NASA TECHNICAL MEMORANDUM

NASA TM X-64806

(NASA-TM-X-64806) LARGE SPACE TELESCOPE (LST) POINTING CONTROL SYSTEM (PCS) ANALYTICAL ADVANCED TECHNICAL DEVELOPMENT (ATD) PROGRAM (NASA) 17 ~~20~~ p HC $4.00 CSCL 14B G3/14

N74-17165

Unclas 30660

LARGE SPACE TELESCOPE (LST) POINTING CONTROL SYSTEM (PCS) ANALYTICAL ADVANCED TECHNICAL DEVELOPMENT (ATD) PROGRAM

By Sherman M.Seltzer
Astrionics Laboratory

February 14, 1974

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM X-64806	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE LARGE SPACE TELESCOPE (LST) POINTING CONTROL SYSTEM (PCS) ANALYTICAL ADVANCED TECHNICAL DEVELOPMENT (ATD) PROGRAM		5. REPORT DATE February 14, 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Sherman M. Seltzer		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared for Astrionics Laboratory, Science and Engineering.

16. ABSTRACT

The purpose of this memorandum is to describe the Large Space Telescope (LST) Pointing Control System (PCS) Advanced Technical Development (ATD) program. The approach used is to describe the overall PCS development effort, showing how the analytical ATD program elements fit into it. Then the analytical ATD program elements are summarized (although alluded to summarily in the introduction and several times in the body of this memorandum, the hardware development portion of the ATD program is omitted). If only the list of ATD program elements were presented and described, the program would appear disjointed. However, by showing how these program elements fit into the overall PCS development effort, their connection to the program and their purpose is then evident.

17. KEY WORDS		18. DISTRIBUTION STATEMENT Unclassified-unlimited	
19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 18	22. PRICE NTIS

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

TECHNICAL MEMORANDUM X-64806

LARGE SPACE TELESCOPE (LST) POINTING CONTROL SYSTEM (PCS) ANALYTICAL ADVANCED TECHNICAL DEVELOPMENT (ATD) PROGRAM

INTRODUCTION

The purpose of this memorandum is to describe the Large Space Telescope (LST) Pointing Control System (PCS) Advanced Technical Development (ATD) program. The approach used is to describe the overall PCS development effort, showing how the analytical ATD program elements fit into it. Then the analytical ATD program elements are summarized (although alluded to summarily in the introduction and several times in the body of this memorandum, the hardware development portion of the ATD program is omitted). If only the list of ATD program elements were presented and described, the program would appear disjointed. However, by showing how these program elements fit into the overall PCS development effort, their connection to the program and their purpose is then evident.

The PCS is described in standard block diagram form on the top of Fig. 1 and is comprised of sensors, the controller, and effectors. The sensors measure to the best of their capability those states of the LST plant that it is felt are needed. These measured states are received by the controller, envisioned to be an onboard digital computer. The controller has programed within it a control algorithm (or law) which utilizes the measured states and, if it is deemed desirable, estimates other states. It uses these states to develop commands to the effectors. The effectors act on these commands to provide a new set of states (or "state vector") or response of the LST. This response is then compared to the desired or commanded states, all of which is schematically indicated in familiar (at least to the control system dynamicist) state vector form of Fig. 1. If the block diagram is topologically mapped into a form more common to program management (we might call it a "program tree"), the chart on the bottom half of Fig. 1 results. A new block appears denoted "system studies." This is where both analytical and computer simulation efforts are applied to bring the PCS into just that - a system.

The design philosophy being applied to the LST is a simple one - simplicity (Fig. 2). In general we equate design simplicity with desirability. For example, if a control system consisting only of control moment gyroscopes (CMG's) for effectors can meet the LST performance requirements, then that would be desirable over a control system consisting of several elements used together, such as CMG's and reaction wheels (RW's). The same argument applies for a system consisting of only reaction wheels for effectors. If analysis and simulation predicts that a combination of CMG's and reaction wheels still cannot meet performance requirements, then perhaps Image Motion Compensation (IMC) must also be included as an effector. Because it is not known at this date if CMG's (or reaction wheels) alone can cause the PCS to meet the LST performance requirements, all promising candidate PCS effectors must be considered. The most promising ones must be developed until such time as it is predicted with a high degree of assurance that a particular set of PCS subsystems can meet the requirements. While this discussion has been confined to effectors to describe the design philosophy, that philosophy of course also applies to the other PCS subsystems.

The remainder of this memorandum will now be applied to the analytical portion of the ATD, omitting the hardware development phase. Principal Investigators (PI) for each element of the PCS analytical development are indicated as appropriate. It should be mentioned that the contents of this memorandum reflect the presentation that was made to Dr. Naugle on January 29, 1974, and have his approval as well as that of the Center Director, Dr. Petrone. It was coordinated with the MSFC LST Task Team and pertinent elements of the Aero-Astrodynamics and Astrionics Laboratories.

ANALYTICAL ATD PROGRAM: EFFECTORS

The effectors part of analytical portion of the ATD program is depicted graphically in Fig. 3. The CMG analyses either underway or in the preliminary definition phase lie in three areas: a CMG trade study, friction model analysis, and development of a Momentum Exchange Controller (MEC) digital simulation model.

CMG Trade Study (P.I. Dr. Borelli, S&E-ASTR-A.) The purpose of this task is to analyze and recommend the number, type, and configuration of CMG's to be used. Three or four of the most viable CMG control systems will be analyzed to determine the best system for meeting LST requirements. This analysis will be closely linked with the hardware development underway in the Guidance and Control Division and analytical CMG control laws being developed within both Aero-Astrodynamics and Astrionics Laboratories. This task has just been underway a few months, and analysis and trade bases are still being defined. Air bearing table performance tests are being conducted on a Bendix CMG at the seismic isolation test site at Martin Marietta near Denver under an ATD contract (COR: Dr. Nurre, S&E-ASTR-A). It is anticipated that the results of these tests will be factored into the CMG trade study.

Friction Model(s) for CMG Gimbal Pivots (P.I.'s Analysis: Dr. Seltzer, S&E-ASTR-A. Simulation, Dr. Nurre, S&E-ASTR-A.) The purpose of this task is to evaluate the effects of gimbal friction on LST dynamics, looking particularly for limit cycle predictions and means of obviating them. Several candidate friction models have been analyzed, simulated, and reported upon.[1-3] Since the so-called Dahl (of Aerospace Corp.) model appears to most closely describe the actual friction (this presently is being tested at the Martin Denver air bearing table site), most attention recently has been applied to it.[2,3] Both continuous and discrete describing functions for this model have been developed (and used) under an ATD contract with Dr. Benjamin C. Kuo of Systems Research Laboratory, Champaign Ill.[4] Preliminary analyses of continuous - data models have been completed, and analyses of simplified digital (sampled-data) models are now underway.

Digital Simulation of a Momentum Exchange Controller (MEC) (P.I. Dr. Seltzer, S&E-ASTR-A.) The purpose of this task is to digitally simulate the dynamics of an MEC. The program has the option of simulating either a single or a double gimbal CMG or a reaction wheel. The model utilizes Prof. Peter W. Likins' (UCLA) hybrid coordinate approach to simulate a spinning flexible MEC rotor in order to determine the dynamic effects (if they exist, which is improbable but possible) of a flexible rotor on the LST. The model also has the ability to include nonlinearities and a six-dimensional shock mount and is portrayed graphically on Fig. 4 . The program is complete and awaits checkout.[5] Because of the expected highly accurate measurements to be obtained on the Martin air bearing table, the MEC simulation will probably now be superfluous. Hence, it is intended for use only as a tool to help understand and interprete air bearing table measurements should it be needed.

Reaction Wheel Trade Study. (P. I.'s: Mr. von Pragenau, S&E-ASTR-A, Mr. Shelton, S&E-ASTR-SD, and Mr. Williamson, S&E-ASTR-SG.) The purpose of this study is to analyze and recommend the number and type of reaction wheels that will be needed, either alone or in conjunction with CMG's. Viable candidate configurations will be identified and their performance predicted by computer simulation. Previously reported results are being searched to determine possible candidates for the LST.

Isolators. (P. I. Mr. Shelton, S&E-ASTR-SD.) It is necessary to determine CMG and reaction wheel isolator requirements and to predict their effect on the LST dynamics. Bandpass requirements will be determined and nonlinear and crosscoupling effects characterized and analyzed. The mathematical models needed to determine bandpass requirements are now programed on a computer.

CMG Steering Laws and Momentum Management. (P. I. Mr. Kennel, S&E-ASTR-A.) The purpose of this task is to investigate CMG steering laws and momentum management schemes, building on existing knowledge of the Skylab momentum management scheme. The approach is to evaluate and compare existing CMG steering laws; if they are not adequate, a new steering law must be developed. Singularity investigations must be made, and resulting CMG momentum size (and/or magnetic torquer power consumption) must be traded against software complexity needed to avoid singularities. Limited work has been performed due to Skylab commitments. Pseudo-inverse (for "baseline" single gimbal CMG's) and OMEGA (for two scissored pairs of single gimbal CMG's) have been programed and tested on digital and hybrid computers, with extensive work being done by Aero-Astrodynamics Laboratory.

Magnetic Torquing System. (P.I. Mr. Politis, S&E-ASTR-SG.) The purpose of this effort is to develop a scheme for desaturating CMG momentum. The approach is to develop and investigate by simulation a dipole control law which will provide both CMG desaturation and a secondary control torque. The magnetometer will be investigated as a source of coarse attitude rate information.

Secondary Mirror Articulation. (P. I. Mr. Waites, S&E-ASTR-SD.) Several means of controlling the seeondary mirror articulation are being analyzed. They are constrained tobe compatible with the IMC concepts under development.

ANALYTICAL ATD PROGRAM: CONTROLLER (Fig. 5)

Conventional Controller. (P. I. Mr. Scofield, S&E-ASTR-SD.) The purpose of this effort is to develop and evaluate several candidate conventional controllers, such as attitude/attitude rate/integral control feedback. In addition to selection of the most promising controller,determination must be made of gains, necessary compensation networks, and sample rate requirements.

Disturbance Absorbing Controller. (P. I. Mr. Skelton, Sperry Support Contract for S&E-ASTR.) The purpose of this task is to develop and expand an existing concept for accommodating the dynamic effects of internal (e.g. sensor and effector noise and vibration and variations in vehicle modal data) and external (e.g. torques induced by the gravity gradient, aerodynamics, and solar heating of the solar panels) disturbances. In essence, the technique first is to find the optimal control policy under nominal conditions (in this case, to find the control policy that makes the first variation of the selected cost functional equal to zero). Then perturbations in the control are selected that minimize the second variation of the cost functional. Disturbances or parameter variations that can perturb the system from optimal or nominal behavior are thus expected and coped with by the control system.

Onboard Digital Implementation. (P. I. Theory and analysis: Dr. Seltzer, S&E-ASTR-A; Simulation: Mr. Shelton, S&E-ASTR-SD.) This task will attempt to define the effect of digital computer sampling on the LST system dynamics. In particular, conditions for self-sustained oscillations ("limit cycles") will be predicted and means of obviating them determined.

Also digital computer sampling rates will be recommended. Existing analytical techniques are being amplified and applied to the LST problem, considering both digital redesign and parameter plane methods.[7,8] A discrete describing function for the Dahl friction model has been developed for use in this task.[4] An ATD contract is in effect with the Systems Research Laboratory, Champaign, Illinois (Dr. Benjamin Kuo, Principal Investigator).

Effector Blending Scheme. (P. I. Mr. von Pragenau, S&E-ASTR-A.) A control method for stable interaction and complementary performance of the several control effectors, if more than one set is used, must be developed. Specific control interfaces between CMG's and/or reaction wheels and possibly IMC, as well as the LST structure, must be analyzed to develop and select a practical optimally-performing controller. The task is now being defined in detail.

ANALYTICAL ATD PROGRAM: SENSORS (Fig. 6)

Sensor and Effector Noise Models. (P.I. Mr. Hunt, Sperry Support Contractor for S&E-ASTR-A.) Under this task analytical models of sensor and actuator noise will be developed to determine the effect of noise on control system performance. Where appropriate and promising, sensor and effector design will be investigated to find design changes that will minimize errors induced by noise. Presently experimental drift rate data for the AB-3 liquid bearing gyroscope are being analyzed by correlation techniques in an effort to define a detailed approach to this task. When they become available the measured data from expected high quality performance tests being run on the air bearing table at the Martin Co. in Denver will be used to better define noise models, at least for the CMG and rate gyroscopes planned for test there.

ANALYTICAL ATD PROGRAM: SYSTEM STUDIES (Fig. 7)

It is here that the PCS development efforts described above are focused into a cohesive ATD program.

Fine Pointing Control System Design. (P. I.'s. Body Pointing: Dr. Nurre, S&E-ASTR-A; IMC: Mr. Shelton, S&E-ASTR-SD; Optical Control: Mr. C.O. Jones, S&E-ASTR-A; Large Scale Hybrid Simulation: Mr. Chubb, S&E-ASTR-SG.) The purpose of this analysis and simulation effort is to evaluate and compare the LST system dynamics when the PCS is composed of the different candidate subsystems already described. Hardware characteristic will be synthesized and their analytical representations incorporated into a hybrid computer simulation. This will be used to aid in recommending the composition and predicting the performance of the PCS. Subsystem design requirements such as computer rate, fine guidance sensor bandpass, secondary mirror actuator bandpass, and small signal properties will be determined. An ATD contract exists with the Bendix Corp. at Denver to study the body pointing aspects of this task. Plans exist for FY-75 funding to begin to support IMC analytical development.

Flexible Body/Control System Interaction. (P. I. Dr. Seltzer, S&E-ASTR-A.) The purpose of this effort is to predict the effect on vehicle dynamics of flexible LST structures such as the Folding Rolled-Up Solar Array (FRUSA). This task is needed as an adjunct to the preceding one because computer storage capacity will not permit the programing of both sets of equations into one program. Even with the development of new techniques for expressing flexible body equations, it is unlikely that all flexible body information can be included into one program. This is because LST pointing requirements require retention of higher bending modes that traditionally were considered to be "rigid body" and hence neglected. The existing spinning Skylab model has been chosen to be recast as an LST model because of its attention to the flexible body - control system interaction (Fig. 8).[9] A new fully flexible model technique is under advanced development within the framework of an ATD contract with UCLA (Peter W. Likins, P.I.) in addition to a new criterion for selecting and retaining (for modeling purposes) modal data. To complement this effort, a contract with the U. of Santa Clara (Dragoslav D. Siljak, P.I.) is underway to develop means of decomposing the large scale set of descriptive equations into analytically tractable subsets that can be used both to de-bug the computer program and to select numerical values for computer parameters.

PCS Requirements Definition. P. I. Dr. Glaese, S&E-AERO-DO.) The purpose of this task is to determine in detail the PCS subsystem performance requirements. The overall LST performance requirements and goals of the scientific investigators will be analyzed to see if and how they may be met. Hardware capabilities, both existing and predicted, will be an important aspect of this study in budgeting the overall requirements into subsystem requirements. This effort will interface with ongoing analytical characterization of maneuver and strapdown navigation scheme development being worked under Mr. Blanton, S&E-ASTR-SG.

ANALYTICAL ATD PROGRAM

A summary of the elements of the analytical portion of the ATD program that have been identified in this memorandum is presented on Fig. 9. Where appropriate, existing or anticipated (labelled "industry") contractors are identified. Also as indicated, MSFC is working on each of the four areas in-house. An associated schedule is presented as Fig. 10. Although the ATD program elements are shown to terminate at the beginning of FY-76 (six months prior to schedule initiation of phase C, D), this does not imply all efforts along these lines will cease. Rather, those elements that must be continued will be supported by other than the ATD program.

CONCLUSIONS

The contents of this memorandum were derived from a presentation by the author to the Director of MSFC and Dr. Naugle, Director, Office of Space Science, NASA Headquarters. With the exception of the digital control system implementation task, the analytical portion of the ATD Program is consolidated and focused systematically under the block denoted "System Studies" (Figs. 1, 7). An attempt has been made throughout to identify key personnel (P. I. 's) within the MSFC organization for each element of the analytical PCS development. Many of the analytical tasks described herein have been and are supported heavily by personnel of the Guidance and Control Division of Astrionics Laboratory. Further that division provides continual advice on existing and predicted hardware performance capabilities and limitations.

REFERENCES

1. Seltzer, S. M., S&E-ASTR-A Memo, "Analysis of CMG Attitude Control of LST," October 25, 1972.

2. Nurre, G. S., S&E-ASTR-A, "An Analysis of the Dahl Friction Model and Its Effect on CMG Gimbal Rate Controller," unnumbered report, October 18, 1973.

3. Seltzer, S. M., S&E-ASTR-A Memo, "Analysis of the Effect of Assumed (Dahl) Nonlinear Model/CMG Gimbal Friction on Large Space Telescope (LST) Attitude Dynamics, October 30, 1973.

4. Kuo, B. C., & Singh, G., Systems Research Lab., Champaign, Ill., "Research Study on Stabilization & Control - Continuous and Discrete Describing Function Analysis of the LST System," NASA Contract NAS 8-29853, January 1, 1974.

5. Orr, W., Computer Science Corp. & Singh, R., Sperry Support Contract in support of Computation Laboratory, MSFC, Job. No. 330490, "LST-Momentum Exchange Control Simulation," December 11, 1973.

6. Schiehlen, W. O., S&E-ASTR-A, NASA TN D-7500, "A Fine Pointing System for the Large Space Telescope," December 1973.

7. Kuo, Singh, Yackel, & Seltzer, AIAA Paper No. 73-894, "Design of a Digital Controller for Spinning Flexible Spacecraft," AIAA G&C Conference, Key Biscayne, Fla., August 20-22, 1973.

8. Seltzer, "Analysis of a Control System Containing Two Nonlinearities," Int. J. Control, 1971, Vol. 13, No. 6, pp. 1057-1064.

9. Franklin, Computer Sciences Corp. in support of Computation Lab., MSFC, Job. No. 310261, "Spinning Structural Analysis," April 25, 1972.

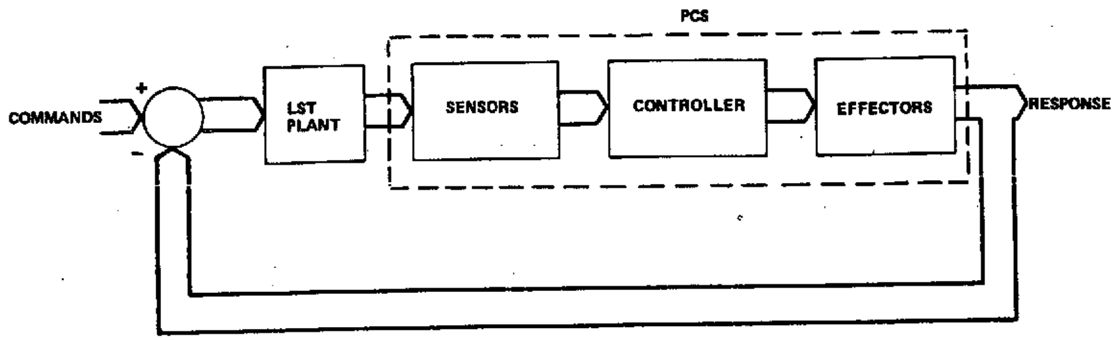

FIG. 1 SYSTEM DEFINITION

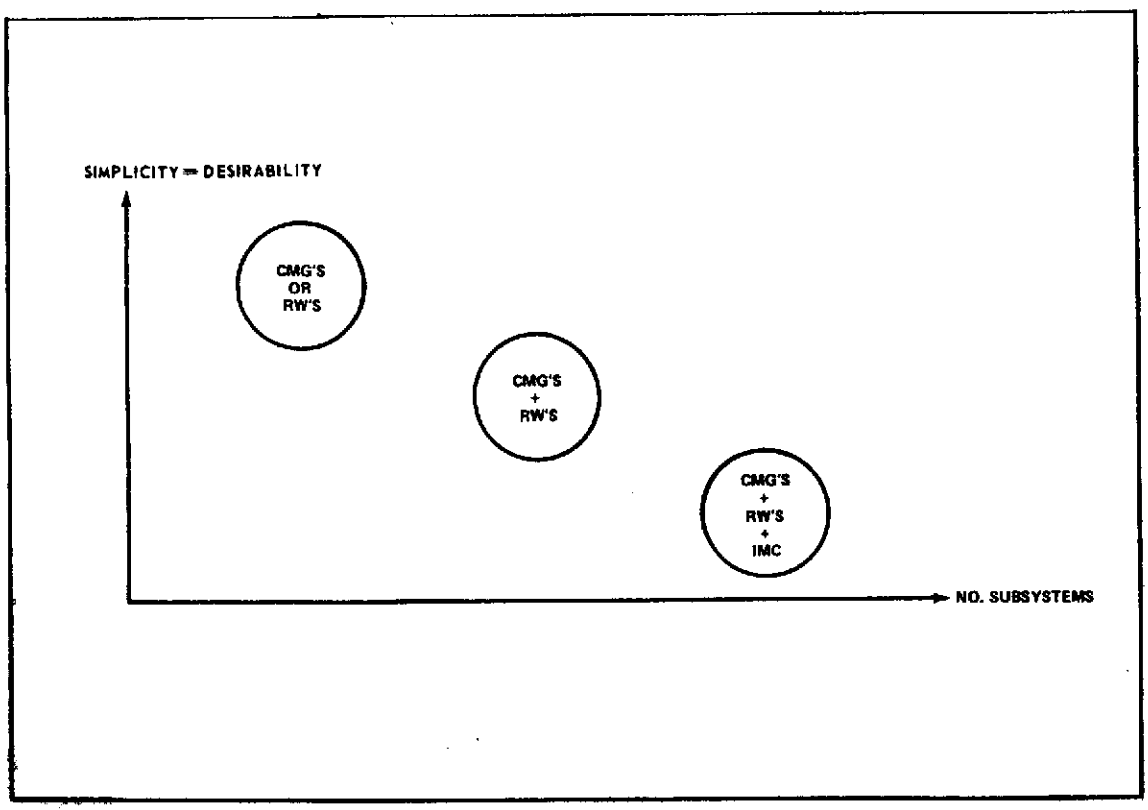

FIG. 2 DESIGN PHILOSOPHY: SIMPLICITY

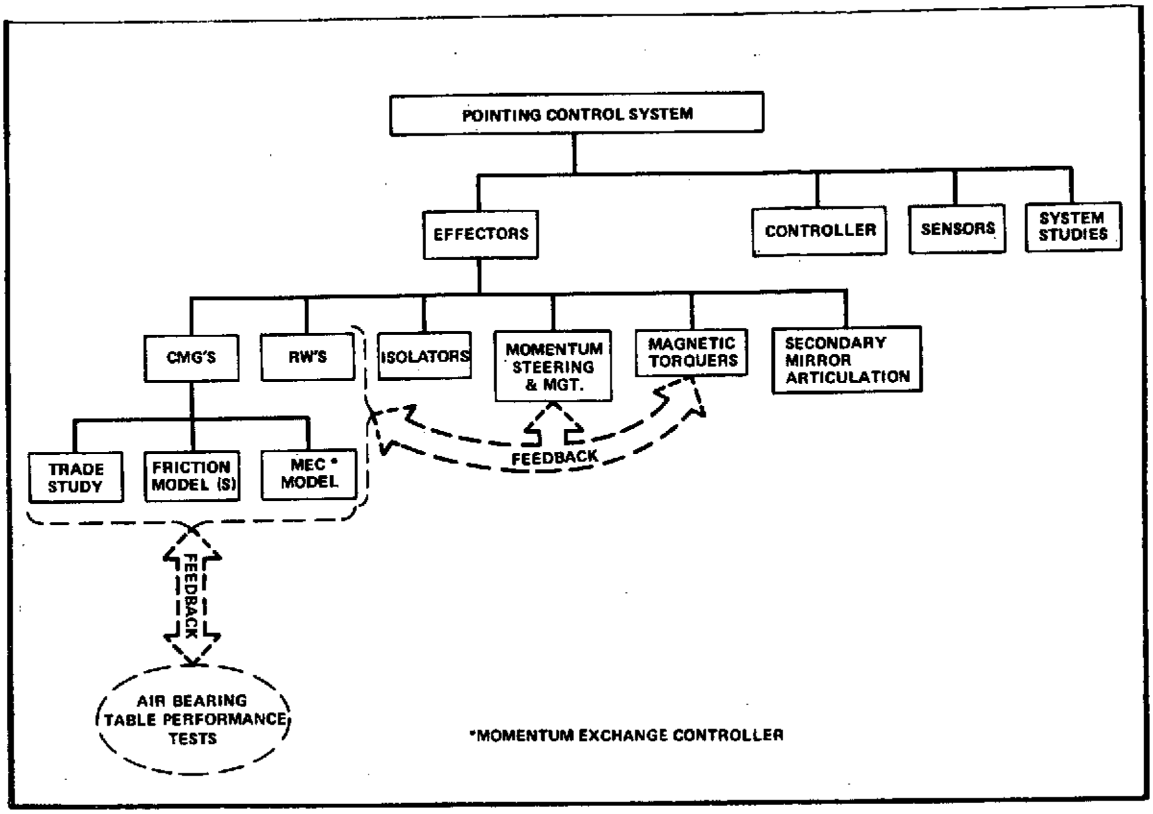

FIG. 3 SUB–SYSTEM DEFINITION: EFFECTORS

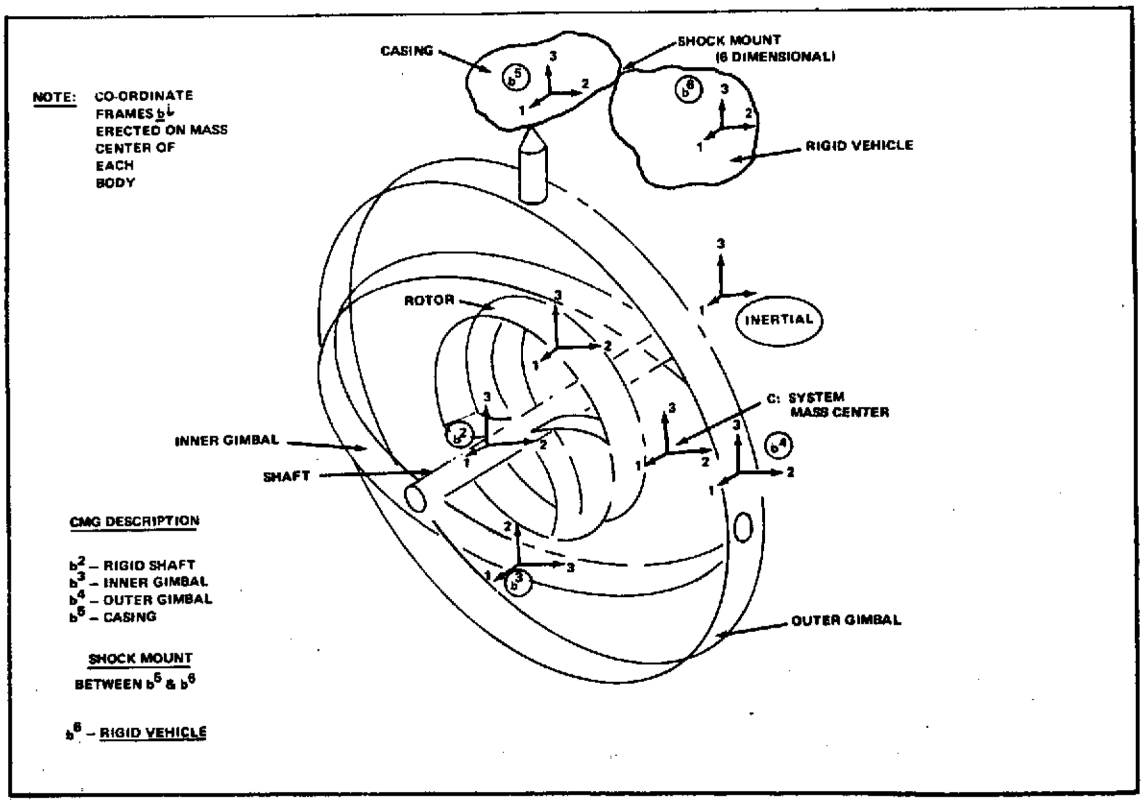

FIG. 4 MEC MODEL

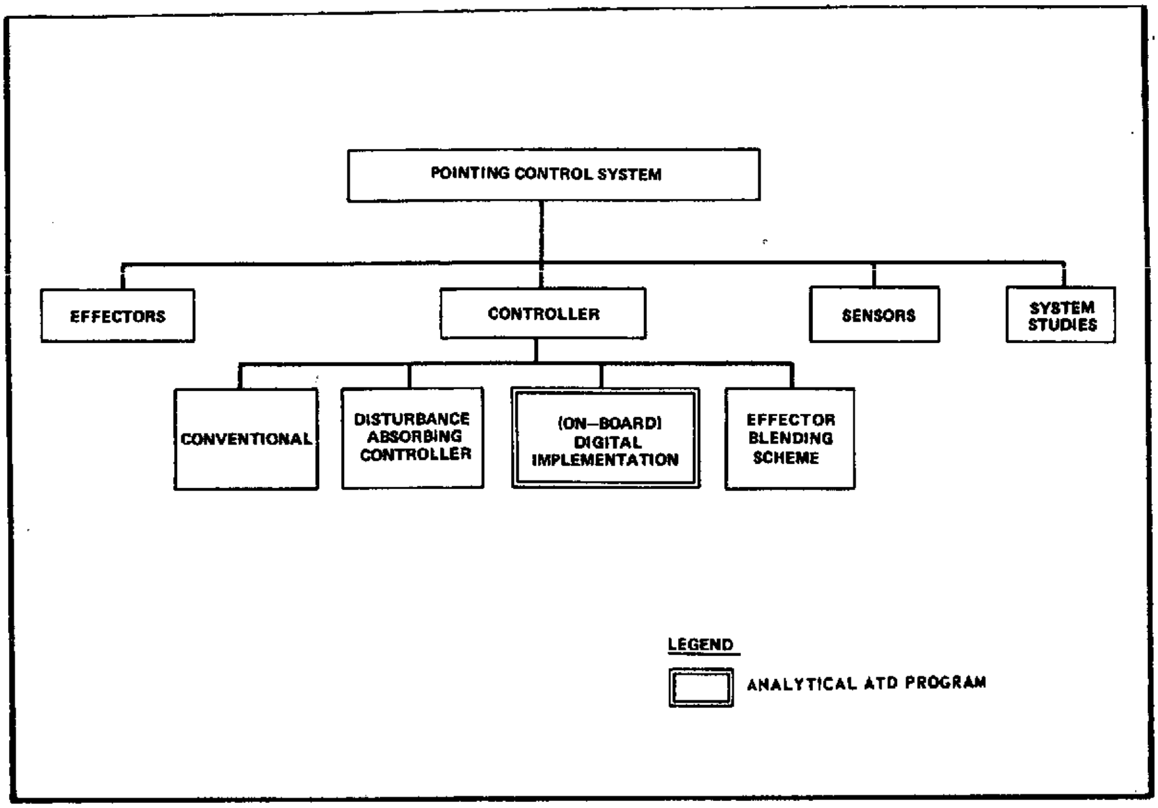

FIG. 5 SUB–SYSTEM DEFINITION: CONTROLLER

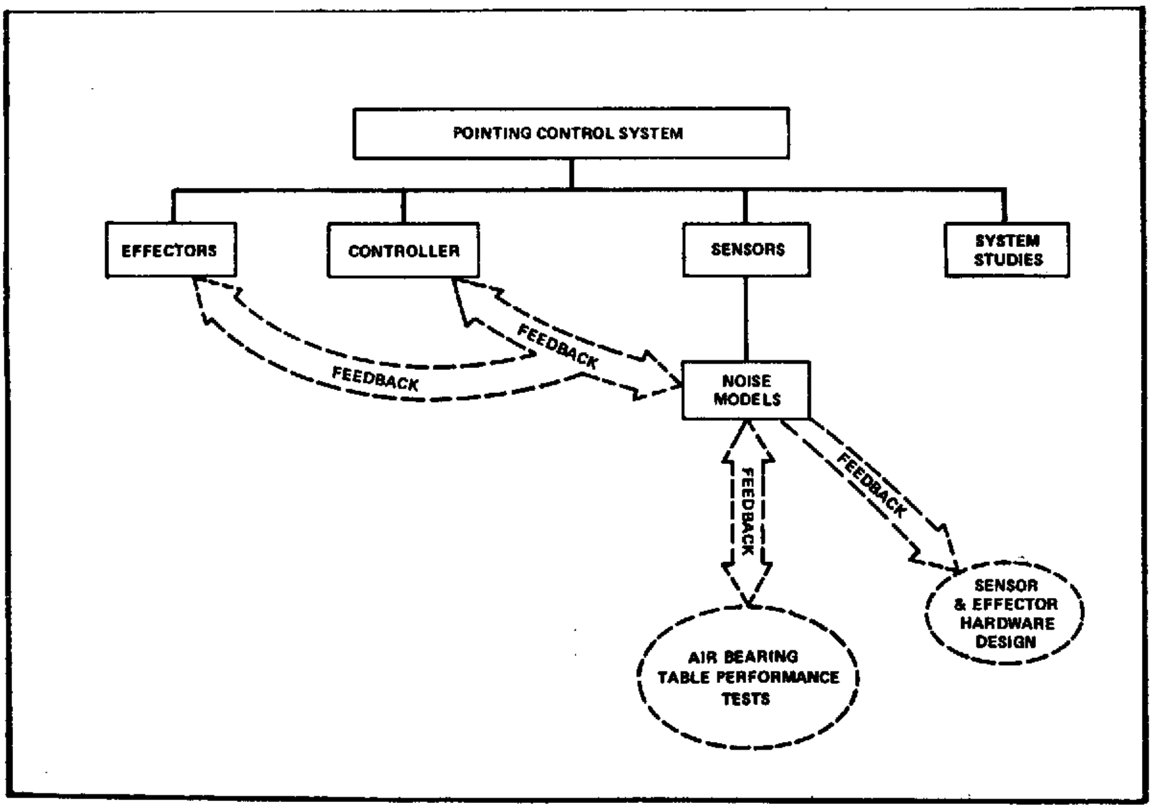

FIG. 6 SUBSYSTEM DEFINITION: SENSORS

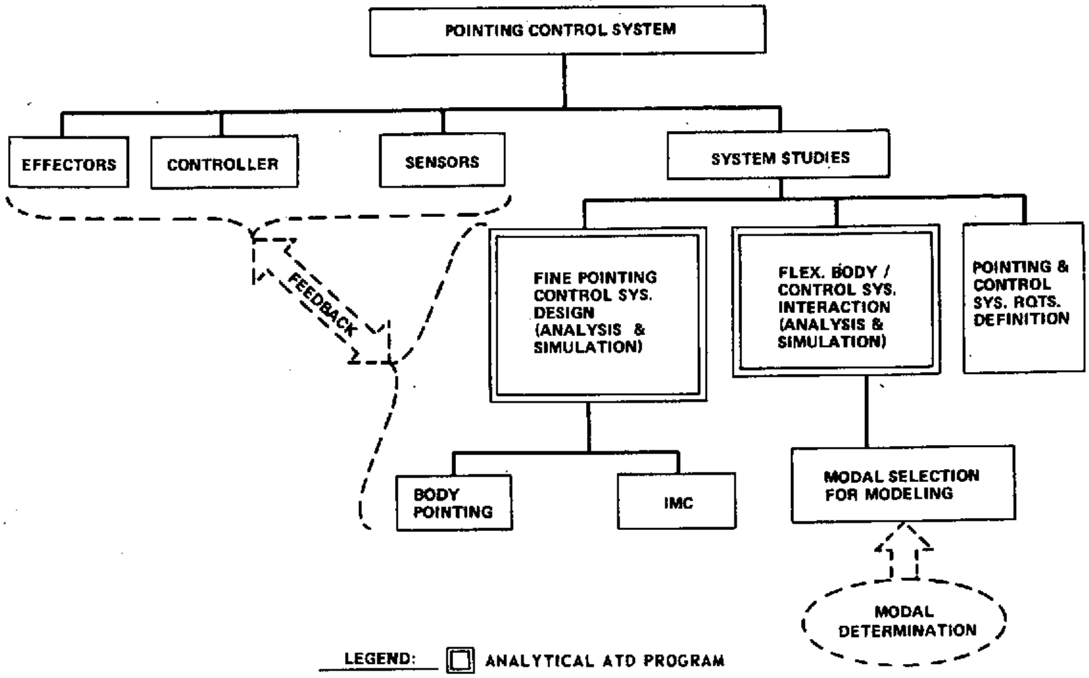

FIG. 7 SUBSYSTEM DEFINITION: SYSTEM STUDIES

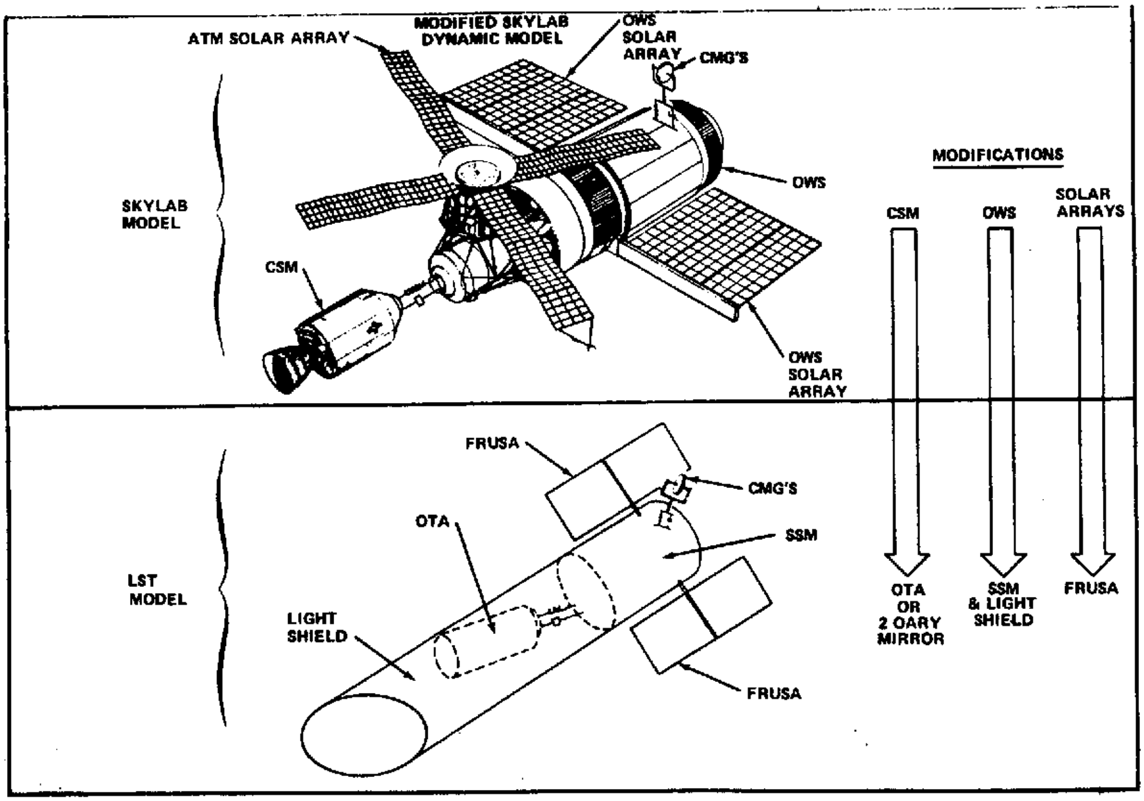

FIG. 8 MODEL OF FLEXIBLE LST AND PCS

1. DIGITAL CTL. SYS. DESIGN/IMPLEMENTATION (MSFC/SYSTEM RESEARCH LAB)
   a. CONTINUOUS & DISCRETE DESCRIBING FNS.
   b. LIMIT CYCLE PREDICTION
   c. SAMPLE TIME DETERMINATION
   d. GAIN & COMPENSATION DETERMINATION
2. IMC ANALYSIS & IMPLEMENTATION (MSFC/INDUSTRY)
3. FINE POINTING CTL. SYS. DESIGN (MSFC/INDUSTRY)
   a. DETERMINE IF NEED IMC
   b. DETERMINE IF NEED RW'S
   c. EVALUATE & SELECT EFFECTOR ISOLATORS
   d. SELECT CONTROLLER
   e. SYS. EVAL. & VERIFICATION
4. FLEX. BODY/CTL. SYS. INTERACTION (MSFC/UCLA/U. OF SANTA CLARA)
   a. ANALYSIS
   b. SIMULATION – VERIFY CTL'R ADEQUACY
      (1) PRELIMINARY MODEL
      (2) FINAL MODEL

FIG. 9 SUMMARY OF ANALYTICAL ATD PROGRAM

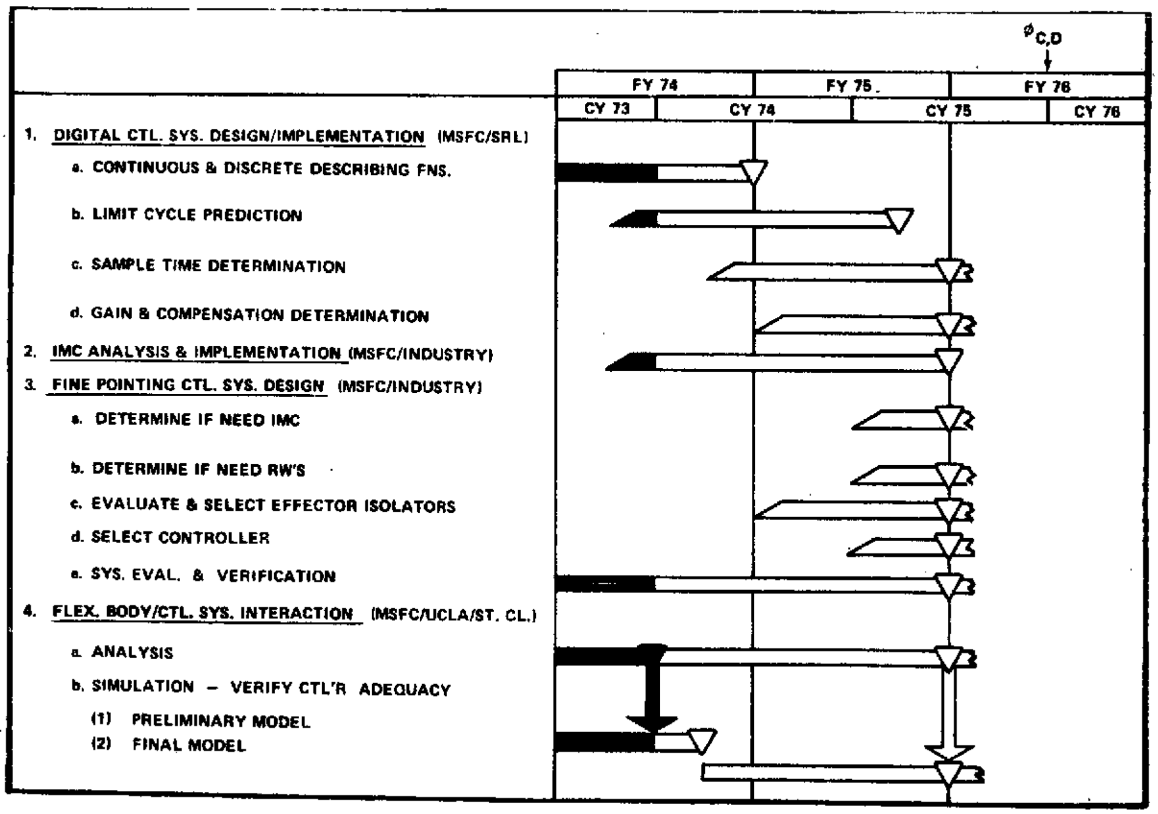

FIG. 10 SUMMARY OF ANALYTICAL TECHNOLOGY PROGRAM

APPROVAL

LARGE SPACE TELESCOPE (LST)
POINTING CONTROL SYSTEM (PCS)
ANALYTICAL ADVANCED TECHNICAL DEVELOPMENT (ATD) PROGRAM

Sherman M. Seltzer

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Hans H. Hosenthien

HANS H. HOSENTHIEN
Chief, R&D Analysis Office

J. L. Mack

JERRY L. MACK
Chief, Systems/Projects Office

Fred Wojtalik

FRED WOJTALIK
Chief, Guidance & Control Division

J. T. Powell

for: F. B. MOORE
Director
Astrionics Laboratory