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U.S. Space Shuttle Back In Orbit

Mission 26: *Discovery*

On September 29, the U.S. Space Shuttle *Discovery* was launched into orbit on the first Shuttle flight since the *Challenger* disaster. On October 3, *Discovery* landed safely at Edwards Air Force base after a nearly flawless mission.

The mission, STS-26, carried five astronauts and a new Tracking and Data Relay Satellite (TDRS) into orbit. Also aboard the Shuttle was a variety of small scientific experiments, including several materials processing experiments.

The astronauts were all veterans of previous Shuttle flights, and included Navy Captain Frederick H. (Rick) Hauck, mission commander; Air Force Col. Richard O. (Dick) Covey, pilot; and mission specialists John M. (Mike) Lounge, George D. (Pinky) Nelson, and Marine Lt. Col. David C. Hilmers (no parenthetic nickname--sorry).

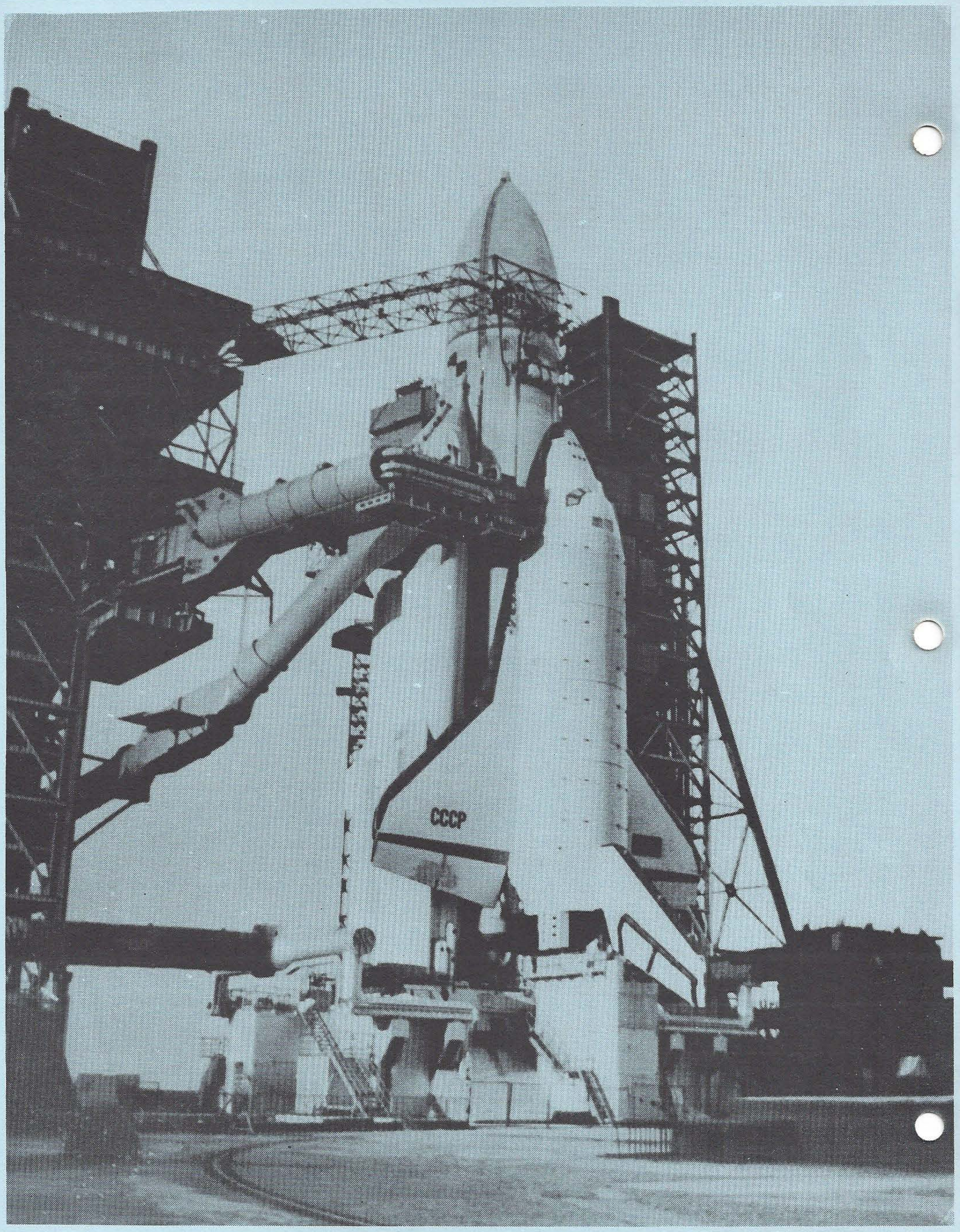
The Tracking and Data Relay Satellite, TDRS-C, replaces the TDRS-B that was destroyed with the *Challenger*. Once on station in geosynchronous orbit, it will be renamed TDRS-3, and will reinforce the TDRS-1 already on station. The TDRS-1 was launched in April, 1983 on *Challenger's* maiden flight, but initially failed to reach orbit. A series of delicate spacecraft maneuvers over 2 months finally placed the satellite in its proper orbit, but at the cost of maneuvering fuel (*C.S.R.*, Aug. 1983).

A third TDRS spacecraft is scheduled for launch in early 1989, again aboard *Discovery*. This new satellite will replace the partially-degraded TDRS-1, which will be moved to a location between the two operational satellites to serve as an operational spare.

The TDRS satellites are privately owned and operated by CONTEL, Atlanta, Ga. NASA leases the services of the satellites under contract. The satellites were built by TRW, with CONTEL acting as prime contractor.

The TDRS communications satellite network will replace many of NASA's ground stations, currently required to maintain communications with spacecraft as they orbit around the Earth. When complete, the TDRS network will be able to provide communications coverage for almost the entire orbital period (about 85%) of user spacecraft. In a single second, a TDRS satellite is capable of transmitting an amount of data equivalent to a 20-volume encyclopedia with 1200 pages per volume and 2000 words per page. This uninterrupted, high-speed data transmission rate is a must for a number of existing and proposed space systems.

Current users of TDRS include the Shuttle, the Landsat earth resources satellites, Spacelab, and a number of scientific satellites. Future users will include the Hubble Space Telescope, scheduled for launch in mid-1989; and the U.S. Space Station. Once the NASA network becomes fully operational, it is expected that private companies will also want to launch and use future TDRSs.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Mission 27: *Atlantis*

The Shuttle scored a second successful flight December 2, with the launch of *Atlantis* carrying a secret military satellite and a crew of five astronauts. The satellite was deployed successfully, and the *Atlantis* returned safely on December 6. A few minor problems occurred during the flight, including difficulties in deploying the satellite, and an unusual amount of damage to the orbiter's heat shield tiles. The cause of the tile damage is still under investigation.

Judging from the media coverage, the payload was about as secret as Gary Hart's love life.. The mission was to place a $500 million Martin Marietta "Lacrosse" radar imaging reconnaissance satellite into a high-inclination orbit, allowing the satellite to overfly all of the Earth's surface between 57 degrees north and south latitudes, including much of the Soviet Union. The radar satellite permits reconnaissance through clouds and in darkness, and can even penetrate foliage under some conditions.

The exact time the satellite was to be deployed in orbit was also supposed to be secret, but the maneuver was observed clearly by amateur astronomers around the world, who tracked the two bright "stars" marking the positions of the *Atlantis* and its payload, which was seen to be floating near the Shuttle orbiter after its initial deployment.

The ideal orbit for such a satellite would have been a polar orbit, rather than just a high-inclination orbit (a satellite in polar orbit passes over the entire surface of the Earth). Had the Vandenberg Air Force Base Shuttle launch facility been active, the Lacrosse satellite would have been launched from there, where polar trajectories are feasible. But the Vandenberg launch site is in mothballs, and mission planners had to settle for the highest inclination they could get from the Kennedy Space Center.

In a tongue-in-cheek interview with the press before the flight, mission commander Robert "Hoot" Gibson told the press that he could save time by reciting the only answers he was permitted to give to reporters about the secret mission: "'Yes,' 'no,' 'I don't know,' 'I can't tell you,' and 'I can tell you, but then I'd have to kill you.'

Soviet Space Shuttle Makes Maiden Flight

On November 15, the Soviet Union successfully launched its own space shuttle on its unmanned maiden flight. The shuttle made two orbits of the Earth, and landed safely at an airstrip near the launch site.

This first Soviet shuttle orbiter was named "*Buran* (snowstorm)." A second orbiter has been completed, and will reportedly be named "*Ptichka* (birdie)." As many as three additional orbiters are said to be under construction.

The launch had been originally scheduled for October 29, but was scrubbed less than a minute before liftoff. Launch control computers halted the countdown when the launch pad's orbiter access arm failed to retract. The access arm (see photo on page 2) allows personnel to enter the orbiter while it is on the launch pad, and must be retracted to clear the way for launch.

The Mission: The shuttle *Buran* lifted off from the Soviet Baikonur Cosmodrome at 8:00 a.m. local time, strapped to the side of one of the new 200-foot tall Soviet Energia heavy lift launch vehicles--only the second flight of an Energia ever attempted. At liftoff, the Energia/orbiter assembly weighed 5.37 million lbs., and the thrust of the Energia engines was 8 million lbs. After dropping the Energia's four outboard boosters (powered by liquid oxygen/kerosene engines), the Energia core module (burning liquid oxygen and liquid hydrogen) continued into space with the orbiter.

Buran then separated from the Energia core, and fired its two orbital maneuvering engines to place it into a 155-mile circular orbit. The core module continued on a sub-orbital trajectory, and was destroyed on reentry over the Pacific Ocean (although the Soviets plan to eventually recover the Energia booster stages, and possibly even the core module, all were expended on this particular flight).

The shuttle made two orbits of the Earth, then reentered the atmosphere for a successful landing at the Baikonur runway 2 hours and 35 minutes after launch. As seen on film, the orbiter's landing, despite the lack of a crew, was nearly flawless. There did appear to be considerable scorching of the heat-resistant outer surface, which could indicate more work is needed on the heat shield system, but the vehicle obviously survived reentry intact. If all goes well, a Soviet shuttle will make its first manned flight on its second or third mission sometime in 1989.

As mentioned in an earlier issue (*C.S.R.*, May, 1987), the Soviet shuttle orbiter was believed to be similar in appearance to the U.S. Space Shuttle orbiter. When the Soviets released actual photographs early in October (including the one in this issue), the similarity was astonishing. This was no surprise to most experts, who were aware that the Soviets had done a considerable amount of "shopping" for U.S. shuttle design details in the United States. To make it even easier, most of this data was in the public domain. In many areas besides aerodynamic configuration, such as computer systems, silica tiles and other heat shield technologies, and fuel cell technology, the Soviets gained a head start on their program from U.S. work.

Still, once one is past the similarities, some major differences in the two shuttle concepts appear. Chief among these is the placement of the main liquid oxygen/liquid hydrogen engines. The U.S. shuttle has these engines (the Space Shuttle Main Engines or SSMEs) mounted on the orbiter. The Soviet shuttle/Energia system has these engines mounted on the Energia booster (only small, orbital maneuvering engines are mounted on the orbiter itself).

There are advantages to both engine location approaches: mounting the engines on the orbiter means they can be recovered with each flight and reused. The engines on the Energia's core module are discarded when the module is destroyed on reentry (some sources believe that the Soviets intend to recover these core modules, which would allow the Soviets to reuse their engines as well, but no such capability has yet been publicly demonstrated). However, the lack of heavy main engines on the Soviet orbiter gives it increased performance. Although the gross weight of the Soviet orbiter at launch is actually less than that of the U.S. orbiter (235,000 and 240,000 lbs., respectively), without the weight of main engines the Soviet shuttle's payload capacity is nearly 67,000 lbs., about 10,000 lbs. more than the current payload limit of the U.S. shuttle. The Soviet orbiter can also land routinely with more cargo on board than the U.S. orbiter can (47,000 lbs. compared to about 32,000 lbs.)

Other comparisons between the two shuttle concepts: The Soviet orbiter has slightly more crew cabin volume--about 150 additional cubic feet. The payload bay is 15 feet in diameter and 60 feet long--identical to the U.S. shuttle. The Soviet orbiter's wing and nose gear are positioned differently from the U.S. orbiter, reflecting the altered center of gravity due to the lack of the heavy main engines. The Soviets may eventually add auxiliary airbreathing jet engines to their orbiter, which would allow it more flexibility in landings and ferrying operations. The U.S. orbiter has no such capability.

The two systems are prepared differently for launch: The U.S. shuttle is stacked vertically onto its external tank and solid rocket motor boosters. This takes place in the huge Vehicle Assembly Building at the Kennedy Space Center. This building was converted for Space Shuttle use after it was no longer needed for its original role as the assembly structure for the Saturn 5 moon rockets. Once the U.S. shuttle is assembled, it is rolled out to the launch pad--still vertical--on a huge mobile launch platform which crawls on tank-like treads. The Soviet shuttle/Energia system, on the other hand, is assembled horizontally on an enormous transporter. This transporter moves the vehicle out to the launch site--probably on rails--and then actually tilts the immense Energia, with the orbiter on its back, into a vertical position for launch.

The Soviet shuttle is the culmination of a 10-year, $10 billion dollar development effort. The Soviets began work on their own shuttle soon after the U.S. began its Shuttle program, although the existence of the Soviet program was consistently denied.

Although much of the Soviet shuttle design is based on U.S. work, the technical achievement represented by a successful, unmanned shuttle launch should not be underrated. Regardless of the "assistance" provided by the U.S. Shuttle program, a considerable amount of original, pioneering work was required by the Soviets to bring off this first flight. Space experts agree that flying this first mission unmanned was more difficult and complex than the manned maiden flight of the U.S. shuttle. The ability to land at the launch site after only two orbits also indicates a well-developed crossrange capability--the ability to land some distance to either side of the vehicle's orbital path. *Buran* has up to 1,240 miles crossrange capability, according to Soviet representatives. The U.S. shuttle is capable of up to 1,000 miles crossrange, although not more than about 600 miles is normally required during a typical NASA mission.

Like the U.S. shuttle, the Soviet shuttle is controversial, even in the Soviet Union. When the Soviet shuttle program began, a decade ago, the U.S. shuttle was billed as a low-cost, more efficient alternative to expendable rockets. The Soviets just had to have one too. By the time it was realized that the U.S. shuttle was a bit of a white elephant, the Soviet shuttle program--building a near-duplicate of said white elephant--had come too far along to cancel.

Now, in an environment of *glasnost*, criticism of the Soviet shuttle program has become more evident. Soviet shuttle detractors, like their counterparts in the U.S., call the vehicle an astounding technological achievement with no real purpose. These accusations are particularly substantive in the Soviet Union, which, unlike the U.S., already has a proven manned space capability based on expendable launch vehicles (ELVs).

Some of the criticism of the Soviet shuttle has originated from the agencies in charge of Soviet ELVs and of their associated programs, which include the Soyuz manned capsule and the Mir space station. According to James E. Oberg, engineer and Soviet space expert, this "traditional" ELV space program is the responsibility of the Soviet Defense Ministry, assisted by civilian agencies. The Soviet shuttle program, on the other hand, originated with a consortium of aviation bureaus administrated by the Zhukovsky Central AeroHydrodynamical Institute. The two programs are apparently quite separate, and not only is there little cooperation between the two, but a certain amount of hostility as well.

Other detractors have come from the Soviet space science community, which sees the Soviet shuttle as a massive drain on their nation's space resources that might otherwise be spent on more scientific, unmanned space exploration efforts. Again, these sentiments echo those of the space science community in the U.S. The Soviets even have a counterpart to James Van Allen, a U.S. physicist highly critical of the American manned space effort. His name is Roald Z. Sagdyev, a Soviet physicist who is retiring as director of the Space Research Institute in Moscow.

Like their U.S. counterparts, the officials from the Soviet shuttle program have become defensive about the usefulness of their vehicle, and also somewhat vague about its purpose in a space program which already has a manned capability. Observers say that the shuttle may be useful in servicing large manned Soviet space stations, eventual follow-ons to the Mir space complex.

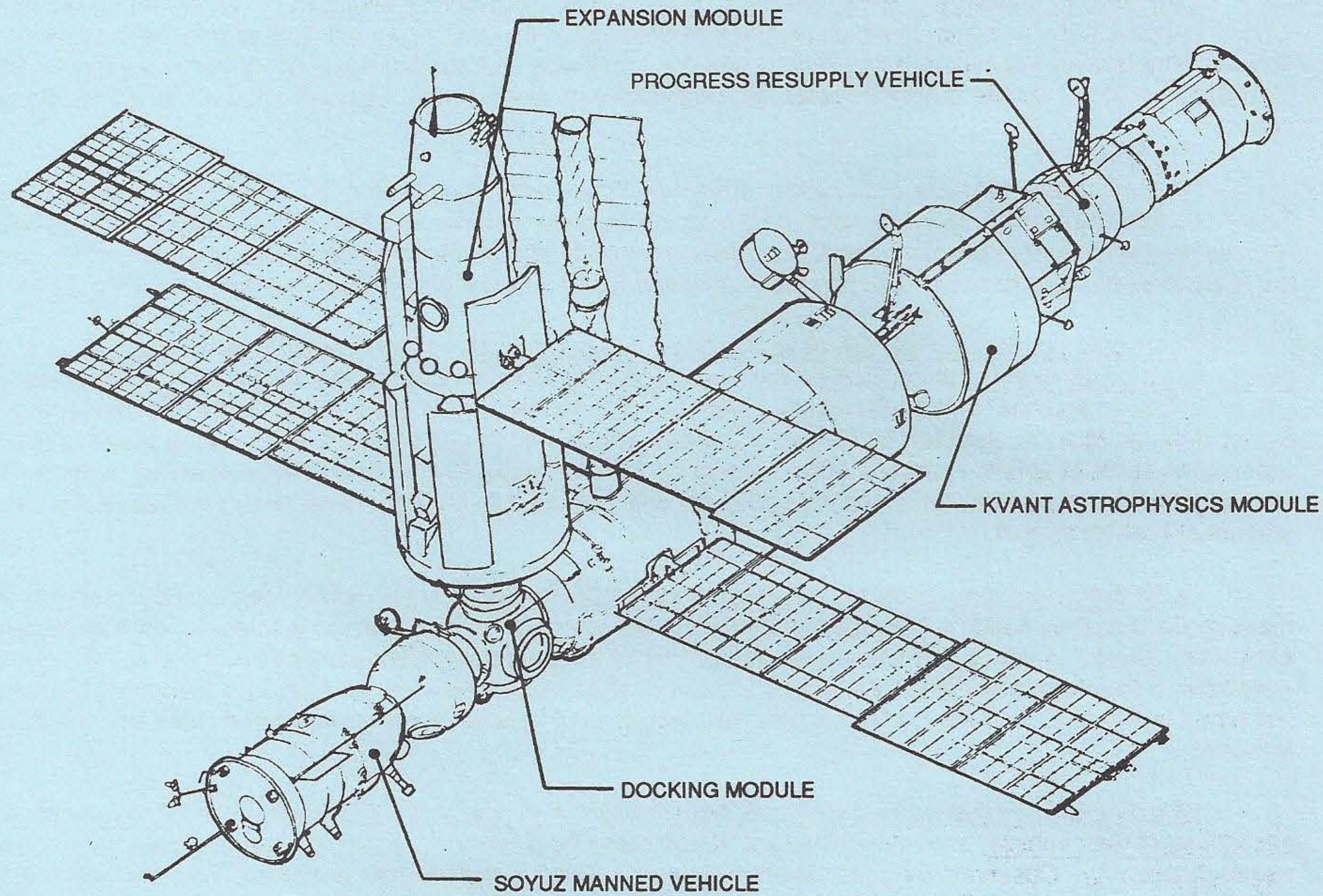
Maybe the Soviets have learned a lesson about eagerly duplicating massive U.S. government technology projects. On the other hand, they learned nothing from their ill-fated supersonic transport program, or their aborted manned lunar landing program, both developed primarily in response to U.S. efforts, so who knows. Recently, the U.S. rolled out its B-2 Stealth bomber, an incredibly expensive aircraft ($500 million a copy) which may or may not have a valid strategic mission. Are the Soviets even now blowing a money bin full of rubles trying to build a Stealth bomber of their own? If so, by draining Soviet military resources, the B-2 may see its finest hour not as a bomber, but as a weapon of economic warfare.

Soviets To Set Space Endurance Record

In the shadow of the Soviet shuttle, the "traditional" Soviet manned space program continues to chalk up milestones. On November 26, a French cosmonaut, Jean-Loup Chretien, was launched aboard a Soviet Soyuz TM-7 space capsule on his second trip to the Mir space station (his first mission was in 1982). He rode with two Soviet cosmonauts, Col. Alexander Volkov and Sergei C. Krikalev, the Mir replacement crew. When Chretien returns on December 21, he will be accompanied by the old Mir crew, which was launched into space on December 21, 1987.

The two crewmen, Vladimir Titov and Musa Manarov, will become the first humans to spend an entire year in space (the previous record was held by Yuri Romanenko, who spent 326 days aboard the Mir in 1987).

Future Mir crew members are expected to work in shorter shifts for the time being, while medical data from the long-duration crew members is evaluated. Soviet cosmonauts that have remained in space under zero-g conditions for extended periods have suffered deterioration of their skeletal, muscular, and cardiovascular systems. Considerably more research is needed to discover the long-term effects of such deterioration, and to find out to what extent the deterioration is reversible once the subjects have returned to Earth. In addition to the physical problems of extended stays on the space station, there are morale problems as well, with monotony and fatigue reducing crew efficiency.



"Visits" from cosmonauts like Chretien who come to the station for short periods and then return no doubt help relieve the monotony of a long space flight. Frequent unmanned resupply flights from "Progress" modules containing--in addition to fuel, air, and other supplies--fresh foods and mail from friends and relatives, are also high points of long-duration missions.

The Mir space station is scheduled to be expanded in April of 1989 by the addition of a new module. This expansion module will be almost as large as the main space station core module (see illustration above), with a length of 12.5 meters (41 feet), a maximum diameter of 4.1 meters (13.5 feet), and a mass of 20.6 metric tons (45,415 lbs.) The new module will be launched into orbit by a Proton rocket, and then docked at the five-port (one end port and four side ports) docking module on the Mir station . The module will be docked initially at the end port, and be moved to a side port later by a remote manipulator arm.

One major purpose of the new module is to support operations of a Soviet Manned Maneuvering Unit (MMU), a thruster-powered "backpack" that will enable a space-suited cosmonaut to maneuver in space near the Mir station complex. The new module will have an exit hatch larger than the standard Mir hatches to permit cosmonauts to enter and leave the station wearing the MMU.

Other expansion modules are also scheduled to be added to the MIR, with the second such module due to be launched in the second half of 1989. It will be docked to the MIR docking module opposite to the first expansion module, to balance the space station configuration (a symmetrical configuration makes control of the station's attitude much easier). A third, fourth, and fifth module will then be added at later dates, filling all the ports on the docking module. The addition of more habitable volume to the MIR station should make long-duration missions less strenuous for the crews.

Lightsat Program Back On Track

The Defense Advanced Research Projects Agency (DARPA) and the Air Force have worked out their differences on Lightsat, the program for the development of lightweight, inexpensive satellites. Originally, Air Force objections threatened to kill the program, which is seen as a potential market for private companies developing small, low-cost expendable launch vehicles (ELVs) (*C.S.R.*, Nov. 1987, July-Aug. 1988). The Air Force viewed the DARPA program as an incursion on Air Force turf.

Under a new agreement, the Air Force will have an expanded role in the Lightsat program. Air Force Lt. Col. Edward Nicastri will manage the program from DARPA's offices in Virginia, and DARPA will use the Air Force Space Division as the principal agent for Lightsat.

The agreement bodes well for further Lightsat funding beyond 1989, now that the Air Force is lending support instead of creating opposition. This is good news for the aforementioned private launch vehicle companies (see Orbital Sciences article later in this issue), as well as companies which would manufacture the satellites.

However, in the next few years, U.S. defense spending is likely to run into a Congressional buzzsaw, with the current perception of a thaw in the Cold War. Private companies would be wise to broaden their customer base beyond Lightsat and other Department of Defense contracts.

Update: Private Launch Vehicle Companies

Orbital Sciences Corporation

Orbital Sciences Corporation (OSC) of Fairfax, Virginia., merged with Space Data Corporation of Tempe, Arizona, making Space Data a wholly-owned subsidiary of OSC. The merger provides OSC with an extensive in-house space engineering and manufacturing capability.

OSC is working on two major programs: the company is developing the Transfer Orbit Stage (TOS), intended to deliver payloads into higher orbits or onto interplanetary trajectories after being deployed in low earth orbit by the Space Shuttle or a Titan expendable launch vehicle. OSC is also working on the "Pegasus" air-launched space booster, designed to place small payloads into low earth orbit (*C.S.R.*, May 1988).

Space Data, founded in 1963, is active in a wide variety of space-related fields, including developing and producing sounding rockets, launch facilities, space and upper atmosphere instrumentation, and payload systems for defense and scientific applications. The company's launch vehicle experience includes design, manufacture, and launch of over 600 large (up to 70,000 lbs.) single-stage and multiple-stage suborbital launch vehicles in 35 different configurations. Space Data has also flown up to 1,000 meteorological sounding rockets each year, has installed and activated launch facilities at 12 sites around the world. Space Data is currently working on the Starbird suborbital four-stage solid-fueled launch vehicle for the Strategic Defense Initiative Organization (SDIO). SDIO has purchased seven Starbird launches.

Combined revenues for the two companies are expected to be about $60 million in 1988, of which $35-40 million is from OSC, and $20-25 million from Space Data.

OSC will be conducting the initial launches of the Pegasus booster for DARPA as part of the Lightsat program. DARPA currently has an option on six Pegasus flights, but has committed to only two flights so far. Plans call for the first flight, scheduled for July of 1989, to carry test instrumentation. If this flight is successful, the second mission would carry a package of small communications satellites. If more funding for the Lightsat program becomes available, DARPA may take out an option on an additional six flights.

American Rocket Company

On September 2, the American Rocket Company (AMROC) completed a full-duration firing of a full-sized, 70,000-lb.-thrust ("70K") hybrid rocket motor. The motor, burning a solid, rubber-like polybutadiene fuel in combination with liquid oxygen (LOX), fired for 70 seconds on its horizontal test stand at the Air Force Astronautics Lab (AFAL) at Edwards Air Force Base in southern California. This is the length of time that an actual flight motor would fire in operation. The full-duration firing marks an important milestone in AMROC's launch vehicle development program (although the company continues to conduct frequent short-duration burns as part of its test sequence). It is an indication that AMROC has solved the problems of unstable combustion that plagued the hybrid design in earlier tests. To accomplish this, AMROC modified the method of injecting LOX into the engine, as well as the geometry of the fuel grain.

The September 2 firing also included a test of the launch vehicle steering mechanism, which uses liquid-injection thrust vectoring. In this test, three injectors, flush-mounted in the hybrid motor's exhaust nozzle, injected hydrogen peroxide (70%) into the side of the exhaust flame. This deflected the direction of the flame which, in flight, would steer the rocket. Liquid-injection thrust vectoring is useful where it is impractical to steer by gimballing the entire engine or even just the nozzle. The technique is used successfully on a number of launch systems, perhaps most notably on the solid boosters of the Titan 3 and 4 expendable launch vehicles.

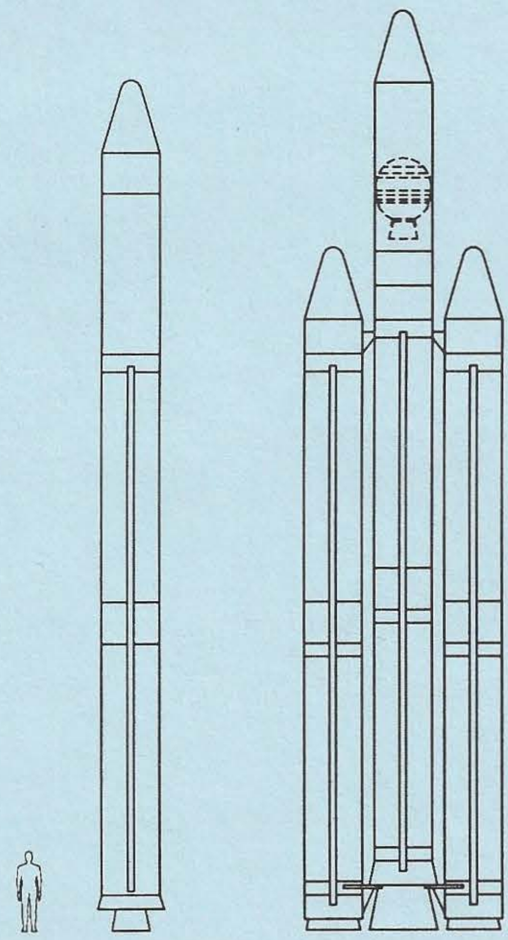
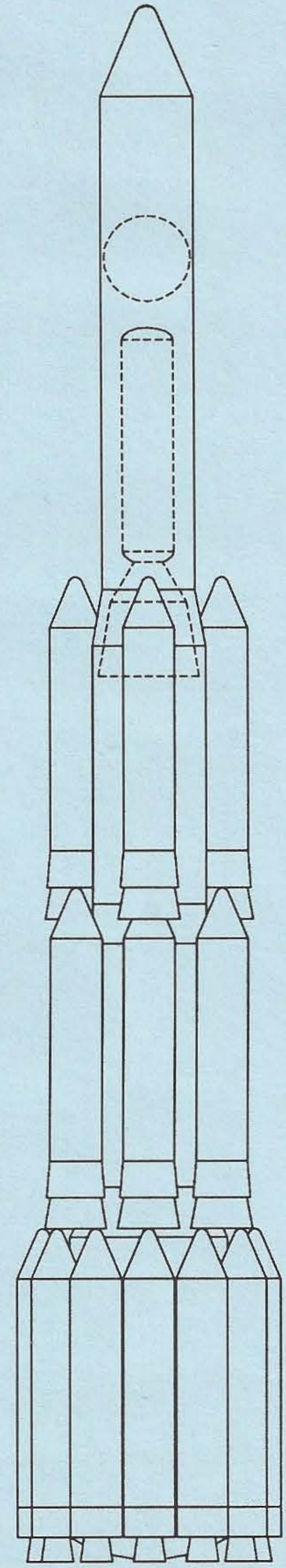
With the success of these tests, AMROC is well on its way to its first suborbital test flight, currently scheduled for sometime in 1989. The first test vehicle will be a heavyweight version of the company's SLV configuration (see below), and will fly to an altitude of about 100 nautical miles.

AMROC is developing three basic launch vehicle configurations based on its 70K motor design (see illustration at right):

The SLV (Single Module Launch Vehicle) is designed for sub-orbital missions. It is built around a single 70K motor. AMROC's first flight will use a test version of this booster, with heavier tanks and other components than the flight version. Although useful as a test vehicle, the SLV could also be profitable if marketed as a sounding rocket.

The second configuration is the ILV-S (Industrial Launch Vehicle-Small or "Slingshot") (*C.S.R.*, Sept.-Oct. 1987, pp. 10-11), an orbital configuration consisting of three 70K modules, with two outboard boosters as the first stage, and one core booster as the second stage. The upper stage is an off-the-shelf solid rocket motor, the Morton Thiokol Star-48 (although other similar motors could be used). The Star-48 configuration of the ILV-S is designed to carry a payload of about 750 lbs. into a 135-nautical-mile, 28.5 degree circular orbit, or about 600 lbs. into a 135-nautical-mile, circular polar orbit.

The third configuration is the ILV-1, an orbital vehicle comprised of twenty-two essentially identical 70K-sized modules assembled into four stages (*C.S.R.*, Aug. 1987). The ILV-1's payload capacity, launching to the same

AMROC LAUNCH VEHICLES

orbits mentioned above, is over 4,500 lbs. into the 28.5 degree orbit, and about 3,100 lbs. into the polar orbit.

AMROC is promoting hybrid boosters as replacements for solid rocket motors on existing expendable launch vehicles. The standard 70 K motor could be used to replace the Castor IV solid boosters on the McDonnell Douglas Delta. A much larger hybrid rocket motor, with a thrust of over 1 million lbs., could be used to replace the two large solid rocket boosters on the Martin Marietta Titan 3.

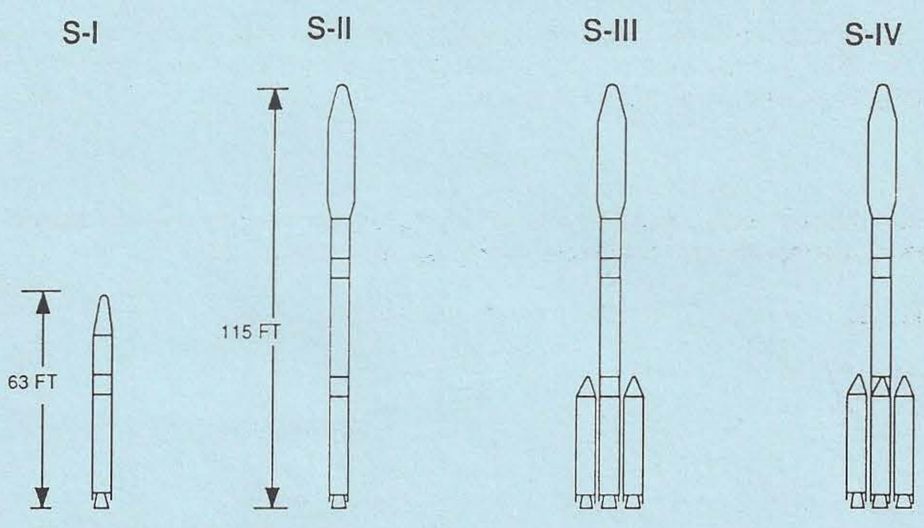
E-Prime Aerospace

E-Prime Aerospace Corporation (EPAC) passed a milestone on November 17 with the launch of a suborbital test rocket from Cape Canaveral Air Force Station. The rocket carried four small scientific payloads, which were recovered downrange despite failure of a main parachute to deploy.

According to E-Prime, none of the payloads was adversely affected by the impact with the water, although some of the payloads were affected by other factors during the flight, which were not specified. The payloads were some plant seeds from high schools in Georgia and Alabama, a materials processing experiment from Morton Thiokol and the Utah State University, a temperature and acceleration measurement experiment from QSI Corporation and Weber State College, and a flight telemetry package from the University of Alabama at Huntsville.

The launch was more symbolic than useful: the rocket, called LOFT-1 (Launch Operations Flight Test) was about ten feet long and about five inches in diameter, and reached a total altitude of about 15,000 feet. Air resistance on the falling payload compartment would tend to spoil any small period of weightlessness that might result from the ballistic trajectory. E-Prime's claim to this being the first commercial rocket launch does not stand up well either: the first such launch is generally conceded to be the flight of the Conestoga I suborbital sounding rocket, launched by Space Services in 1982 (*C.S.R.*, Oct. 1982).

EPAC- S Series Launch Vehicles



Payload (pounds)				
Low Earth Orbit	2,500	6,500	15,800	20,300
Geosync Transfer Orbit	975	2,400	5,900	6,500
Planetary Trajectory	675	1,625	2,900	4,500
Scheduled First launch	4Q 1990	3Q 1991	3Q 1992	3Q 1993

ILLUSTRATION: E-PRIME

E-Prime hopes the flight will attract investors to begin development of the larger, orbital commercial vehicles that the company wants to build. E-Prime's designs for these vehicles have undergone a number of configuration changes, but the basic concept has remained the same: the vehicles' lower stages are based on the MX missile ("Peacekeeper") solid rocket motor. The upper stages are comprised of a variety of smaller off-the-shelf solid motors, primarily from the Morton Thiokol "Star" series. The illustration on the previous page shows four configurations, along with their announced payload capacities.

Space Services, Inc.

Space Services, Inc. (SSI) was awarded a NASA contract to launch a sub-orbital materials processing payload for the University of Alabama in Huntsville. The contract, valued at $1 million, calls for SSI to launch six experiments weighing a total of about 660 lbs. on a Starfire (not to be confused with Space Data's aforementioned "Starbird") solid-rocket booster in March of 1989. The launch will take place from an existing pad at the missile range at White Sands, New Mexico.

The Starfire configuration consists of a Morton Thiokol Mk. 70 first stage, and a Bristol Black Brant 5C second stage. The rocket, 52 feet long, will reach an altitude of 200 nautical miles, and will give the payload about 8 minutes of zero gravity. The payload will be recovered by parachute.

Pacific American Launch Systems

During October and November, Pacific American completed an initial series of ignition tests on its Liberty liquid-fueled test engine. The test series involved the injection of triethylaluminum (or "TEA") into the combustion chamber of a heavyweight test engine. TEA is pyrophoric, igniting spontaneously on contact with liquid oxygen (or air, for that matter, making the substance somewhat tricky to handle). This creates a rapid and reliable ignition source for smooth starting of the liquid oxygen/kerosene fueled engine. TEA has been used extensively in the rocket industry for this purpose.

The first test series took place on a Pacific American-built horizontal test stand at the Air Force Astronautics Laboratory. Work is now beginning on a vertical test stand which will permit long-duration testing of the fully gimbaled flight engine early in the coming year.

* * *

Next issue I will include some photos and impressions of my stay down at Edwards. Again, apologies to the readers for the extensive *C.S.R.* publication delays.

Until next time,

Tom Brosz
December 19, 1988

The Commercial Space Report (C.S.R.) is published monthly, and endeavors to report and analyze developments in the field of private initiatives in space transportation and exploitation.

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