REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1996

3. REPORT TYPE AND DATES COVERED
Master's Thesis, 2 Aug 95 - 7 Jun 96

4. TITLE AND SUBTITLE
The Use of Iridium, a Commercial Telecommunications Satellite System, in Wartime

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Command and General Staff College
ATTN: ATZL-SWD-GD
Fort Leavenworth, Kansas 66027-1352

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 words)*
This study investigates the capabilities and limitations of the commercial telecommunications satellite system, Iridium. In view of the increasing demands for immediate communications in the modern theaters of war, the study analyzes the utility that Iridium could provide the U.S. military telecommunications architecture. The study uses a research methodology composed of a pyramid of subordinate research questions designed to answer a primary question of whether the Iridium system can provide effective support to the U.S. warfighter. A case study of Desert Storm communications demand and a comparative analysis of the capabilities and limitations with existing military Ultra-High Frequency (UHF) communications satellites are accomplished. Effectiveness is determined by examining the suitability, feasibility, and acceptability of Iridium. These factors are systematically determined by identifying any shortfalls in military UHF satellite capacity, analyzing if Iridium can fill such shortfalls, comparing Iridium's capabilities with those of the UHF Follow-On system, and analyzing the cost of the Iridium system. The study's conclusion is that Iridium is both a suitable and feasible supporter of military point-to-point UHF demands. If certain lease limits are met, Iridium's economic acceptability is also assured. Thus, Iridium is an effective system to supplement the military's UHF network.

14. SUBJECT TERMS
Iridium, Satellite Communications

15. NUMBER OF PAGES
107

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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THE USE OF IRIDIUM, A COMMERCIAL TELECOMMUNICATIONS
SATELLITE SYSTEM, IN WARTIME

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE

by

THOMAS L. YODER, MAJ, USAF
B.S., United States Air Force Academy, Colorado, 1982
M.S., University of Washington, Seattle, Washington, 1983

Fort Leavenworth, Kansas
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THESIS APPROVAL PAGE

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ABSTRACT

THE USE OF IRIDIUM, A COMMERCIAL TELECOMMUNICATIONS SATELLITE SYSTEM, IN WARTIME by Major Thomas L. Yoder, USAF, 98 pages.

This study investigates the capabilities and limitations of the commercial telecommunications satellite system, Iridium. In view of the increasing demands for immediate communications in the modern theaters of war, the study analyzes the utility that Iridium could provide the U.S. military telecommunications architecture.

The study uses a research methodology composed of a pyramid of subordinate research questions designed to answer a primary question of whether the Iridium system can provide effective support to the U.S. warfighter. A case study of Desert Storm communications demand and a comparative analysis of the capabilities and limitations with existing military Ultra-High Frequency (UHF) communications satellites are accomplished. Effectiveness is determined by examining the suitability, feasibility, and acceptability of Iridium. These factors are systematically determined by identifying any shortfalls in military UHF satellite capacity, analyzing if Iridium can fill such shortfalls, comparing Iridium's capabilities with those of the UHF Follow-On system, and analyzing the cost of the Iridium system.

The study's conclusion is that Iridium is both a suitable and feasible supporter of military point-to-point UHF demands. If certain lease limits are met, Iridium's economic acceptability is also assured. Thus, Iridium is an effective system to supplement the military's UHF network.

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LIST OF ABBREVIATIONS

CONUS	Continental United States
CRAF	Civilian Reserve Air Fleet
CRIS	Commercial Reserve Information Systems
DAMA	Demand Assigned Multiple Access
dB	decibels
DISA	Defense Information Systems Agency
DOD	Department of Defense
DSCS	Defense Satellite Communications System
EHF	Extremely-High Frequency
EIRP	Effective Isotropic Radiated Power
FLTSATCOM	Naval Fleet Satellite Communications
FOV	Field of View
Hz	hertz (cycles per second)
INMARSAT	International Maritime Satellite
INTELSAT	International Telecommunications Satellite
IOC	Initial Operational Capability
kbps	kilobits per second
KHz	kilohertz
LEASAT	Leased Satellite
LEO	Low-Earth Orbit
MHz	megahertz

MILSTAR	Military Strategic and Tactical Relay Communications Satellite
MRC	Major Regional Contingency
SHF	Super-High Frequency
UFO	UHF Follow-On
UHF	Ultra-High Frequency
USSPACECOM	United States Space Command
VHF	Very-High Frequency

CHAPTER 1

INTRODUCTION

The topic of this thesis is the use of commercial telecommunications satellites during wartime. Space assets have not yet evolved into direct force applicators, but they have definitely become a permanent asset in force enhancement. Space assets enhance the combatant forces by multiplying their combat power. Space resources have improved the capabilities of ground, air, and naval forces in the areas of navigation, targeting, weather prediction, reconnaissance, and communications. The enhancements brought to the battlefields by space-based communications systems include worldwide access and more efficient command and control of forces. In this era of growing operations complexity, multinational coalitions, and increased lethality of weaponry, all avenues to improve communications capability should be examined.

To set the stage for the relevance of this communications satellite topic, a historical account of the contribution of space-borne communications in the Persian Gulf War is provided from the Journal of the Royal United Service Institution, entitled "The First Space War: The Contribution of Satellites to the Gulf War."

> The Gulf was the first occasion on which a full range of military space systems was used in a conflict against another power. Around 60 Western military satellites were directly involved. It was the first real test under war conditions of the $200 billion US space machine, and the first justification in

> combat of the $1 billion French and British investments in space. Communications satellites carried the majority of the military trunk traffic (secure speech, data, facsimile, telegraph) into and out of the theatre. They provided tactical links within theatre and bridges for other terrestrial VHF/UHF radio systems whose line-of-site limitations prevented them from spanning the desert reaches. They provided total communications to ships at sea, to troops on the move and even to military aircraft. They carried home-TV into Coalition troops and TV news reports out to a world public. They brought the Coalition Supreme Commander within a telephone call of the White House, Downing Street, and the Elysee Palace. And when military satellites became overloaded, civil space circuits were leased and pressed into service.[1]

When Saddam Hussein invaded Kuwait on August 2, 1990, the US presence in the theater was austere. Satellite communications served a single administrative unit in Bahrain and two training missions in Saudi Arabia. The United Kingdom and France had no military satellite links. Even though the terrestrial infrastructure was poor, 15 US, French, and British military communications satellites were in orbits overhead, covering the Gulf area and ready to respond. The reliability, flexibility, and quality of the space systems were demonstrated early in the deployment of forces. This almost immediate support of ground and air forces was a testament to the capabilities of space communications systems. Unfortunately, the Coalition forces also demonstrated the growing military dependence on these systems. Considerable ingenuity was required to reconfigure and enhance the space segment and to manufacture, adapt, and modify the ground segment in order to bring the communications systems up to the required operational tempo. On the other hand, the Iraqis had no military space assets. They did have access to the commercial, international systems, International Maritime Satellite (INMARSAT) and International Telecommunications Satellite (INTELSAT), which operated telecommunications satellites covering the

Gulf area. Theater operations removed these Iraqi assets from use early in the war. Martin Faga, Assistant USAF Secretary for Space, summed up the advantage that space communications gave to the Coalition forces: "We could see, hear, and talk all through the war. After a few hours, he (Saddam Hussein) could not."[2]

This chapter begins with a brief discussion of various issues involved with satellite orbital mechanics followed by an introduction to telecommunications satellite terminology. This background provides a basic understanding of the factors that influence the design and operation of telecommunications satellites. This information is required to analyze the capabilities and limitations of telecommunications systems. The chapter continues with a discussion on the importance of maintaining sufficient telecommunications satellite assets and a deeper introduction to the challenges facing the telecommunications issue. To finish the chapter, the research questions are discussed and the various assumptions, limitations, and delimitations are outlined.

Satellite Orbital Mechanics

Orbital mechanics, also referred to as the field of astrodynamics, is the study of laws of motion controlling an orbiting body. These laws of motion and the mathematical equations that result from them allow prediction of satellite motions in orbit around any planet, moon, or sun. A cursory study of these equations is all that is required to understand various capabilities and limitations imposed by these laws of nature on telecommunications satellites.

Orbital Size and Shape

The size of an orbit, denoted by the semimajor axis, a, is one-half the distance from the orbit's closest point to Earth, perigee, and the orbit's farthest point to Earth, apogee. Values range from approximately 400 kilometers, low-Earth orbits (LEOs), to approximately 42,000 kilometers for many telecommunications satellites. This orbital parameter, known as an orbital element, is depicted in Figure 1.

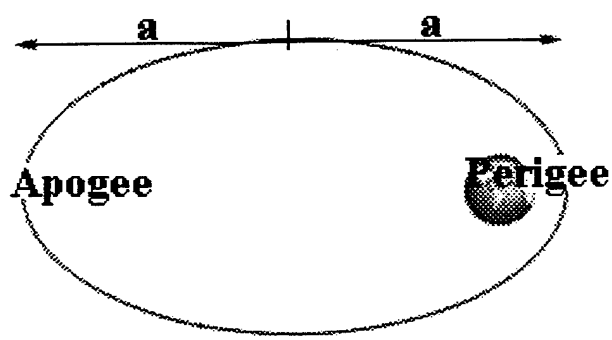

Figure 1. Semimajor Axis, a, of a Satellite's Orbit.

This size is directly proportional to the orbit's specific mechanical energy, ε. The equations defining ε are as follows:

(1-1) $$\varepsilon = \frac{-\mu}{2a} = \frac{V^2}{2} - \frac{\mu}{R}$$

V - magnitude of velocity
R - distance from Earth center
μ - gravitational parameter, 3.986×10^5 km^3/sec^2

In equation 1-1, ε is the sum of the potential energy and kinetic energy of the orbit, disregarding the satellite's mass. The convention used to describe potential energy starts at the Earth's center with no potential energy being assigned a -∞ potential energy. At ∞ above the Earth's surface, highest potential energy is assigned a value of zero potential energy. This convention means that orbits have negative values of ε. Atmosphere-skimming, low-Earth orbits have low (large negative) ε values and large orbits have high (closer to zero) energies.[3] In summary, the larger the orbit, the higher the orbit's energy, and, therefore, the more energy it takes to establish the orbit. Once this convention (lower energies being those with very large negative values) is established, equation 1-1 shows that as size of an orbit increases, energy also increases (approaches zero). Therefore, the satellite's velocity (the right side of the equation) must also decrease. The larger the satellite's orbit, the slower the satellite's speed.

An orbit's eccentricity, e, is a parameter that describes the general shape of an orbit. A value of eccentricity equaling 0, means the orbit is circular with perigee and apogee at equal altitudes. Since the orbit is perfectly circular, the speed of the satellite remains constant throughout its entire orbit. An elliptical orbit, $0<e<1$, does have a perigee and apogee, and therefore the satellite's speed changes throughout the orbit. In the early seventeenth century, Kepler developed his three laws of orbital motion. Kepler's First Law states that all planetary orbits are ellipses with one focus of the ellipse being the Sun. This law also applies to satellites orbiting the Earth. Since a circular orbit ($e=0$) requires the distance from Earth's center to the satellite to remain the same throughout its orbit, it is extremely difficult to attain a perfectly circular orbit. Kepler's Second Law states that orbiting bodies sweep out equal areas in equal times.[4] Another orbital fact follows from this law. Since perigee is the orbit's closest point of approach and therefore the distance from the Earth to the satellite is shorter than at apogee, the satellite must move faster in the vicinity of perigee in order to sweep out the same area in equal time. Therefore, in elliptical orbits, the satellite's speed increases as it approaches perigee and then the speed decreases as it approaches apogee. Figure 2 demonstrates this principle. Again, in circular orbits, the satellite remains at the same speed throughout its orbit.

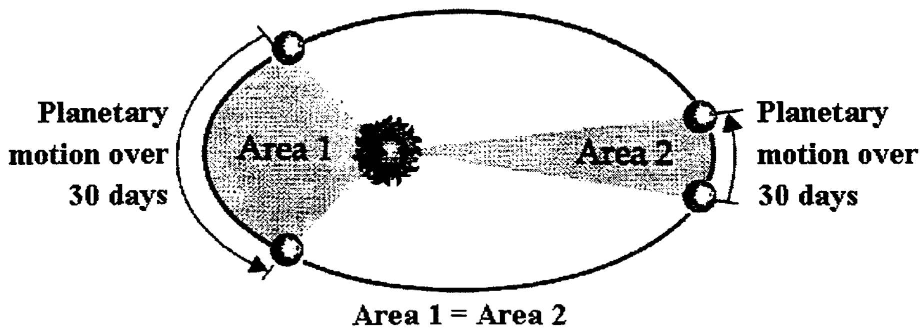

Figure 2. Kepler's Second Law.

Source: Jerry Jon Sellers, Understanding Space: An Introduction to Astronautics (New York: McGraw-Hill, 1994), 37.[5]

Orbital Period

Directly related to orbital size is the orbit's period, P, which is the time it takes for the satellite to complete one orbit around the planet.

(1-2) $$P = 2\pi\sqrt{\frac{a^3}{\mu}} \;;\quad \mu = 3.986x10^5 \text{ km}^3/\text{sec}^2$$

In equation 1-2, the units of P are seconds and a is expressed in kilometers. As the size of the orbit increases, the period increases. In other words, it takes significantly longer for a slower satellite to complete one revolution around a larger orbit. This period directly effects the perceived speed that the satellite appears to move across the sky for a ground observer. For example, if a communications satellite was in an orbit altitude of 400 nautical miles, a warfighter in the field would see this satellite move from horizon to horizon in approximately 10 minutes, fairly fast for a transceiver dish to track. On the other hand, if the satellite was at 22,000 nautical miles, the satellite would appear almost motionless in the sky above the warfighter.

Orbital Inclination

Satellite orbits lie within a plane called the orbital plane. The angle of the orbital plane from the equatorial plane is the orbit's inclination, i. Figure 3 demonstrates inclination.

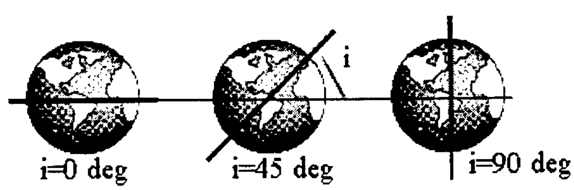

Figure 3. Orbital Inclination.

An equatorial orbit is an orbit with a zero degree inclination; the satellite orbits solely over the equator. A polar orbit is an orbit with an inclination of ninety degrees; the satellite passes over both the north and south poles.

Field of View

A telecommunications satellite's field of view (FOV), sometimes known as its "footprint," determines what areas on Earth are capable of using the satellite's capabilities. This footprint is a function of both the satellite's altitude and the communication system's characteristics. Footprint issues are sometimes of greater importance to the warfighter than any other communications satellite issue. For example, the Iraqi invasion of Kuwait in August of 1990 required numerous satellite adjustments involving footprint issues on the military telecommunications satellites that were operational at the time. A Defense Satellite Communications System (DSCS) III antenna, with a small FOV, previously covered the Persian Gulf area. The Defense Information Systems Agency (DISA) immediately took action to swap the antenna with a wider FOV, multibeam antenna that was previously reserved for use by Continental U.S. (CONUS) strategic defense users.[6] Also, a reserve DSCS III was in orbit, but over the western Pacific Ocean. Its footprint barely reached the Persian Gulf region. This satellite was maneuvered to a position over the Indian Ocean to improve coverage of the Iraq-Kuwait theater of operations.[7]

In general, the higher the satellite, the larger the field of view. Low-Earth satellite's, skimming the atmosphere at 400 kilometers, "see" less of the planet's surface than those satellites at an altitude of 36,000 kilometers.

The communications system itself factors into a telecommunications satellite's FOV. The type of antenna, size of antenna, and the operating frequency determines a system's beamwidth.[8] Beamwidth is the angular diameter of the system's transmitted signal. This parameter becomes a constraint when determining a telecommunications satellite's serviceable area.

An example demonstrates the interplay of these factors in determining a satellite's FOV. The aperture size and visual frequency of the human eye gives it an angular FOV of 130 degrees (65 degrees on either side of center).[9] From an equatorial satellite at 1,000 kilometers altitude, the relative horizon is approximately 60 degrees away from the point directly below the satellite. Since the human eye has a greater FOV (65 degrees either side of center), the limiting factor is the altitude. Therefore, if a set of human eyes were on the satellite, they could see a cone of area on the surface reaching up to 60 degrees north and south latitudes and 60 degrees east and west longitude of center. But, if the communications system used a parabolic antenna with a diameter of one meter, transmitting at one Hertz (Hz), then its beamwidth would only be 21 degrees. This limit would only allow the satellite to view areas 1.65 degrees north, south, east, and west of the point below the satellite. In this case, the beamwidth of the satellite is the limiting factor in the satellite's footprint.

Orbit Types

A few special types of orbits are important to the topic of telecommunications satellites. The first type of orbit deals with the orbit's inclination. An equatorial orbit, inclination of zero degrees, places the orbital plane along the Earth's equator. A telecommunications satellite of this type can provide service to areas around the equator and, depending on its field of view, areas north and south of the equator. Northern and southern latitudes might remain unserviced by this type of orbit if the FOV is not large enough; the satellite is either too low or the beamwidth is too small. Polar orbits, on the other hand, allow the Earth to rotate underneath the orbital plane and eventually the satellite passes over all areas on the planet. This orbit may be desirable for satellite applications, such as weather satellites, that require global coverage at the expense of immediate availability; but telecommunications satellites typically must function continuously.

When a satellite's orbit size is increased, its period increases. If an equatorial orbit is made large enough, a period of 24 hours results. A period of 24 hours means that the satellite will orbit the planet once every 24 hours, which is the same time that it takes the Earth to rotate once on its axis. This special orbit allows the satellite to remain over the same place on the equator throughout its orbital lifetime. These orbits are called "geostationary." The orbit size that creates this orbital period is a semimajor axis of approximately 42,000 kilometers or an altitude of approximately 36,000 kilometers. These two numbers are different because the semimajor axis is measured from the Earth's center and the altitude is measured from the Earth's surface. There are two major advantages of this type of orbit. First, at 36,000 kilometers, the satellite's footprint is very large, giving it a large serviceable area. This large service area requires fewer satellites in the system to service the entire planet. Second, since the satellite remains fixed within its service area, the communications system is continuously available and does not require any special, tracking antennas. A disadvantage also exists. Because of this large distance, these geostationary telecommunications satellites have much higher transmission power requirements compared to a satellite orbiting at 400 kilometers.

Telecommunications Terminology

Some basic terminology is discussed in order to examine the capabilities and limitations of telecommunications satellites. These terms are commonly used in the design and analysis of communications assets.

Bandwidth

Bandwidth is the most commonly used measure of a communication satellite's overall capability. Bandwidth is defined as the total range of frequencies that a communications system is designed to receive and transmit.[10] This measure is analogous to the size of an electrical wire; the larger the wire, the more current can flow through it. The larger the bandwidth, the more communications traffic can flow through that system. These frequency bands are typically categorized into the Ultra-High Frequency (UHF), Super-High Frequency (SHF), and Extremely-High Frequency (EHF) ranges of the spectrum. A description of the frequency ranges found within each of these frequency bands is found in Table 1.[11] A single, voice telephone call requires an extremely small bandwidth to service it, but thousands of voice calls or some video conferencing requirements can quickly require more bandwidth from a system than it was designed to carry. From Table 1, it is clear that much more total bandwidth exists in the EHF band, 270 Gigahertz (GHz) than in the UHF band, 2.7 Gigahertz.

TABLE 1

FREQUENCY RANGES FOR COMMUNICATIONS SYSTEMS

Band	Frequency Range (GHz)
UHF	0.30 - 3.00
SHF	3.00 - 30.0
EHF	30.0 - 300.0

Examples of UHF systems in use by warfighters are the UHF Follow-On (UFO) satellites that provide UHF voice and data services to the field and International Maritime Satellite (INMARSAT), a commercial communications satellite that was leased during the Persian Gulf War to boost UHF capabilities in the theater. UHF frequencies provide omni-directional transmission capabilities that negate the need for large dish antennas and strict pointing tolerances. This feature makes these systems the communications choice for the individual warfighter in the field who seeks ease of use and small, mobile transceivers. Weather or foliage does not adversely affect UHF; but on the downside, they are much more susceptible to noise, interference, and jamming. SHF is not as susceptible to interference and jamming as UHF systems and provides much higher bandwidth and data rate capabilities. EHF systems, the premier system being the Military Stategic and Tactical Relay Communications Satellite System (MILSTAR), provide very high bandwidths and are very difficult to jam.

Transponder

A transponder is a receiver-transmitter combination that simply retransmits the data received by that satellite.[12] Communications satellites and data-relay satellites accomplish their missions through the use of these transponders. Multiple transponders can exist on a single satellite. If a satellite is rated at a bandwidth of 400 Megahertz with four transponders, this bandwidth is not 400 Megahertz on each transponder, but 100 Megahertz per transponder for a total of 400 Megahertz. Typical commercial telecommunications transponders are usually rated at 36 or 72 Megahertz.

Data Rate

The data rate is the number of digital bits per second (bps) a communications system handles.[13] The system's maximum data rate will determine the type of information that the satellite can process. The required data rate for a piece of information is a function of the number of samples per second required and the number of bits per sample. High-resolution pictures contain many bits of data per picture (a high bit per sample). If the samples per second requirement is low (for example, if the user can wait an hour to receive one picture), then the required data rate remains low. If the pictures must come through in a real-time presentation, as in a color television monitor of a video-conference, the pictures per second rate is also high and the system's required data rate is very large.[14] A communications system that is not designed for this high data rate cannot accomplish that function.

Use of Telecommunications Satellites in Wartime

Many of the players that participated in Operations Desert Shield and Desert Storm commented on the lack of communications available in the theater of operations. As planning cells formed in the initial deployments of Desert Shield, many cells found themselves planning the defense of Saudi Arabia with access to one telephone. The Air Operations Center, charged with coordinating the combined air operations of the Navy, Marines, Army, and the Air Forces of various coalition countries operated with a bare minimum of communication assets. This conflict was seen as the world's first war where communications assets played a pivotal role in the outcome.[15] Cursory indications show that present military satellite telecommunications systems are already operating at near maximum capacity in peacetime conditions. If this high usage level is the case, then the telecommunications requirements that result from any large military operation could easily require more from the military's deployed satellites than they are able to provide. During the Gulf War, the coalition allies used a variety of communications systems. The lack of capacity on Western military satellites prompted the coalition to use numerous commercial satellites to bolster the bandwidth requirements. Transponders on Soviet spacecraft were also rented.[16]

Modern battlefield demands on communications requirements have only increased since the Gulf War. The Army's drive to digitize the battlefield requires broad bandwidth requirements. Real-time processing of intelligence information and the projection of this information across all functional areas is pushing data rate requirements into the gigabit per second region.[17] The answer to meeting these needs seems to lie in a combination of three areas. One answer would be to decrease the requirements, which seems a monumental task in the face of the headlong rush to provide more information, at higher fidelity, to more users. Another answer is to build and to deploy more military satellites. In the face of present budgetary constraints, this answer does not appear to be viable. Leasing of commercial satellites to augment military shortfalls is yet another option. This option is the topic of this research project.

Thesis Questions

This thesis examines the use of commercial telecommunications satellites in the role of augmenting military systems. Specifically, this thesis examines the effective military use of the Iridium satellite system under development by Motorola. The primary research question is as follows: Can the commercial telecommunications satellite system Iridium effectively support the theater commander? The word "effectively" requires an analysis of the suitability, feasibility, and acceptability of the Iridium system. "Suitability" means the system must provide a required service. "Feasibility" means the system must fulfill the military needs by providing capabilities the military requires. Finally, "acceptability" means the system must give the military what it needs at an acceptable cost. The thesis seeks to determine if augmentation of telecommunications assets is necessary and if the Iridium satellite system can properly augment the force. Areas of augmentation that are not considered are explained in the "Delimitations" section of this chapter. It is difficult to answer this question directly. There are three aspects of this research question which are based on the three elements of the term "effectively." In order to piece together all the aspects that are contained in the primary research question, the question is divided into three subordinate questions. These three secondary questions are as follows:

1. Can Iridium provide a suitable telecommunications service to the military?

2. Can Iridium provide a feasible telecommunications service to the military?

3. Is the use of Iridium economically acceptable?

These three subordinate questions address three different issues inherent in the primary research question. Initially, the thesis must show the present state of theater communications. If enough assets presently exist, then additional assets in the form of Iridium are unsuitable. The thesis must then describe the capabilities and limitations of Iridium. Capabilities and limitations are examined in order to determine if Iridium is a feasible choice to augment military assets. Feasibility of the system includes issues of compatibility, interoperability, and a tradeoff between capabilities and limitations of the system. Finally, the acceptability of using Iridium addresses the costs of using this satellite system.

The first secondary question addresses whether a shortfall in communications assets is a true and relevant situation. There is no need to augment a theater commander's communications assets if he has all he needs in the first place. The second subordinate question addresses the feasibility of using the satellite system, Iridium. Will these satellites get the job done? Finally, the third subordinate question explores the acceptability of placing the commercially owned satellites under military control during an outbreak of hostilities. In order to further guide the research into specific tracks, each of these three secondary questions are broken into tertiary questions. These questions create a pyramidal approach to answering each of the secondary questions. The following paragraphs describe the approach taken to answer each of the secondary questions.

The first secondary question deals with whether or not the problem situation actually exists. The question is stated, "Can Iridium provide a suitable telecommunications service to the military?" Simply, is Iridium a suitable choice for theater telecommunications assets during contingency situations? To answer this question, the following questions are answered:

1a. What are the present telecommunications assets provided for theater operations?

1b. To what level of total capability are the present telecommunications assets currently tasked?

1c. What are the shortfalls between the requirements and the capabilities of current systems?

1d. Can Iridium meet the shortfall in current satellite capabilities?

The second subordinate question deals with the feasibility of commercial satellite systems: "Can Iridium provide a feasible telecommunications service to the military?" Simply, do these commercially owned satellites have the ability to handle the military's communications equipment, security, procedures, and any special technical requirements? To answer this question, the following tertiary questions must be answered:

2a. What are the capabilities and limitations of Iridium?

2b. What are the capabilities and limitations of UHF Follow-On?

To provide a basis to answer these questions, the technical specifications of the military and commercially-owned systems are analyzed. As is explained in the "Delimitations" section of this chapter, a study of the technical abilities of Iridium satellite system must be accomplished. Iridium, manufactured by Motorola, is the prime example used to address the second subordinate question. Comparisons with a deployed military satellite system, UFO Follow-On (UFO), is accomplished. This work must highlight the capabilities and limitations of the Iridium system.

The third secondary question explores the acceptability of using Iridium, a commercial satellite, as a ready-reserve telecommunications asset. To answer this final secondary research question, answers to the following tertiary questions are required:

3a. What is the cost of the UHF Follow-On satellite system?

3b. What is the cost of using Iridium on a contingency basis?

To answer these questions, the cost of leasing and using Iridium during wartime must be compared with the costs of building and deploying a comparable military system such as UHF Follow-On.

Assumptions

In order to place the research into perspective, the following assumptions are made prior to exploring this research topic:

1. The communications requirements of present day and future theater operations either remain constant or increase in relation to the time of Desert Storm.

2. The perceptions of staff and commanders during the Desert Shield and Desert Storm campaign are valid and reliable indicators of the communications situation in the theater.

3. Motorola, the maker of Iridium, is willing to lease the communications satellite system to the military.

Limitations

Much of the research material involved in this thesis contains classified material on the technical aspects of many military and commercial communication satellites. In a manner similar to military classification systems, corporations do not easily distribute the technical aspects of their products, especially in their research and development phase. This proprietary guarding of information is especially true of Iridium which is a unique system not yet deployed. Therefore, this research did not have unlimited access to the technical and operational information on Iridium.

Delimitations

In the process of answering the research question, the scope of this project must be limited by the following seven constraints.

1. No classified research material or any material related to classified projects is used to answer the research questions.

2. Comparisons between military and commercial satellite capabilities, limitations, and costs are limited to UFO and Iridium.

3. The upgrading of present military systems with increased capabilities is not discussed.

4. The specific capabilities of one commercial satellite system, Iridium, is the only system analyzed.

5. The concept of ready-reserve communications forces is discussed in a general way and the thesis will not attempt to outline specific details of any proposed leasing agreements.

6. The feasibility and suitability discussions are restricted to only the general capabilities of telecommunication systems and they do not address technical specifications and design parameters.

7. The suitability, feasibility, and acceptability study pertains only to the operational and tactical considerations. The thesis will not enter into analyses and conclusions concerned with the strategic factors associated with using commercial satellites for military purposes. Strategic factors include questions, such as the following: How does the country defend against an enemy using a transponder on the same commercial satellite that the U.S. military is leasing?

Endnotes

[1]Peter Anson, "The First Space War: The Contribution of Satellites to the Gulf War," Journal of the Royal United Service Institution 136 (Winter 1991): 45.

[2]Anson, "The First Space War: The Contribution of Satellites to the Gulf War," Journal of the Royal United Service Institution, 46.

[3]Jerry Jon Sellers, Understanding Space: An Introduction to Astronautics (New York: McGraw-Hill, 1994), 111.

[4]Sellers, Understanding Space: An Introduction to Astronautics, 37.

[5]Sellers, Understanding Space: An Introduction to Astronautics, 37.

[6]Alan D. Campen, "Gulf War's Silent Warriors Bind U.S. Units via Space," Signal 45 (August 1991): 82.

[7]Craig R. Jachens, "DSCS Support to Tactical Users During Operations Desert Shield and Desert Storm," Briefing prepared for the Defense Information Systems Agency, DSCS Network Management Directorate, 1991, 10-17.

[8]Wiley J. Larson and James R. Wertz, Space Mission Analysis and Design (Torrance, CA: Microcosm, Inc., 1992), 539-544.

[9]Sellers, Understanding Space: An Introduction to Astronautics, 357.

[10]Sellers, Understanding Space: An Introduction to Astronautics, 530.

[11]Sellers, Understanding Space: An Introduction to Astronautics, 352.

[12]Larson, Space Mission Analysis and Design, 518.

[13]Larson, Space Mission Analysis and Design, 514.

[14]Larson, Space Mission Analysis and Design, 515.

[15]"Communications Problems in the Gulf War," Asia-Pacific Defense Reporter 18 (April-May 1992): 40.

[16]"Communications Problems in the Gulf War," Asia-Pacific Defense Reporter, 40.

[17]"Modern Battlefield Demands Digital Data at Gigabit Rates," Signal 48 (November 1993): 51.

CHAPTER 2

LITERATURE REVIEW

No literature has been written that specifically examines the military use of the Iridium telecommunications system. However, there are many sources of information concerning the proliferation of telecommunications satellite systems. There are also many references concerning the concept of the military use of commercial telecommunications satellite systems. This lease program, called Civilian Reserve Information Systems (CRIS) has been used in the past and provides a dialog on many of the issues that this thesis attempts to address. No analysis of the usefulness of commercial communications satellites could be accomplished without first building an understanding of the engineering aspects of the telecommunications satellite business. Therefore, the literature review is divided into four sections. The first section covers those references that build a background knowledge of engineering of a telecommunications system. This background is crucial in understanding a system's capabilities and limitations and provides a basis for determining a system's usefulness to a military commander. This section also contains descriptions of those references that describe the space environment and basic orbital mechanics. The unique qualities of this environment where satellites operate also helps to determine a communications system's abilities or limitations. The remaining three sections of this chapter correspond to the three secondary research questions. The second section provides references to literature that describes the past military use of commercial telecommunications satellites. Sections three and four introduce the literature that describes the capabilities and limitations of military telecommunications satellites and commercial telecommunications satellites, respectively. The literature in sections three and four is crucial in comparing the Iridium system to present military systems and in determining the feasibility and acceptability of leasing Iridium for military use. Specific subsections are dedicated to the UHF Follow-On (UFO) military system and the commercial Iridium system.

Engineering Aspects of Telecommunications Satellites

This section describes some of the literature used in this thesis to build the engineering background required to answer the primary research question. This literature describes the various system design parameters of telecommunications satellites. These parameters enable an analysis of system capabilities.

A cooperative effort between the United States Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) produced the Space Technology Series. One book of this series Space Mission Analysis and Design contains a complete chapter on communications architecture and a chapter introducing some of the basic concepts of astrodynamics. The author describes the various factors that are considered when designing or evaluating a communications system:

> Individual users will assign different priorities to the criteria for selecting a communications architecture. For example a commercial company will try to reduce cost and risk, but the

military may make survivability the top priority. The factors which affect the criteria are explained below:

Orbit: The satellite orbit determines how much the satellite is in view by the ground station and the potential need for intersatellite links. The satellite altitude determines Earth coverage, and the satellite orbit determines the delay between passes over a specified ground station. Together orbit and altitude set the number of satellites needed for a specified continuity of coverage. Transmitter power and antenna size depend on the distance between the satellites and the ground stations.

R_f Spectrum: The carrier frequency affects the satellite and ground station transmitter power, antenna size and beamwidth, and requirements for satellite stabilization. In turn, these factors affect satellite size, mass, and complexity. The carrier frequency also determines the transmitter power needed to overcome rain attenuation.

Data Rate: The data rate is proportional to the quantity of information per unit time transferred between the satellite and the ground station. The higher the data rate, the larger the transmitter power and antenna size required. Processing the data on board the satellite reduces the data rate without losing essential information, but makes the satellite more complex.

Link Availability: Link availability is the time the link is available to the user divided by the total time. Typical goals for availability range from 0.99 to 0.9999, the latter value applying to commercial telecommunications networks.

Link Access Time: The maximum allowable link access time, or time users have to wait before they get their link, depends on the mission. For example, we usually demand access to a voice circuit in seconds.[1]

Space Mission Analysis and Design also provides a background in basic astrodynamics, the study of satellite orbits. The laws that govern a satellite orbit create a special set of capabilities and limitations that can impact a telecommunications satellite's utility. The book provides information on the basic concepts of orbital motion, constants of motion, standardized description of orbits, and ground tracks.

A more complete reference in this area is Jerry Jon Sellers' book Understanding Space: An Introduction to Astronautics. As the title implies, this literature provides a complete, but less rigorous, introduction to the concepts of orbital motion. The book provides more than adequate descriptions of various orbit types, their advantages, and limitations. It provides a complete development on how an orbit's size affects the satellite's field of view and, therefore, a telecommunications satellite's serviceable area. The concept of multiple satellites in an orbital constellation is the design of the Iridium satellite system. The concept of constellations are summarized in the following paragraph:

> The size of orbit will also dictate the spacecraft's field of view. The *field of view* (FOV) is the angle which describes the amount of the Earth's surface the spacecraft can see at any one time. In other words, the higher you are the more you can see. The total amount of ground seen at any one time is the *swath width*.
>
> Some missions require continuous coverage of a point on the Earth or the ability to communicate from one side of the planet to the other. When this happens, a single spacecraft usually can't satisfy mission requirements. Instead, we build several identical spacecraft and place them in different orbits to cover the required area. A *constellation* is a collection of spacecraft deployed in several orbits to accomplish a single mission. With higher mission orbits, fewer satellites are needed to provide world-wide coverage.[2]

An exhaustive source of literature concerning the engineering aspects unique to telecommunications satellites is the Communications Satellite Handbook by Morgan and Gordon. This reference provides a deeper and more rigorous description of communications satellite design.

As discussed in Chapter 1, communications satellites fall into three general categories: UHF, SHF, and EHF systems. These categories each deliver advantages and disadvantages for the military user. System costs are greater with EHF systems than with UHF systems, but higher bandwidths, and therefore, higher bits per second are achievable with the EHF system. Susceptibility to noise and jamming is also greater in the lower frequencies, especially UHF bands. These issues are discussed in the Journal of Electronic Defense. The journal interviewed Commander Austin Boyd, branch head for naval satellite communications within the Staff of the Chief of Naval Operations.

> For example, "At the UHF level, there is no jam protection," admitted Commander Boyd. UHF receivers will capture the strongest signal in its footprint for transmission; if that signal happens to be jam-induced noise, so be it. Commercial systems also lack any significant antijam capabilities.
>
> The SHF satellites have some inherent antijamming capability, said the commander. While he declined to reveal details, he said antijamming in this frequency requires significant tradeoffs. "As you increase its jamming protection, you will decrease the number of bits going through the pipe," he explained, "And you can achieve very, very great jam protection at a very large penalty to your total throughput."
>
> For mission-critical communication, EHF satcom is the answer. "In the EHF world, you have complete antijam, complete low probability of intercept/low probability of detection capability," Commander Boyd said.[3]

Military Use of Commercial Telecommunications Satellites

There is a moderate amount of literature written on the military use of commercial telecommunications satellites, most of which is of a historical nature. In order to organize this material, this section is further subdivided into three subsections: information from Desert Shield/Storm concerning communications demands; present and future use of commercial telecommunications satellites; and the military leasing program for commercial satellites. These sources document the military use of commercial telecommunications assets during various operations, with Desert Shield/Storm having the most readily available documentation. The first subsection contains most of the literature that documents satellite communications during Desert Shield and Desert Storm. Other literature described in this section outlines the concept of a ready-reserve "fleet" of commercial telecommunications satellites.

Commercial Satellites in Desert Storm

The available literature that describes the military use of commercial satellites during Operations Desert Shield and Desert Storm is abundant, but almost completely in the form of periodical articles and governmental documents. These articles serve to provide information which partially answer the first of the secondary research questions: Can Iridium provide a suitable telecommunications service to the military? "Communications Problems in the Gulf War," from the Asia-Pacific Defense Reporter, documents the use of commercial telecommunications satellites during the war:

> In particular, critical satellite links were vulnerable to jamming, and the lack of capacity on dedicated Western military satellites apparently obliged the coalition to switch to commercial satellites and even lease transponders on Soviet spacecraft.[4]

This same reference also alludes to deficiencies in the deployed military systems, many of which are still in use today:

> In space, the lack of orbiting capacity on the US Defense Satellite Communications Systems (DSCS) presented allied forces with serious problems. Prior to the invasion of Kuwait, the one satellite giving area coverage in the Gulf was already three years past its original design life. As preparations for Desert Storm mounted, a second DSCS satellite was re-positioned in space to act as a back-up for the allies. This vehicle was also beyond its design life, and its primary tube failed the day it was due to be activated. Fortunately, for all involved, the back-up tube in the satellite was still functional.

As well as DSCS, the allies used the UK's Skynet II satellite, and an experimental extra-high frequency capability provided on the US Navy's Fleet Satellite Communications System. It is estimated that up to 25 percent of capacity had to be provided on commercial systems such as Intelsat and Inmarsat.[5]

Other literature documents the various factors that have driven the United States to seek communications augmentation from commercial sources. An issue that is highlighted in these references is the preplanned or "ready-reserve" use of commercial telecommunications satellites. Most of the literature points out that, for various reasons, more attention must be paid to the availability of commercial satellites. The International Defense Review carried an article, "Satellite Communications: More Bandwidth and Terminals Needed," that describes one such reason during the Gulf War:

> The long service life of modern satellites, and the flexibility of their operation, means that forces normally have to fight with the space resources that are in place at the outbreak of a conflict. The United States launched only three satellites during the six months of the Gulf War, and these were all NavStar [GPS - navigational] vehicles that had been on the manifest for several years. By contrast, the USSR launched 29 satellites in 69 days during the 1982 Falklands conflict.
>
> Military planners have long relied on commercial facilities to make up the shortfall. When they looked into this source in the early stages of Operation Desert Shield, however, they found that only one T1 (1.544Mbit/s) trunk for Riyadh was available on any commercial satellite. The rest had already been reserved by television networks for live coverage of the forthcoming war.[6]

This same reference also provides information on the clearinghouse organization the US government maintains to assist in the use of commercial telecommunications satellites:

> The US Defense Information Systems Agency spent some $160 million on commercial satellite services in 1991. US forces alone used more than 20 comsats [commercial satellites] during the Gulf War, including a wide range of commercial facilities. The US National Coordinating Center for Telecommunications (NCC), which is responsible for assisting government organizations in obtaining

critical telecommunications services during a crisis or emergency, acted on 137 requests for such services (involving a total of 430 circuits or systems) during the conflict.[7]

The requirements and demands placed on the communications architecture during wartime is also of concern to this study. Current projections in this area are classified because of the sensitivities involved with creating conclusions as to the US military's capability of handling a future regional war given the present level of satellite communications capability. Nonetheless, some useful information for this research is obtained from case studies of the Gulf War. Peter Anson's article in the RUSI Journal, entitled "The First Space War: The Contribution of Satellites to the Gulf War," provides some useful information about the additional communications load that was required on military SHF communications assets, such as the Defense Satellite Communications System (DSCS). Similar usage rates can be postulated in the UHF bands also.

> The flexibility of space communications was brilliantly demonstrated by US authorities in a reconfiguration of their space segment to match traffic demands. Prior to hostilities, the US space communications workhorse, the SHF Defense Satellite Communications System (DSCS) provided the strategic and tactical telecommunications cover of the area through its Eastern Atlantic (EA) and Indian Ocean (IO) satellites. The total DOD traffic throughput over these two satellites was about 4.5 Mb/s - equivalent to around 70 commercial voice circuits. A little more than 1 month later, with the first US forces in theatre, 48 tactical terminals had been deployed, the traffic throughput had risen to 38 Mb/s (600 voice channels), and DSCS IO was saturated. Traffic demands were still building.
>
> By the time traffic to US forces in the Gulf had peaked, yet another SHF satellite, DSCS Indian Ocean Reserve was available, the throughput had risen to 68 Mb/s (1100 voice circuits) and the earth station population was 115. In commercial terms, US DSCS satellites were providing channel capacity costs at around $14 million per month - had the traffic been carried on commercial carriers.[8]

The Present and Future for Commercial Satellites

Other sources provide a look into the future of military use of commercial systems. Some of these sources draw specific conclusions concerning the coming reliance the military will have on commercial telecommunications satellite systems. For example, The Journal of Electronic Defense in an article, entitled "Catching Falling Stars," concludes that the military will move toward even further use of commercial systems:

> The services therefore should place first priority on refurbishing the capabilities that are most specific to military communications, EHF and UHF. In fact, said the commander [Commander Austin Boyd, branch head for naval satellite communications within the Staff of the Chief of Naval Operations], it probably doesn't make sense for the military to assume responsibility for replacing the DSCS SHF capability at all. Present commercial capability in SHF (in C- and Ku-band) is 100 times greater than the military will require. "That says to the Navy that it's a bad idea for us to specify, design and build within the Services' acquisition force a follow-on to DSCS," he explained. "Because all we need to do is tell the commercial guys to build us something that talks in X-band and pretty much leave the choice up to them what it looks like. The commercial guys are . . . in a much better position to make those decisions, and we could get a much more effective and economic product."[9]

The article goes on to discuss the future in the UHF and EHF bands. It is not as clear whether commercial sources or committed military systems will provide the more effective services to the military in these bandwidths. Much of this question depends on how much money is available, the availability of inexpensive launch vehicles, and the future of placing cross-band capabilities on single platforms and constellations.[10]

Leasing of Commercial Satellites

Literature is also available on the general concept of the military use of commercial assets. The issues associated with the military use of commercial systems are numerous. Not only are system capabilities, survivability, and costs considered, but legal issues are also debated. In a lengthy paper delivered in The Journal of Air Law and Commerce, entitled "Military Use of Commercial Communications Satellites: A New Look at the Outer Space Treaty and "Peaceful Purposes," Richard Morgan, a legal advisor to the United States National Communications System, writes about the legal issues facing the military and its use of commercial telecommunications satellites. The purpose of the extensive article was to explore the extent to which the US military can exploit the growing satellite systems the commercial sector is offering and still remain within the confines of international law. Morgan recognizes the growing reliance the military is placing on commercial systems as defense budgets shrink, military area coverage dwindles, and as civilian companies' technologies outpace the military acquisition process.[11] The legal analysis of the issue of military use of space systems is based on the "1967 Outer Space Treaty," which states, among other articles:

> The establishment of military bases, installations, and fortifications, the testing of any type of weapons and the conduct of military maneuvers on celestial bodies shall be forbidden. The use of military personnel for scientific research or for any other peaceful purpose shall not be prohibited.[12]

The question that gives the legal community the fuel for debate is over the meaning of the words, "peaceful purpose." Is the military use of commercial telecommunications satellites in wartime a violation of the Treaty? The question is especially timely considering the increasing military use of space. Innovative technologies and the force enhancements properties of space communications have caused the Department of Defense (DOD) to dramatically increase its use of off-the-shelf telecommunications satellites. Advanced expertise in the civilian sector means the military looks first to commercial systems when trying to achieve enhanced, yet economic, capabilities. With satellite communications requirements predicted to far exceed the existing and planned capacity of the military satellite communications systems by the year 2010, commercial exploitation is a must.[13]

A Rand study, conducted for the Defense Information Systems Agency (DISA), pointed out several advantages to the military in using commercial telecommunications satellites. Some of those advantages include avoidance of development costs, excess capacity available, and interoperability. Iridium was also mentioned in the report:

> The DISA suggested that Motorola's IRIDIUM and Loral's CELLSAT could meet DOD requirements for handheld "man-portable" voice terminals with connectivity to both the PSN [public switched network] and government switched network from anywhere in the world.[14]

The paper analyzes the charters of the United Nations, the International Maritime Satellite (INMARSAT) organization, and the International Telecommunications Satellite (INTELSAT) organization. The latter two organizations are major international consortiums where consignees agreed to combine efforts to operate commercial satellites. Each of the member nations, similar to the United Nations, signed agreements on the conduct of the organization. INMARSAT contains a "peaceful purposes" clause similar to the "1967 Outer Space Treaty," but

INTELSAT does not. Legal analysis on this issue is similar to the treaty:

> The DISA said that the "peaceful purposes" clause of the INMARSAT Convention "could be interpreted to prohibit military tactical use of the system for combat operations. It has not been interpreted to preclude military administrative and support use."

> The U.S. Department of State, in its written coordination of the USN JAG opinion stated: The Convention does not define "peaceful purposes," and its negotiating history does not suggest a specific meaning. Under such circumstances, the term "peaceful purposes" should be given meaning that it has been accorded under the law relating to space activities. Under such a reading, "peaceful purposes" does not exclude military activities so long as those activities are consistent with the United Nations Charter.[15]

The bottom line appears to be that unless a military activity is specifically addressed in the treaty or charter, the activity will remain legally unchallenged without a formal dispute. No such disputes have ever occurred because of US commercial telecommunications use.[16]

> Those who urge that there is no distinction between peaceful "purposes" and peaceful "uses" do the greatest injustice to the concept. Commercial satellites may be "used" to support tactical military operations involving the use of armed force, yet not have a non-peaceful "purpose." The Gulf conflict is perhaps the best illustration of the distinction between "use" and "purpose." The coalition forces, INTELSAT, and INMARSAT need not be embarrassed about the obvious military uses made of commercial communications satellites there when "use" of commercial satellites was in support of tactical military operations. The "purpose" of the use, however, was in support of U.N. resolutions to restore a "climate of peace."[17]

In addition to the literature concerning the legal issues of military leasing of satellites, other literature describes the actual concept of the leasing agreements. As the US Air Force leases civilian aircraft in time of war to augment their airlift capability, various sources describe the placing of commercial telecommunications satellite systems on a ready-reserve status. This concept is known by many names including the Commercial Reserved Space System Program (CRSSP) the

Civilian Reserve Information System (CRIS). The concept is very similar to the successful Civil Reserve Air Fleet (CRAF) program. The CRAF allows the military to lease civilian airliners during the surge requirements of wartime. During peacetime, the military pays a yearly lease rate to these airlines to purchase the ability to use them should a war or conflict occur that requires a supplement to the military airlift capabilities. Once called to use, the airliners are mostly used for general passenger (troop) transport and standard fees per passenger are paid to the airline. A paper written for the Army War College, entitled "Civil Reserve Information Services (CRIS) Concepts and One Possible Solution," documents how this same general concept of a ready-reserve civilian fleet is extended toward space communications satellites. The paper describes CRIS as:

> A program that is designed to be activated only when a critical need to augment Defense systems exists. The program will fill the gap between day-to-day requirements and surge requirements needed during a crisis. For example, as in the CRAF program, the day-to-day military airlift requirements are handled by Air Force aircraft. Only during a committed expansion beyond the capabilities of the Military Airlift Command is CRAF activated. The CRIS program will be similar. During non-crisis periods, civilian communication and information services will be identified, organized and developed under the CRIS program. These services will be tailored so they can quickly augment the DOD in a national emergency. Because the CRIS program will be voluntary, companies will need encouragement to participate. For those who decide to be part of the CRIS program, the incentives offered must make good business sense. Additionally, any monies needed for modifications to a civilian system, to make it more compatible to DOD requirements, would be paid by the government.[18]

The paper continues on to outline the future of Army communications needs into the twenty-first century. Redundancy, heavy reliance on satellite communications, and mobility are the common threads running through the descriptions of Airland battle into the turn of the century. The U.S. and NATO requirements are projected to center around highly mobile satellite communications systems. The paper claims that the military will seek commercial leasing and buying options to support and augment existing military systems. The U.S. Army Signal Corps supports the future Army with small, mobile satellite communications systems. The deployment of these systems is accomplished with minimum airlift requirements and worldwide coverage. The bottom-line associated with these requirements is obvious: "The worldwide coverage aspect of these systems will become especially critical as the U.S. Army moves to a more CONUS based contingency force."[19] Of the greatest concern to this research, this paper goes on to identify Iridium as a possible candidate for the CRIS program. The Iridium system is described and then examined for its military effectiveness.[20] These six pages are cursory, but provide a framework from which to compare and contrast the research methodology in this project.

Military Telecommunications Satellites

The literature in this section, though plentiful, is more difficult to collect. As delimited in Chapter 1, this thesis will remain unclassified. Much of the existing information concerning military satellites is either classified or sensitive enough to be difficult to acquire. This section is further divided into two subsections. The first will include literature that discusses military communications satellites in general while the second subsection will include those sources that specifically address the military systems in the UHF band.

Military Communications Satellites at a Glance

A short description of the early 1990s satellite systems can be found in Marcia S. Smith's study for the Congressional Research Service, "Military and Commercial Satellites in Support of Allied Forces in the Persian Gulf." She describes the basic capabilities and uses of all the military communications systems operational during the Gulf War:

> The **Defense Satellite Communications System (DSCS)** was developed and operated by the Air Force and is now operated jointly by Air Force and Army Space Commands. DSCS satellites operate at Super High Frequencies (SHF). The **Fleet Satellite Communications (FLTSATCOM)** and **LEASAT** systems, under the control of Navy Space Command, operate at Ultra High Frequencies (UHF); FLTSATCOM also has an SHF uplink. LEASAT stands for Leased Satellite, and, as the name implies, they are leased (from Hughes Aircraft) rather than owned by the government (the satellites are also known as Syncom). Two DSCS II, four DSCS III, two FLTSATCOM, and four LEASAT satellites reportedly are operating now.
>
> The **Air Force Satellite Communications (AFSATCOM)** system consists of transponders on the FLTSATCOM and DSCS satellites. The AFSATCOM system operates at UHF frequencies and is operated by the Air Force.[21]

Military UHF Systems

The Navy, through Naval Space Command, manages much of the Department of Defense UHF satellite fleet. In a January 1995 article in the Journal of Electronic Defense, this UHF capability is summarized:

> Four networks provide satcom [satellite communications] in this frequency band [UHF]: 1) Gap Filler Satellites, the oldest "birds" in the menagerie, now on their way to retirement; 2) LEASAT leased satellite capacity on Hughes Aircraft Co. satellites; 3) FLTSATCOM satellites, which, according to Air Force sources, also contain AFSATCOM UHF transponders; and 4) the UHF Follow-On (UFO) constellation, which is now in the process of being launched. The UFO program will see two satellites in each of four geosynchronous orbital slots, with one spare. The last satellite will be in orbit in 1997.[22]

The article in The International Defense Review, "Satellite Communications: More Bandwidth and Terminals Needed," mentioned earlier in this chapter, specifically outlines the demand in the UHF bandwidth. The article states that the number of UHF terminals is expected to increase to 11,000, up approximately 37 percent over the next ten years. In response, the Navy is quadrupling the capacity of its UHF satellite communications links. The lack of bandwidth becomes apparent with the fact that even today, with only 8,000 terminals in use, the demand on the available UHF bandwidth is so great that routine use is being restricted to senior commanders and special forces. In addition to commercial augmentation, the article goes on to describe many solutions being attempted, such as DAMA (demand assigned multiple access). DAMA is designed to provide a common "pool" of bandwidth that is automatically allotted to users based on assigned priorities. In contrast, the present system assigns a single channel per carrier which allows various channels (equating to bandwidth) to be idle for periods of time.[23]

The UHF Follow-On System

The UHF Follow-On satellite system is managed by the U.S. Navy. The system obtained Initial Operational Capability (IOC) in 1993 and was intended to replenish the rapidly ending mission lifetimes of the other military UHF satellites such as Fleet Satellite Communications (FLTSATCOM) and the GAPFILLER satellite systems. Table 2 summarizes the specifications of the UFO system. The UFO system is at geostationary altitudes to provide coverage over four geographical areas: CONUS, the Atlantic, the Pacific, and the Indian Oceans. The constellation consists of two satellites per each coverage areas and an on-orbit spare. The required UHF channel capacity is divided equally between the two satellites in each coverage area. The UFO satellite consists of a single receive and a single transmit antenna with eighteen 25-kilohertz (KHz) channels and twenty-one 5-kilohertz channels. One of the 25-kilohertz channels has an SHF receiver which allows for an SHF uplink signal whose antijam features gives a more robust fleet broadcast ability on that channel. All transmit (downlink) channels are UHF only. On the fourth and later satellites, EHF packages exist on the satellite for compatibility with the new MILSTAR systems. The EIRP (Effective Isotropic Radiated Power), the basic measure of the power radiated by the satellite antenna ranges from 26-28 decibel-watts for the 25-kilohertz channels to 20 decibel-watts for the 5-kilohertz channels.[24]

TABLE 2

THE UHF FOLLOW-ON MILITARY SATELLITE SYSTEM

Number of Satellites	8
On-orbit Spares	1
Orbit altitude (kilometers)	36,000 geostationary
Orbit Inclination (degrees)	0 geostationary
Area Coverage	CONUS, Atlantic, Pacific, Indian Oceans
Lifetime (years)	14
Terminals	AN/ARC-171, MSC-64, PSC-3, HST-4 (Identical to FLTSATCOM)
Bandwidth	18, 25-kHz channels 21, 5-kHz channels

Commercial Telecommunications Satellites

The literature in this section is again plentiful, but difficult to collect. Much of the specific capabilities of commercial satellites are held tightly by the corporation similar to the classification system of the military. This dirth of literature is especially true of systems that have yet to be deployed, such as Iridium. Much of the available material is historical or cursory in nature.

Marcia Smith's book, mentioned in the previous section, provides a general description of those commercial satellites used by the military during the Gulf War:

> Many countries, companies, and organizations own and operate communications satellites. These systems can be used to transmit non-secure military communications, phone calls home from the troops, and television signals for the media, for example. The following discussion is meant to be illustrative of the types of satellites that are available for use in the Persian Gulf War, and is not all inclusive.
>
> Some of the satellites are owned and operated by the International Telecommunications Satellite Organization (INTELSAT), to which 119 countries belong, including Iraq and Kuwait. According to press reports, Kuwait's access to the Intelsat system was cut on Aug. 2, the day of Iraq's invasion. Iraq has three INTELSAT ground stations, and its service also has been cut, although it is not clear whether it was a voluntary action by Iraq, a decision by INTELSAT (possibly by non-payment), or the result of the antennas being destroyed by air strikes.
>
> INMARSAT (International Maritime Telecommunications Satellite Organization), similar to INTELSAT but for mobile rather than fixed communications, also is playing a significant role. INMARSAT has 63 members, including Kuwait and Iraq. INMARSAT ground stations can be smaller than those for INTELSAT and are transportable, spurring development of portable satellite telephones.[25]

The Iridium System

A four-page article from Signal magazine by Robert H. Williams provides a good introduction to the capabilities of Iridium. Entitled "Iridium Offers Contact to Any Point on Earth," the article provides a good description of Iridium's concept, usage requirements, and technology:

> A point to point satellite communications system that will permit subscribers anywhere in the world to communicate almost instantaneously with anyone in reach of a telephone will begin its demonstration phase in less than two years.
>
> This global network, which is called Iridium, is tailored to the needs of subscribers in the wilds of the Australian outback, in a foxhole in a Third World conflict or flying high over an air traffic jam in New York City.
>
> Current projections call for international consortia to have this revolutionary global digital switching satellite system moving to full operation by 1994 when satellites are to be launched. All of the satellites are to be in position by 1996. The proposed system will provide quality voice and data capabilities, according to Durrel W. Hillis, a Motorola corporate vice president and father of this approach to rapid, world-wide communications.[26]

Further information is available in an extensive article from National Defense, entitled "66-Satellite Constellation Permits Worldwide Links." This article provides some history on the concept behind Iridium.

> A 66-satellite constellation called Iridium, which was conceived as a seamless, wireless, digital network, has become a multibillion dollar system that is expected to bypass the traditional roadblocks that limit global communications.
>
> The name Iridium was chosen because the picture of 77 satellites -- the number of satellites in the original design -- in near-polar orbit around the Earth resembled the classical model of an atom surrounded by electrons. The element having an atomic number of 77 is Iridium.[27]

Even though the number of satellites is now at sixty-six, there is no plan to change the name of the system to mirror the element dysprosium. The article is also a source of specific information on the proposed orbital parameters and capabilities of the Iridium system.

> The network of satellites will orbit approximately 420 miles above the Earth and will include six orbital planes, with 11 operational satellites and one on-orbit spare for each plane, explained Thomas N. Tadano, director of the Iridium bus program, Lockheed Missiles and Space Company, Sunnyvale, California.
>
> Compared to geostationary communications satellites 22,300 miles above the Earth, said Motorola officials, the low orbit of the Iridium satellites will allow communications to low-power hand units on the ground with negligible time delay.
>
> The low orbit, additionally, will help minimize echo, and the receiving antenna will be small enough to be carried on a hand-held subscriber unit, they added.
>
> The use of onboard processing techniques is a major design feature of the Iridium system and is essential to support the satellite-to-satellite crosslinks which will circumvent the need to downlink voice and data traffic to intervening hub stations. Both the onboard processing features and the satellite crosslink capability give the system increased flexibility in message routing at the expense of system design complexity.[28]

Further information is also provided on the usefulness and "user-friendliness" of the Iridium system. The user equipment ranges from solar-powered "phone booths" to standard hand-held digital mobile handsets. The handsets will offer voice, pager, and facsimile capabilities. Data modem capabilities are also envisioned. The phone booths are envisioned as providing world-class communications capability to isolated areas of the world on a scale never before attempted. Due to the lack of reliance on ground networking stations, as with present cellular phone systems, the Iridium system is immune from earthquakes, floods, hurricanes, and other natural disasters. Iridium officials foresee a growing market for their technology in the field of disaster response.[29]

A guide to commercial mobile satellite communications systems, Via Satellite also discusses some of the technical aspects of Iridium. The article confirms the constellation to consist of eleven L-band communications satellites in each of six orbital planes, including an on-orbit spare in each plane. The orbits are circular with an altitude of 780 kilometers. This low-earth orbit (LEO) means the satellite will move from horizon to horizon in about ten minutes. Users are seamlessly handed off from one satellite to another in much the same way as cellular phone users traveling between cell sites in automobiles.[30] The guide also describes Iridium's interface with the terrestrial telephone network and some projected costs.

> Each satellite is being designed to have direct links to adjacent satellites (Ka-band), permitting calls to hop from satellite to satellite. Iridium satellites would project a grid of cells (beams) onto the earth's surface somewhat similar to the grid of cell sites in a cellular telephone network.
>
> Iridium investors will own and operate Iridium gateways (ground stations) within their territories for interconnection to the public switched telephone network. Service will be provided through local and regional wireless network operators, including cellular, paging and personal communications companies. Subscribers (users) will generate revenue for the operators by paying for each minute of usage on the Iridium system. Each gateway will have multiple tracking antennas connecting the user's handheld mobile terminals into terrestrial networks; although handheld mobile terminals could communicate directly with each other because of Iridium's structure.
>
> Most estimates place the cost of the Iridium system at around $4 billion . . . . Motorola has made clear from the outset that it plans to pursue Iridium in partnership with other investors, and in 1993, Iridium announced its first $800 million in investments . . . . More recently, Iridium announced that it had raised an additional $734 million.[31]

Summary

No single source of literature was found concerning the topic of this thesis. Plentiful literature exists concerning all the critical parts of this research. References dealing with the engineering and design parameters of telecommunications satellites are numerous. This literature, which provides a basis for analyzing the capabilities and limitations of telecommunications satellites, crucial for answering the primary research question, is prolific in both cursory and highly technical references. Literature, though difficult to gather, also exists on the commercial telecommunications satellite, Iridium, and presently deployed military systems, such as UFO.

Endnotes

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[3]Stephen M. Hardy, "Catching Falling Stars (US Military Satellite Communications)," Journal of Electronic Defense 18 (January 1995): 62.

[4]"Communications Problems in the Gulf War," Asia-Pacific Defense Reporter 18 (April-May 1992): 40.

[5]"Communications Problems in the Gulf War," Asia-Pacific Defense Reporter, 40.

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[18]Tom M. Nicolson, "Civilian Reserve Information Services (CRIS) Concepts and One Possible Solution" (USAWC Program Paper, U.S. Army War College, 1992), 10-11.

[19]Nicolson, "Civilian Reserve Information Services (CRIS) Concepts and One Possible Solution," 17-18.

[20]Nicolson, "Civilian Reserve Information Services (CRIS) Concepts and One Possible Solution," 19-24.

[21]Marcia S. Smith, Military and Civilian Satellites in Support of Allied Forces in the Persian Gulf (Washington, DC: Congressional Research Service, 1991), 2.

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[24]U.S. Navy, Navy UHF Satellite Communication System Description (San Diego: Naval Ocean Systems Center, 1991), 101-107.

[25]Smith, Military and Civilian Satellites in Support of Allied Forces in the Persian Gulf, 3-4.

[26]Robert H. Williams, "Iridium Offers Contact to Any Point on Earth," Signal 45 (February 1991): 95.

[27]"66-Satellite Constellation Permits Worldwide Links," National Defense 79 (March 1995): 26.

[28]"66-Satellite Constellation Permits Worldwide Links," National Defense, 26-27.

[29]"66-Satellite Constellation Permits Worldwide Links," National Defense, 27.

[30]Roger J. Cochetti, "Mobile Satellite Services," Via Satellite 12 (November 1994): 32.

[31]Cochetti, "Mobile Satellite Services," Via Satellite, 30-32.

CHAPTER 3

METHODOLOGY

The research methodology of this thesis is designed to answer the primary research question: Can the commercial telecommunications satellite system Iridium effectively support the theater commander? This question obviously contains numerous aspects and can be answered with a variety of approaches to the research. To develop an answer to this question, the research was divided into three separate phases that correspond to the three secondary research questions. These secondary research questions were derived from the meaning of the word "effectively" in the primary research question. For this thesis, an effective use means the satellite must be a suitable, feasible, and acceptable system for the warfighter. Each of the secondary research questions provides an answer to each of these conditions for effectiveness. Each of these questions entails a separate phase of research and a research pattern tailored specifically to the special needs of that secondary question.

The entire thesis methodology is a pyramid structure of research questions with the primary question at the top. For an affirmative answer to exist for the primary question, an affirmative answer must exist for the three secondary questions below it. Each of the research patterns designed to answer each of the three secondary questions falls within a separate phase of the research and is described in the sections of this chapter. Within each research phase, there is a similar set of tertiary questions designed to answer the secondary research question associated with that phase. Unique criteria are developed to answer each set of tertiary questions.

Determining Suitability

The first of the secondary research questions is stated as follows: Can Iridium provide a suitable telecommunications service to the military? This question deals with the suitability of the Iridium telecommunications satellite system. To be a "suitable" supporter, there must be a telecommunications shortfall AND Iridium must be able to fill it. To determine suitability, the research must first establish if any shortfalls exist in present military telecommunications capability. If so, the use of Iridium is "suitable" if it can fill the shortfall. To establish the presence of any shortfalls, the tertiary questions are answered in sequential order. The tertiary questions include the following:

1a. What are the present telecommunications assets provided for theater operations?

1b. To what level of total capability are the present telecommunications assets currently tasked?

1c. What are the shortfalls between the requirements and the capabilities of current systems?

1d. Can Iridium meet the shortfall in current satellite capabilities?

The research pattern used to provide answers to these questions begins by gathering data on the present military systems, their bandwidths, number of transponders, present usage levels, and areas of global coverage. These communications system measurements compose the criteria used for this phase of the research. See Table 3 for the criterion matrix.

TABLE 3

EXAMPLE OF CRITERION MATRIX USED IN PHASE ONE

Criteria	Data type	System 1	System 2	System 3	System 4
Name	Self-explanatory				
Number of transponders	Self-explanatory				
Bandwidth per transponder	Frequencies available on each transponder				
Total Bandwidth	Total Frequency range				
Usage Levels	Percent of total bandwidth that is presently being used on the system				
Area Coverage	Geographic areas Known gaps Limited service regions				

First, bandwidth and usage levels are summarized. Second, the Gulf War, Operations Desert Shield and Desert Storm, is researched as a case study to develop an estimate of the additional bandwidth requirements that resulted from that major regional contingency (MRC). Finally, upon factoring in the additional requirements of this MRC, an absence or presence of any shortfalls, either globally or regionally, should appear from the data. The case study of the Gulf War and further research into the precedence for the military use of commercial telecommunications satellites provides the data required to link a shortfall in military assets to the lease of a commercial system. This final linkage would give an affirmative answer to the final tertiary research question and create an affirmative answer for this research phase, the first of the secondary research questions: Can Iridium provide a suitable telecommunications service to the military?

Determining Feasibility

The next secondary research question asks the question: Can Iridium provide a feasible telecommunications service to the military? This question deals with the feasibility of the Iridium satellite system. To be a feasible supporter, Iridium must provide similar utility as present military systems. To determine this utility, the research pattern used is a comparative analysis between Iridium and a currently deployed military telecommunications satellite system, UHF Follow-On (UFO). This comparative analysis can be seen in the tertiary questions of this phase of research:

2a. What are the capabilities and limitations of Iridium?

2b. What are the capabilities and limitations of UHF Follow-On?

To be a feasible system, the pure definition of feasibility would only require that Iridium successfully provide a telecommunications service to the theater commander. This success can mean many things to different users of a telecommunications system. One additional phone call out of the theater to a supporting unit in the States can mean much for a staff planner that otherwise finds a ninety minute wait due to a saturated communications system. A soldier that gets to make an additional phone call home because of Iridium would most definitely call it a good system. On the other hand, a theater joint force commander would hardly recognize a single phone call as being a significant contributor to his communications assets. Therefore, in order to reach a simple "yes" or "no" on the feasibility question, a certain amount of subjective comparison criteria must be established. Some guidance concerning what a significant amount of communications contribution is described as can be found in the functional requirements of the Defense Information Systems Agency (DISA).

The Department of Defense has had a continuing need for satellite communications systems, but until just recently, these needs were not codified to the point of describing the specific system requirements. In December of 1995, DISA with the support of the entire military satellite communications community began to address the requirements of a space-based communications architecture. Along with this study came some identification of innovative and mission-effective means of employing commercial satellite communications systems.[1] This document provides a single, coherent description of all the satellite communications needs in the form of lower bounds to satisfy the theater commander's requirements. Requirements are described in terms of six general characteristics: (1) Connectivity, (2) Protection, (3) Access and Control, (4) Interoperability, (5) Flexibility, and (6) Quality of Service.[2]

Connectivity encompasses quite a few characteristics such as capacity, numbers of satellites, and geographical dispersion. *Protection* is the security of the conversations or data transiting the communications system. The issue of security is not included in this research because the thesis delimits any discussion of security issues and the system is UHF which is inherently unsecure whether it is a military system or a commercial system. *Access and Control* is the certainty that the satellite communications system is available and accessible for use when the warfighter needs it. Assured access and the ability to re-locate the satellite to support operational needs are requirements that the military places on any satellite communications system. Since this study assumes that Motorola is willing to lease the Iridium system to the military and, therefore, assure the military's access to the system, this requirement is assumed to be met. *Interoperability and Flexibility* are requirement categories that describe the system's ability to provide quickly and effectively its service in a variety of environments and situations. Coalition partners should have access to the same equipment required to use the system and the system should work as well in an equatorial desert as it does on the Siberian tundra. This study will take these requirements into account comparing the "user-friendliness" of the equipment needed to operate the Iridium system and the coverage areas of Iridium. Finally, *Quality of Service* is defined as the ability to transfer information in a timely and accurate manner. Some specific requirements that are stated in this category include "good" voice quality (defined as speaker identification and tonal quality) and establishing bit error rates for data transmissions. These requirements are all within the state of present cellular phone technology. This study will examine the quality issue when analyzing the transceivers, but assumes that Motorola will not field such a tremendous technological and financial project without first ensuring the system will meet the modern demands of the cellular business and produce a system with at least the same quality as their present systems. Therefore, this study assumes the final requirement is assured because of the commercial nature of the Iridium project.[3]

On the usability issue, this research defines Iridium as feasible only if the system provides the same ease of use as present off-the-shelf commercial mobile phones. Since this technological capability is widespread, accepting anything less would not be a feasible choice. This study's "ease of use" issue translates into the "Interoperability and Flexibility" requirements of DISA. Specifically, a feasible commercial communications supporter must provide hand-held transceiver capability and the voice and data quality must meet the quality requirements specified by DISA. These requirements are no greater than the present standards. Therefore, in order to analyze this issue, a comparison is made between the transceivers of the Iridium system and the UFO system.

Area coverage is also an issue for success. This coverage issue translates into the "Access and Control" requirements from DISA. Since this study assumes that Motorola will give the military access to Iridium, "Access and Control" reduces, for this thesis, to the requirement of coverage. A feasible supplement for a theater communications system must provide the service no matter where the theater might be established. In order to establish a basis for comparison, this research determines if Iridium can cover an area equal to or greater than the military's premier UHF system, UFO. Allowing any less coverage would mean that certain potential theaters in the world might not receive the service expected by the military in placing its own satellites. Any supplemental support from Iridium would be cursory augmentation at best.

Bandwidth, generally the amount of service the system can provide, is the final issue where a comparative basis must be subjectively established. The DISA requirements speaks of "Connectivity." As discussed in previous paragraphs, these requirements include characteristics of capacity, number of satellites, and geographical dispersion. Since this study includes number of satellites and geographical dispersion under the "coverage" issue of satellite footprints, DISA's "Connectivity" requirement is handled for the purposes of this study as one of capacity. Capacity requirements from the DISA draft study are expressed in terms of network topologies. These topologies are defined as follows:

Broadcast. These systems disseminate information to multiple users simultaneously.

Hub-Spoke. These systems provide full duplex between a central location and multiple remote terminals.

Report back. These systems provide one-way simplex communications from multiple users to a central user.

Netted/Conference/Paging. These systems provide netted voice and data capabilities which allow all users to simultaneously receive the transmission of any other participant without separate action.

Point-to-Point. These systems provide communications between two locations, including switched common-user-type (public phone system) networks in which any user can contact any other user in the network.[4]

In DISA's categorization, Iridium is a point-to-point system. Therefore, this study examines the capacity requirements that the military has placed on only these point-to-point systems. Capacity includes a lower boundary on data rate capability: 1200 kilobits per second (kbps) for voice and data and 1200 kilobits per second for satellite crosslinks.[5] Table 4 outlines all the proposed requirements placed on point-to-point systems by the Department of Defense.[6] Therefore, for this phase of research the criteria for feasibility will include a data rate minimum of 1200 kilobits per second for voice, data, and satellite crosslinks.

TABLE 4

REQUIREMENT CHARACTERISTICS FOR POINT-TO-POINT SYSTEMS

Classes of User	CINCs/Theater Infrastructure/Others
Missions	Warfighting, Essential Support
Type of Service	Voice / Data / Paging
Duty Cycle	Continuous or Non-Continuous
Timeliness	Minutes/Hours
Maximum Tolerable Delay	Double Hop (0.5 sec)
Voice Quality	Intelligible
Bit Error Rate	1 bit per 10^5 bits
Number of Users	Two Users per Requirement
Terminals	Fixed, Transportable, or Mobile
Geographic Dispersion	Dispersed, Worldwide, Limited Polar
Capacity	64 kbps, 1200 kbps desired
Protection	None required (UHF)

Source: Defense Information Systems Agency, DOD SATCOM Functional Requirements Document draft, (Washington, DC: Defense Information Systems Agency, D-8, 1996), 2-30 - 2-31.

Therefore, for the purposes of this thesis work, a "feasible service" is defined as significant in the eyes of the joint force commander and meeting the lower boundaries (established by the DISA report) concerning capacity, dispersion, voice quality/error rate, and terminals. "Significance" is defined as providing at least half as much of the UHF bandwidths as the primary military UHF system, UFO.

To summarize, the research comparison between Iridium and UFO must show Iridium provides the following capabilities:

1. At least 50 percent of UFO bandwidth and channels.

2. Coverage equal to or greater than UFO, including polar coverage.

3. Receiver/transmitter mobility equal to or better than UFO.

4. Voice and data quality equal to or better than UFO.

TABLE 5

EXAMPLE OF CRITERION MATRIX USED IN PHASE TWO

Criteria	Data type	IRIDIUM	UFO
Bandwidth	Frequencies available for operation		
Data Rates	Steady Mbits/sec operation		
Number of transponders	Self-explanatory		
Area Coverage	List any Unified CINC's Area of Responsibility (AOR) that is unserviced		
Mobility of Transmitter and Receiver	Size of antenna Weight of transmitter Power requirements of transmitter/receiver		

The criteria used in this comparative analysis are bandwidth, data rates, number of transponders, call-volume from theater, and mobility of the receiver/transmitter. The Director of Strategic Technology Applications, J-6, United States Space Command (USSPACECOM), confirmed these criteria as viable.[7] See Table 5 for the criterion matrix for this phase.

Determining Acceptability

The final secondary research question asks the following: Is the use of Iridium economically acceptable? This question deals with the acceptability of the Iridium satellite system. To be an acceptable supporter, Iridium must provide the bandwidth at an economical cost per call or cost per bandwidth equal to or better than the UFO system. The tertiary questions that support this research phase are as follows:

3a. What is the cost of the UHF Follow-On satellite system?

3b. What is the cost of using Iridium on a contingency basis?

The research pattern used to provide answers to these questions and link them to an answer of economic acceptability uses comparative analysis. The research begins by gathering data on the Iridium system and the UFO. Data in this phase of research includes proposed usage costs for Iridium and the proposed cost of leasing these satellites for a ready-reserve mission. If no lease cost has been proposed, this study will analyze the applicability of past leasing fees such as with INMARSAT or develop a maximum allowable yearly lease fee that would be acceptable. Data on UFO includes the total cost of the system's design, launch, and support for orbital operations. This data composes the criteria used for this phase of the research. See Table 6 for the criterion matrix.

TABLE 6

EXAMPLE OF CRITERION MATRIX USED IN PHASE THREE

Criteria	Data type	IRIDIUM	UFO
Usage Costs	Cost per minute		N/A
Cost of Terminals / Handsets	Cost		
Leasing Costs	Cost per year for ready-reserve status		N/A
Total Deployment Costs	R&D, Construction, Launch, and On-orbit support operational costs The system's bill to the taxpayer OR Totaled into cost per minute usage	N/A	
Satellite Lifetime	Years	N/A	

The study makes an assumption on the amount of augmentation Iridium will provide. This assumption, or baseline, is established to provide a starting point to compare economic costs. To maintain consistency from the feasibility question, this baseline is 50% of the UFO bandwidth. For Iridium, the comparison requires a total of the costs for usage of the given bandwidths and proposed lease of the system for a period of time equal to the lifespan of a UFO. For UFO, the total cost of design, launch, and on-orbit support is the required data or literature that breaks this total cost into usage costs (cost per minute) would also useful. Additionally, the terminal or handset costs are also compared. If the cost per bandwidth is equal to or less than purchasing and using a committed system, UFO, then Iridium is acceptable.

Summary

This research project is a comparison of Iridium capabilities and limitations to a committed military system, UFO, including a cost-benefit analysis. Capabilities, limitations, and economics are the prime motivators behind the research methodology. Following a pyramidal structure, the primary research question is answered in the affirmative if the research can answer affirmatively to all three secondary questions. A "no" to either the first or second secondary research question creates a "no" to the primary question. A "no" to the final secondary question, economic acceptability, creates a conditional answer to the primary question that places limits on the cost of follow-on military systems or places a limit on the cost of leasing Iridium.

<u>Endnotes</u>

[1]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document draft, (Washington, DC: Defense Information Systems Agency, D-8, 1996), 1-1.

[2]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document, 2-1.

[3]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document, 2-2 - 2-24.

[4]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document, 2-6 - 2-7.

[5]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document, 2-8.

[6]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document, 2-30 - 2-31.

[7]Kenneth J. White, telephone interview by author, Fort Leavenworth, KS, 15 Feb 1996.

CHAPTER 4

ANALYSIS

This chapter contains the research analysis required to answer the primary research question. The chapter is divided into three main sections that correspond to the three phases of research described in Chapter 3, "Methodology." The first section on suitability contains the information and analysis concerned with answering the first secondary research question: Can Iridium provide a suitable telecommunications service to the military? The section on suitability contains a brief case study of the Desert Storm communications situation and the analysis of present communications coverage. The second section regarding feasibility contains the information and analysis to answer the second question: Can Iridium provide a feasible telecommunications service to the military? The section on feasibility contains an analysis of the capabilities and limitations of the Iridium system and compares it to the UHF Follow-On (UFO) system. The final section on acceptability contains the information and analysis to answer the third question: Is the use of Iridium economically acceptable? The section on acceptability contains an analysis of the financial cost of using Iridium as opposed to owning and operating a comparable, military telecommunications satellite system.

Suitability

Analysis in this research phase is directed toward answering the first secondary research question: Can Iridium provide a suitable telecommunications service to the military? To be a suitable supporter, a telecommunications shortfall must exist and Iridium should be able to provide support toward filling the shortfall. This section examines shortfalls either in total bandwidth or worldwide coverage. This analysis is divided into subsections that corresponds with the four tertiary research questions involved with the suitability issue.

Present Telecommunications Assets

This subsection analyzes the present military telecommunications assets provided for theater operations, with the goal of answering the first tertiary research question: What are the present telecommunications assets provided for theater operations? Since Iridium is a UHF system, this analysis is accomplished purely on the present UHF telecommunications systems.

As discussed in Chapter 2, the military operates only four UHF satellite systems. The following tables summarize three of these systems in accordance with the criterion matrix, Table 3, introduced in Chapter 3. Table 7 summarizes the Fleet Satellite Communications (FLTSATCOM) system. Table 8 summarizes the UHF Follow-On (UFO) system, and Table 9 summarizes the Leased Satellite (LEASAT) system. Even though it is a commercial UHF satellite system, LEASAT is included in this analysis because it is used exclusively by the military. Hughes Aircraft Corporation runs the space segment and satellite control, but the U.S. Navy has complete network control of the system.[1]

TABLE 7

FLTSATCOM UHF CAPABILITIES

Number of Transponders/Channels - Bandwidth per Channel (KHz)	9 - 25 12 - 5 1 - 500
Total Bandwidth per Satellite (KHz)	785
Number of Satellites (spares)	4 (0)
Design Life (years)	5
Area Coverage	70°N - 70°S

Source: U.S. Navy, FSCS-200-83-1, Navy UHF Satellite Communications System Description (San Diego, CA: Naval Ocean Systems Center, 1991), 97-98.

The FLTSATCOM satellites are all in equatorial orbits (geostationary altitudes) and are located at the following longitudes: 100, 23, and 15 degrees West and 172 degrees East.[2]

TABLE 8

UFO UHF CAPABILITIES

Number of Transponders/Channels - Bandwidth per Channel (KHz)	17 - 25 21 - 5
Total Bandwidth per Satellite (KHz)	530
Number of Satellites (spares)	8 (2)
Design Life (years)	14
Area Coverage	70°N - 70°S

Source: U.S. Navy, Navy Warfighter's Guide to Space (Dahlgren, VA: Naval Space Command, 1994), 22.

The UFO satellites are in equatorial orbits (geostationary altitudes) and are located at the following longitudes: 177.5 degrees West, 177 degrees West, 105.5 degrees West, 105 degrees West, 15.5 degrees West, 15 degrees West, 72.5 degrees East, and 73 degrees East. The system had its initial operational capability in 1994 and presently there are only five of the planned eight satellites in orbit.[3]

TABLE 9

LEASAT UHF CAPABILITIES

Number of Transponders/Channels - Bandwidth per Channel (KHz)	6 - 25 5 - 5 1 - 500
Total Bandwidth per Satellite (KHz)	675
Number of Satellites (spares)	3 (0)
Design Life (years)	10
Area Coverage	65°N - 65°S

Source: U.S. Navy, Navy Warfighter's Guide to Space (Dahlgren, VA: Naval Space Command, 1994), 21.

The LEASAT satellites are in equatorial orbits (geostationary altitudes) and are located at the following longitudes: 177 degrees West, 105 degrees West, and 72.5 degrees East. The last LEASAT was put into service in 1990.[4]

The military has also used the GAPFILLER satellite system, but this system is slated to discontinue its service in the mid-1990s. The discontinued use is scheduled with the start-up of the UFO system.

Also, the GAPFILLER system is actually old INMARSAT satellites. These satellites were discussed in Chapter 2 where it was established that these satellites will not be used for tactical applications. Since the system's tactical use is illegal and it is slated for retirement beginning last year, the GAPFILLER capabilities are not included in this analysis.

With only a five-year lifespan, the FLTSATCOM satellites have already reached the end of their design life. This analysis would be justified in not including their capability, but in order to present the best possible situation for military UHF capability, their contribution is included in this analysis.

The criterion of "area coverage" requires further examination. Any analysis of UHF coverage must include an examination of the worldwide distribution of the UHF footprint. For example, to have a large proportion of UHF bandwidth covering the CONUS while maintaining little coverage over southeast Asia would highlight a deficiency in that theater of operations even though the total worldwide capacity might appear high. Figure 4 shows the total UHF coverage provided by the UFO, FLTSATCOM, and LEASAT systems.

The information in Figure 4 is the summation of all the footprint regions covered by all the UFO, FLTSATCOM, and LEASAT satellites.[5] Given the background presented in Chapter 1, the beamwidth of the UHF systems and their altitude of 36,000 kilometers (geostationary) does confirm this total footprint. The problem that remains is identifying what capability actually exists under all areas of that total footprint.

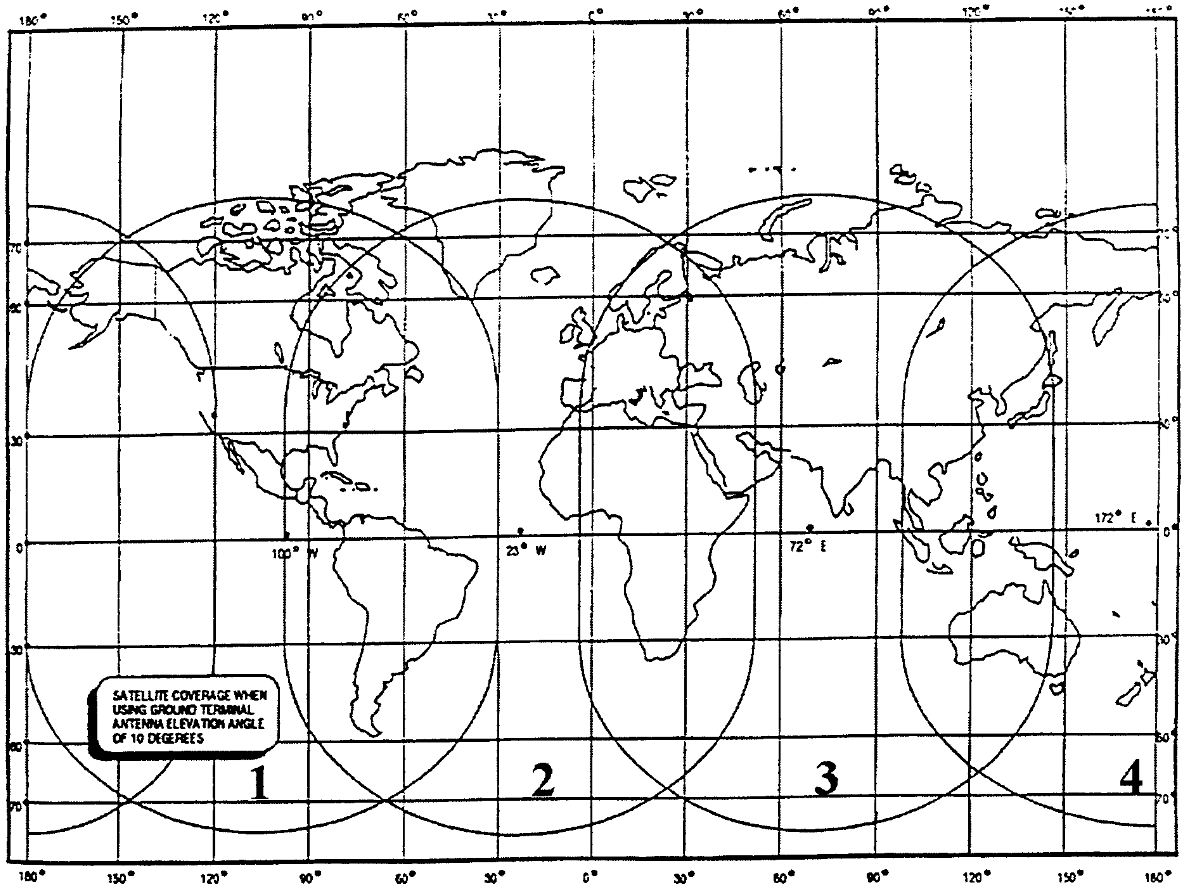

Figure 4. UHF Satellite Coverage. Source: U.S. Navy, FSCS-200-83-1, Navy UHF Satellite Communications System Description (San Diego, CA: Naval Ocean Systems Center, 1991), 93.

Other than the polar regions, this coverage appears quite sufficient. The footprint lobes labeled in the figure are regions defined as follows: (1) CONUS, (2) Atlantic, (3) Indian, and (4) Pacific. Figure 5 places the location of each of the three military satellite systems on the same map as Figure 4 in order to gain a better picture as to the true UHF capability within each of the four regions.

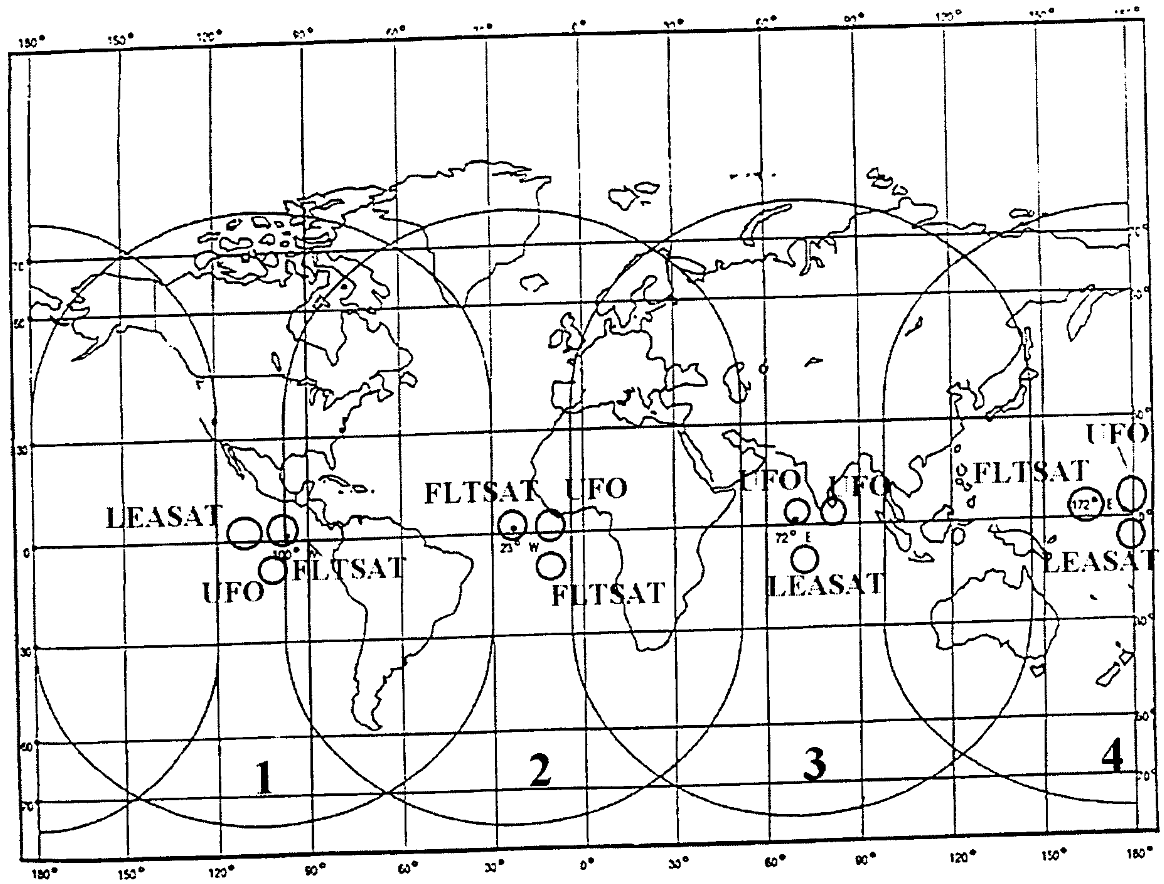

Figure 5. Regional Locations of UHF Satellites

The total channels and bandwidth available in each region are now summarized in Table 10. These figures include only presently operational capability.

The grand total, worldwide UHF military bandwidth is 7.815 Megahertz with 314 channels available. An examination of these regional numbers in Table 10 shows that the capability is fairly evenly distributed across the four separate regions. The low figure in the Indian Ocean region is misleading since the Atlantic region does overlap the western third of the Indian Ocean region, including the Persian Gulf and Middle East area.[6]

TABLE 10

REGIONAL UHF CHANNELS AND BANDWIDTH

	CONUS	ATLANTIC	INDIAN	PACIFIC
FLTSATCOM				
500 KHz Channels	1	2	0	1
25 KHz Channels	9	18	0	9
5 KHz Channels	12	24	0	12
Subtotal Bandwidth (KHz)	785	1510	0	785
UFO				
500 KHz Channels	0	0	0	0
25 KHz Channels	17	17	34	17
5 KHz Channels	21	21	42	21
Subtotal Bandwidth (KHz)	530	530	1060	530
LEASAT				
500 KHz Channels	1	0	1	1
25 KHz Channels	6	0	6	6
5 KHz Channels	5	0	5	5
Subtotal Bandwidth (KHz)	675	0	675	675
REGIONAL TOTALS: (channels) (KHz)	(72) 1990	(82) 2100	(88) 1735	(72) 1990

Source: U.S. Navy, Navy Warfighter's Guide to Space (Dahlgren, VA: Naval Space Command, 1994), 20-24.

Of the three remaining UFO satellites that are scheduled for launch in the coming years, one will be placed in the CONUS region, another in the Atlantic, and the third in the Pacific region. These additional launches will provide a more balanced distribution of satellites.

Current Tasking

This subsection examines the present usage levels on the existing military communications systems with the goal of answering the second and third tertiary research questions:

1b. To what level of total capability are the present telecommunications assets currently tasked?

1c. What are the shortfalls between the requirements and the capabilities of current systems?

The Defense Information Systems Agency (DISA) has provided a brief glance of the growing information requirements in a draft of the Department of Defense Satellite Communications Requirements Document. User demand is increasing at geometric rates. Imagery, targeting, theater and strategic surveillance, environmental, video conferencing, war-gaming, simulation, and sustainment requests on the satellite communications architecture are at all time highs and continue to increase.[7]

The United States Space Command (USSPACECOM) has provided the answer to this research question. On October 16, 1995, USSPACECOM officials briefed the state of UHF satellite communications capacity: it did not describe a good future for UHF satellite users. The military UHF systems, including FLTSATCOM, LEASAT, and the four of eight presently operating UFO satellites, are presently saturated. The demand on the UHF systems are at approximately 150 percent of the present capabilities. The situation is only becoming worse. UHF user requirements are rapidly increasing. Since UHF ground systems are cheap, easy to use, and very mobile, they are attracting more and more users within the military. The emergence of new networks and digitized battlefield requirements, is also contributing to the growing user demand. The U.S. Department of Defense (DOD) also owns all UHF satellite frequencies that they are likely to ever have.[8]

This usage information establishes a present shortfall between UHF capability and requirements. The additional three UFO satellites that are to be launched and come into operation within the next four years will provide a one-for-one swap with the retiring FLTSATCOM and LEASAT systems and will provide an additional 95 kilohertz and 116 channels worldwide, a bandwidth increase of only 1.3 percent and an available channel increase of 42 percent. This increase will not make up the shortfall. The present situation of UHF saturation, barring an unlikely decrease in user demand, will remain. This shortfall situation could be even worse with a Major Regional Contingency (MRC), such as Desert Shield/Storm.

Desert Shield/Storm Study

A study of the Persian Gulf war provides an estimate of the additional telecommunications requirements generated by a modern MRC. The material reviewed in Chapter 2 provides the data necessary to make this analysis. In the first few months of Desert Shield, DOD communications traffic rose dramatically. Table 11 summarizes the loads placed on the telecommunications infrastructure generated by the deployment into the Persian Gulf theater.[9]

TABLE 11

DESERT SHIELD TELECOMMUNICATIONS USAGE

STAGE	THROUGHPUT (Mb/s)	VOICE CIRCUITS/CHANNEL EQUIVALENT
Pre-War	4.5	70
1 Month into the Deployment	38	600
With Total Forces in Theater	68	1100

Source: Peter Anson, "The First Space War: The Contribution of Satellites to the Gulf War," Journal of the Royal United Service Institution 136 (Winter 1991): 46.

This information shows an overall increase in demand from prewar levels of 1471 percent. This data documents the demand placed on SHF assets in the Persian Gulf theater of operations. The UHF situation, although specific numbers were not available, was described as being comparable.[10] This assumption is very probable in light of the fact that UHF is the system of choice for the warfighter. Their light, portable units, omni-directional antennas, and the proliferation of terminals (8,000 today and up to 11,000 by the end of the century) all indicate that as forces assemble into any theater, the UHF traffic will increase in comparable proportions to those figures given for Desert Shield SHF traffic.[11]

Present estimates for the additional capacity requirements, specifically in the UHF narrowband, point-to-point category, are less than those SHF increases shown in the Gulf War, but they are still significant. Peacetime data rates are fluctuating around 90 megabits per second and the total number of channels are at 2022. Estimated numbers for a major regional contingency are 110 megabits per second and 2591 channels (an average capacity increase of 25 percent). Estimated numbers for a low-intensity regional conflict are 102 megabits per second and 2779 channels (also an average capacity increase of 25 percent).[12]

The situation is clear. Present military systems cover the world fairly evenly, providing bandwidth to all conceivable theaters of operation (since an MRC is not likely to occur over the polar regions). However, that bandwidth is saturated even under current peacetime conditions. Current requirements exceed capacity. A MRC in a specific theater will multiply those requirements many times over. With the shortfall now established, the final tertiary question in this research phase remains: Can Iridium meet the shortfall in current satellite capabilities?

Iridium Fills the Shortfall

This subsection analyzes whether the Iridium system can fill the shortfall established earlier with the goal of answering the final tertiary research question. In this phase of research, the phrase "filling the shortfall" simply means providing UHF bandwidth in a theater, or region, that has a shortfall. Analysis first covers Iridium's footprint to determine if its service can support any given theater of operations.

Iridium's 66 low-Earth orbit satellites are described as providing worldwide coverage, but some analysis was accomplished to confirm this claim.[13] Figure 6 shows an artist's conception of the constellation of 66 satellites in low Earth orbit.

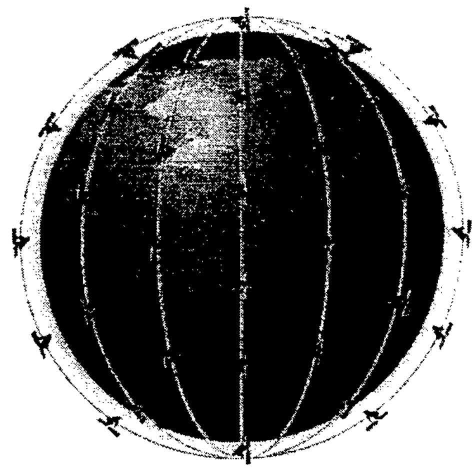

Figure 6. The Iridium Constellation. Source: Motorola, Inc., "Iridium System Networking" Corporate Technical Manual on Iridium Operations (Washington DC: Iridium, Inc., 1995), 2.

Table 12 summarizes some key Iridium orbit and communications system data. By definition, a "cell" is a smaller footprint within the satellite's overall footprint. These hexagonal cells are projected onto the Earth's surface by the satellite's phased-array L-band antennas.[14] A call placed within any cell is either routed to the most advantageous ground station, called a Gateway, to enter the terrestrial phone system or, in austere conditions, the satellite interlinks will place the call directly from handset to handset.[15] What this means for the warfighter is that the call can be placed from anywhere on the planet, regardless of conditions. For example, phones that operated simply as a commander's cellular phone could automatically function as a source of communication during a humanitarian assistance mission after a hurricane has destroyed all terrestrial communications infrastructure within a region.

TABLE 12

IRIDIUM SUMMARY

Number of Operational Satellites	66
Number of Orbital Planes	6 (11 satellites + 1 spare per orbit)
Orbit Inclination	86.4 deg
Orbit Altitude	780 km (circular)
Beamwidth Diameter	4,436 km
Number of cells within footprint	48
User Frequencies	1616-1626.5 MHz
Bandwidth	10.5 MHz

Source: Motorola, Inc., "Iridium System Overview" Corporate Technical Summary (Washington DC: Iridium, Inc., 1995), 32.

There are 236 channels provided within each cell. After factoring out the overlapping of the cells worldwide, the total number of worldwide channels planned with Iridium is 72,000.[16] For the warfighter, this capacity provides the potential of an additional 72,000 simultaneous calls supporting the war effort. Of course, this 72,000 is a worldwide figure. Regional figures are on the order of 11,000 calls. Figure 7 illustrates the projection of these communications cells. Each cell is provided by a separate transponder on-board the satellite.[17]

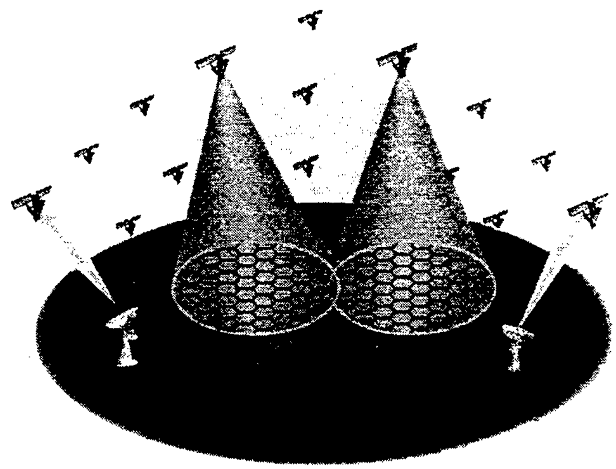

Figure 7. Iridium Cells. Source: Motorola, Inc., "Iridium System Networking" Corporate Technical Manual on Iridium Operations (Washington DC: Iridium, Inc., 1995), 3.

Figure 8 shows the resulting coverage given by 24 satellites. This analysis is accomplished with the communications system footprint information and orbital altitude given in Table 11. The satellite groundtrack picture is taken from information on the ORBCOMM satellite which has an almost identical orbital altitude and antenna field-of-view as Iridium.[18] Further analysis was accomplished with the orbital mechanics software "PC-SOAP."

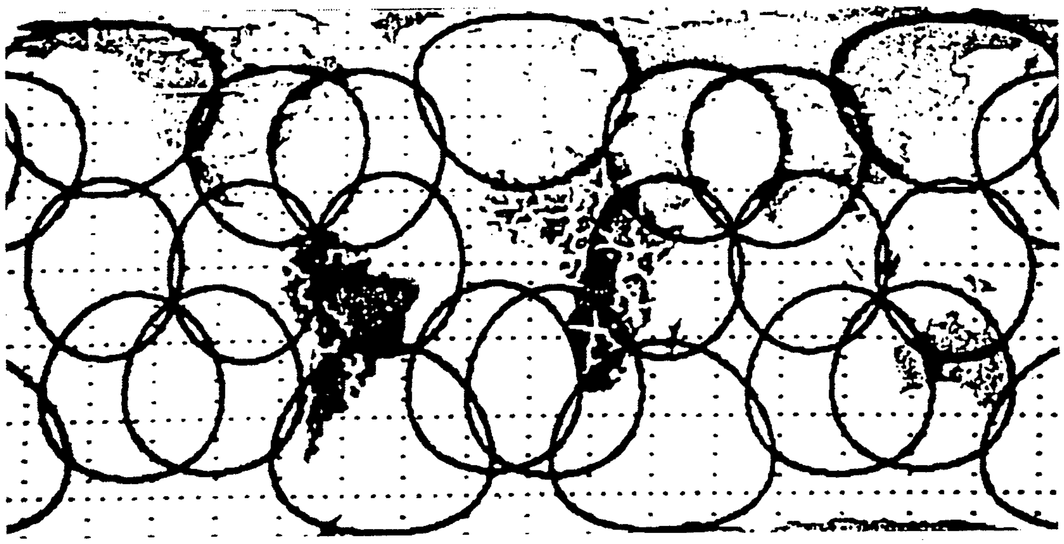

Figure 8. Coverage of 24 Iridium Satellites. Source: Larry Franklin, "An Analysis of the ORBCOMM Commercial Satellite System for Military Use," (Thesis, Naval Post Graduate School, 1994), 12.

This same analysis, extended to 66 satellites in Figure 9, with these orbital parameters does confirm complete, worldwide coverage with multiple overlapping footprints.[19]

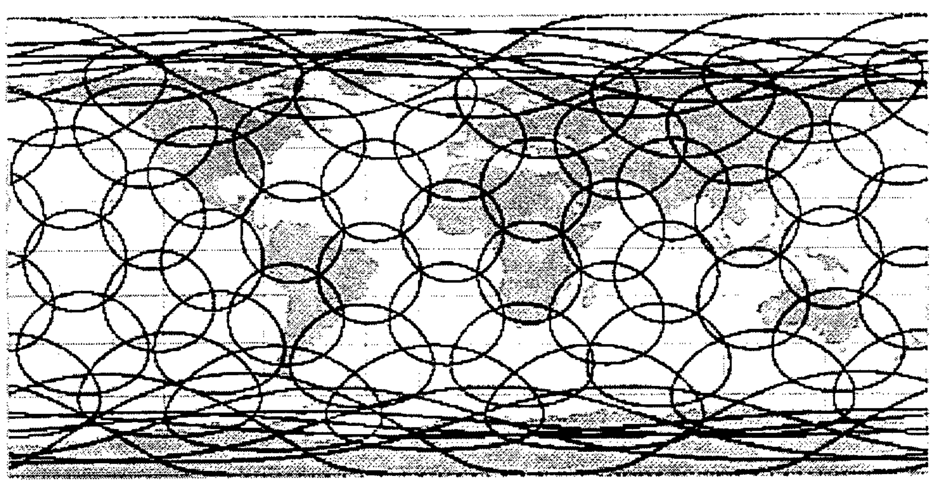

Figure 9. Complete Iridium Constellation at Single Point in Time. Source: Lloyd Wood, "Index to Satellite Constellations," (Surrey, UK: 7 Mar 1995, accessed 13 Mar 1996) available from http://www.ee.surrey.ac. uk/Personal/L.Wood/Constellations/; Internet.

With this footprint information and the fact that the Iridium system, operating in the L-band, provides approximately ten megahertz of UHF bandwidth to subscribers, it appears that Iridium can aid with the shortfall in current UHF capabilities.

Feasibility

Analysis in this research phase is directed toward answering the second secondary research question: Can Iridium provide a feasible telecommunications service to the military? As presented in Chapter 3, feasibility requires Iridium to provide a comparative utility. This analysis examines the relative merits of Iridium when compared to the military's primary UHF communications satellite system, UFO.

The criteria for this analysis were introduced in Chapter 3. Table 13 summarizes the data used in this comparative analysis. Following the methodology in Chapter 3, the analysis of the summarized data shows Iridium in a very favorable light when compared against the UFO system:

1. Iridium provides 247 percent of UFO's bandwidth and 77.6 percent of UFO's usable channels.

2. Iridium provides worldwide coverage, including polar regions, which UFO does not cover.

3. Iridium's receiver/transmitter is a hand-held phone having the length of a ball-point pen.[20]

TABLE 13

COMPARISON OF CAPABILITIES AND LIMITATIONS

CRITERION	IRIDIUM	UFO
Bandwidth (MHz) Total Per Region	 10.5 -	 4.2 1.06
Data Rates	4.8 Kb/s - voice 2400 baud - data (25 Mbps between satellites)	4.8 Kb/s
Number of Channels Total Per Region	 236 per cell	 304 304
Area Coverage	Worldwide	$70^{\circ}N$ - $70^{\circ}S$
Transceiver Mobility	Hand-held voice, fax, pager dual (terrestrial/satellite) mode	FLTSATCOM terminals (some hand-held)

Source: Motorola, Inc., "Iridium System Networking" Corporate Technical Manual on Iridium Operations (Washington DC: Iridium, Inc., 1995), 1.

Expanding on the user-friendliness of the transceiver unit only serves to further establish the feasibility of the Iridium system. The handset, described as a "subscriber unit," contains a standard data interface for fax reception, one hour uncharged talk time, and has a dual-mode operation feature.[21] The Iridium handsets, slightly longer than a standard fountain pen and fitting into the palm of the hand, are proposed to weigh in at under three pounds while the present UFO transceivers range from the heaviest at 348 pounds for a 7-by-9.5-by-16-inch unit (AN/ARC-171)[22] to the lightest at 7.21 pounds for a 7-by-3-by-10-inch unit (HST-4 or AN/PSC-7).[23] Dual-mode operation allows the user to access local, terrestrial cellular networks if available, but when outside the range of any cells, the unit automatically accesses the Iridium satellites. This feature provides the military user with both cost savings and a peacetime use for the hand-sets when not deployed to austere theaters. Mobility and ease-of-use are consistently shown as higher with the Iridium transceivers than those used with UFO.

The radiated power of the hand-set is rated at 16 decibels compared to the 20 decibel rating on the UFO 5-kilohertz channels.[24] Does this lower power mean a degraded link? Analysis shows the answer to be completely opposite than first expected. The UFO system provides a 20 decibel link to a satellite at approximately 36,000 kilometers away as opposed to Iridium's 16 decibel link to a satellite approximately 780 kilometers away. The difference between 20 decibels and 16 decibels is a difference in signal strength of 10 and 6.31, respectively. These figures mean that Iridium provides 36.9 percent less power to antennas at 97.8 percent less distance. Since power density decreases with the square of the distance, the power density striking the Iridium antennas are even higher than UFO's, meaning clearer, sharper signals:

(4-1) Power Density $(F) = P/(4\pi R^2)$
P - power rating (watts)
R - distance (km)

$$F_{Iridium}/F_{UFO} = 1344.1$$

Cursory analysis of equation 4-1 shows that the power density striking the Iridium satellites ($F_{Iridium}$) is approximately two orders of magnitude greater than the power density striking the UFO satellites (F_{UFO}). Of course, this is not the only factor contributing to voice quality since factors such as antenna gain and signal to noise ratios have not been taken into account. Nonetheless, voice quality can easily be expected to be as great as, if not greater than, that of UFO's.

Analysis shows that the bandwidth criterion, the footprint criterion, and the ease-of-use criterion are all successfully met by the Iridium system.

Acceptability

Analysis in this final phase of research is directed toward answering the third secondary research question: Is the use of Iridium economically acceptable? To be an acceptable supporter, Iridium must provide the bandwidth at an economical price. This cost is compared to the committed military system, UFO. First, the costs associated with the Iridium system are analyzed, followed by the costs of the UFO system. Finally, leasing costs are considered and a financial comparison is accomplished between the two systems.

The Iridium system is presently estimated to offer a usage cost of $2.15 per minute. These costs will vary depending on whether the call is placed through the satellite system or through a local, terrestrial cellular system. This cost variance is similiar to present cellular phone pricing structures with local, roaming, or long-distance calls. The base price for monthly service is estimated at between $300 and $400. The price for a handset is also estimated at $2000. The handset price will most likely decrease significantly in order to remain competitive in the commercial cellular market.[25]

The UFO system was purchased by the Department of Defense from Hughes Aerospace Corporation at a price of $1.8 billion for all ten UFO satellites (eight operational and two spares). The contract calls for a satellite lifespan of ten years.[26] Naval Space Command documents the service life of the UFO system as 14 years.[27] The 14 year service life corresponds to the entire operational lifetime of the system which includes the substitution of the spare satellites into the system as malfunctions occur on the older satellites. In order to make the analysis as conservative as possible, the fourteen year lifespan is used. The purchase price of $1.8 billion includes the research, development, procurement, and launch of all ten satellites. The yearly operations and maintenance costs are also totaled. This yearly cost is approximately $220,000 and includes all management of the space operations architecture and maintenance on ground and satellite equipment.[28] The cost of the transceiver equipment use with the UFO system varies widely. Many of the same UHF transceivers that are used with the Fleet Satellite Communications System can also be used with the UFO system. The newest transceiver, the MST-20 or AN/PSE-7, is manufactured by Cincinnati Electronics Corporation. The present cost of these units is approximately $15,200.[29]

Potential leasing costs for the Iridium system have not been considered by either the United States Space Command (USSPACECOM) or the Motorola Corporation at this time. An idea as to the general costs associated with leasing commercial satellite systems is drawn from the leasing costs the U.S. military presently pays Hughes Aircraft Corporation for the LEASAT system described in the first section of this chapter. A total of $12.5 million per year is paid to Hughes Aircraft for the LEASAT system in 1996 ($6.173 million per megahertz per year or $347,222 per channel per year). Future years show lesser amounts as the

the LEASAT system is withdrawn from service.[30] This cost figure would be a poor choice to apply to the proposed reserve-use status of Iridium. The LEASAT satellites, although owned and operated by Hughes, are completely dedicated to military use. The proposed use of Iridium is not to completely dedicate it to military use, but to pay the company an annual fee to ensure that a specific amount of Iridium capability could be made available during a military emergency. Since an amount for this lease has not been proposed, this research will determine the maximum amount that this annual fee should be in order to maintain economical acceptability.

Table 14 summarizes the cost data used in this comparative analysis.

TABLE 14

COMMUNICATIONS SATELLITE COSTS

	IRIDIUM	UFO
Usage Costs (per minute)	\$2.15	N/A
Monthly Service Charges	\$300-\$400	N/A
Leasing Costs (per year)	None Proposed	N/A
Deployment Costs	N/A	\$1.8 billion
Operations Costs	N/A	\$220,000 per year
Satellite Lifetime (years)	N/A	14
Transceiver Costs	\$2000	\$15,200

Analysis of this data shows that the tranceiver cost (handset) of Iridium is much less expensive than the present transceivers purchased for UFO. The total cost of UFO over a fourteen year period, given the costs summarized in Table 14, is $1,803.08 million. This money is for a total of 380 channels (all ten satellites) and 4.2 megahertz of bandwidth. These costs and capabilities equate to $4.75 million per channel ($339,286 per channel per year) or $429.30 million per megahertz ($30.66 million per megahertz per year). The figure of $339,286 per channel per year is also very commensurate with the lease fees presently paid for the LEASAT system. For Iridium to be economical, the total cost of leasing, monthly service, and cost per minute of airtime should remain below $4.75 million per channel and $429.30 million per megahertz. The simplest way to express this requirement would be to designate a total yearly charge for use of a specified number of channels reserved for military use. There is a precedent for this payment scheme. The Department of Defense pays International Maritime Satellite (INMARSAT), introduced in Chapter 2, a yearly contract fee plus a charge of between $6.25 and $13.00 a minute for use of that system.[31] In the area of usage charges, Iridium is clearly economically acceptable since the proposed $2.15 per minute charges are well under the INMARSAT rate.

In summary, the transceiver (handset) cost of Iridium is less than that of UFO and is economically acceptable. Once the amount of channels and bandwidth in reserve to the military is determined, the total yearly cost of the lease contract with Motorola must be maintained under $339,286 per channel per year and $30.66 million per megahertz per year in order for the Iridium system to remain acceptable.

Summary

This chapter analyzed the data available on the Iridium satellite system and compared it to that of the military's UFO system. Three separate areas were examined. First, the suitability of the Iridium satellite system was considered. The section analyzed the present capacity of the military UHF satellite systems. Capacity included both bandwidth and channel access, but also the geographic footprints of the satellite systems. Demand presently exceeds capacity. Both a major regional conflict and the increasing demand of more users added to the system over time creates a situation where the military needs more UHF capacity. Iridium can deliver this capacity in both area coverage and bandwidth. The second section of this chapter considered the feasibility of the Iridium system by comparing it with the capabilities and limitations of the UFO system. Iridium compared very favorably in the areas of bandwidth, channel availability, data rates, area coverage, and transceiver mobility. Finally, cost analysis showed that Iridium's handset price and usage costs are quite favorable. A maximum limit was placed on any proposed lease agreement that would place a portion of the Iridium capabilities at the reserved use of the military in times of war. Remaining below this maximum lease cost, the low cost of the handsets, and the lower usage costs would make Iridium economically acceptable.

Endnotes

[1]U.S. Navy, Navy Warfighter's Guide to Space (Dahlgren, VA: Naval Space Command, 1994), 20.

[2]U.S. Navy, FSCS-200-83-1, Navy UHF Satellite Communications System Description (San Diego, CA: Naval Ocean Systems Center, 1991), 97-98.

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[7]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document draft, (Washington, DC: Defense Information Systems Agency, D-8, 1996), 2-5.

[8]U.S. Air Force, "Military Satellite Communications Demand Assigned Multiple Access (DAMA)" Briefing Delivered at U.S. Space Command Headquarters, 16 October 1995, USSPACECOM, CO, 4.

[9]Peter Anson, "The First Space War: The Contribution of Satellites to the Gulf War," Journal of the Royal United Service Institution 136 (Winter 1991): 46.

[10]Anson, "The First Space War: The Contribution of Satellites to the Gulf War," Journal of the Royal United Service Institution, 47.

[11]Mark Hewish, "Satellite Communications: More Bandwidth and Terminals Needed," International Defense Review (Defense Electronics Supplement) (September 1992): 108-109.

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[22]Jane's Military Communications ed. John Williamson, 16 ed (Alexandria, VA: Jane's Information Group, Inc., 1994), 382.

[23]Jane's Military Communications ed. John Williamson, 399.

[24]Motorola, Inc., "Iridium System Overview," Corporate Technical Summary, 4.

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[26]"Communications Satellite Systems," (Hughes Space and Communications Company: accessed 19 Mar 1996) available from http://www.hughespace.com/hugheshsc/about.html; Internet.

[27]U.S. Navy, Navy Warfighter's Guide to Space, 22.

[28]Cdr. William Baley, telephone interview by author, Fort Leavenworth, KS, 21 Mar 1996.

[29]Daniel Tindall, telephone interview by author, Fort Leavenworth, KS, 21 Mar 1996.

[30]Cdr. William Baley, telephone interview by author, Fort Leavenworth, KS, 21 Mar 1996.

[31]U.S. Navy, Navy Warfighter's Guide to Space, 12.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This final chapter summarizes the findings of the primary and secondary research questions. Recommendations for further research follow the research question findings.

Thesis Questions

The information and analysis presented in the previous chapter provides the necessary basis for answering the secondary research questions. The following subsections compile the answers to all the secondary research questions and then form a final answer to the primary research question.

Secondary Question 1

Can Iridium provide a suitable telecommunications service to the military?

The analysis of all present military communications satellite capability in the UHF spectrum showed that even though all regions of potential theater conflict are fully covered by military UHF satellites, the requirements exceed the capability. Not only are present demands exceeding UHF capability, but the future holds even further user demand. A Major Regional Contingency (MRC) on the scale of Desert Shield/Storm could double or triple these requirements in a given theater. The future deployments of the final three UHF Follow-On (UFO) satellites will not provide the necessary capabilities to eliminate this shortfall. With this established shortfall between capabilities and demands on military UHF satellites, attention turned to the Iridium system. Analysis shows that Iridium's footprint covers all possible theater conflicts and can provide significant UHF bandwidth, additional bandwidth presently not in use by the military. These qualifications makes Iridium a suitable supporter of the military's point-to-point UHF demands and, therefore, the first secondary research question is answered affirmatively.

Secondary Question 2

Can Iridium provide a feasible telecommunications service to the military?

Analysis in this phase of research showed that the capabilities of Iridium compare very favorably with those of the UFO system, the military's primary, committed UHF system. Iridium capabilities even exceed those of the UFO system in some of the criteria areas. Iridium's area coverage is greater than UFO's, bandwidth and channel capabilities are significant, and the ease-of-use of the Iridium handset is better than the present military UHF transceivers. Also, the Defense Information Systems Agency proposed "lower boundary" limitations on capacity, usability, and coverage as described in Table 4 of Chapter 3, such as data rates and voice quality, are also all met or exceeded by the Iridium system. Because of these capabilities, Iridium is certainly a feasible UHF provider for the warfighter and this research question is also answered in the affirmative.

Secondary Question 3

Is the use of Iridium economically acceptable?

Analysis in this phase of research shows that the economics of Iridium compares very favorably with the present UFO system or presently leased commercial communications systems. The cost of the Iridium handsets is much less expensive than the present UHF transceivers purchased by the military for use with the dedicated military satellite communications systems. Usage rates (per minute) for Iridium are expected to be less than the current usage rates for the International Maritime Satellite (INMARSAT) consortium. Since, no lease agreement that reserves a portion of Iridium capability for military use during wartime has yet been discussed, a maximum amount for such a lease was determined. If such a reserve-use lease agreement is considered, maintaining this maximum amount should ensure that Iridium is economically acceptable. If the military simply uses the system on an as-needed basis as a continuous supplement to point-to-point communications capability, the low usage costs and handset purchase prices also makes Iridium an acceptable choice.

Primary Research Question

Can the commercial telecommunications satellite system Iridium effectively support the theater commander?

Following the prescribed methodology from Chapter 3, since the answers to the secondary questions are "yes" to the first, "yes" to the second, and a conditional "yes" to the third, the answer to the primary research question is a yes, but conditional on the final economics of a military lease of the system. Any long-term, reserve-use lease with

Motorola must average out to no more than $339,286 per channel per year and $30.66 million per megahertz per year for the Iridium system to remain acceptable. As a simple, point-to-point communications supplement, the proposed usage fees and handset costs are acceptable, and the answer to the primary research question is an unqualified "yes."

Given the nature of the chosen research methodology, conditional answers are also possible. Some reflection in this area can quickly identify many situations that could swing this answer one way or the other. Changing usage or monthly fees could alter the acceptability issues. Military demand of higher data rates could alter the feasibility issues. Technologically enhanced capability of military UHF satellite systems could alter the suitability issues. A myriad of situations or even simple desires could swing this answer in either direction. Some of these are covered as recommendations for further research in the following section. One fact appears certain. The unique Iridium telecommunications system can provide the warfighter with a supplemental source of telecommunications capability. Whether this supplement supports the soldier in the tank or a larger scale support of the entire Joint Force Commander's theater assets will remain to be seen. Certainly, this unique telecommunications system could generate similar tales in the next war as the Global Positioning System (GPS) generated in Desert Storm. With everyone from cooks to tank operators purchasing GPS receivers on their own credit cards to enhance their personal navigation, it is possible that the next war, with Iridium filling the sky, could draw similar purchases to enhance personal communications.

The military should strongly consider reserving and leasing a portion of this system from the outset.

Recommendations for Further Research

During the preparation of this thesis, many issues have surfaced that warrant further research and discussion. These issues include the operational security of the commercial Iridium system, the probable reality of both the U.S. and a potential belligerent using the same system, the proliferation of Iridium-like handsets among coalition soldiers, and the continued refinement of all legal issues related to the military use of commercial satellite systems.

Since this research has only generally explored the usefulness of Iridium to the military, further research should explore specific strategic, operational, and tactical needs for such a versatile, point-to-point communications system. Further study could specifically focus on the best use of Iridium, either as a part of the reserve communications fleet or as a simple, continuous supplement. Identification of specific guidelines for either the lease of a portion of Iridium as part of a reserve fleet or the use of such capabilities in peacekeeping operations and low intensity conflicts is ground for continued research.

The issue of protection, or ensuring the security of military use on the Iridium system, is one of the primary areas recommended for further research. This study delimited the discussion of this vital area. If the military uses Iridium, even though UHF falls into the "general use" and "unprotected" categories of military communications, the viability of using encoding/decoding equipment compatible with present military systems, such as the STU-III, should be researched further. Also, the security of the Iridium gateways, the satellite linkage to the terrestrial phone system, should be examined.

Along with security, the issue of exploitation, or the use of informational warfare techniques against commercial systems such as Iridium, is another area for further study. Exploitation is taking military advantage of information for tactical, operational, or strategic purposes. Information warfare could encompass tracking of the Iridium handset in use, interception of uplink, downlink, or satellite crosslink signals, hackers breaking into the commercial gateways, or even the direct manipulation of the satellites through hacking into the satellite control systems.[1] The susceptibility of the Iridium system to these acts of aggression should be examined.

A third area for further study includes the ramifications and limitations of the military using the same satellite system as its enemy. Since Iridium is a worldwide, commercial endeavor with international backing, the possibility exists that a future enemy will be sharing the same system during a conflict, much like Iraq using INMARSAT at the beginning of the Gulf War. This contingency should be studied with such systems such as Iridium.

As Global Positioning System receivers were purchased commercially by solidiers in the Gulf War, a future war will surely see the proliferation of cellular/satellite phones in the hands of soldiers, sailors, and airman. Further study should examine the impact of this proliferation, study whether the military should prevent such an event from occurring for the sake of operational and communications security, and analyze courses of action designed to prevent such a proliferation.

Finally, the world community should conduct further analysis and refinement of the international law concerning the military use of space. The need for further refinement is especially true in the area of the military use of commercial space assets. Guidelines for the military lease of satellite communications and other commercial space capability should be proposed and delineated.

Endnotes

[1]Defense Information Systems Agency, DOD SATCOM Functional Requirements Document draft, (Washington, DC: Defense Information Systems Agency, D-8, 1996), 2-9.

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