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A New Era of Space Shuttle

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ABSTRACT

The U.S. Space Shuttle represents the beginning of a new era in transportation and is the critical element in the industrialization of the near-Earth-space. Most of its flights are dedicated to reducing costs of launching commercial satellites.

However, it provides a microgravity environment for processing unique and improved materials which is generating great interest in both civilian and military sectors. The space shuttle is also the necessary step in establishing a permanent space station which could host materials analysis laboratories and commercial processing facilities.

This paper reviews the different elements of the space shuttle transportation system, a typical mission scenario, and discusses current activities in materials processing in space.

1. Introduction

The new era in space opened at 1:21 PM, EST, April 14, 1981. At that time the space shuttle orbiter Columbia landed on Californias Mojave desert after a 54.6-hour flawless voyage into space. It marked the first time a spacecraft had made an airplane-like landing from orbit. Moreover, Columbia survived atmospheric reentry temperatures >1600C. The space shuttle thermal protection system(TPS), largely low-density ceramic tiles, was one of several technology innovations demonstrated by Columbia. Kim(1984) discussed orbiter isotherms, various thermal protection system materials previously.

The size of the space shuttle is about that of a DC-9 jetliner, it is designed to carry multiple payloads in a cargo bay 18 m long and 4.5 m in diameter. It can launch with 29, 484 kg and return with 14,515 kg. Most of its flights are dedicated to reducing costs of launching commercial satellites. The ventures with communication and other satellites are very successful and the business is expanding. The communications satellite has provided concrete economic gains for its users and has facilitated the development and eudcation of Third world countries.

2. Space Shuttle

The space shuttle is composed of the orbiter, manufactured by Rockwell International(1980), Downey, california, an external tank(ET) manufactured by Martin Marietta, Denver, Colorado, which contains the liquid hydrogen and oxygen propellants used by the orbiter's three main engines(SSME) manufactured by Rocketdyne Div., Rockwell International, and two solid rocket boosters(SRB) manufactured by the Thiokol Corp., Utah. The orbiter and SRBs are resuable. The solid rocket boosters which were launched with Columbia were recovered in the Atlantic off Daytona Beach and, returned to operational status after minimal refurbishment.

The flight deck of the orbiter contains the controls and displays used to pilot, monitor, and maneuver the orbiter as well as payload controls. Seating for the crew is provided on this level. The lower or mid-deck contains living quarters, including a food preparation galley, an eating area, personal hygiene facilities, and sleeping accomodations. Below the mid-deck is the environmental control equipment. Electrical power for the space shuttle and the payloads is generated by three fuel cells which use cyrogenically stored hydrogen and oxygen. The quantities of fuel normally carried will be enough to generate about 1530 KWh energy. The by-product of chemical conversion, water, is used for human consumption.

The orbiter data processing system(DPS) provides monitoring and control for the orbiter. It consists of five IBM general purpose computers(GPC) for computation and control, two magnetic tape mass memories for large column storage, time-shared serial digital data buses to accomodate data traffic between the computers and orbiter systems, 19 multiplexers/demultiplexers, three engine interface units to command the SSMEs, and four multifunction CRT display systems for crew interface. In-flight software programs provide various computations and other functions such as guidance, navigation, and control for ascent, landing and so on.

The broad spectrum of shuttle missions requires that the orbiter accomodate many types of payloads. The remote manipulator system(RMS) is also carried in the bay. The RMS is a mechanical arm which maneuvers a payload from the bay to its deployment position and releases it, or grapples a free-flying payload and berths it.

3. Mission Scenario

A typical mission scenario is shown in Fig. 1. A space shuttle mission will begin with installation of the payload into the orbiter cargo bay. The payload will be checked and serviced; only after reaching orbit it will be activated.

At lift-off, the SRBs and main engines ignite to provide a combined thrust of 3.08×10^7N. After about two minutes at an altitude of 27 nm the SRBs will burn out and jettisoned. Relative velocity at this point is 4,625 km/h. The main engines continue to burn from the ET until ≈ 8.75 min from lift-off. Main engine cutoff occurs at an altitude of 60nm and an inertial velocity of 26,715 km/h, 1,363 nm downrange over the Atlantic Ocean. However, the shuttle is in an 80 by 13 nm elliptical orbit. To obtain a desired apogee and perigee of 150 nm(nominal), two insertion burns are made with the two orbital maneuvering engine(OMS). The final insertion burn is completed at 45.25 min into the mission. Each subsequent revolution of the earth takes about 90 minutes. Once established in orbit, the payload doors are opened, both for exposing the payload for allowing deployment of the heat-rejecting radiators. Reaction control thrusters(RCS) provide altitude control and precision velocity changes for rendezvous and docking. They also operate in tandem with the aerodynamic control surfaces during the early portions of entry.

Payload operations in orbit may be multiple, depending on the mission objectives: retrieving or servicing satellites, deploying satellites, conducting experiments, or constructing space platforms.

After orbital operations are completed, deorbiting maneuvers will be initiated with the OMS engines. After a retrograde tail-first firing, the RCS thrusters will turn the orbiter nose forward for entry. Guidance, navigation, and flight control software for the entry phase are initiated by the flight crew about 5 minutes before entry interface(EI), an altitude defined as that at which aerodynamic forces can be sensed. EI occurs at 65.8 nm over the western Pacific Ocean, 4,300 nm from Edwards Air Force Base, and just 32 min from touchdown.

Just prior to EI, the orbiter is maneuvered into a predetermined attitude: roll and yaw equal to zero degrees and a variable angle of attack. In the initial development flight tests, the angle of attack is 40°, but this angle will vary in subsequent missions as the entry thermal envelope is enlarged.

Descent rate and downranging are controlled by bank angles: the steeper the bank angle, the greater the descent rate and drag. Cross range is controlled by bank reversals. The entry thermal control phase is designed to keep backface temperatures within design limits. During STS-1, peak heating of the orbiter lower surface occurred from EI plus 5 min to EI plus 15 min and averaged 60 Btu/ft^2/S. Because of the heat generated as the spacecraft enters into the atmosphere, a shield of ionized air is formed which prevents communication. This period of communication blackout lasts about 15 minutes.

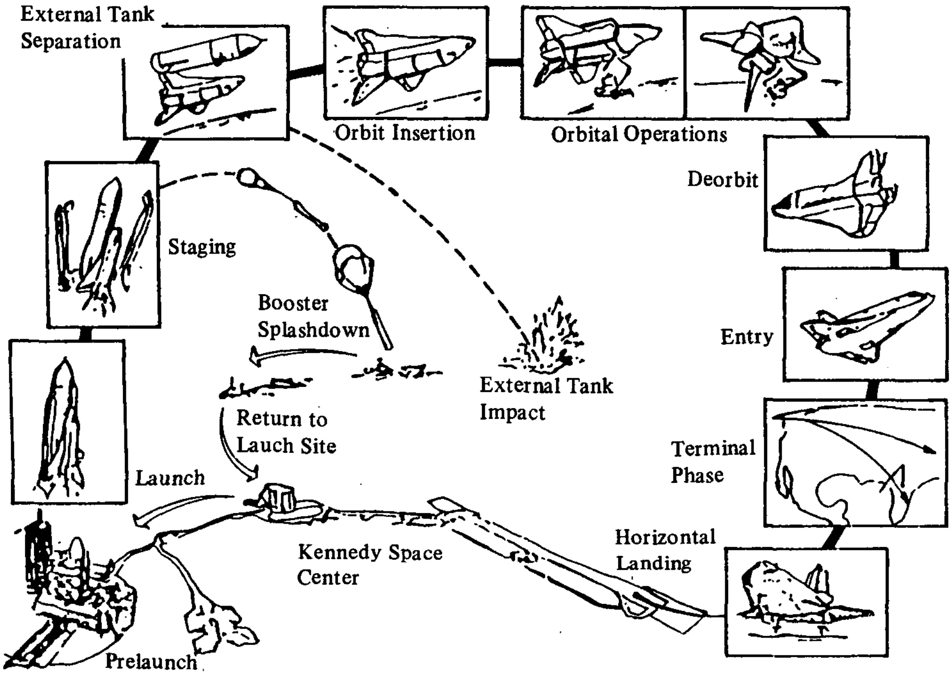

Fig. 1. Typical mission profile.

The fundamental guidance requirement during entry is to reach a target called the terminal area energy management interface(TAEM) at 25,298 m altitude, 762 m/s velocity, and on-range 52 nm from the landing runway. From on orbitial velocity greater than 26,000 km/h the orbiter dissipates its energy to touchdown at a speed of 335 km/h and at a sink rate of less than 0.5 m/min. Following landing and mission completion, the orbiter is towed to ground facilities, where any returned payload is removed. Orbiter turnaround operations, which follow, are currently approximately two weeks.

4. Materials Processing in Space

The interest in the behavior of materials in low gravity grew out of variety of disciplines. The earliest and most compelling need to understand fluid behavior in a spacecraft grew out of the propellant management program. This effort spawned a number of excellent studies of fluids dominated by surface tension and inertia in partially filled containers Studies on the erection of large space structures prompted research on the behavior of metal during welding and brazing processes in low gravity. It was recognized that the low-gravity environment offered unique advantages for processing metals in this molten state, and a number of manufacturing processes to be operated in space were postulated for the production of improved or unique products.

Before the advent of space shuttle, NASA established the SPAR sounding rocket program in 1975. Using the SPAR, considerable experience has been gained in developing and testing new hardware. With the development of shuttle, NASA established agreements with many companies such as McDonnell Douglas, MRA, Fairchild Industries etc. to conduct materials processing experiments. Several disciplines of these research are outlined in Table 1.

Table 1. Areas of current materials processing in space research in the U.S. (NASA 1981)

1. Crystal growth
    - solid solution (HgCdTe, PbSnTe)
    - vapor growth HgI
2. Metallurgy
    - Immiscible alloys
    - Magnetic composites
    - Metal foams
    - Solidification at extreme undercooling
3. Composites
    - Casting of dispersion-strengthened alloys
    - Solid electrolytes with dispersed alumina
    - Particle-pushing by Solidification interfaces
4. Glasses
    - Glass fining
    - Laser host glasses
    - Optical glasses with unique properties
    - Metal glasses
5. Chemicals
    - Monodisperse latexes (Polystyrene microsopheres)
    - Stability of foams and suspensions
    - Colloidal interactions
    - High temp. properties of reactive materials
    - Diffusion-controlled syntheses
6. Seperation Sciences
    - High volume, high resolution electrophoretic cell sep.
    - Protein purif. by cont. flow isoelectric focusing
7. Fluid studies
    - Nonbouyancy-driven convections
    - Wetting and spreading studies
    - Role of convection-in processes (Electrokinetic sep. electroplating, corrosion, etc.)

5. Conclusions

The space shuttle is America's newest and most versatile spacraft. It is a 100-mission reusable aircraft-like ship which is designed for years of service. The spacecraft's large capacity and relatively mild launch environment will enable it to carry into orbit a variety of satellites. Malfunctioning satellites can be repaired in space by the shuttle crew or a satellite can be returned to Earth for repair. The shuttle can also serve as a launch platform for higher-orbit satellites. The space shuttle will be able to transport elements of large space structures to orbit to construct a permanent space station in the future. Materials processing in space, like global satellite communications, could become a profitable and rewarding venture in space industrialization.

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