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Commercial Experiment Transporter—COMET

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A launch system consisting of ground-support equipment, a four-stage rocket, a service module, a recovery system and a recovery site, and an orbital operations center is being assembled. The system is designed to launch 818 kg (1800 lb) to a 552-km (300-n.mi.) low earth orbit at a 40-deg inclination. Experiment space exists in both the service module and the recovery system. The service module provides space for 68 kg (150 lb) of experiments plus telemetry services, attitude control, and power and uses no consumables to maintain attitude. Consequently, the service module can maintain orbit attitude for years. Power of 400 W is supplied by solar cells and batteries for both experiment operation and housekeeping. The recovery system houses an experiment carrier for 136 kg (300 lb) of experiments, a retro rocket, a heat shield, and a parachute. An orbital operations control center provides tracking, telemetry, and commanding for the satellite. The payloads are also briefly described. The first launch was scheduled for 1995.

Introduction

A SYSTEM has been designed and built that allows an 818-kg (1800-lb) payload to be lifted into a 552-km (300-n. mi.) circular orbit. A freeflyer (satellite) consists of a service module and a recovery system. The purpose of the system is to provide experimenters access to a low earth orbit with several years of orbital lifetime. In addition, the recovery system is provided to allow return to earth of a portion of the orbiting freeflyer at a time before natural re-entry of the remainder of the freeflyer. The launch system consists of a portable launch service tower installed on a launch-pad slab, a four-stage rocket, an orbiting service module and recovery system, and an orbital operations center for controlling the freeflyer and integration of experiments into the freeflyer. The system is called COMET— Commercial Experiment Transporter—and is described herein.

Launch System

The launch system consists of a four-stage rocket and a portable launch service tower placed on a new concrete launch pad at Wallops Flight Facility in Virginia. The steel service tower was prefabricated off site in Georgia and shipped to Wallops Flight Facility for assembly. It was designed to be dismantled for shipping to other launch sites. Wiring was installed at the launch site.

The rocket (Fig. 1), 15.7 m (52 ft) tall, consists of three types of solid rocket motors: Castor IVA (2 each), Castor IVB (5 each), and a Star 48 V (1 each). The Castor IVA provides a nominal 489,000 N (110,000 lb) of thrust and a total impulse of 2.7×10^7 N · s (6.1×10^6 lb · s), the Castor IVB provides approximately 4.3×10^5 N (97,000 lb)and 2.7×10^7 N · s (6.1×10^6 lb · s), and the Star 48 V 6.7×10^5 N (15,100 lb, and 5.8×10^6 N · s (1.3×10^6 lb · s). The Castors are approximately 101 cm (40 in.) in diameter and 9.1 m (30 ft) long. The Star 48 V is approximately a sphere of 124-cm (49 in.) diameter. The fuel for the Castors is HTPB polymer with 20% aluminum particles. The Star 48 V fuel is AP 71%, AL 18% with an HTPB binder 11%. Burn times are IVA, 51.7 s; IVB, 60 s; and Star 48 V, 84.5 s.

A total of four Castors, two IVA and two IVB, are ignited on the first stage. They are paired on opposite sides of the core motor. The Castor IVBs have vector-control nozzles and are used for guidance and control of the first stage. The second stage is composed of two

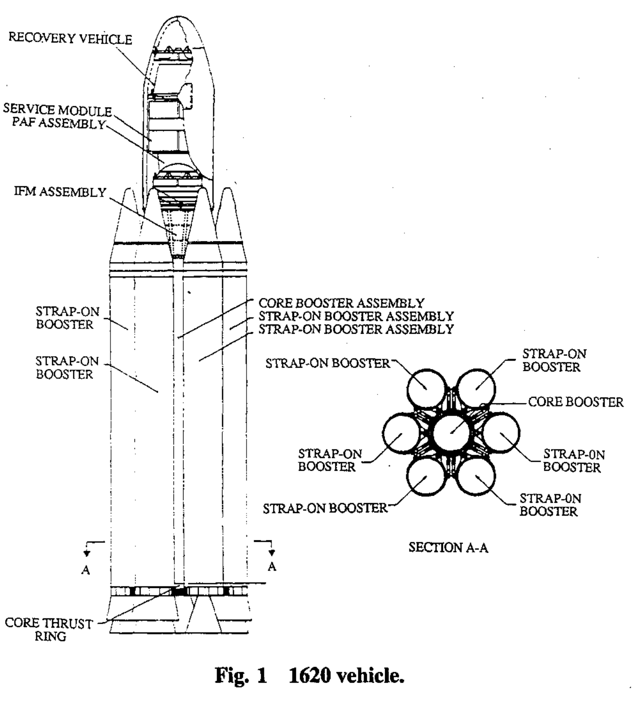

Fig. 1 1620 vehicle.

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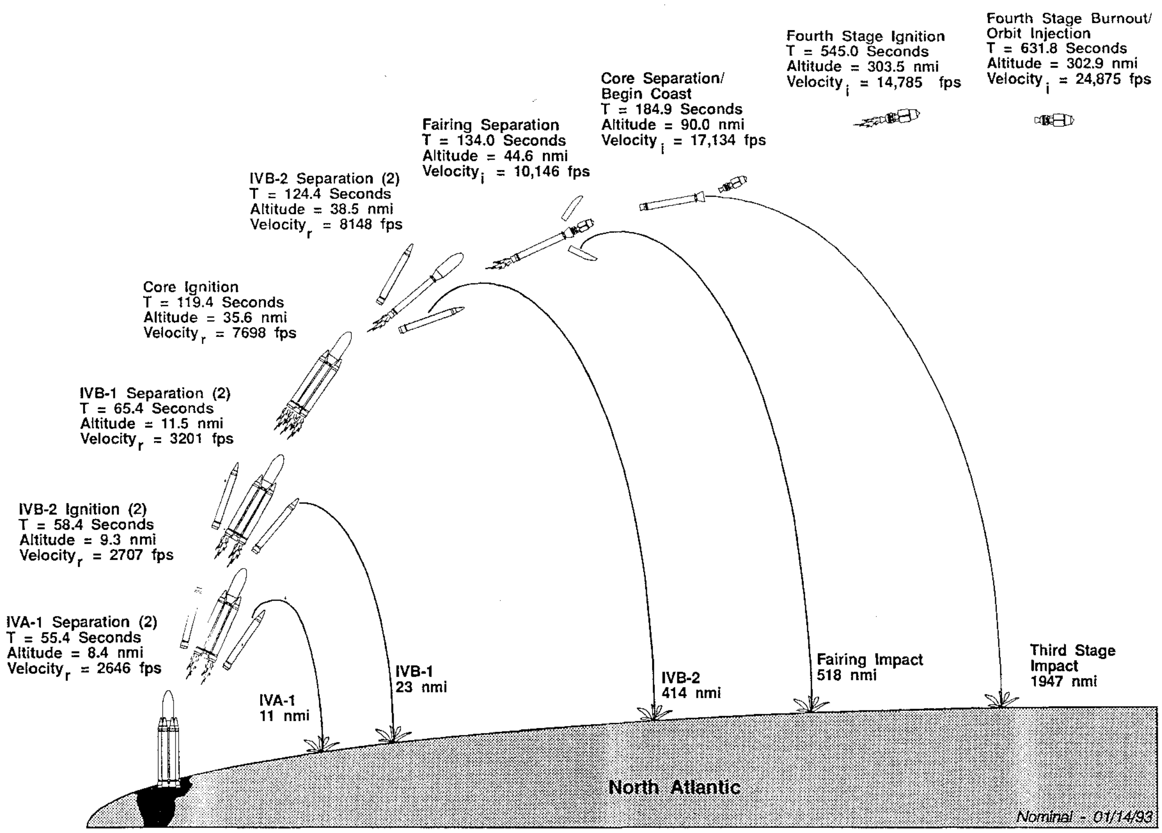

Fig. 2 Mission profile.

Table 1 1620 mission event sequencing[a]

Mission event	Time, s
Liftoff: IVB-1 and IVA-1 ignition	00.0
Maximum dynamic pressure	45.1
IVA-1 burnout	54.4
IVA-1 jettison	55.4
IVB-2 ignition	58.4
IVB-1 burnout	64.0
IVB-1 jettison	65.4
Core B-3 ignition	119.4
IVB-2 burnout	121.4
IVB-2 jettison	124.4
Faring jettison (q < 1.0 psf)	134.0
Core B-3 burnout	183.4
Core and IFM jettison; begin coast	184.9
End coast; 4th-stage ignition	545.0
4th-stage burnout; orbit insertion	631.8
4th-stage separation	751.8

[a] All times are nominal; actual times will vary.

air-ignited Castor IVBs paired on opposite sides of the core motor. These also have vector-control nozzles. The core Castor IVB is air-ignited for the third stage, and the Star 48 V with a vector-control nozzle is ignited for the fourth stage. See Fig. 2 for the mission profile and Table 1 for the mission event sequencing. Roll control is not required for the third-stage burn and is provided by the cold-gas altitude control system of the freeflyer for the fourth stage. The roll control for the first two stages is provided by gimbaling the Castor IVBs.

Ignition of each of the stages occurs when the flight computer issues a firing command through a safe-and-arm device, which ignites ordnance trains that go to the ignitors of the appropriate motors. Ignition of the second, third, and fourth stages is sequenced from the separation signal of the previous stages with appropriate ordnance time delays in the ordnance trains. Ignition of the first stage occurs from ground-support equipment. Separation of the payload occurs on additional signals from the flight computer.

The upper-stage assembly (Fig. 3) consists of the freeflyer (i.e., service module and recovery system) and the Star 48 V solid rocket motor. The upper-stage assembly rests on the interface module, which rests on the core motor. The interface module is also attached to the lower part of the Star 48 V. The upper-stage assembly is separated at the interface module for third-to-fourth-stage separation. A payload attach fitting is attached to the upper part of the Star 48 V and the lower part of the service module. Separation occurs at the payload attach fitting after the Star 48 V has burned out. Both of the separation systems use compression springs and marmon clamp bands.

The fairing also rests on the top of the interface module. The fairing is 4.9 m (192 in.) long with an ogive nose; it is 183 cm (72 in.) in diameter. The fairing is made of fiberglass-reinforced epoxy, and is split into two pieces along a longitudinal seam containing a thrusting joint. The fairing is radio-frequency transparent. This thrusting joint contains an explosive cord within a bellows assembly, which is detonated when the dynamic pressure is less than 6894 Pa (1 lb/ft^2). A clamp ring at the lower end of the fairing is held by two explosive, frangible nuts, which are detonated at the same time as the explosive cord. This causes separation of the fairing.

The fairing has a spring-loaded door on its upper end, which allows a freeflyer cooling-air umbilical to pass from the launch tower to the freeflyer volume. This umbilical is pulled shortly before launch, which permits the outward-opening door to swing shut.

Guidance and control are provided by a Motorola 68020-based flight computer running an open loop, a closed loop, and a coast-mode guidance and control algorithm. The algorithm is a modification of the powered explicit guidance predictor-corrector-method algorithm used to control the National Space Transportation System (Shuttle). Guidance and control considerations led to the requirement of obtaining solid rocket motors of closely matched performance. Angular rates and velocity rates are sensed by an inertial measurement unit, which is shared with the freeflyer. This required close coordination between the builder of the launch vehicle and the builder of the freeflyer. The launch-vehicle flight computer controls all the launch-vehicle systems except the inertial measurement unit, and also controls the freeflyer attitude control system during fourth-stage burn. Two telemetry streams (500 and 25 kbit/s) transmit data on the launch vehicle to ground stations at Wallops Flight Facility, Bermuda, and New Hampshire. Freeflyer telemetry will be received at the Houston orbital control center.

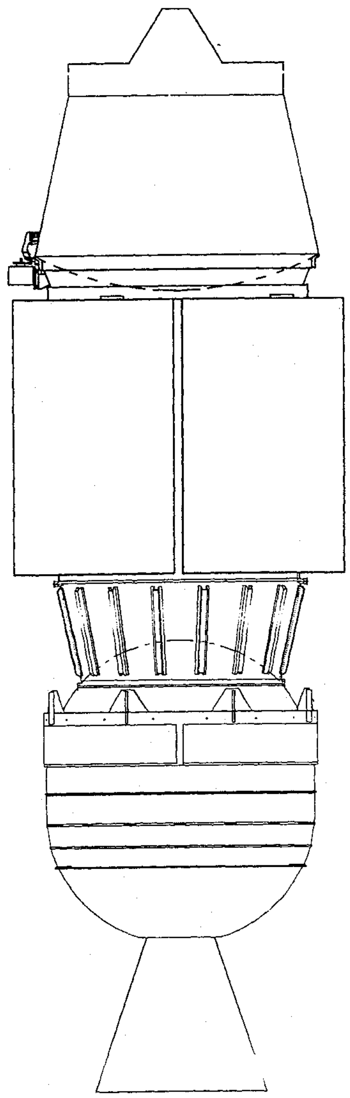

Fig. 3 Upper-stage assembly.

Service Module

The service module provides the primary utilities, including electrical power, thermal management, and internal and external communications during launch, ascent, and on-orbit operations of the COMET system. The service module provides the launch vehicle with guidance, navigation, and control data from the service-module inertial measurement unit, as well as active attitude control for the service-module thrusters. In addition, the service module will provide the recovery system with re-entry commands and active attitude control for deorbit pointing and recovery system-spin-up operations. The service module can also support a limited number of nonrecoverable, unpressurized experiments for extended periods of time. The seven major subsystems of the service module are: structures, propulsion, command control and telemetry, power, attitude control, and thermal control. These are all designed to provide the experiments within the service module and the recovery system with a temperature-controlled environment. The service module is designed for a minimum mission lifetime of 30 days on orbit while mated to the recovery system. The steady-state design parameters are now extended so that the minimum on-orbit life for the service module, once detached from the recovery system, is not less than 2 yr. At the end of its useful life, the service module's orbit is to decay naturally until it is destroyed by re-entry into the atmosphere. A service-module pictorial is shown in Fig. 4, and a freeflyer pictorial is shown in Fig. 5.

The service-module payload carrier accommodates 68 kg (150 lb) of experiment payload. The compartment provides 0.42 m^3 (15 ft^3) of unpressurized internal volume. In addition, there are two areas

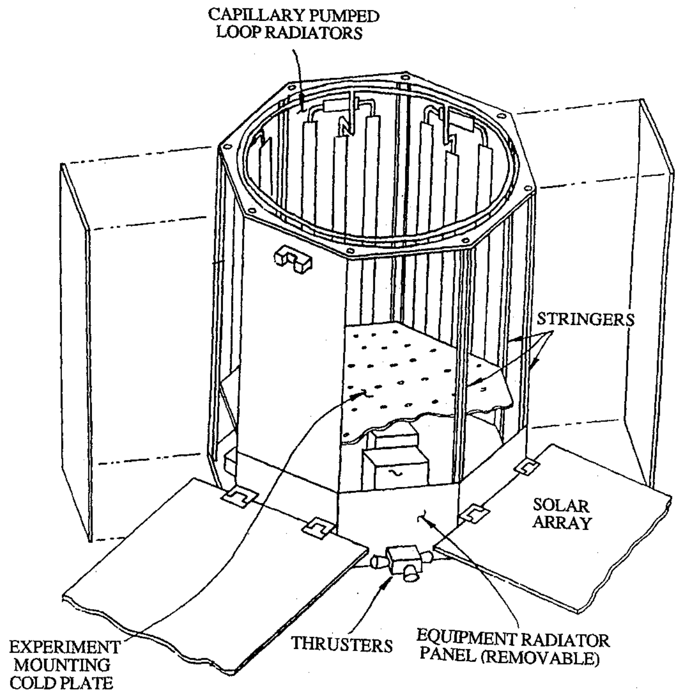

Fig. 4 Service module.

of unpressurized external volume available on opposite faces of the service module, measuring 0.056 m^3 (2 ft^3) and 0.028 m^3 (1 ft^3). Payloads are secured to the service module by bolting to the payload mounting plate. A thermal cooling loop mounted on the back side of the payload mounting plate serves for cooling. The payload is sized to accept payload heat at 400 W transferred at 0.16 W/cm^2 (1 W/in.^{2}) of surface contact, and to maintain a surface temperature of 22 ± 3°C (72 ± 5°F). The coldplate contains four temperature sensors, one in each quadrant. External payload hardware is secured onto load-bearing stringers using captive hardware. Each experiment is required to mount to the service module with a minimum of four mounting bolts. There is no thermal control provided for externally mounted payloads. Service-module standard payloads interface at any of the provided four service-module experiment ports. Each port provides power, data, and video connections. Power provided to the experiment hardware is at 28 ± 4 V dc with less than 0.5% ripple to each port. Table 2 summarizes payload accommodation parameters available to the service module. Current overload protection is provided with a solid-state power control module at each experiment port. Each output is controlled by the flight computer through the power controllers, which provide resettable circuit-breaker functionality and status monitoring/reporting capability. Power on/off control to the service module experiments is selectable from the ground via the command link. Experiment interfaces to the on-board data system are through an RS-422 interface using a modified X-modem software protocol. An experiment health packet is provided by the service module to assess experiment health on orbit. The health packet is sent to the ground as part of the telemetry. It is designed to allow the service module to turn off an experiment at the request of that experiment in an emergency. The experiments can thus be shut off from the ground, for overcurrent conditions, or via health-packet results.

Electrical Power System

The electrical power system generates and distributes 28±4-V dc power to all electrical equipment throughout the freeflyer. It functionally provides 1) power generation, 2) power storage, and 3) power management and distribution.

During prelaunch, 200 W is supplied to the freeflyer through the launch-vehicle umbilical. During launch, ascent, and orbital insertion, 100 W · h is supplied to the experiments by the service-module batteries. Upon deployment of the four solar arrays, the electrical power system provides increased power for the service-module and

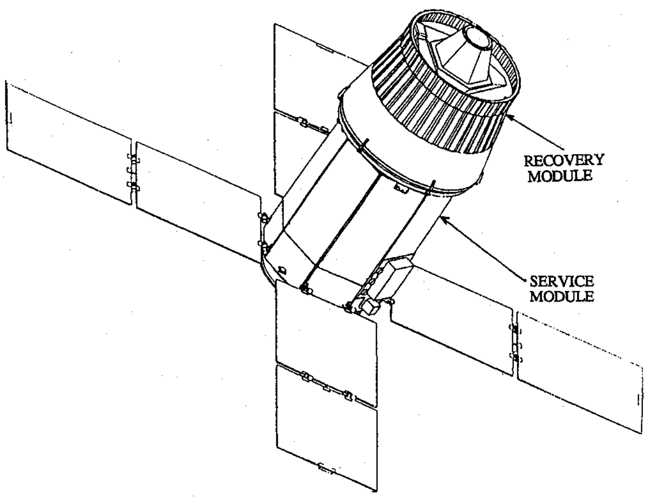

Fig. 5 Freeflyer.

recovery-system experiments and housekeeping functions. The arrays generate a peak of 970 W, which, after orbit, β angle, and other loss considerations, supplies 600 W of power for all activities in the sun-pointing mode. The electrical power for the combined recovery-system and service-module experiments is 350 W continuous, with peak power at 400 W for 200 continuous hours. The service-module housekeeping power allocation is 64 W average, and the recovery-system allocation 35 W. Thus, an additional margin of 100 W is provided for peak loads and component aging.

Solar Arrays

The four arrays consist of series-connected silicon cells arranged in several strings per panel. Each array consists of two panels capable of power generation upon fairing separation. Each 5.7 × 5.9-cm cell has 15 to 16% efficiency and utilizes a 15-mm (0.006 in.) CMX cover glass for environmental protection. These high-efficiency cells are of the back-surface-field reflector type. 970 W is initially collected, but through general array degradation (temperature fluctuations, micrometeroids) the output decreases to 921 W after 150 days.

Command, Control, and Telemetry

The command, control, and telemetry system performs the following functions: 1) communicates/controls experiments, 2) communicates/controls service-module systems, 3) communicates with the recovery system, 4) collects and transmits telemetry data, 5) communicates with the launch vehicle during ascent, and 6) provides for file management and timekeeping.

At the heart of the command, control, and telemetry system lie two 80C186 processors with error-detecting and -correcting memory as well as radiation-hardened random-access memory. One processor is dedicated to attitude-control functions, and the other to controling the service module, experiments, time management, and telemetry. This command processor also has a 4-Mbyte memory partitioned into 1 Mbyte for freeflyer telemetry and 3 Mbyte for experiment data storage. The experiment memory is allocated into files that are used for experiment video and data storage prior to ground station downlink. The ground station can allocate or deallocate varying numbers of files between experimenters.

Radio-Frequency System

COMET's radio-frequency system provides command uplink and telemetry, data, and video downlink with the Ground Station, utilizing omnidirectional antennas to allow communications in any freeflyer orientation. The service module uses a 250-kbps downlink for experiment data, video, and spacecraft telemetry. 10 W is transmitted with a carrier stability of 1 part in 10^{10}. This is a stable, continuous downlink over the ground-station for on-orbit tracking and parameter determination. Total daily visibility times of 40 min are expected.

Table 2 Service-module payload accommodation parameters

Parameter	Value
Payload mass	68 kg (150 lb)
Payload volume	0.42 m^3 (15 ft^3)
Environment	
Microgravity	1×10^{-5} g
Pressure	Vacuum
Baseplate temp.	22 ± 3°C (72 ± 5°F)
Electrical system	
Power-Voltage	28 ± V dc
Continuous	350 W
Peak (200 h)	400 W
Transient	1000 W
Heat rejection	400 W
Communication	
Downlink	250 kbit/s
Uplink	9.6 kbit/s
Pass time	40 min/day

Attitude Control System

The attitude control system provides three-axis attitude control and is capable of pointing and maneuvering the freeflyer as necessary. It communicates with the command, control, and telemetry system to receive commands and relay telemetry. It contains all the software needed to control the freeflyer and is reprogrammable on orbit. The attitude control system functions in five major operating modes:

Mode 1: Initial attitude acquisition. Upon ascent through orbit insertion, the inertial measurement unit is utilized for determining attitude position and angular rates. Utilizing cold-gas thrusters as well as the inertial measurement unit, coarse solar inertial attitude is established. The service module is stabilized in a microgravity configuration of 10^{-1} g within 90 min of fourth-stage burnout.

Mode 2: Solar inertial pointing. The attitude control system maintains a three-axis stabilized, sun-pointing orientation. This is achieved using a fine sun sensor and scanning horizon sensor for attitude determination. Control pointing accuracy of ± 5° is achieved through three-axis magnetic torquers and pitch/yaw reaction wheels. A microgravity environment of 10^{-5} g is established and maintained. Utilizing magnetic torquers and reaction wheels for control minimizes microgravity disturbances and minimizes expendable-gas use.

Mode 3: Recovery-module re-entry pointing. The attitude control system supports maneuvers to orient the recovery system for re-entry. Utilizing the inertial measurement unit, fine sun sensor, and scanning horizon sensor, the attitude control system provides ± 0.1-deg three-axis attitude knowledge. Upon verifying entry targeting, the command generator develops a trajectory for the freeflyer slew-and-hold maneuver. Cold-gas thrusters are used to orient the recovery system to the specified inertial attitude within ± 0.5 deg.

Mode 4: Nadir earth pointing. In this mode, the service-module maintains a constant attitude with respect to the earth nadir vector. Attitude knowledge necessary to control the service module to ± 1 deg is achieved utilizing the horizon sensor (pitch and yaw) and magnetometer (roll). Pointing accuracy is controlled to ±1 deg with a reaction wheel in the bias momentum mode (yaw), a pitch reaction wheel, and the three-axis magnetic torquers. This control assures that the $+Y$ axis is constantly in the positive velocity vector direction, while maintaining a 10^{-5} g microgravity environment.

Mode 5: Upset recovery. This mode is autonomously entered when recovering from a single-event upset or as a result of an out-of-limit condition of any of the angular rate telemetry. Under normal conditions the upset detection task periodically resets the watchdog timer. If the timer is not reset, it will expire (count down to zero) and an interrupt will occur, causing a hardware reset of the system.

Propulsion

A safe, low-cost, off-the-shelf philosophy has been used for the propulsion-system design. The propulsion system consists of six

44.5-N (10-lb) thrusters, three pressure vessels containing compressed nitrogen gas, and various valves, pipes, and transducers. This integrated system provides control authority for the freeflyer prior to orbital insertion and during solar-array deployment and initial attitude acquisition, and provides the capability to resist reaction torques induced by the recovery-system spin-up. Pitch, roll and yaw control is provided by the 44.5-N (10-lb) thrusters when not in a low-g mode or when the magnetic torquers and momentum wheels are unable to stabilize the freeflyer.

Recovery System

The design of the COMET recovery system is intended for an orbiting microgravity laboratory. This laboratory provides the essential services to support modular experiments in a closed environment for 30 days. All of the subsystems are designed to maximize the available payload volume and minimize acceleration disturbances. The essential payload support requirements are listed synoptically in Table 3.

The recovery-system hardware can be divided into two major subsystems: 1) re-entry vehicle and 2) on-orbit payload support. Payload support services include power, thermal control, environmental conditions, data collection, and interface support. Telemetry is through the service module system. Power comes from the service-module solar cells and batteries. The re-entry vehicle includes all of the necessary flight support systems to deorbit and recover the payload experiments. A side view of the recovery system (Fig. 6) shows many of these major subsystems.

Re-Entry Vehicle

The re-entry vehicle has the distinction of being the first recoverable capsule designed to support commercial payloads on orbit and return to a landing zone within the continental United States. The deorbit-and-recovery sequence is shown in Table 4. Several novel design concepts have been used in the hardware development. The principal design drivers included: an overall low-cost commercial vehicle, use of commercially available components where possible, maximum payload support capability, and minimal microgravity disturbances to experiments. The resulting hardware design represents a blend of unique design, existing technology, and efforts to minimize costs.

Table 3 Recovery-system payload accommodation parameters

Component	Capability
Total payload mass	136 kg
Total recovery-system mass	318 kg
Total pressurized payload volume	0.28 m^3
Maximum power and heat rejection	400 W
Payload carrier temperature control	22 ± 3°C
"Late" payload access before launch	6 h
"Early" payload access after recovery	4 h
Microgravity limit	10^{-5} g
Maximum g load (re-entry and impact)	< 10 g
Mission duration	< 30 days

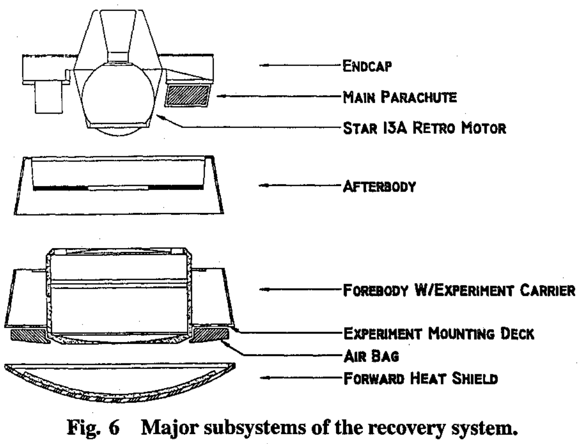

Fig. 6 Major subsystems of the recovery system.

The primary vehicle superstructure is manufactured using a wet layup composite of uni- and bidirectional carbon fibers. After curing, the primary structure is proof load tested to verify structural integrity. The primary structure includes a circular equipment-mounting deck inside the main frame. All subsystems are bolted directly to the primary structure or the equipment mounting deck. The attachment points are unique, with each piece of equipment match fitted, drilled, and mounted.

The exterior of the primary structure is bonded with Acusil© silicone ablative material for thermal protection during re-entry. Acusil© is used as an insulator for the forward heat shield, afterbody, and endcap. Stainless-steel (316 SS) radiators used for the payload thermal rejection system wrap around the afterbody and provide additional thermal protection.

A recovery-system spin-table assembly separates the re-entry vehicle from the service module. This assembly consists of 1) a spin-table primary structure, 2) a spin motor, 3) a spin bearing, 4) spring-loaded release latches, 5) a sequence controller, 6) fail-attached accelerometers, and 7) an electrical disconnect. Separation is initiated via uplink telemetry command to the sequence controller approximately two orbits prior to re-entry. The sequence controller fires a pyrotechnic thrust piston, which separates the electrical umbilical and leaves the re-entry capsule free to rotate on the spin bearing. The spin motor rotates the capsule to 75 rpm in approximately 80 s. After reaching 73 rpm, the sequence controller fires explosive bolts, which open the release latches. Spring pads in each latch separate the re-entry vehicle from the service module at approximately 0.15 m/s (0.5 ft/s).

40 min after separation, the sequence controller initiates re-entry by firing the Thiokol Star 13 A retro motor. The Star 13 A burns for approximately 15 s with 7117-N (1600-lb) thrust, reducing the orbit velocity by 240 m/s (790 ft/s). Upon completion of the burn, two explosive bolts release the Yo-Yo de-spin counterweights and reduce the rotational velocity to 5 rpm just prior to re-entry. A C-band beacon is used to track the capsule flight path from separation through landing at the United States Air Force Utah Test and Training Range.

At 18 km (60,000 ft) above mean sea level (msl), a pilot chute 0.7 m (2.3 ft) in diameter is ejected by mortar from the capsule's endcap. The deployment is initiated by a barostat trigger mounted on the recovery-system equipment deck. The pilot chute deploys a ribbon drogue chute 3 m (9.7 ft) in diameter, slowing the vehicle from Mach 0.8 to 53 m/s (175 ft/s). At 3 km (10,000 ft) above msl the endcap is separated from the capsule with explosive bolts. This separation deploys the main chute, which is 18.3 m (60 ft) in diameter, and reduces the velocity to 5 m/s (16 ft/s) at touchdown. The endcap containing the spent Star 13A remains attached to the drogue and descends at 11.6 m/s (38 ft/s).

The peak acceleration load at impact is mitigated by a dual-chamber passive air bag deployed from the capsule. When the endcap separates, explosive bolts also release the heat shield from the recovery-system primary structure. Physical separation of the endcap and heat shield limits thermal soak back to the experiments during re-entry. The passive air bag is attached to both the heat shield and the recovery system. As the heat shield falls from the vehicle, the Dacron© air bag is inflated. At impact, the air cushion effect of the air-bag system reduces the peak shock level to less than 9 g.

Payload Support

Payload developers have the option of selecting either an environmentally controlled or a space-vacuum location. Payloads that require ambient temperature and pressure are mounted in the payload experiment carrier attached to the equipment deck, which is part of the recovery system. The carrier is built in two separate sections to accommodate late-access payload installation ($L - 6$ h) and early retrieval after landing. When assembled, the two halves form a cylinder 0.84 m (33 in.) in diameter and 0.51 m (20 in.) in length. Up to 136 kg (300 lb) of total payload weight can be supported in the 0.28 m^3 (10 ft^3) of available volume. Experiments that require vacuum are either vented through the canister wall or mounted directly on the equipment deck. The latter location forgoes any thermal control of the experiment.

Table 4 De-orbit-and-recovery sequence

Event sequence	Time, min
Uplink deorbit command	$L - 200$
Initiate recovery-system separation	$L - 100$
Release electrical umbilical	$L - 72$
Begin capsule spin-up	$L - 71$
Separate capsule from service module	$L - 70$
Fire Star 13A retro motor	$L - 30$
Enter blackout	$L - 12$
Exit blackout	$L - 9$
Release pilot chute	$L - 6$
Release main chute	$L - 4$
Capsule touchdown	$L - 0$
Payload access	$L + 240$

Microgravity disturbances created by pumps used in conventional ammonia and ethylene glycol systems exceeded the targeted microgravity limit of 10^{-5} g. In order to minimize acceleration effects, a mechanically passive thermal control system based on capillary pumping of anhydrous ammonia is used. (The same kind of system is used in the service module.) Heat is rejected from the payload canister via conduction through a thermal ring of evaporators attached to the canister lid. A mechanical pump is used to prime the thermal control system and provides backup for the capillary pumps. The canister temperature is maintained at 22°C (72°F) over a range of heat loads (0–400 W) by adjusting the capillary-fluid reservoir temperature from −18 to 40°C (0 to 104°F).

Power (28 V dc) from the service module is delivered to the payloads by the recovery-system power distribution system. The power controller regulates, monitors, and distributes power to both the recovery-system flight avionics and the payload experiments. The maximum allowable current draw for any experiment can be both adjusted and reset through the telemetry uplink.

Most of the payloads manifested on COMET-I have sophisticated data acquisition and control requirements. Payload command and control from the ground, including video data downlink, is accomplished with a direct RS-422 interface between the experiment and the service-module computer. Payloads that require more modest data acquisition and control are supported with two data acquisition systems that reside in the recovery system.

Orbital Operations

A key objective of COMET orbit operations is to provide a low-cost and fully functional satellite control facility. By incorporating the latest in workstation technology and rapid prototyping techniques, COMET is supported by a state-of-the-art mission control center. Some of the goals for orbit operations are successful control of the satellite and payloads, low development costs, an intuitive and friendly user interface, and flexibility to grow and adapt to new technologies.

Command and control for the COMET satellite and COMET mission planning are accomplished in the contractor facility located in League City, Texas. Handoff from the launch vehicle to the COMPOCC occurs after the freeflyer reaches orbit. Thus the tracking station need not be at the launch site. This facility consists of two major functional areas: the Telemetry, Tracking, and Commanding Space Ground Communications Link ground station, and the Commercial Payload Operations Control Center (COMPOCC). Maximum use is made of commercial off-the-shelf products and personal-computer technology to produce an operational satellite control system. Employing a single pedestal-mounted antenna, the facility can provide over 40 min of real-time interactive control with a low-earth-orbit satellite each day for orbital inclinations greater than 15 deg. The COMPOCC is designed to serve three on-site experimenters, as well as up to 10 remote experimenters via modem. Services available to the experimenters include payload commanding, access to raw or processed telemetry in user-defined formats, and payload video.

The Space Ground Communications Link provides the interface between the COMPOCC and COMET and communicates on S-band frequencies of 2075 and 2315 MHz for transmit and receive respectively. The telemetry and video downlink rate is 250 kbit/s, using phase-shift keying, and the command uplink rate is 8 kbit/s, using frequency-shift keying. The telemetry, tracking, and commanding system is a commercially available 3-m antenna, using off-the-shelf technology to provide programmed or automatic satellite acquisition and tracking from horizon to horizon. Figure 7 describes the basic system.

COMPOCC-satellite command and control is exercised through a personal-computer-based Novell local-area-network architecture. All mission support is conducted on 386/486-class workstations using an OS/2-Windows operating environment over a thin-wire ethernet. The basis for real-time control operations is the "pass plan," a predefined set of activities integrating known command and data requirements into a single satellite contact timeline. Major functions accomplished by the COMPOCC are satellite command and control, mission planning, payload/experiment commanding and performance analysis, operational scheduling of satellite and ground resources, data processing, data distribution, and data display. The COMPOCC contains seven workstations for the mission control team and three experimenter/payload workstations.

Figure 8 shows the general structure of the COMPOCC. There are seven main positions in the COMPOCC: 1) the flight director, who directs mission activities, approves commanding, manages group displays, and monitors; 2) mission planning and analysis, which determines orbit and orbit propagation, tracks data reduction, generates an ephemeris, updates scheduler files, develops commands for maneuvers, monitors the attitude control system, and determines the orbital characteristics of COMET; 3) ground operations, which controls the network file server, manages group displays, generates experimenter data tape, stores files, and monitors the telemetry database; 4) satellite operations, which determines COMET's state of health, generates command files, generates the COMET schedule, manages satellite resources, develops spacecraft power profiles, and starts the telemetry feed to COMPOCC; 5) the customer interface, which delivers payload telemetry to the customer services and COMPOCC/experiment and monitors the payload state of health; 6) the communications processor, which maintains satellite/COMPOCC time synchronization, ground-station antenna pointing, video data processing, and video cassette recording; and 7) communications management, which gives command approval and command formatting, processes telemetry, manages data uploads, and directs telemetry feed.

Using the modem interface, operating nominally at 9600 baud, up to 10 remote experimenters are afforded the option to receive telemetry and conduct commanding directly from their facility. In addition to the command and control functions, the COMPOCC provides standalone orbit determination using a combination of commercial off-the-shelf and custom-developed software by processing data collected by the telemetry,tracking, and commanding system. Unique to the COMET mission is a resource scheduling system for preparing uplink communications to the satellite. The scheduler routine takes input from the satellite controllers and arranges the commands so that resource and operational conflicts on the satellite are resolved prior to uplink. This automation reduces the controller real-time workload and the potential for ground-generated command errors. Use of the scheduler helps assure effective utilization of the available resources during the mission to achieve maximum experiment data return. As payload/experiment data are collected, they are made available to the experimenter in near-real time, either in the COMPOCC or at the experimenter's facility. An important feature of the COMPOCC is the ability to decompress digital video, which is incorporated in the telemetry downlink. This video is available to the experimenters as an aid in experiment analysis and control.

The COMET mission-control-center design uses innovative concepts to minimize development costs and provide a flexible "friendly" interface required for today's short-lead-time science missions. Satellite controllers and space experimenters benefit from this flexibility by being able to respond to the dynamic research and development environment and meet science objectives with minimum investment in new equipment or facilities.

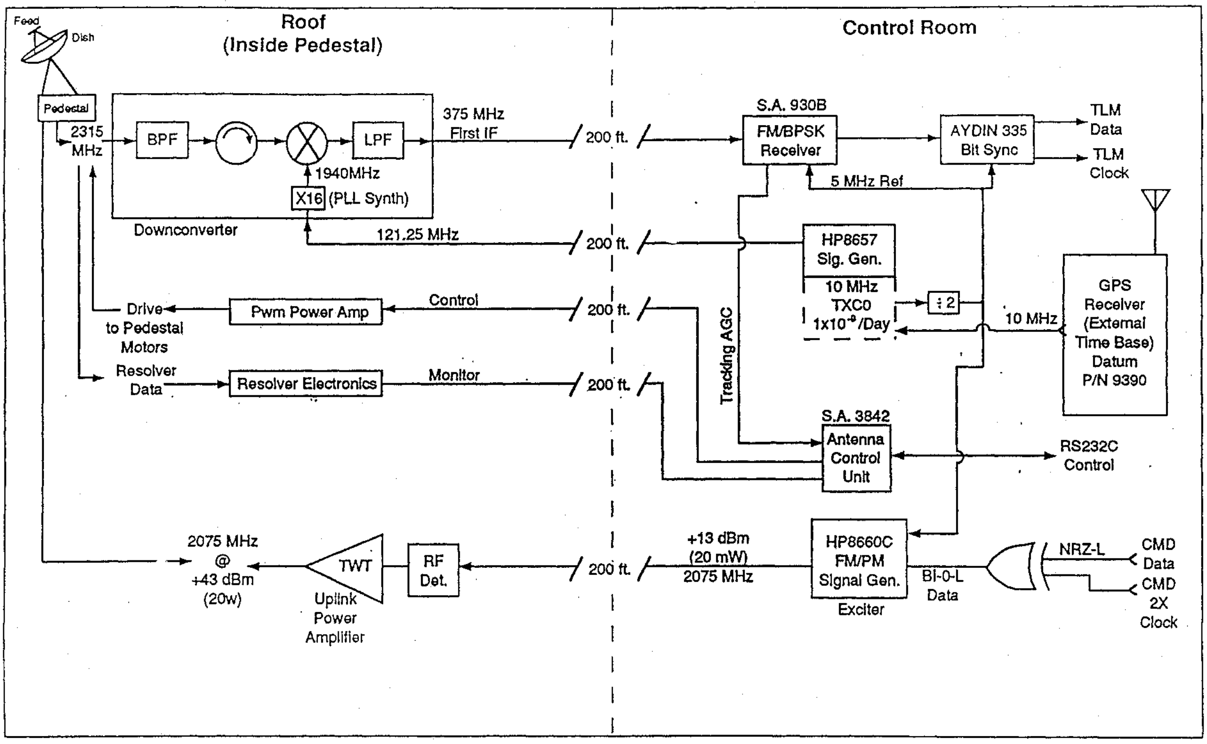

Fig. 7 Basic telemetry, tracking, and commanding system.

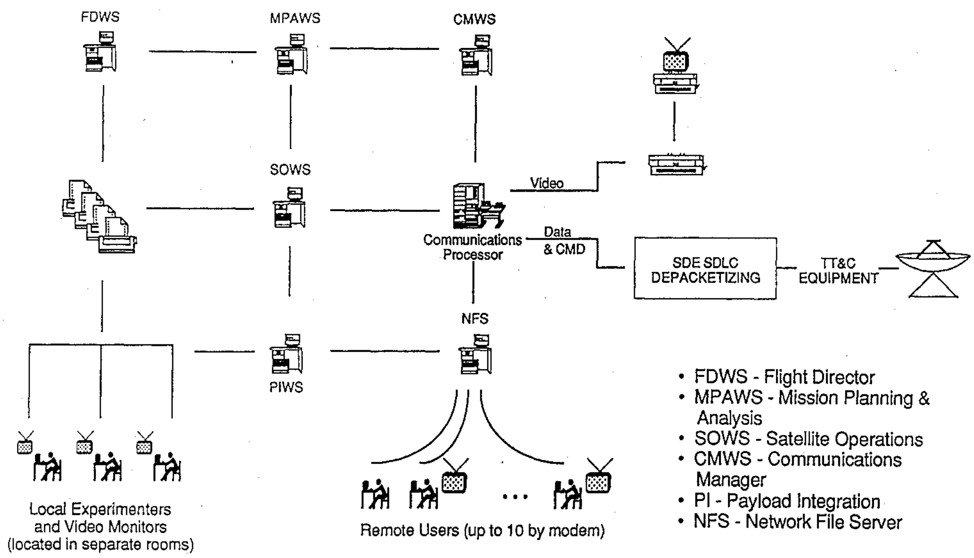

Fig. 8 General structure of the COMPOCC.

Payload Integration

Payload Accommodations

The COMET-1 experiment manifest reflects the concerted efforts of seven Centers for Commercial Development in Space (CCDSs) and their industry affiliates to develop experiments and take advantage of the low earth orbit, deep-space viewing, and the microgravity environment to develop products and services with commercial applications. Table 5 describes the experiments for the COMET-1 payload.

Experiment Development and Integration

Minimal essential design requirements levied on COMET experiments preclude damage to the COMET freeflyer, other experiments, or ground personnel. Experimenters are required to meet interface requirements specified in an Interface Control Document. In addition to meeting interface requirements, all hardware is designed to withstand the natural and induced environments of the COMET flight without damage to the freeflyer or to other payloads. Experiment design also precludes injury to ground personnel associated with such hazards as sharp edges, accidental release of pressurized gases, electrical shock, exposure to high temperatures, fire, pressure-vessel rupture, exposure to toxic or corrosive materials, mechanical ground-support equipment failure, battery rupture, or exposure to laser or high-intensity light.

The combined requirements of all experiments are analytically integrated to assure effective utilization of spacecraft resources. Competing experiment requirements for power and data are often resolved by timelining operations to level out peak requirement periods.

Physical integration of experiments and preparation for launch includes a series of experiment checkouts that begin at the box level at the experimenter's facility and work up to the fully integrated freeflyer and launch vehicle with COMPOCC "end to end" test.

Table 5 Descriptions of COMET-1 commercial payload experiments

Experiment/location/sponsor[a]	Experiment description	Application(s)
Nonlinear optical materials/ recovery system/CMDS	Investigates growth of crystals and thin films by vapor deposition.	Develops materials that allow optical computers to operate faster.
Materials dispersion apparatus/ recovery system/CMDS	Uses compact, automated device to mix 2 or 3 fluids for processing biotechnology experiments, including protein and zeolite crystal growth and fluid sciences.	Drug research and development for pharmaceuticals, and improved materials used in removing contaminants from products developed by petroleum and chemical industries.
3-dimensional microgravity; accelerometer/service module/ CMDS	Measures relative and absolute microgravity acceleration.	Records in-flight acceleration levels to assist scientists and commercial researchers in evaluating experiment results.
Plant-module autonomous space support/recovery system/ BioServe	Demonstrates higher-order plant growth in space.	Develops raw plant materials used in pharmaceuticals, and improves life support systems on earth and in space.
Animal-module autonomous space support/recovery system/ BioServe	Examines various physiological changes caused by prolonged exposure to the environment of space.	Collects data and evaluates how certain diseases (osteoporosis, diabetes, and muscle degeneration) react in space. These data interest pharmaceutical and biotechnology companies, universities, and foundations that want to perform research on these diseases.
Biomodule/recovery system/CCR	Studies effects of microgravity on mammalian cells, plant tissues, protein crystallization, and amphibian tissue.	Data collection and evaluation used in testing pharmaceuticals, and in improving desirable characteristics in plants.
Protein crystallization facility/ recovery system/CMC	Grows high-quality protein crystals by vapor diffusion.	Drug research and development for pharmaceuticals.
Surface reactions of materials on the COMET satellite/service module/ CMDS	Exposes thin-film samples to the atomic oxygen environment of space.	Develops materials and surface treatments for various systems exposed to the harsh environment of space.
Low-earth-orbit experiment/service Module/CSCT	Demonstrates capability of using low-earth-orbit satellites for high-volume flow of voice traffic and data.	Improves earth-satellite voice and data linkage.
Frozen startup of a heat pipe/service module/CSP	Examines thermal behavior of commercial, high-capacity heat pipes in microgravity.	Develops improved, light-weight heat pipes for large-scale heat rejection systems used in satellites, Space Station Freedom, and other space systems.

[a]Key: BioServe: Bioserve Space Technologies, Boulder, CO; CCR: Center for Cell Research, University Park, PA; CMC: Center for Macromolecular Crystallography, Birmingham, AL; CMDS: Consortium for Materials Development in Space, Huntsville, AL; CSCT—Center for Space Communications Technology, Boca Raton, FL; CSP—Center for Space Power, College Station, TX.

Experiment Operations

During the COMET-1 mission, command uplink and experiment telemetry downlink is managed through the COMPOCC. Initial contact between the freeflyer and the COMPOCC will be made during the first orbit (approximately 97 min after launch). During this time, the freeflyer will also perform an on-orbit systems initialization and checkout, which includes deploying its solar arrays; powering up all systems, including experiment systems; and verifying system performance.

During launch and through solar-array deployment and acquisition of the sun line, experiment survival power will be provided by service-module batteries. During this time, the combined service-module and recovery-system experiment survival power will be limited to 100 W. Once the solar arrays have been deployed and the batteries fully charged, the electric power for combined service-module and recovery-system experiments will increase to 350 W continuous, with peak power at 400 W for 200 h.

During the first 30 days of COMET-1, the freeflyer will be in a "solar inertial" attitude, primarily dedicated to recovery-system experiments. The service-module experiments will be turned on periodically during this time to check their health and status; however, they will not be operated until after the recovery-system separates.

Recovery-System Experiments

Initial experiment activation times will depend on individual experiment requirements. For example, the animal module will be powered during the freeflyer's ascent phase and will require no on-orbit activation. On the other hand, the protein crystallization facility, Biomodule, the materials dispersion apparatus, and the nonlinear optical materials ovens will be activated as soon as microgravity is achieved, which should occur about 3 h into the mission. This will be verified by analysis of telemetry data received from the accelerometers and the service-module attitude control system. The plant module will cycle lights on and off for the duration of the mission.

One or two orbits prior to separation, a series of commands will be implemented to prepare the recovery-system experiments for reentry.

Service-Module Experiments

After separating from the recovery system, the service module will be repositioned to a second "three-dimensional pointing" attitude that rolls the spacecraft as it orbits the earth to maintain a deep-space view for the heat pipe.

After 3 weeks, a third attitude, earth nadir pointing, will be commanded to position the orientation of the surface reactions of materials apparatus in the positive velocity vector direction and to begin experiment operations for the low earth orbit experiment.

Conclusions

A new launch vehicle, launch pad, and service tower, a new service module, a new recovery system, and a new commercial payloads operations control center have been built for launching an 818-kg (1800-lb) payload to 552 km (300 nm). The service module has been designed for an orbital lifetime of at least 130 days. However, no consumables are used to maintain orbit attitude, so it is anticipated that the orbital lifetime may be considerably longer than 130 days. The recovery system is planned to re-enter on command. 30 days in orbit are planned for the first mission. This will allow materials experiments and plants and animals to be recovered from orbit. The first launch is planned for 1995.

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Launch – vehicle.	EER Systems Corp.
Service – module.	Westinghouse.
Recovery – system.	Space Industries Inc.
Orbital – operations.	Space Industries Inc.
Payload – integration.	Space Industries Inc.