AUXILIARY CONTROL OF LSS

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The study objective is to provide a top level determination of auxiliary propulsion characteristics for broad classes of Large Space Structures. Boeing Aerospace Company under contract to NASA LeRC is conducting the investigation. The BAC study manager is J. P. Clark.

CONTRACT NAS3-21952

- o PROJECT MANAGER: JOHN D. REGETZ, JR.
- o PERIOD OF PERFORMANCE: 8/28/79 - 11/27/80
- o 3350 MANHOURS

OBJECTIVE:

- o DETERMINATION OF THE ELECTRICAL AND CHEMICAL PROPULSION CHARACTERISTICS AND TECHNOLOGY ADVANCES NECESSARY TO MEET AUXILIARY PROPULSION SYSTEM (APS) REQUIREMENTS ESTABLISHED FOR LARGE SPACE STRUCTURES (LSS)

TASKS

To accomplish the study objective we have broken the study into five major tasks. Generally, we determined LSS characteristics in Task 1, LSS disturbance forces and torques in Task 2, examined APS characteristics and requirements in Task 3, and will look at APS interactions with LSS in Task 4. Task 5 will be a comparison between the ideal APS characteristics and restrictions with currently available systems. This comparison should lead to the identification of specific technology advances needed in APS.

TASKS

1. CHARACTERIZATION OF LARGE SPACE STRUCTURES
   - o LITERATURE SEARCH
   - o DETERMINE LSS CHARACTERISTICS

2. ESTABLISHMENT OF DISTURBANCE CHARACTERISTICS
   - o LITERATURE SEARCH
   - o ANALYSIS OF DISTURBANCES

3. ESTABLISHMENT OF APS CHARACTERISTICS AND REQUIREMENTS
   - o ANALYSIS OF CONTROL FORCES
   - o ESTABLISH APS CHARACTERISTICS
   - o ANALYSIS OF APS CHARACTERISTICS SENSITIVITIES

4. INTERACTION BETWEEN APS CHARACTERISTICS AND LSS CHARACTERISTICS
   - o ANALYSIS OF LSS SENSITIVITIES
   - o OPTIMUM APS DETERMINATION

5. DETERMINATION OF ELECTRICAL AND CHEMICAL PROPULSION TECHNOLOGY ADVANCES REQUIRED

STATUS AND ACCOMPLISHMENTS

Tasks 1-3 have laid the groundwork for the remainder of the study. In these tasks we identified seven generic classes of LSS, identified and analyzed disturbance forces on LSS, and established APS characteristics and qualitative sensitivities.

In Task 1 a literature search was conducted which looked at over 200 sources of information dealing with LSS missions and/or structures. There was an emphasis in this task on identifying generic structure classes and characteristic parameter ranges for each class. We used seven identified classes and idealized them into simple geometric shapes which could be easily modelled. Scaling laws were generated which allowed the seven ideal structures to be continuously scaled as to size and mass properties over their respective size ranges.

Task 2 identified relevant sources of disturbances and compared their effect on LSS. Based on the relative effects and on the applicability of the disturbances to the scope of the study, we selected those sources to be used in the later tasks. Along with each source, a quantification philosophy and methodology was developed.

These disturbances were applied over the range of scaling parameters in Task 3 to generate control force and torque requirements. In this task we identified important APS characteristics and established an APS characteristic sensitivity matrix.

STATUS AND ACCOMPLISHMENTS

TASK 1 - 3 COMPLETED

- TASK 1 ACCOMPLISHMENTS
  - LSS CHARACTERISTICS DETERMINED
  - SEVEN GENERIC CLASSES IDENTIFIED
  - IDEAL STRUCTURES AND SCALING LAWS GENERATED
- TASK 2 ACCOMPLISHMENTS
  - SOURCES OF DISTURBANCE IDENTIFIED
  - DISTURBANCES ANALYZED AND COMPARED
  - SELECTED SOURCES AND METHODS TO BE APPLIED IN LATER TASKS
- TASK 3 ACCOMPLISHMENTS
  - CONTROL FORCE AND TORQUE REQUIREMENTS DETERMINED
  - IDENTIFIED IMPORTANT APS CHARACTERISTICS
  - ESTABLISHED APS CHARACTERISTIC SENSITIVITIES

CHARACTERISTICS EXAMINED

The LSS characteristics looked at in Task 1 are summarized here. The mass properties included total mass, mass distribution and inertias. Orientation requirements were defined by pointing accuracy and slew requirements. Area distribution included the location of radar panels, the solid surfaces, antennas and trusses. The orbit parameters were the range of altitudes and eccentricity needed and figure accuracy requirements were defined for each mission examined.

CHARACTERITICS EXAMINED

- o MASS PROPERTIES
- o ORIENTATION REQUIREMENTS
- o AREA DISTRIBUTION
- o ORBIT PARAMETERS
- o FIGURE ACCURACY

CHARACTERIZATION OF LARGE SPACE STRUCTURES

This chart shows the breakdown on the generic classes into three main categories - planar structures, single antenna systems, and multiple antenna systems. To better fit the wide range of structures examined, we subdivided each of these classes into two or three subclasses. These subclasses are as follows:

1. Planar Structures
   - A. Large flat array
   - B. Cross structure
2. Single Antenna Systems
   - A. Box structue
   - B. Modular antenna system
   - C. Maypole or hoop and column antenna
3. Multiple Antenna Systems
   - A. Modular antenna farm
   - B. Multiple antenna farm

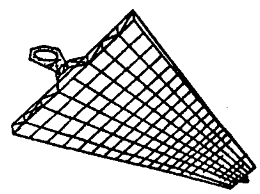
These structures are illustrated in the next three charts.

TASK 1 CHARACTERIZATION OF LARGE SPACE STRUCTURES

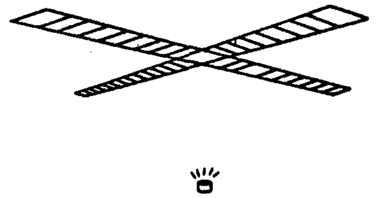
GENERAL CLASSES

1. PLANAR STRUCTURES
   - A. LARGE FLAT ARRAY
   - B. CROSS SHAPED STRUCTURES
2. SINGLE ANTENNA SYSTEMS
   - A. BOX STRUCTURE
   - B. MODULAR STRUCTURE
   - C. MAYPOLE ANTENNA
3. MULTIPLE ANTENNA SYSTEMS
   - A. MODULAR ANTENNA FARM
   - B. MULTIPLE ANTENNA FARM

• PLANAR STRUCTURES

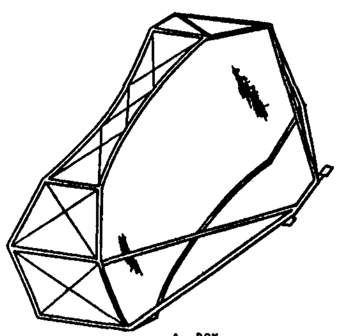


A. LARGE FLAT ARRAY

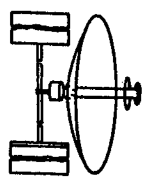


B. CROSS STRUCTURE

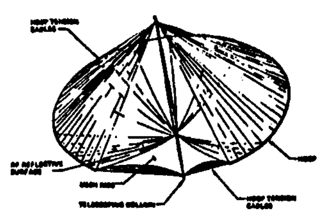
• SINGLE ANTENNA SYSTEMS



A. BOX

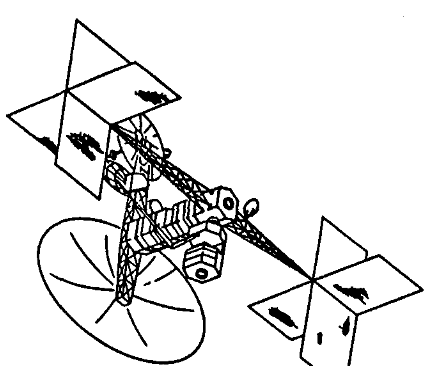


B. MODULAR

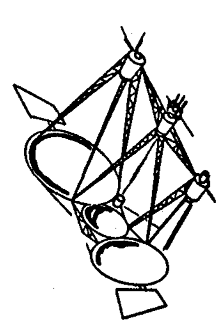


C. MAYPOLE

• MULTIPLE ANTENNA SYSTEMS



A. MODULAR ANTENNA FARM



B. MULTIPLE ANTENNA FARM

SCALING PARAMETER SELECTION

For each of the ideal classes, a single parameter was established from which all structures were scaled. This ideal scaling parameter was generally associated with area but took different form for each class. Listed here are the classes, the scaling parameter, the parameter range, and the corresponding mass range based on the scaling laws established.

SCALING PARAMETER SELECTION

CLASS		STRUCTURE	CHARACTERISTIC PARAMETER	PARAMETER RANGE	MASS RANGE (KG)
I	PLANAR	PLATE	LENGTH	30 - 21000 (M)	170 TO 8.27×10^7
		CROSS	LENGTH	40 - 4000 (M)	560 TO 56000
II	SINGLE ANTENNAS	BOX	LENGTH	82 - 1300 (M)	1.23×10^5 TO 1.95×10^5
		MODULAR ANTENNA	ANTENNA DIA	15 - 200 (M)	2050 TO 27000
		MAYPOLE	ANTENNA DIA	30 - 1500 (M)	100 TO 2640
III	MULTIPLE ANTENNAS	ANTENNA FARM	ANTENNA DIA	15 - 60 (M)	3000 TO 12000
		SERIES OF ANTENNAS	NUMBER OF ANTENNAS	2 - 10	44000 TO 216500

DISTURBANCE CLASSIFICATION

To accommodate the wide range of altitudes and eccentricity requirements, we groundruled four disturbance classifications. The assumption implicit is that the structure will be erected/deployed in LEO, transferred to GEO while providing thrust vector control through slewing of the vehicle with the LSS auxiliary propulsion, and finally stationkept at GEO. One must look at the maximum disturbances at both LEO and GEO to size the system for a worst case distrubance. However, because of the wide separation of requirements in a maximum and nominal case, it was felt that nominal and maximum requirements should be analyzed separately and correspondingly, different APS systems defined.

DISTURBANCE CLASSIFICATIONS

- MAXIMUM DISTURBANCE AT LEO (300 KM)
  - WORST CASE ORIENTATION
- MAXIMUM CONTROL TORQUES DURING LEO-GEO TRANSFER
  - THRUST AXIS FOR EACH VEHICLE DETERMINED
- NOMINAL GEO ON-ORBIT REQUIREMENTS
  - NOMINAL ORIENTATION
- MAXIMUM DISTURBANCE AT GEOSYNCHRONOUS ORBIT
  - WORST CASE ORIENTATION

SUMMARY OF DISTURBANCES

In Task 2 we identified, analyzed and compared various disturbance forces and torques on LSS. Based on this process we selected those sources to be included in the study. We did not include magnetic and thermal disturbances.

Magnetic disturbances are not likely to be significant unless large current loops are present in the vehicle. These loops are very mission dependant and were not considered relevant in our broad study. Likewise, thermal disturbances while clearly significant to LSS are both mission dependent and very difficult to analyze. Furthermore, it is unlikely that a thruster will be used to provide a restoring force for thermal disturbance.

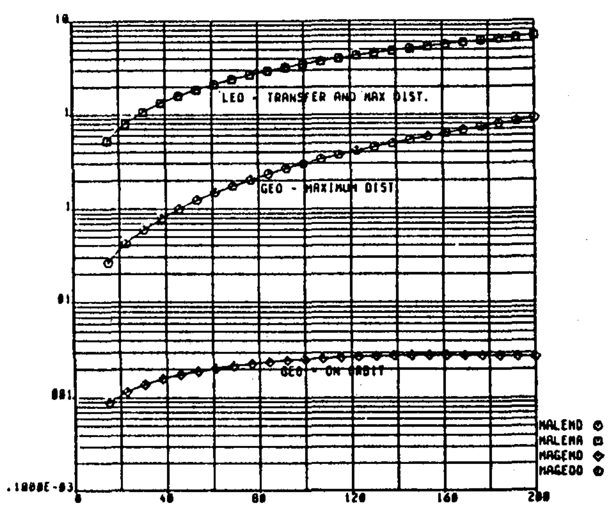
DISTURBANCE	INCLUDED	COMMENT
RADIATION	YES	PHOTON PRESSURE, EARTH ILLUMINATION
GRAVITY GRADIENT	YES	MOST SIGNIFICANT DISTURBANCE
AERODYNAMIC	YES	INCLUDED BELOW 1000 KM
MAGNETIC	NO	DISTURBANCE RELATIVELY INSIGNIFICANT
THERMAL	NO	TOO MISSION DEPENDANT TO BE CONSIDERED
STATIONKEEPING	YES	INCLUDED AT GEOSYNC.

MODULAR SINGLE ANTENNA

The significant disturbance effects were evaluated at each condition for each generic LSS class and summed over the scaling parameter range. The result is a series of curves of the disturbance forces and torques. The chart shows two such plots, one for the force in the Y direction (normal to the orbit plant) and the other for torque about the Z axis (the local vertical). These illustrations are typical only but do show the wide range of effects that generally occur.

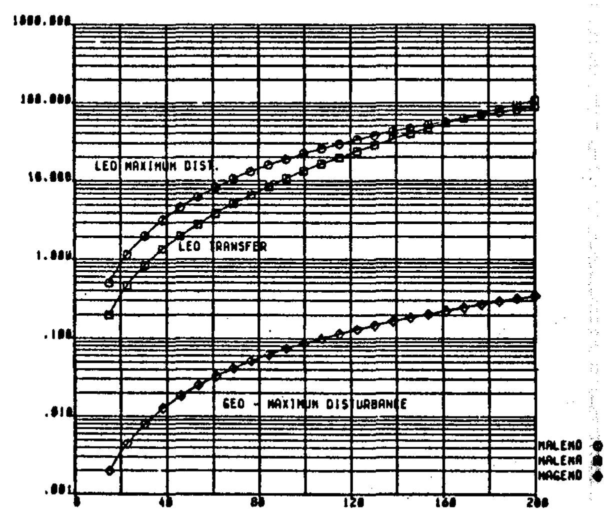
MODULAR SINGLE ANTENNA

FORCE Y (N)



SCALING PARAMETER

TORQUE Z (N-M)



SCALING PARAMETER

SIGNIFICANT APS CHARACTERISTICS TO BE DETERMINED

The significant APS characteristics were identified by considering the basic control tasks of attitude control, shape control and stationkeeping.

Attitude control consists, ideally, of exact cancellation of disturbance torques. The ideal can be closely approximated by delivering periodic torque impulse bits. Thrust level and modulation are thus important characteristics. Transient effects such as the rise and decay profiles may also be significant if limit cycle operation is employed. The significant characteristics for attitude control are then thrust level, modulation and transient effects.

Shape control implies a distributed system thus the number and distribution of thrusters is an added significant characteristic.

Stationkeeping is not a demanding task in general and no additional characteristic appears important.

The four characteristics uncovered above - thrust level, number and distribution of thrusters, modulation and transient effects are operating characteristics. From a systems viewpoint the allowable APS mass must be considered and this has been added as a fifth significant characteristic.

SIGNIFICANT APS CHARACTERISTICS TO BE DETERMINED

- o NUMBER AND DISTRIBUTION OF THRUST UNITS
- o MAXIMUM-MINIMUM THRUST LEVELS
- o RISE AND DECAY PROFILES
- o THRUST MODULATION
- o ALLOWABLE MASS

SENSITIVITY MATRIX

The sensitivity matrix was developed by considering the possible interaction between each of the five identified significant APS characteristics and the major attitude control functions.

The number and distribution of thrusters are particularly important in a shape control application. For more rigid structures the effects are of little consequence. Thrust level is significant in most attitude control functions. It is omitted from the shape control column because timing is more important than thrust level for active damping. Rise and decay characteristics affect the timing of thrust pulses so this too is significant for shape control. Transients also influence limit cycle performance and thus pointing accuracy. Modulation and allowable mass interact widely with most of the attitude control functions.

SENSITIVITY MATRIX

ATTITUDE CONTROL FUNCTIONS / APS CHARACTERISTICS	ATTITUDE CONTROL			SHAPE CONTROL	STATION-KEEPING	DESAT-URATION
	DISTURB. CANCEL.	POINTING	MANEUVER			
NO. AND DISTRIBUTION				S		
THRUST LEVEL	S	S	S		S	S
RISE AND DECAY		S		S		
MODULATION	S	S	S	S	S	S
ALLOWABLE MASS	S	S	S		S	S

FUTURE WORK

Tasks 1 through 3 in many respects lay the groundwork for the remaining work. First the interaction between APS and LSS are to be determined. This task is in effect the description of the parameter relationships; i.e., the process of quantifying the qualitative sensitivities identified in the previous chart. Once this has been accomplished it will be possible to define the ideal APS for control of LSS. Different characteristics may be desirable for difficult classes and there may be variations as a function of the scaling parameter.

In the final task, the desired characteristics will be compared with those available in state of the art and projected systems. Discrepancies will indicate areas in which APS technology advances would be profitable.

FUTURE WORK

TASK 4 INTERACTION BETWEEN APS CHARACTERISTICS AND LSS CHARACTERISTICS

4.1 ANALYSIS OF LSS SENSITIVITIES

- o EXTEND SENSITIVITY STUDIES TO INCLUDE EFFECT ON LSS OF
  - I_{SP}
  - MASS OF APS SUPPORTING EQUIPMENT (TANKS, PPU'S, POWER SUPPLY, ETC)
  - STRUCTURAL STIFFNESS

4.2 OPTIMUM APS DETERMINATION

- DEFINE IDEAL CHARACTERISTICS FOR CONTROL OF LSS

TASK 5 DETERMINATION OF ELECTRICAL AND CHEMICAL PROPULSION TECHNOLOGY ADVANCES REQUIRED

- o COMPARE EXISTING CHARACTERISTICS AND CAPABILITY WITH THOSE DESIRED TO IDENTIFY DEFICIENCIES