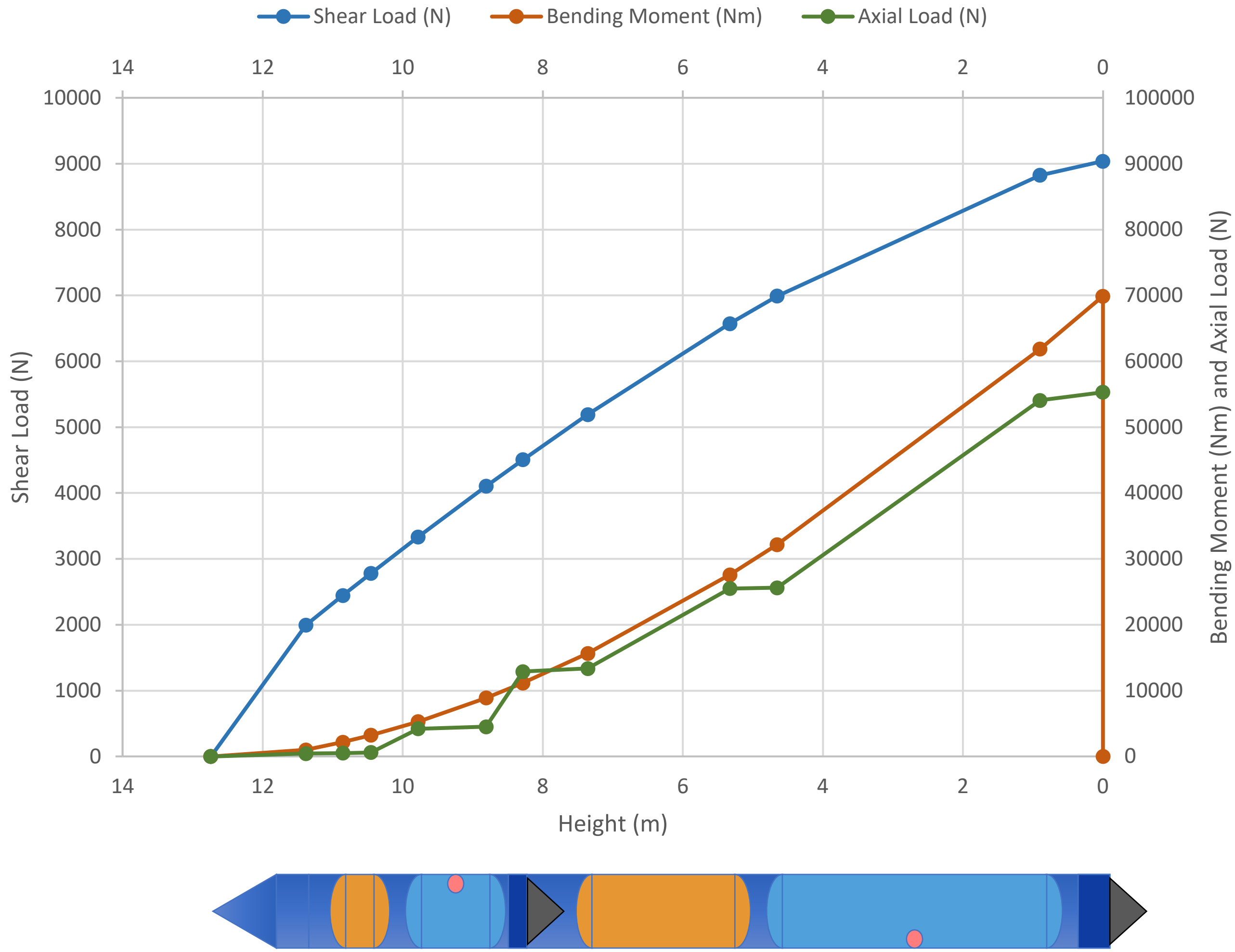
Minerva Engine Assumptions

- In order to estimate the performance of an aerospike nozzle attached to a Merlin-type engine, the following assumption was made:
- Merlin-1C (vac) I_{sp} = 342 sec
- Merlin-1D (sea level) I_{sp} = 282 sec
- Both Isp values are multiplied by 5% in order to simulate the improvement of an aerospike nozzle
- 342 sec x 0.05 = 17.1 + 342 = 359.1 sec $I_{sp\ vac}$
- 282 sec x 0.05 = 14.1 + 282 = 296.1 sec $I_{sp\ sea\ level}$

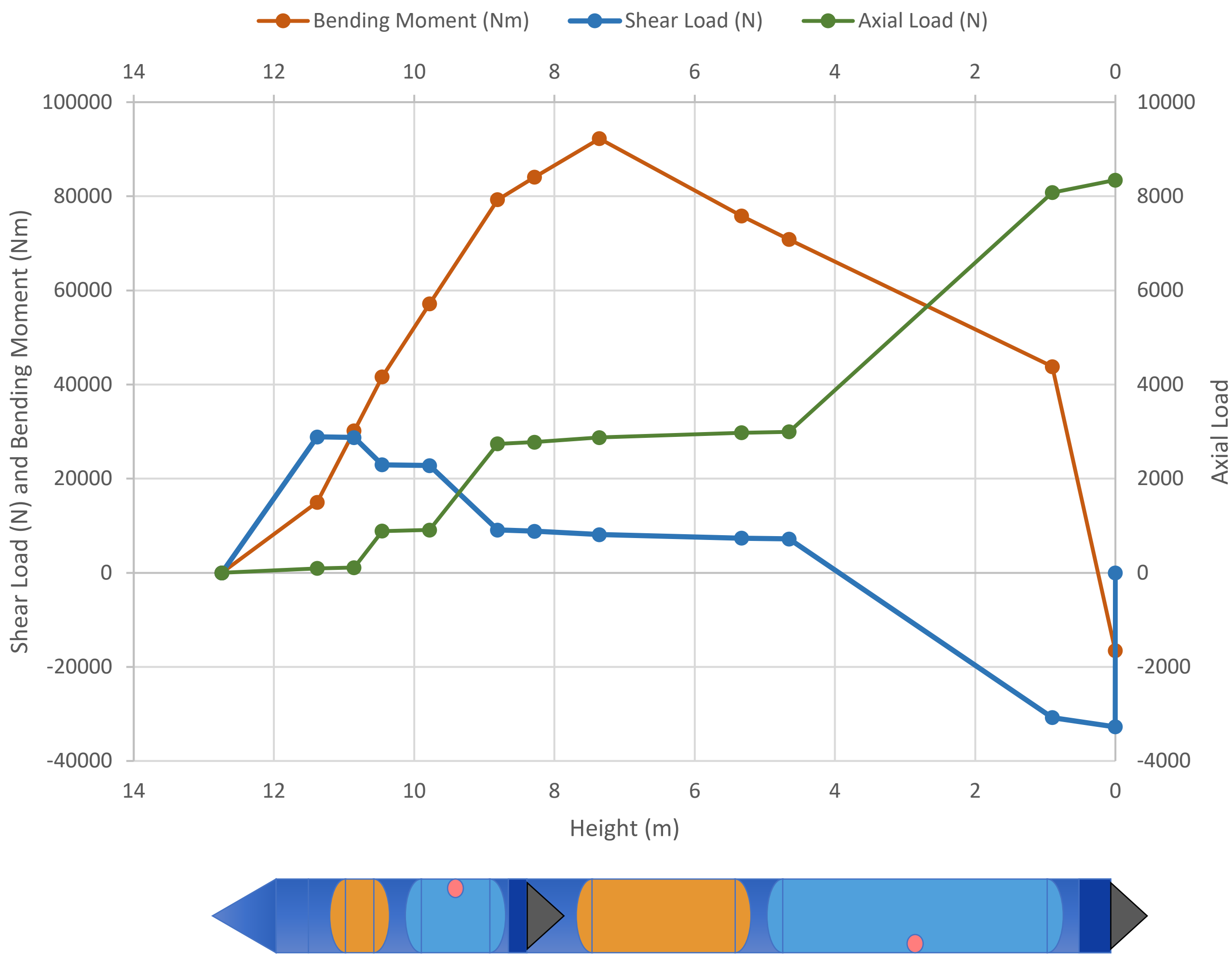
Graph from Transcost



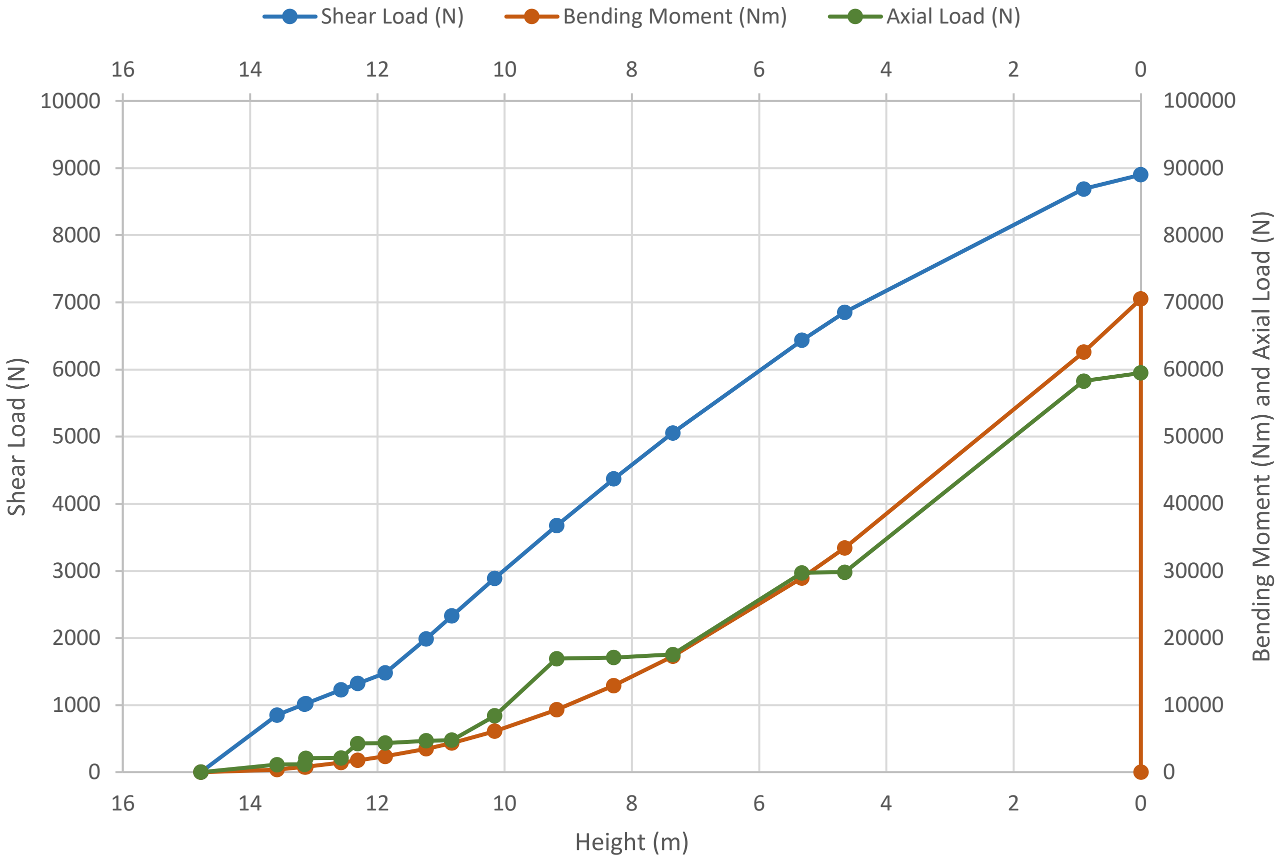
Minerva-1 Ground Loads



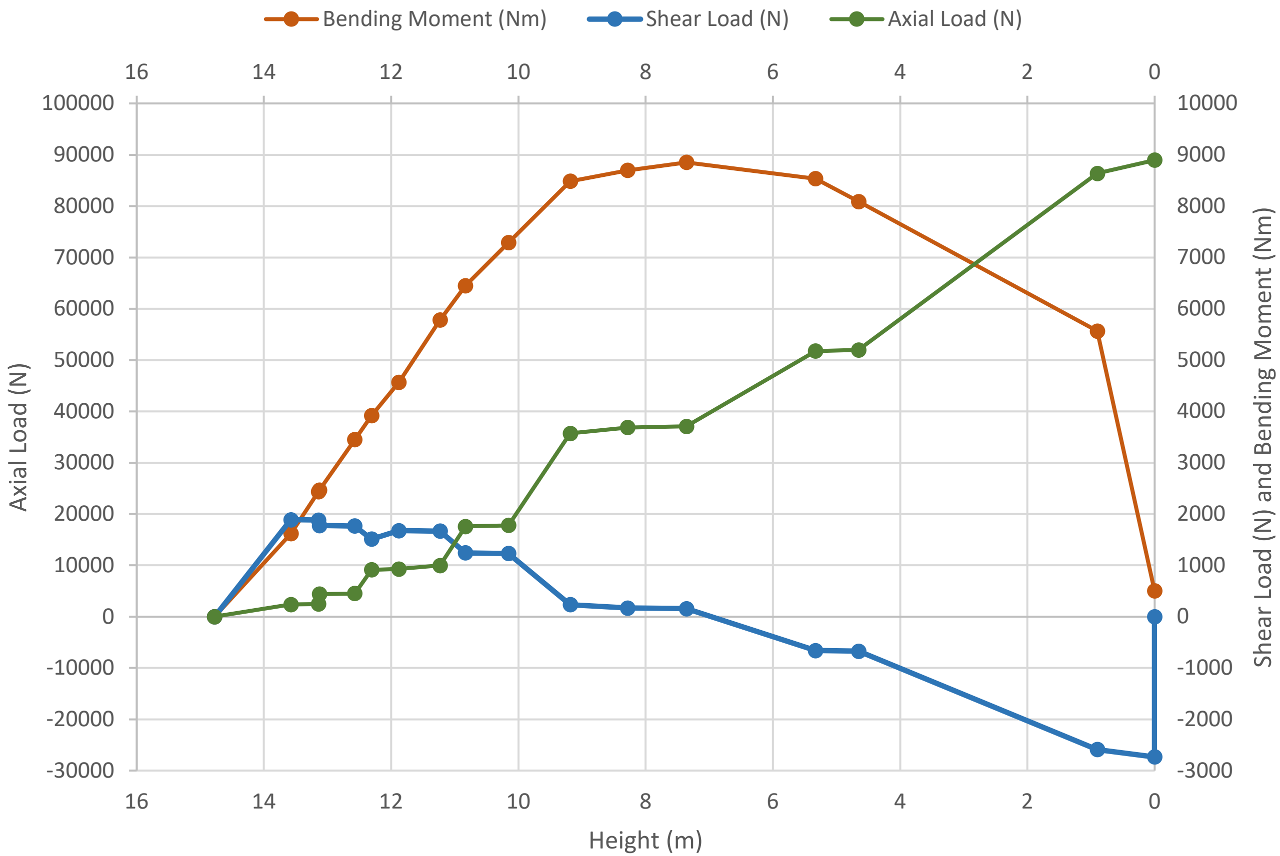
Minerva-1 Wind Loads

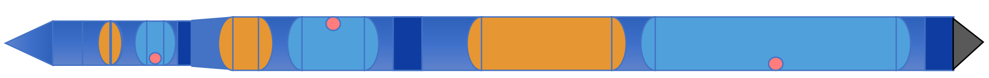


Minerva-2 Ground Loads



Minerva-2 Wind Loads



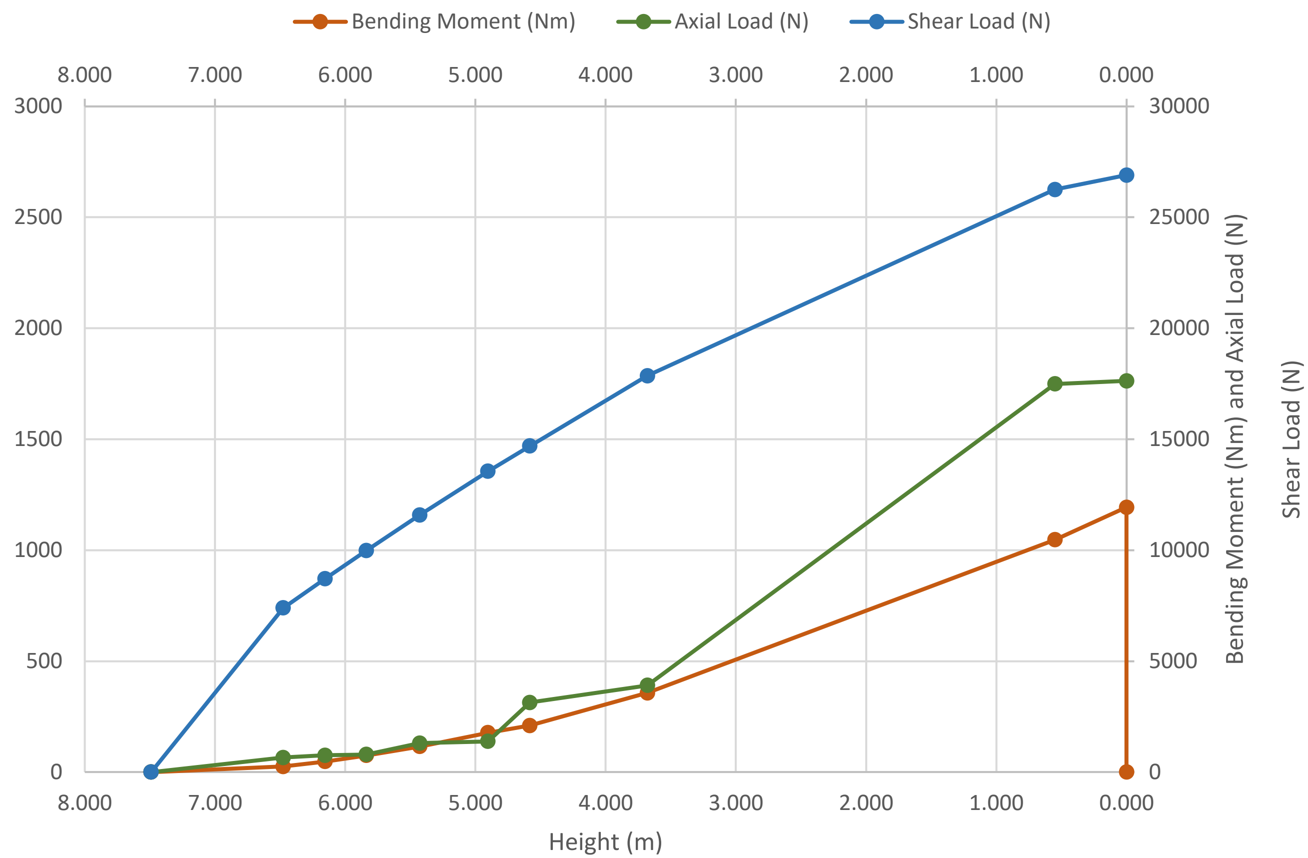


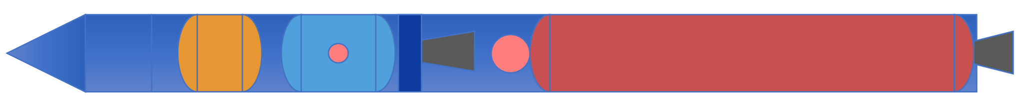
Fault Analysis Reference

Actual Engine Reliability = PDH ("Pretty Darn High")

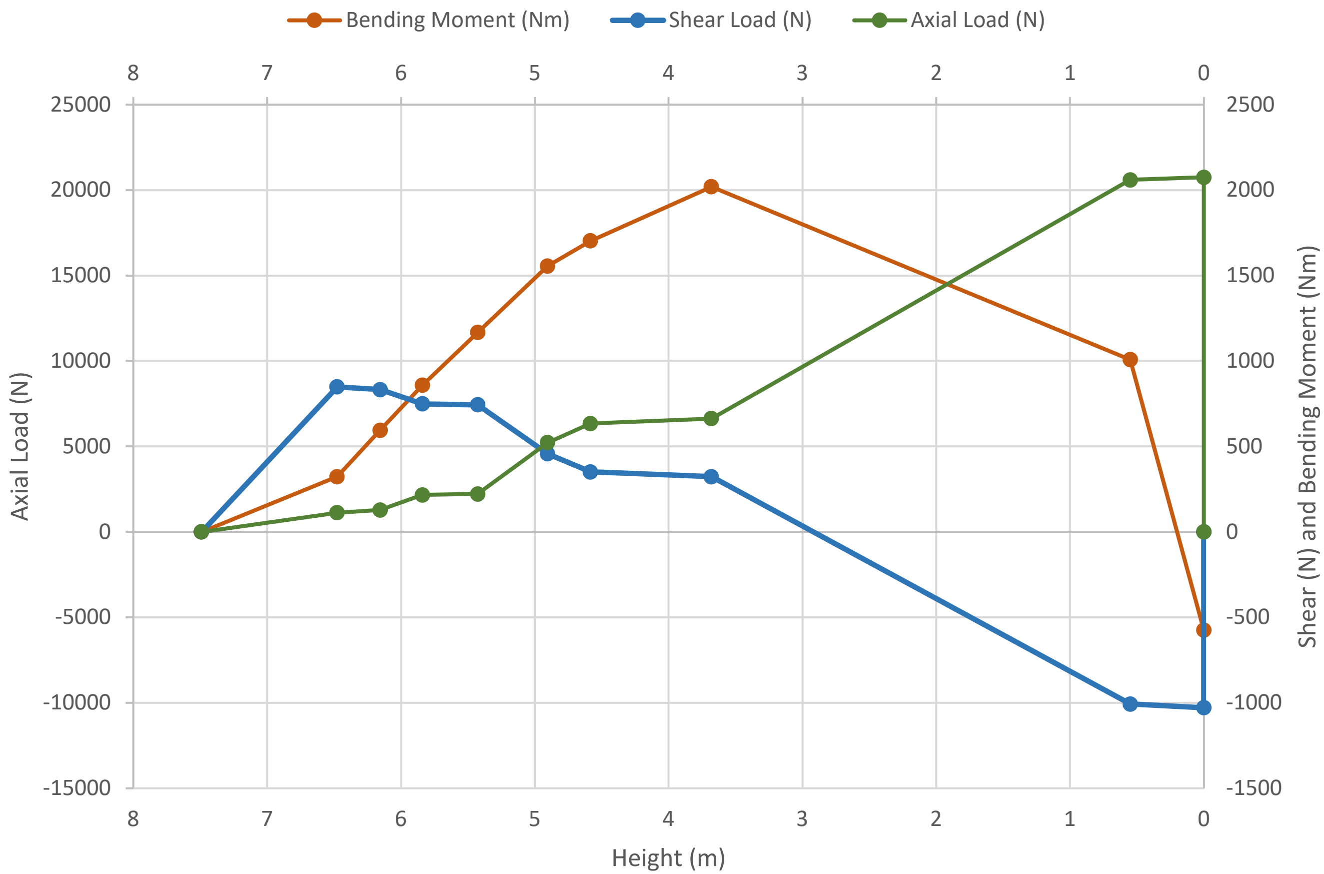
Engine	Qty	Fails/ Uses	Reliability	Vehicle
Merlin 1D	9	1/990*	0.99899 = 99.90%	*Falcon 9*
Rutherford	9	0/162*	1.000 = 100%	*Electron*
RS-25	3	1/405	0.9975 = 99.75%	*Shuttle*
RD-180	1	1/86	0.9883 = 98.83%	*Atlas V*
RD-107/108	5	1/1335	0.9992 = 99.92%	*Soyuz*, post-2000
F-1	5	0/65	1.000 = 100%	*Saturn V*

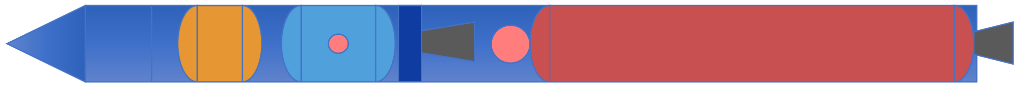
Latona-1 Ground Loads



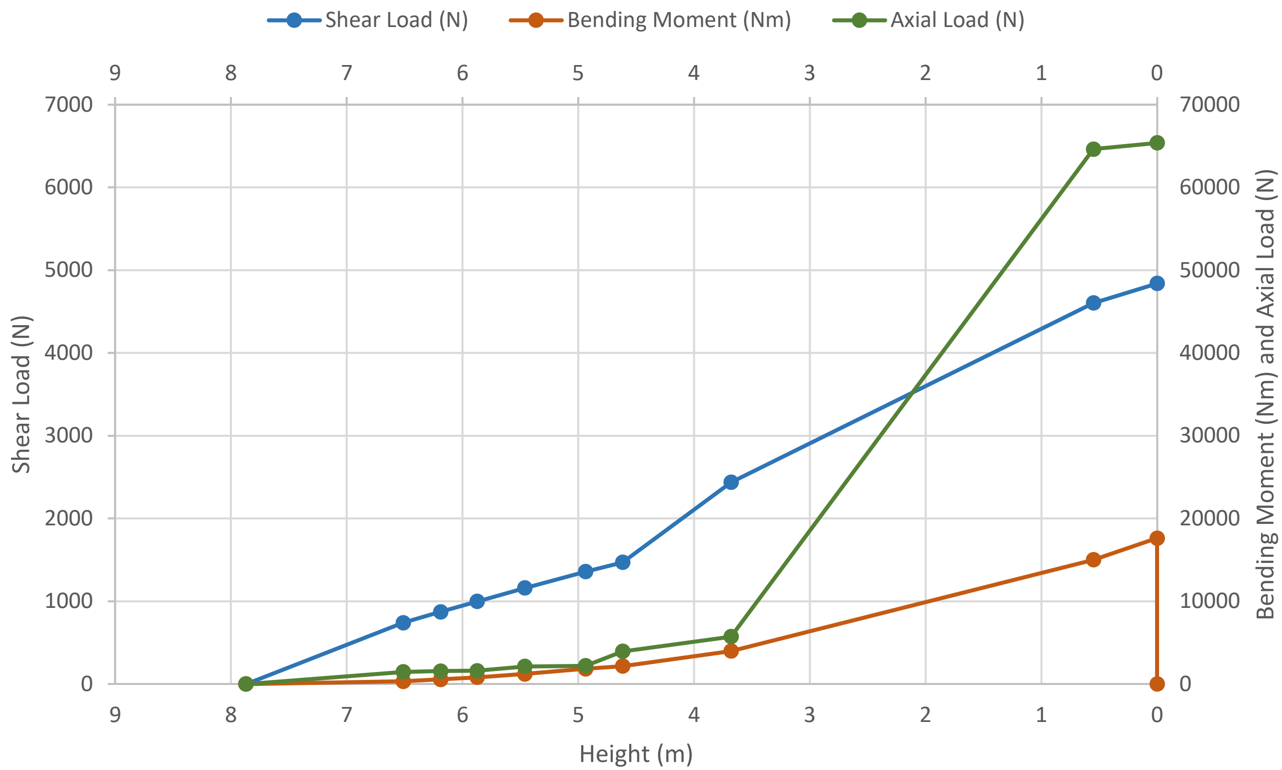


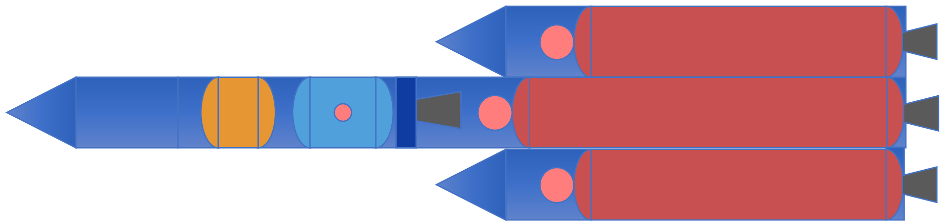
Latona-1 Wind Loads



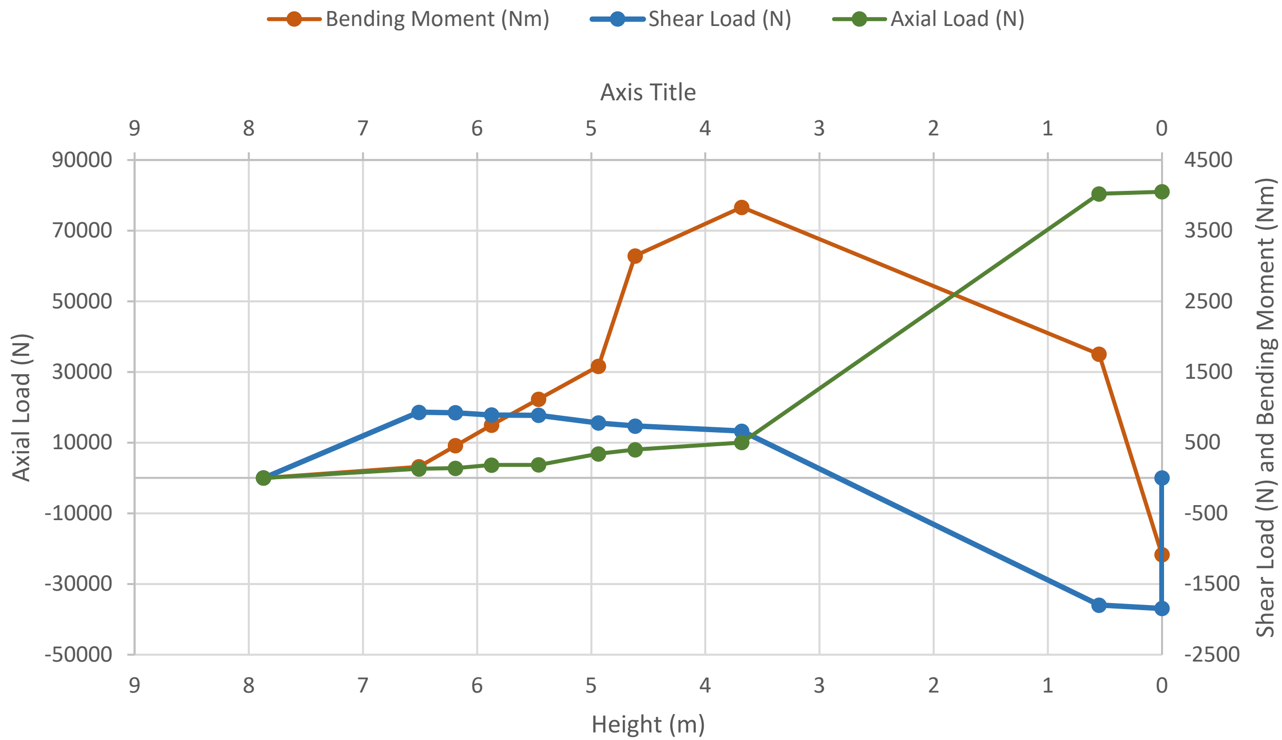


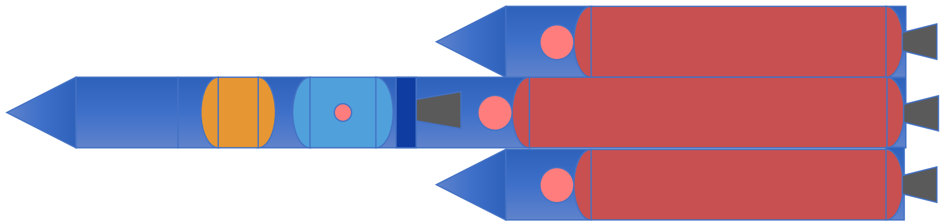
Latona-2 Ground Loads



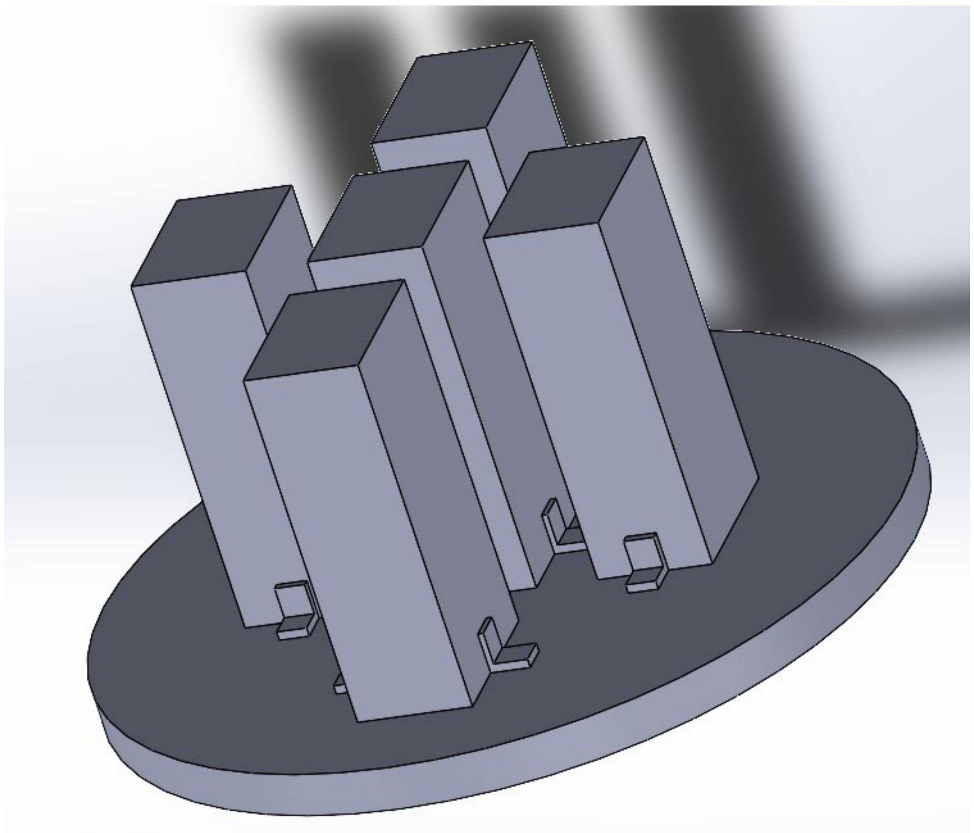


Latona-2 Wind Loads

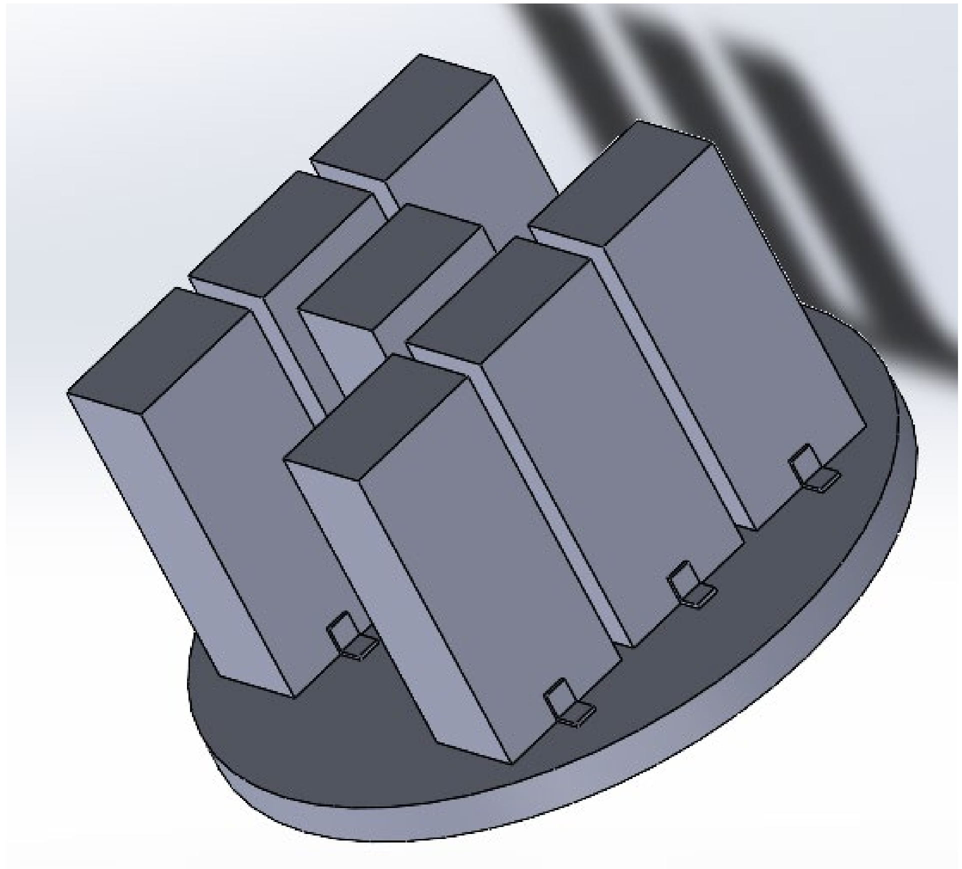




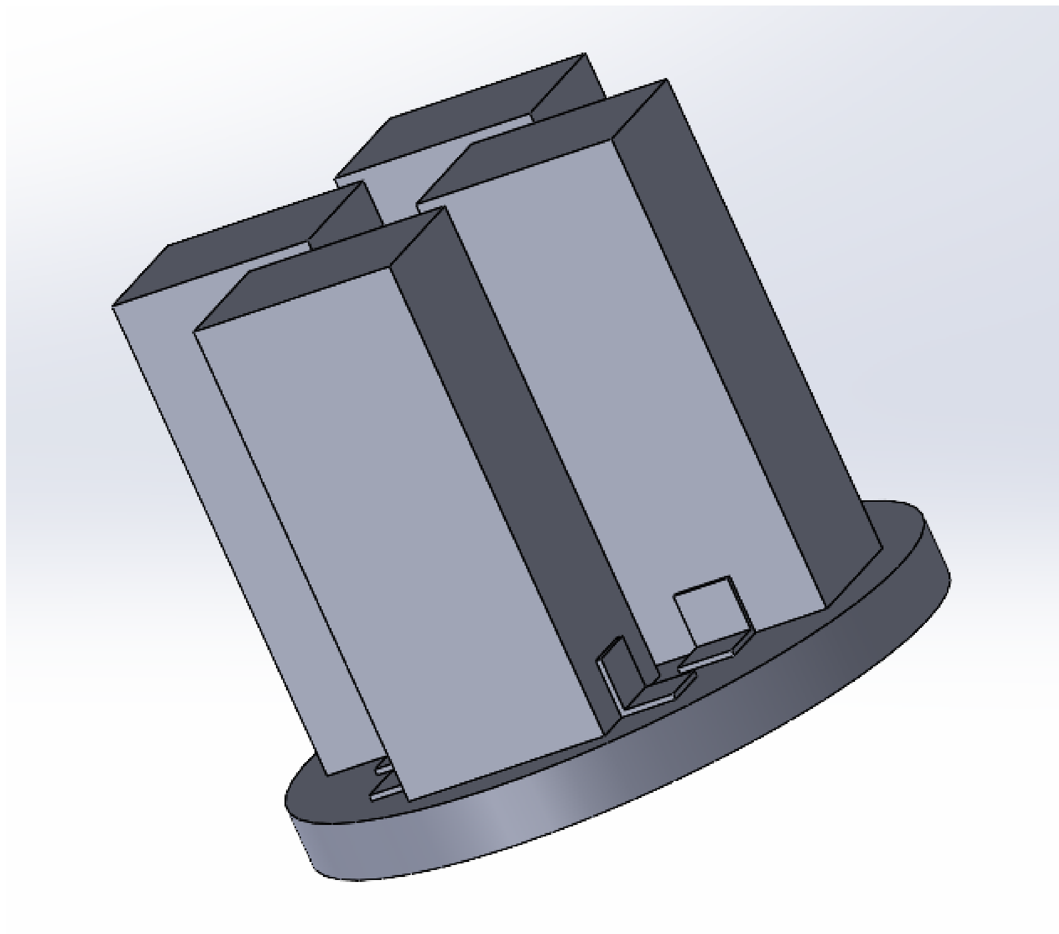
Minerva-1 Payload Accomodation



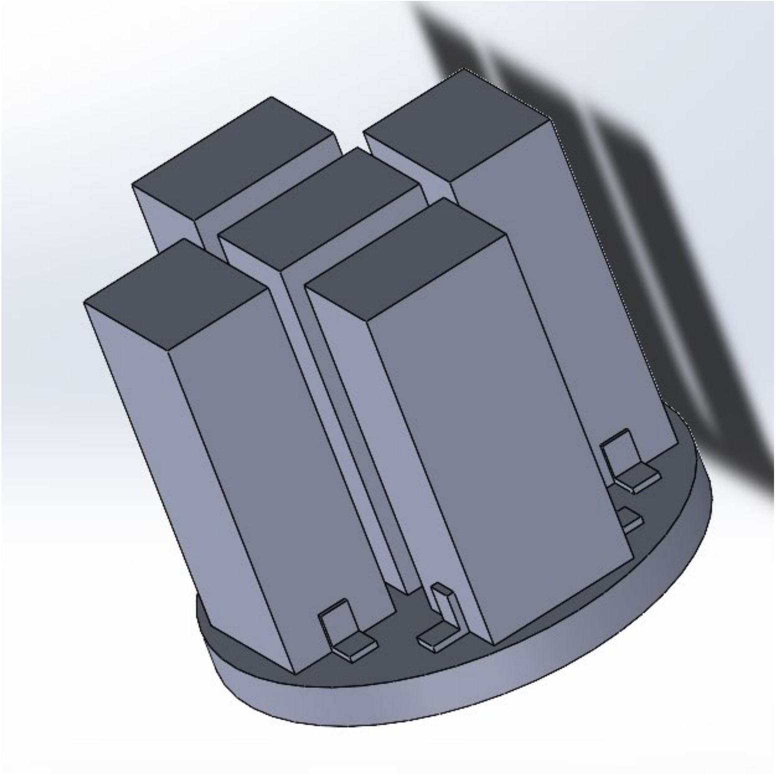
Minerva-2 Payload Accomodation

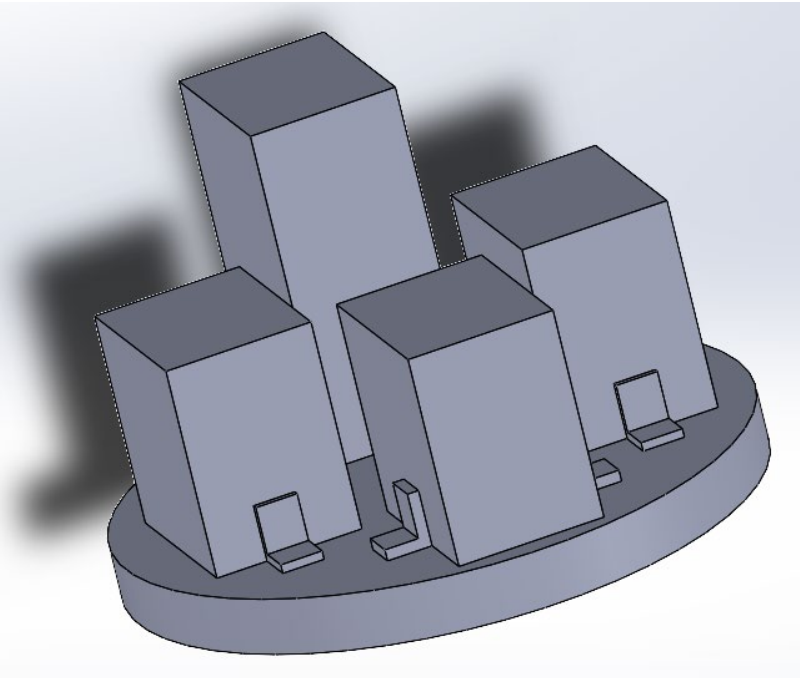


Latona-1 Payload Accomodation



Latona-2 Payload Payload Accomodation





Latona Preliminary Cost Assumptions

- Mission 1 vehicles will be manufactured at a rate of 12/year
- Minerva engines will have 6 qualification firings per turbo-pump engine
- Latona engines will have 4 qualification firings per turbo-pump engine
- All vehicles will be assembled horizontally
- https://www.usinflationcalculator.com/