In Space, No One Can Hear You ‘Oorah’

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[1] Crewed Military Space Operation

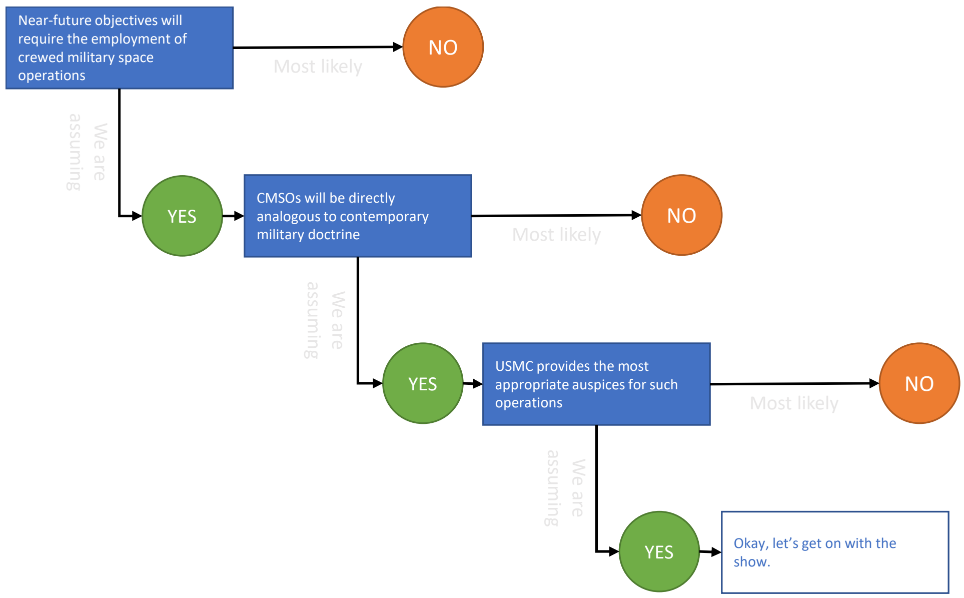

Figure 1: Chain of three key assumptions, most of which are not likely true

This paper outlines an evolution roadmap of crewed space military operations, or CSMOs, for future Marine-like expeditionary forces operating in the space domain. This roadmap revolves around four questions:

1. What near-future objectives will require CSMOs?
2. What TTP[2]s will CSMOs employ?
3. How will operational units be OTE[3]'d to perform such TTPs?
4. How will combatant commanders integrate and employ such units during a conflict?

One critical assumption of such efforts is, in the language of Question #1, that "near-future objectives WILL require the employment of crewed military operations." This assumption can, and should be, subject to considerable debate. However, the objective of this paper is to analyze an evolutionary roadmap under the assumption that this will, in fact, be the case; therefore, such debates are beyond the purview of this document.

Another, more subtle, assumption approaches these questions from the perspective of traditional (late 20th-century) United States military doctrine, emphasizing flexible operational concepts; domain dominance; and information-oriented C2[4] objectives. Similar analysis under different doctrinal assumptions will likely result in different visions and conclusions for identical questions. This assumption is particularly sensitive to variations in force employment and rules of engagement, under which different visions may result in (for example) more direct integration of deniable/unattributed gray-zone-like activities. A logical chain of these assumptions is presented in Figure 1.

The final assumption is more mundane, on the surface, but provides a concrete starting point from which to analyze these questions. This assumption asserts that such operations (specifically, and most relevantly, OTE activities) will be organized under the auspices of the USMC[5]. This assumption is made for two reasons:

[2]Tactics, Techniques, and Procedure
[3]Organize, Train, and Equip
[4]Command and Control
[5]United States Marine Corps

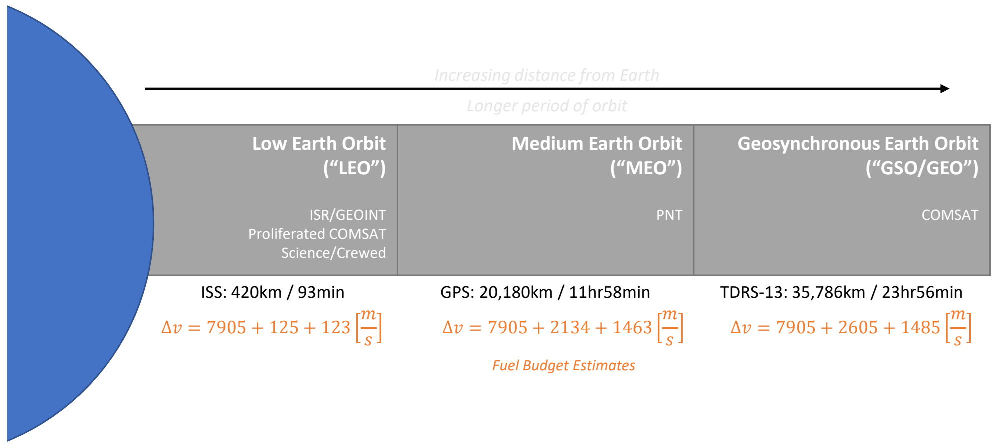

Figure 2: Distribution of missions across earth-system orbit regimes

- Cross-domain, or multi-domain, military operations typically fall under the auspices of either USMC (in the case of amphibious) or SOF[6] (to include MARSOC[7]), as opposed to more domain-centric military services (such as the USAF[8]). Given the historical prevalence of USAF (and its space service branch, the USSF[9]), in particular, where space operations are concerned, this assumption may or may not be warranted.

- Popular science fiction work, across many forms of media, has converged on a consensus that "space marine" (particularly given the naval embarkment analogies) concepts are appropriate and provide a useful memetic reference when considering crewed military operations. These analogies have significant utility and relatability when discussing such hypotheticals.

1 Military Objectives

What near-future objectives will require the employment of crewed military operations? "Space superiority", as described by USSF General John Raymond, is increasingly at risk despite considerable investment in autonomous, unmanned systems across all orbit regimes:

> *"We can no longer assume that our space superiority is a given... If deterrence fails, we must be ready to fight for space superiority."*
>
> - USSF General John "Jay" Raymond, Chief SpaceOps

The past decade has seen notable development and testing of space superiority systems (including ground-based anti-satellite weapons) by dominant and emerging space powers, including India, China, Russia, and the United States. What was once a benign environment where U.S. systems could operate with impunity has become, in the words of United Kingdom Air Chief Marshal Wigston, "a warfighting domain." Remote operations and autonomous systems can operate on a limited command cycle, and are constrained in the tempo under which they can respond to ongoing and changing events.[1]

Ideal doctrinal targets of any military space operations–whether in preparation for, or in the middle of, ongoing combatant activities–will likely be C2 nodes and capabilities enabled by space-based COMSAT[10]s. COMSAT platforms utilized by military operations can include commercial, military, and non-military (civil

[6] Special Operations Force
[7] Marine Forces Special Operations Command
[8] United States Air Force
[9] United States Space Force
[10] Communications Satellite

and intelligence) satellites, most of which operate in GEO[11]. Bandwidth-hungry military operations (particularly when operating away from fixed terrestrial communication channels, and/or in contested environments where terrestrial RF[12] channels may be subject to frequent electronic warfare mechanisms like jamming) may depend upon the utilization of any of these satellites. A breakdown of common orbital regime categories, including related trades, is illustrated in Figure 2.

While such platforms may be subject to both space-based and terrestrial jamming mechanisms to reversibly deny their services, many such platforms incorporate considerable anti-jamming features (including dynamically-allocated spot beams and advanced signal design). Permanent denial of COMSAT platforms through debris or non-debris forming attack mechanisms can involve systems operating on-orbit, but these assets must be prepositioned. These assets can also be tracked and attributed/mitigated. Additionally, they must operate in a semi or fully-autonomous manner which limits their ability to respond to dynamic operating environments. Therefore, CSMOs offer a viable alternative, despite notable drawbacks.

1. CSMOs can utilize on-premises human decision-making and adaptability for considerably more robust attack mechanisms against large COMSAT platforms

2. Large COMSAT platforms present a variety of non-debris-forming mechanisms by which the platform may be compromised and denied to adversary operations

3. GEO COMSATs can be traversed with minimal maneuver cost (compared to systems operating in MEO[13]; LEO[14]; and HEO[15], making it possible for one CSMO team to compromise multiple targets (which can mitigate the considerable expense and complexity involved in CSMO systems and operations)

4. The combination of #1, #2, and #3 means that CSMOs can be employed with utility even if a different attack mechanism must be used for different targets (which would not be possible with a single-mechanism, fixed-CONOPs autonomous system)

2 Tactics, Techniques, and Procedures

We focus on three contexts for defining TTPs of a CSMO: steady-state posturing; transient (before and after) attack; and attack mechanisms. We will focus on the latter first, then expand context until we have defined TTPs for steady-state posturing.

2.1 Attack Mechanisms

We break down a component-based analysis of vulnerabilities of likely COMSAT targets to determine effective attack mechanisms. These are informed by the constraints inherent to a CSMO use case, in which one or more space marines are operating on a satellite in an attempt to deny its military utility. In this context, specialized equipment is discouraged in order to take advantage of human decision-making and adaptability. For example, high-powered microwave devices have a very specific physics-based effect upon a target system that could just as easily be replicated by an autonomous system; there is no reason to employ them within close proximity by crewed operators when more generalized attack mechanisms could work across a variety of component targets and physical effects. Such generalized attack mechanisms can also be more readily adapted to deny potential countermeasures. One component breakdown of large-scale COMSAT platforms enumerates the following:

- Bus (physical structure)

[11] Geosynchronous Orbit
[12] Radiofrequency
[13] Medium Earth Orbit
[14] Low Earth Orbit
[15] Highly-Eccentric Orbit

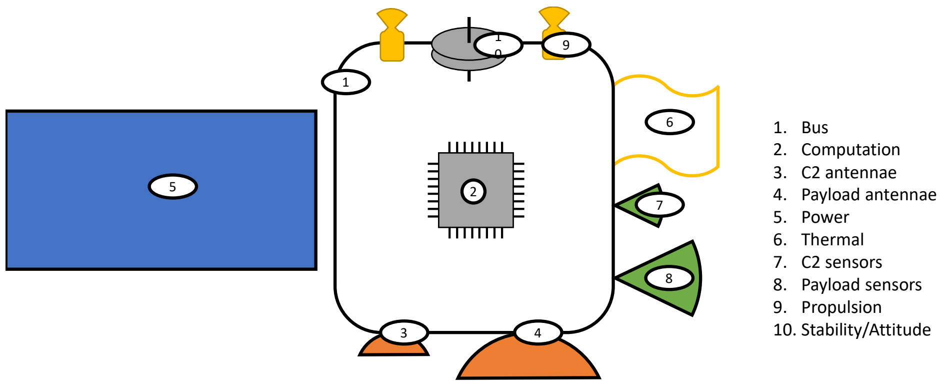

Figure 3: Component breakdown of common satellite subsystems for attach mechanism considerations

- Computational controls
- C2 antennae (uplink/downlink)
- Service antennae (uplink/downlink)
- Power (assume solar panels)
- Thermal controls (including external radiators fixtures, internal transfer mechanisms, etc.)
- Stability and attitude controls
- Auxiliary sensors, including proximity and star trackers
- Propulsion systems (focusing on small-thrust station keeping thrusters, as opposed to large-thrust apogee kick motors)

Which components (illustrated across a rudimentary spatial diagram in Figure 3) are most vulnerable to CSMOs utilizing simple hand-borne technologies? Keeping in mind a preference for non-debris-forming activities (e.g., no explosive activities), the most fruitful vector seems to involve physical severing of connections between components that may be externally exposed. This would have considerable efficacy across a variety of components, particularly those reliant upon the following subsystem networks within the platform:

- Power
- Thermal
- Data (digital)

Any component dependent on these subsystem networks will have attachments that could be modified (e,g., shorted; severed; or otherwise disrupted) to impact efficacy and military utility of the platform. (Note that we avoid component-specific subsystem networks, like propellant feeds, that are both more readily guarded/protected/internalized and potentially pressurized and dangerous for CSMO interaction by hand). To maintain maximum flexibility and minimize dependence on specialized equipment, we hypothesize such modification take place utilizing basic and generalized hand-held tools (with minimal dependence on power supply requirements), like wire-cutters; pliers; and shears.

2.2 Transient Attack

We have defined TTPs for compromising a target satellite utilizing hand-held, powerless tools. These involve modifying the integration of specific satellite components to power, thermal, and digital subsystem networks, in a manner that does not produce debris. We have not defined tactics through which such actions would take place. Specifically, how does a CSMO unit perform these actions? How does such a unit approach, and egress, from one or more target satellites?

We assume a CSMO unit (to be defined in "Organization, Training, and Equipment") to be comprised of one or more members operating from a specific platform. Standard RPO[16] algorithms can be used to determine ingress and egress maneuvers to a target (see ??), but there are special considerations that must be made specific to CSMO unit operations:

- The platform from which a CSMO unit operates is likely to be large (given human support requirements) and highly visible (compared to smaller automated systems). Consideration should be given to ingress/egress algorithms that prioritize low-visibility to external actors (including those optimizing for minimum solar exclusion angle).
- The potential for observation and interdiction of CSMO actions should be minimized. This means shielding operations (using, for example, a deployed sunshade) that could also be optimized to minimize visual magnitude from ground-based observers. This should also take into consideration potential interdiction mechanisms, such as directed energy; microwave; and RF broadcast from the ground. A degree of protection could be integrated into a deployed sunshade by integrating metallic mesh into the composite material utilized. Such a structure will place limitations on the physics of ingress/egress maneuvers, depending on when it is deployed.

Once ingress has completed, CSMO operators must conduct EVA[17]s like those illustrated in Figure 4:

1. Exit the vehicle
2. Stage their approach (including retrieval of tools and/or activation of deployed sunshade)
3. Spacewalk to the target satellite, possibly with the utilization of a manned maneuvering unit
4. Perform the appropriate modifications to the target spacecraft
5. Return to the vehicle
6. Stowage of tools and/or deployed sunshade
7. Reentry to the vehicle

Tactical enumeration of these activities should also include extra time or precautionary margin to evaluate any unanticipated adjustments and adaptations to the above. For example, perhaps the initial approach has been designed around assumptions of a target satellite bus and/or physical arrangement of components that CSMO operators discover are invalid once they approach. In a traditional spacewalk (as might be performed by civilian astronauts conducting maintenance or repairs of a space station or vehicle), such adjustments require the abort of the activity and hours of meticulous re-planning. CSMO operators will need to make on-the-fly adaptations to determine alternate modifications (severing a power connection to solar panel assembly, for example, instead of disconnecting data feeds to an antennae assembly that turn out to be inaccessible).

Ingress and egress maneuvers will also be affected by whether they are the first (in case of ingress) or last (in case of egress) in a sequence of targets for a specific CSMO operation. It may be simpler (and more robust) to conduct operational planning if these maneuvers are separated from orbital insertion or return burns, but it will also be more expensive (both in terms of fuel and time). A relationship between these stages, as part of a fully-enumerated mission sequence, is presented in Figure 5.

[16] Rendezvous and Proximity Operation
[17] Extravehicular Activity

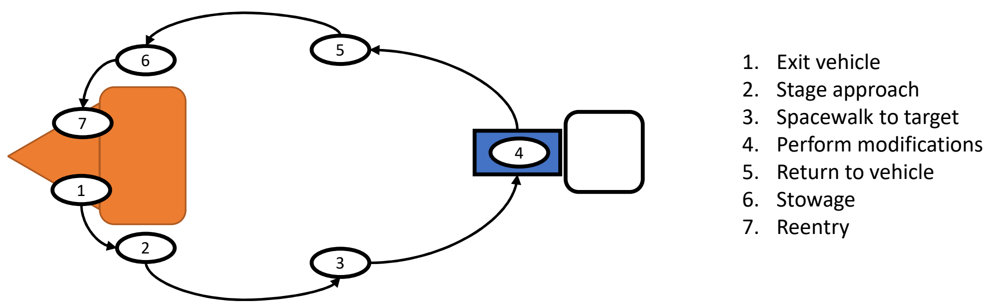

Figure 4: Staged ingress and egress encapsulates a careful, multi-step, coordinated activity

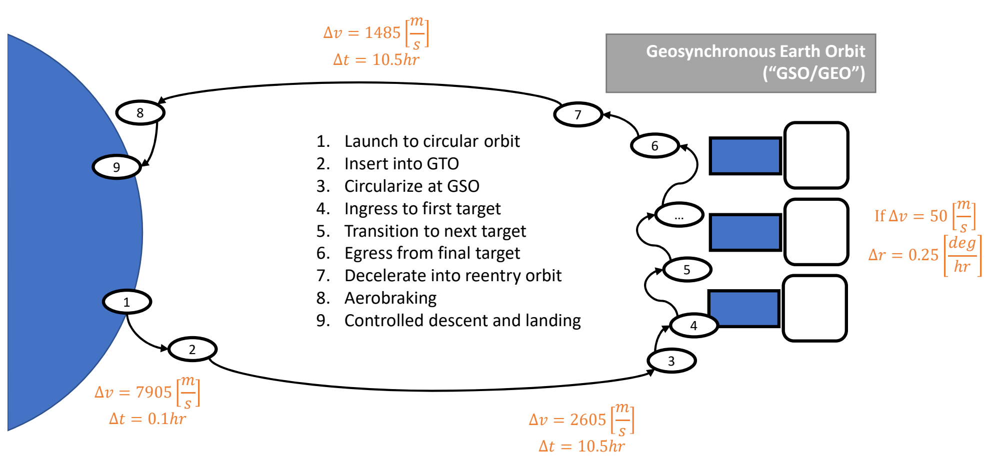

Figure 5: Mission sequence from steady-state through multi-target execution

2.3 Steady-State Posturing

What steady-state posture must exist for attacks outlined in previous sections to be operationally feasible? Most space vehicle launch activities are meticulously planned (operationally-responsive launch aside) months, if not years, in advance, with specific launch windows identified and strict time schedules for go/no-go decision gates. Such constraints may not be realistic for an operationally-responsive capability meant to be flexible and deployed on a moment's notice by a combatant commander. We identify three specific areas where TTPs must integrate steady-state contexts to sustain CSMOs.

1. *Launch*: First, relevant personnel and hardware must be able to launch on short notice. In addition to the demands placed on the operators and systems themselves, this involves negotiation of three very specific constraints:
   (a) *Launch Vehicle*: Most launch vehicles are 8-9 figure expenses that are ordered and assembled long in advance. This is even more so the case for human-rated launch vehicles, with additional requirements for safety and performance (as human-rated payloads are considerably more complex and mass-intensive). CSMO launch operations will require the availability of a human-rated lunch vehicle with considerable excess performance for margin and payload on short notice.
   (b) *Launch Facility*: There are a finite number of launch facilities, many of which include peacetime operations for commercial and civilian activities. These facilities are easily monitored, and are strictly constrained to specific locations for performance (lower latitude is less expensive in propellant requirements) and safety (eastward launch over the ocean preferred for GEO) reasons. A new, less public, and possibly dedicated launch facility may be required.
   (c) *Targeting Windows*: Launch of CSMO vehicles will be constrained by the location of the launch facility and the relative position of the satellites in a mission's target deck. Greater margin of variation in these parameters requires adaptive planning and greater margin of performance (propellant and time) of both the launch vehicle and the payload (crew and systems). Minimizing detectability of on-orbit operations may also require windows to be constrained by ground-based solar exclusion angle of such activities.
2. *Recovery*: Once operations have concluded, the vehicle and crew must be recovered. Infrastructure must exist for discrete recovery activities from a wide area of potential re-entry coordinates, which will likely be determined by egress maneuvers from final satellites in a CSMO target deck. Recovery operations would be significantly less stringent if CSMO utilize a winged recovery vehicle that could maneuver to, and land at, a variety of runway facilities.
3. *Alternate*: What tolerance for risk exists within CSMO activities? Depending on the answer, backup launch vehicles, systems, and crews may be necessary. These would be utilized in the event that a launch of the original "stack" was not possible; that an abort or other mission disruption occurs; or in the event that the original mission could not complete the compromise of all satellites in its target deck. An alternate stack would also give operational flexibility to recover systems and crews in the event they become stranded.

Given the complexity, expense, and time sensitivity of nearly all CSMO mission parameters and dependencies, it seems unlikely that alternate systems and crews would be realistic. CSMO missions will likely be a one-shot opportunity with little tolerance for risk or backup. This does not prevent steady-state posturing of multiple crews and systems, however; it merely means that they would most likely be utilized in pursuit of multiple missions and not in coordination, backup, or support of one another.

3 Organize, Train, and Equip

OTE responsibilities are the cornerstone of a modern military service. The OTE ontology provides a useful way to break down the manner in which military operations may be funded and staffed in such a manner as

Figure 6: Notional service organization

to present combatant commands with valuable military options they may integrate into a strategic combat operation. This section breaks down the manner in which CSMOs undergo OTE as part of a formal military process and organization. We assume, for the time being, that such responsibilities will result from a coordinated effort between the USSF and USMC.[2]

3.1 Organize

The fundamental unit of CSMO activities pivots around a single operations vehicle. Such a vehicle will likely be designed along the lines of a scaled-up X-37B, whose manufacturer (The Boeing Company) has proposed plans for a human-rated X-37C large enough to fit up to six astronauts. Similar vehicles for comparison may include the Sierra Nevada Corporation's "Dream Chaser", which scales to seven. (Recall lifting body vehicles are desirable for flexible, deniable, and discreet/low-visibility recovery operations.) Room for equipment and long-duration life support systems means there will likely be less than full capacity available in either case. This means a basic fire-team analogy is appropriate (four members).

The low volume (even in active operations) of target decks means few CSMO teams are required for the majority of mission plans. However, a full company (or more) of support staff will be required at the marginal scale for each CSMO team, in addition to operational planning, logistics, and facility personnel (likely at the battalion level). Therefore, one possible CSMO organizational structure might look like the hierarchy illustrated in Figure 6.

3.2 Training

For training purposes, we consider two cases:

- Command and Planning Staff
- Operational Teams

Command and planning staff require unique education and experience in closely related fields and military theory for employment and coordination of CSMO units. This includes knowledge of orbital mechanics, space environments, and adversary capabilities, (first) in addition to the specific TTPs performed by operational teams (second). In the first case, similar training may be available from other space-related military service academies (such as the USAF service and graduate academies).

Operational teams require training much like that experienced by a modern astronaut corps. (Indeed, cross-recruiting would be both useful and likely.) While many launch and recovery activities can be (and have been) successfully automated, some degree of training may be required as a fail-safe measure (though it is not clear if the unit vehicles described in other sections may necessarily support onboard piloting).

The most detailed and unique training requirements will involve rehearsal of attach mechanisms themselves, similar to a greatly-expanded EVA rehearsal conducted by civilian space organizations but with less choreographed event plans and greater emphasis on responsive adaptation to evolving circumstances. It may not surprise the reader to learn that there are no precedents at all for such a degree of training activities, at least since the inception of crewed spaceflight itself. The complications involved in groundless physics for physical manipulation of objects in a zero-gravity environment should not be underestimated.

3.3 Equipment

The unique equipment requirements of CSMO post one of the most daunting and unprecedented acquisitions activities in recent memory and push well beyond the current limitations of modern technology. We break these equipment requirements into five categories.

- *Facility*: A unique space launch facility, with strict controls over public access and visibility of operations and support for the unique vehicle (including assembly) and personnel (including training) requirements, may be required. Facilities will require significant acquisition and construction of hardware, including human structures; thoroughfares (for assembled launch vehicles); vehicle structures; launch gantries; C2 systems (such as antenna assemblies and other sensors); and security equipment. This is a substantial fixed cost that will be difficult (if impossible) to hide from aerial and space-based surveillance.
- *Vehicle*: We assume a lifting-body vehicle similar to "Dream Chaser" and "X-37C" will be used as the operating vehicle for CSMO activities. While similar precedents exist, no such vehicle has been flight-proven at the required scale or human-rated. Similar vehicles, with a SWAP ceiling imposed by the Space Shuttle Orbiter for comparison, are presented in Figure 7. The acquisition of such a vehicle in operational quantities poses a significant challenge:[4]
  - Assume 4 CSMO teams (and corresponding platoons)
  - Assume 1 vehicle per team actively available at all times
  - Assume 1 vehicle reserved for training purposes
  - Assume 2 vehicles in recovery and backup/contingency status
- *Unique Vehicle Subsystems*: In addition to the vehicle itself, CSMO activities will require the integration of several unique subsystems. These include sustained life support; caches of nutrients and other biological consumables; limited control systems for launch/recovery contingencies; on-orbit controls for sensing and maneuver during proximity operations; stowage and deployment of the sunshade mechanism outlined in previous sections; means of operator ingress/egress; and storage for crew tools.
- *Crew Subsystems*: To minimize storage requirements and complexity of ingress/egress activities, we assume all operators onboard a CSMO vehicle enter and exit while suited within a vacuum-proof and EVA-capable gear assembly ("space suit"). This can provide the interface for other critical subsystems like life support and equipment storage. Such equipment will also require a degree of reusable maneuvering capability in the form of controllable thrusters and corresponding pressure tanks. In addition to life support capabilities (air recycling, waste), such equipment must also provide radiation shielding and thermal controls.

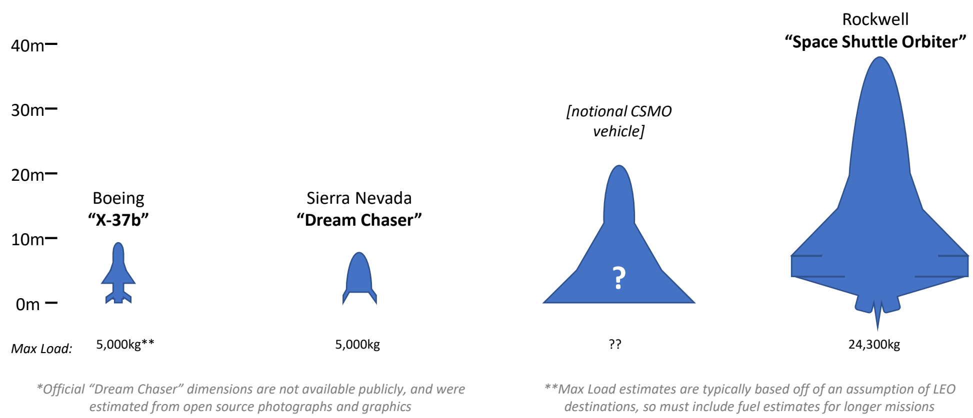

Figure 7: Comparison of three lifting-body spacecraft and notional scale of a CSMO vehicle

- *Crew Tools*: Attach mechanisms outlined within this paper assume the availability of a generalized subset of hand-borne tools. (We differentiate between in-situ personal propulsion, which we assume to be integrated or interfaced to crew subsystems / suit hardware, and hand-borne tools for operations.) These include (as previously enumerated) wire-cutters; pliers; and shears. In addition to mechanisms for attach/detach actions, operators will require means to stow these tools on their person when they are not actively being used. Such equipment may require special adaptation to zero-gravity environments where pivot ("place to stand") points are not readily available.

4 Combatant Employment

Let us assume by now that personnel have been trained in the required TTPs to execute a CSMO mission, and that they have been organized into operational units with the appropriate equipment. How will CSMOs be employed within a combat operation?

Traditional military doctrine (late-20th/early-21st century United States armed forces) outlines phased conflict during which small-scale deniable activities like SOF are used to compromise sensitive adversary targets like C2 nodes in the lead up to major combat operations. Such activities can also provide a key linchpin for critical moments during (as opposed to before) sustained engagements. (For example, strike missions may wait until adversary air squadrons have left their operating airfield and refueled before compromising the airfield and aerial refueling assets.)[3]

Such operations appear to be the closest analogies for CSMO efficacy: specifically, interdicting space-based C2 nodes in the lead up to a major conflict or during critical points during that conflict where adversary surprise at asset loss will result in maximum military utility on the battlefield. CSMOs are unlikely to be deployed before leadup (during peacetime or elevated tension) or after escalation has peaked. Therefore, we focus on these two use cases for combatant employment considerations, as illustrated against a standard doctrinal operation curve in Figure 8.

4.1 Leadup

Leadup operations are part of "preparing/staging the battlefield" or "shaping the conflict" theory in which, much like logistic prepositioning, adversary actions can be constrained or denied by significant operational activities. An adversary intent on engaging in overt military activity within a contested region, for example, may be discouraged from doing so by elevated prepositioning activities that signal a likely response. In the case of CSMO activities, adversary calculus may be impacted by the sudden realization that space-based communications are no longer available.

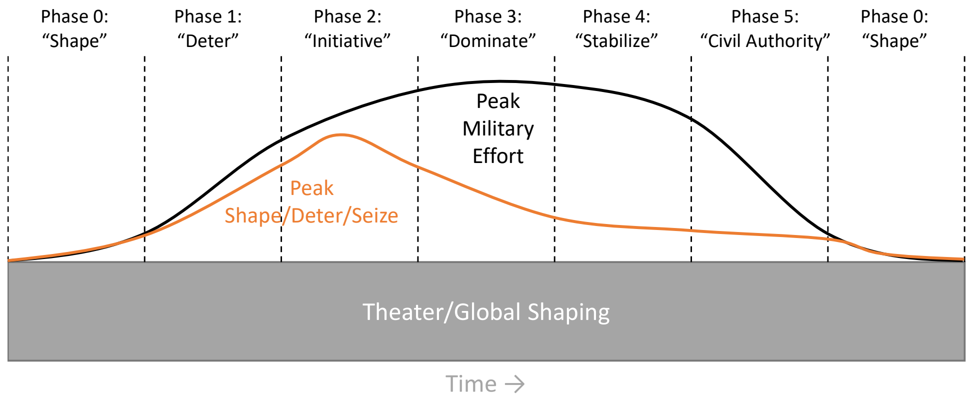

Figure 8: Two likely applications of CSMOs within a standard campaign cycle

However, because such operations take place over a long-term leadup to a major conflict (typically months in planning and execution), synchronization needs are minimal and operational integration does not require significant command or coordination with combatant organizations. Joint forces commanders may, for example, be aware of CSMOs as an alternative or strategic option in the leadup to a conflict, but such activities are more likely to be activated by strategic (executive or intelligence) entities. In the event that a joint forces commander does have direct command of CSMO units, and chooses to activate them in pursuit of a "shaping" phase, they are likely to be one of a large number of loosely-coordinated activities that the combatant commander may choose from.[5]

4.2 Critical

It may be during critical moments of major combat operations that CSMOs can have the most significant, and singular/unique, impact. The sudden surprise of space-based C2 loss can be rapidly exploited and will be less likely perceived or mitigated when many other major combat "pieces" are rapidly evolving. Such deployments will also be less constrained by a need to obfuscate intent or attribution for purposes of deniability when a major combat operation is already underway.

However, such employment will be more tightly integrated with operating tempo of ongoing combat, both before and after the CSMO activities have taken place, and will therefore fall within the direct purview of a combatant commander and the activities they are overseeing. It is tempting to view CSMOs as another unit among many that (for example) a joint forces commander may issue instructions to, much like a Marine unit may be under assignment and accept orders from a regional commander during operations in Afghanistan during Operation Enduring Freedom.

However, the unique nature and activities of a CSMO unit will require considerable training and education to understand how they may be best employed within a conflict tempo. Indeed, there is no clear analogy for CSMO utilization within existing doctrine: What size target deck is permissible under different rules of engagement? Are CSMOs best employed as a strategic deterrent, publicized but rarely utilized? Or should they be utilized as SOF-like activities targeting national infrastructure (deniable but regularly utilized)? Doctrinal questions such as these are open-ended, unresolved, and may even warrant an excursion of their own.

5 Conclusion

We have outlined how combat space military operations may be conducted within a near-future scenario. We have also explored how such CSMOs may fit into existing OTE ontology, and how they may be employed within combatant command structures and operational cycles. All such explorations are, of course, subject to several key assumptions that may not be valid. One particular concern is expense: Having enumerated the unique equipment required, it is clear that standing up and sustaining a CSMO capability will be no small acquisitions feat. Despite these efforts, and even given such assumptions, there remain a number of key open-ended questions and issues:

- *Doctrine*: How will CSMOs fit into military theory? Will cross-domain service (e.g., USMC) or SOFs be a more appropriate analogy? What rules of engagement will exist for CSMO activities, and how will they be best employed between executive, combatant, and intelligence organizations?
- *Realism*: We have attempted to keep theoretical CSMO activities simple and rooted in real, existing technology whenever possible. However, several technological advancements– including responsive personal maneuvering unit capability and (perhaps most significantly) a lifting-body space vehicle sized appropriately with suitable life support capacity–remain undeveloped with only the barest of close analogies in existing systems.
- *Necessity*: It is difficult–and has required both some assumptions and no small degree of motivated reasoning–to justify the necessity of CSMOs given the increasing proliferation of automated and remote-controlled systems operating in space. Mission extension vehicles are reaching a point of proven operation where they may be commoditized as a commercial service, without any Hubble-like on-orbit servicing or repair activities required.

Acronyms

C2 Command and Control
COMSAT Communications Satellite
CSMO Crewed Military Space Operation
EVA Extravehicular Activity
GEO Geosynchronous Orbit
HEO Highly-Eccentric Orbit
LEO Low Earth Orbit
MARSOC Marine Forces Special Operations Command
MEO Medium Earth Orbit
OTE Organize, Train, and Equip
RF Radiofrequency
RPO Rendezvous and Proximity Operation
SOF Special Operations Force
TTP Tactics, Techniques, and Procedure
USAF United States Air Force
USMC United States Marine Corps
USSF United States Space Force

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