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MAN'S PLACE IN SPACEPLANE FLIGHT OPERATIONS:
COCKPIT, CARGO BAY, OR CONTROL ROOM?

by

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A Research Report Submitted to the Faculty

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Disclaimer

Contents

Page

Illustrations

Tables

Preface

I will begin by confessing that I have always been fascinated by manned spaceflight. If the Air Force developed a manned Spaceplane tomorrow, my application for crew duty would already be in the mail. However, I challenged myself to approach this research effort without any preconception or bias. I wanted to gain insight to whether or not a military Spaceplane should be configured to carry crewmembers by considering only such engineering and management parameters as mission performance, cost, technology, program risk and safety. I believe my intention for an unbiased analysis was realized.

Also, I'd like to recognize the people who helped me complete this research project. Special recognition goes to my Air Command and Staff College faculty research advisor, Lt. Col. Mik Beno. Lt. Col. Beno helped this paper reach its fullest potential by continually challenging me with one simple but often confounding question: "So what?" Major Ken Verderame provided me with reference material from the Spaceplane Program Office and helped review the initial draft. For additional assistance with the text, I need to acknowledge Major Marty France at the Air Force Space Command, Major Paul Lockhart at the Johnson Space Center and Major Brian Norman here at Air Command and Staff College. To all of you gentlemen, I say thank you.

And finally to Lorraine, thanks for helping me make it through school—again.

Abstract

This paper begins to investigate the question: “What is the proper role of humans in the operation of a military Spaceplane?” All too often, the question boils down to: “Should it be manned or unmanned?” While it’s true that some man-machine interface types require a man on-board and some don’t, this manned/unmanned oversimplification skews the true context of the issue. Therefore, this paper seeks to put man’s role in military Spaceplane flight operations into a more proper perspective. Each of the paper’s three objectives is achieved.

The first objective is to summarize the current literature which is best characterized as a “manned vs. unmanned” debate. Although existing evidence suggests a manned spaceplane configuration provides maximum mission flexibility and an unmanned configuration will result in a more economical program, other factors such as flight safety and program development risk are more difficult to pin down. Neither the manned nor unmanned argument is clearly compelling, and the debate appears to be at a stalemate.

The second objective is to approach the problem from a different perspective by considering an entire spectrum of man-machine interface possibilities. A generic process is presented where specific mission tasks are mapped to optimum man-machine interface choices by considering such factors as performance, cost, schedule, and risk. Viewed in this context, the optimal man-machine interface for a military Spaceplane is shown to be the result of an iterative design process and not a pre-specified system requirement.

Moreover, the presence or absence of a man-on-board becomes a byproduct of a structured analysis instead of the central focus of an ad-hoc debate.

Using the insights provided by this new approach, the third objective is to conduct a preliminary analysis to answer the question posed by the paper's title. Existing space operations doctrine and preliminary mission requirements are assessed to arrive at a generic characterization of military Spaceplane tasks. These tasks are then linked to man-machine interface types using the results of an existing NASA study on the performance of humans in space. Although selecting a specific man-machine interface design for a military Spaceplane is beyond the scope of this paper, some clear insight into man's role in its operation is achieved. This insight suggests a two-phased approach for military Spaceplane development. The baseline military Spaceplane will be capable of supporting all four space mission areas (Force Application, Force Enhancement, Space Control, and Space Support) but should not require the presence of on-board human operators. However, since some Space Control and Space Support missions will involve tasks that can only be performed via direct human intervention, the baseline military Spaceplane will eventually need to be upgraded to carry humans. Since the focus of these humans will be on satellites and payloads (vice the Spaceplane vehicle itself), this 'second generation' MSP should be configured to carry the crew in a removable cargo-bay module only when dictated by mission requirements. Therefore, the proper place for humans in military Spaceplane flight operations is always in the control room, sometimes in the cargo bay, but possibly never in a traditional cockpit environment.

Chapter 1

Introduction

> *The military potential of manned spacecraft may remain an unresolved question for a long time.*[1]
>
> —Maxime Faget

Background

These words, written by one of NASA's founding fathers and a driving force behind America's first manned space program[2], were prophetic considering the United States Air Force's renewed interest in 'spaceplane' technology during the last decade of the twentieth century. Consider, for example, the *Spacecast 2020*[3] study published in 1994 which envisioned "a squadron of rocket-powered transatmospheric vehicles… capable of placing an approximately 5,000 pound payload in any low earth orbit or delivering a slightly larger payload on a suborbital trajectory to any point in the world."[4] This was followed in 1995 by the *New World Vistas*[5] study which recommended "establish(ing) the technical feasibility of an unrefueled global-range aerospace plane to perform reconnaissance and strike functions anywhere on the globe."[6] Finally, in June 1996 the *Air Force 2025*[7] study accomplished by Air University included a "single stage space plane"[8] among the top ten systems that would best ensure the United States' continued dominance of air and space into the next century. Although each of these studies used different terminology: transatmospheric vehicle, aerospace plane, and multipurpose transatmospheric vehicle, they all clearly pointed to the same underlying capability. Consistent with current initiatives at the Air Force Space Command (AFSPC) and Air Force Research Laboratory (AFRL), this paper uses the nomenclature *military Spaceplane (MSP)* when referring to the reusable, hypersonic, air and space vehicle envisioned by the aforementioned USAF long range studies.

Research Objectives

General

The Air Force has not yet engaged in a rigorous discussion of whether or not a MSP should be configured to carry crewmembers. When broached, this issue is usually posed in the oversimplified terms of a discrete, binary decision: *manned or unmanned*. The overall objective of this paper is to open the discussion of this complex issue by putting it in a more proper perspective.

Specific Objectives

The three specific objectives of this research effort are to:

1. Demonstrate the lack of consensus in the *manned vs. unmanned* spaceplane debate by summarizing the existing literature and contrasting the supporting evidence from each viewpoint.
2. Approach the problem from a different perspective by considering an entire spectrum of man-machine interface (MMI) modes that are possible for MSP operations. Viewed in this context, the presence of man on-board a MSP is a by-product of a structured analysis instead of the central focus of an ad-hoc debate.
3. Using this new approach, conduct a first-order MMI analysis to answer the question posed by this paper's title: Does man belong in the MSP cockpit, cargo bay, or control room?

Assumption

Existing requirements (to be presented in Chapter 2) cite the need for a MSP to perform in all four space operations mission areas: Space Control, Force Application, Force Enhancement, and Space Support. The Air Force operational and acquisition communities have not yet validated a MSP as the best way to satisfy these mission area requirements, but doing so here is beyond the scope of this paper. Nonetheless, this paper assumes that if a MSP is developed, it will have a role to play in all of these mission areas.

Overview of Paper

In addition to documenting the specific objectives of this research, Chapter 1 has briefly touched on the long-range USAF studies that recommend the development of a military Spaceplane. Chapter 2 will present additional background on the current MSP program and build a foundation for MSP system requirements using Air Force space operations doctrine and broad mission area needs. Chapter 3 summarizes the 'manned vs. unmanned' spaceplane debate that currently exists in the literature by reviewing the major arguments presented by each side. It includes a sampling of existing spaceplane concepts to illustrate the widely varying thoughts on how man should (or should not be) used in their operation. Chapter 4 shifts the debate away from a binary *manned vs. unmanned* paradigm towards an entire spectrum of possibilities that should be considered to determine the optimal MSP man-machine interface (MMI). In addition, it presents a task allocation process for selecting an appropriate baseline design, and uses existing data on the performance of humans in space to gain preliminary insight to whether or not MSP missions are well suited to having a human on-board. Finally, Chapter 5 summarizes the key findings and recommendations of this paper to include a prediction of how man will ultimately be integrated into a MSP system configuration. .

Notes

[1] Maxime Faget, *Manned Spacecraft: Engineering Design and Operation* (New York NY: Fairchild Publications, Inc., 1964), 14.

[2] Project Mercury

[3] In September 1993, USAF Chief of Staff General Merrill McPeak directed Air University to identify high leverage space technologies and systems that would best support the warfighter and could be fielded by the year 2020. The result was a study published in 1994 entitled *SPACECAST 2020*. An on-line version of the final report can be found at www.au.af.mil/spacecast/spacecast.html.

[4] Air University, *SPACECAST 2020*, vol.1, (Maxwell AFB, AL: Government Printing Office, 1994), Appendix H, page H-1.

[5] In November 1994, Air Force Secretary Widnall and Chief of Staff Fogleman tasked the USAF Scientific Advisory Board to search for the most advanced air and space ideas and project them into the future. This *New World Vistas* report was published on 15 Dec 95, the 50th anniversary of the very first USAF Scientific Advisory Report: *Toward New Horizons*. The *New World Vistas* summary volume is on-line at http://web.fie.com/htdoc/fed/afr/sab/any/text/any/vistas.htm.

[6] Air Force Scientific Advisory Board, *New Word Vistas: Air and Space Power for the 21st Century*, Attack Volume, (Washington DC**:** Government Printing Office, 1995), ix.

[7] In December 1994, USAF Chief of Staff General Ron Fogleman directed Air University to look 30 years into the future to identify the concepts, capabilities, and techniques needed for the United States to remain a dominant air and space power in the 21st century. The result was a study entitled *Air Force 2025*. An on-line version of the final report can be found at www.au.af.mil/au/2025.

[8] Air University, *Air Force 2025*, (Maxwell AFB, AL: Government Printing Office, 1996), n.p.: on-line, Internet, 23 Sep 96, available from http://www.au.af.mil/au/2025/quiklook.htm.

Chapter 2

A Military Spaceplane: Mission and System Requirements

Before delving into the details of finding the proper place for man, it is first necessary to understand the requirements being levied on the MSP system itself. Since the MSP program is in its infancy, many requirements exist only in draft form. In order to understand the context in which these preliminary requirements were developed this chapter begins with a brief history of the current MSP program. This is followed by an overview of current USAF space doctrine to lay a foundation for the mission areas a MSP must support. A general understanding of these mission areas is necessary for the mission-to-task portion of the analysis conducted in Chapter 4.

Military Spaceplane Program Summary

To flesh out the recommendations for spaceplane development made by such long range studies as *New World Vistas*, *Air Force 2025*, and *Spacecast 2020*[1], Air Force Space Command (AFSPC) and Air Force Material Command (AFMC) co-chartered an MSP Integrated Concept Team (ICT) in 1996. This multidisciplinary team was tasked to further investigate the military utility and technical feasibility of a reusable military Spaceplane capable of operating in and out of the earth's atmosphere to accomplish both sub-orbital and orbital missions. This team, comprised of members from the operational, scientific, and acquisition communities, focused its efforts in four areas: Requirements, Concept of Operations, Technology Development, and Program Integration. In mid-1997, the MSP ICT completed its work by capturing its findings in a number of documents to include a Capstone Requirements Document, Systems Requirements Document, and Mission Need Statement. Although still in draft form, these documents are included in the source documentation for this paper.

In addition to the MSP ICT's activities, a Military Spaceplane Technology Program Office was established within the AFRL (formerly Phillips Laboratory) to serve as the focal point for integrating all MSP research, development, test, and evaluation (RDT&E) efforts. In addition to coordinating in-house technology development efforts, this organization manages MSP related technology development and demonstration initiatives under contract to private industry.

In October 1997, after the ICT had completed its work and the MSP Technology Program Office had been established to manage the fledgling "program," President Clinton line item vetoed approximately $10M that was intended to fund MSP technology development projects already on contract to Lockheed Martin and Boeing.[2] Nonetheless, USAF interest in spaceplane technology remains high, and in-house work on user requirements, technology development, and long-range acquisition planning continues.

Space Operations Doctrine

According to Air Force Doctrine Document 2-2, Space Force Operations focus on controlling the space environment (*Space Control*), applying force (*Force Application*), conducting enabling and supporting operations for terrestrial forces (*Force Enhancement*), and supporting space forces (*Space Support*).[3] Since a MSP will support all four of these mission areas, each will be examined in further detail.

Space Control

Space Control missions gain and maintain *space superiority*. Space superiority, a concept analogous to ‘air superiority’, refers to the freedom to conduct operations in space without interference from the enemy. Space Control missions may take either an offensive or defensive form. Offensive counter-space missions deceive, disrupt, deny, degrade, or destroy enemy space forces by targeting either the enemy’s space assets themselves or ground support elements. Defensive counter-space missions protect our own forces from the enemy’s offensive operations. They may be active (e.g. destroying an anti-satellite projectile, performing a collision avoidance maneuver, or deploying a decoy) or passive (e.g. encrypting satellite communications and hardening against electromagnetic pulse effects). Although our ability to conduct space operations has been relatively unchallenged in the past, the proliferation of military and commercial space systems suggests this may not always be the case in the future.[4]

Force Application

AFDD 2-2 defines Force Application as “attacks against terrestrial targets carried out by military weapon systems operating in space.”[5] It states that although we do not currently possess this capability, developments in technology may change this situation in the future. By not including existing Intercontinental Ballistic Missiles (ICBM) in this mission area, the doctrine obviously takes a very narrow interpretation of the phrase “operating in space,” i.e., suborbital weapons do not meet this criterion.[6] From a pragmatic viewpoint, technology will drive the characteristics (speed, range, weapon release altitude, etc.) of force application missions, and the distinction between *space* force application and *air* force application becomes academic.

Force Enhancement

Force Enhancement encompass "those operations conducted from space with the objective of enabling or supporting terrestrial forces."[7] This type of mission needs little explanation since it accounts for most of today's space operations. The functions that these operations provide (and some current system examples) include: navigation (Global Positioning System), communication (MILSTAR), surveillance and reconnaissance (National Reconnaissance Office platforms), missile warning (Defense Support Program), and environmental sensing (Defense Meteorological Support Program).

Space Support

Space Support operations "sustain, surge, and reconstitute elements of a military space system or capability."[8] Common examples of this mission type include spacelift (to place mission assets in orbit) as well as telemetry, tracking, and control (to sustain them in orbit). Other Space Support missions made possible by reusable launch vehicles include retrieving spacecraft from orbit so they can be refueled and refurbished, or even repairing and maintaining spacecraft on-orbit to prolong their useful life.

MSP Mission Requirements

To support these four mission areas in the future threat environment, AFSPC has drafted Mission Need Statement (MNS) 001-97, *Tactical Military Operations is Space*, which proposes "a new, reusable, launch-on-demand, multi-purpose military space system designed for tactical space operations, called the Military Spaceplane (MSP).[9]" Near term (3-6 years) MSP requirements focus on "defensive counter-space to protect existing assets" (Space Control), and "limited on demand Force Enhancement (surveillance and reconnaissance)."[10] Medium to long term (6-18 years) requirements include: space superiority, space surveillance and space object identification (Space Control); navigation support, intelligence, surveillance and reconnaissance, meteorology and theater/national missile defense (Force Enhancement); and the deployment, repair, refueling and servicing of satellites (Space Support).[11] Draft MNS 001-97 also refers to the need "for rapid, global precision strike to augment conventional delivery systems" [12] (Force Application). As a point of departure for identifying more specific requirements, five Design Reference Missions (DRM) have been identified. These DRMs encompass all four space mission areas and are summarized in Table 1.

Table 1. MSP Design Reference Missions

DRM	Mission Description	Applicable Mission Areas
1	The Military Spaceplane System shall be able to accurately deliver, using a pop-up (i.e. sub-orbital) maneuver, mission assets to any location on earth from any azimuth within 90 minutes from takeoff.	Force Application
2	The Military Spaceplane System shall be able to deliver, using a pop-up maneuver, mission assets to orbit.	Space Support Force Enhancement
3	The Military Spaceplane System shall be able to co-orbit and/or dock with a satellite or other orbiting object, deploy or use on-board mission assets and return to base	Space Control Space Support
4	The Military Spaceplane System shall be able to co-orbit with a satellite or other orbiting object, recover that object and return to base	Space Control Space Support
5	The Military Spaceplane System shall be able to launch into any azimuth and use or deploy mission assets, while in a once around orbit and return to base.	Force Application Force Enhancement Space Control Space Support

Source: Adapted from: Majors Ken Verderame and Andrew Dobrot, *Systems Requirements for a Military Spaceplane, (DRAFT, Version 1.0),* April 1997, 23.

MSP System Requirements

Initial MSP system level requirements are still being formulated. They will continue to evolve as enabling technologies[13] mature, specific threats emerge, and funding support is gained. However, this section provides a thumbnail sketch of MSP requirements as they exist in draft form to offer a glimpse of the envisioned MSP capability.

General Requirements

A MSP will be a reusable system, capable of operating through and above the atmosphere to perform the reference missions listed in Table 1.[14] It will be capable of delivering suborbital payloads anywhere on the earth's surface or operating in orbit for 24-72 hours. What separates a MSP from conventional spacelift platforms is that its operations and support concepts are more "aircraft-like" than those associated with conventional space launch platforms. For example, MSP launch response times will be measured in hours instead of weeks or months. Reliability objectives specify not more than one catastrophic failure in 5000 sorties. A MSP will operate from conventional runways[15] and be all-weather capable. In summary, MSP operations, maintenance, training and testing processes are intended to be "analogous to the processes used (for) military aircraft."[16].

Man-machine Interface Requirements

The *System Requirements for a Military Spaceplane (Draft)* specifies a variety of man-machine interface requirements for a MSP flight vehicle. Consider the following three excerpts:

> The Military Spaceplane System should accommodate male and female crew members of no less than 100 pounds and no more than 240 pounds and a height of no less than 60 inches and no more than 76 inches.[17]

> The Spaceplane…shall be capable of autonomous execution of pre-programmed missions with or without a crew onboard.[18]
>
> The flight crew shall be able to direct the Spaceplane either from onboard the Spaceplane or from the ground or support vehicles via a virtual crew interface. This capability shall be provided with or without a crew onboard.[19]

The first two excerpts require a MSP to operate in *both* the 'manned' and 'unmanned' modes. The third, which refers to a 'virtual crew interface,' implies that other options exist—an observation that will be explored further in Chapter 4. However, it is not clear whether these specified requirements are valid or even appropriate—issues that will also be addressed later. But before pursuing these ideas, the next chapter investigates the focus of the current debate on spaceplane operations: *manned vs. unmanned*.

Notes

[1] The "Background" section of Chapter 1 cites the specific recommendations of these studies.

[2] "Line Item Veto Hits Aerospace," *Air Force Magazine*, December 1997, 16.

[3] Air Force Doctrine Document (AFDD) 2-2, *Space Operations*, February 1997, 5.

[4] Ibid., 5

[5] Ibid., 8

[6] A more appropriate interpretation of this mission area should include weapon systems operating *in, from, or through* space. (See, e.g.: Air Force Space Command, *Military Spaceplane Capstone Requirements Document (DRAFT, Version 4.0)*, March 1997, page 2.) This interpretation is consistent with the current USAF trend to remove the psychological boundary separating the 'air' and 'space' media. It is also consistent with the organizational transfer of USAF ICBM forces to Air Force Space Command.

[7] AFDD 2-2, 8

[8] Ibid., 9

[9] Air Force Space Command Mission Need Statement (AFSPC MNS) 001-97, *Tactical Military Operations in Space, DRAFT (Version 5.9)*, November 1997, 4.

[10] Ibid., 3.

[11] Ibid., 3.

[12] Ibid., 1.

[13] Critical technologies include propulsion, structures, thermal protection, and operations.

[14] Some additional details, e.g. payload mass, payload volume, and orbital parameters, for these Design Reference Missions can be found in the source document for

Notes

Table 1. They are not presented here since they are not critical to the first-order mission analysis conducted in Chapter 4.

[15] Various take-off and landing techniques have been proposed. MSP vehicles designed to take-off/land horizontally will use runways. Vehicles designed to take-off/land vertically (like the McDonnell Douglas DC-X concept vehicle) may simply use concrete pads.

[16] Majors Ken Verderame and Andrew Dobrot, *Systems Requirements for a Military Spaceplane, (DRAFT, Version 1.0)*, April 1997, 8-9.

[17] Ibid., 9.

[18] Ibid., 21.

[19] Ibid., 21.

Chapter 3

The Current Debate—Manned *v*. Unmanned

> *Cockpits will become more and more automated until, about 25 years from now, there won't be any pilots on board.*[1]
>
> Dr. Jan Roskam
> *Ackers Distinguished Professor of Aerospace Engineering*
> University of Kansas

> *Where else would you get a non-linear computer weighing only 160 lbs., having a billion binary decision elements that can be mass produced by unskilled labor?*[2]
>
> Scott Crossfield
> *X-15 Test Pilot*

The purpose of this chapter is to examine the *manned vs. unmanned* debate in greater detail. The supporting evidence from each side will be presented beginning with a generalized overview and progressing to a more detailed discussion. Some existing spaceplane concepts from both camps are included for illustration. Consistent with most current literature on the subject, the terms "manned" and "unmanned" are used extensively.

Principle Arguments

The argument for putting a human operator on board a spaceplane is mostly *qualitative* in nature. It centers on the fact that man's cognition, judgement, and experience provide an inherent flexibility to react to unanticipated events that cannot be matched by machines.[3] Although few human beings would take exception to this view, especially considering the failure of "artificial intelligence" to reach the fruition promised in the 1980's, it is difficult for proponents of manned systems to quantify this benefit. "There is no way that a price tag can be placed on such characteristics as flexibility or serendipity[4] because the essence of these attributes is the ability to capitalize on the unanticipated or unknown."[5]

On the other hand, the argument favoring an unmanned system is primarily *quantitative*. Proponents of unmanned systems quantify their support in terms of lower costs (since the system need not achieve a "man rated" reliability), increased payload capability (since the crew and their life support systems can be replaced with payload), and less risk to human life. Neither of these supporting arguments is as iron clad as each side would like to think. To illustrate this, a point/counter-point analysis will be conducted using specific parameters—cost, safety, technology, and program risk—that should be considered when conducting any system design trade study. A few other issues that often get thrown into the mix are highlighted as well.

Cost

With the possible exception of a spaceplane's empty weight, whether or not it has a human operator on board may be the overriding determinant of its cost.[6] For example, cost estimates of the Skylon spaceplane, a derivative of the British Aerospace HOTOL (HOrizontal TakeOff and Landing) design, suggest that man-rating the vehicle will increase development costs by 50%.[7] Existing data from commercial airliners suggest that 25% of development costs go towards cockpit design.[8] Unmanned systems are expected to provide additional cost savings since the absence of a crew and their associated life support systems reduces the vehicle's total weight.

Unmanned spaceplane advocates also suggest the complexity of an integrated cockpit design can only inflate operating costs. Since "servicing activities become more complex to ensure that the crew compartment and vehicle are safe for the next mission"[9], direct operating costs increase. Furthermore, if these added servicing requirements lead to a decreased flight rate, the average cost of each flight goes up since fixed infrastructure costs are amortized over fewer flights.

Proponents of manned spaceplanes have a different set of cost figures. For example, the designers of the Sanger Spaceplane estimate the per-flight cost of their manned configuration is only 10% higher than an unmanned configuration, assuming 12 flights per year.[10] In general, 'man rating' costs are often overstated since they ignore the fact that a MSP is reusable. Since the vehicle itself will have to survive each sortie, flight profiles and design considerations will keep the g-load, thermal environments, and other stress factors within reasonable bounds. Thus the basic MSP design philosophy will be inherently consistent with man rating considerations, even if no operator is on board.[11] Additionally, unmanned vehicles have hidden development costs for autonomous or remote guidance and control systems and "expert systems" for mission management that often go unmentioned. These may exceed the cost of outfitting the vehicle for a crew.[12] Finally, the cost of installing and operating ground support sites for telemetry, tracking and control (TT&C) erodes the cost advantage of unmanned systems even further.

Safety

From a spaceplane flight crew perspective, the risk to human life is clearly minimized by an unmanned vehicle configuration. But what can be said about the risk to the civilian population beneath the vehicle's flight path?

Proponents for manned system say this is where the flexibility of a human operator is vital. Using the argument presented by the X-30 program (a National Aerospace Plane technology demonstrator), a pragmatic MSP flight test program will require a multitude of alternate landing sites throughout CONUS to allow vehicle recovery when (*not if*) problems occur. "Because of numerous factors (weather, energy state, required test conditions, telemetry coverage, etc.), these recovery bases may not always be the same and, therefore, the (vehicle) must be designed to be capable of recovery into any base/lakebed with a long enough runway. Recovery from orbit will require similar landing flexibility." [13] Manned advocates suggest it would be cost prohibitive to outfit every alternate landing site with either the TT&C equipment necessary for a remotely controlled landing or specialized landing systems (such as Microwave Landing System) required for an autonomous landing. (Existing ILS instrumentation cannot be used since spaceplane final approach profiles are much steeper than the 3 degree glideslope used by conventional aircraft.) Finally, current regulations prohibit flight of unmanned air vehicles outside restricted airspace without a "safety chase" aircraft. Obviously, no aircraft exists that could chase a MSP.

Unmanned advocates are prepared to counter these assertions. First, the technology exists to use GPS signals for a precision approach to any runway with a minimum amount of specialized equipment.[14] (If GPS was jammed during hostilities, back-up navigation aids could be planned for at a minimum number of contingency landing sites.)

Additionally, the requirement for a chase aircraft is simply an example of regulations lagging behind technology. Consider, for example, the aircraft landings that are routinely accomplished today in nearly 'zero ceiling, zero visibility' weather conditions. These landings, made possible by modern instrument landing systems, would have been unthinkable at the dawn of commercial aviation. Similarly, the laws of the land (vice the laws of physics) determine safety chase regulations. They are within our power to change as technology and risk dictate.[15]

Technology

Sending unmanned launchers into orbit and conducting unmanned satellite operations from space is clearly 'old' technology, as this has been the dominant mode of military space operations for nearly 40 years. Commercial airliners, using GPS integrated inertial navigation systems and automated flight controls, are currently capable of auto piloting themselves to their destinations—including landing.[16] According to a recent article on cockpit automation published in Design News, "artificial intelligence and decision-aiding programming (will) turn the pilot's job into that of a flight supervisor," and even military fighter aircraft will "evolve into unmanned vehicles."[17] The growing USAF interest in unmanned air vehicles (UAVs) such as Predator and Dark Star supports this prediction.

Proponents of manned spaceplanes take a more skeptical view of having HAL or R2D2[18] available to fly a MSP anytime soon. Their more pragmatic outlook is dictated by recent history more than the distant future:

> In spite of rapidly increasing cockpit automation, it is expected that airliners will require pilots for the foreseeable future. Unpiloted airplanes to date have fallen short of safety standards required for a Certificate of Airworthiness. It therefore seems prudent to assume that an early spaceplane designed for flight safety will need to be piloted.[19]

Program Risk

Three arguments suggest unmanned systems will have the overall lower program risk. The first relates directly to cost. Since it is generally believed that billions of dollars[20] will be needed to develop an MSP system already challenged with technological obstacles, adding 50% to the development costs to “man rate” the vehicle[21] would make the program completely unexecutable in any conceivable budget environment.

The second point relates to both cost and technology risk. The MSP Program Office has stated its strategy to reduce MSP technology risks by developing a series of technology demonstrators referred to as ‘X-’ vehicles. Assuming initial generation X-vehicles are subscale for cost reasons, they may have to be unmanned since it becomes increasingly difficult to build manned vehicles as their scale decreases. If this is the case, many technical issues (e.g. command and control and operational test procedures) as well as legal issues (e.g. chase aircraft requirements and overflight of populated areas) will be solved during this program phase. Therefore many of the previous criticisms of the unmanned approach could be worked out over the life of the program.[22]

The final point concerns risk to the development program from both the politicians and the public. It is entirely possible that the loss of even one human life during the flight test phase could kill the entire program. Consider the Challenger accident of 1986 when an established space program stood down for nearly three years while design changes were made. It is doubtful a high budget, high-risk MSP development program could survive a similar mishap.

Proponents of manned vehicles have strong empirical data to counter these arguments. When considering technology demonstrators, they suggest that any X-vehicle design *must* be on a large enough scale to accommodate a human operator just to avoid losing an excessive number of flight vehicles during the test program. Consider, for example, NASA's "X-" vehicles (X-1 through X-29) which had a cumulative loss rate of only one vehicle loss per 140 sorties.[23] Compare this to various unmanned drones and cruise missile test programs which exhibited loss rates from about one vehicle in ten sorties to one vehicle in four sorties.[24] Finally, advocates of manned systems suggest that public tolerance to flight test mishaps will be acceptable as long as military test pilots are used. As has been pointed out before, test pilots are "more expendable than civilians."[25]

Other Issues

A MSP could provide for both manned and unmanned operation. If a crew station can be inserted into the payload section, it may be possible to fly a MSP in either mode. "For crewed missions, a capsule is serviced off-line from the launcher…and then inserted into the next vehicle just like cargo."[26] Although the added design complexity of such a bi-modal configuration would certainly have its own costs and issues to be reckoned with, this proposal appears worthy of further consideration and study.

A MSP may transition from manned to unmanned (or vice versa) as the technology and vehicle design matures. There are four reasons why MSP flight operations could evolve from predominantly manned during the flight test program to predominantly unmanned for operational missions. First, it is prudent to expect the unexpected during the initial test flights, and this is precisely the environment where an on-board operator is the most beneficial. Second, obtaining government permission to let an unproven, unmanned 1,000,000-lb vehicle fly over populated areas may be difficult.[27] Third, the manned test flights would collect the hypersonic aerodynamic data required by fully autonomous flight control systems without relying on these same control systems to collect the data. Such data is difficult to model and predict using only computers and wind tunnels. Finally, when the test program is complete and confidence in the vehicle's performance is sufficient, most missions could be flown unmanned to maximize payload capability.[28] A number of current spaceplane concepts, including HOTOL, Sanger, Delta Clipper, and Blackhorse, have proposed this strategy.

Interestingly, the design team for the Skylon spaceplane concept discussed earlier has proposed the exact opposite strategy. They suggest early prototypes should be unmanned to make the program affordable. Only when the vehicle technology matures should manned operation be attempted.[29]

"Man in Space" has historical precedence. It should be remembered that the primary objective of NASA's manned spaceflight programs, from Project Mercury through the Space Shuttle, was to *put* man in space.[30]. Since the *raison d'être* for these programs required a human on board, trade studies to investigate unmanned alternatives were never performed. Since a MSP has military objectives that extend beyond the confines of the vehicle itself, comparing it to manned NASA programs is inappropriate.

Manned systems may be less vulnerable to hostile attack. The presence of a human on-board a military space platform may add to its self-protection capability. As

Lt Col Joseph Carretto suggested in his research paper entitled *Military Man in Space—Essential to National Strategy*:

> The presence of humans provides a deterrent. A satellite in orbit, no matter how expensive, is just a piece of machinery. Nations don't go to war over machines. But put one seemingly insignificant soldier, sailor, or airman on that machine, and suddenly national sovereignty is threatened.[31]

The "destiny" of humans in space. The "manned *v*. unmanned" issue is not only technically complex, but emotionally charged as well. Max Hunter, the aerospace engineer who developed the precursor[32] to the Delta II launch vehicle, stated:

> The reason for suggesting a (spaceplane) program is not merely to solve our current mission requirements in the most antiseptic manner, which might be done with only unmanned systems. It is to create the path to *spaceships* which will take the human race to space.[33]

A statement concerning man's extraterrestrial destiny will not likely find its way into any official USAF requirements document. Whether or not a MSP has a role to play in this area is beyond the scope of this paper.

Summary

As this chapter has demonstrated, most of the existing literature is divided between two firmly entrenched camps—*manned* and *unmanned*. Manned systems are more capable of dealing with unexpected situations and therefore provide increased mission flexibility. Unmanned systems appear to be less expensive overall, but estimates vary by exactly how much. Other considerations, such as technology readiness, program risk, and safety, are more difficult to pin down. Interestingly, most of the literature surveyed for this chapter made almost no mention of the most important parameter of all—*performance*.[34] This suggests a significant gap in the current debate, and helps illustrate one of its major shortcomings.

In summary, both sides need to realize that machines will not replace humans, but people and machines will demonstrate new types of interactions. The relationship between man and machine is an integral piece of the puzzle that must be considered from the start of the design process.[35] Therefore, it is time to proceed beyond the simple *manned v. unmanned* paradigm to explore other possibilities.

Notes

[1] Quoted in Mark Gottschalk, "Computers Take Over the Cockpit," *Design News* 51, no. 52, (4 Nov 96): 98.

[2] Quoted in W. F. Hilton, *Manned Satellites* (New York NY: Harper & Row, 1965), 105.

[3] Lt. Col. Joseph A Carretto, USAF, "Military Man in Space–Essential to National Strategy", Research Report NDU-ICAF-95-S3 (Fort McNair, Washington DC: Industrial College of the Armed Forces, 1995)

[4] The cited reference defines *serendipity* as "the capability of making unexpected discoveries by accident."

[5] Air Force Space Command study, "The Utility of Military Crews in Space" (Draft), 1985 in Wierzbanowski, *Manned vs. Unmanned: The Implications to NASP*, AIAA-90-5265 (Orlando FL: AIAA Second International Aerospace Planes Conference, 1990), 10.

[6] Russell J. Hannigan, *Spaceflight in the Era of Aerospace Planes* (Malabar, FL: Krieger Publishing Co, 1994), 229

[7] Richard Varvill and Alan Bond, "Skylon: A Key Element of a Future Space Transportation System," *Spaceflight* 35, no. 5 (May 1993): 164.

[8] Gottschalk, 98.

[9] Hannigan, 108.

[10] Ibid., 132

[11] Air University, *SPACECAST 2020*, vol.1, (Maxwell AFB, AL: Government Printing Office, 1994), Section H, Appendix C, pgs H-40,41

[12] Wierzbanowski, *Manned vs. Unmanned: The Implications to NASP*, AIAA-90-5265 (Orlando FL: AIAA Second International Aerospace Planes Conference, 1990), 9.

[13] Ibid., 7

[14] The Space Maneuver Vehicle, an experimental vehicle built for a military Spaceplane Technology Program Office by Boeing/North American has an autonomous landing capability using Differential GPS.

[15] The flight test program for the X-33, an unmanned reusable launch vehicle being developed by NASA and Lockheed Martin, calls for suborbital flights between Edwards AFB CA, Michaels AAF UT, and Malmstrom AFB MT. Therefore, in addition to developing and maturing spaceplane vehicle technologies, the X-33 program may also dictate a significant restructuring of the Federal Aviation Regulations.

[16] The author had the opportunity to "fly" in the United Airlines flight simulator facility, Denver CO in 1991. Once programmed, modern airliners can fly final approach

and landing profiles automatically, to include auto-throttling and auto-braking. The only "manual" task required of the pilot is to taxi the aircraft off the runway after it has come to a complete stop!

[17] Gottschalk, 90,94.

[18] The "smart" machines of *2001: A Space Odyssey* and *Star Wars*.

[19] David Ashford, "The Potential of Spaceplanes," *The Journal of Practical Applications in Space* 6, no. 3 (Spring 1995): 224

[20] A 1994 OUSD/A&T report, *Space Launch Modernization Plan*, estimated spaceplane development costs between $6-20 billion. According to Maj. Ken Verderame at the MSP Program Office, recent estimates are closer to $2B for one sub-orbital concept demonstration vehicle and one orbit capable spaceplane.

[21] Varvill and Bond, 164

[22] The X-33 may be a case in point. (See Endnote 16.)

[23] Jay Miller, *The X-Planes, X-1 to X-29*, in Wierzbanowski, 10.

[24] Wierzbanowski, 9.

[25] Carretto, 35.

[26] Hannigan, 108.

[27] Again, the NASA X-33 may break new ground in this area which would benefit future military Spaceplane flight-testing. (See Endnote 16.)

[28] Ibid., 228.

[29] Varvill and Bond, 164.

[30] For a comprehensive review of the objectives of these manned programs, see: US House of Representatives, Committee on Science and Technology, Subcommittee on Space Science and, Applications, *US Civilian Space Programs, 1958-1978*, 97th Congress, 1981

[31] Carretto, 27.

[32] The "Thor" Intermediate Range Ballistic Missile

[33] Max Hunter, "The SSX – A True Spaceship," *The Journal of Practical Applications in Space* 4, no. 4 (Summer 1993): 34. (emphasis in original)

[34] Performance was often addressed indirectly in terms of throw-weight (or payload fraction) for space lift missions, which could then be translated into vehicle cost savings for a given payload mass. For on-orbit spacecraft servicing missions, Walz addressed performance considerations more than most, but he asserted that "there is no best systematic approach to delineating man/machine roles." (Walz, pg 179) This assertion is challenged in the next chapter.

[35] Donald M. Walz, *On-Orbit Servicing of Space Systems* (Malabar, FL: Krieger Publishing Co., 1993)

Chapter 4

The Man-Machine Interface Spectrum

> *There is no such thing as an unmanned system: everything that is created by the system designer involves man in one context or another*[1].
>
> —Stephen B. Hall
> Editor, *The Human Role in Space*

As suggested in the conclusion of the previous chapter, man-machine interface (MMI) design choices are not limited to two extremes: 100% manual or 100% automatic. This idea is now explored further in order to arrive at an analytical approach to determining man's proper place in MSP flight operations. Using NASA's *The Human Role in Space (THURIS)* study as a reference, the first half of this chapter defines seven MMI modes for conducting space operations, presents a generic MMI selection process, and summarizes specific *THURIS* results pertaining to the utility of humans in space.

The second half of the chapter then steps through a preliminary MMI analysis for a MSP. MSP functional tasks are inferred from the mission requirements presented in Chapter 2. When these tasks are combined with specific performance data from the *THURIS* study, some insight to man's role in MSP flight operations is achieved.

The Human Role in Space (THURIS) Study

The Human Role in Space (*THURIS*) was a NASA study completed in 1984 designed to: (1) investigate the role of humans in future space missions, (2) establish criteria for allocating tasks between men and their machines, and (3) provide insight into the technology requirements, economics, and benefits of humans in space.[2] By identifying common tasks, baselining human performance capabilities, and accounting for cost and technology factors, the researchers were able to:

> provide a methodological framework by which system engineers and decision makers could evaluate early in the conceptual design process the relative advantages and disadvantages of alternative modes of man-machine interaction.[3]

This study provides both a logical framework with which a MSP man-machine interface problem can be attacked and some specific findings that can be used to assess the value of having a man on-board a MSP flight vehicle.

Defining the MMI Spectrum

The *THURIS* study identified seven MMI modes, spanning a "spectrum" from direct manual control to completely autonomous operation. Table 2 lists these modes and provides an example of each.

As will be shown in the next section, optimal MMI selection starts by considering the *tasks* that a system must perform. Since most complex systems perform a variety of tasks, it should be expected that some systems might incorporate more than one MMI mode. Consider the Space Shuttle as an example. The Shuttle ascends to orbit using an autopilot monitored by the astronauts (Supervised, On-board). Once in orbit, satellites are deployed using the Remote Manipulator Arm (Teleoperated) and retrieved by pressure-suited astronauts attached to manned-maneuvering units (Supported). During the final approach and landing phase, the pilot "flies" the Shuttle not unlike a glider (Manual), but has a number of sensors and instruments to assist him (Augmented). To relate this to the paradigm of the preceding chapter, if at least one task is executed with an MMI mode that requires a human on board, the system is considered *manned* in the conventional sense.

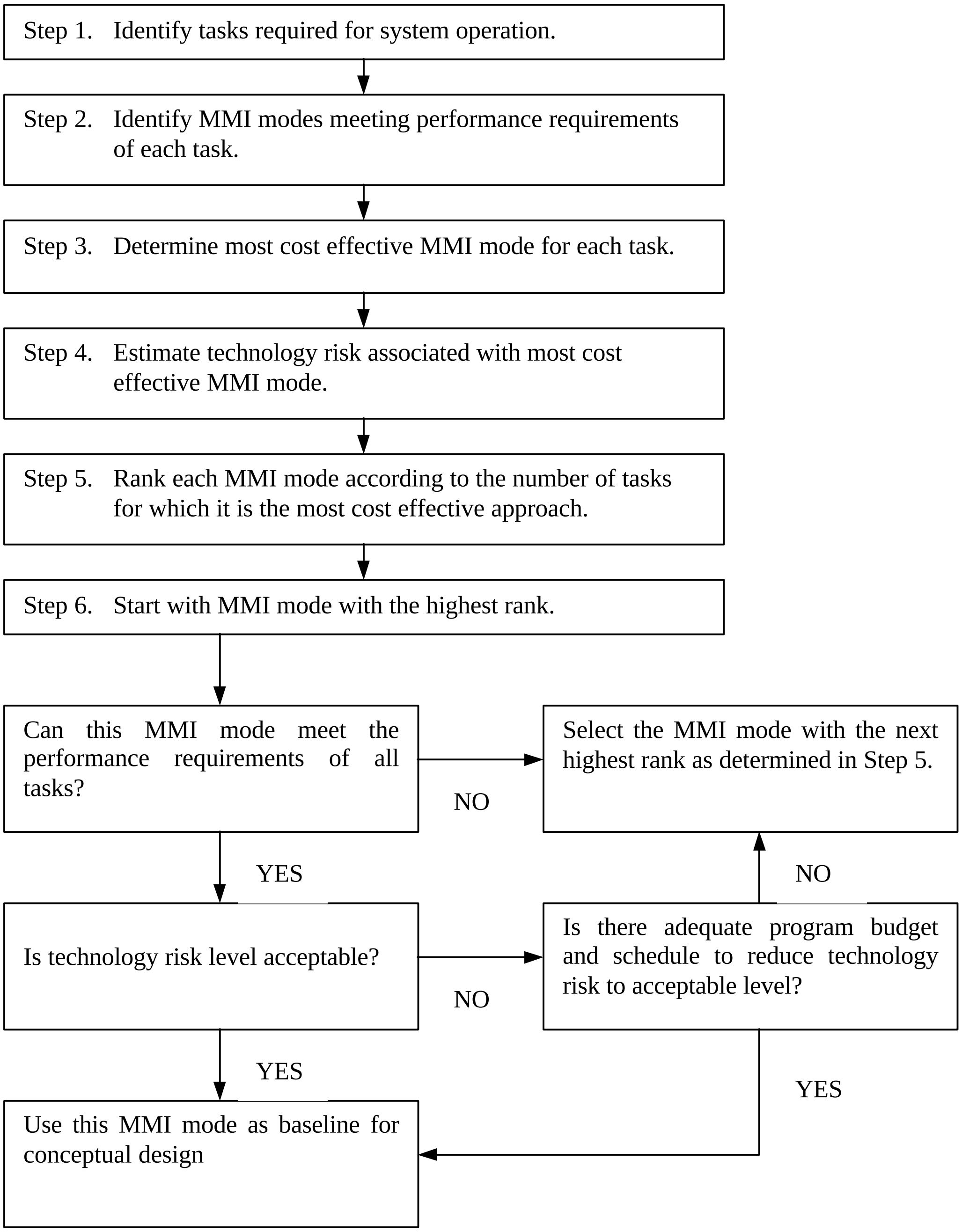
Table 2. The Spectrum of Man/Machine Interface (MMI) Options

MMI Mode	Description	Example(s)
Manual	Unaided human operation	"Seat of the pants" piloting
Supported	Requires supporting machinery or facilities	Pressure suits; Manned maneuvering units
Augmented	Amplification of human sensory or motor capabilities	Electro-optic sensors (amplify sensory capabilities), Power tools (amplify motor capabilities)
Teleoperated	Use of remotely controlled sensors and actuators allowing humans to be removed from work site	Remote manipulator systems
Supervised (On-board)	Replacement of direct, human control of system operation with computer control under human supervision. Human supervisor on-board vehicle.	Shuttle guidance, navigation, and control (GNC) system (monitored by astronaut)
Supervised (From Ground)	Same as above, but human supervisor is on ground.	Expendable launch vehicle GNC system (monitored by ground controller)
Independent	Self-actuating, self-healing, independent operations with minimal human intervention. (Requires automation and artificial intelligence.)	Deep space probes

Source: Adapted from Stephen B. Hall, ed., *The Human Role in Space* (Park Ridge, NJ: Noyles Publications, 1985), 2.

A Generic Man-machine Task Allocation Process

The generic MMI task allocation process outlined in the *THURIS* study is shown in Figure 1. This conceptually straightforward algorithm considers performance, cost, schedule, and technology risk in arriving at a baseline MMI mode design. Although Figure 1 is largely self-explanatory, additional details on each step of the process are included in Appendix B.



Source: Stephen B. Hall, ed., *The Human Role in Space* (Park Ridge, NJ: Noyles Publications, 1985), 21.

Figure 1. A Generic MMI Task Allocation Process

After inspecting Figure 1, four observations can be made. First, performance consideration is an integral part of the process as indicated by Step 2. In the “manned *v.* unmanned” debate of the previous chapter, performance considerations were notably absent. Second, since the four space operations mission areas may require different functional tasks (a supposition that will be supported in the next section), it is conceivable different missions will be best suited to different MMI modes. The performance penalty paid by implementing a single ‘sub-optimal’ MMI mode must be traded off against the dollar cost of implementing multiple MMI modes. Third, although conceptually simple, this process will require a great deal of effort to execute properly. It requires engineering trade studies, modeling and simulation efforts, and detailed cost estimates. Finally, it is important to recognize the output of this selection process is one of the seven pre-defined MMI modes shown in Table 2. Whether or not man ends up on board the flight vehicle is a *by-product* of this selection. This is in contrast to the conventional approach of the previous chapter that argued man should be placed either inside or outside the flight vehicle as a pre-determined requirement.

Generic Space Tasks Identified in *THURIS*

The *THURIS* study analyzed six space systems (ranging from manned space stations to unmanned satellites) in detail and concluded, “the same basic activities were found to be required in different operations and in different missions.”[4]. These ‘activities’, which totaled 37 in number, were subsequently referred to as “generic space tasks”’. The study went on to evaluate the degree to which man’s on-board participation contributed to the successful completion of each of these tasks.[5] The result, shown in Table A.1 (Appendix A), orders the 37 generic space tasks from those which *most* require or benefit from a human on-board, to those which *least* benefit from a human on-board.

MMI Selection for a Military Spaceplane: A First Order Analysis

As previously stated, the MMI selection process shown in Figure 1 will require a great deal of effort to execute fully, and doing so here is beyond the scope of this paper. However, Table A.1 can be used as a tool to approximate this comprehensive process. To understand this, consider Figure 1 as a function that maps a task (input) to a specific MMI mode (output). Table A.1 does essentially the same thing but with less precision. Tasks listed near the top of Table A.1, where man's on-board participation is "essential," should be expected to map into the upper portion of the MMI spectrum shown in Table 2 (i.e. near the "Manual" end.) Conversely, tasks near the bottom of Table A.1 should map into the lower portion of the MMI spectrum, closer to the "Automatic" end. This conceptual construct can be viewed as a "first-order" estimate of the comprehensive MMI task allocation process.

Using this construct, a first-order MMI analysis for a MSP is reduced to a two step algorithm. First, generic MSP tasks are logically inferred from the mission requirements described in Chapter 2. Second, Table A.1 is used to gauge each of these tasks in terms its need for direct human intervention. Although this first-order analysis will not result in a specific MMI design, it will point to a MMI mechanization that either does or does not have a man on-board. To organize this analysis, tasks common to all MSP missions will be considered first, followed by those which are unique to the Force Application, Space Control, Force Enhancement, and Space Support mission areas.

MSP Tasks Common to All Missions

Common MSP tasks include mission planning, launch, mid-course trajectory execution, and vehicle recovery. Conceptually, these can all be defined in terms of generic tasks listed in Table A.1.

Mission Planning will involve defining procedures, schedules, and operations (Task 3) and making decisions about targets, trajectories, and other mission specific variables (Task 1). When a military commander decides to launch a MSP sortie (Task 1), he/she will issue an order to implement pre-defined procedures, schedules, and operations (Task 2). As shown in Table A.1, man's participation in all these tasks is "essential," but they are all performed before the MSP ever leaves the ground.

Man's role changes significantly once the vehicle is launched. The predominant MSP task throughout launch, mid-course trajectory execution, and recovery will be staying on a pre-planned[6] trajectory. This explicit guidance function can be defined as a compensatory tracking task (Task 30). Throughout the mission, subsystems and payloads will be activated and deactivated (Tasks 27, 34), sensor data will be processed and computationally manipulated (Task 31), commands may be uplinked and mission data may be downlinked (Task 29), and sensor data may be recorded for post flight analysis (Task 37). According to Table A.1, man's on-board role in all these tasks is "not significant." UAVs, expendable launch vehicles, and on-orbit satellites are all consistent with this assessment.

But what happens if the MSP encounters an unplanned event, such as a subsystem failure, hostile attack, or forced change in landing site? Deciding on an appropriate course of action (Task 1) will most certainly require human intervention—although *from where* is not yet clear. The probability of an unplanned event occurring, its effect on the mission, and man's ability to affect the outcome depend on a wide range of factors. These include the specific MMI mode implemented, the reliability of the MSP system, the maturity of its technology, and the fidelity of its environmental and threat models. These are the issues considered by the full-blown MMI Task Allocation Process shown in Figure 1. Resolving them in detail is a challenge left to the MSP system designers.

MSP Tasks Unique to Specific Mission Areas

If kinetic energy munitions are used, Force Application and Space Control missions will require physical weapons to be released via a mechanical interface (Task 11). Although Table A.1 defines man's involvement in this task as "beneficial to essential," many examples exist to suggest this assessment is application specific. Reentry Vehicle release from the upper stage of an ICBM is a case in point. And even in the F-16, where a human pilot is present, the actual weapons release task could be categorized in Table 2 as Teleoperated[7] or Supervised[8], but certainly not Manual.

No hardware need be deployed in such Force Enhancement missions as photo-reconnaissance and communications support. While precision alignment of optics, sensors, and antennae might be required (Task 13), man's participation may not necessarily be "beneficial" as indicated by Table A.1. There are scores of unmanned remote sensing and communications satellites in orbit today, with very precise pointing and attitude control requirements, that do not require a human on board for successful operation.

Space Support missions are a different story however. Looking beyond the simplest case of space lift and toward more aggressive missions involving the repair, refueling, or even retrieval of on-orbit satellites, a variety of challenging tasks is easily envisioned.

Repair missions will require inspection of damaged components (Task 17) and precision handling of tools and equipment (Tasks 7, 10). On-orbit refueling will require connection/disconnection of fluid interfaces (Task 9) and materials replenishment (Task 13). Satellite retrieval will require positioning objects precise enough to secure a mechanical interface (Task 11). In each of these tasks, man's on-board presence is considered either essential or beneficial. Therefore, complex Space Support missions will definitely benefit from, and may in fact require, on-board human operators.

One final comment on Space Control is in order since this mission area covers such a broad area. As has already been discussed, *destructive* Space Control missions that deploy hard-kill projectiles may not require on-board human operators. However, *disruptive* Space Control operations that might range from simply observing to even spoofing a hostile satellite are different. These missions might require close inspection (Task 17), precision manipulation (Task 7), and even physical disruption (Tasks 8, 9, 11). Resembling Space Support more than Force Application, this special case of Space Control may also greatly benefit from (or even require) on-site human participation.

Summary

This chapter has shifted the focus away from a *manned vs. unmanned* decision to one involving seven MMI alternatives. Man is inevitably involved in each of these seven alternatives, but he need not be on-board for all of them. A generic MMI task allocation process was presented as an example of a structured process that could be used to select the optimum MMI type for any system. Applying this process in detail to a MSP was beyond the scope of this paper. However, by intuitively breaking down MSP mission requirements into elementary tasks and coupling them with results of NASA's *The*

Human Role in Space study, a first order assessment was made. This assessment concluded that an on-board human operator could have a major role to play on most Space Support and some disruptive Space Control missions. On Force Application, Force Enhancement, and destructive Space Control missions however, the value added by a man on-board is far less certain. The implications of these findings on MSP operating concepts and program development strategies will be explored further in the final chapter.

Notes

[1] Stephen B, Hall, ed., *The Human Role in Space* (Park Ridge, NJ: Noyles Publications, 1985), 2.

[2] Ibid., v.

[3] Ibid., 2.

[4] Ibid., 4.

[5] Ibid., 22 (Figure 18).

[6] The assumption that a MSP trajectory will be pre-planned is logical. All current space launches follow pre-planned trajectories into well-defined orbits. Even aircraft air-to-ground strike missions are planned using defined ingress routes, target attack headings, and egress routes. Therefore, both space launches and aircraft missions have "trajectories" that are defined in terms of time and space.

[7] In the CCIP (Continuously Computed Impact Point) delivery mode, for example.

[8] In the CCRP (Continuously Computed Release Point) delivery mode, for example.

Chapter 5

Conclusions and Recommendations

A military Spaceplane could play a key role in helping the United States Air Force transform itself from an *air* force into an *aerospace* force. Many long-range studies have concluded a reusable, hypersonic vehicle operating in both the air and space media should be developed to ensure our space dominance in the 21st century. The purpose of this essay has been to investigate just one part of military Spaceplane (MSP) development—the concept for man's participation in MSP flight operations. The first two objectives—(1) contrasting the supporting evidence from each side of the "manned *v.* unmanned" debate, and (2) approaching the problem from a different perspective by focusing on an entire spectrum of man-machine interface possibilities—have been achieved. The key findings and recommendations from each will be summarized here. The third objective—(3) conducting a first-order analysis to answer the question posed by the paper's title—was started in the previous chapter but will now be brought to a final conclusion.

The Old Paradigm: "Manned *v.* Unmanned"

The majority of the current literature on this subject focuses on two diametrically opposed spaceplane options: *manned* and *unmanned*. The strength of the manned argument centers on the fact that humans provide flexibility to deal with unknown and unplanned situations. The more quantitative unmanned argument focuses on the decreased cost that results from not needing to man-rate the vehicle and the ensuing performance advantages of not having to lift the mass of the crew and their life support systems to orbit. Other factors such as technology readiness, program development risk, and flight safety are less easy to resolve in general. The expert opinions, supporting data, and logical development presented by each side are equally compelling. Considering body of literature surveyed, this debate is stuck at an impasse.

A New Approach: The Spectrum of MMI Options

What each side in this debate fails to acknowledge, however, is that man-machine integration is not limited to an all or nothing choice. We must progress beyond the old paradigm of *manned vs. unmanned* and focus instead on the *degree* of man's involvement in spaceplane operations. There are many possible man-machine interface modes, and man has a role to play in each of them. Whether actively piloting a MSP from its cockpit, monitoring mission operations from a cargo bay, remotely controlling its flight from a ground operations center, or simply pushing a button to initiate an otherwise autonomous mission, man *will* be a part of spaceplane flight operations.

Determining which of these roles man will play requires a detailed engineering analysis integral to the baseline design of a MSP system. Mission requirements must be broken down to their most elementary level tasks. For each task, MMI modes capable of meeting its performance requirements should be ranked according to cost of implementation. A structured analysis can then be followed to arrive at the optimal MMI solution for the system as a whole, based on performance, technology, cost, risk, and schedule considerations. This solution may be a single MMI mode that accommodates all tasks or a set modes if no single one will suffice. A generic, conceptual selection process was outlined in Chapter 4, but the messy details of actually working through this process is left for the MSP design team.

Two important implications of this MMI selection process are worth emphasizing. The first is that the appropriate MMI implementation for a MSP is a solution of, not a requirement for, the design process. Therefore, MSP program requirements documents, such as Mission Need Statements, System Requirements Documents, etc., should avoid specifying any particular MMI implementation. Instead, the USAF should specify detailed MSP mission requirements. This will facilitate the designer's ability to parse missions into elementary tasks to facilitate MMI mode selection. Furthermore, the USAF should prioritize these mission requirements and focus its efforts accordingly. As currently envisioned, a MSP will be an 'multi-role' platform, satisfying the Space Control, Force Enhancement, Space Support, and Force Application mission areas. Since different tasks are needed to satisfy each of these mission areas, the optimum MMI modes for each will also be different. Attempting to design an all-purpose MSP can only have two possible results. Either the total cost of the vehicle will increase to implement a variety of MMI configurations, or the performance of any one mission will suffer as a result of sub-optimal design choices.

The second implication of the MMI selection process clearly distinguishes this new approach from the traditional manned vs. unmanned paradigm. By considering an entire spectrum of MMI possibilities in the analysis, the presence (or absence) of a man on-board a MSP is a *byproduct* of a structured analysis. This is in direct contrast to the traditional approach where the presence (or absence) of a man on-board is the *central focus* of an ad-hoc debate.

Man in a Military Spaceplane: Cockpit, Cargo Bay, or Ground Control?

So which man-machine interface is best for a military Spaceplane? To answer this question would violate the findings of this paper since many detailed analyses, much of them unique to specific MSP concepts, have yet to be performed. However, some insight into which end of the MMI spectrum the answer resides has been gained.

Based on a first-order analysis of MSP tasks linked to existing data on the performance of humans in space, Force Application, Force Enhancement, and destructive Space Control missions benefit little from man's 'hands-on' participation. These missions involve tasks that have already been performed by a variety of 'unmanned' systems, to include expendable launch vehicles, unmanned satellites, and ICBMs. Conversely, aggressive Space Support missions, such as repairing and refueling on-orbit satellites, and disruptive Space Control 'spoofing' missions could benefit greatly from man's on-the scene participation. These missions rely more on the precision handling, close inspection, problem solving, and ingenuity that only man can provide.

These findings suggest a military Spaceplane system that can be implemented in two phases. The first generation MSP could function without a man on board, but whether it will operate autonomously or under the close supervision of ground controllers remains to be seen. This first generation MSP could execute at least a portion of all four space mission areas. It could overfly any point on the planet to either deliver a strike payload or conduct a reconnaissance mission. On a counter-space mission, it could destroy hostile satellites using ‘space-to-space’ missiles just as the F-15 conducts counter-air missions to shoot-down enemy aircraft. Finally, as a reusable launch vehicle, it could perform a simple yet critical space support mission—satellite deployment.

Many reasons support the development of a first generation MSP without men on-board. First, it could conceivably satisfy both of the near term mission requirements identified in the draft Mission Need Statement—surveillance/reconnaissance and defensive counter-space.[1] Additionally, it could perform at least a limited role in all four space mission areas. As the less expensive alternative, it stands a greater chance of being funded in a declining budget environment. Finally, the absence of a crew, their life support equipment, and a dedicated cockpit help reduce the vehicle’s operating weight. Given the technical challenges involved with attaining single-stage-to-orbit flight, any opportunity to reduce the vehicle’s mass is a step in the right direction.

But how will the more complex Space Control and Space Support missions be performed if they require direct manned intervention? The answer may reside in a second-generation MSP upgrade in which a removable “Crew Support Module” is installed into the payload bay. This module could carry humans to orbit where they would operate outside the confines of the MSP (using spacesuits and possibly manned-maneuvering units) to accomplish their tasks. This would afford their uniquely human talents, such as problem solving, close inspection and precision handling, the maximum freedom of maneuver to accomplish these more demanding missions.

Inserting a Crew Support Module into the payload bay would eliminate the need to develop a totally unique MSP for crewed operations. Integration of the module to the baseline MSP would be simplified because the mission focus of the men on-board will be *external* to the vehicle, either on the friendly satellite to be serviced or the hostile satellite to be disrupted. In fact, any effort to turn the Crew Support Module into a "cockpit" could significantly increase the cost and complexity of the module itself (since additional controls and displays would have to be added) and the baseline MSP (since multiple control and feedback paths would have to be incorporated). Although having the capability to manually "fly" a MSP using on-board controls sounds appealing, the costs and benefits of doing so need to be considered carefully.

In closing, this paper has proposed a new perspective from which to approach the "manned *v*. unmanned" spaceplane problem. Even though the applicability of its specific findings should be tempered by the "first-order" nature of the MMI analysis conducted, some interesting insight has been achieved. Clearly man will play an active role in MSP flight operations, and there could never be a truly unmanned spaceplane. But for most missions, the appropriate place for humans appears to be on the ground in the control room. Stated more generally, these findings suggest *man-in-the-loop* does not necessarily mean *man-on-board.*

On those missions that do require human intervention in orbit, man might be most valuable operating out of a Crew Support Module installed in the cargo bay, with the focus of his efforts concentrated on a friendly satellite to be repaired or a hostile satellite to be disrupted. In such a scenario, the on-board operators' attention is more attuned to the external environment than the MSP itself. Extrapolating this finding to general terms suggests a highly provocative question—Are *manned vehicles* necessarily *piloted vehicles*? Our ability to satisfactorily answer this question will depend on our technology. But our willingness to just explore the possibility will depend greatly on our organizational culture.

Notes

[1] See Chapter 2 section entitled: “MSP Mission Requirements” for MSP mission area prioritization.

Appendix A

Generic Space Tasks Identified by *THURIS* Study

Table 3. Benefit of Man's Participation in Space Activities

No.	Generic Space Task	Overall Benefit from Man's On-Board Participation	Comments
1	Problem Solving/ Decision Making	Essential	Man essential by definition.
2	Implement Procedures/ Schedules	Essential	Activity dependent on man's participation by definition.
3	Define Procedures, Schedules, Operations	Essential	Wholly dependent on man's intellectual activities.
4	Apply/Remove Biomedical Sensors	Essential	Cannot easily be automated.
5	Handle/Inspect Living Organisms	Essential	Activity cannot be automated in most cases.
6	Surgical Manipulations	Essential	Activity not appropriate for automation.
7	Precision Manipulation of Objects	Most Often Essential	Man's manipulative skills cannot be duplicated by automatic devices.
8	Connect/ Disconnect Electrical Interfaces	Beneficial to Essential	Typical utilization of man's basic capabilities.
9	Connect/ Disconnect Fluid Interfaces	Beneficial to Essential	Typical utilization of man's basic capabilities.

No.	Generic Space Task	Overall Benefit from Man's On-Board Participation	Comments
10	Gather/Replace Tools and Equipment	Beneficial to Essential	Man can vary tool selection with respect to task.
11	Release/Secure Mechanical Interface	Beneficial to Essential	Exemplary utilization of man's capabilities in space activities.
12	Replace/Clean Surface Coatings	Beneficial to Essential	Infrequency of activity negates automation.
13	Replenish Materials	Beneficial to Essential	Degree of benefit is dependent on nature of task.
14	Display Data	Beneficial to Essential	Man important in selection of data to be displayed.
15	Information Processing	Beneficial to Essential	Essential interaction between man and computer.
16	Detect Change in State or Condition	Beneficial to Essential	Strongly dependent on characteristics of activity.
17	Inspect/Observe	Highly Beneficial	Man's selective observations superior to automated monitoring.
18	Adjust/Align Elements	Beneficial	Most Alignment Operations within man's capabilities.
19	Deploy/Retract Appendage	Beneficial	Seldom repeated activities are poor candidates for automation.
20	Measure (Scale) Physical Dimensions	Beneficial in Some Cases	Man is best alternative in some situations.
21	Position Module	Beneficial in Some Activities	Man's benefit highly dependent on type of activity.
22	Remove Module	Beneficial for Some Activities	Man's benefit highly dependent on type of activity.
23	Remove/Replace Covering	Beneficial for Some Activities	Man's benefit highly dependent on type of activity.
24	Pursuit Tracking	Could be Significant	Dependent on specific tracking task.
25	Transport (Loaded)	Dependent on Characteristics of Task	Characteristics of tasks can vary extensively for this activity.

No.	Generic Space Task	Overall Benefit from Man's On-Board Participation	Comments
26	Transport (Unloaded)	Dependent on Characteristics of Task	Characteristics of tasks can vary extensively for this activity.
27	Activate/Initiate System Operation	Not Significant	Automatically activated systems will predominate.
28	Allocate/Assign/Distribute	Not Significant	Primarily automated operations.
29	Communicate Information	Not Significant	Communication links established automatically.
30	Compensatory Tracking	Not Significant	Highly dependent on nature of tracking task. Nullifying error signal can be automated.
31	Compute Data	Not Significant	Man's role in data computation is negligible.
32	Confirm/Verify Procedures, Schedules, Operations	Not Significant	Man would usually function in a "back-up" role.
33	Correlate Data	Not Significant	Man would usually function in a "back-up" role.
34	Deactivate/Terminate System Operation	Not Significant	Automatically deactivated systems will be the norm.
35	Decode/Encode Data	Not Significant	Basic computer function.
36	Plot Data	Not Significant	Primarily a computer function.
37	Store/Record Element	Not Significant	Man's participation of benefit only in isolated cases.

Source: Adapted from Stephen B. Hall, ed., *The Human Role in Space* (Park Ridge, NJ: Noyles Publications, 1985), 8-9.

Appendix B

A Man Machine Task Allocation Process

This Appendix provides additional details to Figure 1, "A Generic MMI Task Allocation Process." A more thorough description of each step in the process follows.[1]

Step 1. Identify Tasks Required in System Operation. The basic tasks to be performed during MSP mission operations must be identified. These tasks should be defined in very elementary terms such as "communicate information," "detect change in condition" and "pursuit tracking."

Step 2. Identify MMI Modes Meeting Performance Requirements of Each Task. This step eliminates those MMI modes that will not even meet the basic performance requirements of the task being considered. In other words, any candidate MMI mode must first pass the litmus test of effectiveness prior to being ranked for efficiency.

Step 3. Determine the Most Cost Effective Mode for Each Task. For each MMI mode from Step 2, the associated costs must be calculated. Although conceptually straightforward, great care must be taken to account for *all* of the costs unique to each of the MMI modes. MMI modes involving humans on-board should account for not only the crew interface and life support systems, but also the costs associated with increased vehicle size, training, servicing, etc. Conversely, MMI modes on the other end of the spectrum must account for additional AI software development and maintenance increased TT&C infrastructure and operations, etc.

Step 4. Estimate technology risk associated with most cost effective MMI type. Performance and cost are not the only parameters that need to be assessed. The maturity of the technology required to implement any particular MMI mode is a crucial determinant when establishing the baseline design for any system. Given the rapid advances in computer and communication technologies, this dynamic must be given careful consideration.

Step 5. Rank each MMI type according to the number of tasks for which it is the most cost-effective approach. Since there will probably not be a single MMI type which is most cost effective for all of the identified tasks, each MMI mode can be initially prioritized according to the number of tasks for which it is the most cost effective. In other words, MMI modes which can satisfy the greatest number of tasks at the lowest cost should be considered first.

Step 6. Select the MMI mode with the highest rank, and complete the decision tree. If this MMI mode is capable of accomplishing all identified mission tasks, and the technology risk associated with it is acceptable, it is an obvious candidate MMI for incorporation in a baseline vehicle design. If not, other MMI options should be considered (in rank order from Step 5) for both performance and risk acceptability. MMI options that meet the performance requirements for each task but are technologically risky can be considered if a MSP program has sufficient schedule and budget margin to mature the required technology. If no single MMI mode is possible, it will be necessary to select the minimum set of modes that simultaneously encompass all the requisite mission tasks and satisfy the cost, risk, and schedule limitations.

Notes

[1] Stephen B, Hall, ed., *The Human Role in Space* (Park Ridge, NJ: Noyles Publications, 1985), 21-24.

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