THE LIGHTCRAFT PROJECT

RENSSELAER POLYTECHNIC INSTITUTE

Rensselaer Polytechnic Institute has been developing a transatmospheric "Lightcraft" technology which uses beamed laser energy to propel advanced shuttlecraft to orbit. In the past several years, Rensselaer students have analyzed the unique combined-cycle Lightcraft engine, designed a small unmanned Lightcraft Technology Demonstrator, and conceptualized larger manned Lightcraft — to name just a few of the interrelated design projects.

The 1990-91 class carried out preliminary and detailed design efforts for a one-person "Mercury" Lightcraft, using computer-aided design and finite-element structural modeling techniques. In addition, they began construction of a 2.6 m-diameter, full-scale engineering prototype mockup. The mockup will be equipped with three robotic legs that "kneel" for passenger entry and exit. More importantly, the articulated tripod gear is crucial for accurately pointing at, and tracking the laser relay mirrors, a maneuver that must be performed just prior to liftoff.

Also accomplished were further design improvements on a 6-inch-diameter Lightcraft model (for testing in RPI's hypersonic tunnel), and new laser propulsion experiments. The resultant experimental data will be used to calibrate Computational Fluid Dynamic (CFD) codes and analytical laser propulsion models that can simulate vehicle/engine flight conditions along a transatmospheric boost trajectory. These efforts will enable the prediction of distributed aerodynamic and thruster loads over the entire full-scale spacecraft.

INTRODUCTION

Rensselaer's concept of an advanced "Lightcraft" (space shuttle) relies on beamed energy propulsion to greatly lower launch weight and to improve specific impulse. Beamed energy propulsion employs a remote energy source to deliver power to the vehicle through a direct, line-of-sight transmission link. The vehicle is equipped with a receiving antenna which reflects this power into a "propulsion energy converter." The latter device transforms the received beam energy into usable thrust.

Rensselaer's futuristic aerospace transportation system is based upon orbiting Satellite Power Stations (SPS) which transmit energy to the Lightcraft, in the form of a laser (or microwave) beam. The Rensselaer design team concentrates its attention on the *vehicle technology* only, and assumes the feasibility of an SPS power grid. A Lightcraft is slaved to the beamed power that energizes its multicycle airbreathing engine. This advanced airbreathing propulsor consumes a very small amount of propellant (e.g., 5 to 10% of TOGW) mostly in the final two engine modes: the *MHD-Fanjet*, and *rocket* for orbital insertion[1].

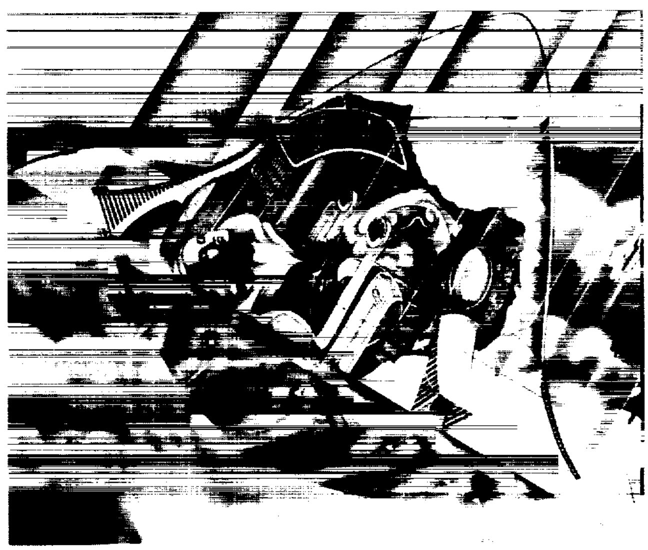

Fig. 1. Artist's Conception of Mercury Lightcraft.

Figure 1 is an artist's concept of a single-place Mercury Lightcraft under a laser boost to orbit. Note that the vehicle is axisymmetric, and is still in the first engine mode, which produces laser-generated thrust upon the aft centerbody surface shortly after takeoff. The laser beam is brought in from above, reflected by the large annular primary optics onto smaller secondary (cylindrical reflecting) optics located under the engine cowl. The beam is finally brought to a tight focus across the vehicle aftbody, causing air breakdown and the formation of spherical (or cylindrical) blast waves that momentarily contain high pressures. These high pressures act to produce engine thrust.

Several of the Lightcraft's major interior features are visible in Fig. 1. The passenger (or pilot) is seated in a reclined position in the center of the capsule. Trackball controls are integrated with the chair armrests, and advanced flat-screen color displays facilitate a friendly interface between the pilot and the mission computers. The pilot's luggage is stowed in twin compartments under the armrests, and steps are recessed into the interior surface of the door for easy entrance and egress. Robotic tripod landing gear and a small propellant tank are placed under the pilot within the aftbody. Altogether, these key features create an ergonomic environment for the passenger or pilot during the short ascent (approximately three minutes), and brief travel time (a maximum of 45 minutes to any point on the globe).

This academic year, our Advanced Design class completed the detailed design of the Mercury Lightcraft components and began construction of a full-scale engineering prototype mockup.

Other students designed and constructed experimental apparatus used in proof-of-concept tests on the Lightcraft's laser engine. The overall progress of each design team is summarized below.

PROTOTYPING OF THE MERCURY LIGHTCRAFT

At the beginning of the 1990/91 academic year, the design class was divided into seven teams, six of which worked on the prototype mockup design. The various prototype design teams are listed in Table 1.

TABLE 1. Mercury Lightcraft Mockup Design Teams

Team 1:	Exterior Aeroshell and Door
Team 2:	Human Factors and Information Systems
Team 3:	Robotic Tripod Landing Gear
Team 4:	Annular Shroud and Actuation System
Team 5:	Primary Optics and Engine Mockup
Team 6:	Major Structure

Team 1, the Exterior Aeroshell and Door team, was responsible for designing and constructing an accurate exterior surface for the prototype, and for integrating a retractable door into the vehicle. The Human Factors team designed and began construction of an ergonomic interior for the Lightcraft and started work on the computer-based flight control/simulation system. The Landing Gear team designed and constructed a single full-scale robotic landing gear leg. The Shroud and Actuation System team designed and constructed the vehicle's annular shroud; they also developed the concept for a shroud translation system needed for the Lightcraft's variable geometry airbreathing engine inlet. The Primary Optics team designed a manufacturing process for the prototype's primary receptive optics and applied this process in fabricating a full set of 24 mirrors. Finally, the Major Structure team designed the load-bearing primary structure for the prototype mockup.

Exterior Aeroshell and Door

The Exterior Aeroshell and Door team was responsible for designing and constructing the external surface of the prototype mockup. Dimensioned engineering drawings of the external surface are shown in Fig. 2. The Aeroshell design team chose epoxy/fiberglass composites to keep the exterior surface lightweight, and, for ease of construction, to build the aeroshell in identical quarters. They began by first building an accurate male mold.

To assure an accurate cross-sectional mold contour, full-scale CAD drawings were traced onto two 3/4" plywood silhouettes and mounted at 90° to each other. Then a large number of bulkheads (spaced about 4-inches apart) were attached to this rigid frame, as shown in Fig. 3. Next, blue styrofoam was glued between the bulkheads and sanded down to form a smooth external contour; a rigid layer of epoxy/fiberglass was then applied to the external surface. CAD drawings were again used to create a stiff aluminum template that could be rotated about the vehicle axis of symmetry, to both generate and check the male mold surface contour. Automotive body filler was then

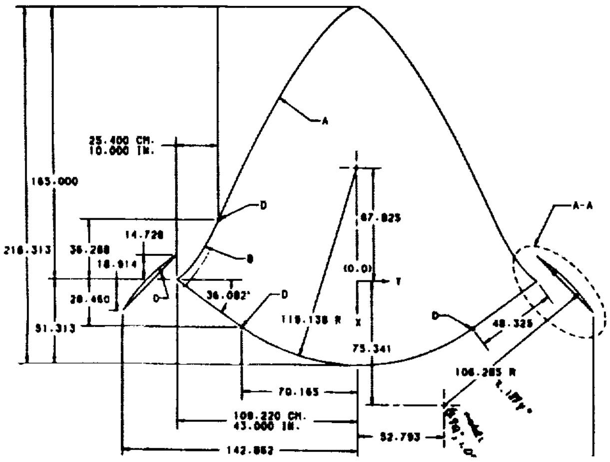

Fig. 2. Engineering Drawing of Mercury Lightcraft with Dimensions.

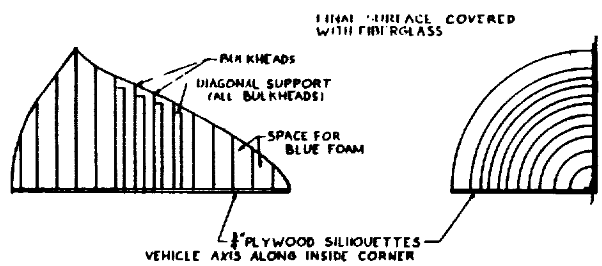

Fig. 3. Schematic of Male Mold Construction.

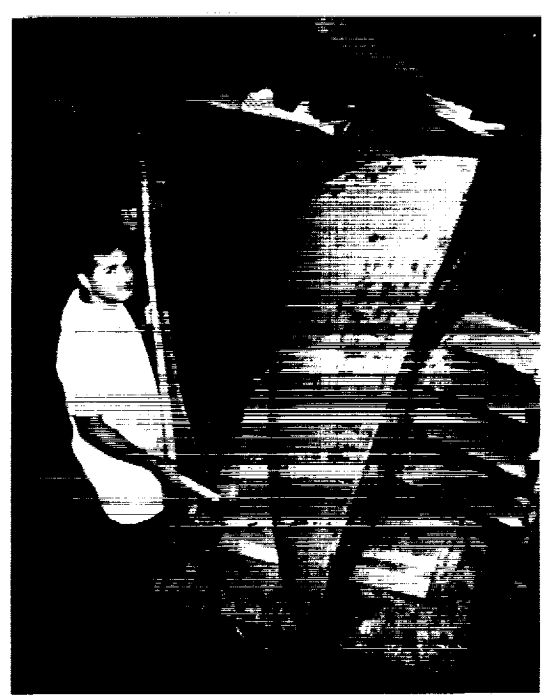

Fig. 4. Complete Male and Female Molds.

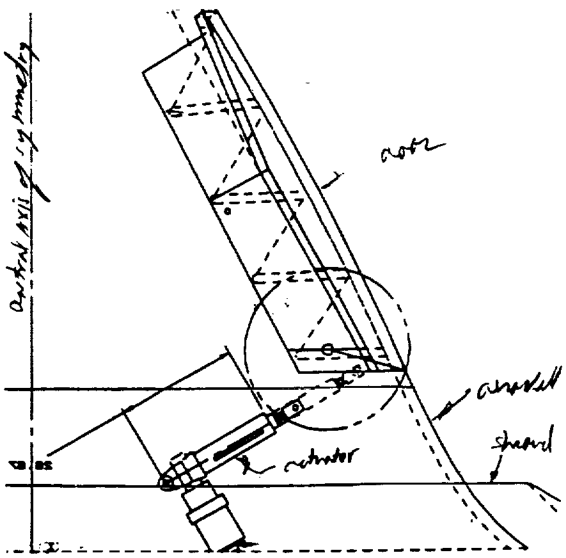

Fig. 5. Schematic of Door Actuation System.

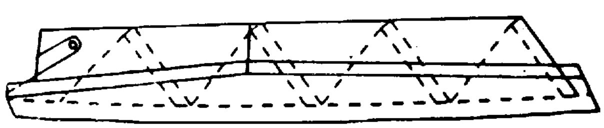

Fig. 6. Stairs are Integrated into the Lightcraft Door.

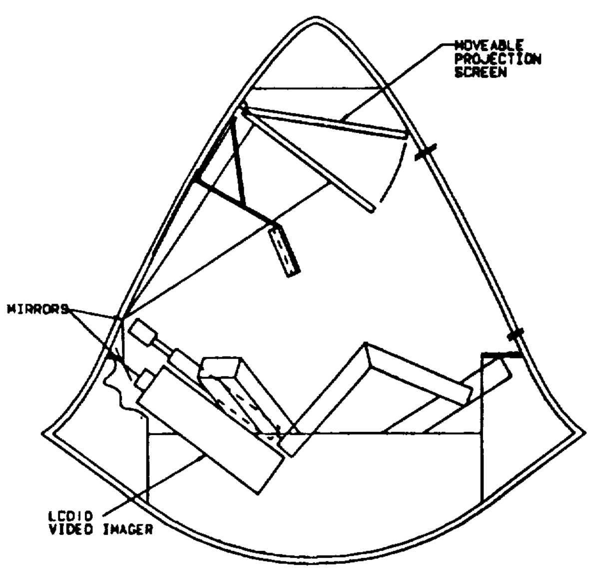

Fig. 7. Schematic of Prototype Mockup Interior Design.

swept across the surface to make it exactly conform to the template. Finally, a female mold was pulled off the male mold. The finished molds are pictured in Fig. 4.

The next step for the Aeroshell team is the construction of four composite sandwich skins which will be joined together to make the exterior surface of the prototype mockup. This composite sandwich will consist of two layers of 10 oz./yd^2 fiberglass cloth on both sides of a 1/4" thick foam core for increased stiffness. The aeroshell has several areas where openings are needed (e.g., for the door, tripod landing gear, etc.); these will be devoid of foam, to eliminate delamination problems.

In parallel with the spacecraft mold effort, the Aeroshell team designed and began construction of the mockup's retractable door (see Figs. 1 and 5). The fiberglass/foam/epoxy door is to be deployed with a four-bar linkage by a single Duff-Norton electromechanical actuator with a 6-inch throw (see Fig. 5). The staircase has five steps that are integrated with the interior surface of the door (see Fig. 6). The preliminary design for the door is essentially complete, but refinements are necessary.

Human Factors and Information Systems

The Human Factors and Information Systems team was responsible for the interior design of the prototype mockup, including a comfortable chair for the passenger/pilot, a user-friendly interface with mission computers, and a ventilation and lighting system. A schematic outline of the prototype interior is portrayed in Fig. 7. Flat screen displays and (possibly) a projection video screen monitor will communicate information to the pilot, and twin trackball I/O devices will control these displays. The pilot chair, shown in Fig. 8, is positioned for maximum comfort while accommodating 99% of the adult population.

Robotic Tripod Landing Gear

The mission of the Robotic Tripod Landing Gear team was to design, analyze, and construct a prototype tripod landing gear system capable of safely positioning the Lightcraft mockup in all required entrance, egress, and satellite-tracking orientations. The landing gear system had to be robotically actuated because the vehicle must tilt to approximately 26° from normal, in any direction, as it tracks the laser power relay satellite just prior to liftoff. Shown in Fig. 9 is a schematic diagram of the gear, each of which is actuated by two Duff-Norton electromechanical actuators with a 12-inch throw and 1500-lb load capacity. A single landing gear leg was actually constructed from 6061-T6 aluminum, and actuators are now being exercised for initial checkout. During the design effort, a finite-element stress analysis was performed on the gear. This analysis indicated that the gear was over-designed, having a minimum factor of safety of about five.

Work was also initiated on the computer control system for the landing gear. For a given vehicle orientation, the control system must predetermine the deployed length for each of the six actuators and then guide the actuators to this position along a safe path (see Fig. 10). A computer program was written to achieve this end, and to explore the envelope of possible prototype orientations. This code proved to be not only an effective design tool, but also the first step towards developing a landing gear control system.

Annular Shroud and Actuation System

The Lightcraft's shroud and support struts were designed and constructed from aluminum by the Annular Shroud and Actuation System team. To fabricate an accurate male mold, 63 aluminum ribs were first cut from 1/8″-thick 6061 T6 aluminum on a numerically controlled milling machine. These ribs were then fastened together and the exterior surface was taped to form a smooth male mold, which represents a full-scale 1/24th segment of the annular shroud. Next this mold was taken to a local foundry to cast 24 replica shroud segments out of aluminum. Figure 11 shows the partially assembled shroud, placed about the wooden templates which bound the interior mockup of the Lightcraft prototype.

As mentioned above, the annular shroud must be translated to accurately simulate the variable geometry feature of the Lightcraft inlet. This will be accomplished by 24 Duff-Norton screw actuators, equally distributed around the perimeter, all connected with universal joints and driven by a single electric motor. A schematic diagram of the cross-section for one shroud actuation section is shown in Fig. 12. Construction and debugging of the complete actuation system is the principal remaining task for this design team.

Primary Optics and Engine Mockup

The Primary Optics and Engine Mockup team had several goals: to design an effective manufacturing process for the prototype's primary optic mirrors; to use this process in constructing 24 identical mirrors; and to design and fabricate four MHD generator mockups for the Lightcraft's MHD-Fanjet engine. The team decided to fabricate the primary optic mirrors from 1/8″-thick acrylic plastic mirror material, by thermomechanically deforming it in an accurate mold-press to produce precisely contoured, highly reflective mirrors. The manufacturing process involved several stages of heating in both boiling water and an electric oven before the acrylic material was finally inserted into the molds and pressed into shape.

Mockups of the laser-heated MHD generators incorporated the same acrylic plastic mirror material, and strategically placed light sources to simulate the luminosity produced in actual operation. The MHD generator design also incorporated a pressurized CO_2 fog system to simulate the high velocity MHD exhaust stream.

Primary Structure

The Primary Structure team was responsible for designing the load-bearing structure of the Lightcraft prototype mockup. This structure had several dominant requirements: it must protect the pilot from all possible failure modes, as well as provide hardpoints for the landing gear, door and shroud actuation systems, and the seat. An additional requirement was that the structure must provide lift points so that the prototype mockup can be maintained and transported to other locations.

Fig. 8. Detail of Prototype Pilot Chair.

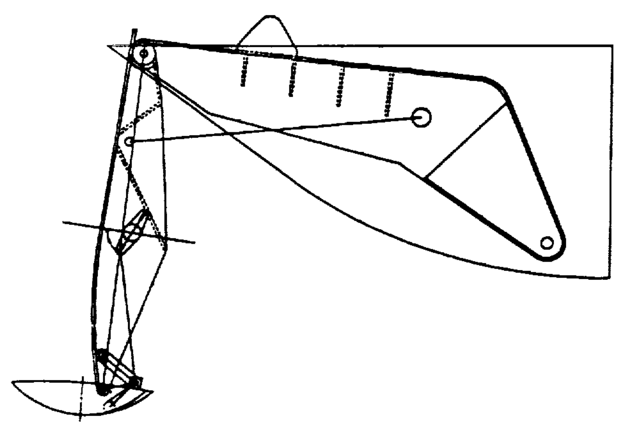

Fig. 9. Schematic of Robotic Tripod Landing Gear Leg.

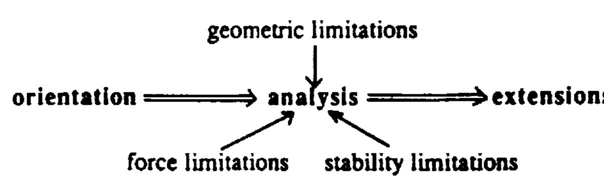

Fig. 10. Landing Gear Control System Moves Lightcraft Between Safe Orientations.

The primary structural design utilizes three U-channels (which house the robotic landing gear), and twin annular bulkheads to provide mounting points for the aeroshell, all actuation systems, and the pilot seat. A roll cage is positioned around the pilot to protect against possible catastrophic failure of the robotic landing gear system; also, both upper and lower structurally-reinforced lift points are provided (see Fig. 13).

Fig. 11. Shroud Assembled Around Lightcraft Contour.

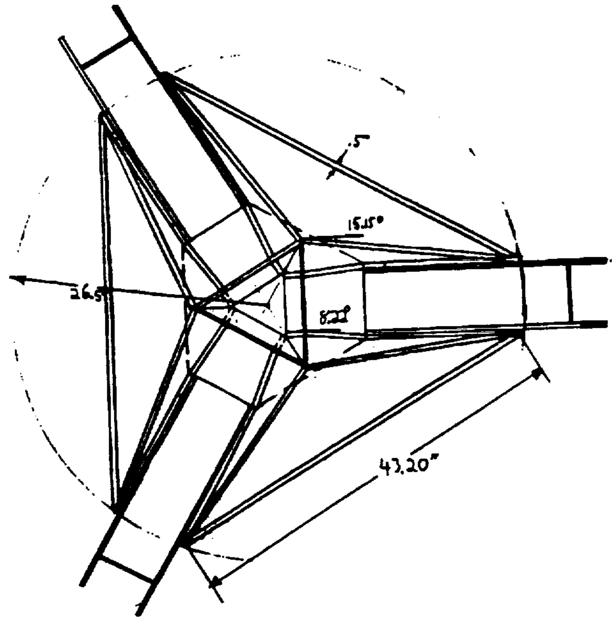

Fig. 13. Schematic of Lightcraft Major Structure.

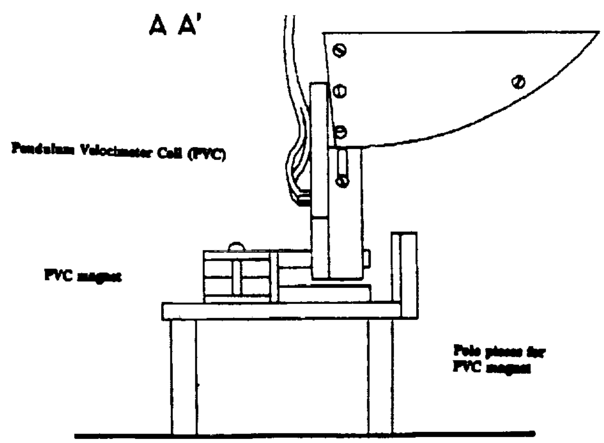

Fig. 14. Pendulum Motion is Measured By a Coil (PVC) Moving Through a Stationary Magnetic Field.

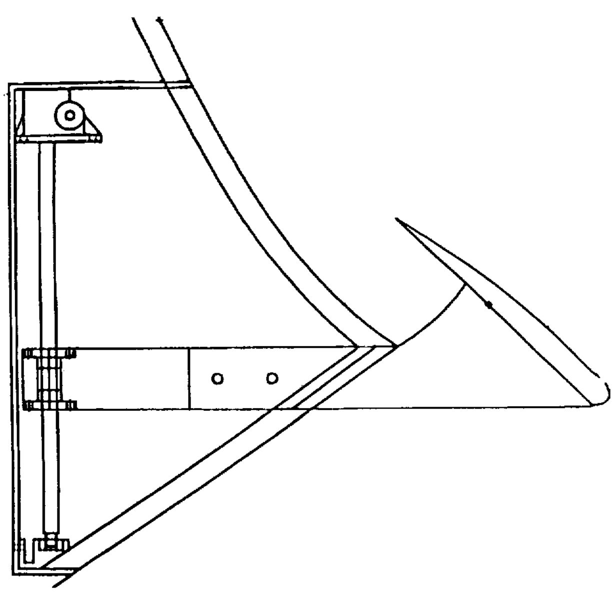

Fig. 12. Schematic of Shroud Actuation System.

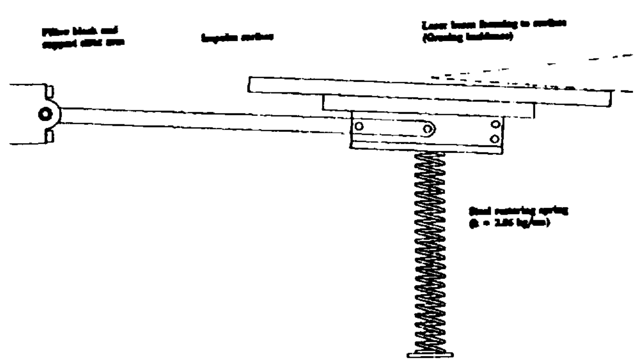

Fig. 15. Schematic of Horizontal Pendulum.

EXPERIMENTAL APPARATUS

Another design team worked apart from those dedicated to the Lightcraft mockup. These students designed experimental equipment that was constructed with the aid of the Rensselaer SC machine shop, and then tested with a 1-μm Nd-glass laser at the Naval Research Laboratory (NRL) in Washington, DC. A detailed description of the experimental equipment and the actual tests is contained in reference 2. Basically, the static engine performance measured in this first year of airbreathing laser propulsion tests at NRL was roughly equivalent to that demonstrated by the first afterburning turbojets. The potential for further improvement is promising.

These laser propulsion experiments used ballistic pendulums to measure the impulse delivered by the laser-induced breakdown of air (at standard sea-level atmospheric pressure). The pendulums were mounted either horizontally or vertically, and the impulse was measured by the voltage induced in a wire coil that moved through the poles of a small permanent magnet (see Fig. 14).

The horizontally mounted pendulum required that the target surface be supported by a coiled spring in order to produce the same characteristic motion as the vertical pendulum (see Fig. 15).

SUMMARY AND FUTURE WORK

The prototype mockup of a single-person Mercury Lightcraft is now underway. Male and female molds of the spacecraft exterior aeroshell have been completed, and the Lightcraft door is nearly 50% complete. The prototype seat, flight computer I/O devices, electromechanical actuators for the landing gear (and door), and three flat plasma display screens have been acquired. One complete robotic landing gear leg has been assembled, finite-element structural analysis of the gear has been performed, and actuation software programming has been initiated. The annular shroud, support struts, and primary receptive optics have been fabricated, and the shroud actuation system has been designed.

In addition, several proof-of-concept experiments are also underway to validate the Lightcraft propulsion system. Hypersonic inlet testing and CFD verification of the results have been performed[3,4]. Laser propulsion tests are well underway, and results indicate promising performance[2].

Next year's design class will complete the design and construction of the Mercury Lightcraft prototype mockup. The robotic landing gear will be activated and fully tested, and the possibility of creating a Transatmospheric Flight Simulator will be explored. Both hypersonic and laser propulsion testing may be continued, and the aerodynamic testing will be expanded to include low supersonic and subsonic regimes. As with last year's class, the 1991/92 design class will be exposed not only to the spacecraft design process, but also to the engineering prototyping process as well. Much progress is expected toward the goal of an operational Lightcraft technology.

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