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The Merge

In air combat, "the merge" occurs when opposing aircraft meet and pass each other. Then they usually "mix it up." In a similar spirit, Air and Space Power Journal's *"Merge" articles present contending ideas. Readers can draw their own conclusions or join the intellectual battlespace. Please send comments to aspj@maxwell.af.mil.*

Stealing Zeus's Thunder

Physical Space-Control Advantages against Hostile Satellites

CAPT JOSEPH T. PAGE II, USAF*

IN THE DEEP, dark depths of space, unmanned spacecraft go about their business collecting intelligence information on US military forces. This information, collected and analyzed, could tip the balance of power in a conflict. Imagine the chaos that would result if the satellite did not function as expected—remote-sensing satellites blinded to the changes happening on Earth and communication satellites without signals to relay back to the ground station. The civilian term for intentionally causing catastrophic failure of satellite resources is *space warfare*. In the realm of military science, the concept of space warfare is quite young, having come into existence only when the space age came about approximately five decades ago. Many different areas of space warfare exist, most of them developed as an extension of land-, air-, or sea-warfare techniques adapted to the space environment.

Since space warfare is pushing its way to the forefront of the US government's national strategic concerns, we should clearly define space warfare and strategy for the coming decades, without the overwhelming influences of land-, naval-, or air-warfare doctrine. The current situation resembles the one faced by airpower proponents in the early twentieth century. With weapons such as a parasitic attitude control system (PACS) with antisatellite (ASAT) capabilities and the tactics on how to use them, space warfare can begin to break the bonds of 50 years of earthbound politics and thought, thereby fulfilling its potential.

The United States has divided counterspace doctrine into two categories: defensive counterspace (DCS) and offensive counterspace (OCS). In official parlance, DCS operations "preserve US/friendly ability to exploit space to

*Captain Page is an assistant flight commander and ICBM combat crew commander (Squadron Command Post) at the 741st Missile Squadron, 91st Space Wing, Minot AFB, North Dakota.

its advantage via active and passive actions to protect friendly space-related capabilities from enemy attack or interference."[1] Active defense seeks to increase US situational awareness in space while passive defense ensures the survivability of space assets and their information. Although DCS is an important part of a space strategy, the implicit understanding of defense means it will not increase the balance in our favor but only "hold the line" against enemy attacks.

The Five Ds

On the opposite end of the spectrum, OCS seeks to "preclude an adversary from exploiting space to his advantage" through deception, disruption, denial, degradation, and destruction (the five Ds).[2] There is no division into active or passive since in any particular situation, the methods may be one or the other (or both), depending on their usage. One uses physical damage as an overwhelming defining discriminator of OCS methods. The dichotomy of OCS breaks into methods that produce physical damage and those that do not:

- Deception—usually none
- Disruption—usually none
- Denial—usually none
- Degradation—usually some
- Destruction—usually much, possibly all

If the United States were able to develop a means of effective OCS that performed most or all of the five Ds, what impact would it have? How would the world react to it? More importantly, would US space forces use this technology to full advantage? Even though the answers to these questions seem to lie in the realm of policy and strategy, a commercial system currently in the research-and-development phase has the potential to turn ASAT warfare and the concept of space control on its head.

A New Way of Thinking

The five Ds of OCS exist as ways to hamper the enemy's ability to use space to his advantage—an effect easily attained through satellite control. US space forces' control of enemy satellites by means of an additional attitude control system (a PACS) would all but assure exercise of the five Ds. Supplementing or supplanting a satellite's integrated ACS allows control of the orientation of payload and bus (the structural shell that houses the mission-performing payload). Most work on the PACS has dealt with topics of extending the life of satellites on a particular mission, primarily communications. Previous research dealt with refueling satellites in orbit and using a satellite's own control system, but the PACS concept disregards the integrated ACS and provides control through an add-on system. Depleted fuel tanks no longer mean the end of a satellite's mission life—with the PACS, the mission extends until PACS fuel runs out or the payload fails.

The control result remains the same when one uses a PACS on a normally operating satellite for space-control purposes. The controller of the PACS has ultimate power in moving the satellite, not only by primary use of its thrusters to throw it out of control but also by making changes in the moment of inertia for spinning satellites or in the center of gravity for three-axis-stabilized satellites. Since payload-pointing accuracy depends heavily on stabilization of the satellite bus, additional thrusters that cause unwanted movement or stabilization changes will affect the target satellite's mission performance. Whatever the technique or intention, the PACS allows control over a satellite by using means other than its original attitude-and-orientation subsystems, an extraordinary capability in the realm of space control and space warfare.

Attitude Control Systems 101

Before delving into the aspects of surreptitious command and control (C2) of hostile satellites, one should acquire a basic understanding of the ACS. The design and operation of satellites include many unique but integrally coordinated subsystems that work in conjunction to carry out the required mission. Although subsystems may vary according to design and although some satellites may not require all subsystems, each satellite includes most of them:

- Structure and Mechanisms—physically support the entire satellite
- Thermal Control—monitors and controls internal and external temperatures
- Electrical Power—generates, stores, and distributes electrical power to other systems
- Command and Data Handling—processes commands and stores data
- Communications—maintains contact with ground controllers
- Propulsion—changes spacecraft's orbital position and orientation
- Attitude Control—determines spacecraft's position and orientation[3]

The last of these subsystems, sometimes known as the attitude determination and control subsystem or guidance, navigation, and control, is used in tandem with the propulsion subsystem, also known as the reaction control subsystem (RCS). ACS sensors measure the orientation of the satellite compared to other known quantities such as star brightness, magnetic fields, or infrared radiation against the cold background of space.

If the correct orientation does not exist, the ACS will adjust it or direct corrective action. Active ACS mechanisms operate *when commanded* to measure and adjust the orientation. Passive ACS systems do not adjust to stimuli; rather, they use physical characteristics such as gravitational attraction to maintain stability. With the ACS directing corrective actions, the propulsion system or RCS uses thrusters or actuators to move the spacecraft physically. The determination of identifying thrusters with propulsion or reaction control depends on their main purpose; if the satellite is already in a proper orbit, no propulsion subsystem is needed, and the thrusters (RCS) are identified with the ACS, whose functions are vital to spacecraft operation—both bus and payload. The ACS is usually doubly or triply redundant due to the importance of the mission. Impairment of these systems can cause degradation or complete failure of the mission; extension of their abilities can extend mission lifetimes.

Refueling Origins of the Parasitic Attitude Control System

The original idea for a PACS called for extending the life of geosynchronous satellites. Factored into the creation of every satellite from the different components and subsystem mean-time-between-failure (MTBF) rates, design life is the length of time the satellite will remain useful. In addition to MTBF rates, onboard ACS fuel-consumption rates from the available fuel supplies also help determine satellite life span. Once the onboard fuel runs out, the satellite is dead in space—its payload may still work, but its attitude will drift, degrading the pointing accuracy of its payload and C2 antennae.

Currently, there is no way to refuel a satellite's fuel tanks in space. However, astronauts Kathryn Sullivan and David Leestma conducted tests in refueling satellites aboard STS-41G, transferring fuel between two vessels inside the shuttle's cargo bay.[4] Although not the same as refueling satellites, this act did prove that manned shuttle missions could refuel low Earth orbit spacecraft such as reconnaissance satellites.[5] The fact that the target satellite must have docking couplers for fuel transfer creates an obstacle to refueling satellites. Future systems may incorporate this feature into the design process, but past and present systems do not have the ability to refuel. The solution created by engineers of the Orbital Recovery Group, a commercial venture, uses a "strap-on" thruster system to augment or supplant the original ACS, skipping the need to refuel the satellite's fuel tanks.[6]

A Parasitic Attitude Control System for Space Control

The idea of covertly supplanting a satellite's ACS is technologically feasible and may become a desired, mature capability when conflict arises in space. The Orbital Recovery Group is working on a life-extension package for high-interest geosynchronous satellites such as high-revenue-generating commercial communication satellites. Discussion of Orbital Recovery's technical plan concentrated on the topic of refueling communication satellites, but the key focus for space warfare remains on the intent of the system: *to help extend the life of aging geosynchronous satellites by adding an additional ACS.* For space control, the actions remain remarkably similar to refueling, but the intent of the user differs markedly. The space-control angle of the additional ACS (hereafter referred to as space-control PACS [SC PACS]) involves *controlling an enemy satellite by supplanting its original ACS and negating the satellite's mission with the PACS.* An SC PACS can control a satellite in numerous ways, incorporated within the five Ds of OCS:

- Depleting the satellite's primary ACS fuel until the satellite is drifting (denial/disruption). Once a satellite runs out of maneuvering fuel to counter drifting, it is considered dead.
- Stressing and straining the satellite bus until body-part separation occurs from changes in angular-momentum spin rates (destruction). Assuming the satellite is three-axis stabilized, enough rotational velocity would put tremendous stress on the solar panels/deployed antennae. Application of enough stress and strain will separate the appendages, depending upon the rate of spin applied to the satellite bus.
- Realigning C2/payload antennae for friendly-force intelligence collection by moving the directional antenna's "footprint" away from hostile ground-station coverage areas and towards space-based signals-intelligence satellites or simply aiming the antennae into deep space, away from Earth (deception/denial). Although such movement will not directly affect omnidirectional antennae due to their 360-degree orientation, their altered pickup patterns will result in less collected signal strength.
- Pushing the satellite into transfer orbit for atmospheric reentry or physical capture (destruction/denial/degradation/disruption). Deliberate movement of the satellite out of its expected orbital plane would allow the PACS controller full, positive control over the satellite's designated path. Physical capture by friendly spacecraft and crews becomes possible by bringing the satellite down to an acceptable orbital altitude. If the plan calls for its physical destruction, lowering the satellite's altitude and speed can allow atmospheric friction to heat up and structurally weaken or burn up the satellite bus and payload.

Concerns about Orbital Debris

The purpose of SC PACS is to create an ASAT capability with a low probability of destruction. Pieces may break off the satellite bus when torqued, but the system seeks to minimize orbital debris, unlike the kinetic-kill ASM-135 or nuclear-tipped Program 437 ASATs.[7] Designers planned for early ASATs to destroy hostile satellites with a kinetic kill (i.e., an explosion on or near the target spacecraft), but these produced too much dangerous orbital debris, affecting other friendly systems. Early satellite experiments such as West Ford, a communications program, dumped hundreds of thousands of small copper needles in near-Earth space, much to the chagrin of research scientists and military space planners.[8] Paint flecks impacting on the space shuttle's window have shown us how dangerous space debris can become.[9] SC PACS renders orbital debris negligible; however, secondary effects may occur with intentional physical damage to the satellite (bending and twisting around the center of gravity).

Military/Intelligence Functions of a Space-Control Parasitic Attitude Control System

The military functions of SC PACS offer a great leap in terms of legitimate space-control ability for any nation that possesses it. The advantage of physically removing a problem from the situation without destroying it lends a "kindler, gentler" approach to warfare operations and may earn the user some respect in the eyes of the world community. When dealing with hostile nations and their space operations, the United States must contend with eavesdropping intelligence satellites that monitor activities around the globe: high-resolution imagery satellites that photograph troop movements or buildup operations (similar to the buildup during Operation Iraqi Freedom in the Middle East in 2003). Following the Air Force's five Ds, SC PACS offers many avenues of approach to neutralize enemy satellites without necessarily obliterating them.

Satellite "Drifting"

SC PACS exerts space control primarily by depleting the satellite's ACS fuel until it drifts. Disturbance inputs such as gravity forces, solar-radiation pressure, Earth's magnetic field, and atmospheric drag all require corrective actions from onboard thrusters. Slight nudges provided by SC PACS exacerbate the expected problems of unwanted movement, and the combined attachment provides greater differences in gravitational force by magnifying the torque. Gravity forces cause spacecraft to act in mostly predictable ways. For example, physically long spacecraft tend to align themselves with the more massive end pointed towards Earth. Sometimes system designs include gravity effects, like the Navy's Transit navigation satellite. By introducing unexpected changes to the satellite bus, such as lengthening the satellite with an attachment of SC PACS, gravity will affect the vehicle in ways unexpected by the ground controllers.

Satellite "Breaking"

Changes in angular momentum also occur during attachment of SC PACS and rotation of the combined system around an axis. The resultant forces provide unaccounted stress and strain on the satellite bus until separation of appendages (i.e., solar panels, antennae, etc.) occurs. Since all spacecraft undergo a battery of tests to determine their response to stress and strain, SC PACS will push the vehicle to its limits and beyond. SC PACS will need a greater tolerance to these forces during its operation, but as long as it spins the satellite into damage or destruction, it may not need to remain connected. Minor changes in torque compel onboard systems to counter the action with momentum wheels and ACS thruster burns, using vital battery power and fuel supplies.

Antennae Realignment

If satellite destruction is not the goal, realignment of the command, control, and communications system as well as the payload antennae is possible. Moving the sensor from its prescribed limits negates the enemy's intelligence collection. The concept of shutter control requires organizations to refrain from imaging particular areas of interest for various political or financial reasons; complete camera control with SC PACS guarantees that no imagery collection will occur. Additionally, realigning enemy transmitters towards friendly intelligence-collection capabilities (ground- or space-based) by realigning their ground-coverage footprint gives US forces a better opportunity to collect, analyze, and understand foreign intelligence-collection methods in space.

Satellite Capture

US intelligence agencies have considerable knowledge of other countries' space programs, obtained mostly by distant-surveillance techniques such as radar or optical tracking. Other methods of intelligence collection include open-source information, such as *Jane's Space Directory* or fact sheets from satellite developers. Depending on the manufacturer or after-delivery modifications, some information remains hidden until after the satellite detaches from the launch vehicle's shroud. The US intelligence system would benefit immeasurably if technicians and engineers could closely examine hostile spacecraft and determine the technological advancement of another nation's manufacturing processes or intelligence-collection capabilities.

If an SC PACS spacecraft succeeds in attaching itself to a hostile spacecraft of interest, moving the satellite towards a friendly pickup vehicle will not present a problem. Coplanar rendezvous between two automated spacecraft has become more common in spaceflight—note for example the rendezvous between the International Space Station and Russian Progress resupply rockets. Remote rendezvous for satellite servicing is an important topic of interest for Air Force Space Command, whose stated purposes for satellite rendezvous are benign, aimed at retrieval or repair of damaged spacecraft.

Atmospheric Reentry

If destroying the spacecraft is a better option, an SC PACS burn can place the satellite into a terminal path through Earth's atmosphere. Commercial and civil entities use atmospheric reentry to destroy low-flying spacecraft, relieving them of the responsibility of actively dealing with on-orbit trash or worrying about liability issues if their derelict spacecraft collides with someone else's satellite.[10] In space warfare, atmospheric reentry prevents hostile nations from retrieving either information or physical specimens of the capabilities and limitations of friendly systems. Aiming through the thickest part of the atmosphere increases friction on the satellite or its payload, enhancing the probability of destruction through thermal means. This could occur as a result of orbital decay, whereby negative acceleration slows the spacecraft down, which in turn requires the spacecraft to spend more time in the atmosphere, which slows it even more in a constantly repeating cycle. The key to this destructive process of orbital decay is the interaction of atmospheric particles (air) against the spacecraft; that is, atmospheric interaction raises the external temperature, severely weakening the satellite's protective structure or burning up the spacecraft.

A Real-World Prototype of a Parasitic Attitude Control System?

Launched in early April 2005, the Air Force Research Laboratory's (AFRL) XSS-11 satellite (see fig.) is a test bed for emerging space technologies. The 11th satellite in the Experimental Satellite Series, XSS-11 has performed many amazing tasks during its time on orbit, including capturing images of the Minotaur launch vehicle that placed it into orbit.[11] Other mission areas covered by XSS-11 and mentioned by the AFRL's Space Vehicle Division fact sheet include proximity operations and autonomously conducted rendezvous—two activities key to a possible SC PACS. Additionally, according to the XSS-11 fact sheet, "the performed advancements will enhance Air Force Space Command's possible future missions [e.g., space servicing of military space systems, damage assessment of disabled space systems, space support, and efficient space operations]."[12]

If XSS-11 proves successful, its mission profile and new technologies may lay the foundation for an increase in space-control capabilities, even though it may not yet offer a direct translation to physical space-control techniques. The size of the XSS-11 satellite bus (less than 100 kilograms) places it directly in the microsat realm. Although the 100-kilogram satellite class may not offer a long-term or powerful PACS, its usefulness lies in prototyping for larger follow-on systems for future deployment.

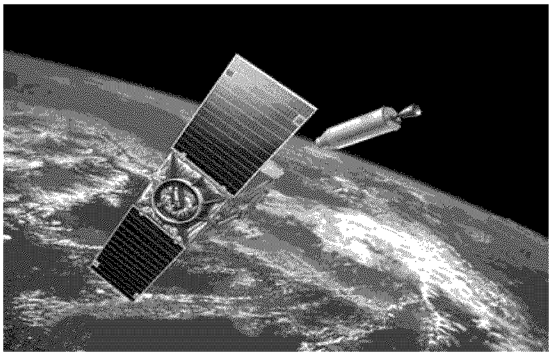

Figure. Artist's rendition of XSS-11's imaging of expended upper stage of launch vehicle. Courtesy of the AFRL Space Vehicle Directorate.

Will a Space-Control Parasitic Attitude Control System Change the Balance of Power?

Although the few SC PACS functions mentioned above are not all-inclusive, they suggest the immense utility of having such a system available for space warfare. How other countries will react to having such a system poised against their assets is another story. Most, if not all, spacefaring nations know the extraordinary advantages that satellites offer to their military, commercial, and civil sectors and recognize the same attributes in other countries' space programs. When one country develops technology to counteract another's advantages, a definite shift in the balance of power will occur.

The United States enjoyed an advantageous position during the so-called space race. Only two coequal nations in terms of technology—the United States and the Soviet Union—opposed each other. Since the fall of the Soviet Union, its technology has proliferated into second-world nations (China, France, etc.) and third-world nations (North Korea, Iran, etc.), shifting the strategic situation from one threatening nation to many. The proliferation of commercial remote-sensing assets has directly contributed to the increasing number of spacefaring nations. Imaging satellites such as Ikonos and Orbview as well as synthetic-aperture-radar satellites such as Canada's RADARSAT-1 give amazing views of nationally vital information, and now anyone with a credit card can purchase all of these products.[13]

If the United States decides to place an offensive space-control system in orbit, hostile nations will contemplate whether to use their space systems against the United States and its allies and risk losing them—or allow the United States to continue its space activities. Physical space control will become a reality for space systems. The question is whether the United States should drive the technological revolution for the safety and security of its space systems or allow another country to set the pace and force the United

States to catch up. If the United States truly intends to become *the* preeminent space power of the twenty-first century, the technological revolution of physical space control must begin here. ❑

Minot AFB, North Dakota

Notes

1. Air Force Doctrine Document (AFDD) 2-2.1, *Counterspace Operations*, 2 August 2004, 3.
2. Ibid., 48; and AFDD 2-2, *Space Operations*, 27 November 2001, 12.
3. Thomas P. Sarafin, ed., *Spacecraft Structures and Mechanisms: From Concept to Launch* (New York: McGraw-Hill Publishing, September 1995), 449–58, especially 451, table 14.1.
4. National Aeronautics and Space Administration, "Mission Archives: STS-41G," http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/archives/sts-41G.html.
5. William E. Burrows, *Deep Black: Space Espionage and National Security* (New York: Random House, 1986), 290–91.
6. Orbital Recovery Group, "The CX OLEV Space Tug," http://www.orbitalrecovery.com/cxolev.htm.
7. See Lt Col Clayton K. S. Chun, *Shooting Down a "Star": Program 437, the US Nuclear ASAT System and Present-Day Copycat Killers*, CADRE Paper no. 6 (Maxwell AFB, AL: Air University Press, April 2000), 2, http://www.maxwell.af.mil/au/aul/aupress/CADRE_Papers/PDF_Bin/chun.pdf.
8. Donald H. Martin, "A History of U.S. Military Satellite Communication Systems," *Crosslink* 3, no. 1 (Winter 2001/2002), http://www.aero.org/publications/crosslink/winter2002/01.html.
9. Theresa Hitchens, "CDI Fact Sheet: Space Debris," *CDI: Center for Defense Information*, 12 April 2005, http://www.cdi.org/program/document.cfm?DocumentID=3106&from_page=../index.cfm.
10. See Leonard David, "Scientists Prepare to Deorbit Compton Satellite," *Space.com*, 24 May 2000, http://www.space.com/scienceastronomy/astronomy/compton_reentry_000524.html.
11. Dawn Stover, "Spy Satellites That Spy on Satellites: First Photos," *Popular Science*, October 2005, http://www.popsci.com/popsci/aviationspace/c75af8183ef27010vgnvcm1000004eecbccdrcrd.html.
12. Air Force Research Laboratory, "XSS-11 Micro Satellite," fact sheet, December 2005, http://www.vs.afrl.af.mil/FactSheets/XSS11-MicroSatellite.pdf.
13. *Space Imaging*, http://www.spaceimaging.com; and MacDonald, Dettwiler and Associates Ltd., "Geospacial Services: Satellite Imagery Products: RADARSAT-1," http://www.rsi.ca/products/sensor/radarsat/radarsat1.asp.

Comprehensive space situation awareness (SSA) and defensive and offensive counterspace capabilities are the foundational elements of our Space Superiority efforts.

—The U.S. Air Force Posture Statement, 2006