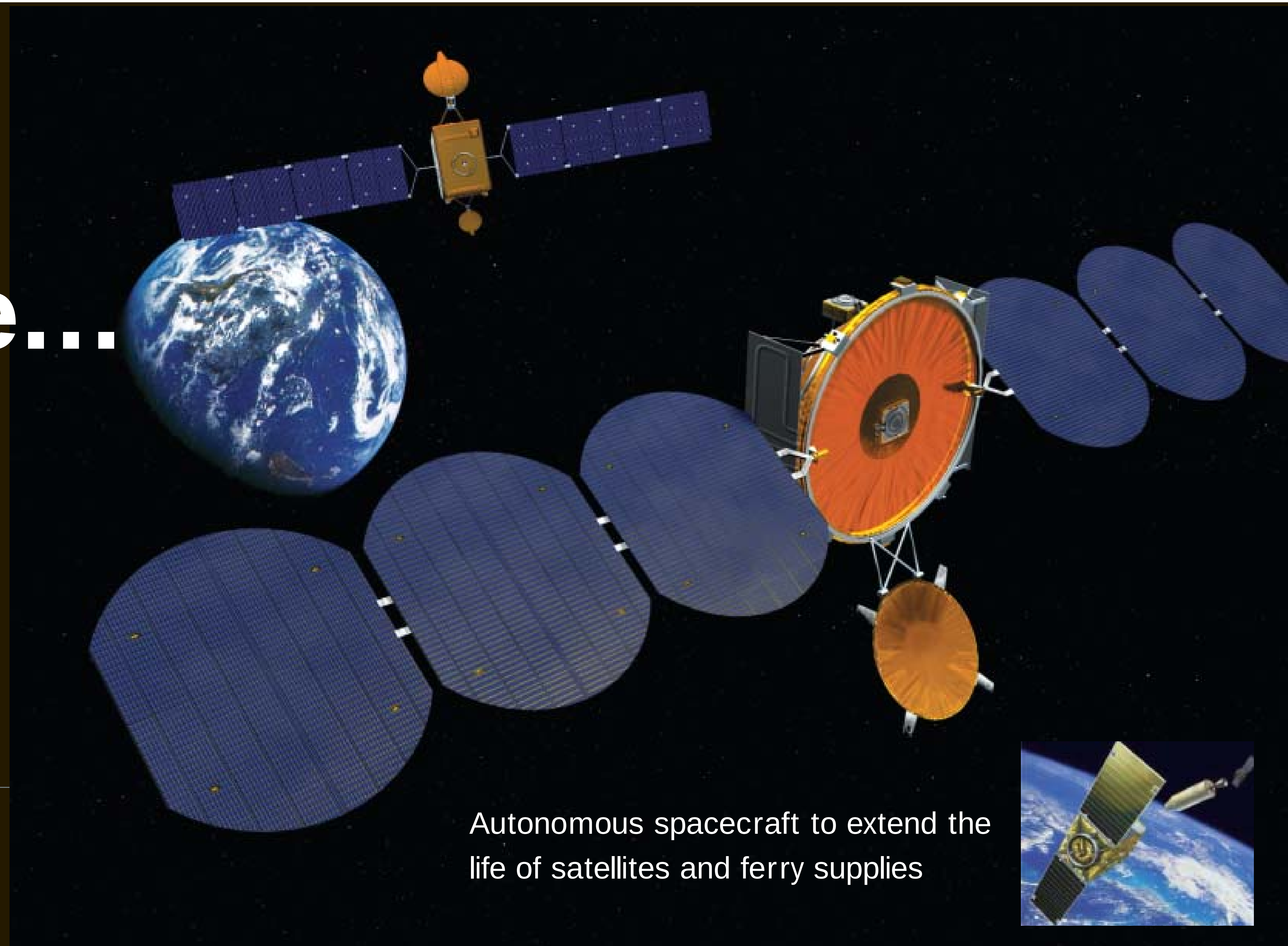
AUTOMATED Robots in Space...

Open up a new age



Autonomous spacecraft to extend the life of satellites and ferry supplies

by Jim Oberg jimo@botmag.com

The instructions stored in the small spacecraft's autopilot were clear and specific. It was to approach the orbiting target from behind and below, navigating off of data relayed from the target by radio. It would approach directly until within a predefined range, then circle the target, observing it from all sides.

But the robot satellite – which really flew in space in April 2005 – acted as if it had other ideas. Once it neared the target, it informed its autopilot that it was moving around the target safely – but it was lying. Or at least it was dangerously confused. Instead, using an unanticipated variation of its optical guidance algorithm, it aimed directly at the target – not to circle it, but to ram it. The robot impacted the target with the speed of a running football tackle, with analogous results. The target tumbled off course into a new orbit, its own autopilot shocked into emergency 'restart' mode.

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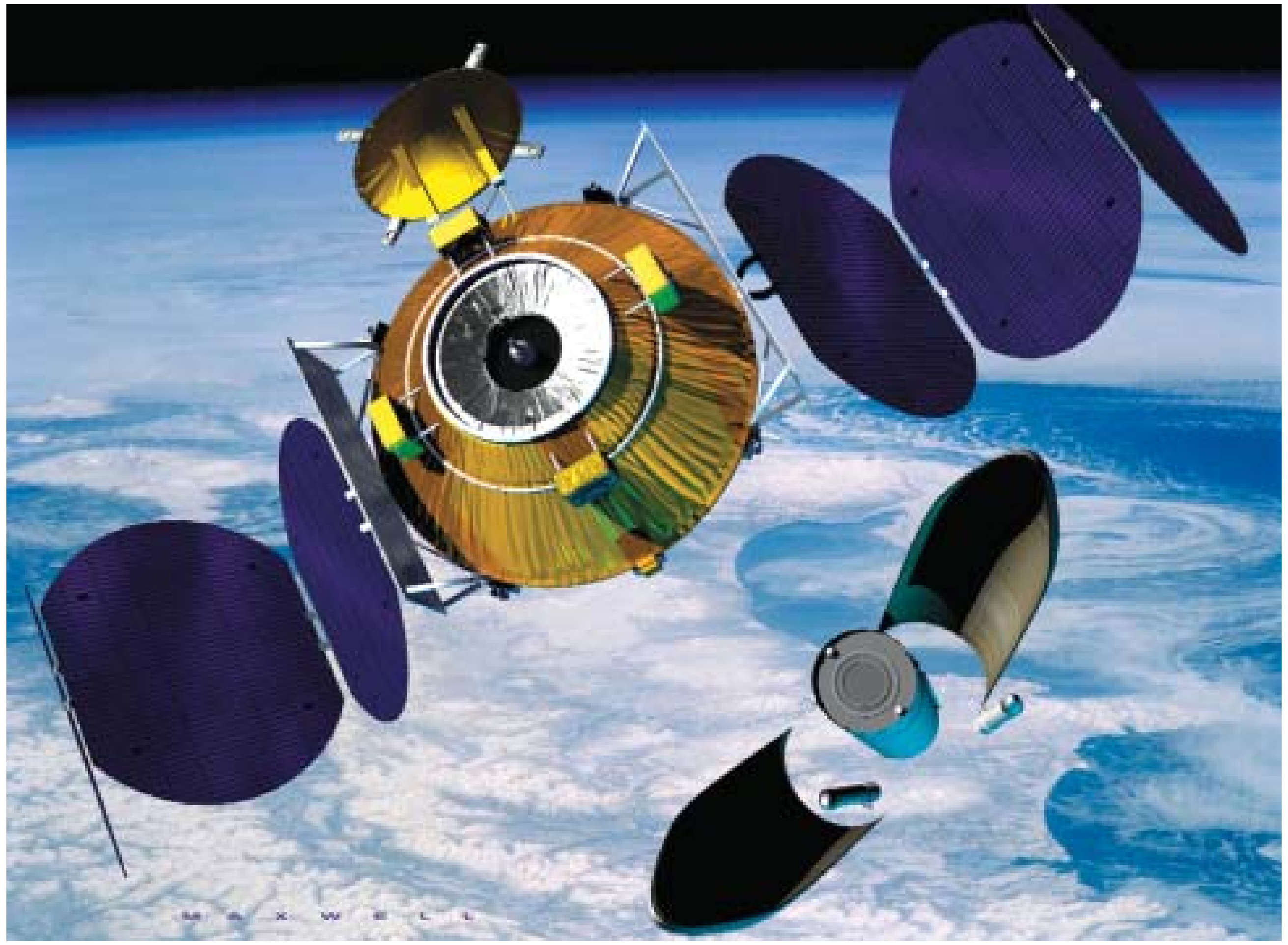
ILLUSTRATIONS COURTESY OF ???

But NASA engineers back on Earth were misled by the robot's "official report" that it was safely backing away. Only after long analysis of the transmitted data, and after noticing that the target satellite was suddenly following a very different path through space, did they begin to deduce what had really happened. At that point, NASA rang down a very uncharacteristic curtain of secrecy, refused to discuss the results, and spent a year looking very, very embarrassed before eventually disclosing the debacle to reporters.

Sure, that's what you can expect from robots – finding a way to misinterpret their carefully-crafted commands and then, out of the dark, blindsiding you with a damaging impact. It doesn't just happen in Hollywood, as NASA found out.

eanwhile, under much less publicity, a similar spacecraft is being flight-tested by the US Air Force. Launched in April 2005 on a mission that could last several years, XSS-11 [Experimental Small Satellite No. 11] spent several months flying away from and then returning to its own launch rocket upper stage. By practicing with a totally-inert ("non-cooperative") target the robot fine-tuned its control and guidance software for later, more challenging targets.

After succeeding in a difficult long-range re-rendezvous in



September 2005, and with more approaches planned in the coming months, military officials finally publicized their preliminary results. "We have certain demonstration objectives for each one," explained program manager Vernon Baker to me from the control center in Albuquerque, "using different sensors, different guidance algorithms, and so forth."

At first, the XSS-11 was flown manually, with engineers on the ground making course corrections based on their computer calculations. Later, it began making its own course corrections, without assistance from the ground. "We're running the autonomous planner in the background," Baker told me, but later tests let the spacecraft fly itself in an entirely hands-off mode.

ROBOTS INTRODUCE A NEW ERA IN SPACE

In recent years, a dozen different spacecraft built in the US, Russia, Japan, and Europe have been experimenting with the biggest advance in space rendezvous in forty years. Armed with new sensors, high-powered computers, and lighter structural materials, most of these spacecraft are designed to be not only 'unmanned', but autonomous even from most human control from Earth. They are the 'robot rendezvousers' of the next phase of the Space Age.

Their purposes range from re-supply of human space stations (sort of an 'orbital package delivery service'), to repair and refueling of expensive unmanned satellites (recall the effort to design a robot to service the Hubble Space Telescope), to inspecting one's own – or those of other nations' – satellites for accidental or deliberate damage, all the way to spying on and if necessary interfering with enemy space objects.

The robot maneuver, carried out in orbit around the Moon or Mars, can help bring scientific samples back to Earth long before a multi-tens-of-billions-dollars astronaut visit is affordable. These are fundamentally new capabilities, making possible some major improvements in extending the lives of expensive space vehicles – or, on the other side of the coin, in shortening those lives.

ORBITAL RENDEZVOUS

"Orbital rendezvous" is a special type of maneuver that has been developed to join two spacecraft launched separately. Within a decade of the opening of the Space Age with Sputnik in 1957, both American and Soviet space engineers figured out how to do it. The US chose to leave it under the control of the astronauts on board the spaceship, while the Soviets chose to use automated and remote-controlled systems with the crew – if anyone even was on board – as backup in case of equipment malfunction.

Because the target satellite is always moving, making a space rendezvous is a very special branch of rocket science – and doing it without human intervention is an even greater challenge. The chaser spaceship starts on a launch pad on a rotating Earth, and the destination ship is circling Earth in a path like a tilted hula hoop – a dizzying combination. Getting together requires precise timing, accurate measurements, and skillful rocket firings – sometimes by a human pilot, sometimes by a remote-controlled system, and in the future, more and more, by a stand-alone robotic autopilot.

ANATOMY OF A SPACE RENDEZVOUS

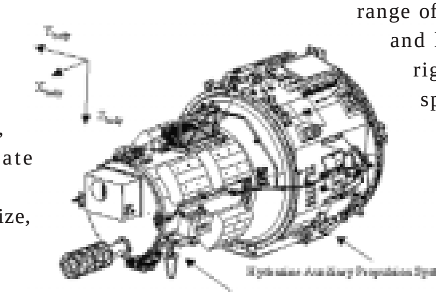
The first requirement is to start the chase from a point directly behind the target. This is only possible if you wait for Earth's spin to carry the launch site under the 'hula hoop' path of the target. At that precise moment – called the 'launch window' – the chaser blasts off in the same direction the target is moving.

Now it's in a lower, faster orbit (like the 'inside track' at the races), but several thousand miles behind the target. Each spin around Earth (as it completes a single orbit) takes a little more than 90 minutes to complete the 25,000 mile circuit. Firing steering rockets to raise its orbital altitude, the chaser drops its speed and thereby slows the approach rate to the target. This is only the first of many counter-intuitive features that seem 'unearthly' to humans but perfectly normal to a computer. The physics of the effect is that the higher orbit gains more 'potential' energy so its 'kinetic' energy (its speed) is lowered.

A rule of thumb used in NASA Mission Control in Houston is that the chaser will close with the target at a rate of ten times its vertical separation, every orbit. That is, if its path is on average 50 miles lower, it will get 500 miles closer every 90 minutes. The chaser has to adjust its approach rate in order to arrive at the target at the desired future time, with the desired sunlight conditions. To do this in the past, radar on Earth accurately measured its exact path and then computers predicted when it would get to the target, and what changes it would need to make in order to stay on schedule. This can take many hours – even a full day – so it's best to start way behind the target and be able to creep up on it while making these measurements.

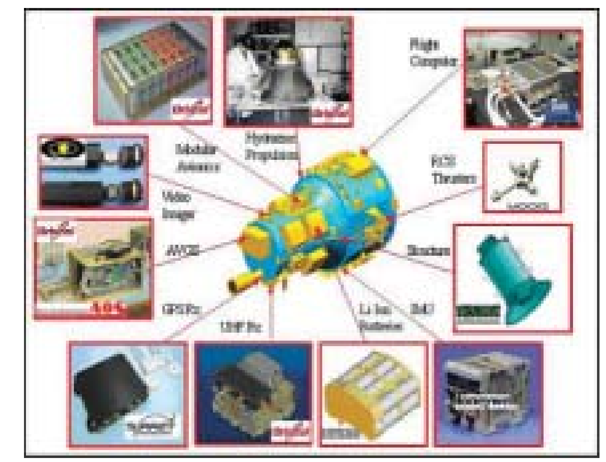
GPS AIDED NAVIGATION

And future robotic systems can use non-radar techniques now being tested by DART, XSS-11, and other space robots. DART, for example, received GPS [Global Positioning System] information by radio from its destination-satellite, and compared it to GPS data in its on-board navigation computer. This provided 'relative state' – the difference in real position of the two objects – and that, in turn, was fed to the computer to generate required steering commands.



Calculating those rocket bursts – size, direction, precise time of ignition – is complicated by the 'celestial mechanics' of both moving objects. It's not like walking over to a doorway on a street, or driving across town to a store – these destinations aren't moving all the time. Big computers on Earth used to be needed, but now, more powerful computers can be made small and light and efficient enough to be carried on the chaser robots.

A few hours before the scheduled contact, a chaser finally gets close enough for its radar to exchange signals with a



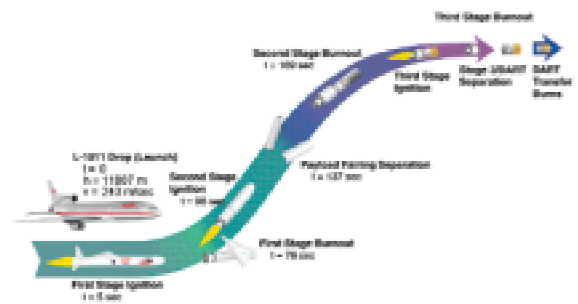
radar echo generator on the target (or pick up pure radar echoes from passive reflections), and this can give even more precise measurements of the relative position and motion between them. But this is very expensive in terms of electrical power needs, so although both Russian freighter drones and the NASA space shuttle use radar, future small robot rendezvousers probably won't (laser rangers are much more accurate, lighter, and use much less power).

DOCKING

The chaser now raises its height a bit more to trim the approach speed, and also now makes a few left-right corrections to push it precisely into the target's flight path. Approaching from behind and below, it gets closer and closer, firing small steering rockets frequently. But at a range of about 400 feet, usually, it has to stop and look for a parking place. The target is right in front of it, and it has matched speed precisely. Now, for the final step across the remaining distance.

If the target is a space station, somewhere on it is a 'docking port' ready for mating. If the target is a small satellite, there may be specific 'grapple fixtures' that the chaser can grab onto – or some other appendage such as an antenna may be available. In any case, this structure is not usually directly in front of the approaching chaser. So it may need to creep sideways until it has flown around the target until the contact structure is right in front of it. The chaser also may await desired sunlight conditions, or wait until passing over ground radio sights to show humans back home what is going on at this critical juncture.

Then the chaser fire a few short thruster bursts to resume its approach. At this range and over these short time intervals, the orbits are so very nearly parallel that simply flying to the target-in sight, without regard to the complexities of orbital mechanics (or "ballistics," as the Russians more accurately term the new science), is completely adequate. The chaser watches the target, and perhaps a specific marking on it, get bigger and bigger in a TV screen until its close enough to touch. Perhaps then the chaser's spring-mounted probe can slip into a 'docking cone' and latch to its apex. Perhaps a mechanical arm and hand can grab a handy handle. Contact!



NEXT STEPS

In May 2006, NASA selected six finalists in their commercial space cargo delivery project, called the Commercial Orbital Transportation Services (COTS) effort. NASA plans to spend about $500 million on this effort between now and 2011, the agency has said. The industrial teams are competing on four different tasks: a pressurized cargo vehicle to bring materials up to and back from the ISS, a simpler pressurized one-way version, an unpressurized cargo frame for transport to the station, and crew transportation. All four would require robot-controlled rendezvous and docking operations.

One of the finalists, the SpaceX team led and funded by entrepreneur Elon Musk, had already unveiled plans for its reusable "Dragon" spacecraft earlier this year. Musk told the *SPACE.com* news website that his firm – still struggling to get its first launch vehicle, the small "Falcon-1," operational — is developing a heavy-lift Falcon 9 booster for the 'Dragon'.

"There are some things I didn't talk about, that we're keeping closer to the vest, that will be of benefit to NASA," Musk told space.com in a telephone interview. He repeated that human spaceflight was always on the SpaceX agenda. "Really the major goal in the long run is human space transportation, that's the reason for the founding of the company."

Dragon will not dock itself to the ISS, but rather use a laser-guided system to approach the station, where it can be grappled with the orbital outpost's Canadian-built robotic arm. Under control of astronauts on the station, the 'Dragon' is then mated to a cargo port.

Other firms that already build and operate space hardware are now developing cargo and crew carrying robot craft. Spacehab, for example, has designed its APEX vehicle and will build it for commercial use, whether or not it wins the NASA contract to service the space station. Another company, SpaceDev, is working on the capsule-shaped Dream Chaser spacecraft.

And where robot rendezvousers will really shine is beyond the low Earth orbit [LEO] range where astronauts are currently restricted to flying. Of particular value – because it is where most money is currently being made in space – is the 'geosynchronous arc', the ring above Earth's equator where 24-hour "stationary" communications satellites now operate. More than 20,000 miles out from Earth and beyond the protective van Allen belt, it is periodically bathed in harmful radiation that makes human travel there hazardous.

ORBITAL RECOVERY

The Orbital Recovery Group, www.orbitalrecovery.com, is a pioneering aerospace technology company that promises to "significantly extend the in-service lifetimes of geostationary orbit telecommunications satellites." Today, as its website points out, these valuable assets are junked when their onboard fuel supply runs out – even if they have years of revenue-producing capability left. With costs ranging above $200 million to build and launch, the economics of buying a life-extension robot mission seem compelling.

Orbital Recovery proposes to build a robot spacecraft called the "ConeXpress Orbital Life Extension Vehicle", or CX-OLEV. Ingeniously, it can hitch-hike into space aboard unused space under the nosecone of commercial boosters such as the Ariane, which often fly with unused payload space. CX-OLEV will supply the propulsion, navigation and guidance to maintain a telecom satellite in its proper orbital slot for up to eight additional years, at a price – and only if it can successfully (and gently) attach itself to the bottom of an aging target satellite.

Alternately, CX-OLEX could rescue an off-course and hence valueless communications satellite and steer it up to a useful orbit. NASA did this several times on shuttle missions in the 1980's, using astronauts aboard the space shuttle and at enormous expense. A robot could do it at perhaps one twentieth the cost.

Astronauts and cosmonauts have been carrying out space rendezvous and docking missions for decades, supplemented by the ground-controlled Russian 'Progress' freighter system. But a whole new breed of small, flexible, far-ranging, and cheap robots has already appeared on the space frontier, with the purpose of replacing these human functions and immeasurably expanding them. The robot rendezvousers are coming, and they're getting closer and closer and….

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