Super-ARLISS
Level 3 Project

Version 1.1

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Change History:

Version 1.1:

Updated sustainer descriptions to reflect modification decisions made leading to the ARLISS event.

- We decided to use a CD3 unit to eject the payload instead of black powder
- We added a piston to help eject the body parachutes.
- The support for the servomotor deployment of the main parachute in two-stage flight was dropped in favor of a low-pyro concept. This concept will be documented later.

Version 1.0:

Major additions were made in this version.

- Updated the Interstage Coupler images
- Remove detailed drawings and refer to drawing web site instead.

Version 0.2:

Major additions were made in this version.

- Remove redundant detail from concept drawings.
- Add avionics sub-section to booster design section.
- Provided more detail on sustainer recovery strategy
- Added description of booster airframe tube and coupler reinforcement

Version 0.1:

Major additions were made in this version.

- Initial project specification.

1 PROJECT OVERVIEW 4

1.1 The Design Concept 4
1.2 The Sustainer Stage Concept 4
1.3 The Booster Stage Concept 7
1.4 Special Problems to be Solved 8

2 THE DESIGN PROCESS 10

2.1 Exploration using RockSim 10
2.2 Mechanical Design 10
2.3 Electronic Design 10
2.4 Final RockSim Simulation 11
2.5 Pre-Flight Testing 11

3 STRUCTURAL DESIGN 12

3.1 The ARLISS Configuration 12
3.1.1 Thrust Transfer Path 12
3.1.2 Avionics 14
3.1.3 Recovery system 15
3.1.4 Payload carrier 16
3.2 Booster Stage 16
3.2.1 Thrust Transfer Path 16
3.2.2 The Interstage Coupler 18
3.2.3 Avionics 20
3.2.4 Parachute Deployment Shock Analysis 21
3.3 Sustainer Stage 21
3.3.1 Thrust Transfer Path 21
3.3.2 Recovery system 22
3.3.3 GPS location Transmitter 24
3.3.4 The Tether Pass-thru Payload Carrier 24

4 DETAILED DRAWINGS 25

1 Project Overview

The goals of this project are to design, build, and successfully fly a rocket which:

1. Meets all of the requirements for the ARLISS-M program. It is expected that most of the flights made by this rocket will be lifting student payloads at ARLISS launch events.
2. Satisfies Tripoli project requirements for a High Power Level 3 certification project.
3. Is configurable into a two-stage rocket that is capable of lifting a 6 lb. payload and deploying it at 30,000 feet.

Meeting ARLISS requirements establishes several key characteristics of the design.

- The airframe diameter is 6 inches. This is the common diameter for ARLISS M-series rockets.
- The motor compartment is designed to accept 98 mm motors. A M1419 reload must be able to deploy the student payload at an altitude between 10,000 and 12,000 feet.
- The standard 5-7/8" diameter by 11-7/8" long ARLISS payload carrier must fit in the rocket's payload compartment.
- The rocket's avionics system must be able to deploy the student payload(s) at apogee+6seconds. There must be no obstructions to the deployment of this payload. Flight computers used for payload deployment should be redundant.
- A standard 98 mm motor case and closures must be used.

The rocket used for Tripoli Level 3 certification must be powered by a class M total impulse motor, but neither be multiple stages nor use clustered motors.

However, goal #3 is not achievable by any currently certified single 98 mm motor.

To achieve all three of the above goals, a 6" diameter two-stage rocket will be designed. The upper stage (sustainer) shall be configurable for single stage flight. The sustainer stage alone shall be submitted for Tripoli Level-3 certification and be capable of standard ARLISS flights.

1.1 The Design Concept

The rocket being designed has two stages. The upper stage is called the sustainer. The lower stage is called the booster. For single stage flights, the sustainer can be launched by itself and achieve altitudes of 8,000 to 16,000 feet depending on the motor used. As a two-stage rocket, altitudes of 34,000 feet are achievable.

Note that concept drawings are not to scale are not intended to show exact construction. Please refer to the detailed drawings at the back of this document for exact construction, scale and dimensions.

1.2 The Sustainer Stage Concept

The sustainer stage consists of three sections, the lower sustainer airframe, the upper sustainer airframe, and the nosecone.

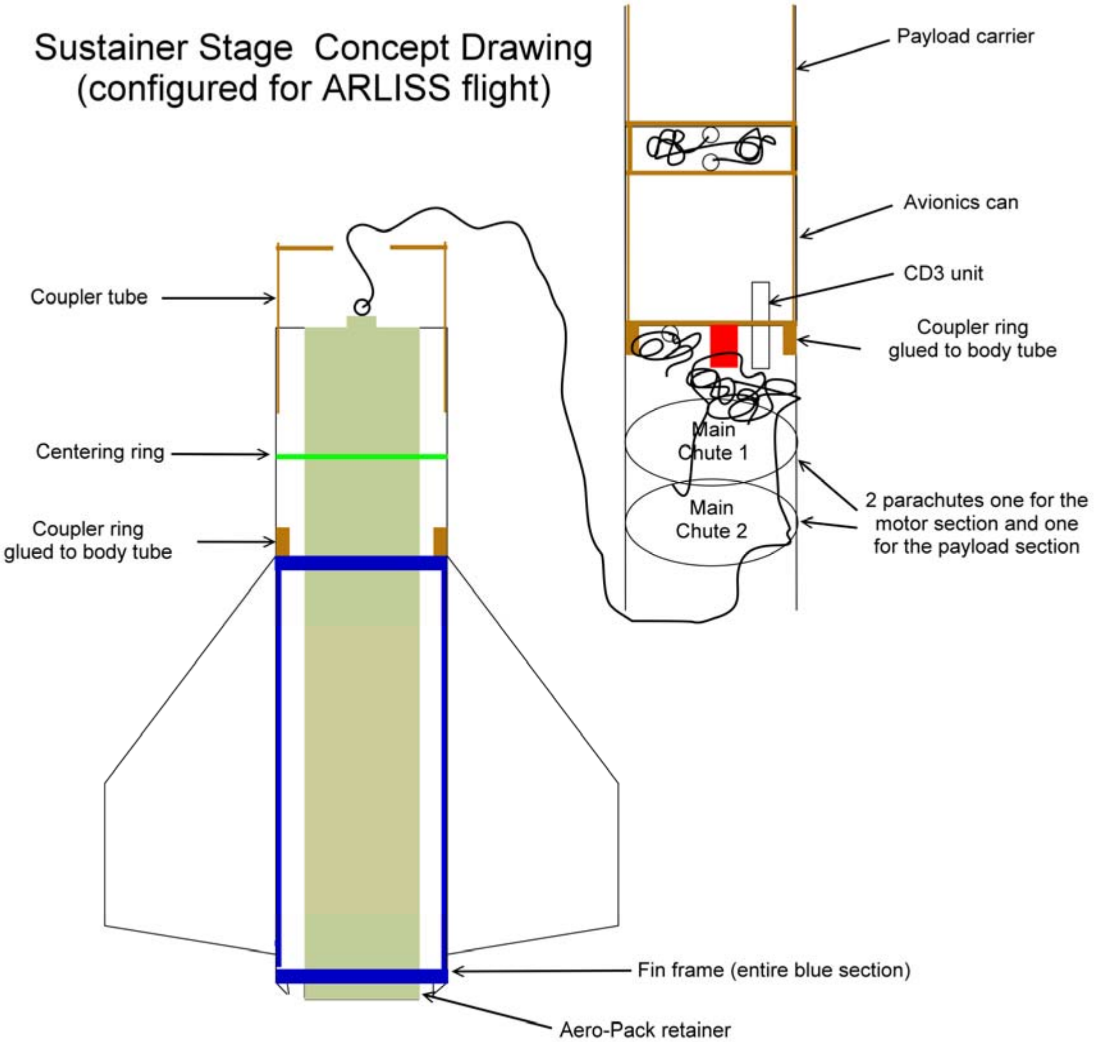


Figure 1. ARLISS Concept

The above drawing shows the sustainer configured for single stage ARLISS flight. The concept drawing looks like any other standard M-Class ARLISS made from the 2004 design template. The unique design points become clear when the sustainer is configured for two-stage flight.

At apogee, the sustainer's flight computers separate the upper and lower airframe tubes, deploying the two main parachutes. Six seconds later, the flight computers eject the nosecone and the payload carrier. A small parachute is used to recover the nosecone. The lower sustainer airframe, the upper sustainer airframe, and the nosecone independently drift to earth.

For two-stage flight, the motor case is extended 4" beyond the aft centering ring. This makes the motor case a key structural element in strengthening the joint between the booster and sustainer stages. It also changes the way thrust is transferred throughout the sustainer and the way the motor is retained.

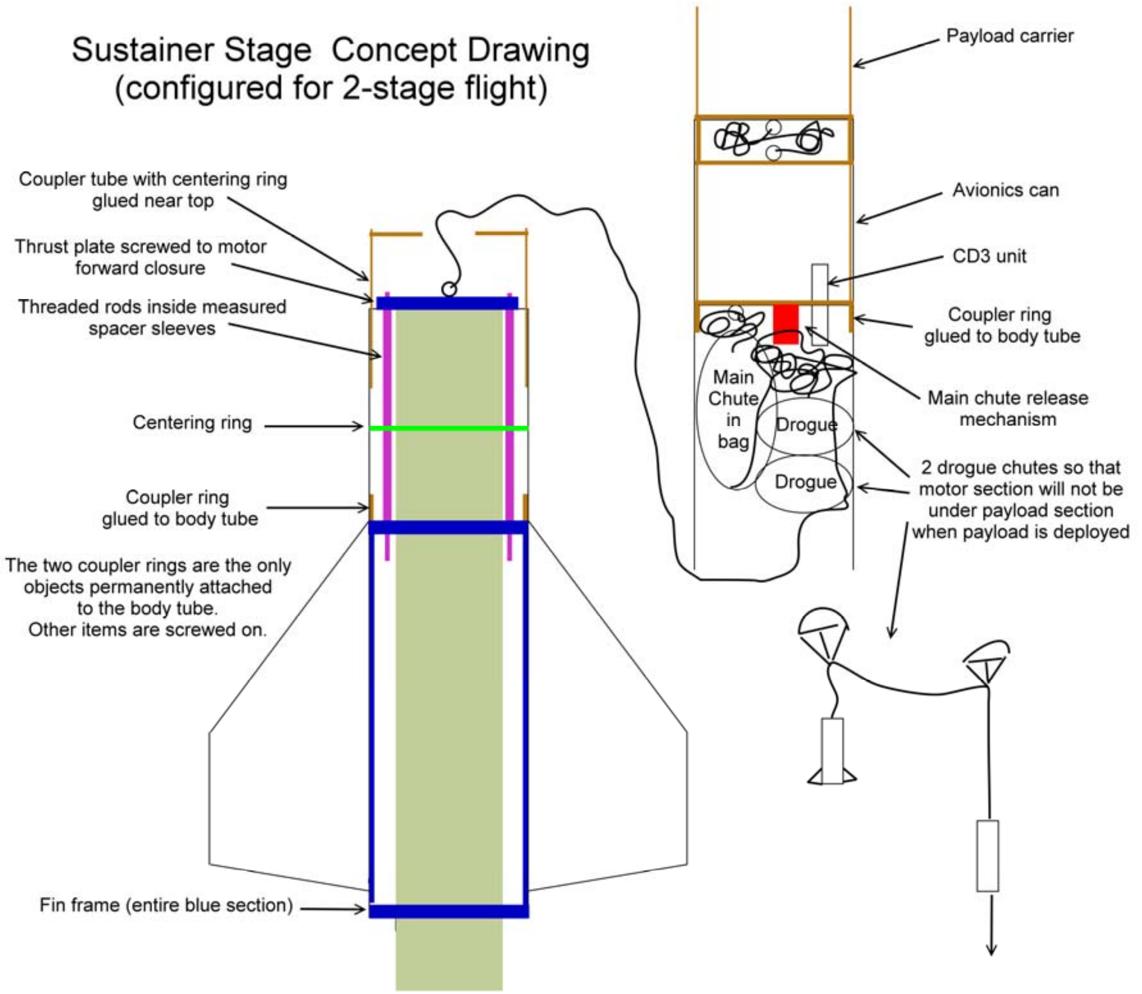


Figure 2. Sustainer Concept

The AeroPack motor retainer is removed and the forward thrust plate assembly is added. Motors used in this configuration have specially modified forward and aft closures. The aft closure is machined such that the outer diameter (OD) of the closure matches the OD of the motor case. This permits the aft closure and the end of the motor case to slide into the sleeve in the booster's interstage coupler.

The forward closure's center pillar is threaded. The thrust plate is slid over the center pillar and fastened to it by a bell nut. Attached in this manner, the thrust plate is used to transfer motor thrust to the fin frame through a set of threaded shafts and to retain the motor.

The recovery strategy of the sustainer also changes when configured for two-stage flight. For standard ARLISS flight, the main parachutes are deployed at apogee, about 12,000 feet. Deploying the main parachutes at the 30,000 foot apogee of a two-stage flight would result in a very long recovery chase. It is also undesirable to have the rocket descend in multiple independent pieces from this altitude.

Instead all of the sections of the sustainer will be tethered together. At apogee, two drogue parachutes will be deployed. It is expected that the two drogue parachutes will cause the upper and lower sections of the sustainer to drift apart, so that neither is directly below the other. Six seconds later, the payload and nosecone are ejected. A modified payload carrier design will be used so that the nosecone can be tethered to the payload carrier. At about 800 feet a main parachute will be deployed.

1.3 The Booster Stage Concept

The booster also consists of a lower and upper airframe. There is an avionics compartment in the upper airframe, just below the interstage coupler. The booster's flight computer will ignite the sustainer motor a fixed interval after lift-off. The ignition of the sustainer's motor will separate the stages. The booster will coast to its apogee, where the flight computer will deploy the booster's main parachute.

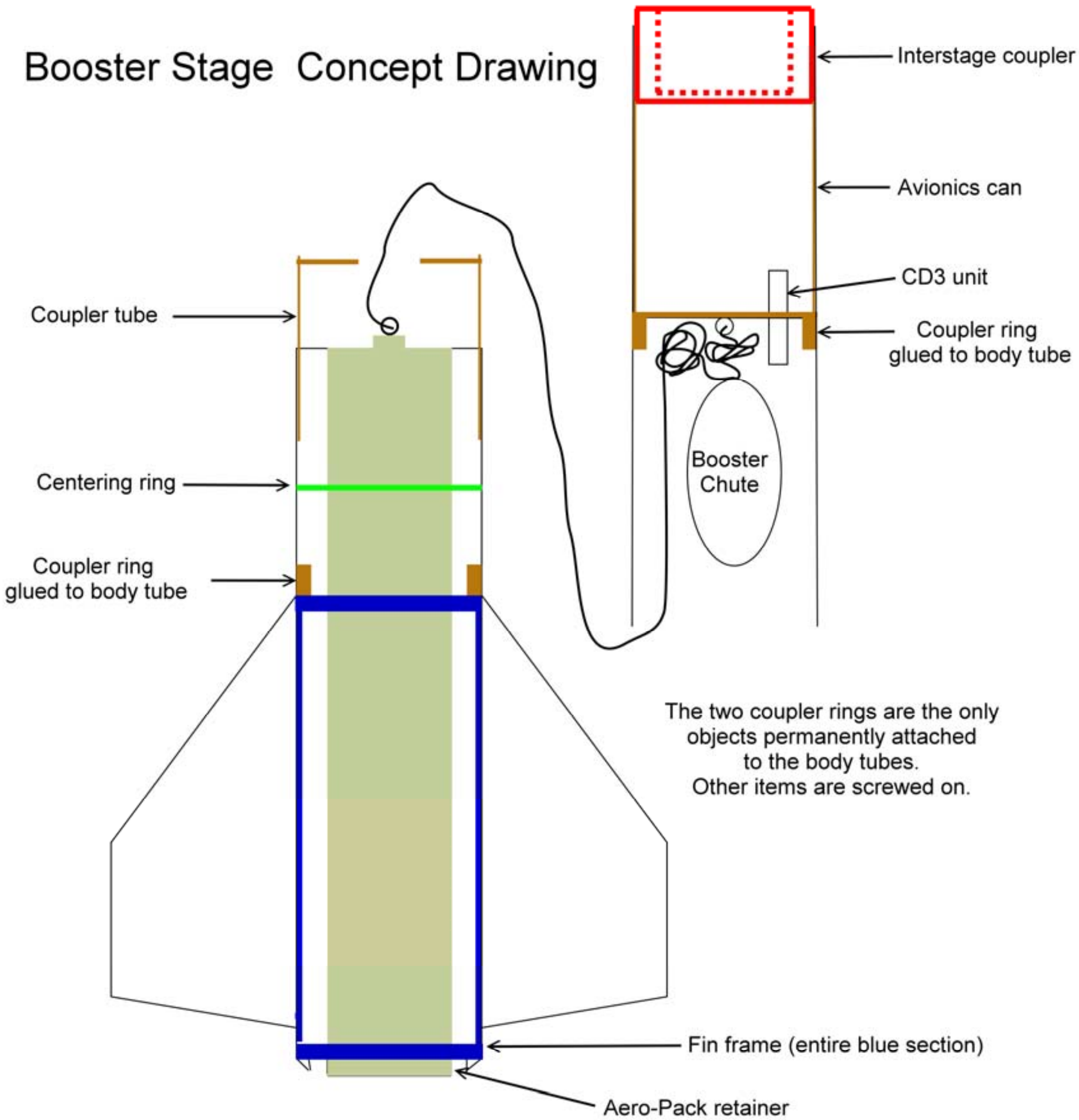


Figure 3. Booster Stage Concept

1.4 Special Problems to be Solved

The above design presents several problems.

1. Hanging the motor out the back of the sustainer stage presents problems in the thrust transfer from the motor to the sustainer airframe and in motor retention.
2. The drogue parachute(s) (deployed at apogee) and a main parachute (deployed at 800 feet altitude) must be deployed from the same compartment. It is also desired to deploy all parachutes without black powder.
3. The booster airframe needs to handle the thrust of an N2000 motor and accelerate the heavy mass of the sustainer stage. The junction between that booster's lower and

upper airframe and the junction between the booster and sustainer stages have been deemed critical stress points.

4. Design of an interstage coupler that provides strength to the joint between stages, while providing dependable stage separation.
5. Tethering the sustainer upper airframe, payload carrier, and nosecone together, such that neither the tether nor the nosecone interferes with payload deployment.
6. It is expected that the sustainer will achieve Mach 1.4 speed. Substantial stress is expected in the fins and fin to airframe joint.

The above problems are addressed through the design of:

- The booster and sustainer fin frames.
- The interstage coupler.
- The main parachute deployment device.
- The tether pass-thru payload carrier.

These devices will be discussed in detail.

2 The Design Process

The most important aspect of the design process is the collaboration and advice received from my rocketry colleagues. Many engineering disciplines are needed in the design and construction of a high power rocket. Without their ideas, comments, and help, the results of this project would be significantly diminished. Rockets are very unforgiving projects. One error and the entire project is often destroyed.

A combination of several deign tools were used to plan and develop this rocket. The general process was to construct a design concept that could satisfy the goals, specify and visualize the design in detail, identify the weak points in the design, and verify that the weak points could be sufficiently strengthened.

2.1 Exploration using RockSim

Initial RockSim simulations showed that with a six-pound payload, a variety of rocket configurations would be stable in flight. They also showed that a two-stage flight using M1939W motors in the booster and sustainer an altitude just below 30,000 feet would be achieved. Using a N2000W in the booster and a M1939W in the sustainer achieved an altitude of about 34,000 feet. From these simulations, it was decided to design the booster to accept N2000W or smaller motors and the sustainer to accept the M1939W or smaller motors.

2.2 Mechanical Design

- The junction between the booster and sustainer was closely examined. The interstage coupler was designed to eliminate suspected problems.
- The thrust transfer paths in the booster and sustainer were identified and analyzed.
- Parachute deployment shock transfer paths were identified and analyzed.
- Tensile and shear stress/strength analysis was performed at critical points.
- Strength rated materials were used in stress locations, where they were available.

Mechanical Computer Aided Design (MCAD) software was used to specify and visualize the design. We decided to use Alibre as our primary MCAD tool. I started using Turbo-CAD Professional v7, but that version of Turbo-CAD is not parameter driven and making changes to parts was very labor intensive.

Calculations were performed using Excel spreadsheets.

2.3 Electronic Design

The servo controller for the Main Parachute Deployment Device was described using TinyCAD, a freeware schematic capture tool. The design was initially constructed, testeded and tuned on a breadboard. The design is intended to be implemented on a single sided three-hole pattern Vector prototype board.

My plan is to test the Main Parachute Deployment Device and the controller on one my old rockets before installing it in the new project.

2.4 Final RockSim Simulation

Once the part masses can be calculated accurately, the design will be simulated using RockSim to calculate the center of pressure and estimate the minimum payload weight needed to ensure stable flight.

2.5 Pre-Flight Testing

Before the Level 3 certification launch, the ejection systems will be ground tested to verify coupler fit, payload carrier fit, parachute fit, and CD3 charge sizing.

3 Structural Design

Although this project is for TRA Level 3 certification using an ARLISS configured rocket, the goals of the project would not be met if the rocket design did not simultaneously consider all flight configurations from the very beginning. TRA TAP reviewers may want to focus only on sections that deal with the ARLISS configuration. However, their feedback would be very much appreciated on all sections.

In many places coupler tubes are secured by screws that are inserted through holes drilled in the body tube. Unless otherwise stated, #8-32 machine screws will be used and they will be secured by PEM nuts attached to the inside of the coupler tube.

3.1 The ARLISS Configuration

This section describes the rocket's sustainer stage configuration for standard single stage ARLISS flights.

Key elements of the ARLISS configuration are its:

- Thrust transfer path
- Avionics
- Recovery system
- Payload carrier

3.1.1 Thrust Transfer Path

Motor thrust generates upward stress upon the rocket airframe. In a rocket that is free to move, this stress is dissipated across the airframe proportionally to the amount of rocket mass in front of the point being analyzed in the thrust path. This means that the stress is greatest at the motor and the least at the tip of the nosecone.

The thrust path originates at the forward combustion chamber wall of the motor case. On Aerotech style certified motors, thrust may be transferred from the motor directly from the motor's forward closure or through the motor tube through the aft motor closure. For the purpose of this structural analysis, we will assume that the motor generates 1000 lbs. of thrust and that the minimum design safety factor is 2x. That is, the weakest link in the design must be able to handle twice the force exerted by the 1000 lb. thrust motor.

3.1.1.1 AeroPack Motor Retainer

The aft motor closure is secured by and transfers thrust through the AeroPack Retainer. Thrust is transferred through AeroPack retainer via an aluminum cylinder. The cylinder is under compression and appears to be about 4" dia. with a wall thickness of 0.090". An area of 1.1 square inches. The failure mode would seem to be the column buckling of a cylinder of a 4" dia. cylinder with a wall thickness of 0.090" and 0.60" height. The cylinder is reinforced internally by the motor case. Even though AeroPack does not specify the Aluminum alloy used, under compression Aluminum is very strong and this structure should withstand far more than the stress load it is subjected to (2000 lbs; 1000 lbs. motor thrust times the 2x safety factor. The AeroPack Retainer is mounted on and transfers thrust to the aft centering ring of the fin frame.

3.1.1.2 The Fin Frame

The fin frame is a pair of Aluminum centering rings attached to four vertical ¼" x 1¼" Aluminum bars (Figure 4. Fin Frames). The fins are screwed into these vertical bars. Two fin frames have been have been developed, called the booster and sustainer fin frames. Either fin frame may have an AeroPack Motor Retainer attached to their aft centering ring. The sustainer fin frame is the one that is used in the ARLISS configuration.

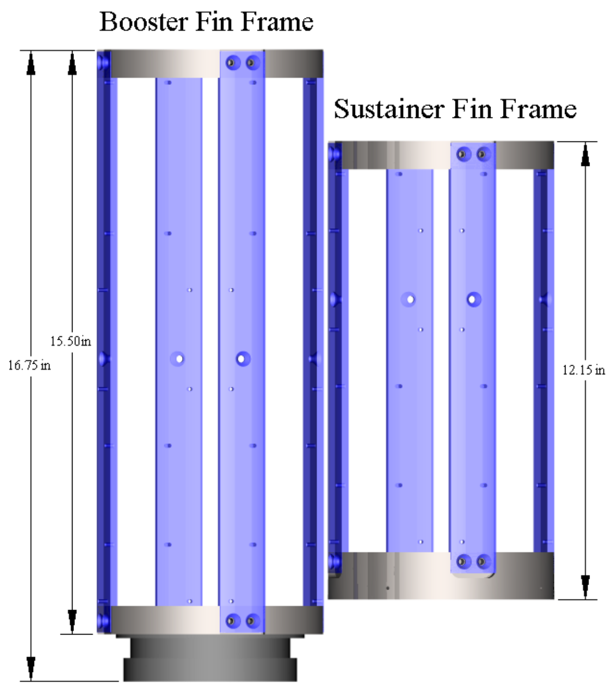


Figure 4. Fin Frames (Booster shown with motor retainer)

Motor thrust will be transferred from the fin frame aft centering ring to the vertical frame bars. This transfer is made through eight #10-32 screws. These screws are rated at a minimum shear strength of 144,000 psi. In the fin frame configuration each screw can withstand over 1500 lbs of shear. So any single screw could handle the nominal motor thrust. The eight screws provide a safety margin of 12x.

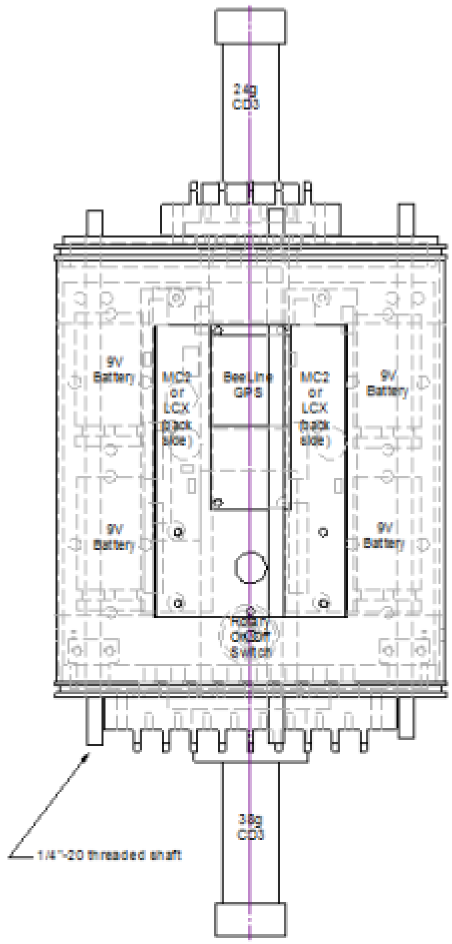
The force on these bars is compressive and their combined cross-sectional area is 1 square inch. The primary role of the reinforcement is to prevent the fin frame from twisting. The reinforcement provided by the fiberglass airframe tube and the fin root edges are ideal to prevent this twisting.

The thrust is transferred from the fin frame to the airframe tube through the 24 fin attachment screws and through the thrust ring that is epoxied just above the fin frame (see Figure 1. ARLISS Concept). From this point on, the thrust transfer path and magnitude is the same as any other standard ARLISS rocket.

3.1.2 Avionics

Redundant flight computers are used. The avionics compartment is designed to support a G-Wiz MC2 and a G-Wiz LCX. Each flight computer has separate 9V batteries for electronics and pyro power sources. This guarantees that firing a pyro charge will not glitch computer power.

Figure 5 Sustainer Avionics Layout



The computers are programmed to ignite an electric match at apogee to trigger a CD3 CO_2 ejection unit and deploy the main parachutes. Six seconds after apogee a second electric match is ignited, which fires a black powder charge to separate the nosecone from the upper airframe and deploy the payload. The CD3 has provisions for two electric matches. One is wired to the MC2 the other is wired to the LCX.

There is room on the avionics platform for a BeeLine GPS location transmitter, its antenna and 3.7V battery. The presence of the GPS transmitter requires that the avionics compartment and platform be constructed out of RF transparent materials.

The avionics compartment is constructed from phenolic carrier tube. The platform is .094" G-10 fiberglass. Stepped aluminum bulkheads seal the top and bottom openings of the avionics compartment. A 24 gram CD3 unit, e-match terminal block, and an off-center eye-bolt is affixed to the outer surface of the top bulkhead. A 38 gram CD3 unit, e-match terminal block, GPS antenna feed-thru connector, and an eye-bolt are fixed to the outer surface of the bottom bulkhead. Three ¼”-20 threaded rods hold the two bulkheads and platform in place. The compartment is seated upon a coupler tube ring that is epoxied to the airframe and then held in place by screws.

The avionics compartment is also designed to support the future addition of a main parachute deployment device. This device is not used in the ARLISS configuration and is describe in a later section.

Electronics units are fastened to the surface of the avionics platform by machine screws. Batteries are fastened to their terminal clips and the surface of the platform by nylon cable ties. Nylon cable ties are also used to fasten the avionics platform to the threaded shafts.

Rather than cutting a hatch into the side of the avionics compartment to permit access to the arming controls the controls will be positioned in accessible positions behind pressure equalization ports.

3.1.3 Recovery system

ARLISS rockets are recovered in three separate pieces, the lower airframe, the upper airframe, and the nosecone. (Note that deployed payload objects have their own independent recovery systems.) Each of these pieces is brought to earth under control of its own parachute.

The parachute compartment in the base of the upper airframe holds the parachutes for the lower and upper airframes. The compartment has been sized to hold two Rocketman R-12 parachutes. (see the appendix for dimensioned drawings) The R-12 parachutes provide a very slow (<40 fps, RockSim calculated) decent rate and are planned to be used on very calm days. R-9 parachutes may also be used to recover the lower and upper airframes. The R-9 parachutes provide a faster (<xx fps) decent rate and are planned to be used on windier days. A Rouse-Tech CD3 CO_2 ejection device is used to separate the lower and upper airframes and push out the parachutes. Ejection testing without a piston showed that both parachutes could not be reliably expelled by the CD3, so we added a piston to push out he parachutes.

The nosecone parachute is housed in the hollow base of the nosecone. This parachute fits loosely in its compartment and is tethered to the nosecone and the top bulkplate. When the payload deployment pyro charge is fired, the payload carrier pushes the nosecone out of the upper airframe, breaking the shear pins at the base of the nosecone. The drag on the bulkplate pulls the nosecone parachute out of its compartment so that the parachute can inflate.

3.1.3.1 Parachute Deployment Shock Analysis

Two large parachutes are used in the ARLISS configuration. The lower airframe parachute is anchored to a forged eye-bolt (rated for 1300 lbs) threaded into the forward motor closure. Since the motor accounts for more than 50% of the lower airframe's mass, it dissipates most of the parachute deployment shock. The remaining deployment shock force is transmitted through the same path that is used for motor thrust transfer.

The upper airframe parachute is anchored to a eye-bolt in the bottom avionics compartment bulkhead. The deployment shock from the parachute is transferred from the bulkhead to the upper airframe through the adjacent 1" wide coupler ring that is epoxied to the airframe tube.

3.1.4 Payload carrier

This rocket is designed to support the standard ARLISS payload carrier. The payload carrier sits on top of and is tethered to the avionics compartment. The payload carrier is ejected by a CD3 unit that is mounted on the top avionics bulkhead.

3.2 Booster Stage

For two-stage flight, the booster stage is responsible for lifting the rocket from its launch pad, achieving stable flight velocity before reaching the end of the launch guide rail, and achieving an altitude of about 10,000 feet. At a specified time interval after launch (initial acceleration), the booster's flight computer will ignite the sustainer stage motor. The ignition of the sustainer's motor will cause the booster stage to separate from the sustainer stage. Later, when the booster reaches the apogee of its flight, the boosters parachute recovery system is activated.

In its two-stage configuration, the rocket is very long and slender. Flight stresses that could break the rocket in half are a concern. A major cause of flight stress is the breaking of the sound barrier. RockSim simulations show that the rockets flight propelled by the booster will be subsonic.

Key elements of the booster are its:

- Thrust transfer path and tube reinforcement
- Interstage coupler
- Avionics
- Recovery system

3.2.1 Thrust Transfer Path

Thrust transfer in through the booster stage is a major concern because of the large mass that the booster needs to lift. The booster is designed to handle a N2000 high thrust motor. At liftoff, this motor generates nearly 1000 lbs of thrust and much of this thrust must be transferred through the entire booster thrust path and into the sustainer stage.

The thrust path originates at the forward combustion chamber wall of the motor case and is transferred to the booster's lower airframe through a path that is very similar to the one described in the above ARLISS section. The primary difference is that the booster's fin frame is longer. The additional length shortens the column length of the airframe that is subjected to buckling stress and provides 4 more fin screws through which force can be transferred.

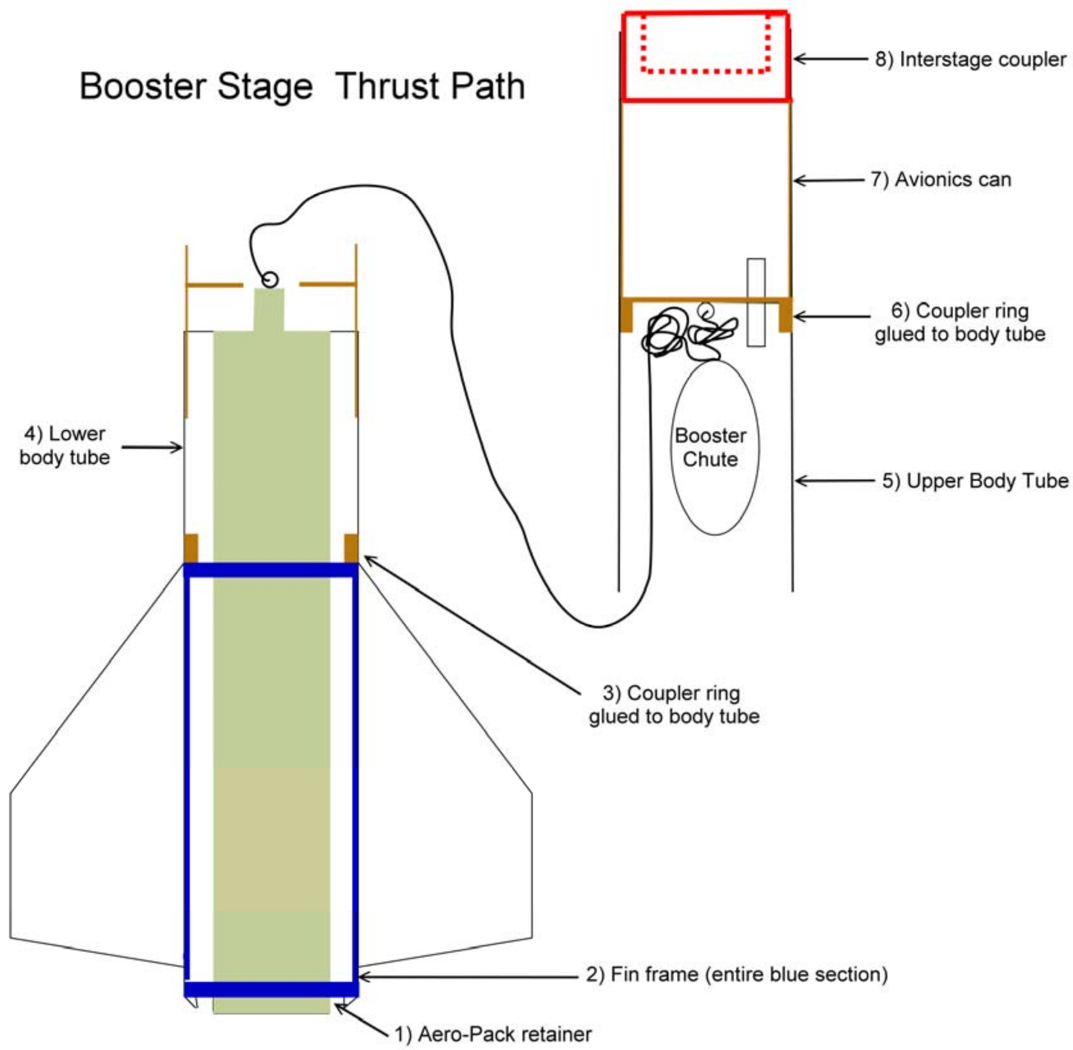


Figure 6. Booster Thrust Path

The thrust is transferred from the lower airframe tube to the booster's upper airframe through an abutment joint where the airframe tubes meet. This joint is perceived to need reinforcement. Several steps are taken to reinforce this joint.

- A 12" long coupler tube (one inch greater than the one used in the upper stage) is used.
- The coupler is lined with a sleeve made from another coupler tube, giving it double wall thickness.
- The coupler tube is reinforced by a ½" thick centering ring near its top.

- Two layers of 9 oz. (?) fiberglass tape are laminated outside the body tube in the vicinity of the joint. First a layer is 4" wide with a 45 degree weave. The second layer is 6" wide with a standard weave. The booster body tube will be reinforced before it cut.

The thrust is transferred to the interstage coupler via two paths. The primary path is through the ¾" coupler ring, through the avionics compartment bulkhead and coupler tube to the interstage coupler. The column length between the coupler rings (for body tube buckling calculations) is 11-¼ inches. The coupler length under compression is 5 inches. The secondary path is from the upper airframe tube through 4 screws to the interstage coupler. Materials strength data on the body tube and coupler tube materials is not available, so failure calculations can not be performed, but the column lengths along primary path are reasonably short and not judged to be a problem at this time.

3.2.2 The Interstage Coupler

The junction between the booster and sustainer stages is critical. The joint must be strong enough to transfer thrust between the stages and handle the bending moment of the long thin aspect of the two-stage configuration. It must also be able to separate dependably and efficiently at the specified staging time.

The interstage coupler is designed to solve these problems. It is a very strong link in thrust path. It is bolted with four 8-32 threaded rods to the avionics coupler and bulkhead and transfers thrust from them to the sustainer's aft centering ring.

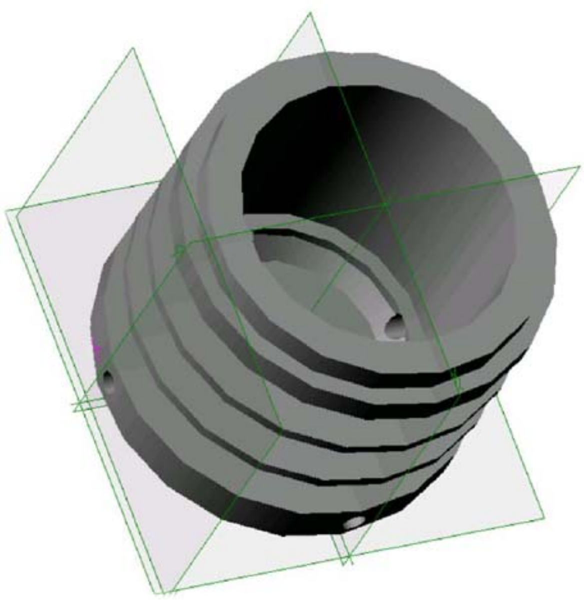


Figure 7. Interstage Coupler

Bending stability is achieved by extending the sustainer's motor case 4-¼" below the bottom of the sustainer's aft centering ring. The motor case extends into and is closely fitted inside the interstage coupler. The top of the interstage coupler also closely fits into a ½" flange on the outer diameter of the aft centering ring.

The interstage coupler is machined out of a 6.25" dia solid Aluminum rod. The body is turned to fit snugly inside the fiberglass airframe tube. The diameter of the upper rim is reduced to fit closely into the sustainer fin frame's aft centering ring. The diameter of the lower rim is reduced to fit into and act as the upper bulkhead of the avionics compartment coupler. A deep hole, called the cup, is bored into the top of the tube. The hole is deep enough to accept the sustainer's motor's projection and an additional ½". The top 4.25" of this hole is widened to be hold a nylon-MdS sleeve inside which the motor case slides. These design aspects anchor the interstage coupler solidly into the booster and closely to sustainer fin frame, while being easily separated by a separating force applied along the axis of the rocket.

A Nylon MDS sleeve between the sustainer motor and the interstage coupler was chosen for several reasons:

1. As a low friction material it eliminates potential aluminum to aluminum galling of the sustainer motor case to the coupler which could jam the staging release
2. It provides some protection for the coupler from the sustainer motor gases, and is cheap enough to be disposable.
3. This material is available as a hollow cored rod for low cost and ease of machining.

The sleeve is retained by nylon screws to the coupler so it is normally retained in the booster after separation. However, the screws are sized to shear at 2x the normal interstage shear screw strengths as a backup staging mechanism, should the primary shear screw system fail or jam.

A boss is formed at the center of the cup. The a shallow hole is drilled in the center of the boss to accept a 1/8"dowel. Ignition of the sustainer motor is achieved by fastening an igniter to the top of a dowel and mounting the dowel in the boss's hole. The igniter leads are routed through an exhaust hole (discussed below), along the outside of the rocket and back in through an avionics compartment pressure hole. The sustainer igniter dowel rod is retained and secured for flight dynamics by a socket head screw in the coupler that is accessible through one of the coupler exhaust ports.

To prevent the stages from prematurely separating, the interstage coupler is attached to the sustainer's aft centering ring by four #4-40 nylon screws. These screws are only rated to resist a shear force of 39 to 74 lbs. So, given the 11.9 square inch area under the motor, when the motor pressurizes the cavity under the coupler to 100 psi, the rated shear strength of the screws will be exceeded by a factor of 4. Since the motor will generate pressure far in excess of 100 psi, the motor should have no problem shearing the screws and separating from the booster.

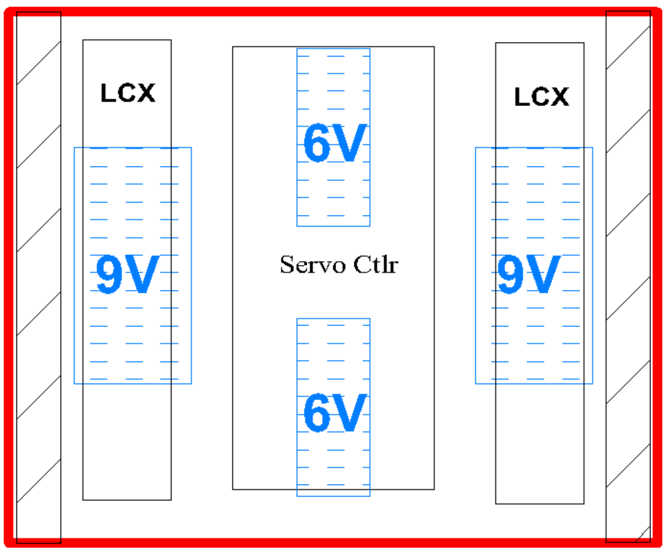
Four exhaust holes are drilled from the outside into the cavity under the motor. These holes are to permit sufficient exhaust airflow to permit the igniter's hot pyrogens to flow out of the motor. They must be large enough to permit the igniter to light the motor and small enough to guarantee the needed separation pressure in the coupler. The exhaust hole diameter is sized such that the area represented by the exhaust holes approximate the area of the M1939 motors nozzle throat.

The interstage coupler is then lightened by turning grooves in non-critical areas of the outer surface.

3.2.3 Avionics

Redundant flight computers are used. The avionics compartment is designed to support a two G-Wiz LCXs. Each flight computer has separate 9V batteries for electronics and pyro power sources. This guarantees that firing a pyro charge will not glitch computer power.

Booster Avionics Layout
5.5" x 4.5"



At a specified time interval after launch (initial acceleration), the booster's flight computers will ignite the sustainer stage motor. Later, when the booster reaches the apogee of its flight, the flight computers trigger a CD3 CO_2 ejection unit and deploy the booster's parachute.

There is room on the avionics platform for a Servo Controller (described in the sustainer design section) and servomotor batteries. This permits future launches to utilize dual deployment recovery strategies.

The avionics compartment is constructed from fiberglass coupler tube. The platform is ¼" plywood. Stepped ½" plywood bulkheads seals the bottom openings of the avionics compartment. The Interstage Coupler acts seals the top opening. A CD3 unit and U-bolt are attached to the outer surface of the bottom bulkhead. A pair of 8-32 threaded rods hold the interstage coupler, bulkhead and platform in place. The compartment is seated upon a coupler tube ring that is epoxied to the airframe and then held in place by screws.

Electronics units are fastened to the top surface of the avionics platform by machine screws. Batteries are fastened to their terminal clips and the bottom surface of the platform by nylon cable ties. Nylon cable ties are also used to fasten the avionics platform to the threaded shafts.

A hatch is cut into the side of the booster avionics compartment to permit access to the arming controls. The hatch lid is held in place by screws during flight.

3.2.4 Parachute Deployment Shock Analysis

The booster parachute is anchored to a forged eye-bolt (rated for 1300 lbs) threaded into the forward motor closure and to a U-bolt in the bottom avionics compartment bulkhead. The motor accounts for more than 50% of the booster's mass, it dissipates much of the parachute deployment shock. The remaining deployment shock force is transmitted through the same path that is used for motor thrust transfer.

3.3 Sustainer Stage

The primary difference in the sustainer stage used in two-stage flight and ARLISS flight are the:

- Beginning of the thrust transfer path
- Recovery system
- Payload carrier
- Motor retention

3.3.1 Thrust Transfer Path

The sustainer motor is extended several inches beyond the end of the sustainer aft centering ring. This prevents the use of the AeroPack motor retainer and changes the first few steps of the thrust transfer path. As before, the thrust path originates at the forward combustion chamber wall of the motor. The thrust is transferred through the forward motor closure to a thrust plate that attaches to it.

The thrust is then transferred to the upper fin frame centering ring through three #10-32 stainless steel threaded rods in tension. The rods have the minimum tensile strength of 70,000 psi. Since a single rod is rated support 1265 lbs, three rods provide a 3.7x safety factor. From this point, the thrust transfer path is identical to the ARLISS configuration.

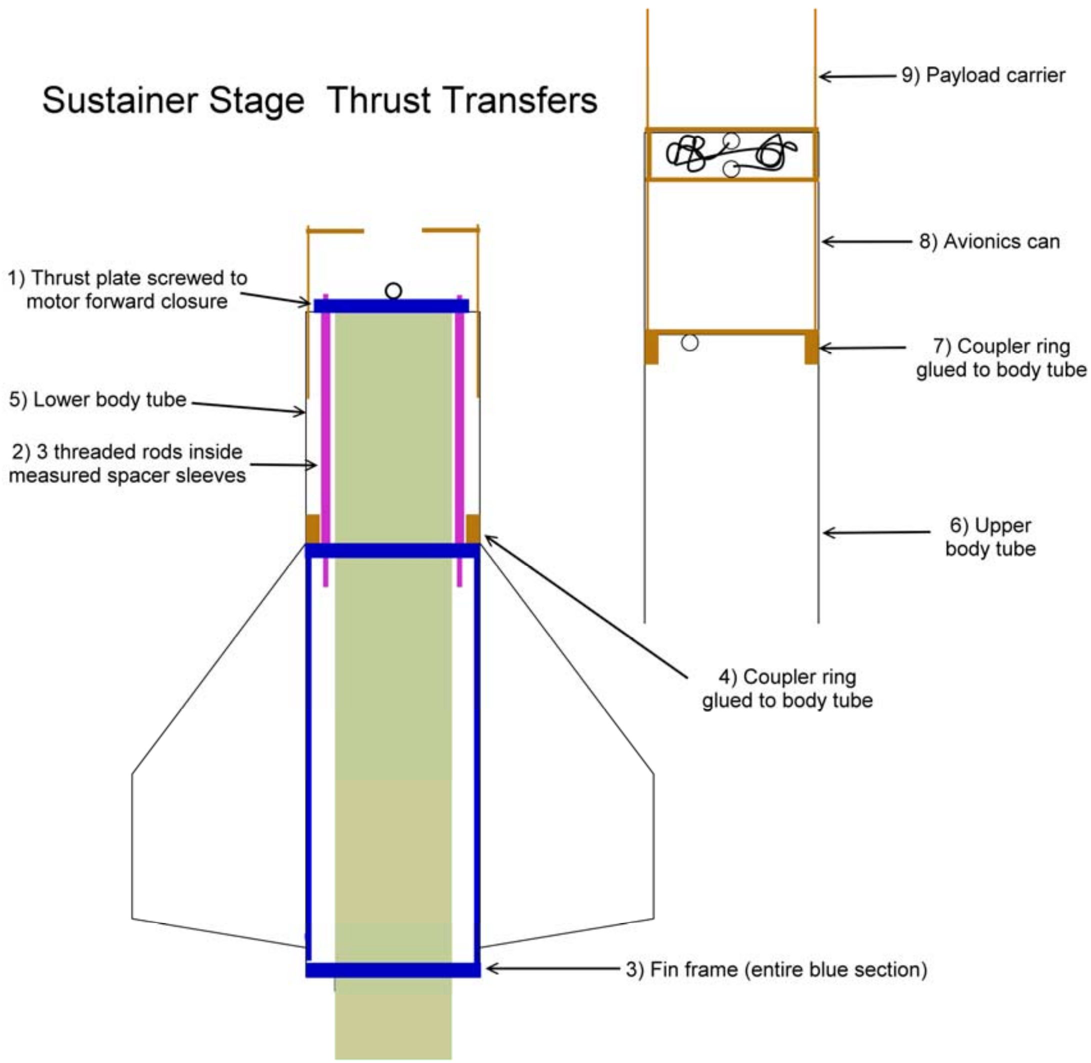


Figure 8. Sustainer Thrust Transfer Path

3.3.2 Recovery system

The sustainer is expected to achieve an altitude of over 30,000 feet, three times higher than the ARLISS configuration. Opening a main parachute at this altitude would result in a very long chase to retrieve the rocket, so a drogue/main parachute deployment strategy is desired. It is also undesirable for the sustainer to be recovered in three separate pieces.

The recovery system for the sustainer is designed to:

- Keep the sections of the sustainer tethered together.
- Deploy drogue parachutes at apogee and deploy a main parachute at 800 feet.
- Deploy the drogue parachutes and the main parachute from the same compartment.

A nylon flat cord is used to connect the lower and upper airframes. The cord attaches to several objects in the below sequence.

1. The eye-bolt in the forward motor closure.

2. Drogue#1 parachute swivel
3. Drogue#2 parachute swivel
4. A quick-link that anchored to the Main Parachute Deployment Device
5. The main parachute inside a deployment bag (the bag is tethered to the avionics bulkhead)
6. The U-bolt in the bottom avionics bulkhead

At apogee the flight computers fire a CD3 ejection device, which separates the upper and lower airframes and releases the two drogue parachutes. Two drogue parachutes are used so that neither airframe segment is directly above or below the other when the payload is deployed and when the main parachute is deployed. If the lower airframe was directly below the upper airframe when the payload is ejected, impacting the lower airframe section could damage the payload. If the upper airframe was directly below the lower airframe when the main parachute deployed, the main parachute could be damaged or snagged by the lower airframe.

Forged steel eye and eye swivels (load rated for 800 lbs) are used to attach the parachutes to the tether cord. The swivels are needed because multiple parachutes are attached to the same tether cord. Multiple parachutes will prevent free rotation of the collection of tethered objects.

At 800 feet altitude, the flight computers trigger a Pyro circuit that releases the main parachute. The Main Parachute Deployment Device is used to release this parachute.

3.3.2.1 The Main Parachute Deployment Device

The deployment device consists of a shackle with a sliding release pin. The shackle is attached to the bottom avionics bulkhead. A high torque miniature servomotor is used to slide the pin to the release position. The shackle is constructed so that the parachute drag force is borne completely by the shackle. Only a small increase in sliding friction is seen by the servo motor. When the Servo Controller signals the servo motor to rotate to the release position, the release pin is retracted and the drogue parachutes pull the main parachute out of its deployment bag and the parachute compartment.

The servomotor is run from a dedicated pair of redundant 6V batteries. The servomotor consumes very little power when the motor's shaft is in the commanded position. If external forces attempt to move the shaft position, the motor power consumption increases to generate the torque needed to resist the force. External forces of this type are not expected to occur for any duration that would compromise battery life. When he servomotor is commanded to change its shaft's position, the motor consumes power as needed to generate the torque required to turn the shaft.

3.3.2.2 The Servo Controller

The Servo Controller generates a stream of pulses to the servomotor. The widths of the pulses signal the servomotor to rotate its shaft to specific positions. Two positions are implemented, closed position and release position. Normally the controller generates pulses to keep the servo shaft in the closed position where the shackle retains the main parachute's quick-link.

When the flight computers fire the main parachute release Pyro circuit, the controller receives this signal and changes the pulse widths being generated to command the servomotor to rotate its shaft to the release position.

Power is provided to the controller from both "electronics" 9V batteries through isolation diodes. The diodes prevent a failure in one battery circuit from effecting the other. The controller only uses a few milliamps of current so power loss through the diodes is not a concern.

The controller also contains circuitry to detect and satisfy the constant continuity testing that is performed by the flight computers.

3.3.3 GPS location Transmitter

The significant altitude that can be achieved has made GPS location-tracking desirable. Space in the avionics compartment has been allocated for a BeeLine GPS location transmitter, its antenna and battery.

3.3.4 The Tether Pass-thru Payload Carrier

Since we don't want the nosecone to have an independent parachute, we will tether the nosecone to the payload carrier. This will require a specially constructed payload carrier. If the flight goal is to deploy three CanSats, a three-CanSat carrier will be constructed that passes the tether through the center of the carrier divider. Otherwise the payload must make accommodation for a 1/8" x 1/2" strap glued flat along the inside of the payload carrier.

4 Detailed Drawings

For a complete set of detailed drawings please see www.feretich.com/rocketry.