NG Two-Stage Supersonic Rocket

Testing Plan - 486C

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Design Requirements Summary

Customer Requirements (CRs)

The customer requirements set by the client were stated initially in the proposal. After multiple meetings with the client, the customer expanded on some of the definitions of the requirements made in the initial proposal and added a few additional requirements. The requirements added and removed were due to the class and the client wants to see specific analysis. All the customer requirements are stated in the list below:

- CR1- Develop a two-stage launch vehicle.
    - The vehicle needs to be a two-stage rocket. Two stages mean the rocket needs an initial booster that will eject off the vehicle after being used to maximize the flight time and velocity. The second stage will continue the flight after the first stage ejects off the vehicle.
- CR2- Use of a specific stage separation device.
    - The client wants the team to use a specific separation method discussed. The specific information on the separation system is proprietary Northorp Gruman information and cannot be shared in the report.
- CR3- The vehicle will be constructed of composite materials.
    - The client would like the vehicle to be constructed out of a composite material for strength and lightweight capability. The client would also like composite material to be used to be reused.
- CR4- Vehicle will reach an altitude of at least 30,000 ft AGL (Above Ground Level).
    - The client would like the vehicle to reach the height of 30,000ft. This is a hard number that is not subject to change. The launch site we chose to launch the vehicle at has an altitude ceiling of 48,000ft ASL.
- CR5- Final launch vehicle will be required to carry a maximum 10 Lb payload that will fit within a 6” diameter bay
    - One of the major requirements set by the clients is the vehicle should have a payload bay that should have a 6” diameter. The vehicle should have the ability to carry at least a 10 lbs payload. As stated by the client, this requirement is important as the vehicle is for research uses.
- CR6- Vehicle required to reach a maintain over Mach 2 or roughly 1500 mph and maximize time spent at that speed or greater.
    - This is a major requirement set by the client. The client would not just like the vehicle to reach Mach 2, but also maximize the time spent at Mach 2 or greater. Mach 2 is equivalent to about 1500 mph. The rocket being at this speed will result in the application of compressible flows and non-linear representations.
- CR7- Acceleration of the vehicle needs to meet a minimum of 12g’s.
    - The force acting on the vehicle at launch should result in at least 12g acceleration.
- CR8- Vehicle trajectory will be simulated in Rocksim.
    - The trajectory of the vehicle should be modeled in both Rocksim. Rocksim is a modeling application for rockets, you can set the parameter you need to predict certain measurements on the vehicle.

- CR9- Vehicle required to use commercial rocket motors.
  - The team must use solid fuel commercial rocket motors to easily replace and reuse the vehicle.
- CR10- Recovery of entire launch vehicle for reuse.
  - The client would like the team to design the entire vehicle to be reused after each launch. Other than the motors, the entire vehicle needs to be reuseable.

Engineering Requirements (ERs)

Engineering Requirements are derived from the customer requirements stated above. There are not as many engineering requirements as customer requirements due to some of the requirements being combined. In the customer requirements stated above, the customer set goals for the vehicle and the team to reach. As the team met with the client, the engineering requirements were changed from what the team initially set to what the current requirements are.

- ER1- Max Velocity – Mach 2 or 1500 mph
  - The velocity is the speed of the vehicle as it flies. This requirement is one of the major engineering requirements. The goal is to reach and maximize the time at Mach 2 /1500mph. The goal time duration at Mach 2 the team is aiming for is at least 30 seconds.
  - The requirement is a two-sided constraint as this can be engineered by the body size, but the other requirements will affect the velocity of the vehicle. Every part of the rocket will affect the velocity of the vehicle as the more weight we add the or take off it will affect the velocity.
- ER2- Separation Event – Successful or unsuccessful separation
  - This requirement as it pertains to the project is just a yes or no if it works. The project is not specifically designing a separation system, but rather the vehicle needs to have two stages. The team just needs to know if the separation works with the device that will be chosen.
  - This requirement is a one-sided constraint as the only constraint that would affect the separation event is the separation device and method. Nothing else affects the separation event.
- ER3- Altitude – 40,000 ft AGL (Above Ground Level)
  - Altitude is one of our major engineering requirements, as the altitude can be measured and engineered by the team. The client also stated they want the vehicle to reach this height. The capstone instructor initially set the altitude goal as 50,000ft as it is the highest altitude the main launch site the team has chosen has as a ceiling.
  - This requirement is a two-sided constraint, like the velocity requirement every aspect of weight and speed will affect the altitude the vehicle is able to reach. For example, if you change weight this will affect the altitude, same with fins of the vehicle.
- ER4- Payload Weight – 10lbs
  - As this is a research vehicle, the client is adamant that the vehicle has the capability to sustain supersonic flight with a 10 lbs payload. The team does not know exactly what the payload is, but the vehicle needs to be able to safely return

to the ground. The measurement of the payload will be how many pounds max the vehicle can carry to while maintaining supersonic flight.

  - This requirement is a one-sided constraint since it cannot change due to the client. This goal is set and will only affect other requirements, rather than being able to engineer this requirement.

- ER5- Cost of production - $7000 USD
  - This is the requirement is relatively important as the client would like this not to be a expensive vehicle and something that could be used multiple times, but they could build more without excessive cost. For this purpose, we would say this requirement could be related to the project budget. We have a budget of roughly $7000, if the team does not exceed that price, then this engineering requirement will be fulfilled. If the team can build the vehicle with less of the budget, then that would result in a better result of the engineering requirement being fulfilled.
  - This requirement is a one-sided constraint as we cannot really design for a low cost of production. We can only design our rocket and with the lowest price possible by low material, not super expensive parts, but the cost of production does not really affect this specific project.
- ER6- Reusable – more than 1 use
  - The requirement will be measured by the number of uses the vehicle will have before needing major maintenance or needing to be replaced. For our purposes, the team cannot launch the final product more than 1 or 2 times. Therefore, if the vehicle has minimal damage after our launches, the team will predict the number of uses the vehicle has, before needing major maintenance or being replaced.

- ER7- Payload Volume – 282.7 in^3
  - This requirement was the least regarded as important as the client did not have any specific volume requirement and the payload weight is more important than the payload volume. The team has assumed that most 10 lbs payloads would approximately be less than 10 in tall. The volume measurement will be measured in cubic inches. If the team can reach the goal of 282.7 in^3 this engineering requirement would be considered successful.
  - This is a two-sided constraint due to the team being able to engineer this, and this would for example affect the lightweight constraint. This both has an effect and can be affected by other requirements. This could be seen as a one-sided constraint, but it is really a two-sided constraint.

Top Level Testing Summary

List all the tests that you will be performing and map your Design Requirements in a table like this:

Success Levels	Goals
Complete Mission Success	- Separation system works as expected, successful separation and second stage motor ignition. (CR1, CR2, ER2) - Payload safely delivered and landed. Data captured. (CR4, CR7, CR6, CR10, ER1, ER3, ER6) - Launch vehicle performance meets altitude goal. (CR5, CR6, CR9, ER2, ER3, ER4, CR3) - Launch vehicle recovered in reusable condition, no damage to vehicle at all. (CR3, CR5, CR8, CR10, ER6, ER5) - Recovery system performs as expected and designed. (CR1, CR2, CR10, ER2, ER6) - No anomalies (drastic angle change, bird strike, etc.) during full flight and payload mission until completed flight and recovery (All CRs and ERs)
Partial Mission Success	- Flight success (All CRs and ERs) - Velocity and altitude requirements met (CR4, CR6, CR7, CR9, ER1, ER3) - Payload flown but no data recorded. (CR5, ER4) - All components are recovered and reusable with minor damage. (CR1, CR3, CR10, ER4, ER6)
Partial Mission Failure	- Failure of payload or launch vehicle performance (All CRs and ERs) - Successful flight with failure of payload data recording or delivery (CR5, ER4) - Velocity or altitude requirement missed. (CR5, CR6, CR9, ER2, ER3, ER4, CR3) - Vehicle or payload systems damaged during flight or landing (CR1, CR3, CR10, ER4, ER6)
Complete Mission Failure	- Failure of both launch vehicle and payload systems (CRs and ERs) - Failure of recovery system deployment and beyond reasonable repair state (CRs and ERs) - Failure of vehicle before, during, or after flight (All CRs and ERs)

Table 1: Mission success criteria

Detailed Testing Plans

The main question that will be answered is will the vehicle survive being launched and reach all the flight goals. The flights goals are reaching Mach 2, 40,000ft AGL, have a successful separation event, and not damage to the vehicle after recovery. The isolated variables are speed and altitude. There are parts that may be damaged, but the vehicle is already designed for this purpose. The may body of the launch vehicle is not to be damaged, along with the payload.

The equipment that will be needed to test launch the vehicle will be a launch tower, GPS, and flight computers. GPS and flight computers are already incorporated into the design of the vehicle. The software needed to run the GPS and flight computer are going to be used to record the flight path, speed/velocity, and altitude. From this data, the team will be able to derive speed, altitude, and make other calculations requested by the client. This test has a set goal of altitude, separation, and speed/velocity with a 10 lb payload meaning we are not determining how efficient the vehicle is. We are just setting out to reach the goals set, this is a fundamental design project.

Procedure

Assembly prep at Launch site:

1. Set the Altimeter and GPS prior to putting the vehicle together completely.
2. Inspect all connections of the vehicle to ensure connections are secure. Should be done with the required tool.
3. Prep the propellant to be inserted into the motor casing.
4. Insert propellent into the motor casing into the main vehicle motor.
5. Insert propellent into the motor casing of the booster stage.
6. Depending on if the motor casing is not inserted into the rocket, insert motor casings into each stage of the vehicle. Securing the motor casing by screwing it in.
7. Ensure igniter is connected to the flight computer and the motor on both stages.
8. Ensure there is no play in the fin canister assembly
9. Connect both stages at the separation device connections.

Pre-flight setup

1. Assemble and secure the launch tower.
2. Ensure rail is secured to the launch tower.
3. Ensure rail connectors are secured tightly to the launch vehicle.
4. Connect the launch vehicle by the rail connectors to the launch tower.
5. Visually check to make sure the launch vehicle has no anomalies on the rocket body. All fins are connected securely.
6. The launch vehicle should be angled 90 degrees from the ground, aligning with azimuth.
7. The launch vehicle should be resting on the blast plate of the tower.

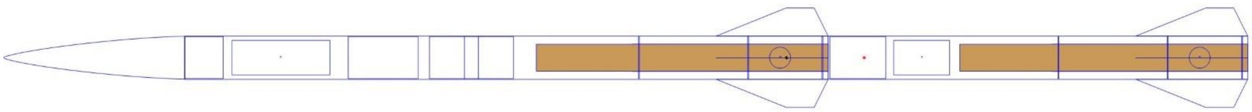
Launch

1. Turn on and connect to flight computers and GPS.
2. Last visual inspection of the launch vehicle.
3. Retreat to a minimum safe distance of 1,000 ft or 300m.
4. Before launch, check to see if vehicle is connected to device running the flight computers.
5. Last visual inspection of minimum safe distance red zone. Radius of 1,000 ft or 300m.

6. Last visual inspection of near by air space. If there is a visible entity within the air space wait to launch.
7. After all last check and visual inspection, launch vehicle is ready.

Result

The vehicle is expecting to reach 40,000ft AGL, reach Mach 2.0, and have a separation event. Along with return to the ground safely with not damage. The result should be successfully reached, both flight simulation software used show all flight goals being achieved and vehicle being recovered safely with no damage.



Simulation	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Max. acceleration Gees	Velocity at deployment Miles / Hour	Velocity at launch guide departure Miles / Hour	Time to apogee	Total flight time
32		[N4800T-0] [N1000W-P]	35160.11	1031.52	15.17	67.11	83.41	43.98	167.26
33		[N1000W-0] [N4800T-P]	37464.90	1736.92	24.68	37.46	45.75	51.42	126.51
34		[N1000W-0] [N4800T-P]	37074.15	1726.73	24.67	39.13	45.75	51.14	126.23
35		[N1000W-0] [N3300R-P]	33637.47	1453.03	16.54	35.58	48.00	49.17	120.88
36		[N1000W-0] [N3300R-P]	34243.44	1461.02	16.54	24.77	48.00	49.65	121.95
37		[N1000W-0] [N3300R-P-1]	34496.06	1456.19	16.62	34.18	48.00	50.50	122.87
38		[N1000W-0] [N4000-0]	35465.22	1566.36	16.94	49.42	43.40	51.70	121.52

Figure 1: Rocksim flights Simulation

Flight

Options Simulations

	Motor(s) Loaded	Max Alt (ft)	Max Vel (ft/sec)	Time to Apogee (sec)		Optimum Wt (lb)	Max Alt (ft)	ViewData
▸	N1000W (AT) | N3300 (AT)	46,432	1,565.5	58.9	Optimize Wt	48.750	46,670	View Data
*								

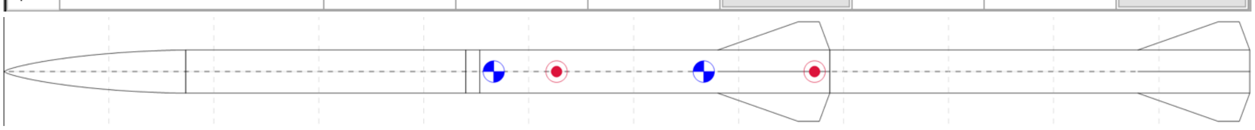


Figure 2: RasAero Flight Simulation

Conclusion

Successful flight test and recovery with no damage to the payload or vehicle. Be able to be launched again that day. However, due to price of propellant the team will only be able to launch the vehicle once. If recovered with no damage to the vehicle or any of its parts, team can assume the vehicle can be launched again, fulfilling the reusable requirements.

Specification Sheet Preparation

Customer Requirement	CR Met?	Client Acceptable
CR1	Yes	Yes
CR2	No	Yes
CR3	Yes	Yes

CR4	Yes	Yes
CR5	Yes	Yes
CR6	Yes	Yes
CR7	Yes	Yes
CR8	Yes	Yes
CR9	Yes	Yes
CR10	Yes	Yes

Table 2: CR Summary Table

ER	Target	Tolerance	Measured/Calculated Value	ER Met?	Client Acceptable?
ER1- Max Velocity	Mach 2 or 1535mph	±100 mph or ± 0.13 Ma	Measured	Yes	Yes
ER2- Separation Event	Successful or unsuccessful separation	N/A	Measured	Yes	Yes
ER3- Altitude	40,000 ft AGL	±500 ft	Measured	Yes	Yes
ER4- Payload Weight	10 lbs	± 0.5 lbs	Measured	Yes	Yes
ER5- Cost of production	$7,000 USD	N/A	Measured	Yes	Yes
ER6- Reusable	>1	N/A	Measured/Calculated	Yes	Yes
ER7- Payload Volume	282.7 in^3	±50 in^2	Measured	Yes	Yes

Table 3: ER Summary Table

QFD

The CRs and ERs in the project were linked to one another greatly. You could not change a CR without changing 1 or 2 ERs. The QFD below shows some older requirements set, but the team found they were able to reduce the body diameter and increase the size of the motors. Which positively affected all the ERs and CRs making the goals set more attainable. Beyond that the QFD has not changed since this update.

System QFD

Project: Two Stage Supersonic Rocket
Date: 3/18/2024

		Altitude	Body Diameter	Vehicle Speed	Vehicle Acceleration	Payload Weight	Seperation Event	Reusable	Payload Volume	Body Material
1	Altitude	(++)								
2	Body Diameter		(++)							
3	Vehicle Speed	(++)		(++)						
4	Vehicle Acceleration	(++)		(++)	(++)					
5	Payload Weight	(+)	(+)	(+)	(+)	(++)				
6	Seperation Event		(+)	(+)			(++)			
7	Reusable		(+)	(+)	(+)	(+)	(+)	(++)		
8	Payload Volume		(++)			(+)			(++)	
9	Body Material		(+)	(+)		(+)	(+)	(++)		(++)

Technical Requirements

	Customer Needs	Customer Weights	Altitude	Body Diameter	Vehicle Speed	Vehicle Acceleration	Payload Weight	Seperation Event	Reusable	Payload Volume	Body Material
1	Lightweight	4	9	3	9	9	9	1	3	1	9
2	Altitude	7	9	1	9	9	9	9		1	3
3	Max Velocity	8		1	9	9	9	9		1	3
4	Payload Weight	5	3	9	9	9	9				1
5	Cost of Production	3		3				1	9	1	9
6	Separation Event	6	1	1	3	1		9	1		1
7	Payload Volume	1		9	1		3			9	
8	Reusable	2		1	1	3		1	9	1	9
	Technical Requirement Units		ft	in	mach	g's	Lbs	N/A	# of uses	in^3	lbs
	Technical Requirement Targets		40000	6.25	2	12	10	Successful or not	5	282.7	45
	Absolute Technical Importance		120	98	237	228	219	198	63	33	137
	Relative Technical Importance		12.0	9.81	23.7	22.8	21.9	19.8	6.3	3.3	13.7
			6	7	1	2	3	4	8	9	5

Customer Opinion Survey				
1 Poor	2	3 Acceptable	4	5 Excellent

Body Ranking System	
Strong	9
Moderate	3
Weak	1
None	0

Figure 3: Quality Function Deployment/ House of Quality