NEPTranS; A Shuttle-Tended NEP Interplanetary Transportation System

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Abstract. Recently, a study was performed by a team from JPL and the DoE to develop a mission architecture for a reusable NEP Interplanetary Transfer Vehicle, a "Space Truck". This vehicle is designed to be used for delivery of payloads from Earth to a variety of destinations, including Mars and Venus, dependent on mission needs. In addition to delivering payloads to the target bodies, the vehicle is designed to perform autonomous rendezvous and capture of sample return capsules at the destination for return to Earth. In order to maximize the utility of the vehicle, its design is optimized for servicing between missions with the Space Shuttle. Fuel tanks, ion thrusters, and Power Management and Distribution electronics are all on-orbit replaceable units, located at the payload interface end of the spacecraft to ensure a minimal radiation dose to the Shuttle and crew during maintenance and resupply operations. Operational flexibility is maximized through the use of replaceable fuel tanks and thrusters, allowing tailoring of fuel load to any given destination and payload mass. This paper discusses the preliminary design developed for the NEP Interplanetary Transfer Vehicle, including its configuration and design features, and outlines the concept for mission design, including discussion of unique requirements for launch, deployment and operations with the Space Shuttle, and rendezvous and servicing by the Shuttle in Earth orbit following a return from each target destination.

INTRODUCTION

NASA has placed new emphasis on the development of advanced propulsion technologies including Nuclear Electric Propulsion (NEP). The application of this technology provides multiple benefits including high delta-V capability and high power for long duration science operations. For outer planet missions where solar energy is very scarce, the use of nuclear reactors is enabling for a wide variety of science missions. For the inner planets, however, the benefits of NEP are less obvious, given the relative abundance of solar energy. One potential mission application of this technology that has the potential to be enabling for a variety of future missions is to provide a reusable deep space transfer vehicle for multiple transfers to and from the inner planets. Such a space "truck" would make full use of the high delta-V capability enabled by the NEP system, while providing additional benefits to the payload. It could be used for multiple transfers from the Earth to the inner planets or other near-earth objects (NEOs), supporting sample return or science observation cargoes. A design has been developed for such a vehicle dubbed "NEPTranS" for NEP Transportation System. In order to extend the operational life and utility of this system, the NEPTranS vehicle is designed to be launched and serviced between missions using the Space Shuttle. A baseline operational scenario would include refueling of the vehicle and changeout of wear-limited components (eg., ion thrusters) by the shuttle crew between planetary missions. The versatility of such a system has broad implications for the establishment of a long-term deep space transportation infrastructure for the next decade and beyond.

MISSION CONCEPT

The NEPTranS mission concept is based on providing the ability to perform multiple robotic inner planet rendezvous missions. The key word is "multiple." NEPTranS is an unmanned spacecraft designed to make round trips between the Earth and Mars and/or Venus to deliver payloads and return samples collected from these planets on each trip back to Earth. The baseline vehicle design comprises an NEP system carrier with a fully integrated (and shielded) complement of flight hardware subsystems to support multiple round trip missions to inner planet target bodies. This has driven a design that incorporates the capability for autonomous rendezvous and capture of a sample return capsule in Mars or Venus orbit inserted by a corresponding ascent vehicle. The design must also be compatible with rendezvous and capture by the space shuttle in low Earth orbit. This capability enables the potential for a variety of payloads (e.g., multiple landers/rovers, science instruments, etc.) to be delivered to Mars or Venus on subsequent trips from Earth, and at the same time allows change-out of consumables and other limited life items such as ion thruster assemblies. The shuttle interface also allows for delivery of sample return capsules in a controlled manner eliminating the need to rely on direct entry and descent. In addition, the high sustained power levels available from the NEPTranS nuclear power system enables application of the basic vehicle to other uses such as high gain/high bandwidth radio and optical communications relay, microwave or optical power transmission, as well as being able to support a host of high-power science instruments (radar, magneto-sounding, laser ablation, etc.) In essence, NEPTranS is more than just a simple space truck – it is a highly versatile space utility vehicle.

Trajectory

A sample mission trajectory for a 100 kWe NEPTranS vehicle is shown in Figure 1, which illustrates a typical round trip mission to Mars.

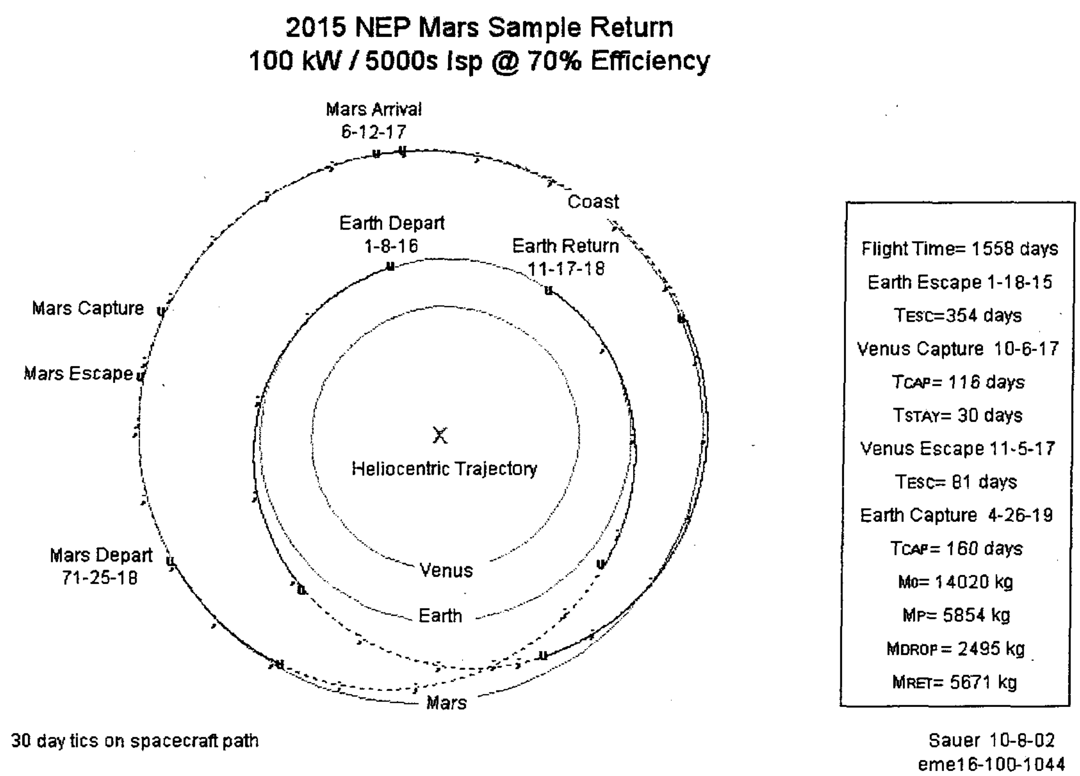

Figure 1. Representative NEPTranS Roun-trip Mission to Mars.

Sample trajectories were run using a vehicle dry mass estimated at 4500 kg, excluding Xenon tankage. Vehicle dry mass was scaled from relationships developed in previous joint studies by JPL, MSFC and GRC. It is important to note that this mass assumption is quite optimistic when compared to recent studies looking at current state-of-the art systems. This design study is assumed to represent a second-generation system that incorporates a number of technology developments now under study that are predicted to bring power and propulsion system masses down to the levels estimated within the next decade. In addition to the vehicle dry mass, the trajectory model assumed an outward-bound payload mass of 2500 kg, which was dropped after spiraling into a 500 km orbit at the destination. The stay time at the destination planet was assumed to be at least 30 days, and the vehicle was assumed to pick up a 5 kg sample return payload for return to Earth. Ion engine Isp was assumed to be 5000 s and the launch date was specified as 2015.

It is seen that for the Mars case, the total round trip time is about 4.3 years. Round trip times for the case of Venus missions were found to be quite similar, for the same design assumptions. Given a 15-year operating life, the NEPTranS vehicle operating at 100 kWe should be able to perform at least three round trip missions to Mars, Venus, or any combination of the two target planets.

Mission Phases

Initial Launch and Deployment

For its initial launch the NEPTranS vehicle, with its planetary payload attached, will be delivered to a 500 km circular orbit at a 57-degree inclination by the space shuttle. Following establishment of the parking orbit the shuttle payload bay doors will be opened and the NEPTranS vehicle will be deployed from the Orbiter's payload bay. The Orbiter will then perform a maneuver to separate to a minimal safe distance to allow vehicle and deployment operations to occur, while retaining the capability to return to the vehicle should contingency operations be required.

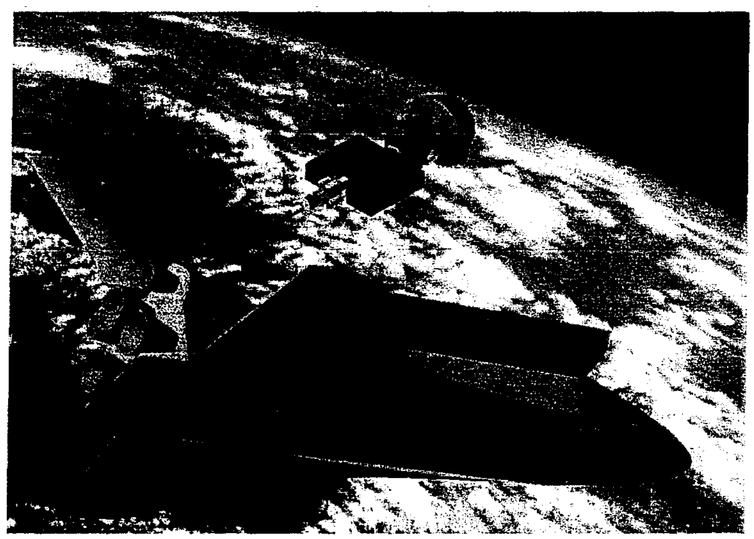

Figure 2. NEPTranS Deployment from the Shuttle Orbiter.

The NEPTranS vehicle's major deployment operation will begin with extension of its main separation mast. Mast extension will also effect the deployment of the power system radiators, which are structurally tied to the mast assembly. Following verification of nominal mast and radiator extension, the deployment operations will continue with the extension of the solar array wings, the three thruster booms and the HGA boom. All of the non-nuclear subsystems will then be activated and checked out. Upon verification of nominal subsystem operation, the Orbiter will reposition to a safe distance within the power system's shield cone and a command will be sent to initiate automatic start-up of the reactor system, monitored by ground crew and the shuttle astronauts. After the reactor is brought to full power and all operational parameters are verified to assure nominal operation, the ion propulsion system will be activated to begin the spiral process to place the vehicle on a trajectory to its target planet.

Planetary Target Operations

On approach to Mars (or Venus), the NEP system will provide thrust to place the spacecraft on a capture spiral trajectory. The NEP system will provide the delta-V necessary to lower the vehicle orbit to the desired altitude for deployment of the payload and/or rendezvous with the sample return canister. Following establishment of the final planetary orbit, the NEPTranS vehicle will deploy the lander payload for its descent to the landing site. The NEPTranS spacecraft will then loiter in planetary orbit with the reactor power throttled down to a low level until rendezvous and capture of the sample canister is completed.

Figure 3. NEPTranS Delivery Payload to Mars.

Ascent vehicle rendezvous and sample canister capture

The Sample Return landed system is assumed to acquire and store a sample in a return canister, which is subsequently launched directly into the orbit of the NEPTranS vehicle at about 500 km altitude. In the case of Venus, the baseline assumption is that, following collection and packaging of a surface sample, a helium balloon will lift an ascent vehicle containing the sample return canister to approximately 66km altitude from which point three solid propellant rocket stages will lift the canister to the NEPTranS orbit. The NEPTranS vehicle will track the sample canister in orbit and initiate autonomous rendezvous and capture. Fine maneuvering during this phase will be accomplished using the vehicle's monopropellant hydrazine RCS system.

Figure 4. NEPTranS Capturing Sample Return Canister.

Mars (or Venus) to Earth leg

Once the canister is captured by the NEPTranS vehicle the reactor will be brought back up to full power and the NEP system will provide thrust to place the return spacecraft on a spiral trajectory for escape and transit back to Earth. On Earth-approach the NEPTranS vehicle spirals down to a high-inclination circular orbit at a shuttle-serviceable altitude of about 500 km. Upon reaching this orbit the reactor is shut down and safed in preparation for rendezvous with the space shuttle and all vehicle power requirements are turned over to the auxiliary solar array power system. Shuttle rendezvous is timed to take place a minimum of 30 days after reactor shutdown to provide time for daughter-product radiation to decay to manageable levels. At the end of this decay time the Orbiter will rendezvous with the NEPTrans vehicle and grapple it with the shuttle robot arm. The space shuttle can then service the spacecraft, which will as a minimum consist of removing the depleted fuel tanks and attaching full ones sized for the next mission. The thrusters and certain other orbit-replaceable subsystems may also be replaced or upgraded during the servicing mission. Finally, the Orbiter crew will attach a new payload to the NEPTranS vehicle for a subsequent planetary delivery mission.

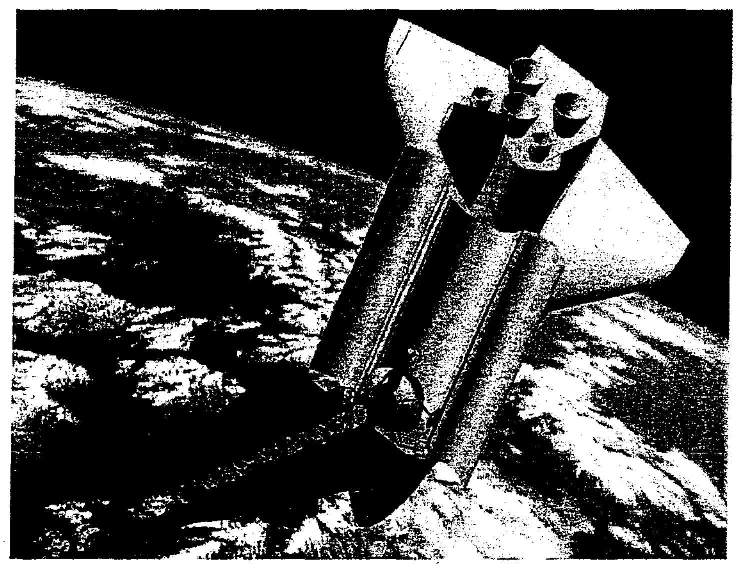

Figure 5. NEPTranS Being Serviced and Resupplied by Orbiter.

If the NEP carrier spacecraft does not require servicing for its next mission it has the option to swing by the Earth and release the sample return canister for direct re-entry into the Earth's atmosphere. The vehicle could then return more quickly to Mars or Venus to rendezvous with another return payload, if desired.

FLIGHT SYSTEM

The conceptual flight system developed for the NEPTranS vehicle is illustrated in Figure 6. The vehicle configuration is driven by the multi-use mission design and by the requirement for shuttle maintenance and servicing.

Vehicle Configuration

The vehicle design developed for this study assumed a nuclear power system level of 100 kWe. All payload attachment and on-orbit serviceable units are grouped at the payload end of the vehicle, inside the 15° half-cone angle of full shielding provided by the reactor shield. The Xenon propellant tanks are mounted on the sides of the spacecraft bus, and are modular units with quick release fittings to allow them to be changed out by the Orbiter's robot arm. The size of the tanks can be varied from mission to mission to accommodate a range of destinations and mission designs. The ion engines used in the design are mounted in three clusters of three engines each placed on articulated booms to allow clearance of the payload. Two engines of each cluster of three are required for nominal operations; the third in each cluster is a spare. In addition, the thruster booms are articulated such that any two booms can maintain thrust through the center of mass of the vehicle should one cluster fail. The mounting of the thrusters at the payload end facilitates their changeout between missions, should that be required. It should be noted that current ion engine designs are throughput-limited and it is expected that each round-trip mission will probably require at least the six primary thrusters to be changed out before beginning a subsequent mission. The modularity of the thruster mounting design will also allow for thruster upgrades, should technology developments result in significant thruster improvements between missions.

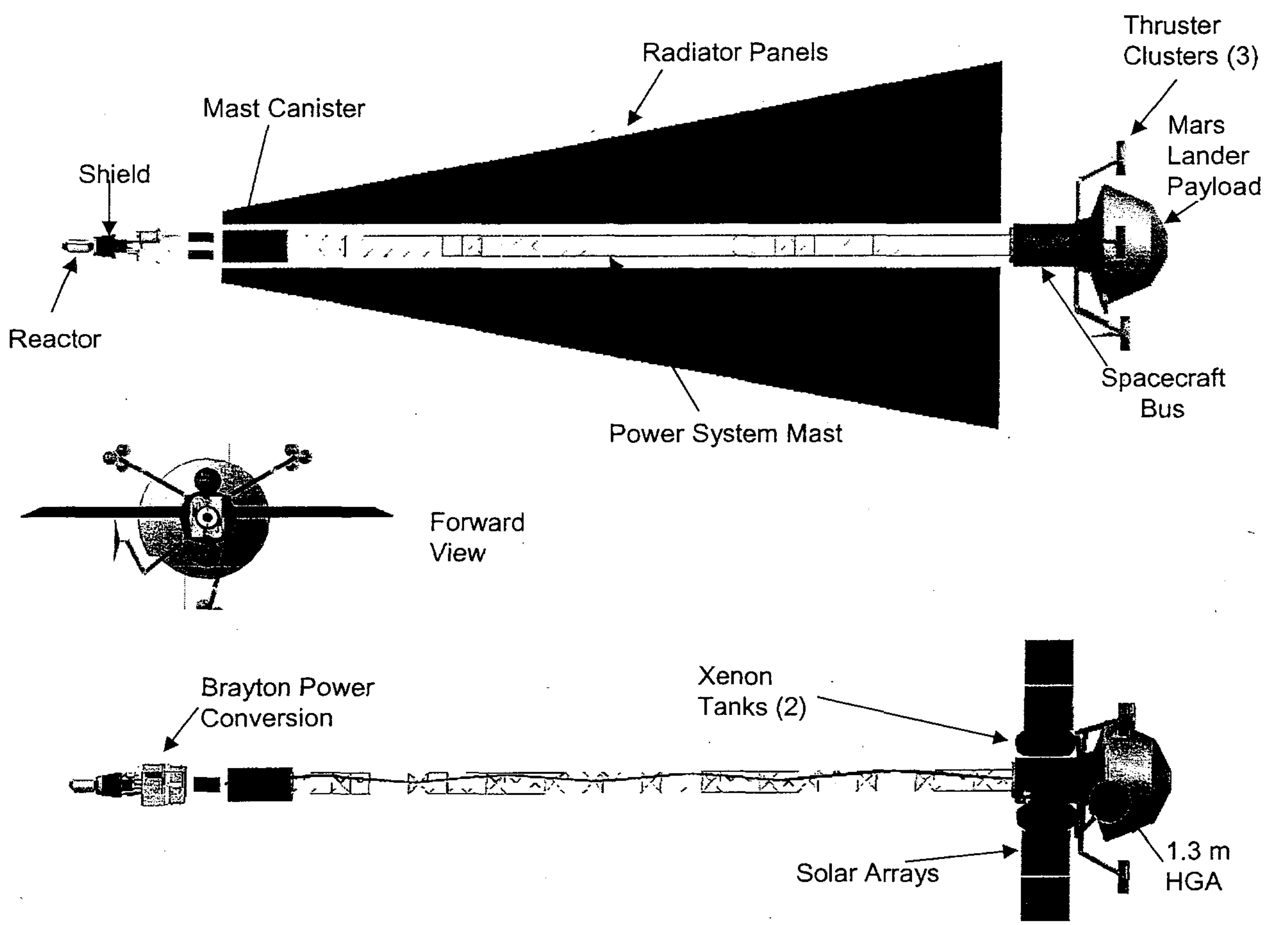

Figure 6. NEPTranS Vehicle Configuration

Spacecraft bus avionics and the reactor's Power Management and Distribution (PMAD) electronics will also be accessible from the payload end of the vehicle and may be designed as orbit-replaceable units as well. This will allow versatility and a capability to upgrade vehicle avionics unmatched since the Hubble Space Telescope.

The launch configuration of the NEPTranS vehicle fits into the Shuttle payload bay as shown in Figure 7.

Shuttle Launch and Servicing Considerations

The Space Shuttle PSRP (Payload Safety Review Panel) would have to review all aspects of what would likely be one of the more complex payloads flown on the shuttle. The mission operations for the rendezvous, capture, servicing, and redeploy of the spacecraft for the multiple missions envisioned for NEPTranS would be challenging but probably no more so than a Hubble or Station servicing mission. The standard payload safety review process for shuttle payloads is probably sufficient to ensure shuttle and crew safety even for a payload this complex. While many aspects of the design will likely be similar to systems already flown on the shuttle, complex payloads frequently require additional attention without considering the added challenge of the nuclear feature. An important aspect of the payload safety review process to keep in mind is that the nominal phased safety reviews for complex payloads are quite often supplemented by special topic TIMs (Technical Interchange Meetings). Experience has shown that where the payload has complex or unique design features these TIMs have been of great benefit for both the payload and the Shuttle Program in establishing an acceptable safety path for the payload to follow.

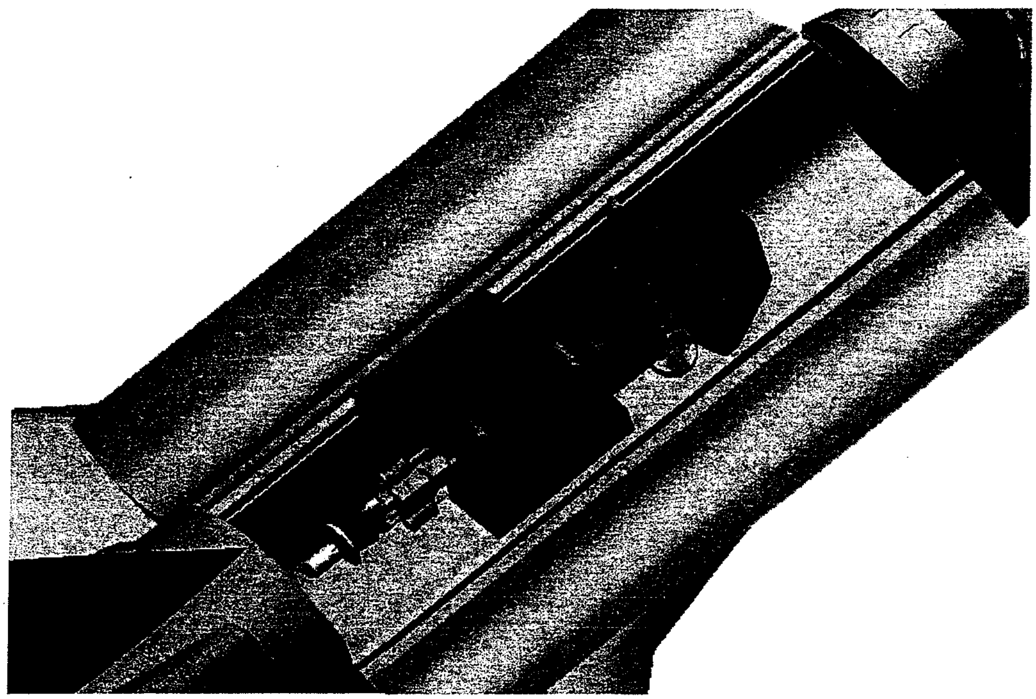

Figure 7. Launch Configuration of the NEPTranS Vehicle (with Payload)

While there are likely to be several aspects of the design that will be challenging from a shuttle safety perspective at least two that may require complex solutions come to mind. In order to minimize the radiation shielding needed to protect the orbiter and crew the reactor will probably need to be kept as far above the payload bay as possible. One of the suggested design solutions is an extendable mast of the type used on the Shuttle Radar mission and the Space Station solar arrays. While this approach has been demonstrated in flight the potential dynamic structural interaction with the Shuttle attitude control system must be well understood. This approach typically has required an additional jettison interface to meet the fault tolerance requirements for shuttle payload bay closure. The potential effects of ionizing radiation from the reactor on the shuttle and crew for the servicing missions are an aspect of the payload that deserves early attention. It is likely that acceptable crew exposure limits will be the more difficult criteria to establish since there are not currently well-defined limits for the intentional exposure that may occur during a servicing mission. Although the reactor will have been shut down for a minimum of 30 days prior to any shuttle approach, the gamma radiation resulting from daughter product decay will still need to be managed in order to afford the crew time to complete the servicing and resupply mission without exceeding crew exposure limits. The 15° gamma ray shield cone area provided by the vehicle during servicing operations is shown in Figure 8.

Since these two aspects of the payload design would appear to have a potentially significant impact on the radiation shield design alternatives to the single shield design may need to be considered. Possible solutions such as splitting the shielding, part attached to the NEPTranS and part deployed from the orbiter payload bay, use of the orbiter RMS or other robotics to perform certain aspects of servicing, or performing the servicing mission from the Space Station where several automated rendezvous and remotely controlled, (station crew) servicing scenarios are already in work.

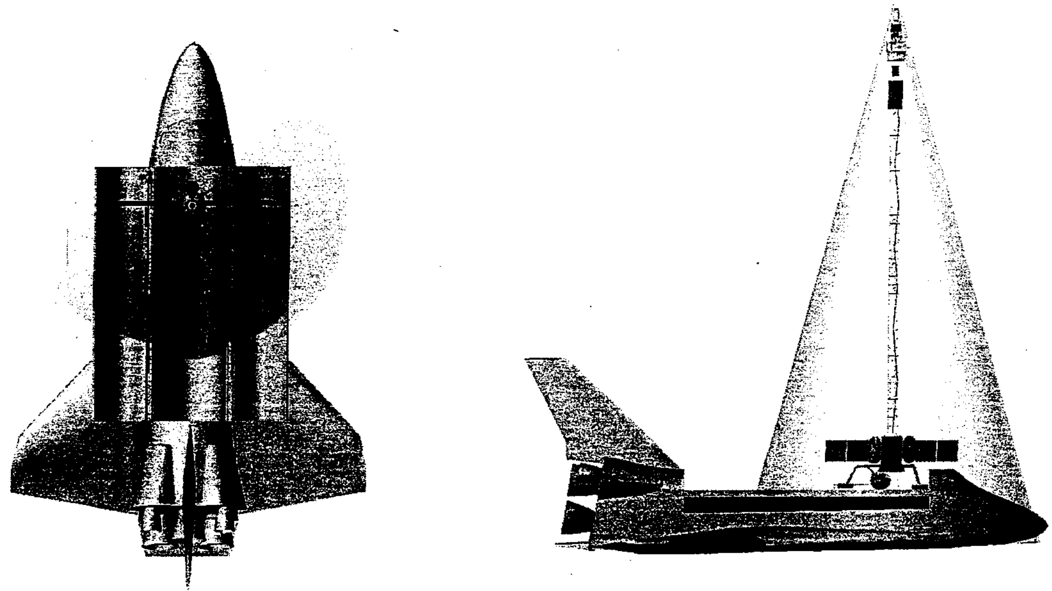

Figure 8. Illustration of 15° Shielded Area During Orbiter Servicing Operations.

Some thought toward contingency operations early in the design process is useful in so much as it helps guide the designers in choosing solutions that don't preclude continued operations in the event of failures. A typical contingency operation is a deploy flight retrieval in the event of a critical system failure, (reactor start, critical appendage deployment, etc.). The important aspect of these scenarios for the designer to keep in mind is that the payload must have the capability to restore the fault tolerance required for systems having potential catastrophic hazards in order to demonstrate compliance with the Shuttle safety requirements.

CONCLUSIONS

The NEPTranS vehicle and operations concept could provide a major benefit to inner planet exploration in the next decade. The availability of a reusable, upgradable vehicle that can be adapted to a wide variety of diverse missions without major on-orbit modifications has broad implications for future mission planning activities. The design developed in this study will require additional analysis to verify the mass and performance that have been assumed are attainable, but the study team is confident that the basic concepts, both for vehicle and mission design, are realistic and would provide a valuable addition to any long-term interplanetary mission architecture.

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