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# IMPROVING SPACE-ASSET RESPONSIVENESS USING THE SHUTTLE EXPENDABLE ROCKET FOR PAYLOAD AUGMENTATION (SHERPA)

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## ABSTRACT

The Air Force has a growing mission need for highly-responsive, reliable and orbit-flexible micro-satellites. To respond to this need, the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VS), in collaboration with the Missile Defense Agency (MDA) and Space Test Program (STP), is developing the SHuttle Expendable Rocket for Payload Augmentation—SHERPA. The SHERPA system will be a reliable, low-cost asset that will provide orbit flexibility and multi-mission capability from the Shuttle Hitchhiker Experimental Launch System (SHELS) and other launch platforms. Technologies that will be developed under SHERPA include hybrid chemical propulsion, Hall Effect electric propulsion, modular bus architecture, separation systems, miniature star tracker technologies, and guidance, navigation and control systems. Modularity is used to enhance the responsiveness and multi-mission capability of the SHERPA system. SHERPA is designed with capability for multi orbit changes, station keeping, and de-orbiting at the completion of a mission. The system is being developed toward a proposed flight demonstration in the 2005 timeframe.

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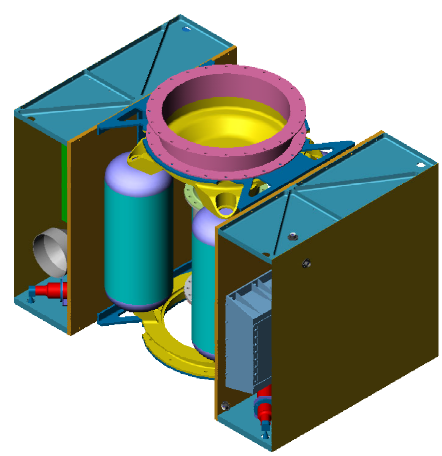

**Figure 1: Concept Design of SHERPA**

## INTRODUCTION

The SHuttle Expendable Rocket for Payload Augmentation (SHERPA) (Fig. 1) is a rocket-powered orbital transfer system for research and development micro-satellites. It is currently being developed for a proposed flight demonstration by the Air Force Research Laboratory Space Vehicles Directorate (AFRL/VS) to support the need of the Space Test Program (STP) to send satellite payloads to higher orbits cheaply, responsively, autonomously, and reliably. SHERPA, which can also be called a Transfer Upper stage Guided (TUG) system, will be 56 kilograms in mass and capable of boosting a 125-kg satellite payload from an orbit of 350 kilometers to 700 kilometers.

The STP utilizes a variety of systems to fly its payloads. One system employed in the past is the Space Shuttle and its Shuttle Hitchhiker Experimental Launch System (SHELS). Although the current plan for the SHERPA flight demonstration is to use the SHELS carrier (Fig. 2), opportunities exist to also launch as a secondary payload aboard an expendable launch vehicle (ELV). The SHERPA team, consisting of AFRL/VS and several Small Business Innovative Research (SBIR) contractors, is designing the core technologies for this effort to be as flexible as possible to allow use of these individual technologies in other applications.

The SHERPA system will fly as a secondary payload and deploy after the Space Shuttle has completed its primary mission. After SHERPA and its strapped-on satellite payload have completely launched from the Shuttle, it will wait on orbit until the Shuttle is safely away from SHERPA. The TUG will then orient the payload stack with an attitude control maneuver and fire its propulsion system to initiate a Hohmann transfer orbit. This boost will have a total change in velocity (delta-v) of 240 meters per second and accomplish a one degree plane change for collision avoidance. After the stack has coasted to the final mission orbit apogee, the propulsion system will fire again, inserting the satellite payload into its final mission orbit. SHERPA will then separate itself from the satellite payload and fire a Collision/Clearance Avoidance Maneuver (C/CAM), ensuring it is clear of the satellite and guaranteeing the pressurized propulsion tanks are emptied as much as possible before re-entry. After this final maneuver, SHERPA is in its lowest possible orbit and ready for rapid re-entry.

**Figure 2: SHELS Carrier**

## RESPONSIVE SPACE

The SHERPA system promotes responsive space in three major ways: allowing satellites to be stored on-orbit and then moved into position as needed, promoting reconfigurable and maneuverable assets, and producing a low cost space system that can be easily procured.

First of all, the basic principle of the SHERPA program is that satellites will be stored on-orbit and then moved into position as needed. Currently, secondary payloads employing the Space Shuttle launch option to orbit are limited in final orbit altitude selection based on primary Shuttle mission goals. SHERPA will be able to be reconfigured to support other lunch options besides just SHELS.

Secondly, SHERPA is a reconfigurable and maneuverable asset. The TUG team is developing three configurations of SHERPA using the same technology and components, but each serving a slightly different purpose to maximize reconfigurability. Each SHERPA launched in the future would be programmed to maneuver to the specified orbit and inclination in order to achieve the mission goals of the satellite it successfully boosted.

Finally, SHERPA will be a low-cost, lightweight, and reliable space system that can be easily procured. Besides the orbit-raising capability, the TUG will be capable of multiple orbit changes, station keeping, and de-orbiting at the completion of a satellite's mission.

## SHERPA REQUIREMENTS

The Air Force Space Test Program has laid out some strict but achievable requirements to support its foreseeable future missions, listed as follows:

1. TUG Mass: 56 kg
2. Stack (TUG + satellite) Mass: 181 kg
3. Stack Volume: 66 x 106 x 115 cm
4. One degree plane change for collision avoidance
5. Total delta-v: 240 m/s
6. Natural Frequency: not < 50 Hz
7. Center of Gravity Location: cannot exceed 61 cm as measured from the base along thrust axis and within 6.3 mm of the thrust axis
8. Comply with Shuttle and International Space Station (ISS) safety requirements

## SHERPA CONFIGURATIONS

The SHERPA orbital transfer system can be configured in three ways, increasing responsiveness and flexibility.

### MARK I

The Mark-one SHERPA is the simplest configuration. It utilizes only one propulsion module (PM). This configuration could be used to augment existing satellite systems. The purpose of this configuration would be to only provide simple propulsion for satellites containing all other sub-systems. However, some satellites need their own GN&C capabilities, for example, so using anything besides the Mark-one SHERPA could cause unneeded redundancy.

### MARK II

The Mark-two SHERPA is the most complex configuration and will be the demonstration capability for the TUG. This configuration is actually a stand-alone satellite all in itself, but would strap to another independent satellite requiring the orbit-raising boost. The current plan for the demonstration is to put a chemical PM on this configuration so that the boost time is less than one day. However, the Mark II SHERPA, depending on the mission requirements, could be configured with an electrical PM as either the primary or even as a back up PM. This SHERPA also would have the option to have deployable panels and/or booms depending on the needs of the mission defined by the user.

### MARK III

The Mark-three SHERPA will provide navigation and guidance, attitude control, and propulsion just like the Mark II SHERPA. However, this configuration is not designed to support a stand-alone satellite, but instead it will be a platform for various space experiments. In addition this configuration will be able to provide communications and long-duration power systems. It could use either the chemical or the electrical PM for the boost depending on mission allocations and also for orbit corrections and/or de-orbiting. This TUG would remain at the final orbit and provide housekeeping functions for the experiments. The mission duration for this version is up to one year, potentially longer than the Mark I or Mark II. The Mark III will maximize flexibility and responsiveness by being capable to support a choice of plug and play devices depending on mission needs.

## SHERPA ELEMENTS

The SHERPA program consists of several SBIR contracts focused on various parts of the overall system. The end result will integrate all of these efforts to meet the STP TUG requirements.

### HYBRID PROPULSION ROCKET

SpaceDev, Inc. (Poway, California) is developing the primary propulsion module (PM) for SHERPA. The hybrid propulsion rocket (Fig. 3) will use nitrous oxide oxidizer and Plexiglas as the propellant, be 51.4 cm in diameter, and stand 50.3 cm tall. This compact PM can be used in every SHERPA configuration and will have adequate thrust/volume characteristics necessary to support STP missions requiring short boost times while simultaneously meeting the rigorous Space Shuttle safety requirements. The PM is currently proposed to be 43 kg out of the 56-kg SHERPA mass. The propellant selected is nontoxic, non-corrosive, and nonflammable.

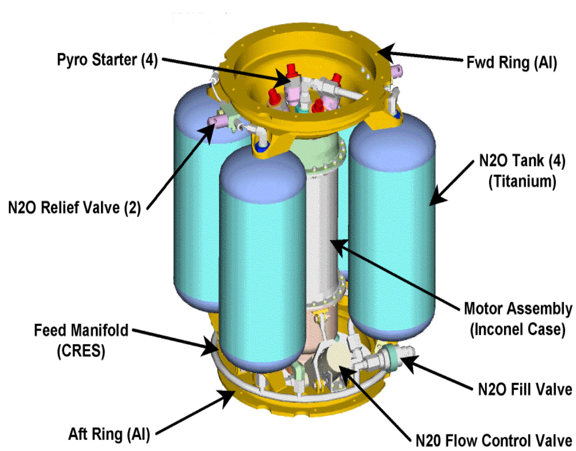


**Figure 3: SpaceDev's Hybrid Propulsion System**

### HALL EFFECT THRUSTER

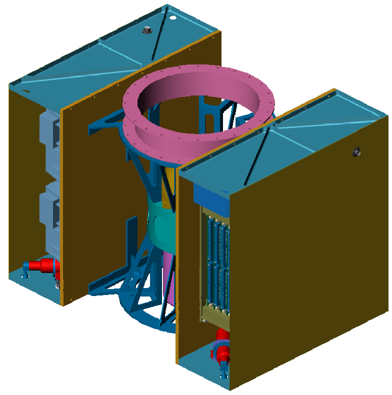

**Figure 4: Busek's Hall Effect Thruster**

Under a SBIR managed by the AFRL Propulsion Directorate at Edwards Air Force Base, California, Busek Co. Inc. (Natick, Massachusetts) is developing a backup PM to the hybrid propulsion rocket. Instead of using an oxidizer, this is an electric propulsion system applying Hall Effect thruster technology (Fig. 4). Inert xenon gas and physics drive this efficient thruster. Since it delivers thrust in the milliNewton range, this thruster would fire continuously for approximately a month for the orbit-raising maneuver. This time frame is not as responsive as the hybrid propulsion rocket but could be used if mission requirements allow more flexibility in boost time.

### GUIDANCE SYSTEM

Avidyne Corporation (Lincoln, Massachusetts) is developing a flexible, lightweight, and fully capable guidance, navigation and control (GN&C) system for SHERPA. Besides being a vehicle controller, Avidyne's "Silicon Pilot" can be used for orbit determination. Avidyne is currently working on developing a digital inertial referencing unit (IRU), which has a mass of 400 grams. This device offers excellent performance while meeting the strict mass and volume requirements of the TUG configuration. This unit is also low-cost, at less than $100K, consisting of 3 accelerometers, 3 gyros, Global Positioning System (GPS) interaction, and a processor. The novel software that was developed for the "Silicon Pilot" is designed as an open-ended architecture. This flexibility allows the software to host other GN&C algorithms as needed for each individual SHERPA payload.

## ATTITUDE CONTROL SYSTEM

Avidyne's "Silicon Pilot" will also provide attitude determination and control using the thrusters and actuators onboard SHERPA. The SHERPA team plans to incorporate three-axis thruster stabilization using up to 16 thrusters to serve as the primary attitude control system (ACS) actuator. This ACS would orient the payload prior to each burn and could share tankage with the main PM.

In addition AeroAstro (Ashburn, Virginia) is considering contingency plans to back up Avidyne's system for attitude control. These include simple, low-cost, and low-mass sun sensors, earth sensors, magnetometers, and a star tracker. Even if these devices do not find their way onto a future SHERPA, the research will prove valuable to others in the space community. The star tracker being developed has a 300 g mass and 300 cubic centimeter volume. It is less precise than current star trackers out there, but definitely smaller and cheaper by using Complementary Metal Oxide Semiconductor (CMOS) technology instead of traditional charge-coupled device (CCD) technology.

## SATELLITE BUS SYSTEMS

AeroAstro will also provide complete bus capability for SHERPA. Depending on mission needs, AeroAstro can perform all areas of design and development from concept through launch and operations, and is very flexible. AeroAstro is providing the support structure, the power system, and expertise in the areas of data handling, communications, ground equipment, and integration issues. AeroAstro will have a very important role in ensuring the integration of various payloads and spacecraft subsystems using modular assemblies. The modular satellite bus design utilizes this "plug-n-play" hardware configuration, making SHERPA flexible but straightforward for reconfiguration on a mission-by-mission basis. AeroAstro components are typically offered in an off-the-shelf version, but they can also be tailored to meet the requirements of a particular mission.

## PAYLOAD SEPARATION SYSTEM

Planetary Systems Corporation (Silver Spring, Maryland) is developing the SHERPA payload separation system. This space vehicle mechanisms manufacturer has developed many lightweight, low-shock, non-pyrotechnic separation technologies for small satellite deployments already in use. One system Planetary Systems Corporation is considering for SHERPA is the "Lightband," (Fig. 5) which is ideal and tested for deployment of small vehicles. It has already been successfully used on Lockheed's Starshine-3 to separate from an Athena-1 Launch Vehicle. "Lightband" has also already been selected for future use on University NanoSat, Techsat 21, and other upcoming missions.

**Figure 5: Planetary Systems Corporation's Lightband Separation System**

## SHERPA ISSUES

The greatest technical challenge for the SHERPA program is to develop a complete system in a 56-kilogram package. The use of innovative and responsive technologies, such as the Avidyne "Silicon Pilot," the Planetary Systems Corporation "Lightband," multi-functional structures, and a "plug-n-play" architecture, supports achieving this strict mass budget.

The greatest programmatic challenge is integration of all the various technologies and contracts. The AFRL is using existing bus technology and architecture contracts with AeroAstro to develop a small satellite bus as an integration approach to meet the TUG requirements. The SHERPA team is currently meeting on a bi-monthly basis via teleconferencing headed up by AFRL/VS.

Shuttle safety is also a very important consideration and driving force for engineering decisions. For example, SpaceDev chose nitrous oxide and Plexiglas, since this fuel oxidizer/fuel combination is nontoxic. The TUG will not interfere with Space Shuttle primary operations at all, will only deploy after all the primary missions are complete, and will not activate any propulsion maneuvers until safely clear from the Space Shuttle. The SHERPA team is also ensuring complete avoidance of the International Space Station (ISS).

## CONCLUSION

The SHuttle Expendable Rocket for Payload Augmentation will provide the Air Force and small satellite community with a new and necessary capability. This project has brought together several SBIR contracts and provides a technology transition path for each of those contracts. The TUG concept demonstrates and flight qualifies innovative technology, and provides responsive flexibility for a wide range of payloads. The core technologies involved in the SHERPA effort will be as flexible as possible to allow use in other applications.

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