N87-16019

ACTIVE CONTROL EVALUATION FOR SPACECRAFT (ACES)

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First NASA/DOD CSI Technology Conference
November 18-21, 1986

THE LARGE SPACE STRUCTURE CONTROL PROBLEM

Historically, spacecraft have been relatively small and stiff, with alignment and pointing performed by rigid-body techniques. Because of new requirements for large space structures (high-resolution radars and antennas, large optics, and lasers) requiring accurate pointing and tracking, flexible-body control methods must be used. Figure 1 is an artist's illustration of a representative spacecraft with an offset-feed antenna that will require active control of the alignment of the feed mast. The Air Force goal is to develop vibration control techniques for large flexible spacecraft by addressing sensor, actuator, and control hardware and dynamic testing. The Active Control Evaluation for Spacecraft (ACES) program will address the Air Force goal by looking at two leading control techniques and implementing them on a structural model of a flexible spacecraft under laboratory testing.

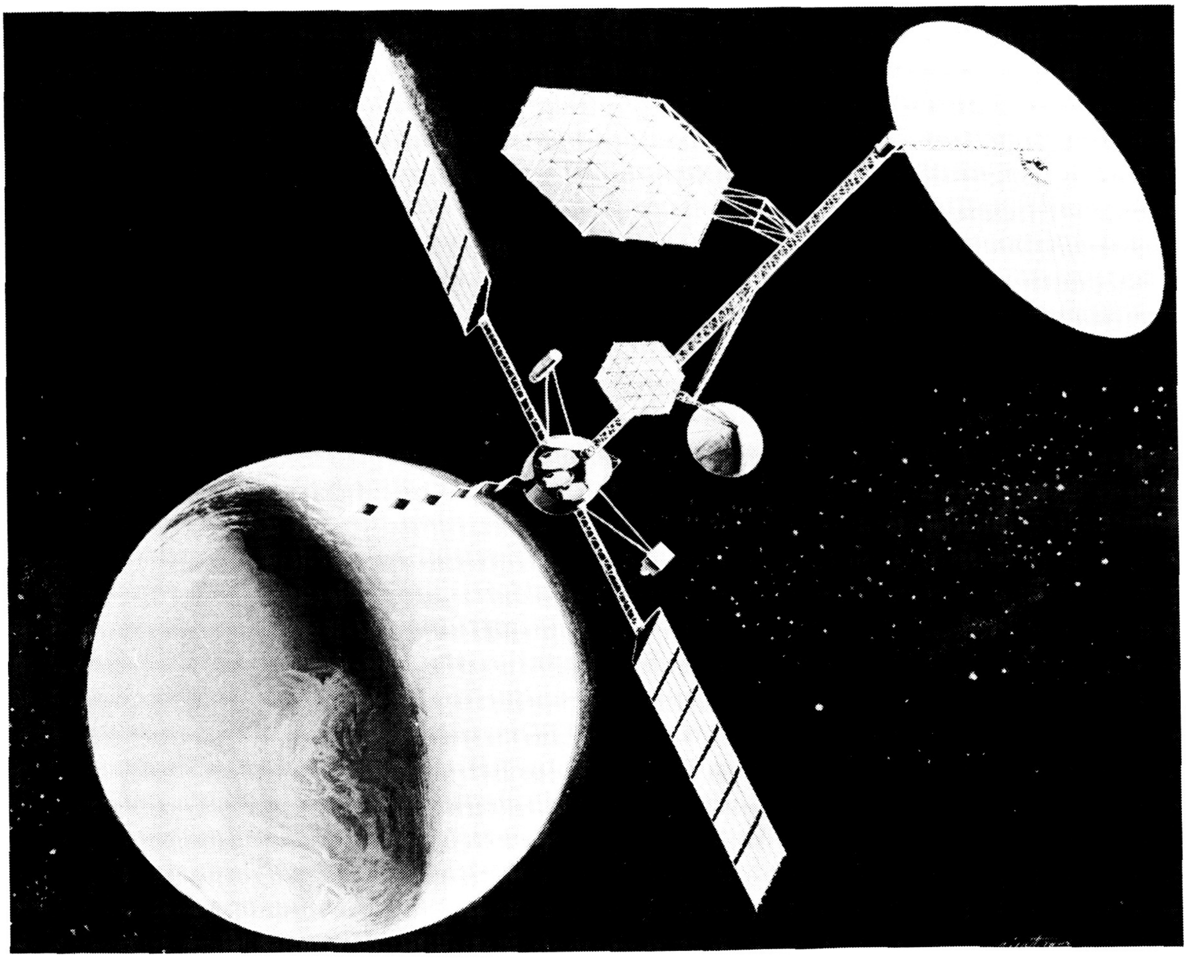
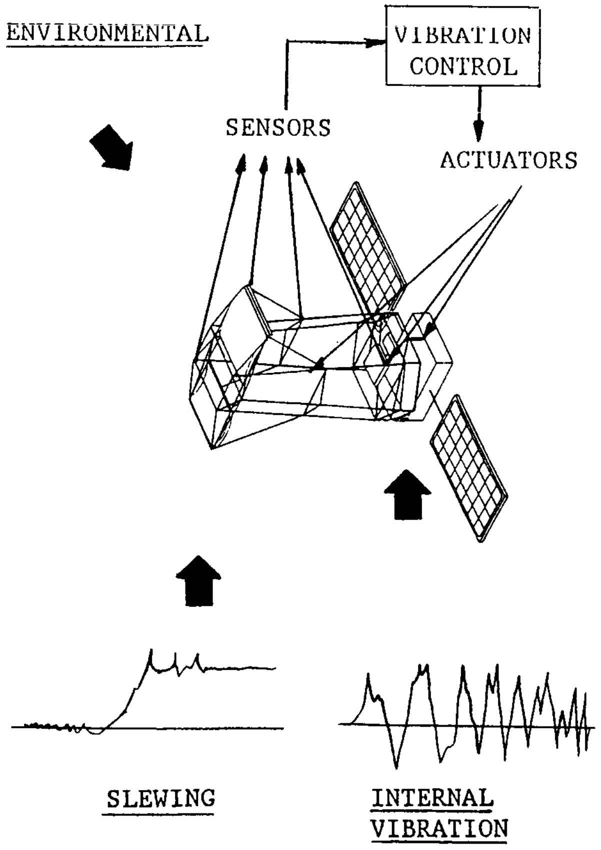


Figure 1

ACTIVE CONTROL OF SPACE STRUCTURES (ACOSS) STUDIES

The control techniques that will be studied in this program were initially investigated in the Active Control Of Space Structures (ACOSS) program sponsored by Defense Advanced Research Projects Agency (DARPA). The ACOSS program started in 1978; in six years it involved eighteen contracts and seven major contractors to develop and demonstrate the technology to suppress vibration in large space structures. The control goal was to meet the stringent line-of-sight and jitter control requirements of representative spacecraft. Various experiments with beams, plates, trusses, and frame structures were conducted using damping augmentation and elastic mode control. Disturbance models were developed, sensors and actuators were surveyed, and system identification studies were performed (Figure 2). The ACOSS studies were chiefly analytical, with limited laboratory testing. The leading techniques resulting from this program were High Authority Control/Low Authority Control (HAC/LAC), Positivity, and Filter Accomodated Model Error Sensitivity Suppression (FAMESS).



- ANALYTICAL DEVELOP ACTIVE CONTROL CONCEPTS
  - LOW FREQUENCIES
  - SPACECRAFT MODELS
  - CONTROL ALGORITHM
- SLEWING AND ENVIRONMENTAL DISTURBANCES
- QUANTIFYING POINTING PERFORMANCE

Figure 2

VIBRATION CONTROL OF SPACE STRUCTURE (VCOSS) HARDWARE

The VCOSS I program extended the ACOSS program by applying modern control techniques and state-of-the-art hardware concepts to the Draper Model two structure developed under ACOSS. The VCOSS II program was a cooperative effort between the NASA Marshall Space Flight Center (NASA-MSFC) and the Air Force Wright Aeronautical Laboratories (AFWAL) to build state-of-the-art control hardware (optical sensors and linear proof mass actuators) and apply it to a laboratory test structure consisting of a modified Astromast (Figure 3). The hardware was tested at the NASA-MSFC Ground Test Verification Facility. TRW developed the control hardware and Control Dynamics Company developed the test structure for the VCOSS II program (Refs. 1-3).

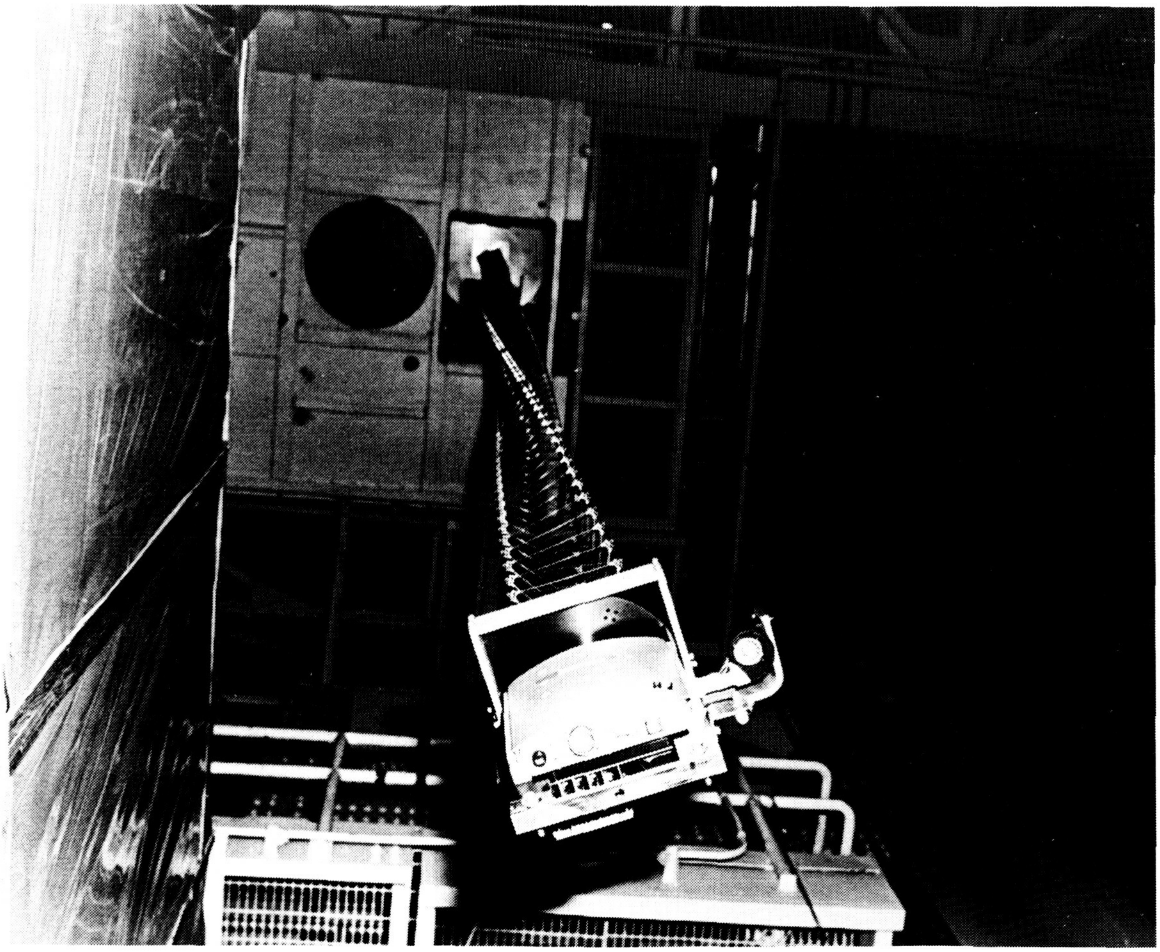


Figure 3

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ACES PROGRAM DEVELOPMENT

With the analytical work and control hardware development completed under ACOSS and VCOSS, the next step was to utilize the available structure and hardware for comparing the control techniques. The Strategic Defense Initiative Organization (SDIO) was interested in evaluating the relative control performance of the techniques on the same structure and sensor/actuator hardware. The Active Control Evaluation for Spacecraft (ACES) program is designed to carry out this evaluation in a cooperative DOD/NASA effort (Figure 4). A portion of the ACES work will be contracted to Control Dynamics Company, who will prepare the structural hardware and control algorithms for testing in the Marshall facility.

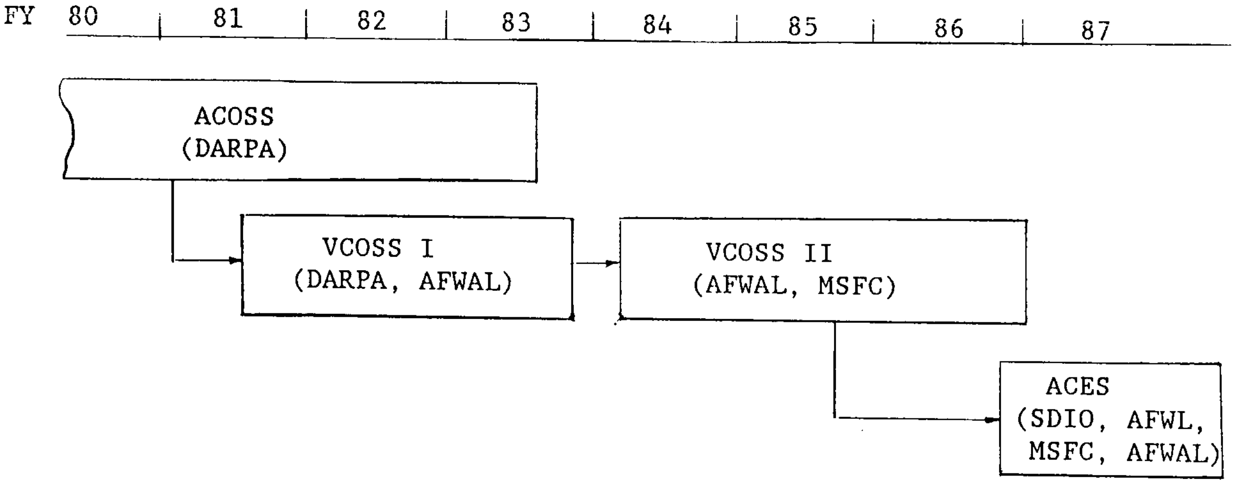


Figure 4

PROGRAM OBJECTIVES

The objective of ACES is to assess leading control techniques for large space structure vibration control (Figure 5) using a common structure and fixed configuration of sensors and actuators. These control techniques will be implemented in hardware and tested on the modified VCOSS structure with optical position sensors and proof mass actuators. The control objective is to minimize a line-of-sight pointing error between the structure's offset antenna and the end of the feed mast structure.

- IMPLEMENT AND ASSESS LARGE SPACE STRUCTURE CONTROL DESIGN TECHNIQUES
- TEST THE CONTROLLERS IN THE NASA-MSFC LSS GROUND TEST VERIFICATION (GTV) FACILITY
- MINIMIZE LINE-OF-SIGHT POINTING ERROR BETWEEN STRUCTURE'S ANTENNA AND FEED MAST

Figure 5

ACES STRUCTURE

For the ACES program, the VCOSS structure is configured with an offset antenna and counterbalance arm weights (Figure 6). The 13-meter truss structure is cantilevered vertically from a hydraulic shaker table and gimbal motors. Truss members are made from fiberglass and are connected such that a helical triangular cross section truss is created; the truss supports only tension loads. There are two bays, located at the midpoint and free end of the structure, for placement of control actuators. A laser source is mounted at the top of the structure and aimed at a mirror on the offset antenna; the reflected beam will be used as feedback by the controller to reduce the jitter to less than a specified line-of-sight error between the antenna and the end of the feed mast.

Figure 6

PROGRAM APPROACH

The first phase in the ACES program is to review and to assess the HAC/LAC and FAMESS control techniques for testing on the modified VCOSS structure (Figure 7). Appropriate sensors and actuators will be available for use with both techniques; locations will be the same for both techniques. The control actuators will be positioned at the midpoint and free end of the structure. The laser source for the optical sensor is mounted on the feed mast. The beam will be reflected from a mirror on the offset antenna onto the detectors mounted above the shaker table bay. The next phase is to develop an analysis simulation with the control algorithms implemented for dynamics verification. The third phase is to convert the control laws into high level computer language and test them in the NASA-MSFC facility. The final phase is to compile all analytical and test results for performance comparisons.

- REVIEW AND ASSESS PROPOSED TECHNIQUES FOR TESTING ON VCOSS II STRUCTURE
- SUPPORT DESIGN, FABRICATION, AND INSTALLATION OF NECESSARY HARDWARE
- APPLY TECHNIQUES TO STRUCTURAL MODEL USING VCOSS II SENSORS AND ACTUATORS
- DEVELOP A GENERIC SIMULATION TO EVALUATE PERFORMANCE OF CONTROL LAWS
- COMPILE ALL ANALYTICAL AND TEST RESULTS FOR PERFORMANCE COMPARISON

Figure 7

ACES CONTROL HARDWARE

Major components of the control hardware will be provided by NASA-MSFC. Existing hardware set up at the NASA facility for the testing includes a shaker table from which the structure is suspended, three-axis base accelerometers and gyros, and three-axis tip accelerometer and rate gyros (Figure 10). The base shaker table will be used to apply the two disturbance spectra to the ACES configured structure. A disturbance signal generator, gimbal torque amplifiers, and a system health monitor will be tied into a Hewlett Packard 9020 computer that is dedicated to control. The HP 9020 is also linked with NASA's mainframe COMSEC computer. Additional equipment to be added are bidirectional cold gas thrusters, an optical detector system, and two gimbal systems.

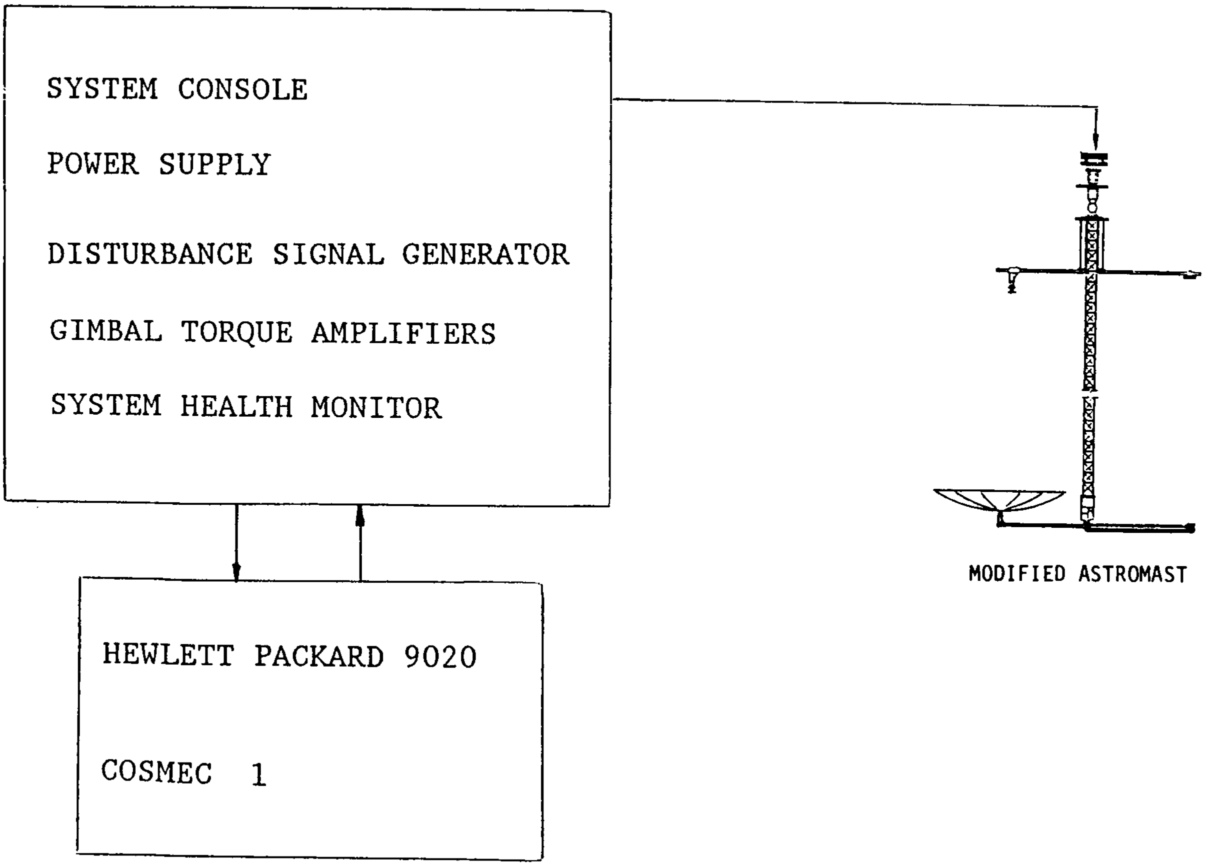
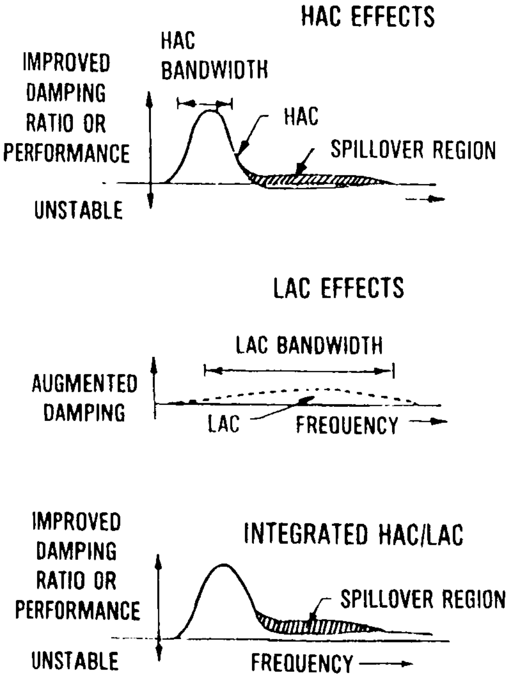


Figure 10

HIGH-AUTHORITY/LOW-AUTHORITY CONTROL TECHNIQUE

The HAC/LAC control technique, developed by Lockheed, addresses the particular problem of instabilities in the system created by spillover (Figure 11). Spillover is the interaction of the controller with unmodeled modes. The control design must not destabilize poorly known high frequency modes while controlling the low frequency modes. HAC/LAC approaches this problem on two levels. The HAC design incorporates high damping over a low bandwidth to meet performance goals; this is a frequency-shaped extension of LQG methods. The second level, the LAC design, incorporates low damping over a high bandwidth to eliminate spillover-induced instabilities (Ref. 4).



HIGH AUTHORITY

- LARGE DAMPING RATIO CHANGES
- EIGENVECTOR CHANGES
- LQG SYNTHESIS WITH FREQUENCY SHAPING
- ENHANCED CONVENTIONAL LQG ROBUSTNESS

LOW AUTHORITY

- BROADBAND DAMPING AUGMENTATION
- ROBUST AGAINST MODELING ERROR
- SIMPLIFIED SYNTHESIS (LEAST SQUARES, JACOBI'S PERTURBATION)

Figure 11

CONTROL CRITERIA

The goal of this test is to have the controller minimize line-of-sight error between the antenna and the feed mast (Figure 14). In minimizing this error, several criteria will be considered in evaluating each technique's performance. These will include total reduction of line-of-sight error, computational efficiency (meeting the speed and memory requirements of the available digital system), and robustness (controller performance for off-optimum structural parameters). These criteria will be applied to both disturbance spectra.

- MINIMIZE ANTENNA/FEED MAST LINE-OF-SIGHT POINTING ERROR
- DETERMINE PERFORMANCE OF CONTROL TECHNIQUES:
  - ROBUSTNESS
  - COMPUTATIONAL EFFICIENCY

Figure 14

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PROGRAM RESULTS

The results of this evaluation will give a better understanding of the trade-offs involved with each control technique (Figure 15). With the number and location of sensors and actuators fixed and the control goal specified, a good evaluation of the techniques can be performed. By eliminating particular sensors or actuators and observing how well the control techniques respond to this change in the system, robustness will be determined. The control design must meet the requirements of the digital system in terms of computational speed and memory capacity. The effects of sampling and computational lags should also be accounted for by the control technique. The degree of line-of-sight error correction will determine the limits of control technique capability with the available hardware.

- BETTER UNDERSTANDING OF CONTROL TECHNIQUE TRADE-OFFS
- ROBUSTNESS, COMPUTATIONAL EFFICIENCY, AND PERFORMANCE OF TECHNIQUES DETERMINED
- A COMPARISON OF THE TECHNIQUES PERFORMED

Figure 15

PROGRAM APPLICATIONS

The payoff from this program will be twofold. Capabilities of these control techniques will be better understood, and these techniques may then be applied to specific control problems in other programs (Figure 16). The Air Force Weapons Laboratory plans to use the results of this program in determining a control technique for their Joint Optics/Structures Experiment (JOSE) program. AFWAL plans to incorporate one of the ACES techniques into the Large Space Structure Active Vibration Control program and into their in-house Large Space Structure Technology Program. The results from the ACES evaluation will also increase the confidence in each technique.

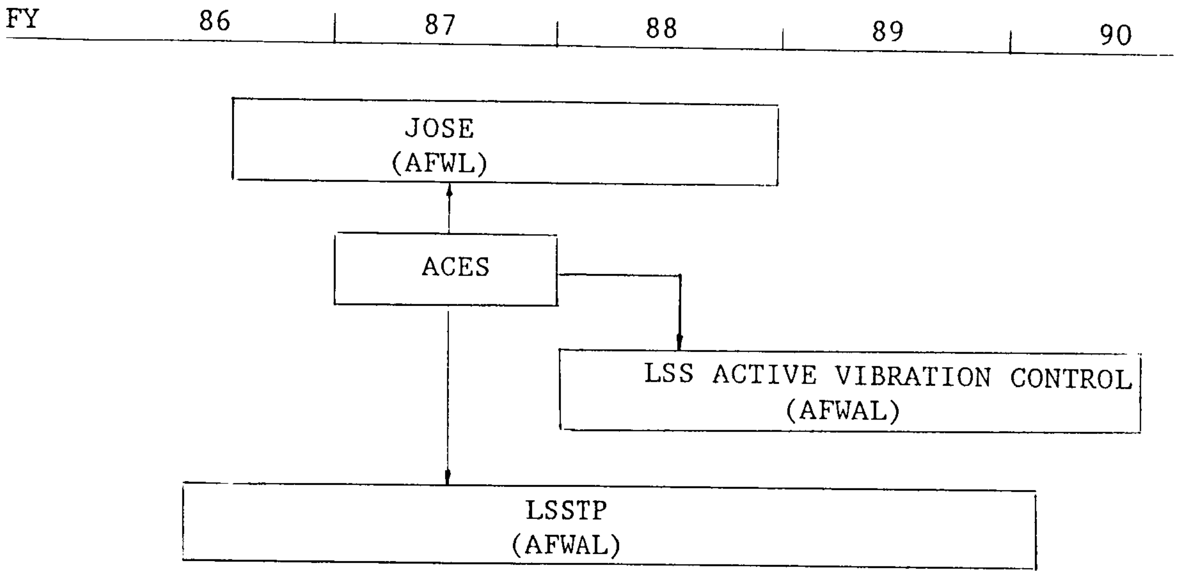

Figure 16

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