Introduction

The design problem for the Fall 1999 semester is adapted from that used in Fall 1998. It is for a manned aeroassist orbital transfer and reentry vehicle. You are to determine whether the existing designs can be improved enough to make the design goals feasible. If you determine that the design goals are not feasible, then this should be demonstrated unambiguously. A successful preliminary or conceptual design is a prerequisite for a decision on proceeding to detailed design and manufacturing.

The design will be submitted in a final Design Disclosure Report, including an Executive Summary. Details of the requirements are on the following pages. Design teams will be formed during the first week of class.

The project is to be a team effort. One member of each team is to be selected as Project Leader as soon as possible. The Project Leader is responsible for overseeing and coordinating the design effort, in addition to his or her other responsibilities.

A schedule for progress reports will be handed out separately. The final Design Disclosure Report is due on Monday, 6 December 1998, at 12:00 noon, and the oral presentation of that report will be given on Thursday, 9 December 1999. Four copies of this report are required, with three copies of the appendices. No late reports will be accepted. Groups are encouraged but not required to hand in a draft copy of their report by Monday 22 November 1999. If received, these draft copies will be returned, with comments, but no grade, by Monday 29 November. More details are given below.

Aeroassist Orbital Transfer and Reentry Vehicle

This AOTRV vehicle is a space tug capable of transporting satellites to and from the Int’l Space Station. The satellite may be in one of several low earth orbits (LEO), or in geosynchronous orbit (GEO); for this semester, we will again focus on satellites in the LEO Iridium constellation. The satellite may be returned to the space station for repair, or it may be deployed from the space station to replace a damaged or malfunctioning satellite. Inspection and replacement of malfunctioning satellites may be important for space defense or for the determination of satellite failure modes. A low cost and rapid method of performing this mission would be of interest to industry, NASA, and the Defense Department.

The AOTRV is to perform these missions by using the earth’s atmosphere to assist in making the orbit plane changes, and to decelerate to the space station orbital velocity. Additionally, the AOTRV will double as an auxiliary Assured Crew Recovery Vehicle that will be used as a space station lifeboat capable of returning space station crew members to earth in the event of an emergency onboard the space station requiring immediate evacuation.
General Mission Requirements

The AOTRV is primarily a space tug designed to transport communications satellites to the Iridium orbits (780 km and 86.4 degrees inclination), from the space station orbit at 220 nautical miles (407.4 km) and 51.6 degrees inclination. Additionally AOTRV shall be capable of returning incapacitated satellites to the space station for inspection, repair, and refurbishment; thus, the vehicle must be manned for the rendezvous and capture of satellites. A two person crew is required, with a pilot and satellite specialist.

Although not designed primarily as an assured crew recovery vehicle, the AOTRV shall be capable of returning the astronauts (and a satellite) to earth from the space station in case an emergency evacuation is required. Thus, the vehicle must survive earth entry. Crossrange during this earth entry must be sufficient to allow ready landing at established sites in the United States, such as Edwards AFB and Kennedy Space Center.

Vehicle Requirements

The vehicle must be transported to the space station on an existing operational launch system, such as the space shuttle cargo bay, or an existing expendable rocket. The vehicle mass will be used as a crude measure of cost, so it should be minimized. The vehicle mass is limited to the maximum that can be launched with an existing system. The vehicle will remain docked to the space station until needed. The vehicle may be carried to the ISS with near-empty fuel tanks if necessary, and then fueled from tanks delivered in a separate launch.

The AOTRV will have the propulsive capability of lifting itself and a 700 kg, 3-m long, 1-m diameter satellite from the space station orbit to an Iridium orbit. Likewise, it will be supplied with sufficient propellant to return the same 700 kg from an Iridium orbit to the space station. It should be able to carry the satellite on both legs of the trip. Preferably it should be able to replace any of the Iridium satellites. If some are in orbits which make this prohibitive in terms of propellant cost and vehicle mass, the particular satellites which cannot be reached should be described, and the reasons discussed.

If this mission is attempted using only exoatmospheric propulsion, the vehicle weight and cost become prohibitive. This design effort is therefore initiated to determine if synergetic maneuvers can be used to achieve significant reductions in propellant requirements (Ref. 1). Such high-efficiency synergetic maneuvers may be enabled by the recent development of ultra-high-temperature ceramics allowing the use of sharp noses on hypersonic vehicles. Repeated atmospheric maneuvers are allowed. The propellants should be storable; if cryogenics are to be used, methods of handling the boil-off problem should be described in detail. In addition to the primary rocket engines, the vehicle will be supplied with an orbital maneuvering system to control attitude, and be capable of supplying a 400 ft./sec. velocity increment for rendezvous and docking with both the satellite and the space station.

Because it uses synergetic maneuvers that require entry into the earth’s atmosphere, the vehicle must have an aerodynamically efficient shape, be supplied with a thermal protection system (TPS), and accommodate the payload entirely within the vehicle. It is expected that the vehicle will be controlled aerodynamically during the synergetic maneuvers to further conserve consumables. The TPS shall be reusable for 100 flights thus eliminating the use of ablators. Since maneuvers may be accomplished in the upper atmosphere, viscous interaction will occur and degrade the aerodynamic performance relative to inviscid values. The
Fall 1998 designs identified high-altitude rarefied flow and viscous interactions as significant limitations to vehicle feasibility. Your effort should determine whether this is in fact the case; if so, improved models of these effects are to be incorporated in the design analysis, in the hope that more realistic models will allow feasible designs to be developed.

The TPS will be designed using the new Ultra High Temperature Ceramics recently flight tested by NASA and the Air Force (see http://kauai.arc.nasa.gov/projects/sharp/pl1.html). This new TPS material enables the revolutionary use of sharp leading edges on hypersonic vehicles (Ref. 2). This enables an increase in lift/drag ratio from roughly 1-2 to about 4 or more. The primary motivation for this RFP is to determine whether this new material, and the design changes it permits, will enable a revolutionary improvement in AOTRV performance.

The AOTRV shall be capable of sustaining its two person crew for the length of the probable missions, plus a 24-hour reserve. A 10-psi pressurized cabin is needed for rapid entry of astronauts from the ISS in the event of an emergency. However, an airlock is not necessary, since space suits can be used for probable satellite repair mission lengths of a day or two. Life support consumables (oxygen, etc.) shall be sufficient for the satellite-repair mission plus a 24-hour reserve. Vehicle accelerations must not exceed the following values in g’s: Ascent: 5.0, and Reentry/Aeromaneuvers:3.0.

At the end of an earth reentry trajectory, the vehicle will land with the use of a parafoil. A hatch of size 1.5 by 1.5 meters must open on top of the vehicle, near the center of gravity, for release of the drogue chute and parafoil, which have a mass of 140 kg and occupy a volume of 0.4 cubic meters. Also allow 0.3 cubic meters of volume and 300 kg for communication, guidance, and power generation equipment.

**Booster Requirements**

An existing and proven launch vehicle shall be selected to launch the vehicle to rendezvous with the space station.

**Revisions to RFP**

The requirements specified in this RFP are a current best-estimate of the desired capabilities. The preliminary design work may show that some of the requirements make the design unfeasible, or grossly limit the design with insufficient cause. Proposers are encouraged to discuss the requirements with Prof. Schneider. They may be encouraged to submit a written Request for RFP Modification, giving justification for the requested change. If such a request is approved, it will be distributed to the other groups as an alternate version of the RFP.

**Design Disclosure Report**

This report shall be organized as follows. All data are to be reported in SI units.

Executive Summary – 10 pages maximum (separately bound)

A brief clear description of what the system is, what it can do, and how it meets requirements. It should include key performance results and design trades. Use figures, plots, etc., in conjunction with the text to effectively communicate your results. Include at least one
three-view drawing of your vehicle design, with the overall dimensions, the initial and dry masses, and the synergetic efficiency. Write the Executive Summary assuming it may be the only thing an important customer/evaluator may read.

**Introduction to the Design – 10 pages maximum**

This section should give an introduction to the design problem as a whole, and to your vehicle.

**Comparison to Fall 1998 Design(s) – 10 pages maximum**

This RFP is similar to one issued in Fall 1998, for which four design reports are available. Compare the performance of your design to that of the Fall 1998 designs, and discuss the reasons for the changes in vehicle design and performance. If you based your analysis code on one of their codes, identify any errors you may have discovered.

**Boost Vehicle Design and Performance – 30 pages maximum**

Describe the booster design indicating stage thrust and Isp values, and show that the vehicle is capable of achieving rendezvous with the space station. Present a drawing of the combined ascent vehicle, a complete mass statement, and show that the vehicle is controllable during ascent (i.e. that each booster stage has thrust vector control sufficient to accommodate the upper stages and maintain control including 95 percentile worst month winds). Present plots of critical boost trajectory parameters, such as time variations in velocity, thrust, mass, altitude, flight path angle, acceleration, and stagnation point temperature. Show the impact locations of all booster stages, and make sure booster impact is not near populated areas.

**Trajectory/Performance Analysis – 50 pages maximum**

Discuss the various Iridium orbits, and the relative difficulty of performing the mission for these various orbits. Select one (or several) orbits for detailed analysis, and give the justification for the selection. Describe the synergetic maneuvers used to boost the vehicle to the Iridium orbit(s), and return. Compare the synergetic performance to the performance of exoatmospheric pure-propulsion trajectories. Discuss the tradeoffs involved in selection of the synergetic trajectory. Develop a time line for departure from the space station and rendezvous with a satellite and the subsequent return and rendezvous with the space station. Show ΔV requirements for each portion of the mission. Provide a graphical summary of these maneuvers including normal and lateral load factor histories, aeroheating, synergetic efficiency, and so on. Discuss the proportion of overall energy losses used up in the rarefied-flow viscous-interaction aerodynamic regime.

In addition, describe the maneuvers to be used in reentry. Show the crossrange obtainable and the footprint envelope the vehicle can achieve over the United States. Analyze the ground track for repeatability, and show what conditions are necessary for the vehicle to land at one of the specified locations. The trajectory calculations should show that the vehicle can arrive within 0.5 degrees of latitude and longitude from the landing site coordinates at 10 km altitude, after which the parafoil is used to execute a landing. Present detailed information about typical reentry trajectories, such as the time variations of velocity, altitude, flight path angle, latitude, longitude, heading angle, acceleration, and surface temperatures at several locations on the vehicle.
Propulsion System – 20 pages maximum

Describe the propulsion system and propellant requirements (mass and volume). Use an existing flight-proven propulsion system rather than designing your own. Show propellant use schedule for each maneuver (e.g. to transfer orbit, boost, circularization, deorbit retrofire, etc.) If the system is used within the atmosphere during the synergetic maneuvers, account for the effects of the atmosphere on performance. Describe the attitude control and orbital maneuvering system and show propellant requirements, including the 400 ft./sec. \( \Delta V \) required for maneuvering.

Aerothermodynamics – 30 pages maximum

Develop an aerodynamic model for the vehicle in hypersonic and supersonic flow, and determine lift, drag, and moment coefficients. For appropriate center of gravity locations, examine trim and stability in pitch and yaw. Correlate L/D ratio with crossrange capability. Develop empirical lift and drag coefficients for supersonic flow and provide a smooth transition from hypersonic to supersonic flight conditions. Determine if a significant portion of the overall vehicle energy is lost in the rarefied-flow viscous-interaction regime, and if so implement improved models for this regime.

Provide aerodynamic heating environments for all missions. Select TPS material and specify thickness requirements to keep substructure temperatures within required limits. Show temperature histories for critical structural components.

Structures and Loads – 30 pages maximum

Describe the structural design of the vehicle and materials used. Show how all parts fit within the available space. Show the structural margins for major components. Provide a complete mass statement including the masses and center of gravity of all components including expendables and personnel. Provide three-view drawings, inboard profile, and plan view drawings showing the location of major components. Describe the life support systems.

Appendices – No page limit and separately bound

Do not put any essential material in the Appendices. They should be viewed as backup data which an evaluator can consult for additional detail if desired. Extended tables should be provided electronically, in ASCII. Codes should be listed in printed form and also provided in electronic form. Code documentation in the form of comments should be sufficient to allow the reader to use and modify the code.

General Notes

The reports shall be presented on one side of the page only. Any section with more than the above specified number of pages will be judged on the contents up to the allowable number of pages. A table of contents with page numbers will be provided. A compliance matrix will also be provided: this is a cross reference of all the requirements in the RFP, with the page number in the report where the requirement is shown to be satisfied.

Graphs and figures do not have to be a full page. In fact, several smaller figures are often more useful than one large figure. All figures should be referred to in the text by number so
that the relationship of the figures and text is clear. The data plotted in the figures should be provided numerically in the appendices.

In all sections, describe the reasons for major design decisions. Is the design a ‘best’ or excellent one? In what ways, and why do you think so? What were the limitations on your ability to come up with the ‘best’ design? What are the most important limitations in your analyses? What are the next steps you would take if authorized (or funded) to proceed further with the design?

**Evaluation of the Designs**

Grades will be determined by Prof. Schneider based on the individual’s work, and their ability to communicate and interact in a timely manner with the other members of their team. The following factors are also of importance:

- Innovation
- Understanding of all aspects of the problem
- Technical validity
- Design completeness
- System integration
- Ability to meet requirements
- Neatness and professional presentation (without embellishments)

**References**
