ATA

Applied Technology Associates, Inc.

Stabilized Sensor Platform for Manned Space Observation

Final Report

CDRL 001A1

Prepared by:
Henry R. Sebesta

Submitted by:
APPLIED TECHNOLOGY ASSOCIATES, INC.
P.O. Box 9154
Albuquerque, New Mexico 8''119
Under Contract F04701-90-C-0071

Submitted to:
DEPARTMENT OF THE AIR FORCE
HQ Space Systems Division
Mission Planning Divsion SSD / CLPD
P.O. Box 92960
Los Angeles, AFB 90009-2960

31 October 1991

CONTENTS

Abstract 1

1.0 Introduction 2

2.0 SSPMSO System Requirements 3

3.0 Phase I Technical Problem and Design Concept 4
- 3.1 Optical Issues 7
- 3.2 Stabilization and Pointing Control Issues 8
- 3.3 STS Safety, Constraints and Environments 9
- 3.4 Key Innovative Features of Design 9

4.0 Phase II Technical Plan 14
- 4.1 Objectives 14
- 4.2 Phase II Approach and Program Plan 16

5.0 Conclusion 18

Appendix A SSPMSO System Requirements Report
Appendix B SSPMSO Phase I Final Report - Rockwell International Subcontract
Appendix C SSPMSO Phase I Results Briefing: SBIR AF90-140
Appendix D SSPMSO Phase II Program Plan Briefing: SBIR AF90-140
Appendix E SSPMSO Phase II Proposal

FIGURES

1. SSPMSO in operating configuration provides precision pointing and stabilization for viewing ground objects through the STS aft flight deck overhead window.

2. The Exocentric gimbal in an annular configuration controls payload pointing and accommodates the LOS jitter suppression subsystem.

3. The SSPMSO modular design flexibly hosts a variety of optical payloads.

4. SSPMSO Phase II Tasks and Completion Schedule with Prototype Demonstration after 12 Months

ABSTRACT

A stable, highly magnified line-of-sight (LOS) is a key enabling technology to enhance man's active participation in a whole range of important space experiments and tasks. Man's ability to visually identify and observe ground objects from an orbiting vehicle is limited because the human eye is a relatively small collecting aperture. The human eye when augmented with magnification aids which allow objects of a few meters to be distinguished becomes an important space experiment asset. However, the magnification makes viewing sensitive to LOS jitter and implies more accurate pointing to acquire and maintain the viewed object in the field of view. The main thrust of this work is the development and Space Transportation System (STS) flight demonstration of a prototype sensor stabilization platform (SSP) which provides precision stabilization and control of a magnified LOS. The solution offered is founded on an innovative application of an ATA-developed sensor for angular motion measurement; a Rockwell Exocentric gimbal; and other innovative technologies for LOS stabilization and control. The angular motion sensor uses the principle of magnetohydrodynamics (MHD) to produce a signal proportional to angular rate. The sensor has a very low noise floor, operates over a broad bandwidth, and is relatively low in cost. In addition to ATA's innovative technologies, the ATA/Rockwell team is knowledgeable of current DoD secondary payload optical systems and their stabilization limitations. Phase I established a feasible image stabilization design concept. The next stage in solving the problem is to be accomplished in Phase II with the implementation and validation of the design. The technology and its spinoffs show good commercial promise.

1.0 INTRODUCTION

This report documents the technical efforts performed for the Phase I SBIR project "Stabilized Sensor Platform for Manned Space Observation (SSPMSO)", Topic AF90-140. Phase I established a feasible design concept for a gimbal system with an appropriate level of precision pointing and stabilization to enable man's active participation in space observation tasks.

The work for Phase I was divided into six activities that included the following tasks:

1) Identification and documentation of technical performance and operational requirements;
2) Identification and interpretation of design constraints and environments;
3) Application of innovative technology and configurations to fulfill the requirements;
4) Completion of critical concept design activities, supporting analyses, and tests;
5) Preparation of a Phase II program plan;
6) Documentation of Phase I results.

This report provides a summary overview of the work accomplished results from the Phase I SBIR Project. The majority of the details of the work are contained in the five Appendices included with this document.

The Phase I work reported herein and including the Appendices were prepared with contributions from ATA and Rockwell International Space System Division.

2.0 SSPMSO SYSTEM REQUIREMENTS

The first two tasks performed in developing the concept design for the SSPMO were to define and document the system requirements. A separate report, "SSPMSO System Requirements", ATA Report No. 90R0192, November, 1990 was written to document the requirements. The report addressed those requirements which had direct impact on the concept design work.

The System Requirements Report is included herewith as Appendix A.

3.0 PHASE I TECHNICAL PROBLEM & DESIGN CONCEPT

The human eye operating in space environments is an under-utilized asset because of its inability to distinguish objects at great distances. If its performance can be enhanced by external systems to resolve objects only a few meters in size on the earth's surface, then it becomes a significant space experiment asset, surpassing cameras and other image data collecting devices that are not capable of making intelligent judgments that distinguish useful data from ordinary pictures. Trained observers equipped with such a tool will eliminate this major shortcoming of purely remotely operated data collection sensors. Many missions will be greatly enhanced by providing high resolution visual information to the military specialists in space (and civilian scientists as well) so that they can provide real-time interpretation and control of observation and data collecting functions.

Two key aids are needed to enhance the human eye so that it will be more effective in space observation tasks. First, the optical resolution of the eye must be enhanced by addition of magnifying optics. Second, the optical system needs to be precisely pointed and stabilized so that the line-of-sight stays on the viewed object. In Phase I ATA and Rockwell have established a feasible design concept for a gimbal system which fulfills the requirements for precise pointing and stabilization. The next stage in solving the problem is to be accomplished in Phase II with the implementation and validation of the design.

The Stabilized Sensor Platform for Manned Space Observation (SSPMSO) integrates innovative electromechanical and optical approaches to implement the aids. Figure 1 illustrates the SSPMSO in operation. An astronaut in the orbiter will use the SSPMSO to locate and observe objects which are 140 - 215 nmi away on the surface of the earth. The goal is to be able to visually resolve objects which are as small as 1-5 meters. The SSPMSO gimbal attaches to the aft flight deck (AFD) window. It is constructed in an annular configuration and holds and points the optical magnification device. Figure 2 illustrates the gimbal pointing capability with an 8-inch telescope attached. ATA proposed a 4-inch telescope laboratory demonstration of the SSPMSO; however, the technology is easily scaleable to the 8-inch manned space experiment version or other sizes.

A critical function performed by the SSPMSO technology is the suppression of the line-of-sight (LOS) jitter. A SSPMSO subsystem combines a unique angular vibration sensor, a high performance digital signal processor, and an adjustable wedge device to isolate the LOS from jitter inducing effects. Hence, the user will be presented with a stable image for observation or recording with a film or electronic camera. The SSPMSO is configured in a modular design so that it can accommodate a large selection of optical payloads. The gimbal, LOS jitter suppression, and payload modules are depicted in Figure 3.

The ATA/Rockwell team recognized that several factors were important influences and needed to be recognized in defining system requirements and selecting a design concept. The SSPMSO design concept has been defined with specific attention to:

(1) LOS stabilization and pointing control performance;
(2) Existing DOD secondary optical payloads characterized by:
  - Diverse mounting and configuration requirements;
  - The need to maintain maximum optical quality;
(3) Space Transportation System (STS) safety standards;
(4) Constraints and environments for STS flight deck crew experiments.

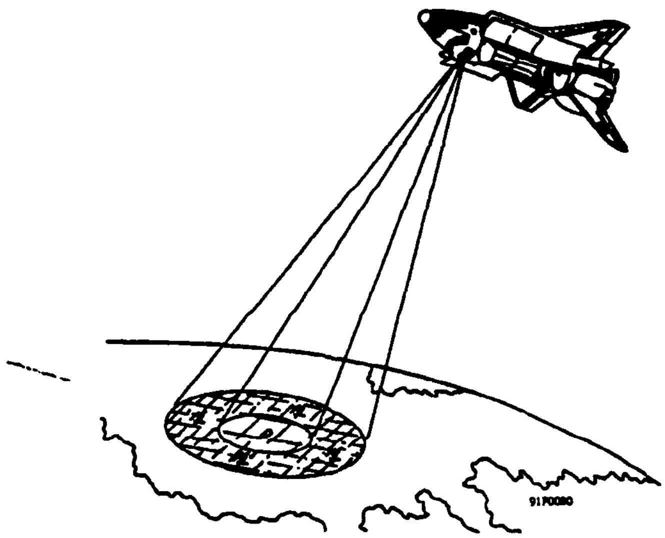

Figure 1. SSPMSO in operating configuration provides precision pointing and stabilization for viewing ground objects through the STS aft flight deck overhead window.

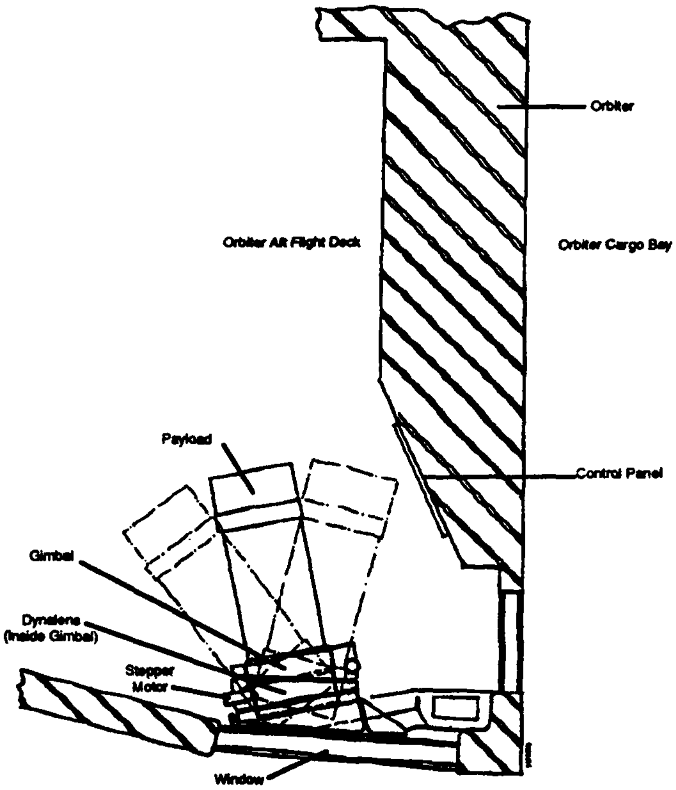

Figure 2. The Exocentric gimbal in an annular configuration controls payload pointing and accommodates the LOS jitter suppression subsystem.

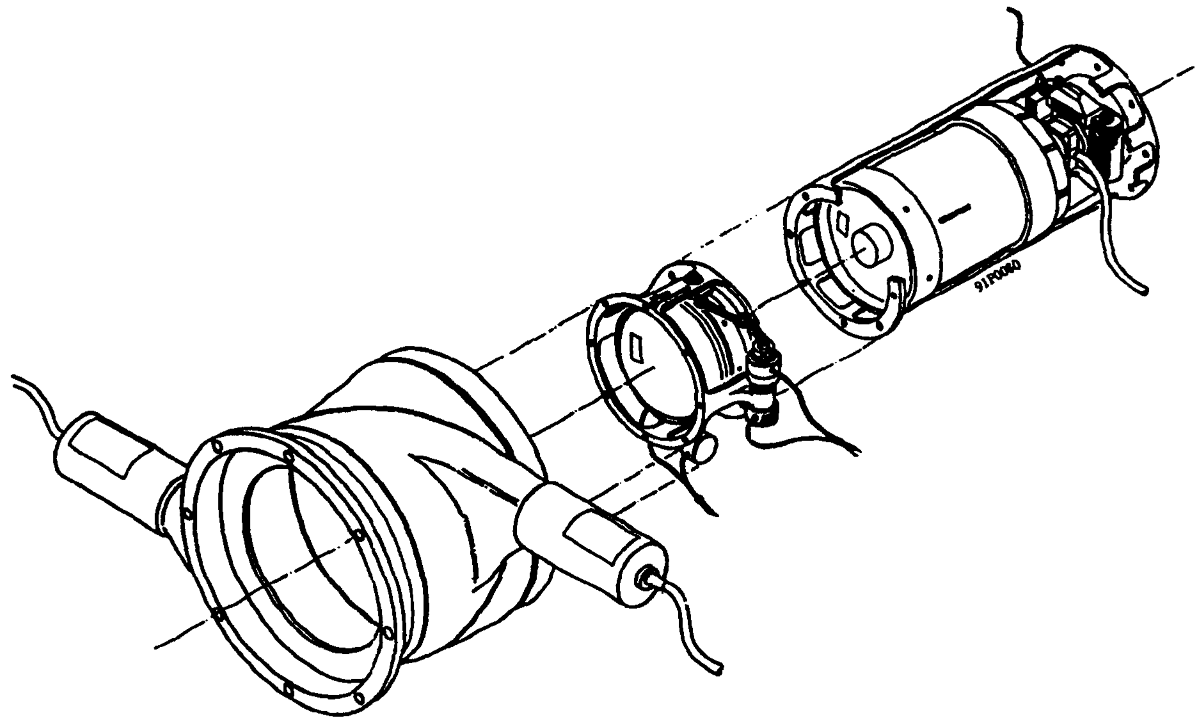

Figure 3. The SSPMSO modular design flexibly hosts a variety of optical payloads.

3.1 Optical Issues

Without a magnifying optical system, a crew member in an orbiting vehicle is limited in ability to resolve objects and features on the ground. The resolving capability of the human eye, like any optical imaging system, is subject to limits which are determined by the area of the collecting aperture and distance to the object. Assuming diffraction limited angular resolution and a 2 mm pupil diameter for a typical unaided human eye, the astronaut in Figure 1 would be limited to observing objects which are a 100 meters or larger in dimension. The effective diameter of the collecting aperture can be increased by placing a telescope in front of the eye (or image recording sensor). For the purpose of constructing a SSPMSO design concept, an optical magnification system corresponding to a typical 8-inch (203 mm) diameter Schmidt-Cassegrain telescope was chosen as a baseline. An off-the-shelf design by Celestron[1] for such a telescope specifies an angular resolution of 0.57 second of arc (or 2.7 μrad). For the previously described viewing geometry and with use of the 8-inch telescope the ground dimensions of the diffraction spot are on

[1]Celestron is a registered trademark of Celestron International, Torrance, CA

the order of 1 meter. Of course, such a resolving capability is predicated on there being no degrading effects from the orbiting vehicle's window or the earth's intervening atmosphere between the observer and the ground object. In reality, achieving diffraction limited imaging is a goal that is very difficult to obtain, and one should recognize that actual optics will not reach the theoretical resolution of perfect optics.

It is planned that manned observation experiments will be conducted through the AFD overhead window. The optical quality of this window is being evaluated. Test data indicates that the present windows in the orbiters will degrade the resolution of viewing systems with apertures larger than 4 or 5 inches. This has implications for the specifications of the SSPMSO technology.

An attractive concept for performing the LOS jitter suppression is a device which continuously controls a variable fluid wedge. The fluid wedge is contained between two optical flats which are rotated by minute amounts to offset disturbances to the LOS. The optical quality and transmission of the flats and the fluid wedge are critical issues for the SSPMSO. Our Phase II plan includes specific early actions to address these issues.

3.2 Stabilization and Pointing Control Issues

The increase in optical aperture provided by the telescope does not come free. The high magnification makes the viewing more sensitive to LOS pointing and stabilization angular errors. The latter is commonly termed jitter. The effect of jitter is to make the LOS move in relation to the object being viewed. High frequency jitter has the effect of making the viewed object appear to be blurred or smeared over an area that is larger than its true size. Thus, one is led to an implied requirement that the angular jitter in a high resolution viewing and image recording experiment needs to be controlled so that it is less than the smallest angular subtense of the viewed object. Interpreting this requirement in the context of the diffraction spot sizes noted previously leads to the conclusion that LOS jitter should be on the order of 1 μrad RMS or less. A system to accurately point and stabilize an optical LOS so that residual jitter is less than 1 μrad is a significant technical challenge.

A system with large enough optical magnification to view small objects on the ground will necessarily have a small field of view (FOV). The FOV of the previously described baseline 8-inch telescope is 0.6° (10 mrad). It is challenging for the user to locate and maintain pointing alignment of the FOV at a specific ground object within a reasonable portion, say 10%, of the FOV. The angular rates of the LOS between the orbiting STS and the fixed ground object add further to the difficulty. For the case when the STS is operated in an inertial attitude mode, angular rates of the LOS may be calculated as 0.028 and 0.018 mrad/s, respectively, for the two altitude cases noted previously. Put in another way, a ground fixed spot is passing under the shuttle at a relative rate which is approximately 7.2 km/s. Thus, for the SSPMSO system to be effective, it is necessary to maintain very low levels of jitter while simultaneously slewing the LOS at significant rates and with pointing accuracy on the order of 1 mrad.

3.3 STS Safety, Constraints, and Environments

A key result from Phase I was the definition of a design concept which establishes feasibility of satisfying the challenging 1-mrad pointing and 1-µrad stabilization performance requirements. Adding to the SSPMSO technical challenge are the desired goals of having a system which is compact enough to be stowed in a standard modular stowage locker; designed for simple assembly and mounting to the overhead window of the aft flight deck in conjunction with on-orbit crew experiment operations; compatible with cabin environments, safety constraints, and available power; and sufficiently flexible to accommodate a number of different optical and image data collection units for a large variety of viewing geometries, ranges, and kinematics. To the maximum extent possible, it is desirable that the operation of the system be independent of STS services and interfaces.

3.4 Key Innovative Features of Design

During Phase I our project team focused on and completed six technical objectives:

1) Identification and documentation of technical performance and operational requirements;
2) Identification and interpretation of design constraints and environments;
3) Application of innovative technology and configurations to fulfill the requirements;
4) Completion of critical concept design activities, supporting analyses, and tests;
5) Preparation of a Phase II program plan;
6) Documentation of Phase I results.

The results of the work performed during Phase I and the Phase II program plan have been documented in two briefings[2] that were presented to the Air Force personnel responsible for SBIR

[2] SSPMSO Phase I Results and Phase II Program Plan, presented to Space Test Program Division, Los Angeles, CA, by Applied Technology Associates, Inc., March 6, 1991.

project AF 90-140. Within the framework of Objectives 3) and 4), a feasible SSPMSO design concept was devised.

The SSPMSO design concept developed by ATA and Rockwell in Phase I includes six major elements:

1) Structural support hardware;
2) A gimbal assembly;
3) A LOS jitter suppression assembly;
4) A digital processor subsystem;
5) An optical payload carrier assembly;
6) Crew compartment services and interfaces (power, data, control, overhead window attachments, mid-deck lockers, etc.).

Fully within the spirit and constraints of the SBIR Phase II program, the project's next development step is implementation of a prototype and laboratory demonstration of the key technologies that comprise elements 2), 3), and 4). These elements address the key goal and requirements of the SSPMSO, providing a accurately pointed and stabilized LOS for an optical payload suitable for manned observation tasks. Optical payloads may include a variety of optical experiment apparatus which may be used by a flight crew member to see and record high quality images of ground objects from the STS aft flight deck overhead window. The structural support hardware provides the basic means of SSPMSO attachment to the orbiter overhead windows. Gimbal subsystems provide the manually operated, motor driven 2-DOF pointing and control of the payload to observe a ground object through the STS window. The optical payload carrier and the LOS jitter suppression assemblies will be mounted in tandem and attached to and pointed by the gimbal. The digital processor subsystem makes measurements of LOS stabilization and pointing errors and produces electrical control signals which cause the LOS jitter suppression assembly to create a stable and accurately pointed LOS. The digital processor also generates commands which points the gimbal to slew and hold the payload FOV on a target with known location. The STS data and control interface element accommodates power and two way data transfer for the SSPMSO. This latter interface will be achieved in the flight version by use of the Payload and General Support Computer (PGSC).

The SSPMSO design concept, illustrated in Figures 2 and 3, incorporates four innovative technologies to satisfy SSPMSO performance and operational requirements:

3.4.1 Rockwell International's Exocentric Gimbal

The Exocentric gimbal[3] controls the orientation and slew rate of the optical payload in two angular degrees of freedom so it remains accurately pointed at a designated object. It performs this primary SSPMSO function while achieving compactness, compatibility with aft deck overhead window attachment, optimal viewing geometry relative to window, and manual or automated drive operation.

3.4.2 Sigma Dynamics Corporation's Dynalens

The Dynalens[4] is a transmissive, active optical element which is used in the SSPMSO to perform precision pointing and stabilization of the LOS. Two optical flats confine a fluid wedge which is continuously adjusted by a servo system to achieve an inertially stabilized LOS. The servo system controlling the Dynalens also incorporates fine pointing of the LOS.

As shown in Figure 3, the Dynalens is mounted between the gimbal and the imaging instrument. The Dynalens is the active line of sight stabilization element. As such, it is the only optical element in the SSPMSO system. Preliminary assessments indicate that the Dynalens does not degrade image quality for high quality imaging instruments. Issues to be addressed are:

1) Optical figure and homogeneity of the Dynalens windows.
2) Strength and stiffness of the windows.
3) Optical characteristics of the fluid.
4) Optical quality of the integrated prism.

Early tests will be conducted on an existing Dynalens to further support assessment of optical performance.

Safety in the STS environment is also a major consideration. While this Phase II will not explicitly demonstrate compliance with NASA STS requirements, hardware will be designed with the intent to eventually qualify it under other programs.

[3]The Exocentric gimbal is a patented device of Rockwell International.
[4]Dynalens is a registered trademark of Sigma Dynamics Corporation.

3.4.3 ATA's MHD Angular Rate Sensor

The Magnetohydrodynamic Angular Rate Sensor (MHD ARS)[5] provides low noise measurements of the inertial rates of the Dynalens optical flats and hence provides the feedback signals for inertial stabilization of the LOS. The performance of the MHD ARS is compatible with the stringent jitter suppression requirements of SSPMSO.

3.4.4 ATA's DSP-based Digital Pointing and Stabilization Servo Implementations

The servo systems in SSPMSO are implemented using Digital Signal Processor (DSP) technology. The DSP-based servo systems collect measurements from the SSPMSO inertial and relative angle transducers; process these measurements in control algorithms; and output actuator command signals to the Dynalens. This implementation provides advantages in flexibility, performance, reliability, and life cycle cost over conventional fixed analog electronic servo designs.

Upon completion of the performance verification and demonstration of the Phase II prototype, the SSPMSO technology will be ready for commercial exploitation in several anticipated markets. First, to fulfill the AF 90-140 need in the area of manned space observation, it is anticipated that the user organizations would provide resources for preparation, integration, and flight of the SSPMSO equipment as part of and in conjunction with an on-orbit secondary optical payload and experiment series. Beyond the manned space observation need, ATA, Rockwell, and Sigma Dynamics, jointly and individually, have identified market opportunities to which SSPMSO technologies are applicable. The technologies are easily scaleable to sizes other than the envisioned 4-inch laboratory demonstration or a fully-developed 8-inch manned space experiment version.

The work performed for Phase I included contributions by Applied Technology Associates, Inc. and by Rockwell International Space Systems Division. The inputs from Rockwell were incorporated in the SSPMSO Systems Requirements, Appendix A; the Phase I Design Concept; and into the Program Plan and Proposal for Phase II. Appendix B provides a summary descriptions of the effort supplied by Rockwell International.

[5]The MHD ARS is a patented device of Applied Technology Associates, Inc.

The Phase I Design Concept was summarized in a briefing to the project sponsor, Mission Planing Division, Space Test Program Branch (SSD/CLPD) on March 6, 1991. Appendix C is a copy of the viewgraphs used for this presentation. At the same time, a preliminary version of a Phase II Program Plan was described to the sponsor. The briefing viewgraphs are included herein as Appendix D. Subsequently, a detailed written proposal was prepared and submitted. The next section gives highlights to the recommended Phase II activities.

4.0 PHASE II TECHNICAL PLAN

4.1 Objectives

The work proposed for Phase II is focused on achieving eight technical objectives for implementing and demonstrating the prototype SSPMSO technology. The overall intent and scope of Phase II is to optimize use of the available resources with the goal of obtaining flight-ready technology for use in manned space observation experiments. The objectives for Phase II include the following:

1) Finalization of detailed requirements, specifications, and interfaces for prototype SSPMSO equipment;
2) Definition of SSPMSO technology verification and demonstration requirements and plans;
3) Completion of an SSPMSO test article design;
4) Test article fabrication, assembly, and subsystem testing;
5) SSPMSO system integration, performance verification, and demonstrations;
6) Technical support for design and integration of SSPMSO equipment into flight experiments;
7) Phase III product development and marketing plans;
8) Management and documentation of the Phase II project work.

Objective 1) will result in refining and finalizing all details of the requirements, specifications, and interfaces. The process will start with those devised and selected at a design concept level in Phase I and set the stage for flight-compatible designs which are suitable for a prototype demonstration. The critical equipment items include the gimbal assembly, the LOS jitter suppression assembly, and the digital processor subsystem. Rockwell will be the lead organization in the design and fabrication of the gimbal assembly. Sigma Dynamics will design and fabricate the Dynalens. ATA will add inertial sensors and relative position sensors and implement the DSP-hosted digital servos to perform the precision pointing and stabilization. ATA will be the responsible organization in areas of interfaces, integration, system engineering, and system testing.

In preparing the prototype demonstration equipment, it will be cost-effective to distinguish between requirements which are mandatory for flight equipment versus those requirements which are essential for the demonstration of required SSPMSO performance and those operational requirements. Objective 2), fulfilled in parallel with fulfilling Objective 1), ensures that only those requirements essential to technology performance and operational requirements are levied on the prototype SSPMSO design, fabrication, testing and demonstration. However, the design team will seek to ensure that future upgrades to the equipment to make it flight ready are straightforward and clearly identified.

After Objectives 1) and 2) are satisfied, the design team will complete the design details for the test article (demonstration prototype) and conduct a review to discuss its characteristics and documentation. The design review serves the purpose of providing full visibility to all details of the prototype SSPMSO design and to permit all involved organizations to give a final critique of the system prior to committing to fabrication.

Once the design is completed and all review items of concern resolved, the requisite activities turn to Objective 4). This task involves ordering materials and parts; fabricating equipment items; assembling the items; and conducting subsystem functional and performance tests. The key milestone for each team member is the delivery of their respective pieces of the SSPMSO to ATA for system level integration and testing. Implementation and checkout of digital processor software elements are also included within the scope of Objective 4). Ground test fixtures, test article optical payload, and support sensors and data collection are also fabricated and/or procured under the scope of Objective 4). The work towards accomplishing Objectives 3) and 4) and the associated the purchases of materials and manufacturing services constitute a large component in the Phase II project.

Under Objective 5) the SSPMSO demonstration prototype assemblies and subsystems are integrated and evaluated. Interface, functional, calibration, and performance verification testing constitutes the major work activity necessary to achieve Objective 5). During the integration activity, we will make adjustments and changes to improve function and performance. A key milestone under this objective is a SSPMSO technology review and demonstration. The review and demonstration would be given to the sponsor and potential users of SSPMSO technology . Our program plan schedules this milestone approximately 12 months after Phase II start.

Objective 6) efforts support the transition of the SSPMSO technology from the demonstration prototype to one or more versions of flight hardware. Technical support to assist users in planning integration; cleanup of designs and modifications that are identified during system tests and demonstrations; accomplishing designs for specific payloads; finalization of STS interfaces and services; and definition of appropriate flight qualification tests are typical of the kinds of efforts to be accomplished within this objective.

We consider completion of Objective 7) a very important factor in the ultimate success of our Phase II SBIR program. The intent and purpose of the SBIR program is to develop technology that solves the government sponsor's problem and which has commercial viability. Our team will carry out activities and invest non-SBIR resources to assess market opportunities for the SSPMSO technology. Early (pre-test article design solidification) survey results from known potential users will identify any critical parameters which will be considered for incorporation into the test article. Key deliverables which are produced within the scope of this objective include market assessment data and a plans to commercialize SSPMSO technology to address market opportunities.

The last objective in our Phase II project plan recognizes the importance of providing good documentation of project progress and results. Documentation of the results from SSPMSO functional and performance verification tests are an important consideration in decisions by potential users of the technology.

4.2 Phase II Approach and Program Plan

The objectives listed in the previous section will be accomplished using a work plan that is described in detail in subsections which follow. The work is divided into eight tasks, each corresponding to one of the technical objectives. An overall schedule for the Phase II SSPMSO is depicted in Figure 4. While it is envisioned that the SSPMSO Phase II contract effort will span 18 months, our work plan emphasizes a fast-track development strategy which is arranged to achieve completion of the prototype verification and demonstration as early as practical. In recent discussions, Air Force's SSD/CLPD staff have indicated there are a number of STP Board approved experimenters who may be able to commit resources to acquire SSPMSO flight hardware in support of their programs. To accommodate the users at the earliest opportunity, our team believes it is advantageous to aggressively proceed with design, fabrication, integration, and verification testing of the critical SSPMSO equipment items. This approach would make proven SSPMSO technology and support systems available to potential users as early as 1 year after the initiation of Phase II. The 6-month period following completion of the prototype demonstration serves to facilitate the transition of the SSPMSO technology to users conducting manned space experiments and other commercial market opportunities.

The schedule for accomplishing the program, as laid out in Figure 4, includes eight tasks. The details of the work plan for each task area are documented in the Phase II Proposal. See Appendix E.

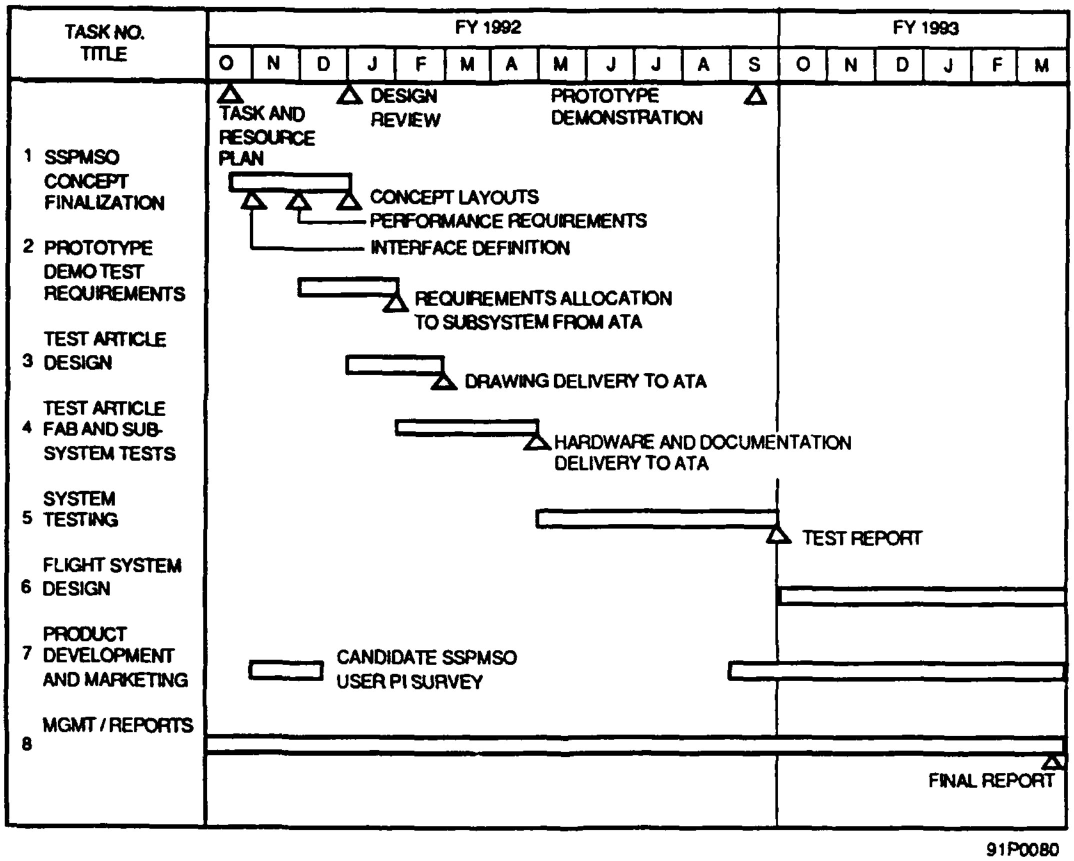

Figure 4. SSPMSO Phase II Tasks and Completion Schedule with Prototype Demonstration after 12 Months

5.0 CONCLUSIONS

The work performed in Phase I to identify system requirements and to define a design concept for a stabilized sensor platform for manned space observation resulted in the following conclusions:

- Technology exists to support the development of a stabilized platform;
- The most critical issue for the system is controlling LOS jitter to sufficient precision;
- The LOS stabilization requires integration of several technologies;
    - Inertial sensors to measure the LOS jitter,
    - Active optical element to compensate for jitter causing disturbances,
    - Electronics to implement the LOS jitter compensation,
- A gimbal to provide accurate, programmable LOS pointing and which is compatible with viewing through the STS aft deck window is also a critical issue;

A program which supports the development of a stabilized sensor platform for manned space observation is feasible. The detailed design work, the fabrication of prototypes, and a comprehensive integration and test series can proceed will relatively low risk. Such a laboratory program should be completed prior to commitment to a STS demonstration.