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A MAGNETIC TORQUING SYSTEM FOR EMERGENCY STABILIZATION AND BACKUP CONTROL OF THE LST

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By Michael E. Polites
Systems Analysis and Integration Laboratory

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This report describes a magnetic torquing system for emergency stabilization and backup control of the Large Space Telescope (LST). The system uses magnetic torquers, a magnetometer, and rate gyros. Simulation results are presented to verify the scheme.

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SYMBOLS

B_1, B_2, B_3	components of the earth's magnetic field in vehicle axes, w/m^2
$\langle B^2 \rangle_{ave}$	control law gain set equal to the approximate average square of the earth's magnetic field, $(w/m^2)^2$
I_1, I_2, I_3	vehicle principal moments of inertia, $kg - m^2$
$\vec{i}_r$, $\vec{i}_t$, $\vec{i}_n$	unit vectors of a local vertical coordinate system
K	control law gain, $\frac{n\text{-}m}{rad/sec}$
m_L	control law saturation value of dipole moment commands, $a\text{-}m^2$
m_{3B}	control law bias dipole moment command, $a\text{-}m^2$
m_{1c}, m_{2c}, m_{3c}	dipole moment commands in vehicle axes, $a\text{-}m^2$
V1, V2, V3	vehicle axes
β	angle between the sunline and the orbit plane, deg
ϵ_1	direction angle between the V1 and the $\vec{i}_r$ axes, deg
ϵ_2	direction angle between the V2 and the $\vec{i}_t$ axes, deg
ϵ_3	direction angle between the V3 and the $\vec{i}_n$ axes, deg
ω_{3B}	control law bias rate command, rad/sec
ω_1, ω_2, ω_3	vehicle rates in vehicle axes, rad/sec

TECHNICAL MEMORANDUM X-64912

A MAGNETIC TORQUING SYSTEM FOR EMERGENCY STABILIZATION AND BACKUP CONTROL OF THE LST

SUMMARY

This report describes a magnetic torquing system for emergency stabilization and backup control of the Large Space Telescope (LST). The system uses magnetic torquers, a magnetometer, and rate gyros. Simulation results are presented to verify the scheme.

I. INTRODUCTION

In recent years, the space program has entered an era in which cost has become a major factor influencing spacecraft design. Emphasis is placed upon reducing program costs by selecting hardware which is common to other programs and eliminating hardware where possible by making maximum use of onboard equipment. In the spirit of the latter, this report proposes a magnetic torquing system for emergency stabilization and backup control of the LST which uses, almost entirely, components which are required on the vehicle for other purposes. Depending on requirements imposed by the Shuttle or other LST systems, this system can either eliminate the need for a reaction control system (RCS) for emergency stabilization and backup control, or be an inexpensive backup to it.

The format of the report is to briefly describe the LST, describe the magnetic torquing system for emergency stabilization and backup control, and present simulation results to verify the scheme.

II. DESCRIPTION OF THE LST

A conceptual design of the LST is shown in Figure 1. Fundamentally an unmanned, earth-orbiting astronomical telescope, it is to be inserted by

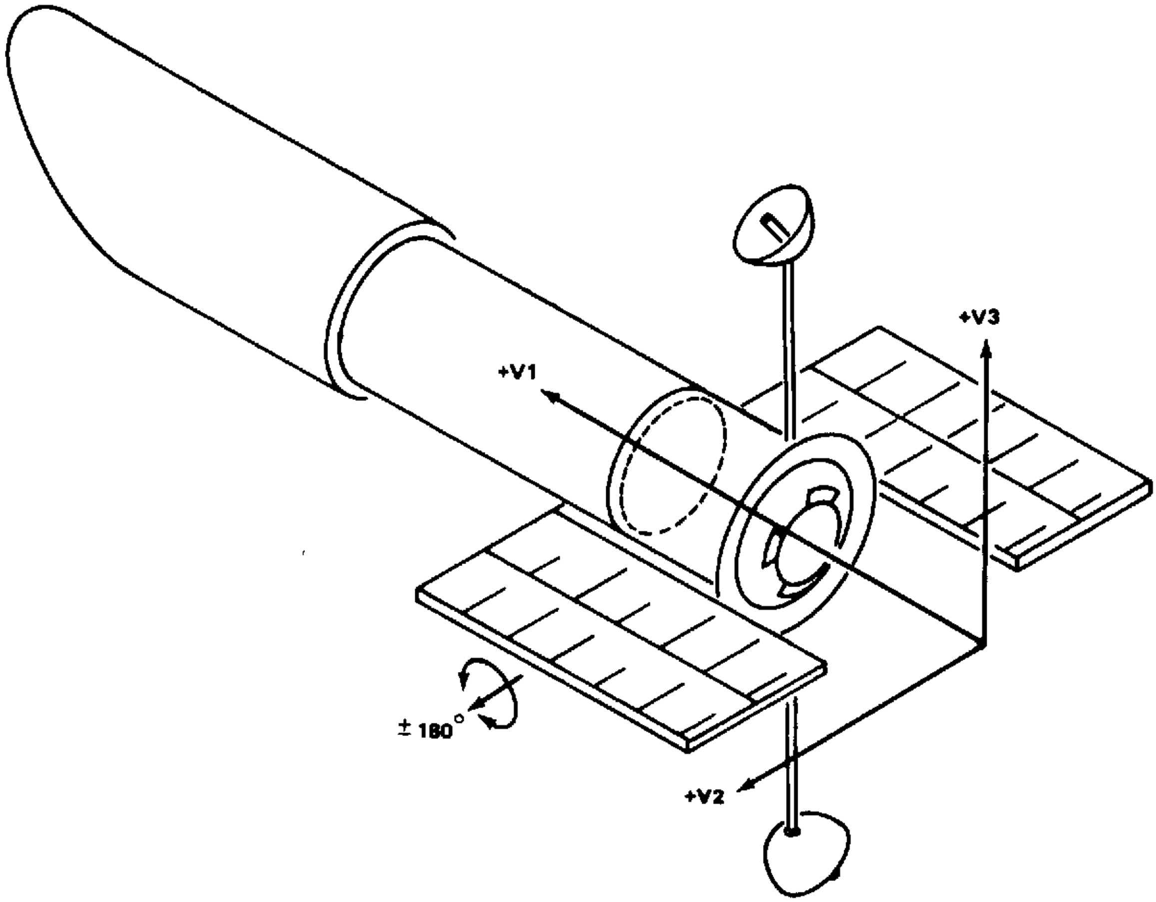


Figure 1. LST conceptual design.

the Shuttle into a nominal circular orbit with an inclination of 28.8 degrees and an altitude of 500 kilometers. Periodically, the vehicle will be retrieved by the Shuttle for on-orbit maintenance or ground refurbishment.[1]

Referring to Figure 1, the vehicle has two solar panels which can be gimballed through ± 180° about the V2 axis. For any celestial target, the vehicle can be rolled about the telescope line of sight and the solar panels oriented perpendicular to the sunline for maximum power. Onboard sensors for vehicle control include rate gyros, startrackers, and magnetometers. Momentum exchange devices (either reaction wheels or control moment gyros) are the primary actuators for vehicle control and are desaturated by magnetic torquers. An RCS has been considered as a backup to the momentum exchange devices during release of the LST from the Shuttle, during an unsuccessful attempt by the Shuttle to capture the LST, and in an emergency where the

1. "Requirements and Guidelines Document for the LST Study," Internal Document, Marshall Space Flight Center, Alabama, December 31, 1974.

momentum exchange devices are inoperative [1]. However, the magnetic torquers can also be used to perform these functions and hence can provide either a backup to the RCS or perhaps a substitute for it. A magnetic torquing system to do this is described in Section III.

III. MAGNETIC TORQUING SYSTEM FOR EMERGENCY STABILIZATION AND BACKUP CONTROL

Figure 2 is a block diagram of the magnetic torquing system proposed for emergency stabilization and backup control of the LST. It uses three rate gyros, a magnetometer, three or more magnetic torquers, and an electronics package which computes the magnetic torquer dipole moment commands based on the outputs of the rate gyros and the magnetometer. Except for the electronics package, all of these components are required on the vehicle for other purposes. Figure 3 presents a control law which has been found to stabilize the vehicle and can be implemented easily in the electronics package.

When the momentum exchange devices are inoperative and the magnetic torquing system is used for emergency stabilization, the control law is configured to damp out the vehicle rates in such a way that the vehicle settles out in one of the two local vertical attitudes shown in Figure 4. A torque is

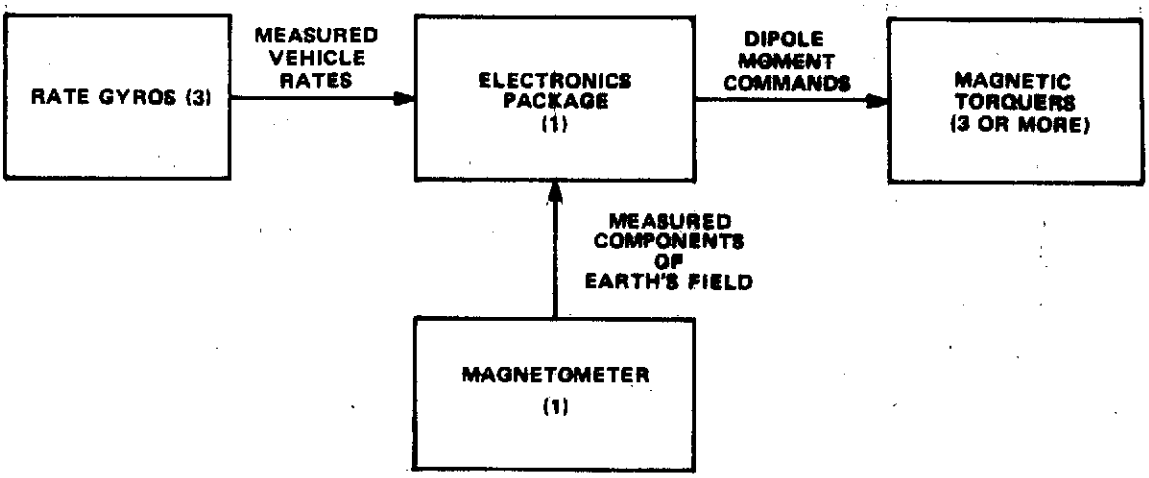
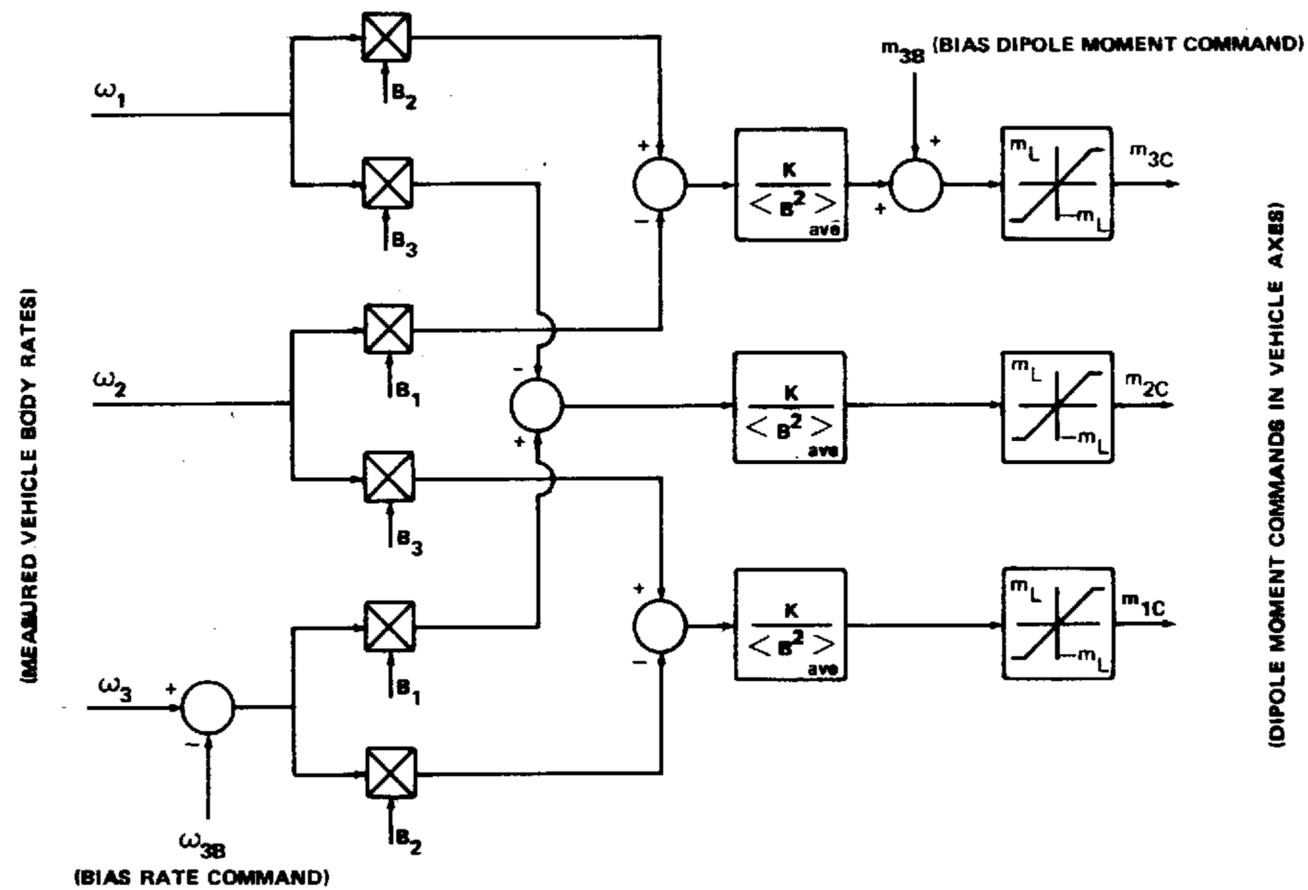


Figure 2. Magnetic torquing system block diagram.



(B_1, B_2, B_3): MEASURED COMPONENTS OF EARTH'S FIELD IN VEHICLE COORDINATES

Figure 3. Magnetic torquing system control law.

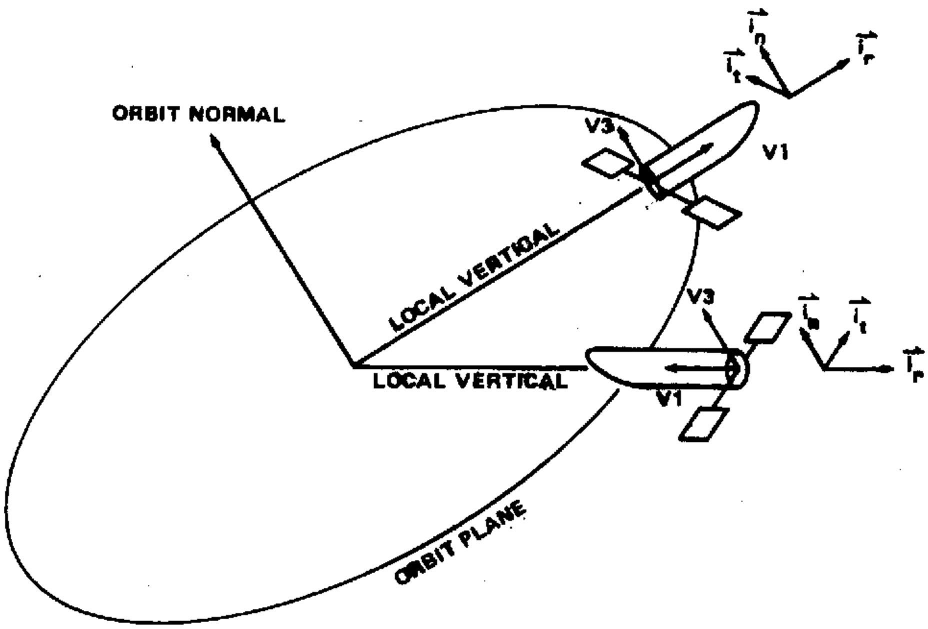


Figure 4. Possible equilibrium attitudes of the LST.

generated by means of the bias dipole moment m_{3B} that tends to align the V3 axis with the earth's magnetic field, which is in the general direction of the orbit normal when the inclination of the orbit plane to the magnetic equator is relatively low, as shown in Figure 5. The gravity gradient torque tends to align the V1 axis with the local vertical and the bias rate command ω_{3B} biases out orbital rate in order that the orientations of Figure 4 become equilibrium attitudes. It has been found best to execute the emergency stabilization scheme in two steps. When the system is first enabled, m_{3B} is set equal to a large bias value and ω_{3B} is set to zero so that the V3 axis becomes aligned with the earth's magnetic field and the vehicle rates become small. When this quasi-inertial attitude is reached, the ground sets m_{3B} equal to a smaller bias value and ω_{3B} equal to orbit rate so the vehicle settles out in one of the two local vertical equilibrium attitudes of Figure 4. It may also be possible to choose an appropriate point in orbit to change m_{3B} and ω_{3B} in order to select a preferred equilibrium orientation, if one exists, and decrease the settling time of the V1 axis to the local vertical. In any event, the equilibrium orientation of the vehicle can be determined from the outputs of the magnetometer, telemetered to ground. Then knowing the angle, β, between the sunline and the orbit plane, the ground can command the solar panels to the position shown in Figure 6 for optimum power.

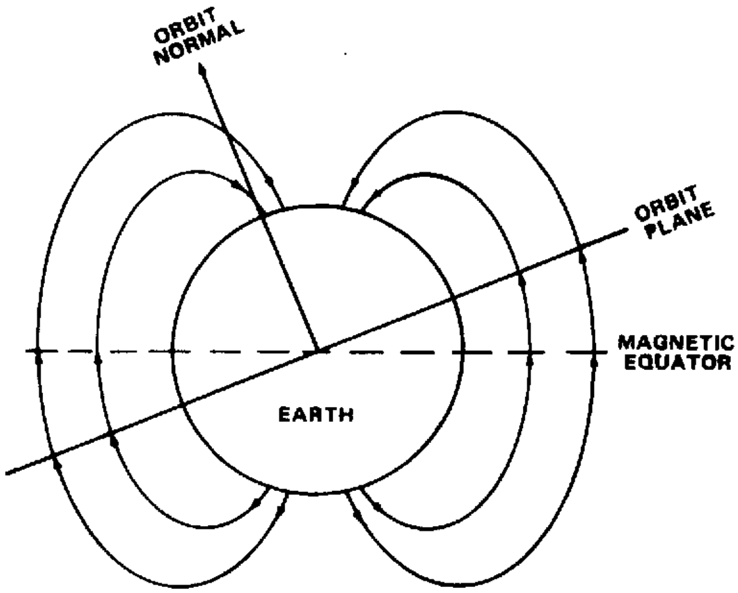


Figure 5. Directions of the Earth's magnetic field, relative to the orbit plane.

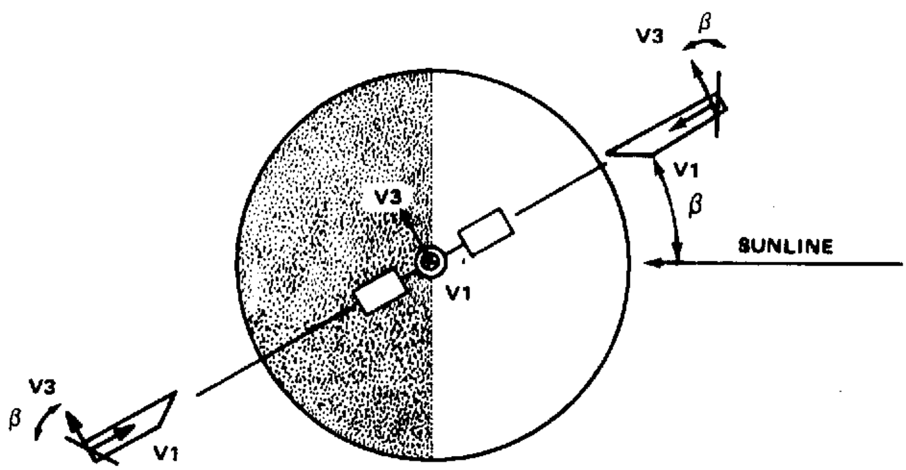


Figure 6. Optimum solar panel position for local vertical attitude.

When the magnetic torquing system is used as a backup to the momentum exchange devices during stabilization of the LST after separation from the Shuttle or after an unsuccessful attempt by the Shuttle to capture the LST, m_{3B} and ω_{3B} are both set to zero so the system merely damps out the vehicle rates to prevent the momentum exchange devices from saturating.

IV. SIMULATION RESULTS

To verify the performance of the scheme, a digital simulation was developed which models the vehicle rigid body dynamics, gravity gradient torques, earth's magnetic field, and the magnetic torquing system. The earth's magnetic field was modeled as that produced by a simple magnetic dipole located at the center of the earth, inclined 11.5 degrees to the earth's spin axis. A nominal orbit with an altitude of 500 kilometers and a relative inclination of 28.8 degrees to the magnetic equator was chosen. For vehicle principal moments of inertia of

$$I_1 = 1.75 \times 10^4 \quad \text{kg - m}^2 \ ,$$

$$I_2 = 4.29 \times 10^4 \quad \text{kg - m}^2 \ , \quad \text{and}$$

$$I_3 = 4.17 \times 10^4 \quad \text{kg - m}^2 \ ,$$

suitable control law parameters were found to be

$$K = 124 \ \frac{\text{n - m}}{\text{rad/sec}} \ ,$$

$$\langle B^2 \rangle_{ave} = 0.105 \times 10^{-8} \ (\text{w/m}^2)^2 \ , \quad \text{and}$$

$$m_L = 4000 \ \text{a - m}^2 \ .$$

Limiting the dipole moment commands in each axis to 4000 a-m^2 is compatible with a configuration of magnetic torquers previously proposed for momentum desaturation [1]. This configuration consists of six magnetic torquers, two aligned with each axis of the vehicle. Each torquer provides up to 2000 a-m^2 dipole moment, has a mass of 23.5 kilograms, and consumes a maximum of 5 watts of power.

Vehicle responses were obtained for tip-off rates of 0.75 °/s, the maximum to expect from separation with the Shuttle, according to Shuttle interface specifications [2]. For the first two orbits, m_{3B} was set equal to 1500 a-m^2

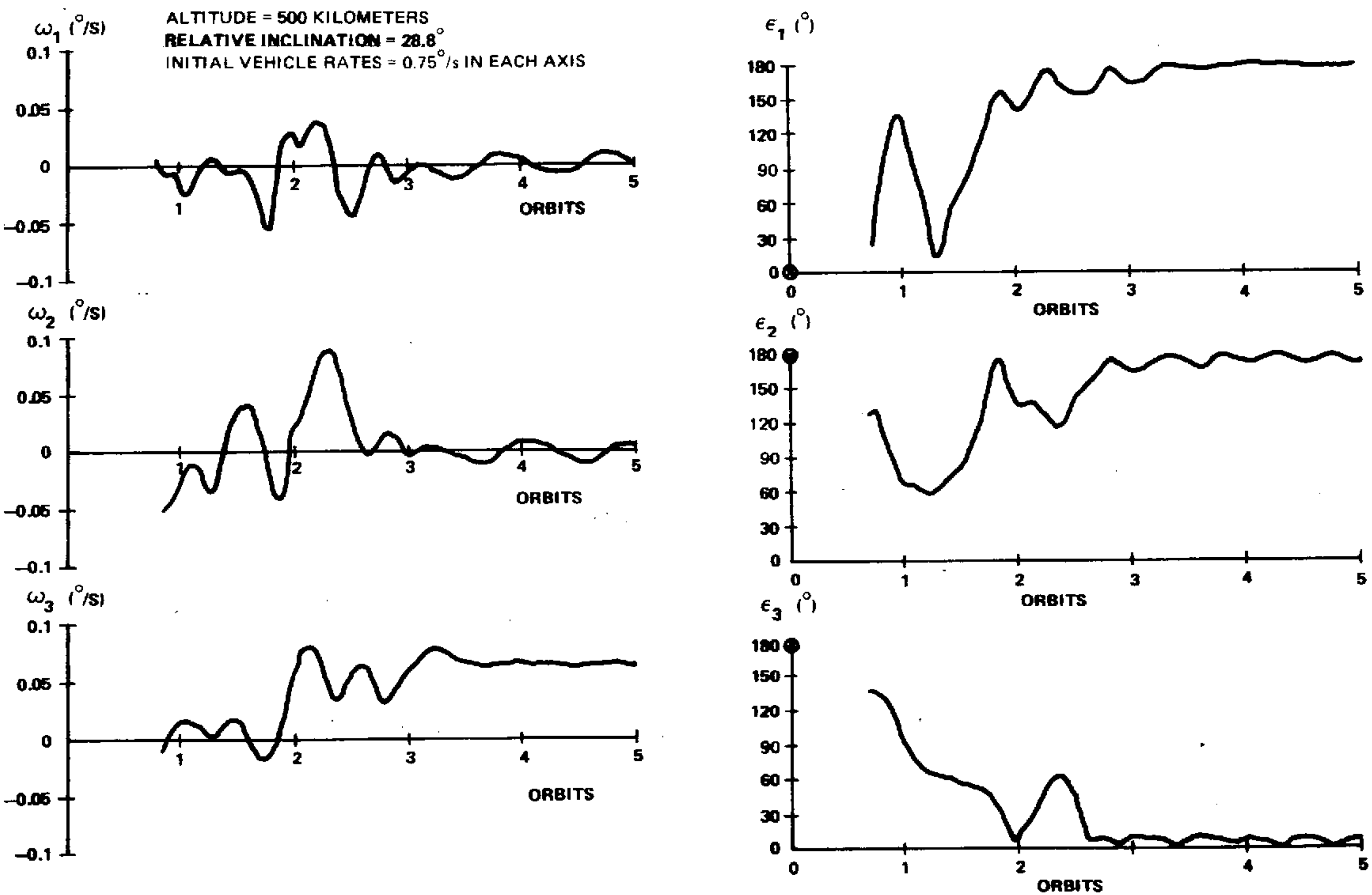


Figure 7. LST response for a nominal orbit and worst case tip-off rates.

and ω_{3B} to zero. Subsequently, m_{3B} and ω_{3B} were set equal to 500 a-m^2 and 0.00108 rad/sec, respectively. The results are presented in Figure 7. The plots on the left hand side show the time responses of the vehicle body rates (ω_1, ω_2, ω_3). Those on the right hand side show the vehicle attitude with respect to the local vertical coordinates ($\vec{i}_r$, $\vec{i}_t$, $\vec{i}_n$) expressed in terms of the direction angles (ϵ_1, ϵ_2, ϵ_3) defined in Figure 8. The results indicate that after four orbits, the V3 axis is within 10 degrees of the orbit normal, the V1 axis is within 10 degrees of the local vertical, the vehicle rates ω_1 and ω_2 are less than 0.01 °/s, and the vehicle rate ω_3 is equal to earth orbit rate, about 0.065 °/s.

V. CONCLUSIONS

The simulation results indicate that for a nominal orbit and worst-case vehicle tip-off rates, the proposed magnetic torquing system, with a configuration of magnetic torquers previously proposed for momentum desaturation [1], stabilized the LST to within 10 degrees of the local vertical in four orbits. Vehicle rates after four orbits were less than 0.01 °/s in two axes and equal to earth orbit rate, about 0.065 °/s, in a third. Assuming this kind of performance satisfies the requirement for emergency stabilization and backup control of the LST, this system can either eliminate the need for an RCS on the LST or else be an inexpensive backup to it.

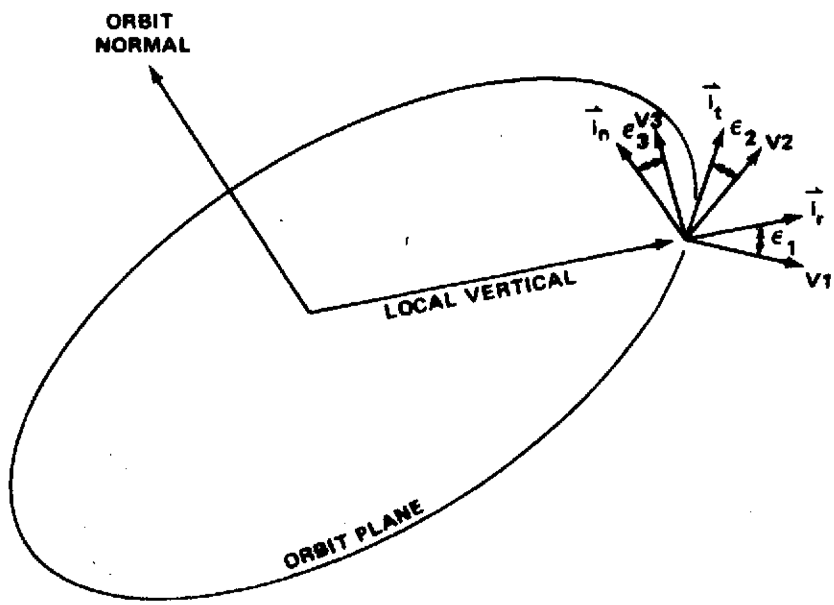


Figure 8. Direction angles which relate LST vehicle coordinates to local vertical coordinates.

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2. Anon: Shuttle Flight and Ground System Specification: Level II Program Definition and Requirements. JSC 07700, Volume X, Revision A, Johnson Space Center, Houston, Texas, January 2, 1974, p. 3-46.

APPROVAL

A MAGNETIC TORQUING SYSTEM FOR EMERGENCY STABILIZATION AND BACKUP CONTROL OF THE LST

By Michael E. Polites

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.

W. B. Chubb

W. B. CHUBB
Chief, Flight Systems Analysis Branch

T. P. Isbell

T. P. ISBELL
Acting Chief, Systems Engineering Division

H. E. Thomason

H. E. THOMASON
Director, Systems Analysis and Integration Laboratory

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