Design and Manufacture of an Open-Hardware University Rocket Airframe using Carbon Fiber

ME493 Final Report - 2016

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Sponsor:

Portland State Aerospace Society

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Executive summary

The Launch Vehicle 3 (LV3) team was tasked with designing and manufacturing a new composite airframe for the Portland State Aerospace Society to use as their next generation launch vehicle. The primary deliverables for the project were a composite nose module, composite tail fins and both 18” and 24” cylindrical modules. Also required was adequate documentation of the design and manufacturing process for future teams to be able to rapidly gain the knowledge required to reproduce or iterate any of the modules produced.

The composite layup process used has evolved from the process passed down from the 2014 capstone team. While overcoming numerous significant challenges with materials, the cylindrical modules have been successfully manufactured. Designs for both the nose and fins have been created. At the time of writing, a design for the fins has been successfully created and manufactured, however a weakness has been discovered and the design will need to be iterated in the future. Similarly, a nose design was successfully created. Due to manufacturing issues though, a new process was needed on a short timeline. This required design changes and the manufacturing process is currently in progress and on track to be completed before the launch date.

Despite the challenges faced, our sponsor is satisfied with our progress and timetable moving forward toward launch.

Introduction

The amateur and university rocketry communities are rapidly reaching higher altitudes with more sophisticated rockets. However, most groups are still using heavy airframes made of metal or fiberglass. Commercial off-the-shelf airframes are either too expensive for low-budget university groups or too small to use as a platform for high altitude experiments. A capstone team of mechanical engineering seniors at Portland State University is developing a low-weight, modular carbon fiber airframe as an open-hardware technology for university rocketry. This team is continuing the work of a 2014 capstone team, who developed a carbon fiber layup process with promising results. This will enable low-budget groups like the Portland State Aerospace Society to explore high altitude science and compete in the university space race.

The Portland State Aerospace Society (PSAS) is an interdisciplinary group of engineering students, community members, and alumni of Portland State University (PSU) with the long term goals of being the first university to reach an altitude of 100km (the Karman line, traditionally marking the edge of space), and putting a cubesat, a small satellite, into orbit with their own rocket. Their current airframe, named Launch Vehicle 2 (LV2), has served for over 12 years, representing 10 of the group's 13 launches, and hosted experiments ranging from custom patch antennas and long range WiFi technology to GPS navigation and a cold gas reaction control system (figure 1). The LV2 platform is mostly constructed of aluminum with a fiberglass shell, with many of the parts having been fabricated in home garages. This makes for a robust but heavy design.

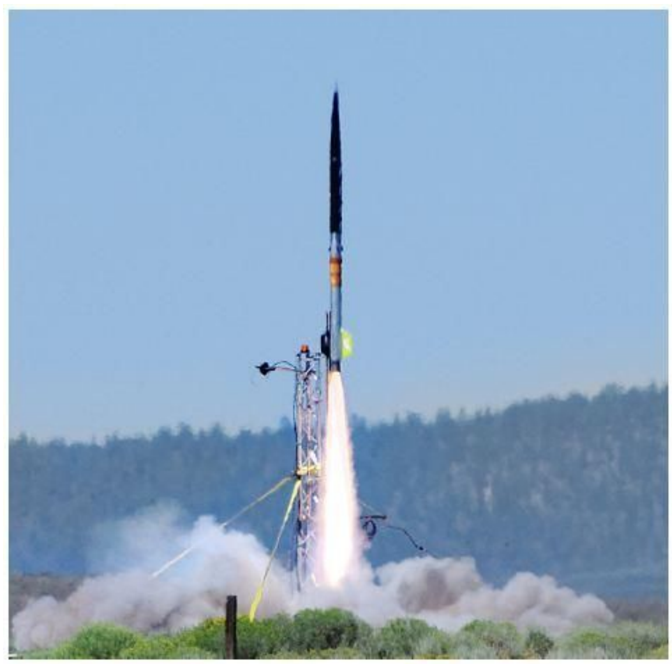


Figure 1. PSAS's LV2 rocket lifting off for the group's 13^{th}launch. The custom cylindrical patch antenna can be seen as a brown band around the middle of the rocket.

Additionally, this airframe is built with a 4.5 inch inner diameter which PSAS's experiments have outgrown.

The new airframe being designed, named Launch Vehicle 3 (LV3), aims to address these issues. The LV3 platform uses a 6 inch inner diameter, modules composed of carbon fiber and thin aluminum coupling rings, a carbon fiber nose cone, and a carbon fiber fin section. All of the airframe components connect via standardized rings, to accommodate future experimental modules and tight configurations. The cylindrical LV3 airframe modules already outperform the old design with an 80% reduction in weight.

Future goals of PSAS is to launch a rocket capable of reaching 100 kilometers in the pursuit of delivering a University built and sponsored communications satellite. To successfully achieve this goal, the current version of the rocket must be modified to include composite material and other lightweight materials to attain the required escape velocity. To assist PSAS, metal-leading edge fins and a carbon fiber nose cone would need to be carefully designed and manufactured with considerations to fin flutter, drag, and heat. PSAS would also need comprehensive manufacturing manuals for all parts designed to pass on to new capstone projects to be followed and modified for performance.

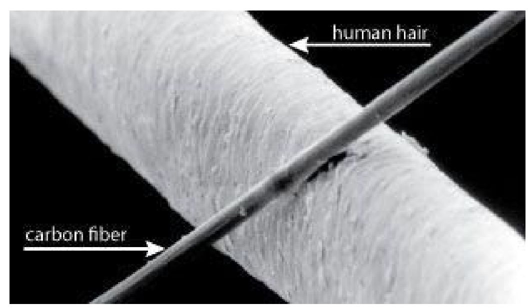


Figure 2. A carbon fiber strand held against a human hair under a microscope

What is Carbon Fiber?

A carbon fiber is a long, thin strand of material about 0.0002”-0.0004“in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber incredibly strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The yarn or fabric is combined with epoxy and wound or molded into shape to form various composite materials.

Mission Statement

The LV3 composite airframe team will follow the manufacturing process left to us by previous capstone teams to further the design of fully composite and aluminum airframes while also designing metal-leading edged fins, a carbon fiber nose cone, and all necessary tooling. PSAS will also need a comprehensive manufacturing manual detailing all steps and materials used which will serve as a how to for later groups replicate and modify for performance.

Design Requirements

The capstone team was charged with specific tasks at the onset. These were the Project Design Specifications (PDS) deliverables.

- Design a 6" inner-diameter nose cone optimized for Mach 3 velocity co-molded with aluminum coupling rings for modular assembly
- Manufacture (2) flight ready nosecones made of carbon fiber using the new design
- Manufacture (2) 18" cylindrical airframe modules ("payload module") from carbon fiber co-molded with aluminum coupling rings
- Design tail fins optimized for Mach 3 velocity, attachable to a 24" module, with metal leading edges
- Manufacture (2) fully assembled fin canister modules consisting of:
    - 24" cylindrical airframe module made of carbon fiber co-molded with aluminum coupling rings
    - 3-4 fins, made of carbon fiber using new design, attached to the 24" module optimized for stability, drag, and fin flutter.
    - Upper motor retaining ring, referred to as a "spider", made from aluminum
    - Lower motor mounting plate made from aluminum
- Redesign takeoff stabilization system, called "rail buttons"
- Manufacture rail buttons using new design
- Verify / alter / improve carbon fiber composite manufacturing process created by 2014 capstone team

- Test one (1) of every manufactured part under appropriate conditions for strength and performance
- Create informational document detailing the entire design and manufacturing process and test results for use by future teams as an instructional guide.

Table 1. Product Design Specifications for the LV3 project

Category	Description	Priority	Complete
Research	Design fin can for weight, flutter and heat in MACH3	Must	Yes
	Redesign Rail Buttons	Must	Yes
	Design nose cone for weight, flutter and heat in MACH3	Must	Yes
Manufacturing	New process for development of fins and canister	Must	Yes
	New process for development of nose cone	Must	Yes
	Tooling for nose cone	Must	In Process
	Build 2 LV3 airframes	Must	Yes
	Build fin can	Must	Yes
	Manufacture payload/avionics/spare module	Must	Yes
	Build nose cone	Should	In Process
	Build third airframe for destructive test	Should	Yes
	Metal leading edges on fins	Should	Yes
	Create mfg process for airframes, nose cone, and fin can	Should	Yes
	Manufacture Rail Buttons	Should	Yes
	Recovery module	May	No
	Module rings, CTI 98mm motor adapter	May	In Process
Testing	Non-destructive test all models	Must	Yes
	Destructive Test third airframe	Should	Yes

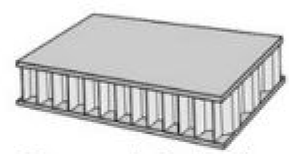
Documentation	Full documents on all design	Must	Yes
	Write up on all manufacturing processes	Must	Yes
	Document test results (particularly fin can)	Must	Yes

Design concept overview

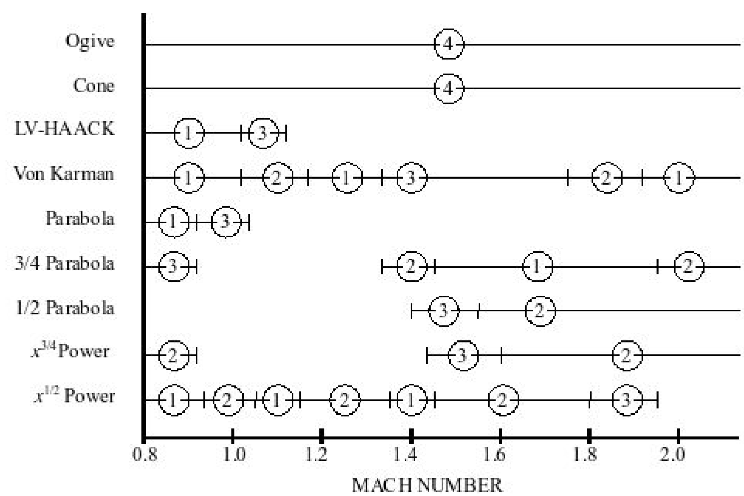
Figure 3. A 24" module

Cylindrical Modules

The design of the cylindrical modules was not changed relative to the 2014 capstone team. They utilize Nomex honeycomb core between 2 layers of carbon fiber in a “honeycomb sandwich” configuration. The carbon fiber is co-molded with standardized aluminum coupling rings (also designed by the ‘14 team). The modules are 2 lengths, 18” and 24” (the payload module and tail module respectively).



A slight modification of the 2014 design was created, using adhesive as a cosmetic surfacing over the carbon fiber. The purpose of this is to allow sanding of the module without reducing its strength and to eliminate any patches where the carbon fibers are not in an epoxy matrix (dry cells).



To quantify the improved surface finish of the adhesive-surfaced modules, profilometer measurements were made on each design. It was found that the non-surfaced modules had surface roughness features about 0.008” tall, due to transitions between dry and wet cells. The surfaced modules had surface roughness features only 0.00015” tall, when sanded to 1500 grit.

A final decision has not been made on whether to use the surfaced or non-surfaced design. The cost, weight, number of dry cells, durability, and supersonic surface roughness drag of each design must all be considered together, with the latter two being non-trivial questions.

Axial compression tests were also done on an adhesive surfaced-module and on a defective module with nearly complete delamination of the carbon fiber from the aluminum rings and the honeycomb. The surfaced module began pinging (equivalent of yield) at 7,000 lbf, with ultimate failure at 10,000 lbf. This represents a factor of safety of about 20, for loads experienced during launch. The defective module failed below the noise floor of the load cell used in the test.

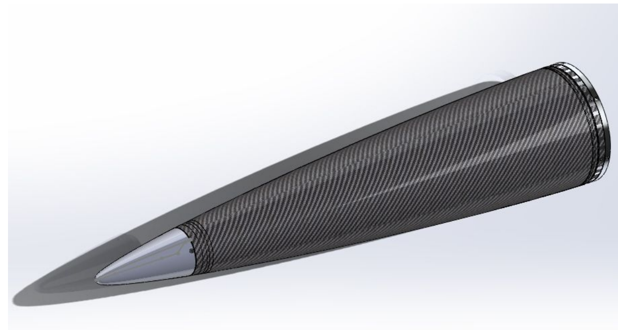
Additionally, tests from the LV4 team indicate that the modules are highly vulnerable to concentrated surface loads, crushing in at only about 100 lbf with a contact area of a few square inches. When crushed like this, the layers delaminate and the damage can be invisible. Together with the results from the defective module, this suggests that the most likely mode of failure is the modules being delaminated via surface impacts at landing - hitting a rock, for example - and then relaunched without adequate inspection. To address this, future teams will need to develop a method for nondestructively testing the modules. Ultrasonic examination is an attractive choice for this.

Nose Module

With the requirement that the module be optimized for mach 3, our options for possible shapes were immediately limited to 2 options: Power series and Von Karman.

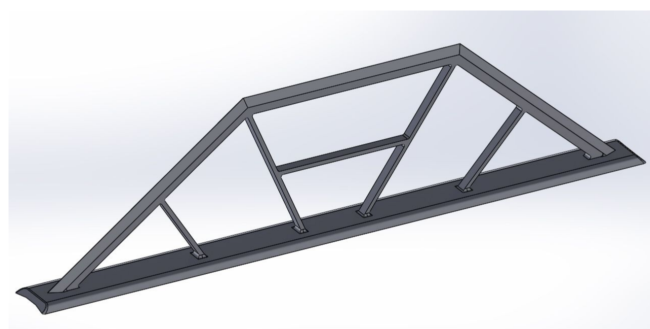
We chose the Von Karman profile based on its low wave drag properties near and above mach 2.

Originally, the manufacturing process for the nose module was going to utilize the same process as the cylindrical modules, using an upper and lower coupling ring modified to match the contour of the nose. However after significant challenges in producing the tooling were recognized, and it was determined it was beyond the financial scope of our team or our donors to overcome, a new process had to be implemented.



The nose module will now be created using the “reverse” process. An external mold of the nose will be machined and the layup procedure will happen inside a mold rather than outside a mandrel. The two halves created from the mold will be trimmed and bonded together with an extra layer of carbon fiber.

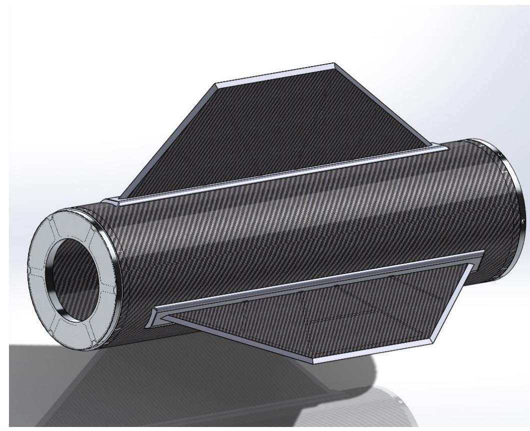
Fin Frames



The fin design, in addition to providing adequate stabilization of the rocket, needed to incorporate metal leading edges and be very resistant to “flutter”, a type of oscillating deflection produced in fins at high speed.

After much deliberation, a single piece aluminum frame with a mounting flange was chosen to provide not only the leading edge but provide the strength to resist flutter. After consultation with machining expert Brian McCabe at Machine Sciences Co., an internal support structure was added to the frame to prevent warping and collapse during the manufacturing of the frames due to thermal stress.

Motor Module Assembly



After completing the fins and 24” cylindrical module, a motor module is produced by attaching three fins mounted at 120° from each other. A rail sled device is attached for stabilization during liftoff. These pieces are cured on th the outside of the cylinder using the same adhesive as the carbon fiber. A motor mount and motor centering device are added and the module is complete.

Materials

Composite materials, the tooling to manufacture them, and the containers to properly store and cure them are expensive items to purchase; especially on a University club budget. Much of what was required and used either came completely donated to our group by local industry or was purchased at a student discount. If it weren’t for the donors this project could have been largely incomplete.

Boeing, Pacific Coast Composites (PCC), and Machine Sciences (MSci) are three companies who donated much of the material used in the manufacturing of LV3. Table 2 displays who donated what material or what materials were purchased at a discounted rate. Establishing a relationship with contacts for PSAS is a valuable achievement and will benefit other teams for years to come.

Table 2: Donor information spreadsheet

Company	Material	Donated/ Purchased	Discount %	Contact Name	E-mail/ Phone
Boeing	Prepreg plain-weave carbon fiber Prepreg unidirectional carbon fiber Meltbong 1515-3m adhesive Fiberglass Cytec 777 Stringer lower vacuum bag	Donated	Free	Sandi Hallman	sandie.h.hallman@boeing.com
Pacific Coast Composites	Prepreg plain-weave carbon fiber 3M AF- 30 adhesive 350 degree prepreg fiber glass 250 degree prepreg fiber glass Unidirectional carbon fiber tape 3M AC 130 surface treatment	Donated	Free	Kevin Fochtman	kevin@pccomposites.com
Machine Science	Coupling Rings 12 pair 12 Fin Frames	Donated	Free	Brian McCabe	brian.mccabe@machinesciences.com
Fiberlay	Ceramical Vacuum bagging tape	Purchased	20%	Marlin	(503) 228-1222
Fibreglast	High Temp paste wax PVA Release	Purchased	None	Customer Service Representative	1 (800) 838-8984
ACP Composites	E-Z Lam High temp resin Resin Kit	Purchased	10%	Customer Service Representative	1 (800) 811-2009
General Plastics	FR4718 High temp tooling board	Purchased	23%	Customer Service	1 (800) 852-8509

Conclusion and Recommendations

This year's PSAS capstone team was able to successfully complete the tasks asked for in the PDS (Table 1). Not only was the 2014 manufacturing process followed for the manufacturing of the carbon fiber modules, but it was improved and modified for the creation of other parts. These parts were tested in a variety of ways to ensure the highest quality parts for PSAS' summer launch.

Manufacturing processes were created for each of the parts designed and created by the LV3 team. The nose module will be built over the summer.

Appendix

Carbon Fiber Layup Procedure

Materials

- orca skin
- orca seal
- shrink tape
- Non-perforated release film
- Vacuum bag sheets
- Vacuum bagging tape
- Vacuum bagging breather material
- Vacuum pump (of some sort)
- Air hose
- 320 grit sandpaper
- 600 grit sandpaper
- 1500 grit sand paper
- acetone
- powderless nitrile gloves
- insulated gloves (gardening gloves will work)
- a small piece of acrylic (optional)
- paper towels
- Utility knife
- Scissors

Mandrel preparation

In figure A1 below is shown the waxed mandrel along with a container of Orca Skin, and Orca Wax.

- use a piece of acrylic or a popsicle stick to scrape away any chunks of epoxy or adhesive from the previous layup
- wet sand with 320 grit paper, to remove the remaining epoxy and adhesive from the previous layup
- wet sand with 600 grit paper, removing the marks from the previous sanding
- wet sand with 1500 grit paper, removing the marks from the previous sanding (figure 1)
- put on powderless nitrile gloves
- wipe with acetone and a paper towel until the towel comes back clean
- apply 2 coats of orca seal
- apply 7 coats of orca skin, 10 minutes between coats
- wait 1 hour

Figure A1: the waxed mandrel on the preparation table, along with a container of Orca Skin, and Orca Seal.

Dummy ring preparation

- wet sand with 600 grit paper to remove any stray adhesive from the previous layup
- clean with acetone or water
- Apply mold release to the female dummy ring

Coupling ring preparation

- place the mandrel on the mandrel-holder
- put on powderless nitrile gloves
- wet sand the adhering surfaces with 600 grit paper
- clean all surfaces with acetone
- continuously apply the anti-galvanic 3M-130 part A to the adhering surfaces for 3 minutes
- continuously apply the anti-galvanic 3M-130 part D to the adhering surfaces for 3 minutes
- take care not to touch the adhering surfaces from this point on
- apply 1 coat of orca seal to the innermost surface
- apply 3 coats of orca skin to the innermost surface, waiting 10 minutes between coats
- wait 1 hour

Cutting films and fabrics

- select the appropriate cutting template for the desired film or fabric
- lay the film or fabric over the plastic surface of the work bench
- place the template over the film or fabric

- while one person moderately presses down on the template, another person should cut along the edges with a utility knife. It also works well to place weights on the templates while cutting.

When cutting the overexpanded nomex honeycomb core material, make sure the template is oriented correctly. You should only be cutting single rows of cells (don't cross from one row to another). The overexpanded cells only bend in one direction. Make sure the template is oriented so that the nome will be able to bend around the cylinder.

Layup Assembly

Shown below are two stages in the layup process. figure 2 shows the mandrel has been sanded and chemically treated. The first wrap around layer of release film has been added. In figure 3 below the first layer of carbon fiber has been added over the release film.

- put on powderless nitrile gloves
- screw the coupling rings into the dummy rings
- without touching the molding surface of the mandrel, slide the ring assemblies on to the mandrel
- screw the dummy rings to the mandrel
- place the mandrel back on the mandrel holder
- lay a layer of blue release film on the mandrel. It should span the entire molding surface of the mandrel and not overlap with the coupling rings (figure 2).

Figure A2: mandrel wrapped in release tape

- lay the adhesive strips onto the lower adhering surface of each coupling ring. Make sure that the adhesive strips are slightly skinnier than the adhering surface of the coupling rings to prevent adhesive from flowing onto the mandrel.
- lay the inner layer of carbon fiber onto the mandrel. It should overlap the adhesive strips completely, butting up flush against the step of the rings (figure 3). It should overlap itself by about an inch. Don’t worry too much about small wrinkles, they will be automatically smoothed during the cure cycle. Do not tug or pull on the CF in an attempt to remove wrinkles. If you need to remove large wrinkles, re-lay the CF instead.

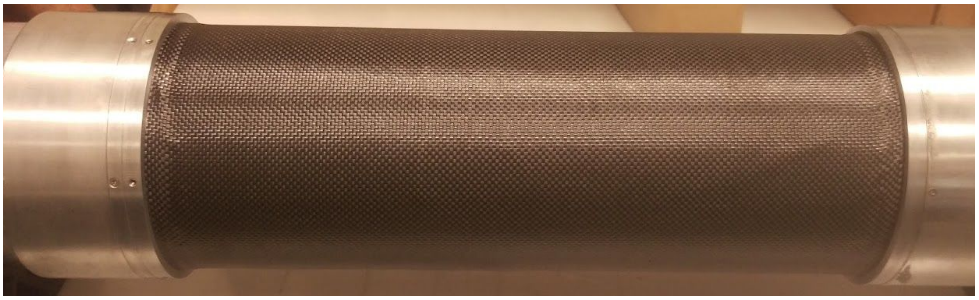


Figure A3: The first layer of carbon fiber added to the layup

- lay the inner adhesive layer over the carbon fiber. Rotating the mandrel while someone holds down the adhesive (wear powderless nitrile gloves) works well here.
- once the adhesive is well aligned, peel a section of it back. Someone should still be holding it down.
- roll the adhesive back down onto the carbon fiber
- roll back the remaining adhesive
- roll the adhesive film back onto the carbon fiber.
- Use a heat gun to tack down the adhesive to the CF. You only need to get it hot enough to be glossy. Be careful not to adhere it to your gloves.
- lay the overexpanded nomex honeycomb core over the mandrel
- perform the same roll-back technique to adhere the nomex to the adhesive film
- While rolling the nomex onto the adhesive it is helpful to use the low setting on a heat gun to assist the nomex in sticking and not unrolling.
- scrunch the overlapping portion of the nomex, so that it sits flat on the cylinder
- Use a heat gun to warm the adhesive below the nomex and then firmly press the nomex into the adhesive. Be careful not to overheat the nomex. If it starts to noticeably warp, it’s warm enough. If it starts to darken, you got it too hot.
- use the roll technique to adhere the outer layer of adhesive film to the nomex. Be careful not to have any adhesive extending over the lip of the male ring. If it is, the female dummy ring will adhere to the male ring. If this happens, they are very difficult to separate.
- Tack the adhesive down to the nomex with a heat gun.
- use the roll technique to apply the outer layer of carbon fiber to the outer layer of adhesive film. There should be about an inch of overlap between the carbon fiber and itself. Take care not to tug on the carbon fiber. The shrink tape will remove any wrinkles better than you can. Take care that the CF does not extend over the lip of the male ring.
- If you’re making an adhesive surfaced module, add another layer of adhesive to the outside of the module. Take care that it does not extend over the lip of the male ring.

Shrink Tape

- Arrange the shrink tape on a spool so that the outer surface may be easily applied to the layup. (underhand from the spool; overhand onto the layup)
- Set up a lamp, illuminating the layup.

- Use kapton or flash tape to fix the shrink tape onto one of the dummy rings. Use lots of tape to fix it in place. If it comes loose, the layup will be ruined.
- Use your dominant hand to tension the shrink tape against the layup.
- Use your off hand to rotate the layup, wrapping the shrink tape around it.
- Adjust the position of your dominant hand so that each turn of the shrink tape overlaps the previous one by 50%. This should result in the appearance that the surface is covered in a single sheet of double-thick shrink tape. If there are any gaps or triple-overlaps, you must roll the layup backwards and redo those sections. Such defects will become ribbing in the final module.
- Every 3 or 4 rotations, add a piece of kapton or flash tape to save your progress. Adjust the positions of the lamp and tape spool to your convenience as you go.
- When you reach the end of the opposite dummy ring, cut the shrink tape and securely fix it to the dummy ring using kapton or flash tape.
- Add 3 strips of kapton or flash tape spanning the entire length of the module to fix the shrink tape against nudges during the vacuum bagging process.
- If you are using perforated shrink tape, add a layer of non-perforated release film to the outside of the layup, using kapton or flash tape to hold it in place.

Vacuum bagging

After adding the final layer of release film, the layup is ready to be vacuum bagged. Figure A4 shows the layup wrapped in it’s final layer of release film.

- lay the breather material (“diaper”) over the mandrel
- secure the breather material with either kapton tape or flash tape
- form a 7 inch diameter tube of vacuum bag material by joining a sheet of it along one edge using the yellow vacuum bag tape (“goop tape”). This tube should be at least 1.5 feet longer than the mandrel.
- gently pinch any air channels out of the goop tape
- form a 7 inch diameter tube using the same method
- stand the mandrel upright
- slide the larger tube over the mandrel
- slide the smaller tube into the mandrel
- place the mandrel on its side, on the plastic surface of the work bench
- adjust the bags so that they are centered around the mandrel
- using the goop tape, seal one end of the inner tube to the corresponding end of the outer tube
- take care that there is no air channel formed by the overlap of the outer tube with itself. Everybody makes this mistake at least once.
- gently pinch any air bubbles or air channels out of the goop tape
- cover the end of the vacuum hose with diaper, securing it with kapton or flash tape
- place the diaper end of the vacuum hose onto the dummy ring near the open end of the bag
- tape down the hose using kapton or flash tape

- carefully apply goop tape to the vacuum hose, so that it may seal to the tubes
- carefully apply a ring of goop tape to the inner surface of the outer tube
- seal the inner and outer tubes to each other
- gently pinch any air channels out of the goop tape, taking special care to make sure the hose and tubes form a complete seal. Make sure there is no air channel formed by the overlap of the outer tube with itself.

Figure A4: layup wrapped in final layer of release tape and ready to be vacuum bagged.

Curing

- set up the aluminum (not plastic) mandrel holders in the oven
- thread the vacuum hose through the hole in the oven wall
- gently place the mandrel on the aluminum mandrel holders in the oven, while someone holds them in place
- attach the outside end of the vacuum hose to the venturi pump
- attach the venturi pump to a compressed air supply
- while slowly turning on the compressed air supply, check the bag for hissing (this indicates a leak which must be sealed with goop tape)
- turn the air supply on fully
- arrange the thermocouple to be directly underneath the mandrel, or inside of it
- close and latch the oven
- make sure the oven is plugged into two separate circuit breakers
- make sure both relays on the side of the oven are in the “on” position
- ramp up the the oven at 3°F per minute until it reaches 350°F
- Place the snorkels/fume hoods above the oven, open all the doors of the room, and place a fan in at least one doorway

- after it reaches 350°F, hold the oven at that temperature for two hours
- ramp down the oven temperature by 5°F per hour. Use the oven door to control this cooldown, opening it slightly for faster cooling.

Removal from mandrel

- once the oven has reached 100°F, open the door and slide vacuum hose into the oven, through the hole in the oven wall, using insulated gloves
- remove the mandrel from the oven using insulated gloves and place it on the mandrel holders on the workbench
- cut open and dispose of the vacuum bag
- remove the hose, diaper, and release film from the mandrel and dispose of them
- Unscrew the dummy rings from the mandrel
- Place the layup vertically on the table and slide the module up. It should easily slide off. If it doesn't wait until it cools to room temperature. If it still does not come loose:
    - place four mandrel removal blocks on the floor
    - place the mandrel in the blocks, using insulated gloves
    - place a piece of wood on the top of the mandrel
    - tap the piece of wood with a hammer to release the mandrel from the module
    - with one person holding the mandrel with insulated gloves, gently pull and wiggle the module off the mandrel in the direction of the male ring. Take care not to damage the module or mandrel. If necessary, run cold water through the inside of the mandrel. This will thermally shrink the mandrel, allowing it to slide off easier.
    - If the module remains stuck, place it on a piece of plywood with the removal blocks holding it up.
    - place the wooden plug inside the mandrel on top.
    - Place a 2x4 on the plug
    - Hammer on the 2x4 with a large weight (~50 lb) to slowly separate the mandrel and module. Stack chunks of 2x4 under the removal blocks to get more height.
    - If you need to do this, you did something wrong with the mold release and/or release film.
- place the mandrel back on the mandrel holders on the workbench
- remove the blue perforated release film from the inside of the module

Results

If done properly, this should result in a module with maybe a few thin creases from flaws in the shrink tape. Adhesive-surfaced modules should be finished with 600 and 1500 grit wet sanding. (do not submerge!)

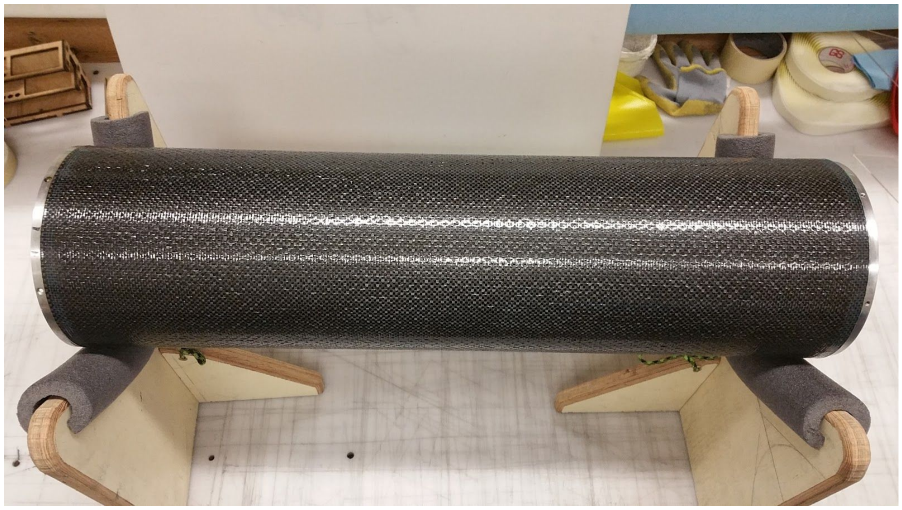


Figure A5: Final carbon fiber rocket module

Material Contact Information

Boeing

Donations Contact: Sandi Hallman sandie.h.hallman@boeing.com

Composites Expert: Thomas Falasco thomas.j.falasco@boeing.com

Plain weave carbon fiber

Unidirectional carbon fiber

Cytek 1515 Structural Adhesive

Vacuum bagging kits and materials

Pacific Coast Composites

Owner and Donations contact: Kevin Fochtman

kevin@pccomposites.com

Plain weave carbon fiber

3M AF30 Structural Adhesive

250°F fiberglass

350°F fiberglass

Machine Sciences

Owner and Donations Contact: Brian McCabe brian.mccabe@machinesciences.com

Donations Contact: Dani Yeager dani.yeager@machinesciences.com

Aluminum stock

Machine time/ skilled labor

ESCO

Donation contact: Kyle Meeuwsen Kyle.Meeuwsen@escocorp.com

MasterCAM design

Machine time

Fiberlay

Sales representative and tech support: Marlin (503) 228-1222

Professional expertise & sales

Provides student discount

Ceramic (nose cone work around)

Orca clean & seal

Fiberglast

1(800)838-8984

Professional expertise & sales

Provides student discount

High temp wax and release agents

ACP Composites

1(800)811-2009

Professional expertise & sales

Provides student discount

High temp resin & resin kit

General Plastics

1(800)852-8509

Professional expertise & sales

Provides student discount

FR 4718 High temperature machinable foam