

## **H Structures and Packaging (GG, TS)**

The packaging design represented the main task for the Structures team. The Structures team had to collect all of the necessary physical requirements for each subsystem and then feasibly and efficiently pack all these subsystems together. In order to feasibly and efficiently pack all the EMFFORCE subsystems successfully, the Structures team used a CAD modeling tool, as well as mock subsystems made out of paper, cardboard, and other simple materials. After finding a feasible configuration for the subsystems, the Structures team designed all of the attach points to ensure each subsystem's physical requirements were met.

### **H.1 Physical Packaging Requirements (GG)**

The requirements surrounding the packaging include:

- Physical requirements of all subsystems
  - Metrology: 360 degree unobstructed view
  - Communications: vertical antenna towards top of vehicle
  - Reaction Wheel: placed at center of electromagnetic force
  - Electromagnet: EM batteries must be physically close (within 15 cm) of EM power input leads
  - Vertical CO<sub>2</sub> tank orientation for gas carriage gas supply
- Packaging must be feasible
  - Maintain rotational symmetry, keep center of mass to within 1cm of axis of rotation
  - Keep mass towards bottom of vehicle for stability
  - Attach points must withstand forces exerted on them
  - Allow for easy replacement of consumables (batteries, liquid nitrogen, CO<sub>2</sub> tanks)
  - Keep mass and moment of inertia as small as possible (GG)

#### **H.1.1 Power (TS)**

The physical requirements for the power subsystem on-board each vehicle are as follows:

- 1 Voltage Regulator power board
- 2 Electromagnet power boards
- 1 Reaction Wheel power board
- 3 on/off switches for power boards (EM-1, EM-2, RW)
- 1 AA-cell battery pack (consisting of 8 or 16 AA batteries)
- Wires to connect Voltage Regulator board to AA batteries and other subsystems
- 3 D-cell battery packs for EM (each consisting of 3 D-cell batteries in series)
- 1 D-cell battery pack for RW (consisting of 4 D-cell batteries in series)

Optional components:

- 1 small fan for each EM, RW power board
- 1 extra D-cell battery pack for RW (placed in series with existing battery pack)

## H.2 Packaging Design (GG)

The packaging design is comprised of a list of components and a plan for attaching them together into the EMFFORCE vehicle test-bed.

### H.2.1 System Components

The Structures team needed to develop a design to physically package the following components:

1. Two electromagnet rings of median diameter 890mm
  - a. Super-conducting rings are encased in foam toroid containers with a liquid nitrogen flow for cooling. These rings must be orientated perpendicularly.
2. Reaction wheel assembly consisting of
  - a. Cylindrical motor approximately 75mm tall and 50mm in diameter
  - b. Reaction wheel approximately 20mm tall and 440mm in diameter
3. Power subsystem that includes
  - a. 15 D-cell batteries for actuation
  - b. 16 AA-cell batteries for electronics
  - c. Three power boards approximately 100mm by 50mm by 20 mm
4. Avionics board approximately 70mm by 160mm
5. Metrology subsystem
  - a. Three sensors need an unobstructed 360-degree view of the surroundings and must lie in the same plane as the metrology transmitter. The metrology transmitter must also have an unobstructed view of each sensor.
6. Communications board approximately 20mm by 30mm with antenna at top of vehicle
7. Liquid nitrogen container for excess cooling liquid
8. Air Carriage system
  - a. Three pucks at base of vehicle
  - b. Upright tank approximately 230mm tall submersed in a cool water bath

### H.2.2 Attach Points and Assembly

The CAD model proved useful in designing the attach points and finalizing the packaging geometry. Figure H.2-A is the CAD drawing of the EMFFORCE vehicle illustrating the layout packing methods and describing attach points. Figure H.2-B is a picture of the EMFFORCE vehicle illustrating the electronics mount.

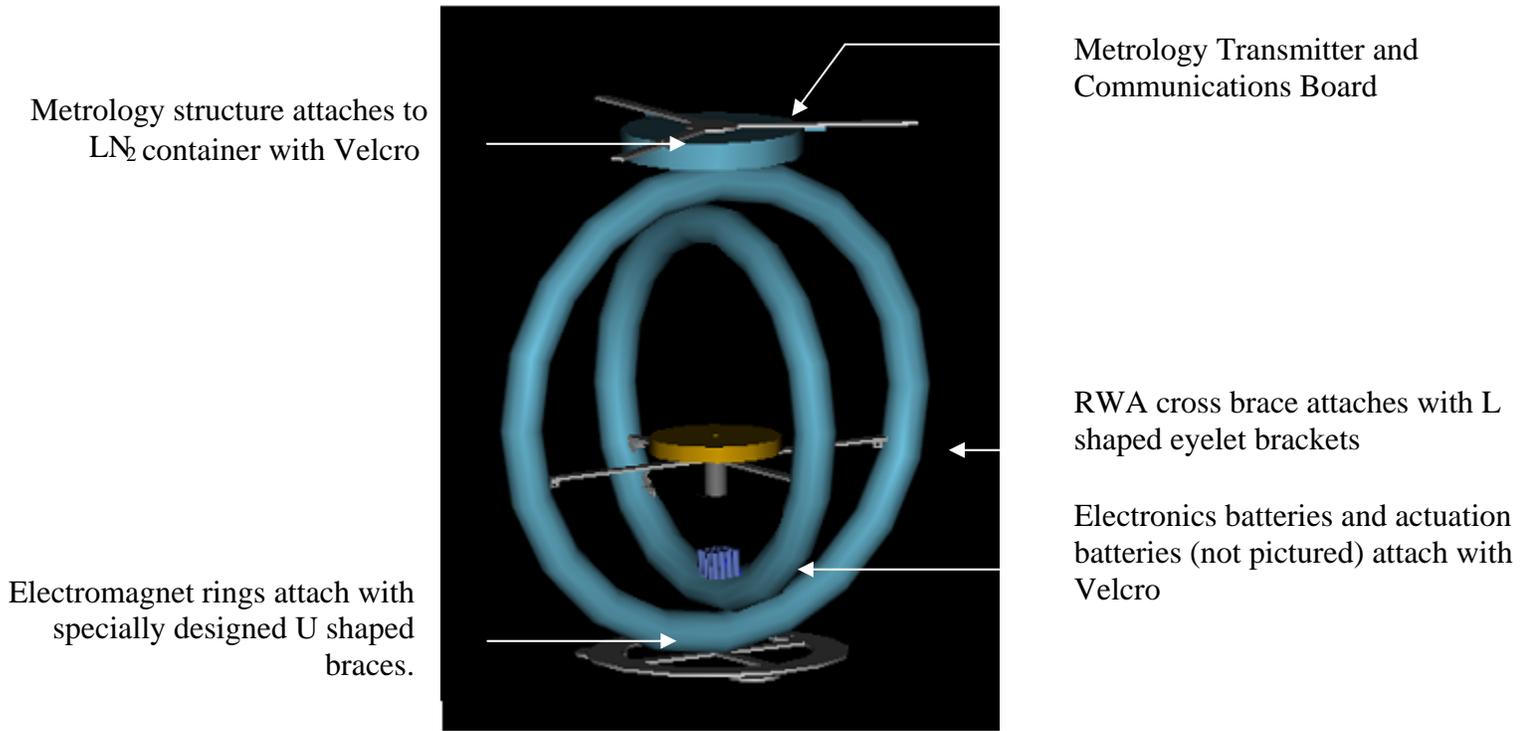
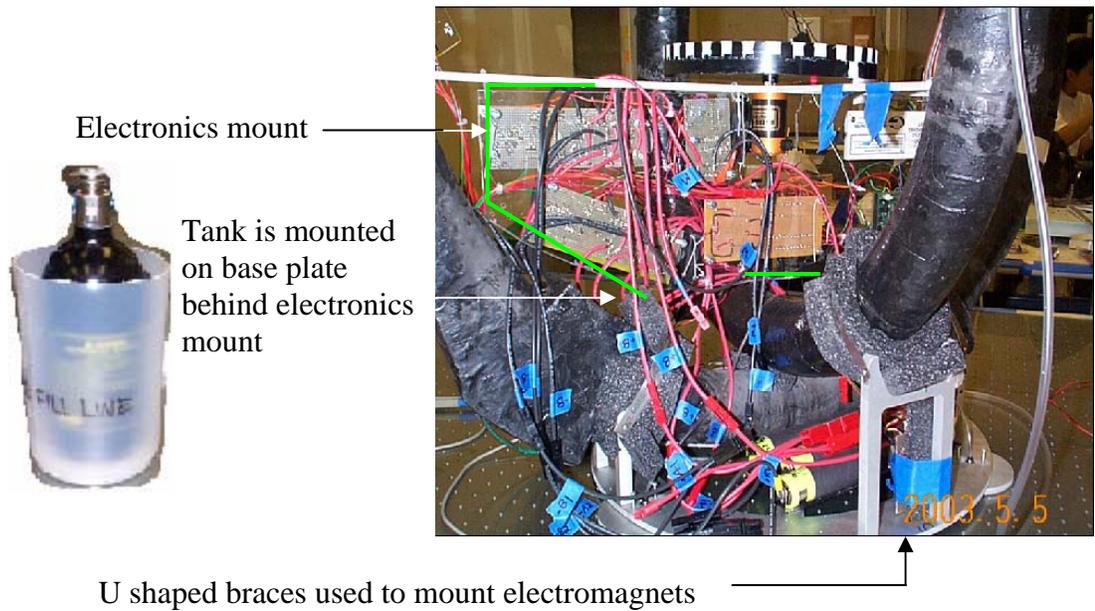


Figure H.2-A: Attach points.

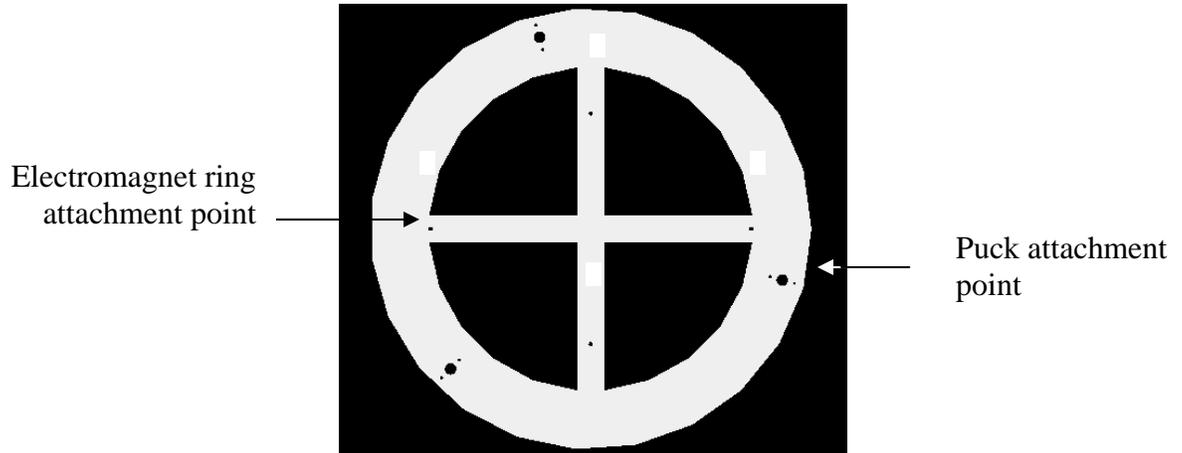
Also not pictured in the above figure are the electronics boards and tank, which are seen in the photograph below.



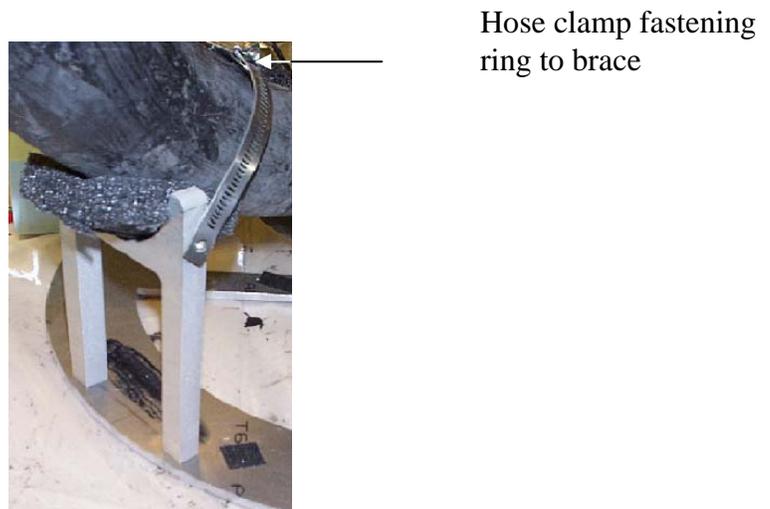
**Figure H.2-B: Electronics mount.**

The current packaging design of the subsystems utilizes a spherical volume created by the two electromagnets to package the avionics board, power boards, electronics batteries, and reaction wheel assembly. The spherical volume attaches to a base plate that provides the planar area needed to float on the flat floor. This base plate was specially designed to attach to four points on the electromagnets and to three air pucks attached at 120-degree separation angle. Figure H.2-C is a picture of the base plate, the electromagnets attach at the struts and the pucks attach on the circular section.

The electromagnets attach with U-shaped braces specially designed to the correct dimensions, see Figure H.2-D. The air carriage pucks must stay parallel to the flat floor even if the base plate for some reason is not parallel. Because of this, the pucks attach to the plate with springy washers that give the three pucks the ability to maintain planarity. The holes in the plate represent the attachment points. The outer most diameter of the base plate is 480mm.



**Figure H.2-C: Base plate.**

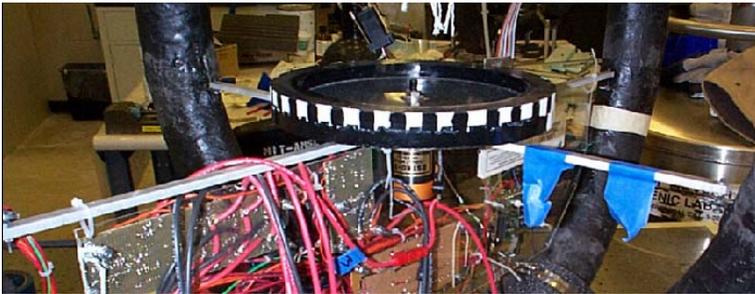
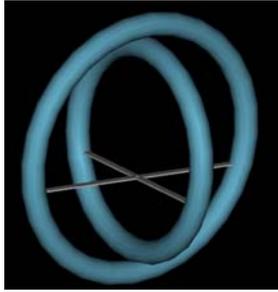


**Figure H.2-D: U-shaped brace.**

The actuation batteries for the vehicle sit on the circular base plate at the bottom of the vehicle. This helps to keep the mass toward the bottom of the vehicle for stability, and also allows the batteries to be placed near the power leads to the electromagnets. The actuation batteries as well as the electronics batteries that are located inside the spherical volume at the bottom most point, are all secure in place with Velcro. This method, which allows for easy removal and replacement, is favorable to the power subsystem because of the need to continually replace batteries between each test.

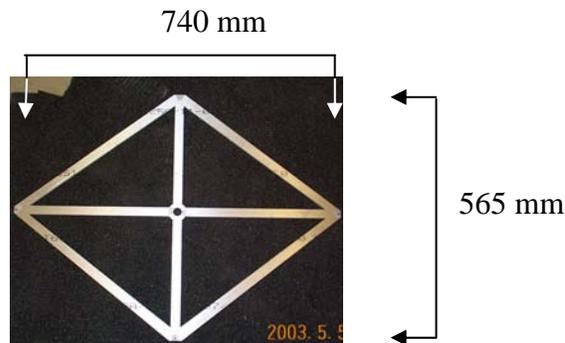
A cross-shaped brace will attach to four planar points on the rings to support the motor for the reaction wheel, and ultimately the whole reaction wheel assembly. A Plexiglas plate will hang vertically from the longer strut of the RWA brace and act as the mount for the avionics board as well as the three power boards. Figure H.2-E shows a CAD drawing of the electromagnet rings and RWA brace as well an actual photograph of the rings, with the RWA and Plexiglas electronics mount in place. The larger electromagnet has an

outer diameter of 798mm; both electromagnets have a cross-sectional diameter of 80mm. The braces are manufactured from one-fourth inch aluminum sheet metal.



**Figure 0-E: RWA Cross brace across electromagnet rings.**

A modified RWA mount may also be implemented to help keep the electromagnets perpendicularly aligned. This mount is photographed in Figure H.2-F.



**Figure H.2-F: RWA modified mount.**

The liquid nitrogen container sits on top of the rings where gravity allows the liquid nitrogen to flow into the toroid electromagnet containers and cool the coils (see Figure H.2-A). Above this container sit the metrology sensors on a large Y-shaped structure at whose center point sits the metrology transmitter. The communications board then sits on top of metrology transmitter making the antenna the highest point of the system.

Attachment points were designed as specially manufactured brackets that permanently attach to the foam rings with a cryogenic epoxy. The epoxied brackets and foam ring are then wrapped in fiberglass strips for added strength. Brackets like the once pictured in Figure H.2-G hold the cross-braces for the avionics and RWA subsystems. The metrology structure attaches to the lid of the LN2 container with Velcro. Below is a picture of an L-

bracket attached to a foam ring as well as to a cross-brace. Note the oval-shaped hole in the L brackets to account for the expansion and contraction of the electromagnets.



**Figure H.2-G: L-brackets attached to foam ring and cross-brace.**

Because tests have shown that magnetic interference will most probably not be present on the EMFFORCE vehicles, the current packaging design does not include the use of shielding. However if magnetic shielding becomes necessary, implementation will consist of wrapping the electronics components in the shielding foils obtained from MuShield, a magnetic field shielding manufacturer.

### H.2.3 Attach Points Parts List

Attach Point Part	Material	Method of Manufacture
Base Plate	1/4" thick 6062 aluminum sheet metal	Cut on OMAX operated waterjet cutter
RWA Mount	1/4" thick 6062 aluminum sheet metal	Cut on OMAX operated waterjet cutter
U Shaped Braces	1/2" thick 6062 aluminum sheet metal large hose clamps	Cut on OMAX operated waterjet cutter. Hose clamp attachment holes drilled and tapped to 6-32 specifications using drill press. Steel hose clamps cut in half using Dremel
L Brackets	1/8" thick 5051 aluminum sheet metal	Cut on OMAX operated waterjet cutter, bent at 90 degrees on brake.
Plexiglas Electronics Mount	1/8" thick Plexiglas	Cut on bandsaw