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SATELLITE-TO-SATELLITE TRACKING EXPERIMENT FOR GLOBAL GRAVITY FIELD MAPPING*

Triveni N. Upadhyay
Mayflower Communications Company, Inc., Reading, MA 01867

Christopher Jekeli
Air Force Geophysics Laboratory, Hanscom AFB, MA 01731

Introduction

The satellite-to-satellite (STS) tracking concept for estimating gravitational parameters offers an attractive means to improve on regional and global gravity models in areas where data availability is limited. The extent to which the STS tracking measurements can be effectively utilized in global field models depends primarily on the satellite's altitude, number of satellites, and their orbit constellation. The estimation accuracy of the gravity field recovery also depends on the measurement accuracy of the sensors employed in the STS tracking concept. A comparison of the obtainable accuracies in the gravity field recovery using various STS tracking concepts (e.g., high-low; low-low) was presented by Jekeli [1].

This paper summarizes the results of a feasibility study for a specific realization of the STS high-low tracking concept. In this realization, the high altitude satellites are the GPS satellites (altitude approximately 20,200 km), and the low orbit satellite is the space shuttle (orbiter). The GPS satellite constellation consists of 18 satellites in 6 orbital planes inclined at 55° (Kruh, et al [2]), The shuttle orbit is at approximately 300 km, with an inclination of 30°. This specific configuration of high-low satellites for measuring perturbations in the gravity field is named the Air Force STAGE (Shuttle-GPS Tracking for Anomalous Gravitation Estimation) mission. The STAGE mission objective is to estimate the perturbations in gravity vector at the shuttle altitude to an accuracy of 1 mgal or better. Recent simulation studies (Jekeli [1], Upadhyay and Priovolos [3]) have confirmed that the 1 mgal accuracy objective is near optimum for the STAGE mission.

Measurement System Concept

The STAGE measurement system concept involves the measurement of total forces acting on the shuttle using precision GPS carrier phase measurements from four or more GPS satellites and the measurement of non-gravitation forces using a precision IMU accelerometer package.

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From these GPS and IMU measurements we estimate the perturbations in gravity vector at the shuttle orbit. There are several advantages of the STAGE mission which makes it attractive, among other STS concepts, for gravity field estimation. These advantages are: (1) the continuous visibility of the low satellite (the shuttle) from the high satellite (GPS satellites); (2) measurement of the estimated line-of-sight accelerations to three or more GPS satellites results in determination of the gravity vector instead of 1 component recovery; (3) low cost of the mission because the major cost items associated with the satellites, i.e., GPS and the shuttle, are already funded. In addition to these advantages of the STAGE mission for gravity estimation, another important benefit of this Air Force mission is that the STAGE data will support other DoD and NASA objectives of precision space navigation and precision pointing and tracking in space, e.g., SDI and Space Station. The STAGE payload for a shuttle flight consists of : (1) a multi-channel GPS receiver utilizing existing upper and lower fuselage installed antennas on the orbiter; (2) an experimental IMU consisting of strapdown RLG (ring laser gyro) and accelerometer assembly; (3) an electronic processing assembly to control the experiment hardware and to integrate the orbit timing buffer; and (4) a flight recorder with ground support equipment provisions.

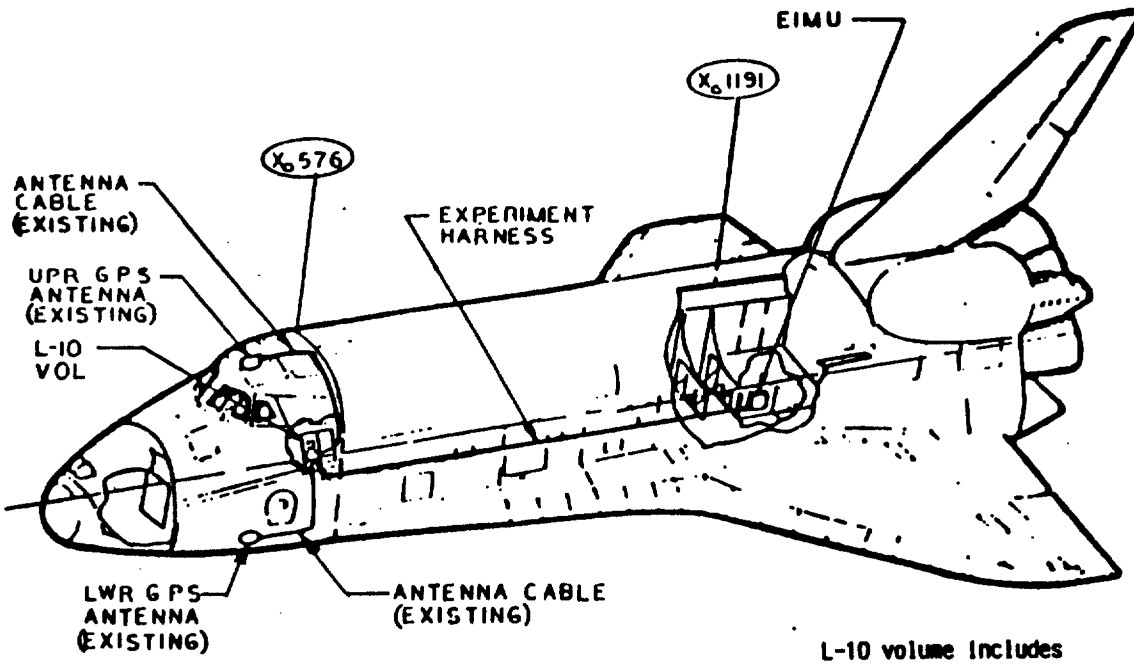
Results

We have made a preliminary selection of the payload hardware (i.e., GPS receiver, IMU, recorder) to carryout the STAGE mission. A payload integration study for the STAGE mission was carried out by Rockwell International, Space Transportation Systems Division, which has lead to the recommended installation configuration, as shown in Figure 1. In this installation configuration the GPS receiver, the processor and the recorder will be installed in the crew compartment (area L-10), and the IMU will be installed near the C.G. of the shuttle, as shown. The GPS receiver will utilize the existing upper and lower GPS antennae.

The feasibility study for the STAGE mission involved a detailed error analysis to determine whether or not the 1 mgal measurement accuracy can be achieved. The analysis (with support from EG&G Washington Analytical Services Center) considered all the major error sources and their affect on the measurement accuracy. In particular, we considered the GPS receiver measurement noise, phase bias, satellite clock error, GPS orbit errors caused by uncertainty in the geopotential field, solar radiation pressure, tracking station location error, etc., and the IMU errors caused by gyro and accelerometer bias, scale factor errors and misalignment. The results of this analysis, supported by simulation results, indicated that the STAGE mission objective of 1 mgal accuracy at the shuttle orbit can be realized (for a 75 second averaging) provided that certain measures are taken to mitigate the effect of the primary error sources. The primary errors identified in this study are: GPS satellite clock errors, IMU accelerometer bias error, and the IMU misalignment error. Techniques to mitigate the effect of these primary errors are under investigation. An IMU transfer alignment (between the shuttle IMU and the STAGE IMU) technique which employs the shuttle

GRAVITY ANOMALY ESTIMATION USING GPS MEASUREMENTS
ONBOARD THE STS

ORBITER EXPERIMENT INSTALLATION



Rockwell International
Space Transportation Systems Division

Figure 1

L-10 volume includes GPS Receiver, Processor and Recorder - Crew Module

rotation maneuvers has been developed and is being evaluated. We believe that the on-orbit transfer alignment accuracy goal of 1 mrad for the STAGE mission can be achieved. Bias and scale factor errors in the accelerometers are controlled similarly by special on-orbit calibration techniques. These techniques are proven, and we anticipate an accuracy of 0.13 mgal. The largest source of error is the instability of the GPS clock frequency as described by its Allan variance. By monitoring the short-term fluctuations of the GPS clocks at ground stations possessing more stable clocks, it is possible to model corrections to the observed phase and reduce the effective clock error by one to two orders of magnitude. This is an essential component of data processing to bring the gravitational acceleration error below 1 mgal.

While processing techniques to further improve the measurement accuracy for the STAGE mission are in development, we feel very confident in reporting that a payload hardware configuration has been developed and the baseline STAGE configuration is compatible with shuttle mission. The STATE mission can be flown on future shuttle flights on a non-interfering basis.

References

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