SKIPPER: AN AMERICAN-RUSSIAN SPACE EFFORT

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ABSTRACT

In an experiment that seeks not only scientific information but information about how two very different cultures can work together, the Skipper satellite project is a ground-breaking partnership between Russian and American scientists that will explore the physical mechanisms that produce spacecraft optical emissions. Built jointly by the Americans and Russians, the satellite will be integrated with a Russian Molnia rocket and launched from the Bakinor space center in Kazakhstan. The origins of this unusual project, how its design evolved to meet time and funding constraints, and how the satellite will operate in space are the subject of this paper.

Background

A year ago, during the annual AIAA small satellite conference held at Utah State University (USU), Gennady Malyshev of the Moscow Aviation Institute proposed an ambitious project: a scientific satellite built and launched by a team of U.S. and Russian university researchers. Scientists at the Space Dynamics Laboratory (SDL) of USU, excited by the prospects of such a joint venture, accepted Malyshev's challenge. What follows is a description of the program that emerged and how it came into being.

As envisioned by Malyshev, the joint U.S.-Russian satellite would be the secondary payload of the Indian IRS satellite the Russians plan to launch in late 1994 from Bakinor, Kazakhstan. It would be fitted into a small—1 meter in length by 0.8 meter in diameter—unused space inside the torroidal liquid-oxygen tank of the fourth stage of the Molnia launch system (Figure 1), which will lift the Indian spacecraft into a circular,

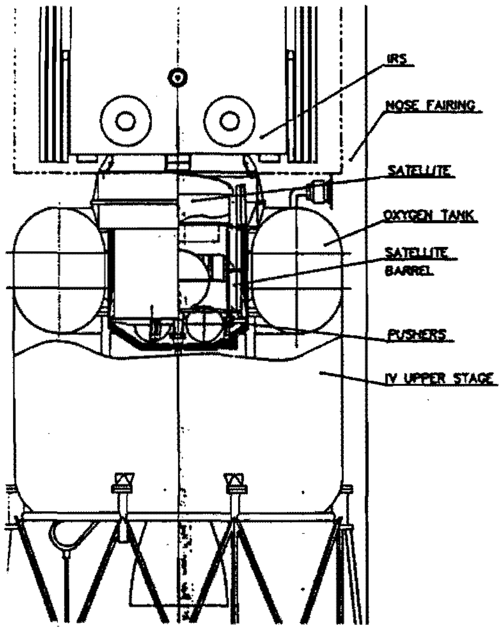

Figure 1. The Skipper satellite placed in the fourth stage of the Molnia launch vehicle.

819-km sun-synchronous orbit. Major participants in the program were to include the Moscow Aviation Institute as the point of contact for both hardware and scientific efforts, the Russian aerospace research institute TSNIIMACH for instrumentation and basic scientific support, and Utah State University's SDL as the prime contractor and fabricator of the scientific payload.

It quickly became obvious that no U.S. university by itself had the financial resources to build an international spacecraft without the help of outside funds. The same was true of Russian universities and institutes. Added to this was the time constraint: to build and launch a satellite in just over 2 years would be extremely difficult, even if the program and funding were in place. Without either, the task was formidable. Thus, the program would have to be managed in a very time- and cost-effective manner, which implied finding a funding sponsor that was willing to assume some risk.

To increase the program's chances to obtain funding, SDL decided that the primary purpose of the project had to be related to fundamental science that could be openly shared by the two countries. Any other objective would significantly decrease the probability of getting either U.S. State Department or Russian Ministry of Defense approval and funds. This meant that as much work as practical needed to be carried out jointly. Both U.S. and Russian instruments needed to be onboard the spacecraft, and scientists from both countries needed to be actively involved. Joint work on the spacecraft's bus would also be necessary. Integration with the launch system and the launch itself would, of necessity, be performed by the Russians; however, the telemetry system and data handling would be performed by the Americans. Two important criteria were formulated: that no leading-edge technology be used and that students from both countries be involved.

The first challenge was to develop an experimental payload that met those criteria and that could be built both quickly and inexpensively. SDL scientists formed a committee to review candidate ideas, and after lengthy discussions, narrowed the list of potential ideas to three—a tethered satellite dynamics/electrodynamics experiment, an *in situ* survey of orbital debris smaller than could be measured from the earth's surface, and a study of mechanisms that produce optical emissions in the vicinity of a spacecraft both on orbit and upon reentry.

Hoping to obtain funding from more than one agency, the satellite team concentrated its initial efforts on designing a spacecraft that could perform all three tasks. However, only the Strategic Defense Initiative Organization's (now Ballistic Missile Defense Organization) office of innovative science and technology showed interest in funding a joint American-Russian proposal. Because its interest lay primarily in the area of high-velocity vehicle aerothermochemistry, it agreed to fund only the optical emissions measurements as a continuation of the "Bowshock" 1 and 2 suborbital programs that had just been successfully completed by SDL. Spacecraft design limitations mandated this choice of experiment as well.

A "People" Experiment . . .

Not too surprisingly, the program's emphasis has been modified over the past year. Normally, the primary mission objective of such an undertaking would be to conduct meaningful scientific measurements. With Skipper, however, the scientific outcomes have become less important than determining whether a DOD-funded program can be conducted within the Russian aerospace community. If Skipper proves successful, it will pave the way for more ambitious joint programs. Skipper will also answer questions about whether cold war hostilities and suspicions on both sides have relaxed to the point that the governments will truly allow such joint efforts and whether tensions within industry, educational institutions, and individuals have been eased sufficiently to permit such an endeavor to succeed. Such questions can be debated endlessly by political scientists, but the U.S.-Russian Skipper team will be conducting an empirical and pathfinding experiment that will provide definitive answers. Another objective of the project is to determine whether such a program can be conducted within the severe time and budget limitations that have been placed on it.

. . . As Well as a Scientific One

Skipper's scientific mission is to measure the physical mechanisms that cause a spacecraft to produce optical emissions both while on orbit and during reentry. The satellite's initial, 819-km orbit is above the altitude that "spacecraft glow" is significant and far above altitudes where shock-heated air would be obsErved as an emission source. To be able to make measurements as a function of altitude, the most reasonable approach was to place the spacecraft into an increasingly elliptical orbit that, eventually, ends with its reentry. These increasingly lower perigee orbits would provide researchers with measurements over a wide range of altitudes between apogee and perigee while minimizing spacecraft heating since little time would be spent at the lower altitudes. Because of the chosen elliptical orbit, the satellite acquired the name "Skipper."

Nearly all spacecraft emissions are optically thin (an important exception being the atomic oxygen resonance triplet at a 130.4-nm wavelength) so it makes little difference if measurements are made from outside the spacecraft looking back through the emissions or if measurements are made from inside the spacecraft looking out through the emissions. However, spacecraft glow is believed to be due primarily to a surface-related reaction between nitric oxide and high-velocity atomic oxygen; therefore, an inside-looking-out-measurement would be limited to observing spacecraft glow that takes place at the surface of a transparent window. Because the catalytic properties of metals and window materials differ, a window is likely to produce glow differently than a metal surface. Despite this problem, Skipper researchers decided it was simpler to make the measurements from inside the spacecraft looking out (Figure 2).

Much of the scientific interest will focus on the emissions from shock-heated air encountered in the reentry bowshock. The spacecraft's shape thus takes on increased importance since it must be able to be modeled reliably using computational fluid dynamics to predict radiating species and their spectral intensity. The shape of the shock surface chosen by the Skipper team was a sphere with a 1-m radius. This design requires a spacecraft attitude control system to ensure that the instruments looking through the windows in the spherical shock surface are pointed along the velocity vector into the bowshock instead of in some random direction. Behind the shock surface will be a cylindrical spacecraft that will best use the cylindrical space allotted the satellite within the launch vehicle.

The windows in the shock-producing surface will be made of UV-grade quartz that remains acceptably transparent to about 200 nanometers even under considerable aerodynamic heating. This will allow the measurement of nitric oxide emission bands that are predicted to be the major radiating specie during reentry.

Converting a circular orbit to an elliptical one and having to continually lower the spacecraft's orbit requires a propulsion system. The Skipper team initially considered using electric thrusters. Electric thrusters, however, require deployable solar panels, which the team thought could cause severe drag and heating problems at low altitudes. Solid fuel motors of various sizes were also considered, but it was found that the scientific objectives of the mission were best served by using a rather sizable hydrazine thruster system similar to that flown by the Russians on their "Phobos" craft. Using a Russian-made thrust system has the added advantage of lessening considerably any potential export license problems.

Instrumentation carried aboard the spacecraft will measure spectra and radiation intensities from the far-red end of the visible through the vacuum ultraviolet. Although there was considerable interest expressed by BMDO in IR measurements, such measurements could not be accommodated within the project's budget, time, and physical constraints. There was also considerable interest in the extreme ultraviolet (EUV) portion of the spectrum, but again, the program's budget, time, and physical constraints

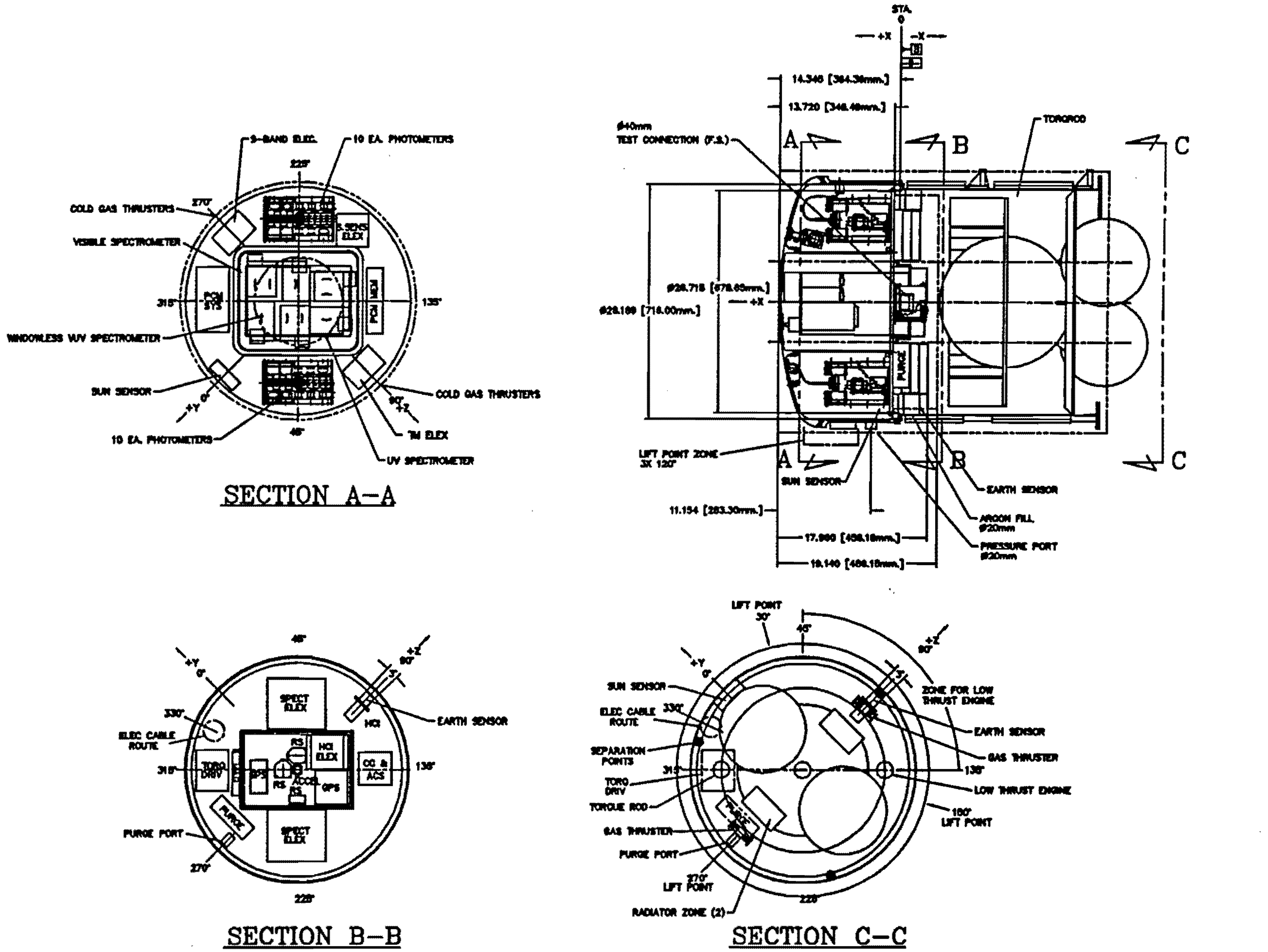

Figure 2. The Skipper spacecraft and its dimensions.

did not permit the development of a "window-less" experiment. To cover the 110-nm to 800-nm wavelength range, the spacecraft will be carrying three 0.3-m scanning spectrometers supplied by the University of Pittsburgh. Each spectrometer will use either two or three photomultiplier detectors operating in a photon-counting mode (for high sensitivity) and in an analog mode when the photon flux is greater than can be counted. Changes in high voltage and the ability to mechanically switch apertures will provide the required dynamic range.

Twenty fixed-wavelength photometer channels will measure the total radiation within the bandwidth of the chosen interference filters. These instruments will be used at selected wavelengths between 200 nanometers through the visible. In order to use multiple instruments having the same view position and to establish that view position at will on the spacecraft, the instruments are designed with flexible quartz fiber optics. As with the spectrometers, a very wide dynamic range is desired. These instruments will use photomultipliers operating in three modes. For greatest sensitivity, they will operate in the photon-counting mode. This mode overlaps onto an analog measure of the anode current as the photon count rate begins to become non-linear due to pulse pile up at very high rates. As the maximum anode current of the photomultiplier is reached, the dynamic range is extended by operating the photomultiplier in a constant anode-current mode. This is accomplished by servo-controlling the photomultiplier's high voltage. The total dynamic range that can be achieved with a UV photomultiplier without any mechanical or electrical switching is approximately 10 orders of magnitude.

An ionization cell having a calcium fluoride window and carbon disulfide fill will be used to measure atomic oxygen radiation at 130.4 nanometers. The dynamic range of this cell will be extended using a UV Geiger tube detector supplied by the Russian research institute TSNIIMASH. Both instruments, as well as the shortest wavelength spectrometer, must look through open apertures in the shock surface of the spacecraft. During reentry, the dynamic pressure will cause gas that is opaque to these wavelengths to flow into the instruments. An argon purge system will be used so that during that portion of the flight when there is significant dynamic pressure, these instruments will be surrounded with a transparent gas or—as in the case of the spectrometer—filled with transparent gas.

Because the mission calls for perigee altitudes as low as can be safely achieved, the overall spacecraft configuration needs to be as aerodynamically simple as possible to minimize aerodynamic torques. As mentioned above, this consideration eliminated the use of deployable solar panels and made the spacecraft design very power critical. The average power available on orbit is approximately 40 watts, which means that measurement time must be significantly limited. The present experiment plan calls for up to 1 hour of measurement time per day during a portion of the orbit(s) to be selected by the joint U.S.-Russian science committee. Data will be stored in solid-state memory and will be downlinked once a day. For a mid-latitude ground station, that means there are two to four usable contacts daily. One will be used for scientific data telemetry, and the others will be used to monitor spacecraft health and to issue commands that will be executed the following day. Spacecraft time and raw data for ephemeris calculation will be provided by an onboard GPS receiver.

The mission plan calls for an initial 819-km circular orbit. Injection of the Skipper satellite into orbit will follow the injection of the IRS satellite by about 10 seconds. During this interval, the booster oxygen tank will be vented through a nozzle to reorient the fourth stage. This reorientation, which occurs before Skipper's ejection, will send the Skipper spacecraft in a different direction and at a slower initial velocity than the IR satellite. The Skipper spacecraft will have an Ithaco horizon-crossing detector, magnetometer, and torque-rod neutation dampener as well as a solar-aspect sensor to provide attitude control information. The spacecraft is intended to be spin-stabilized along its axis of symmetry by a cold-nitrogen thruster system. This is necessary to deal with thrust misalignment difficulties when the hydrazine retro thrusters are fired. Major attitude control maneuvers are to be accomplished by a hydrazine thruster normal to the spacecraft spin axis; trim is to be provided by the cold-gas system. Attitude control maneuvers are minimized because with spin stabilization, attitude is fixed in inertial space and a retro burn at what will become apogee automatically aligns the instruments to look along the velocity vector at perigee, which is where the major scientific interest lies. During the final reentry, the attitude control system will be used to position the spacecraft so that the spin axis is coaligned with the velocity vector to within about 5 degrees over the altitude range of 150 to 80 kilometers.

After Skipper has been in a circular orbit for 2 weeks, the hydrazine retro thrusters will be fired to produce an orbit with perigee at 150 kilometers and on the dark side of the earth. During an approximate 1-week period, the thrusters will be used to incrementally lower the perigee in such a way so as not to stress spacecraft's thermal properties nor its attitude-control system. The final perigee is expected to be about 130 kilometers. Since the spacecraft life is very short at this altitude, the spacecraft perigee will be returned to a "safe" altitude, possibly a circular orbit of approximately 420 kilometers. By then, drag will have decreased the apogee to this value. After the spacecraft has regained thermal equilibrium and is in the proper location, an additional retro thruster burn will cause the spacecraft to reenter over Kwajalein. Table 1 gives

S/C wet mass (kg)	I_{sp} (s)	m_{FUEL} (kg)	ΔV (m/s)
240	217	36	346.0
230	223	37	383.7
220	230	39	440.3

Table 1. Nominal, maximum, and minimum ΔV for the Skipper spacecraft.

the range of velocity-change capabilities available to the Skipper spacecraft to execute an orbit change. This range is based on the variation in the spacecraft wet mass, the performance characteristics of the propulsion system, and the amount of hydrazine fuel used by the attitude control system requirements.

Calculated apogee and perigee plots as a function of mission time are shown in Figure 3.

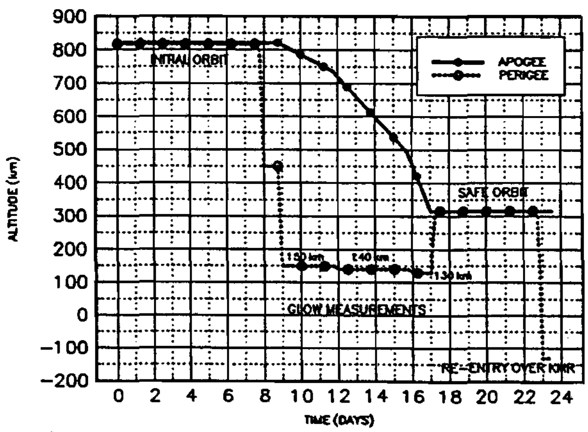

Figure 3. Apogee and perigee timeline.

Figure 4 shows the anticipated minimum maneuvers that will be required during the mission.

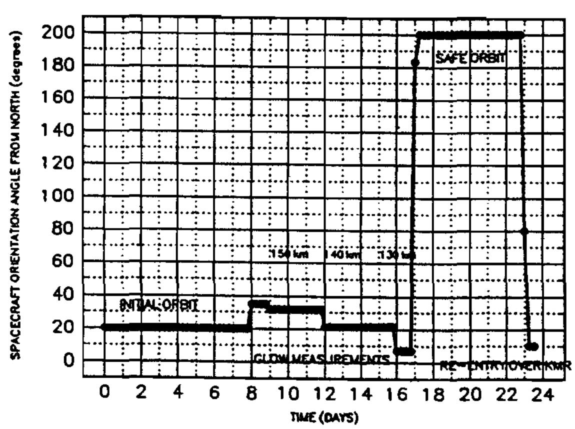

Figure 4. Spacecraft orientation timeline.

Bringing it Together

An important part of the Skipper program is to produce a very close working relationship between the SDL scientists and their Russian counterparts. At the same time, it is hoped that the tasks can be maintained separately enough so that the interfaces become simple and easy to define. While it could be said that the United States is building and integrating an autonomous instrument and that Russia is building the spacecraft bus and integrating it to the launch vehicle, reality is not so unambiguous. For example, the satellite's solar arrays are Russian as are its batteries, and Russians will also regulate battery charging. The numerous temperature monitors aboard the satellite are Russian platinum resistors. However, the electronics that measure the resistance and produce telemetry signals are American. The thruster systems, both cold gas and hydrazine, are entirely Russian, but the computer and algorithms for controlling the valves are American. Finally, the Russians are responsible for modeling the motion of hydrazine in a partially filled tank in a spinning spacecraft.

Still, the actual interface remains very simple. Both U.S. "space" and Russian "space" have been negotiated within the spacecraft volume. There is a single bolt circle that attaches the two parts together. Beyond a few connectors that must be mated, there is very little else. Arming and safety systems for such pyrotechnic devices as valves and ejection systems will be done by the Russians in compliance with their standards and procedures. Integration with the launch system will be done entirely by the Russians. In a very unusual departure from U.S. practice, there will be no umbilical connection to the spacecraft after it is integrated into the Molnia nor will there be any power on any system until the time of separation from the boost vehicle.

Obviously Skipper demands a great deal of coordination and communication. Throughout the design phase,which began last November, the Americans and Russians have met at least every month or two at either design reviews or technical interchange meetings. These meetings have been held in both countries. To ease the language barrier, SDL has employed two, nearly full-time interpreters who are native Russian speakers and who have either a technical or linguistics background. The documents produced for these meetings are being used to develop an English-Russian/Russian-English technical dictionary that codifies the unique vocabulary of the Skipper project. In addition, SDL has opened an office in Moscow that is staffed around the clock. About a third of the time a native American is available as a liaison. Many of the technical people in Russia have some knowledge of English that, in general, is much better than the Americans' command of Russian. When meetings are held in the United States, the Russians have typically brought a technical translator, which means that with three translators, there can be at least three technical discussions held simultaneously. When meetings are held in Russia, a variety of translators are used.

Communications have been established between the Moscow Aviation Institute, the Lavochkin Association, TSNIIMASH, and USU/SDL by FAX and by electronic mail. The usual propagation time for electronic mail is on the order of 8 hours. FAX messages—in either English or Russian and occasionally in both—are also sent. Every meeting results in a signed "protocol." The Russian idea of a protocol differs somewhat from the American concept in that it more closely resembles meeting minutes or a memorandum of understanding. The use of common software such as Autocad has also been very helpful and effective.

Conclusion

The Skipper project is approaching its first major milestone, the preliminary design review, which will be held at Utah State University in mid September 1993. If the government sponsor approves the design that they have refined over the last 9 months, the American and Russian scientists will have achieved a significant—and unique—goal: demonstrating that two countries, once fierce enemies, can turn the intellectual and scientific energies of their best minds to focus on cooperative efforts that will help all mankind.