AFWAL SPACE CONTROL TECHNOLOGY PROGRAM

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ABSTRACT

The space-oriented control technology programs under way in the Air Force Wright Aeronautical Laboratories (AFWAL) predominantly are being done in the Flight Control and Structures and Dynamics Division of the Flight Dynamics Laboratory. The nature of these programs extends from basic research performed in-house to exploratory development and advanced development programs done under contract. The objective of this paper is to overview only those programs that are applicable to flexible large space structures. Sufficient information about each program will be provided for the reader to understand the objective of the program, the approach used to perform the study, and the final payoff expected. The names of the people involved in the program are provided along with their organizational symbols and telephone numbers. Through contacting these people, information to any level of detail desired can be acquired.

In general, the spacecraft control activity in the Flight Dynamics Laboratory is interdisciplinary, bringing together activities in structures, structural dynamics and control. This is very important since the large flexible structures to be controlled have many physical factors that influence the final controllability of the vehicle. Factors such as rigidity of both structural elements and joints, damping inherent in both the material as well as discrete dampers located throughout the structure, and the bandwidth of both sensors and actuators used to sense motion and control it are several examples of those physical factors that are interdisciplinary and influence control.

The Flight Dynamics Laboratory spacecraft control program is not complete within itself, rather, it augments work already under way and planned at NASA, the Air Force Space Technology Center, and other organizations by addressing issues needed by those missions that have a military goal. The work being done relies heavily on the expertise of the Laboratory gained through activities associated with developing technology for advanced aircraft. This is possible because the closer technology is to basic research, the more generic it becomes, having application to both aircraft and spacecraft with relatively minor changes in the given conditions.

INTRODUCTION

Traditionally, the AFWAL Flight Dynamics Laboratory has been involved in advancing technology for controlling military aircraft and tactical missiles since its formation. Considerable experience has been gained in areas of technology that not only include control but also the structural and dynamic characteristics that impact the control of the vehicle. Some of this experience is generic and with minimal modifications can be applied to the development of technology for space vehicles. Hence, when it became obvious that the military use of space would require technological advancements in some technology in areas where experience existed, programs were intitiated first in the Structures and Dynamics Division of the Laboratory and later in the Flight Control Division. Our approach to the technology efforts is interdisciplinary in nature. In it we bring together the structures technology that deals with the strength and elasticity of the structure with the structural dynamics technology that defines the dynamic response of the structure to both operational and environmental loads and then combine these with the controls technology that defines both the algorithms and the system for controlling this dynamic structure. We feel this interdisciplinary approach is essential in successfully controlling space structures because in these structures strength, flexibility, and control are inseparable. We also recognize that as the structure becomes larger, it becomes more flexible since rigidity is related to weight and weight must be kept within practical bounds. This flexibility places greater demands on the control system since many of the missions planned for spacecraft require very precise aiming, shaping, and vibration or jitter limiting. Additional considerations that require the interdisciplinary approach to the design for military operations include the need for autonomous operation and high reliability.

Many spacecraft to date have been designed and built as "one-of-a-kind" research or operational vehicles. If space is to be used as an effective support for the military, the devices that are used will need to be produced in "more-than-one" quantity with standards established to increase reliability and limit cost. This requires that design techniques be shared and standards developed. Using the experience base on which to build and the somewhat unique qualities of the military need as the drivers, the AFWAL Flight Dynamics Laboratory has programs both under way and planned that are directed toward providing a technology base to meet future military needs. Care is being taken not to duplicate work done by NASA or other governmental agencies in DoD. Our work is what we call "full spectrum" - it includes basic research in-house efforts as well exploratory development and advanced development contracted efforts.

The purpose of this paper is to overview the work under way in the AFWAL community that is applicable to the control of flexible antenna systems. The information here does not cover work being done in other laboratories of the Air Force nor does it cover work being done in AFWAL that is applicable to spacecraft such as the Advanced Military Spaceflight Capability (AMSC) and/or the Transatmospheric Vehicle (TAV). Work applicable to such vehicles falls outside the scope of this conference.

In the following descriptions of programs, an attempt is made to provide sufficient information to the reader to gain an understanding of what is being done, how it is being approached, and what the payoff is if successful. In addition, and most important, the people working the area and responsible for contracts in AFWAL are listed with their telephone numbers to simplify contacting them. Discussions are important to us; differences of opinion and reinforcement of opinion need to be brought forth.

The following descriptions start with programs that are in-house basic research in both the Flight Control and Structures and Dynamics Divisions followed by contracted exploratory development programs in both Divisions. Only on-going work is described.

IN-HOUSE SPACE-ORIENTED CONTROL ACTIVITIES

All of the in-house control activities to be reviewed are oriented toward application in space. They are fundamental basic research studies and, as such, are actually generic in nature and can apply to many control problems. Orienting them toward space only means that the test problems used and the application jargon applied are spacecraft oriented with weights, frequencies, bandwidths, etc. being those common to flexible space structures and their control systems rather than to aircraft. All of the work overviewed is supported by the Air Force Office of Scientific Research.

Reduced-Order Control Theory

In general, the high-frequency dynamics of large, flexible space structures are not well known with the order of the dynamics too large to design an effective controlling system. Methods are needed to control the low-frequency modes without exciting the high-frequency dynamics inherent in the structure. This is the objective of this study; it has been under way since 1982.

For study purposes, a reduced-order model is used as a "design model" while a full-order model is used as an "evaluation model." The approach used is a frequency-shaped linear quadratic Gaussian (LQG) methodology that makes it possible to apply less control energy to the high-frequency modes and more to the low-frequency modes to better regulate or control all modes. This is done by choosing the quadratic state and control weighting in the LQG methodology as functions of frequency. If the standard LQG methodology is used, it can apply equally to the whole dynamic spectrum possibly causing the control gains to spill over into the high-frequency modes causing instabilities. Weighting prevents this.

The study approach that has been used is to examine the step-by-step application of this frequency-shaped LQG methodology to better understand the reduced-order control design theory. As work progresses, the payoffs and costs of the methodology are documented so that guidelines can be developed for choosing the frequency dependent quadratic state and control weightings. To aid in understanding the meanings of these weightings, they are being interpreted in terms of classical control concepts. For example: it has been shown that shaping the state weighting is the same as using a dynamic compensator in the feedback loop; also, shaping the control weighting is the same as using a roll-off filter in the feed forward loop. The major cost of using this method is the additional states required in the design model. For simple systems, this is no problem because the additional hardware needed for implementation is simple and increases in computational burdens are minimal. For realistic space structures, however, the addition of states could require that some design states must be discarded for a realistic control design thus leading to losses in model information.

The researchers working this area are Dr. Siva Banda and Capt. Brett Ridgely of AFWAL/FIGC. Their telephone numbers are Area Code 513, 255-8677, and 255-8678 respectively. Their past publications are noted in References 1, 2, and 3.

Vibration Control of Flexible Space Structures

The objective of this basic research program is to design the structure and its control system of a large space satellite to either eliminate structural vibration or reduce it to a desired level within a reasonable time span. Both active and passive means for vibrational control are being considered. The computation issues being addressed include the accurate dynamics modelling of the structure, modelling disturbances, the optimization of the structure for vibration resistance, and the development of control algorithms for large-order systems. A matter of prime importance is the integration of a large-order structural optimization with the algorithms for a closed-loop control system so that both can be used to effectively control the large-order system. Arrangements have been made to use the CRAY computer to support this work.

The payoff of this work will be the analysis techniques for synthesizing the algorithms for large-order systems. An example of a system that will benefit from this work is space-based lasers where significant vibration or jitter reductions is required as well as precise pointing, slewing, and focusing.

The optimization of such a system using both active and passive means not only improves system effectiveness but also reduces the control input required. The ability to solve linear optimal regulator problems of 100 state variables with between 50 to 100 actuators now exists in this program. This structural dynamics capability generates the state and control weighting matrices to solve either infinite time control problems, finite time control problems or control saturation problems.

The AFWAL researchers working this area are Drs. V. B. Venkayya and N. S. Khot, and Ms. V. A. Tischler, AFWAL/FIBR. Their telephone number is (513) 255-6992. Their publications are noted as References 4, 5 and 6.

Robustness of Multivariable Control Systems

In large space structures, there are a number of uncertainties that can impact the control system because they can't be anticipated and modelled during the control system design process. These uncertainties can be either in the spacecraft or plant that is being modelled or the environment in which the plant operates. Examples of these include plant parameter variations due to manufacturing, assembling and deploying in space; spacecraft dynamics either not modelled at all or not modelled well; on-board disturbances from power sources; structural deformations from unmodelled solar radiation gradients; space dust impact; sensor errors, etc. Robustness of the control system refers to the property of the closed-loop control system that allows it to tolerate these uncertainties without losing stability of the plant or allowing a degradation in plant performance. The objective of our program is to develop the technological fundamentals that will support the design of a robust multivariable control system. This includes the development of the tools to analyze and synthesize the control system and the techniques for applying these tools to the design process. The primary military need for robustness of the control system is the ability to operate autonomously, i.e., without continual monitoring by and adjusting through a network of satellite ground stations.

The robustness concept is not new. Classical controls engineers have been concerned with it since the beginning of control theory. Rather than calling it robustness, they called it feedback and used it to reduce the sensitivity of the system to both plant and operational variations. There are both stability robustness and performance robustness of a system - the AFWAL work has concentrated on stability robustness. This work uses singular values to analyze and test the robustness of the system. Several singular value robustness tests can be used; they are not equivalent and they do not imply that the resulting system is a practical system. These robustness tests are very conservative, which is related to the structure of the uncertainty. To reduce the conservatism of the test, norm-bounded test procedures are now being used to account for the structure of the uncertainty. This work is continuing; upon completion it will be applied to a practical structural space system.

The researchers working this area in AFWAL are the same ones noted above in the Reduced-Order Control Theory section plus Lt Tim McQuade, telephone number, Area Code 513, 255-8675. Past publications in this area are listed as References 7-10.

CONTRACTED SPACE-ORIENTED CONTROL ACTIVITIES

The work overviewed in this section is contract supported by both Small Business Innovation Research (SBIR) and exploratory development. Even though many of the technical details of the work discussed are generic in nature and can apply to a variety of systems, the emphasis here will be on the application to large space structures. One program overviewed, Vibrational Control of Space Structures (VCOSS I), has been completed; but since it forms the foundation for a follow-on program, VCOSS II, it is included for completeness. The financial support for the programs is through AFWAL.

Robustness Technology

Since robustness technology for large space structures is not as yet well understood, there is no consensus on the best way to achieve robustness as well as on how to apply it. Hence, it is best to examine a number of researchers' ideas on robustness so that no high-payoff idea is overlooked. With this in mind, three Small Business Innovation Research (SBIR) contracts have been let with the objective to examine and compare various methods of achieving robust control to evaluate the benefits, drawbacks and applications of each method. The SBIR contract is a vehicle by which a researcher is provided a small amount of seed money to pursue a concept to the first stage of proving its feasibility. If feasibility is shown, then the next stage can be contracted, thus developing the concept. This second stage can have a much larger contract amount. Using the experience and knowledge gained by the AFWAL personnel working in the robust control areas that were noted above, these SBIR contracts are being monitored closely and their results carefully judged on the basis of their worth.

The three contracts, the organizations working them and the contract durations are as follows:

a. Stevens Institute of Technology
Time Domain Design of LQG Regulators
1 June 1984 to 1 June 1985

b. Alphatech Inc.
Robust Decentralized Control-Singular Value Theory
16 August 1984 to 15 February 1985

c. Scientific Systems, Inc.
Robust Decentralized Control-Algebraic Theory
15 August 1984 to 15 February 1985

The robust technology developed under each of these contracts will be applied to a space structure chosen by the researcher. Because of the size of the contracts, these structures will be rather simple in nature.

The AFWAL contract monitor for these efforts is Dr Siva Banda, Area Code 513, 255-8677.

Large Space Structures Pointing and Shape Control

The Department of Defense has sponsored considerable work directed at developing the analytical tools and techniques for understanding the dynamics and control of large flexible space structures. These efforts have resulted in a number of uncoordinated reports from a number of studies that include the DARPA-funded ACOSS and AFWAL-funded VCOSS I programs. Coupling this to the extensive NASA technology activities in this same area indicates that a rather large body of technical results exists that deals with the control of flexible space structures. This program is directed toward bringing together this state of knowledge in an orderly controls study to establish procedures and tools for the preliminary design of control systems for flexible space structures that have stringent slewing, pointing, shaping, and vibrational controlling specifications.

The thrust of the program is to develop control algorithms for a large space antenna of a type that could be used for surveillance or reconnaissance. The structural design of the antenna was left to the contractor with the requirements that it be realistic and that it meet the operational and accuracy requirements established by AFWAL. These requirements are rather arbitrary, being established primarily to test the control design so that (a) useable results for a range of spacecraft configurations would result and (b) the maturity and completeness of the state of the art of technology developments in areas of dynamics and control could be determined. In the program, the contractor is required to mathematically model the structure and structural dynamics of the antenna resulting from both the vehicle motions and the environmental disturbances, model these motions and disturbances, and develop algorithms for simultaneously slewing, pointing, shaping and vibrationally damping the structure. Using the noted foundation information, trade-off studies will be made to evaluate actuators and sensors to accomplish the control actions. These studies may lead to the establishment of performance specifications that exceed existing hardware capabilities for control system hardware that are needed to control military large flexible structures in space. Other trade-off studies to be done will examine the trade-offs between active control and passive damping for the control of the vibration of space structures. Application of robustness concepts will be included as well as an attempt to define an optimal control scheme for the antenna structure being studied.

The resulting program, which started in September 1983, is 31 months long. General Dynamics, Convair Division, is the prime contractor with H. R. Textron subcontracting to them. Figure 1 diagrammatically illustrates the objective of the program. Figure 2 is a 3-section view of the antenna that has been modelled. In general, it is a 100-meter offset antenna made up of a truss structure. A complete NASTRAN model of the structure has been established with the model characteristics defined up to 100 modes. Only 45 modes are being considered to develop the control algorithms. Figure 3 describes the program. There are four tasks: model definition, control algorithms, trade-off studies and documentation. The first task is completed now: it prepares the structural definition of the antenna, its dynamic characteristics, and the mathematical models of the disturbances that result from the mission and environment. The second task will define the control system componentry and element placement and develop the candidate operational algorithms to meet the needs of the mission. It is roughly one-half complete. The third task examines the influence of structural and control system variables on performance, seeking an optimal mix of passive and active control. The final task documents the results of the study. Figure 4 diagrammatically shows the interaction of the four elements of control being studied. This figure emphasized the significant interaction between pointing and vibrational control in a large flexible antenna structure such as this. For example, when the structure line of sight is changed, stopping this slewing motion - or using pointing control - causes the structure to vibrate due to the change in momentum of its members.

The AFWAL Project Engineer of this program is Capt. Brett Ridgely, Area Code 513, 255-8678. The Task I report is currently being reviewed and will be available in the near future (ref. 11).

The Application of Robust Control Technology to Large Space Antennas

This program is a new Exploratory Development program under contract to the Honeywell Systems Research Center. The objective of the program is to apply robust control technology to the large RF antenna being studied under the Large Space Structures Pointing and Shape Control program described. The contractor will use the structural dynamics characteristics of the antenna model, the disturbance characteristics, and the control requirements for slewing, pointing, shaping, and vibrationally controlling the model that General Dynamics has developed under Task 1 of that program (see Figure 2). This robust control program will provide practical analysis and design techniques for applying robust control techniques to a large space antenna. It will address critical issues of model reduction for robust control design for achieving performance and stability robustness, and for making control law simplification for design implementation.

The start of the program is keyed to the completion of Task 1 of the previously described program. The program period is 14 months in length so that the study results can fold back into the large space structures program before Task 3 of that program is complete.

The Project Engineer for this program is Dr. S. S. Banda, AFWAL/FIGC, (513) 255-8677.

Vibrational Control of Space Structures (VCOSS)

The VCOSS program consists of two efforts: VCOSS I and VCOSS II. Although VCOSS I was completed in mid-1983, its results form the foundation for VCOSS II requiring that it be summarized to form the foundation for VCOSS II.

VCOSS I used the Draper Model 2 as a study configuration. Two contractors performed parallel studies: Lockheed Missiles and Space Company, Inc. and the Space and Technology Group of TRW. The objective of these studies was to apply modern control techniques and state-of-the-art sensor and actuator hardware concepts to actively control the vibration of the Draper Model 2 and compare the line-of-sight error and cost to a passive, stiffness-oriented design. Inherent in this objective is the assessment of the characteristics of sensors and actuators, the placing of them on the structure to gain their greatest benefit, and the evaluation of the resulting mass loading on the structure.

As expected, the study results from each contractor differed somewhat in specifics because they used different sensor/actuator sites, but they agreed in general. Both showed significant reductions in line-of-sight error through a closed-loop active control system. Both also showed that the power required and weight added by the active control system were a cost factor to be considered during preliminary design.

Both contractors differed in the number and type of sensors and actuators used and their location on the study structure. The VCOSS A by LMSC used HAC/LAC hardware implementation(12) and VCOSS B by TRW used momentum exchange and truss damping control hardware(13). Both selected hardware as well as sensor and processor hardware that was compatible with their control implementation. Actually these differences added value to this Exploratory Development program in that they illustrated that different implementation techniques and analysis philosophies can be used to control a flexible structure. The overriding conclusion common to both was that much larger reductions in LOS error can be achieved through rather simple active control systems than can be achieved by structural stiffening. The AFWAL Project Engineer on the VCOSS I study was Mr. Jerome Pearson, AFWAL/FIBG, (513) 255-5236.

To test the conclusions achieved during VCOSS I, a program was planned that would compare the predicted to the measured influence of active control on a realistic space structure. This program is now under contract to the TRW Spacecraft Engineering Division and is called Large Space Structure Vibration Control - VCOSS II. The test model to be used is the Astromast suspended arrangement located at the NASA Marshall Space Flight Center. It includes the mast and an offset feed parabolic antenna (Figure 5). The Astromast has the same design as the masts flown on Voyager and Mariner Satellites. The objectives of VCOSS II are twofold: 1) to develop and optimize the sensor and actuator combinations for application to a test structure, and 2) to assess the adequacy of the analytical models for control system design by comparing experimental results to analytical predictions.

The issues to be addressed during this program are those that are common to the design of either a spacecraft or a test arrangement. These include the technique to be used for the test, sensor sensitivity and saturation, actuator, nonlinearities such as friction, etc. (Figure 6). The payoff of this type of test program is that it should verify the analysis and modelling techniques used, showing ways to improve our ability to model the structure and develop control algorithms. In the long run, this should yield greater control accuracy for flexible large space structures contributing to the design of lower weight structures. The AFWAL Project Engineer for the VCOSS II program is Maj. Hugh Briggs, (513) 255-5236.

COMPONENTRY DEVELOPMENT

Included within the AFWAL Laboratories is a Flight Control Actuator Laboratory that has a significant history of developments for the actuation of aerodynamic surfaces for aircraft and missiles. This laboratory has done pioneering work in both hydraulic and electromechanical linear actuators. Based on this experience and the military interest in space, work is under way to develop two actuation concepts that have a possible use in large space structures. These are overviewed in the following.

Hydraulic Linear Actuator

The positioning of one element of a large space structure with relation to another element without a residual force or torque can be useful in the shaping of such structures. The residual force and torque of a rocket controller and a control moment gyro have to be counteracted to stop the motion and can be costly in energy. An actuator that requires low power, is responsive and low in weight is an ideal solution but it must also be able to operate over a large temperature range and with steep temperature gradients typical of the space environment. The objective of this activity is to develop such an actuator based on the use of a hydraulic fluid (Figure 7).

The actuator design conceived and built (Figure 8) is an enclosed system using a high flash point silicon fluid as a working fluid. The silicon fluid has the property of having a minimal expansion with temperature change allowing the fluid to be contained within bellows in the actuator (Figure 9). Although the pump in the laboratory model (Figure 10) is an electrically operated displacement device, it is possible to make this pump work by the piezoelectric principle and, thereby, reduce the power required.

The laboratory test model has been fabricated (see Figure 10) and will shortly start undergoing testing. The project manager of the effort is Mr. Greg

Cecere, Area Code 513, 255-2831. The work is performed by Dynamic Control, Inc., an on-site contractor.

Piezoelectric Technology

Piezoelectric devices are currently used industrially and are being studied by aerospace companies for use in space. Another program just starting in the AFWAL actuator laboratory has as its objective to apply this technology in conjunction with the hydraulic linear actuator just described both as actuator and as a high-pressure fluid transfer pump. Figure 8 illustrates a piezoelectric actuator element as integral with the actuator rod of the hydraulic actuator. This combination can provide large motion at high force levels along with extreme positioning accuracy and up to 1000-Hz frequency response for small strokes. Primary development problems that must be addressed are hysteresis in the discs and the control circuitry required to achieve desired positioning accuracy as well as high frequencies. Figure 11 illustrates a disc stack that has potential for this application along with expected actuator characteristics.

The project manager for this activity, which is starting this fiscal year, is also Mr. Greg Cecere and the work performed by the on-site contractor as noted above.

SUMMARY

The foregoing is an overview of the AFWAL activities that are currently under way and are relevant to the control of large flexible space structures. The method of carrying out this work is interdisciplinary with the Flight Control and Structures and Dynamics Divisions working closely together on the various technology efforts. The work is supported or funded by the Air Force Office of Scientific Research in the basic research area and AFWAL in the exploratory development area. Hence, the work covers the spectrum from the very fundamental analytic research level to the fabrication and testing of large structural components. No attempt has been made to present details of the work being done; rather, only sufficient information is provided to tell the reader the who, what and why of each program. In all cases, the people performing and/or managing the work are cited along with their AFWAL symbol and telephone number. Contacting them will provide details to whatever depth the reader desires.

Not all the space-oriented dynamics and control work in AFWAL has been overviewed. Work is either in planning or under way on technologies applicable to the control of vehicles categorized under the Advanced Military Spaceflight Capability (AMSC) activity and the Transatmospheric Vehicle (TAV). This work differs from that overviewed because the structures are more rigid and some of the vehicles are planned to be manned. Air data sensor work has been supported in the past and is planned for future support to measure real gas densities in the region near the outer reaches of the atmosphere for use in control system gain computations for maneuvering of an AMSC/TAV. Linear actuator development for application to either large space structures or AMSC-type spacecraft is also under way. If information is desired on any of the work not overviewed, contact the author at AFWAL/FIGC, (513) 476-1075.

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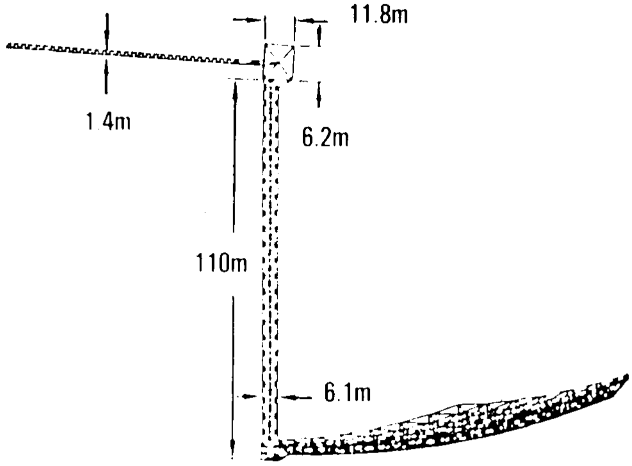


OBJECTIVE:

DEVELOP ONE CONTROL ANALYSIS / DESIGN METHODOLOGY FOR REALISTIC LARGE SPACE ANTENNA FOR:

SLEWING
POINTING
SHAPING
VIBRATION CONTROLLING

APPROACH:

- MODEL REALISTIC ANTENNA AND ACTUATOR / SENSORS
- DEFINE MISSION DRIVERS AND ENVIRONMENTAL FACTORS
- DEVELOP CONTROL ALGORITHMS
- PERFORM CONTROL TRADE-OFF STUDIES
- REPORT OPTIMAL ALGORITHMS AND HARDWARE SHORT FALLS

CONTRACTOR:

- GENERAL DYNAMICS CONVAIR DIVISION
  SUB: HR TEXTRON

PAYOFF:

- FOCUS CONTROL TECHNOLOGY ON REALISTIC CONFIG.
- TEST TECHNOLOGY MATURITY / COMPLETENESS

Figure 1. Large Spacecraft Pointing and Shape Control Program Objective.

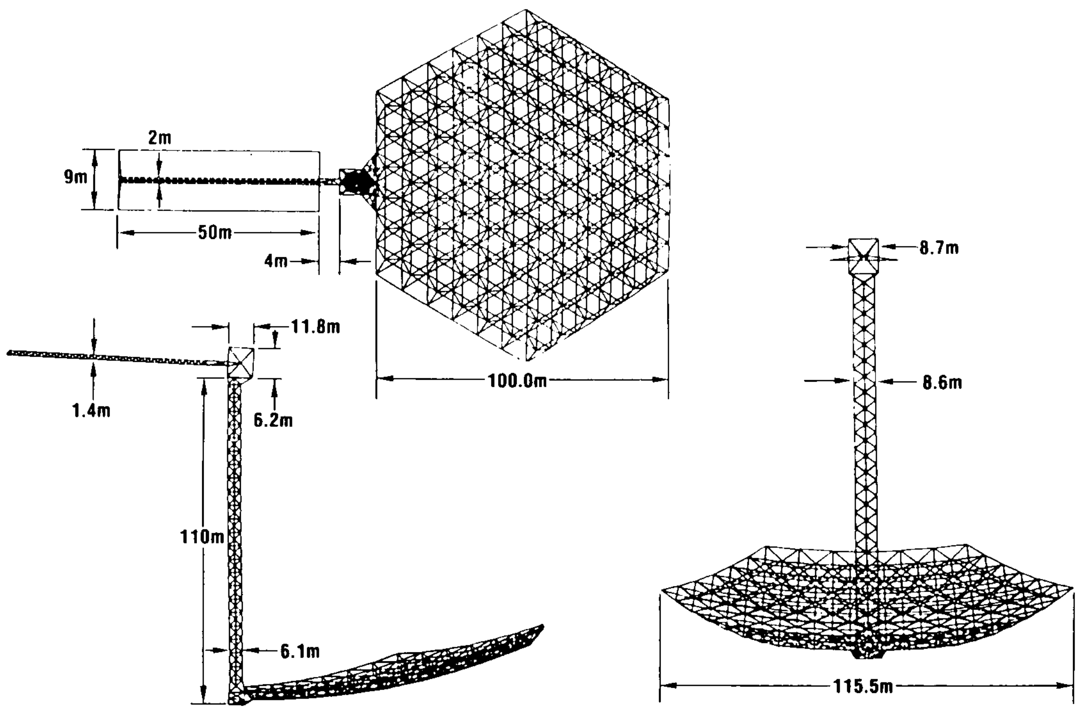


Figure 2. Program Spacecraft Geometry.

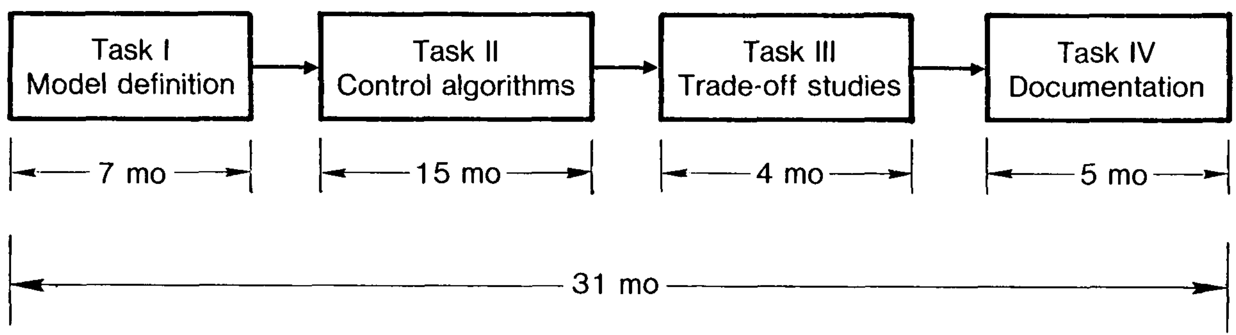


Figure 3. Program Contract Tasks and Timing.

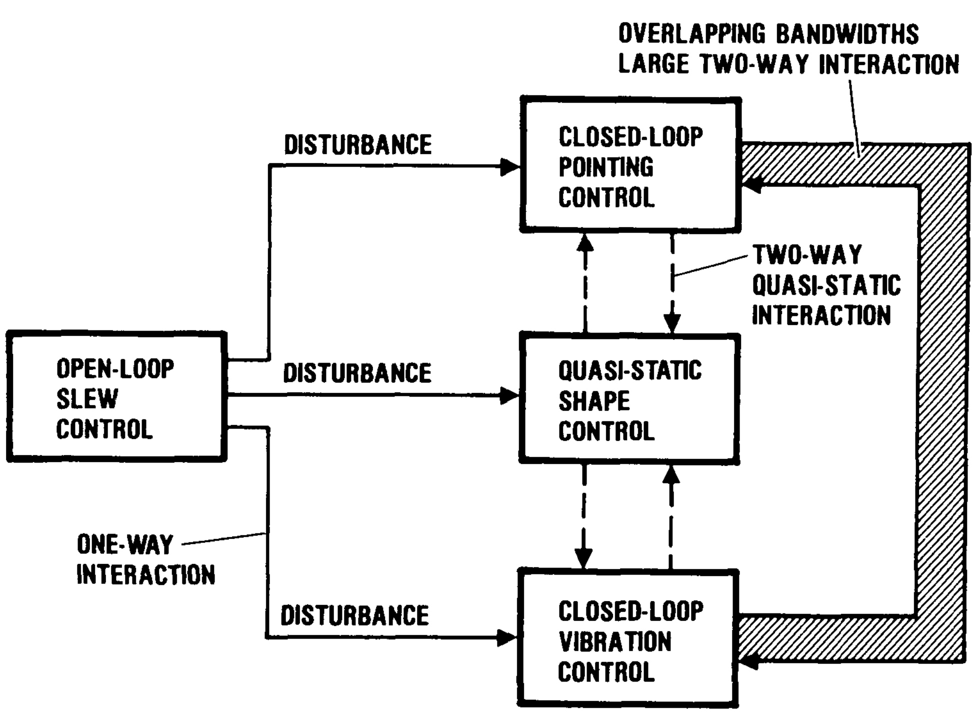
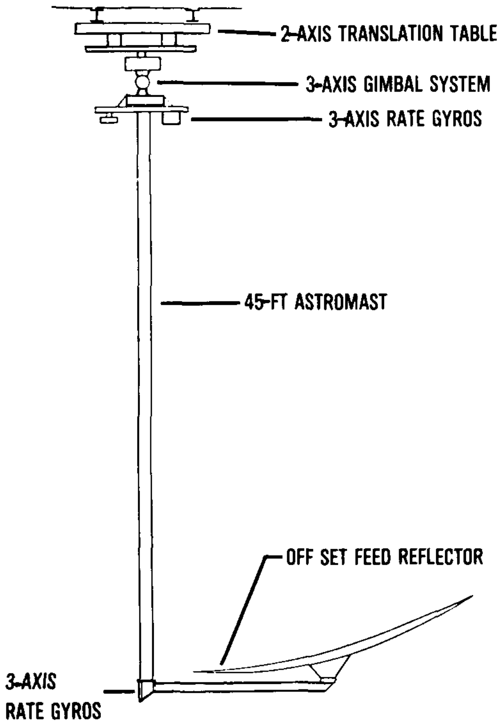


Figure 4. Control Subsystem Interaction.



OBJECTIVES

- DEVELOP AND OPTIMIZE SENSOR / ACTUATOR COMBINATIONS
- COMPARE EXPERIMENTAL RESULTS TO ANALYTICAL PREDICTIONS TO ASSESS ADEQUACY OF ANALYTICAL MODEL

TEST MODEL

- LOCATED AT MARSHALL SPACE FLIGHT CENTER
- SUSPENDED ASTROMAST SAME AS FLOWN ON VOYAGER/MARINER
- SUSPENDED THRU GIMBAL SYSTEM

CONTRACT

- TRW-SPACECRAFT ENGINEERING DIVISION APR 84 - SEP 86

Figure 5. VCOSS II Program Test Arrangement.

* TECHNICAL ISSUES
  * Lab Testing Techniques
  * Sensor Sensitivity and Saturation
  * Actuator Stiction
  * Sensor/Actuator/Structure Interactions
  * Control Algorithms

* PAYOFFS
  * Lab Confirmation of Analytic Studies
  * Improved Dynamic Modeling
  * Improved Control Algorithms
  * Lighter Space Structures
  * Greater Alignment Accuracy

* GROWTH POTENTIAL
  * Space Shuttle Test
  * Distributed Control of Reflecting Surfaces
  * Improved Adaptive Control Algorithms

Figure 6. VCOSS II - Program Specifics.

OBJECTIVE:

- DEVELOP HYDRAULIC LINEAR ACTUATOR CAPABILITY THAT CAN WITHSTAND TEMPERATURE RANGE / GRADIENT IN SPACE

MILITARY NEEDS:

- ABILITY TO POSITION SPACECRAFT COMPONENTS WITHOUT RESIDUAL FORCE / MOMENT ACTING ON TOTAL SPACECRAFT
- LOW WEIGHT, RESPONSIVE, LOW POWER, LINEAR ACTUATOR FOR SBL, AMSC, ETC.

APPROACH:

- ELECTRO-HYDRAULIC USING SILICON BASED FLUID-FLASH POINT $>$ 500°F
- ENCLOSED SYSTEM WITH POTENTIAL FOR MTBF $\geq$ 10 YRS
- LABORATORY TEST MODEL:
  - POWER = $\sim$ 25 WATTS
  - FORCE = 40 LBS
  - FREQUENCY $\sim$ 1 Hz MAX
  - TEMP. RANGE: $-200 \leq T \leq +300$°F
  - STROKE: $\pm$ 1 INCH, 0.1 IN / SEC

SCHEDULE:

- CONCEPTUAL DESIGN-COMPLETE
- TEST MODEL DESIGNED / FABRICATED - SEP 84
- BENCH TEST (VACUUM, TEMPERATURE) - SEP 85
- DEVELOP DESIGN GUIDE SPEC - JAN 86

Figure 7. Hydraulic Linear Actuator Program.

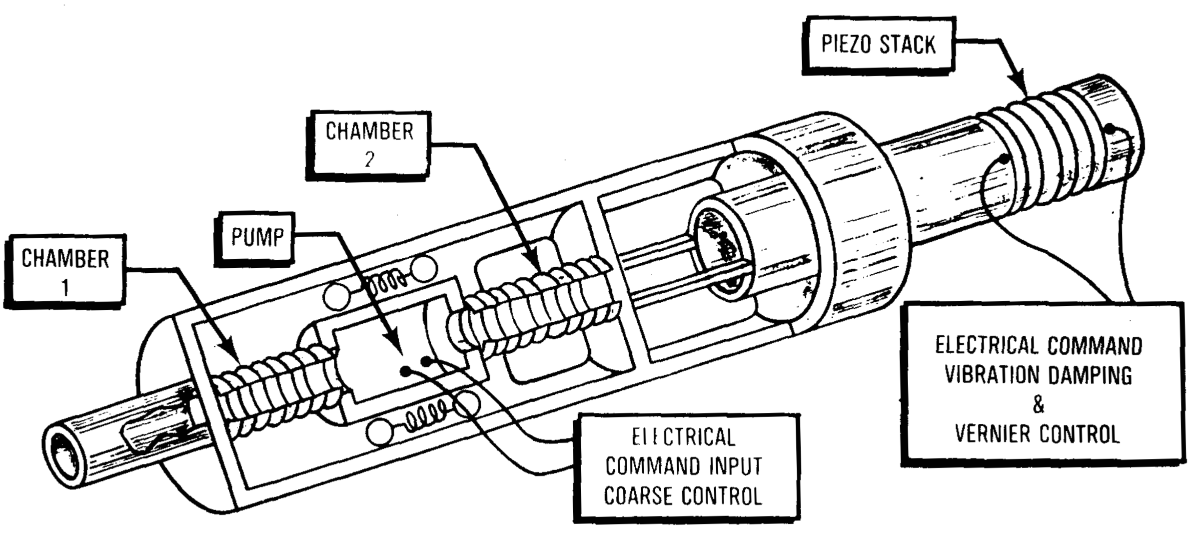


Figure 8. Hydraulic Linear Actuator Schematic.

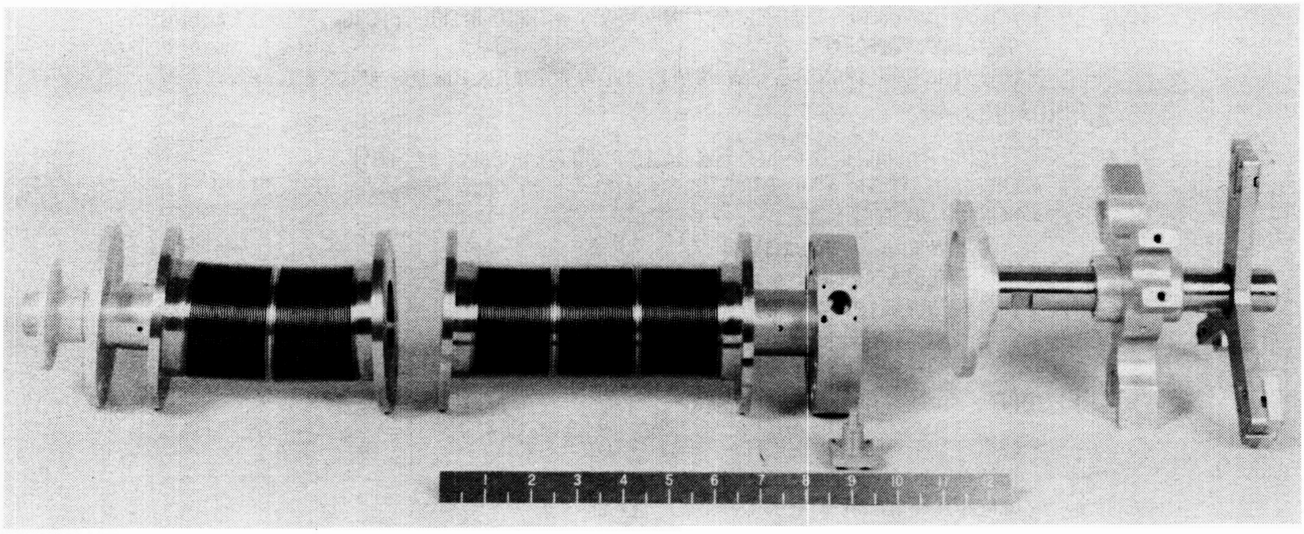


Figure 9. Linear Actuator Componentry.

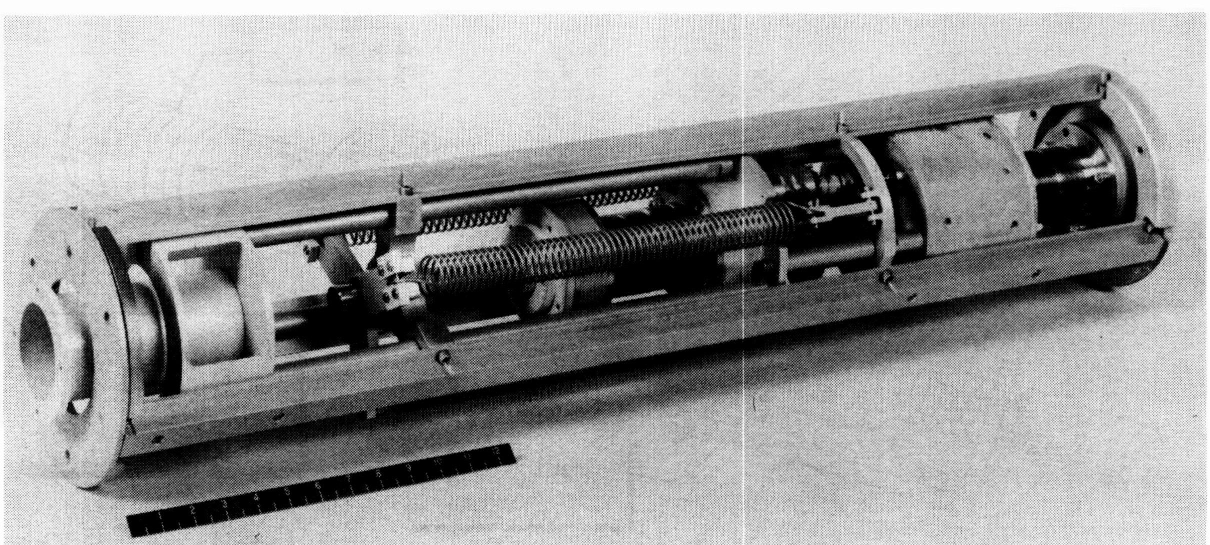
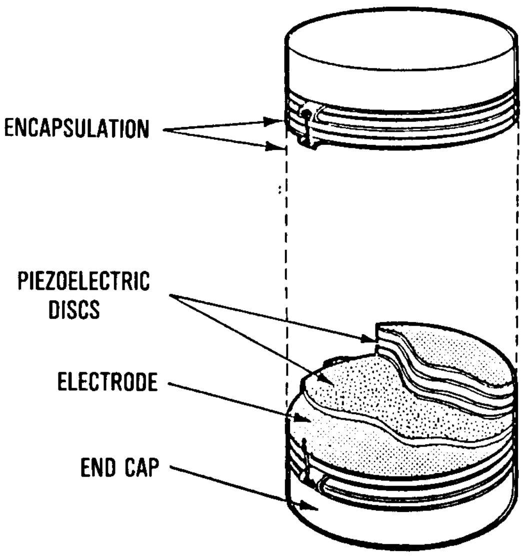


Figure 10. Bench Test Configuration of Linear Actuator.



OBJECTIVE:

- TO DEVELOP ABILITY TO APPLY INDUSTRIALLY AVAILABLE PIEZOELECTRIC TECHNOLOGY TO SPACECRAFT

APPLICABILITY:

- LARGE FORCE, WIDE BANDWIDTH, PRECISION LINEAR ACTUATOR
- HIGH-PRESSURE FLUID TRANSFER PUMP FOR HYDRAULIC ACTUATOR

MILITARY NEED:

- MIRROR CONTROL IN SBL

POTENTIAL PERFORMANCE CAPABILITY:

- POWER - 10 WATTS MAX.
  (DEPENDS ON NO. OF DISCS)
- FORCE - 200 - 300 LBS
- FREQUENCY - $\leq$ 1000 Hz
- TEMPERATURE - $-270° \leq T \leq 300°C$
- STROKE 0.0015 IN. / .001 IN. DISC THICK

SCHEDULE:

- DEV. PROG. START - FY85

Figure 11. Piezoelectric Actuator Program.