FIELD COMMAND OF A TACTICAL SATELLITE SYSTEM*

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ABSTRACT

One way to ensure tactical satellite systems remain fully responsive to a field commander's needs would be to place all command and control aspects of the system under direct field control. This paper presents the results of a study to evaluate the feasibility of field command of a notional tactical imaging satellite system. The study indicates that such a system is feasible. A satellite constellation can be designed to provide the field commander with significant, timely, tactical data. The hardware is available, or will be within the near term, that enables field command and control facilities manned by a team fully integrated into the existing force structure. Use of GPS receivers on the spacecraft, greater satellite autonomy, and a higher tolerance for individual spacecraft failures can reduce the work load on ground-based controllers to manageable levels. However, field command will place constraints on the amount of imagery that can be obtained due to limited data transmission times and field commands with overlapping areas of interest competing for system access.

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INTRODUCTION

Great strides have been made in recent years in miniaturizing all aspects of satellite systems. Prototype small satellites have been developed and demonstrated. Launch vehicles optimized for small payloads are under production. User equipment for many applications has been miniaturized. Special purpose command and control facilities are being prepared for several systems. Few studies have been done, however, to see how many aspects of the system can be combined to produce a complete system that would be responsive to a remote control site. We prepared this study to estimate the feasibility of tactical satellite field control.

We examined current telemetry, tracking, and control (TT&C) schemes to identify the minimum elements necessary for successful field satellite command. The critical element needed is greater satellite autonomy. Two potential design enhancements that would reduce satellite dependency on complex ground based control networks and thus, improve spacecraft autonomy are independent satellite navigation systems and improved fault management systems. Additionally, mobile field command and control components were studied and two possible versions using currently available or near term hardware assets are presented.

A tactical satellite system is useless if it does not provide data in a timely manner to the battlefield commander. This study investigated the time lines needed to generate satellite tasking at the field level, the ability to receive significant data during the limited pass times, and the impact of multiple users competing for access to the system.

We used a notional tactical imaging satellite system developed in earlier studies as our baseline. This system was comprised of a constellation of satellites at 500 km altitude, with a 700 km swath width.

GROUND SUPPORT CAN BE MINIMIZED

Complex ground facilities are presently used for spacecraft tracking, navigation updates, telemetry interpretation, fault management, and mission tasking. This elaborate command and control structure is manpower intensive and requires large, globally distributed facilities and antennas. Clearly this infrastructure and approach is not acceptable to a battlefield tactical satellite commander. To minimize ground control, satellites with more autonomy are needed. Autonomous satellites must be able to manage the day-to-day housekeeping functions, correct detected faults, and independently determine position and orientation.

Autonomous housekeeping is becoming fairly routine for many of today's satellites. Power management and thermal control functions, as well as payload related activities such as tape recorder conditioning and fine sensor gain adjustments are some examples of functions being performed by newer satellites without ground interaction. There are, however, longer term variations in housekeeping resulting from gradual changes in the satellite's orbit and seasonal changes in average sun angle and sunlit hours per day that require resolution. These effects may be too difficult for preprogrammed autonomous operation, but the impact on ground requirements will be slight if adjustments are required only infrequently.

On board fault management and anomaly resolution is a key improvement needed to improve satellite autonomy. There are generally three classes of anomalies: those that can be anticipated and easily corrected (such as failure of primary systems that have redundant back-up systems), those that can be anticipated but require involved procedures to correct (such as failure of a non- critical component that can be worked around), and those true anomalies that do not fit any anticipated failure mode (such as those caused by single-event-upsets in a central processing unit).

The first class of events can be, and often is, managed autonomously by current satellites, with a message down to the control center informing the operators of the change. The issue affecting development of field control of a lightsat system is how much capability to resolve the other two classes of events should be built into the satellite versus how much capability should remain with the operator.

Those anomalies that require compromising some aspect of the satellite's mission should be resolved on the ground, while those that are transparent to the user should be incorporated into a more sophisticated on-board fault management scheme. When the perturbation is a true anomaly, the most cost effective system solution is likely to be shutting down that satellite. This "disposable" concept is driven by three constraints. First, the personnel training, on-site references, and work area needed to aggressively pursue anomalies would be extensive. Second, a field unit will be too involved in collecting data and preparing orders to be able to deal with complex problems affecting only one part of the overall system. Finally, building an infrastructure that would allow the field to hand-over problem satellites to another entity would be expensive and could jeopardize the field control concept.

The last, but most significant, aspect of satellite autonomy is satellite attitude control and navigation. An autonomous navigation system and Attitude Determination and Control System (ADACS) must compensate for or predict changes in spacecraft position and attitude that occur due to forces on the spacecraft while in orbit. Atmospheric drag is the major contributor to these orbital changes in low earth orbit. ADACS exist, nearly in off-the-shelf form, to maintain the proper satellite orientation. Accurately determining orbital position is, however, the main stumbling block toward acheiving true satellite autonomy.

Several navigation methods are being examined by satellite designers. The best of these, employing GPS receivers, relies on external signals, but generates very accurate ephemeris data. Advanced earth, moon, and sun triangulation schemes for navigation do not require externally generated inputs and also appear promising, although these methods are not as accurate as GPS-based systems.

The addition of GPS receivers on individual satellites would significantly enhance satellite autonomy. Each satellite would be able to receive signals from the GPS constellation and precisely determine its own position, ephemeris, and possibly attitude as well. This would eliminate dependency on the Air Force Satellite Control Network to calculate exact orbital parameters and would be the most important single step toward giving the tactical commander sole control over the satellite.

Off-the-shelf space qualified GPS receivers are currently available which meet lightsat size and weight restrictions. Within five to ten years several manufacturers plan to market single circuit card GPS receivers for satellites. Which will allow the GPS system to be included as an integral part of the satellite's command and control module, further reducing total satellite size and mass.

Relying on GPS signals for navigation does involve some risk, however. GPS is an outside signal source and thus the satellite system would not be totally autonomous. This is mitigated somewhat by the fact that if the GPS system is placed at risk during times of conflict, its inherent redundancy and survivability ensures that derived positional accuracy will degrade in a gradual manner.

To summarize this section, several steps can be taken to minimize ground station interactions with a small satellite system. The satellite can be made more autonomous by taking on the navigation, housekeeping, and simple maintenance responsibilities. The satellite and the ground controller can share modest fault management activities. In this architecture, an indigenous capability for complex anomaly resolution is not required and should not be instituted.

GROUND SUPPORT HARDWARE IS AVAILABLE

Field telemetry, tracking, and control (TT&C) sites must be mobile and flexible enough to operate under a wide range of battlefield conditions. Modular hardware currently exists, or is under development, to build these field TT&C units. We examined two implementation concepts. The first would be able to conduct mission tasking and limited TT&C. The second concept would expand the TT&C capability to permit monitoring and maintenance of the spacecraft. In each case, we explored the ability to utilize planned upgrades to existing military vehicle chassis and mobile van concepts.

We assumed the facility would normally be located at the Corps/Division level, that it would be integrated into the contiguous command facilities, and that fuel, water, and crew support would be available on site.

The mobile site with limited TT&C capabilities would be designed to execute:

Mission related activities:

-- Data commanding
-- Data receipt
-- Quick-look analysis
-- Data transfer to existing processing and exploitation centers

TT&C related activities:

-- Monitor aggregate spacecraft health
-- Evaluate quality of data downlink
-- Modest anomaly resolution via menu-driven algorithms

The mobile site with expanded TT&C capability would perform all of the functions assigned to the limited site and be able to execute:

Additional TT&C related activities:

- -- Monitor payload and bus subsystem status
- -- Initiate limited orbit station-keeping maneuvers
- -- Conduct improved anomaly resolution

Figure 1 illustrates notional implementation concepts for both versions. Each system could be compatible with the new Family of Medium Tactical Vehicles. The electronics, hardware, and shelters/chassis are standard. Power would be supplied by a very high speed, compact, turbine driven generator. No enabling technologies are required.

The limited site could be fully contained within a 30-foot standard van or trailer. This would include an integral S- or X-band tracking antenna, the power generator, air conditioning, work space, chemical-biological-radiation (CBR) change out area, and electronics. Alternatively, the limited site could be packaged in a 20-foot van if a conventional diesel power generator is towed and CBR capability is reduced to sealed operation only.

The fully capable system would require additional software, hardware (up to five Aircraft Transportable Racks (ATR) widths), and more work table and reference area for aggressive anomaly resolution. In addition, it would be provisioned for independent inital start up and limited duration operation. It could be fully contained within a 40-ft van or packaged in a 30-ft van if the power generator is towed and CBR capability is reduced as in the limited site version.

Either site would require three shifts of three people, an Operations Mission Controller, a Communications Specialist, and an Equipment Maintenance Specialist/Backup Operator. The enhanced version would place a higher work load on both the Mission Operator and Communicator. In addition, they would require a higher degree of systems engineering competence to handle higher order anomaly resolution.

TIMELY DATA CAN BE DELIVERED

Unlike other tactical assets available to the battlefield commander, a small imaging satellite system would be confined to fixed orbits and may give only limited coverage of desired target areas. Figure 2 shows the extent of the satellite control area (assuming a 500 km altitude orbit and a 5 degree elevation angle) along with the relative position and size of coverage circles for four different ground target locations (assuming a 700 km swath width for the imager and a range of 300 km from the command site to the center of the target area). For perspective, the areas are shown superimposed on the United States.

Figure 3 shows the time lines associated with a typical target pass. The satellite will enter the field of view of the ground site 3 to 5 minutes before crossing into the target area. It will spend up to 2 minutes over the target area, with only 5 to 10 seconds to view a specific 30 to 60 km square target site. The satellite will then have 3 to 5 minutes to downlink the data.

If the data can be downlinked at 20 megabits per second (typical for an X-band tracking antenna) a satellite would be able to transmit twelve to twenty 30 km square, 5 m resolution images without data compression.

Figure 4 illustrates the time lines associated with mission tasking, both for a preplanned mission and for an immediate request. During preplanned missions, collection management functions will require the longest lead times. All requests will be submitted through command channels and proceed through the normal intelligence collection management process. This process helps to formulate detailed collection requirements into precise mission tasking while ensuring the the required information does not already exist and that the appropriate assets are used to collect the data. The mission manager determines the need for lightsat support. The asset manager conducts mission planning and coordination and directly tasks the ground control assets. The asset manager could be located at Corps or deployed in the field with the satellite ground support equipment. In either case the asset manager is the direct link between satellite operation and mission management. Immediate requests will be submitted directly to the asset manager. The asset manager could consolidate the immediate request with planned overflights or preempt missions. The time line accuracy will depend on the work load at the Corps level, the priority of the imagery request, and the satellite availability.

The limited time available to command and then collect data from a satellite could be further constrained if more than one command center is deployed in a theater. Figure 5 shows the extent of the overlap for two command sites in a European theater. The widely varying geometries of successive satellite passes would make it difficult to arrange for a satellite's pass to be divided between the command centers in discreet time blocks. Three precedence schemes that could be used include:

-- Allocate specific satellites to specific command centers. (This will limit the total passes available to any one center)

-- Have a coordinating authority prioritize the requests. (This greatly increases the complexity of t h e command lines and limits the local commander's flexibility. It also runs the risk of the coordinating authority taking over the asset.)

-- Encode the requests with a priority and have the satellite sort the requests and deliver according to a n optimization scheme resident in the satellite c e n t r a l processor. (This increases the complexity of the satellite software and runs the risk of the users abusing the prioritizing scheme.)

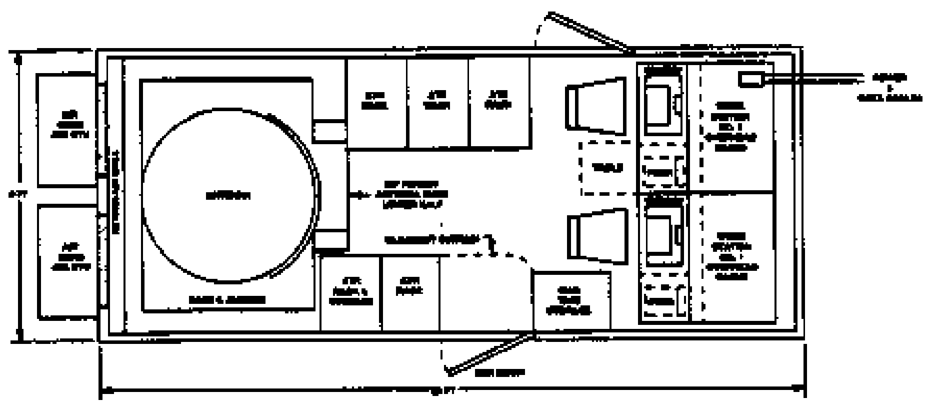
To summarize this section, while contact times are extremely limited, it is feasible that the satellite could deliver near real time images to the field commander. The mission tasking can be accomplished at the field site. Multiple users will complicate the satellite tasking, but reasonable options exist to solve the precedence problem.

CONCLUSION

We presented the results of a study to evaluate the feasibility of field command of a notional tactical imaging satellite system. The study indicates that such a system is feasible. A satellite constellation can be designed to provide the field commander with significant, timely, tactical data. The hardware is available, or will be within the near term, that enables field command and control facilities manned by a team fully integrated into the existing force structure. The use of GPS receivers on the spacecraft, greater satellite autonomy, and a higher tolerance for individual spacecraft failures can reduce the work load on ground-based controllers to manageable levels. However, field command will place constraints on the amount of imagery that can be obtained due to limited data transmission times and field commands with overlapping areas of interest competing for system access.

Figure 1. Mobile Site Concepts

PROPOSED 20' X 8' SHELTER
(LIMITED TT&C)



PROPOSED 40' X 8' VAN
(AUTONOMOUS OPERATION)

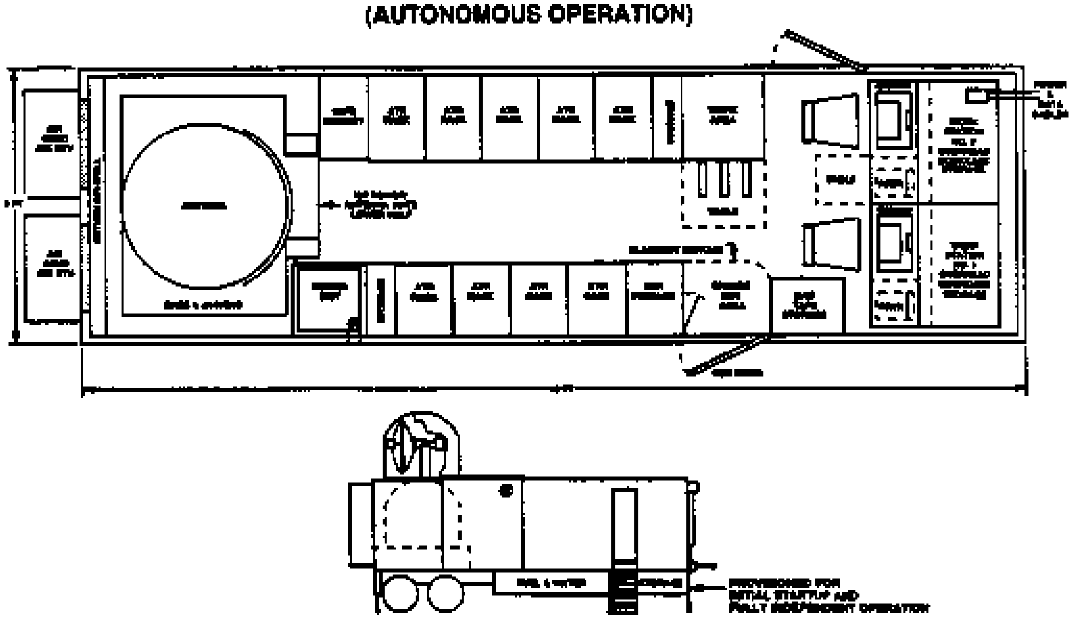
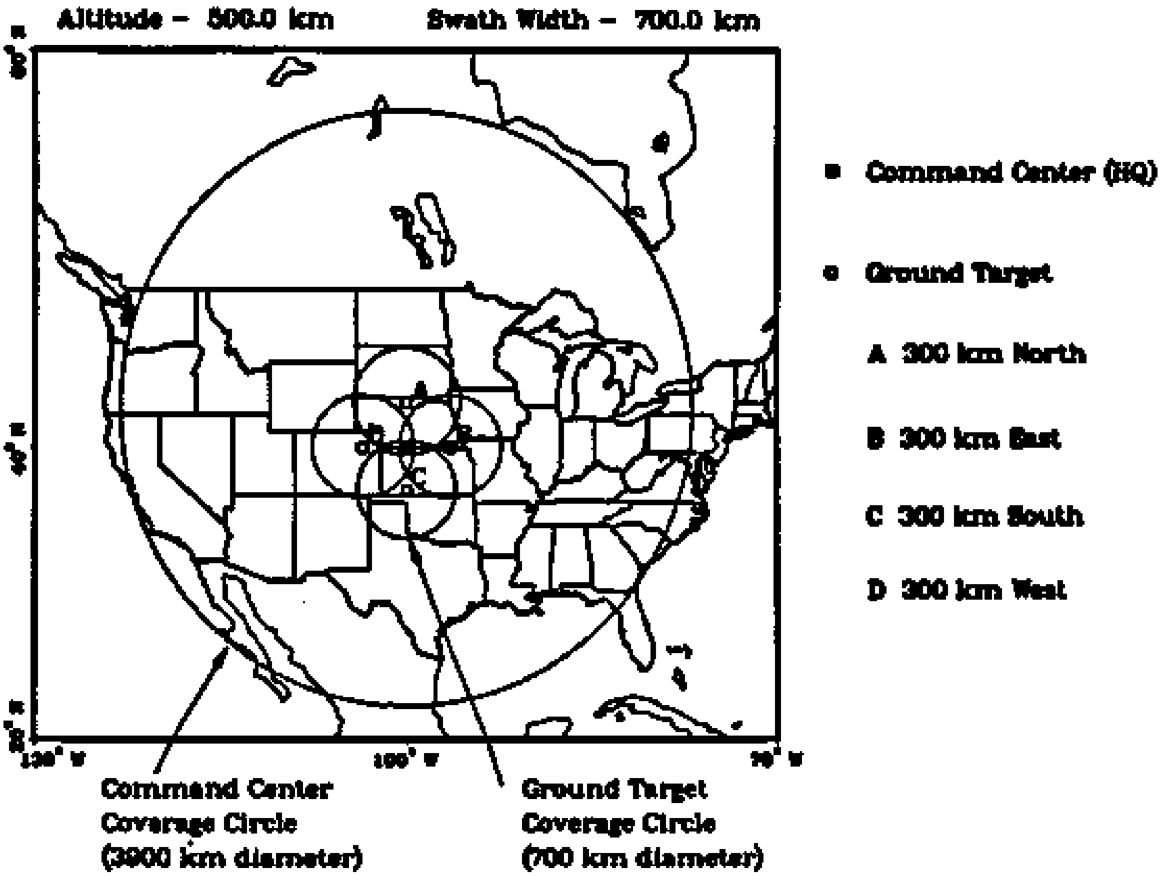
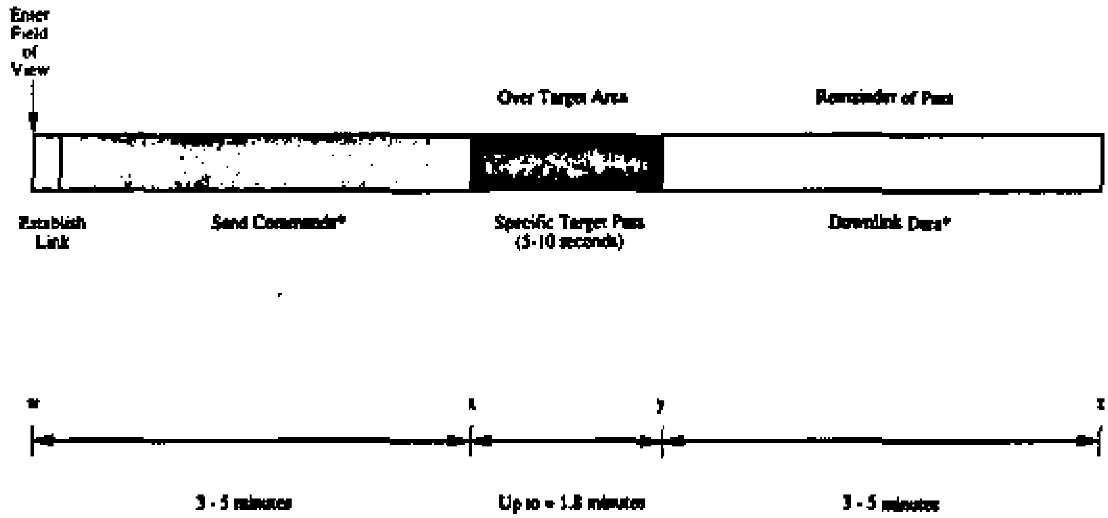


Figure 2. Coverage Area



Drawn on CONUS overlay to illustrate scale

Figure 3. Typical Coverage Timelines



* TT&C Downlink and Uplink Opportunities Shared Between Time Before and After Target Pass

Figure 4. Command Timelines

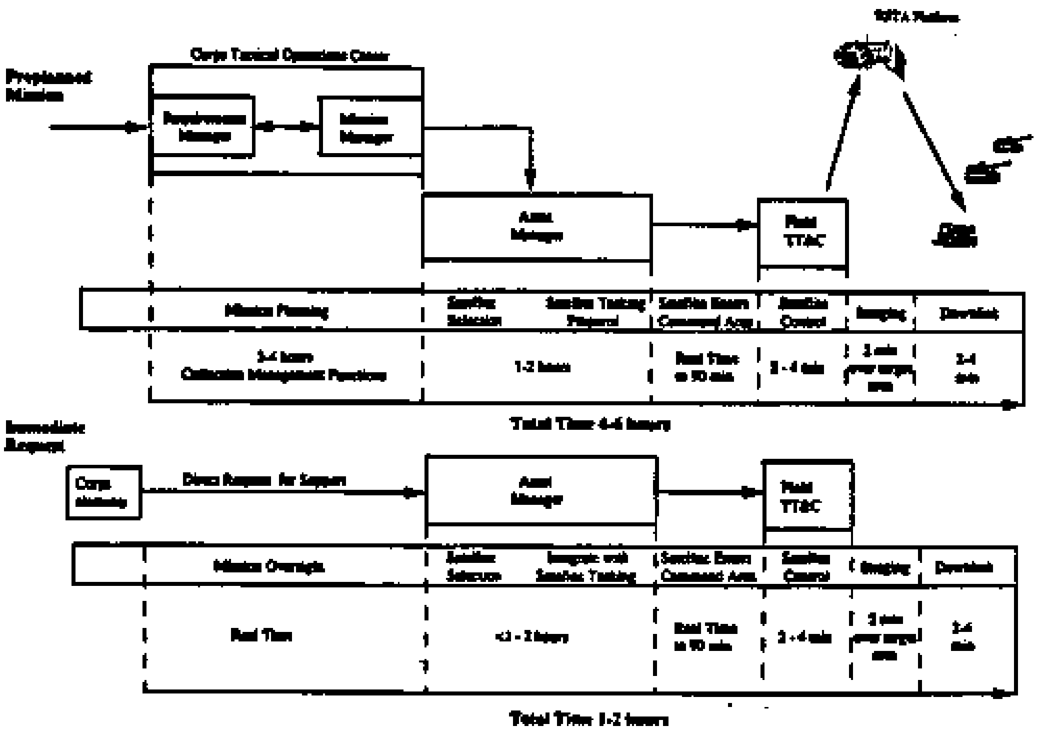


Figure 5. Satellite Control Area Overlap