The High-Low Mix: A New Concept In Military Space

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Abstract. U.S. military forces are dependent on space systems for communications, navigation, and other critical support functions. As we learned in Desert Storm, however, the requirements for space capability are difficult to forecast and easy to underestimate.

The current U.S. approach relies on high-capacity, high-orbit satellites. Such satellites are relatively cost-effective: the larger the satellite, the lower the cost per pound to orbit it, and the lower the cost per unit of capacity. However, cost-effectiveness is not always the appropriate standard for selecting military systems. Combat forces must be provided with the capability they need to operate and win.

This paper examines a "high-low mix" augmenting the large satellites now used with rapid-reaction launch vehicles (either purchased commercially or developed from Minuteman ICBMs) and tactical satellites (TacSats). Advances in technology now allow military missions including communications and imagery intelligence to be accomplished by satellites weighing under 200 kilograms (kg).

U.S. space forces today are constrained by the lack of an affordable, highly responsive launch system and by the inability to add or replace satellite capability during a crisis. This paper documents those requirements and examines the feasibility of meeting them with a low-cost tactical space system based on proven technology.

Introduction

Twenty years ago, the Air Force was re-equipping its tactical fighter units. If financially possible, the service would have purchased a force entirely made up of F-15s. Because this option proved unaffordable, the Air Force purchased the F-16 as a lower-cost complement. This "high-low mix" of fighters created a practical force which turned out to be very potent in combat.

In military satellites, a high-low mix would mean complementing the small numbers of expensive geosynchronous spacecraft now deployed with low-Earth-orbit (LEO) tactical satellites, or TacSats. For the purposes of this paper, a "TacSat" is a satellite weighing under 300kg, designed for storability, quick checkout, and rapid launch, and optimized for one or, at most, two functions.

As with any new military system, before we recommend the development and purchase of a new capability, we must first establish that the requirement for this capability exists. Then the recommended solution must be shown to be capable, feasible, and affordable.

Background: the Gulf War

The 1991 conflict in the Persian Gulf was widely dubbed "the first space war." Satellites providing communications, missile warning, navigation, and weather data were vital to the U.S. and Coalition victory.

The bulk of the communications workload fell on the Defense Satellite Communications System (DSCS) constellation, used for the first time for intra-theater communications. The two satellites already within range of the Gulf were quickly overloaded, and a third spacecraft was moved from its spot over the Pacific. Despite this effort and the leasing of commercial satellite links, a lack of capacity, especially in the UHF band, hampered U.S. and Coalition forces throughout the war.[1]

Moreover, the Gulf War was a single Major Regional Conflict (MRC). The current U.S. Military Strategy requires the ability to fight two MRCs "nearly simultaneously."[2] If one MRC severely strained our satellite communications system, it is logical that two would completely overwhelm it.

The war also revealed shortcomings in the satellite planning and command structure. With only a few satellites in service, it was logical that they be centrally planned and controlled. While this is the most efficient way to use a small number of expensive assets, it was not perceived as "user-friendly." As documented in the postwar Gulf War Air Power Survey,[3] theater commanders felt frustrated by the slow and complex chains of approval (different for each satellite system) which they had to navigate to obtain additional space support.

When the war ended, the Services initiated studies on how to prevent a satcom bottleneck in a future crisis. Many of these studies focused on the development of constellations of small satellites as "a key technology area" in responding to such problems.[4]

The MACSAT Example

The reason small satellites became an item of interest was largely because of a fortunate coincidence. When the Desert Shield buildup began, one operational Multiple Access Communication Satellite (MACSAT) was in orbit. Two 68kg MACSATs (one of which had failed due to human error) had been orbited in May 1990 as a technology demonstration funded by the Defense Advanced Research Projects Agency (DARPA).

The MACSAT carried two UHF transmitters and was placed in a low polar orbit. It was a store-and-forward satellite, able to uplink and downlink limited amounts of data. A squadron belonging to the 2nd Marine Aircraft Wing was given exclusive use of this satellite. Throughout the buildup and the war, the squadron used the MACSAT to exchange logistics information, data, such as supply orders, with its U.S. headquarters.

When the Gulf War was over, DARPA's MACSAT program manager proclaimed the use of the MACSAT had demonstrated that small spacecraft were useful and "will be an important part of the defense communications infrastructure."[5]

In this example, the TacSat was not used for critical operational communications. However, the Marines felt it had been an important contributor to the smooth functioning of their unit. The squadron especially praised the concept of dedicating the satellite to the service of one unit.

Pre- And Post-War Interest

Even before the MACSAT was employed, several organizations within the Department of Defense (DoD) had been studying the utility of TacSats. A year before Iraq invaded Kuwait, DARPA had already funded several TacSat development programs plus the development of the air-launched Pegasus and ground-launched Taurus launch vehicles by Orbital Sciences Corporations (OSC). These rockets were mainly intended to provide responsive launch for TacSats.

In July 1990, the Joint Requirements Oversight Council approved the Tactical Space System (TSS) Mission Need Statement (MNS). As described in this document, the TSS would use small satellites which could be tailored to any of several different missions. These would be delivered to launch crews as "certified rounds" and, when launched, be dedicated to a specific theater of operations. The TacSats would be combined with low-cost, quick-response launchers and standardized ground systems. A 1992 addendum to the MNS broadened its scope somewhat, substituting more general descriptions of capabilities required for the specific systems mentioned in the original document.[6]

Also in 1990, a study by the Planning office of the Air Staff (HQ USAF/XOFS) listed several deficiencies in the U.S. military space architecture. These included:

- Lack of assured availability of satellite communications capacity
- Inability to augment, replace, or reconstitute space assets
- No responsive surge or replenishment capability
- Over-reliance on small constellations vulnerable to attack.[7]

All these conditions are still true of military space, as attested by the deficiencies listed in Air Force Space Command's Mission Area Plans.[8] All are items which, TacSat advocates believe, can be addressed by small spacecraft.

On the Army side, the Center for Space Systems at Fort Monmouth designed a 136kg EHF communications TacSat providing 30 narrowband secure voice or data channels. This was to be launched on a Pegasus booster on 72 hours' notice. This project was approved in 1990 by the Army Space Council as the Lightweight Tactical Advanced Satellite System (LTASS). It later became the Advanced Space Technology EHF Communications Package (ASTEC). The Army, however, cut off funds for the project in 1994, and subsequent efforts have not advanced beyond the concept phase.[9]

Despite the MACSAT success, the Army's program was not the only one abandoned as Desert Storm receded into history. In 1992, Congress deleted funds for a Navy program to orbit six Arcticsat UHF relay TacSats.[10] The entire DARPA lightsat program was ended, along with the office that managed it.

Recent Developments (1994-Present)

In 1994, the Air Force's Space and Missile System Center did contract with Rockwell for a study on an intelligence TacSat concept called the Tactical Surveillance System. Rockwell's report recommended deployment of a TacSat-based surveillance system. This report cited several advantages of using TacSats, including the capability for rapid deployment, short revisit times, use of commercial off-the-shelf (COTS) hardware, and use of tracking, telemetry, and commanding (TT&C) systems compatible with current terminals. The estimated cost was under $35 million (Fiscal Year 1995 dollars) per satellite. The study postulated a satellite weighing 590 kilograms, which does not fit everyone's definition of a TacSat.[11] However, the general advantages this study listed for TacSats have broad applicability.

Also in 1994, the Ballistic Missile Defense Organization (BMDO) flew the second TacSat in its MSTI (Miniature Seeker Technology Integration) series. MSTI-2 successfully tracked launches of a Minuteman ICBM and two smaller Sergeant rockets. MSTI-3 was launched in 1997. This satellite weighs 212kg and carries more advanced instruments for the infrared detection and tracking of missile launches. This technology could be adapted to an operational missile warning TacSat. Another small spacecraft orbited for the Air Force was the 1994 RADCAL, which weighed 86kg and providing radar calibration, GPS-based satellite positioning, and bent pipe as well as store-and-forward UHF communications services.

Interest in TacSats for operational missions has picked up in 1996 and 1997, driven partly by high costs and partly by advances in the miniaturization of satellite technology. TacSats launched or scheduled to launch in 1997 include the Geosat Follow-On (GFO), which will downlink sea state information directly to Navy warships, and MUBLCOM, a DARPA-funded initiative to adapt the commercial ORBCOMM 40kg comsat to military use. Commercial launches include imagery TacSats capable of resolution of 3 meters or better. OrbView-3, scheduled to launch in 1999, will deliver 0.8-meter imagery from a satellite weighing only 146kg.[12]

Several additional projects are in the development stage. These include Clementine II, which will test technology applicable to a space control TacSat. The FORTE (1997) and MTI (1999) TacSats will develop capabilities for detection of nuclear tests and installations. Warfighter-1 is a planned Air Force technology demonstration in which the service will purchase hyperspectral imagery from the OrbView-3 satellite (being built by OSC's ORBIMAGE subsidiary) and test the concept of downlinking imagery directly to the battlefield in real time.[13]

Why Consider TacSats?

The initiatives just discussed are still the exception in the DoD space community. In general, the U.S. military still views TacSats mainly as R&D vehicles. This view is in error. There are compelling reasons for the U.S. military to take another look at operational TacSat capabilities.

Returning to the tactical fighter analogy, the larger F-15 is the most cost-effective plane, in that it delivers ordnance at a lower unit cost per kilogram. However, cost-effectiveness is not the same as affordability. For instance, assume the Air Force has determined it must purchase one more 20-plane fighter squadron to cover its commitments. The service would prefer F-15s, but the total price of an F-15 squadron might simply be unaffordable. Settling for F-16s would be greatly preferable to not fielding the required fighter squadron at all.

The fighter analogy continues to hold for TacSats. Let's look at one example:

communications satellites. The 1995 DoD Satellite Communications Master Plan, stated that, even when the full large-satellite architecture (eight UFO, five DSCS III, and four Milstar spacecraft) is in place, it "will not satisfy the projected capacity needs for a combined-MRC scenario in the early 2000-2010 time frame."[14] Even this statement assumed all satellites would be functioning properly and the enemy (whoever that might be) would take no action to jam or attack them. Accordingly, it is a near-certainty that a military crisis, especially a two-MRC scenario, would strain or overtax our satellite communications capacity. It is an absolute certainty that the United States lacks the capability to build or launch satellites rapidly enough to augment capacity in a crisis or to replace spacecraft lost to malfunction or enemy action. As DoD does not have the hundreds of millions of dollars necessary to provide on-orbit spares for all its large satellites, it is logical to look at cheaper systems to augment the existing capability.

TacSats vs. Large Satellites

Like any system, TacSats have a mixture of capabilities and limitations. TacSats are more expensive than large satellites per unit of data transmitted (or other measurement of capability), and they provide much lower capacity for a given number of spacecraft. However, their total cost, the numbers in which they could be provided, and, especially, the relative speed with which they can be built and launched makes them the superior choice in some scenarios.

To provide one cost example: it would cost approximately $14 million to build a GEMstar-class comsat and launch it using a Minuteman-based launch vehicle.[15] Maintaining a Minuteman-derived booster on alert for almost instant launch would cost an estimated $1.5 million a year, plus the cost to store and monitor the satellite.[16] In contrast, Hughes' contract to build and launch the first UHF Follow-On (UFO) satellite was for $172 million. The UFO has many times the capacity of the GEMstar, but, if the UFO fails, it will take weeks to move one from another orbit (moving the DSCS in the Gulf War 108 degrees took 29 days) and months to launch a new one (years if the replacement spacecraft must be built first). In a war, that kind of time may not exist.

Alternatives to TacSats

Two alternatives to a rapid-augmentation capability are the leasing of commercial capacity and on-orbit sparing. These strategies are often useful, but have important limitations. DoD cannot order commercial operators of communications, imagery, or other satellites to launch or move systems into appropriate orbits to support a given operation. In the case of communications satellites, another complication is that some bands heavily used by the military, especially the lower UHF frequencies, are not served by commercial operators.

Placing spares on orbit has been used for the Navstar Global Positioning Satellites, among other systems. However, the building a launching of a spare may cost hundreds of millions of dollars. DoD cannot afford to provide spares for all its critical satellite constellations.

The State Of Technology

While the MACSATs remain the most famous example of a TacSat demonstrating operational utility, small satellite technology has continued to improve since 1990.

Communications

More recent examples of small communications satellites include the GEMstar satellite, built by CTA. The GEMstar weighs 130 kilograms. It contains two UHF store-and-forward transmitters and was built to provide Internet connectivity and Email as well as transmission of specialized digital packet communications. The first satellite was lost in a launch vehicle failure: the manufacturer's 1997 estimate for building a new GEMstar is $4 million.[17] The smaller ORBCOMM satellites, built by OSC as part of a planned 36-satellite network, weigh only 40kg each and cost about $2.5 million.[18] (NOTE: At this writing, OSC is planning to purchase CTA's Space Systems unit.)

Any TacSat program would be more salable in today's budget climate if it included a variety of payloads for different missions. Adapting a single off-the-shelf bus to multiple payloads is the ideal option, providing flexibility and quick adaptability to mission requirements. All of the major light satellite makers, such as Orbital Sciences, TRW, and Ball Aerospace, have developed standard buses which can be tailored for the customer's requirements. The smallest of these is AeroAstro's 1kg, $100,000 Bitsy.

UHF is not the only band communications TacSats can operate in. An EHF package weighing only 91kg was built for FLTSATCOM, and MIT's Lincoln Laboratories estimated this could be reduced to 25kg. The Army's ASTEC would have used an EHF package weighing about 68kg on a satellite totaling approximately three times that weight.[19] Nor are small satellites and launchers limited to low orbits: OSC and Ball Aerospace designed a system in 1989 incorporating a Pegasus and a 182kg communications satellite to be placed in geosynchronous orbit.[20]

A fully capable low-orbit communications system for a given theater of operations, providing continuous "bent-pipe" as well as store-and-forward communications, requires a constellation of spacecraft to ensure that at least one satellite will always be in contact with the user. Such a system was successfully tested by DARPA in 1991 when a single launch vehicle orbited seven 23-kilogram UHF Microsats, which provided voice and data communication. Tom Velez of CTA Space Systems, the system's builder, commented, "We actually built a little handheld unit and we could use it to close the link, by voice, with another user anywhere in the satellite footprint, which was 3,000 miles. It had limited channel capacity, but the whole system, including launch, cost under $20 million."[21]

Imagery

An example of a small satellite which could provide militarily useful imagery is the commercial EarlyBird, slated for a late 1997 launch. The planned orbit is sun-synchronous at 500 kilometers (km). This 284kg satellite provides panchromatic (black and white) imagery with 3-meter resolution and multispectral views with 15-meter resolution.[22] 15-meter resolution will display harbors, mountains, and other useful terrain features, plus large installations like airfields. 3-meter imagery can detect aircraft and units of troops or vehicles, such as the mobile SCUD launchers that gave the U.S. such trouble in the Gulf War.[23] Lockheed-Martin will launch a larger satellite with 1-meter resolution soon after EarlyBird is orbited. By 1999, as mentioned earlier, OrbView-3 will be delivering 0.82-meter images from a satellite weighing only 146kg. Imagery with this resolution enables an analyst to classify types of aircraft, missiles, and ground units.

Other Intelligence Missions

Another TacSat function in the area of Intelligence, Surveillance, and Reconnaissance (ISR) was demonstrated by France's CERISE, launched in 1995. This 50kg spacecraft was designed to detect and monitor HF emissions from ground locations to demonstrate technology for an operational signals intelligence TacSat.[24] Other ISR tasks include the detection of nuclear, chemical, and biological agents, known collectively as weapons of mass destruction (WMD). The above-mentioned FORTE and MTI TacSats are designed to demonstrate technology for the nuclear portion of this mission.

A 1993 report for the Army by Science and Technology Corporation concluded that chemical detection could also be accomplished using a TacSat constellation in LEO. The satellites would mount infrared spectrometers using a "point and stare" approach to characterize any detected emissions.[25]

The Tactical Launch Study

The Air Force Space Command Force Applications Division (AFSPC/DRM) and the Air Force's ICBM System Program Office have sponsored a concept study of a TacSat system which would respond to the Tactical Space System MNS. The study examined using COTS TacSats in combination with retired Minuteman II missiles converted to launch vehicles. The Minuteman configurations were designed for the Air Force under the now-expired Multi-Service Launch System (MSLS) contract (since replaced by the Orbital/ Suborbital Program (OSP)). Minuteman-based boosters have been tested in suborbital flights and may launch in an orbital configuration as early as 1998. The orbital configuration would replace the third stage, guidance system, and payload fairing with commercial products. The proposed operational follow-on would place squadrons of converted ICBMs on both coasts to launch a variety of COTS TacSats and possibly other payloads.[26] The results and cost estimates produced by this study are reviewed in more detail below in the section on launch vehicle options.

DoD TacSat Policy

The examples discussed earlier, such as GFO and MUBLCOM, indicate some renewal of DoD interest in TacSats. TacSats were endorsed in the Air Force's 1996 Mission Area Plans to supplement large satellites in a number of missions, including weather/environmental monitoring, space surveillance, and UHF communications for mobile users.[27]

A longer-term forecast appeared in *New World Vistas*, a major study on future aerospace power directions by the Air Force Scientific Advisory Board. The Board projected that future reconnaissance spacecraft would be small satellites in distributed constellations. For all military satellites, the study recommended a move to light, single-purpose spacecraft.[28]

Despite these documents, it is still true that DoD sees large satellites as the mainstay of its operational space systems. In May 1997, Richard McCormick, Deputy Assistant Secretary of the Air Force for Space Plans and Policy, explained the current approach. He agreed that small satellites were one of the options for reducing costs, and that using TacSats facilitated the rapid injection of new technology as satellites are replaced. However, he stated the proper approach is the "right-sizing" of satellites for a given mission. Mr. McCormick also pointed out there is no consensus on the definition of a "small" satellite, observing that, "GPS is a small satellite - if you're comparing it to Milstar." He added that, since the planned Evolved Expendable Launch Vehicle (EELV) would reduce the cost of launching medium and heavy payloads, new options would be open for using "right-sized" satellites.[29]

Mr. McCormick voiced a similar opinion concerning the requirement for a rapid-reaction launch capability, saying, "it's usually cheaper to keep a spare on orbit than it is to maintain a standing army to do quick launches."[30]

The High-Low Solution

An operational TacSat system to provide a "high-low mix" of satellites is an affordable and achievable response to the deficiencies documented in U.S. military space capability. TacSats, although limited in capacity, s could provide communications and other services rapidly to theaters where other assets are overloaded. The cost of a TacSat system is modest by satellite standards: as mentioned, the Gemstar would cost perhaps $4 million per satellite, a continuous Microsat constellation about $8 million. While companies making small imaging spacecraft are reluctant to disclose their costs, an estimate based on a variety of published sources places the unit cost (assuming the manufacturer has already absorbed or earned back the R&D expenditures) in the $40-50 million range.[31]

Command and Control

Implementing the high-low mix would also allow a reexamination of the current planning system, under which priorities of the combat units may be subject to pre-emption by national-level planners who believe they have a better sense of "the big picture." The ongoing tug-of-war between central and decentralized approaches might be eased if TacSats were dedicated to the theater of operations, while the large satellites remained under central control.

Because of the limited contact opportunities between a point on the Earth and a satellite in low orbit, the actual TT&C links for TacSats might best remain in the U.S., with operators directing the satellites in response to the priorities of the theater commander. Whenever possible, imagery and other satellite products should be downlinked directly to the theater. This could be easily accomplished with COTS technology like MacDonald-Dettwiler's Fast TRACS, a transportable system costing about $10 million which can accept imagery from most of the current and planned commercial imagery satellites.

Options for Launch

Responsive satellites require responsive launchers. There are basically three options to launch military TacSats:

- Contracting out launches
- Air Force purchase of launch vehicles
- Development of an Air Force launch vehicle

The first option is to contract out all launches. This course of action is encouraged by U.S. government policy statements, such as the 1994 National Space Transportation Policy, assuming the mission requirements of cost and responsiveness can be met.[32] The logical step for the military would be to issue a Request for Information (RFI) and allow the launch industry to offer their solutions. The list of potential bidders is a long one, and might include OSC, AeroAstro, Microcosm, E' Prime, Alliant Techsystems, Kelly Space and Technology, and Kistler, all of whom have small launchers on the market or in development. Foreign launch vehicles, some of which (e.g., Cosmos) offer attractive records of cost and reliability, are ruled out for launching operational military payloads by DoD policy.

The second option is to purchase launch vehicles and operate them. While the Air Force does this today with aircraft, it is not immediately clear that the service could operate vehicles more economically than the manufacturers, given the need to duplicate or contract for the supporting expertise and logistic infrastructure the manufacturers already have in place.

The third option is to develop (or contract for development of) a new Air Force launch vehicle. This option is worth examining because of the Air Force's large stockpile (over 400 sets) of retired Minuteman II ICBM stages. The service has in place the support infrastructure and knowledge base to operate Minuteman-based systems, although basing arrangements using them as space launchers must be worked out.

Factors to Consider

While the Pegasus and Taurus were designed for quick launch, that capability has never been tested. All the commercial small launch vehicles, including the industry-leading OSC Pegasus XL, have suffered initial reliability problems.

A 1995 analysis of Minuteman-based launch vehicles by the Phillips Laboratory Office of Aerospace Studies reported that such vehicles were a technically feasible option. The analysis estimated recurring costs in the neighborhood of $8 million per launch.[33] Even if this proves to be unrealistically low, such a launcher would be competitive with commercial alternatives on cost. A Taurus launch, for instance, was just scheduled by the Air Force for October 1999 at a cost of $15 million.[34] Basing the launcher on a vehicle designed for rapid response and already supported by an Air Force logistical, operations, and maintenance infrastructure contributes to the practicality of this approach.

Tactical Launch System Concept

To properly compare the option of an all-military launch system with commercial alternatives, such a military system must be planned and costed in some detail. This was accomplished in the course of the recent Tactical Launch Study carried out by ANSER for the U.S. Air Force.[35]

The working concept used for this exercise placed Tactical Launch Squadrons at Vandenberg AFB, CA, and Cape Canaveral AS, FL. (While other locations, notably Kodiak Launch Complex and the Wallops Flight Facility, are possible, Vandenberg and Canaveral would offer the lowest cost, having Air Force support units already in place.) Other features of the notional Tactical Launch System include:

- Six launch vehicles stored at each location, with additional assets kept in storage at Navajo Army Depot (where Minuteman missile stages are stored).
- All Minuteman stages (which will be at or beyond the end of design life) to be remanufactured under the planned Propulsion Replacement Program.
- An initial purchase of 12 COTS TacSats (a mix of GEMstar comsats, MicroSat constellations, and OrbView-3 imaging satellites).

- Two research and development launches.
- Two launch vehicle options, both using Minuteman II stages 1 and 2.
- Option 1 adds an Orbus 7S third stage. Maximum capacity for this system (launching from Canaveral into a 540km orbit at 28.5 degrees) is estimated at 210kg.
- Option 2 would deploy a mixture of the three-stage launchers used in Option 1 plus a four-stage version capable of carrying much heavier TacSats by adding a larger payload section and a STAR 48 fourth stage. Maximum payload for this configuration (under the same conditions as Option 1) is estimated at 350kg.

Costs were estimated using the DoD-approved Automated Cost Estimating Integrated Tools (ACEIT) software program. Cost estimates included Engineering and Manufacturing Development, production, and operations and support for the first five years. Results (in Base Year FY97 dollars):

Option 1: With 12 comsats: $364 million
Cost without payloads: $298 million

Option 2: Mix of 3-stage and 4-stage vehicles with eight comsats and four imagery sats: $590 million
Cost without payloads: $362 million

While the use of surplus missiles is understandably opposed by U.S. commercial launch vehicle makers, it is permissible under the 1994 National Space Transportation Policy if it supports a military requirement for which there are no comparable commercial services. The decision to initiate development of Minuteman-based launch vehicles would depend on the results of the above-mentioned RFI. If a similarly responsive and affordable capability could be provided by other systems, with an equally low degree of technical risk, the use of Minuteman-based vehicles would not be supportable under the National Space Transportation Policy.

Conclusion

The development of a TacSat system is a low-cost option to allow the U.S. to expand communications satellite capacity quickly in a crisis. It would also provide a hedge against losing a comsat during a critical time to malfunction or enemy attack. It bears repeating that augmenting or replacing satellite capacity within a reasonable time is currently impossible for the U.S. The technology involved continues to mature, demonstrating the capability to provide increasingly capable communications services and a variety of other functions.

It is the responsibility of the DoD space command structure - the Space Architect, U.S. Space Command, and the appropriate commands of the Services - to provide adequate satellite services to the warfighters. Providing a TacSat capability as the low end of a high-low satellite mix will fulfill that responsibility in an affordable and effective manner.

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