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OPTIMIZATION OF MANEUVER EXECUTION FOR LANDSAT-7 ROUTINE OPERATIONS*

E. Lucien Cox, Jr.†

Abstract

Multiple mission constraints were satisfied during a lengthy, strategic ascent phase. Once routine operations begin, the ongoing concern of maintaining mission requirements becomes an immediate priority. The Landsat-7 mission has tight longitude control box and Earth imaging that requires sub-satellite descending nodal equator crossing times to occur in a narrow 30-minute range fifteen (15) times daily. Operationally, spacecraft maneuvers must be executed properly to maintain mission requirements. The paper will discuss the importance of optimizing the altitude raising and plane change maneuvers, amidst known constraints, to satisfy requirements throughout mission lifetime. Emphasis will be placed not only on maneuver size and frequency but also on changes in orbital elements that impact maneuver execution decisions. Any associated trade-off arising from operations contingencies will be discussed as well. Results of actual altitude and plane change maneuvers are presented to clarify actions taken.

Introduction

The Landsat-7 spacecraft is in a Sun-synchronous, frozen polar orbit currently at a 705-kilometer altitude. During its mission lifetime, Landsat-7 will take numerous images of the Earth at many longitudes. These imaging activities are made possible by the spacecraft orbit conforming to a World Reference System groundtrack grid path. The World Reference System (WRS) is a global notation system used to characterize Landsat image data.[1] Satellite imagery ("scenes") is designated or identified by path and row. Landsat-7 orbits the Earth in a 16-day repeat cycle containing 233 orbits equally spaced around the equator. These orbits create a grid pattern of reference longitudes, approximately 170 kilometers apart, thus facilitating imaging. As Landsat-7 orbits the Earth, the Local Mean Solar Time (LMST) at the descending nodal equator crossing must remain between 9:45 AM and 10:15 AM. In addition to the LMST condition, the longitudinal point at which the Landsat-7 spacecraft crosses the equator must be controlled to within +/- five (5) kilometers of a WRS reference longitude. The ascent phase completed for the Landsat-7 mission

† Aerospace/Electrical Engineer, Flight Dynamics Analysis Branch, Guidance, Navigation and Control Center, Goddard Space Flight Center; Phone: 301-286-6222; email: ecox@pop500.gsfc.nasa.gov

low solar flux data will produce burn results farther to the western control box boundary than predictions generated with high solar flux data. Studies of these type produce results to help "bound" the drift predictions and the associated choice of maneuver duration to use when the solar activity is not certain. The risk of selecting a maneuver duration that ultimately causes the spacecraft to drift beyond its constraints is then minimized. Maneuver planning predictions that are performed within a three-week time period use the daily JR files. Predictions performed longer than three weeks in advance should use the Schatten monthly files.

Landsat-7 Inclination Maneuvers

The choices for inclination maneuver (Δ**i**) execution depend upon what LMST evolution is desired. Landsat-7 has a 30-minute range for its nodal crossing but utilizes only fifteen minutes of this range. Once a target inclination is determined, the resulting LMST curve must be observed. Landsat-7 ascent phase planning observed LMST drift data based on targeted launch dispersion insertion inclinations of 98.165 degrees to 98.265 degrees. A value of 98.215 degrees was chosen because it suited the agreed upon two-minute launch window (18:32-18:34 GMT), resulted in an initial LMST range of 10:03 – 10:05 AM, and kept the LMST values within the mission constraints of 9:45 – 10:15 AM for approximately two years.

Inclination maneuvers can be planned so that the LMST requirement is not violated. It is important to plan the execution of the inclination maneuver prior to LMST violation. To optimize the inclination maneuver for acceptable results, the actual decay in orbit inclination must be observed to determine the magnitude of delta velocity (ΔV) maneuver duration needed to achieve the target inclination. Inclination decay can be plotted and compared to the LMST evolution over a two-year period. The amount of inclination decay allowable is arbitrary as long as the corresponding LMST has not gone beyond the 9:45 AM boundary. The target inclination desired and associated ΔV required to achieve that value must be determined. The requirements for an inclination maneuver are widespread. For Landsat-7, targets to achieve a Sun-synchronous inclination or returning the inclination to the insertion value were investigated.

An inclination value for a spacecraft in a Sun-synchronous orbit will depend on the altitude of the spacecraft orbit. Goddard Space Flight Center (GSFC) engineers performed analysis on this subject and determined inclination values for spacecraft in altitudes ranging from 200 km to 5900 km.[2] Using Eq. 1,

$$d\Omega/dt = -(3/2)\, \mathbf{J_2}\, \{\mathbf{R_e}^2/(a^2(1-e^2))\} \sqrt{(\mu/a^3)}\, \cos(i) \qquad (1)$$

where

$\mathbf{J_2}$ = spherical harmonic associated with Earth's oblateness

$\mathbf{R_e}$ = Earth's mean equatorial radius

a = semimajor axis of satellite's orbit

e = eccentricity of satellite's orbit

μ = Universal Gravitational constant

i = inclination of satellite's orbit

Sun-synchronous inclinations were determined. The mission orbit semimajor axis and eccentricity were used in Eq. 1 to determine what the Sun-synchronous inclination would be for Landsat-7. A value of 98.1845 degrees was determined. Prior to launch a study was performed to assess inclination maneuver magnitudes approximately two (2) years after launch. A maneuver of about 25-30 minutes would be necessary to increase the inclination by 0.07 degrees. Spacecraft engineers and project personnel agreed that this maneuver duration would be a risk to thruster performance and interrupt image operations for the science community. To remain conservative, GSFC flight dynamics engineers investigated measures to return the orbit inclination to its insertion value of 98.215 degrees. This value produced an optimal LMST drift within required constraints and the ΔV maneuver duration was acceptable to spacecraft engineers. Fig. 2 and Fig. 3 respectively, show Lansat-7 inclination decay and LMST evolution post ascent.

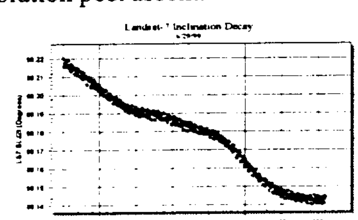

Figure 2

The data in these figures were used to plan the first Δi maneuver for Landsat-7. LMST evolution was well within constraints peaking at a time of 10:05:10 (10.0865) and reaching 9:55:30 (9.925) in two years. Inclination decay was on the order of 0.01degrees every 100 days. At 200 days, a maneuver of 9 minutes was needed to restore 0.025 degrees of inclination decay.

Results

Results for the June 6, 2000 (day 158) drag make-up maneuver, the first inclination maneuver, performed November 9, 1999, and a proposed inclination maneuver for mid-October 2000 are presented.

Operationally, the Landsat-7 WRS longitude drift is controlled within 2 km west and 1 km east of the control box center. The maneuvers to date have been on the average of 17 seconds. Figure 4 and Figure 5 show pre- and post-maneuver WRS longitude drift data respectively for the June 6, 2000 maneuver.

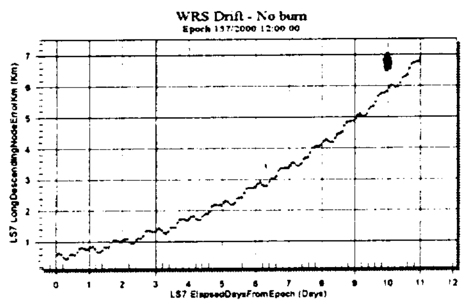

Figure 4

The maneuver was planned for 16 seconds and effectively stopped the eastward drift (shown in Fig.4) and returned the drift westward at about 500 meters per day (Fig. 5). Also noticeable is that the desired control box interval is maintained and the drift period is on the order of 14 days (Fig. 5).

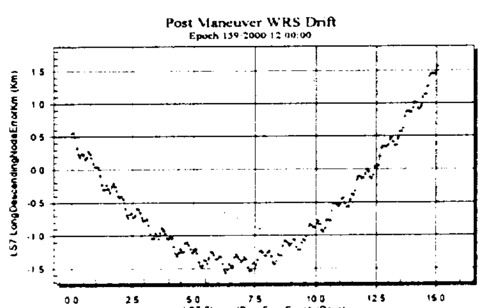

Figure 5

Results of the inclination maneuver, held on November 9,1999, are shown in Figure 6 and 7. Figure 6 shows the resulting LMST profile based on maneuver goals designed to return the orbit inclination to the insertion value; i.e. Figure 3 is almost identical to Figure 6. Figure 7 shows the resulting inclination decay after the November 9th maneuver. The profile is quite similar to Figure 2.

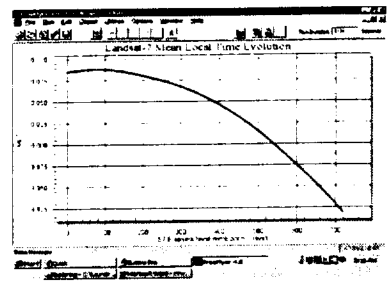

Figure 6

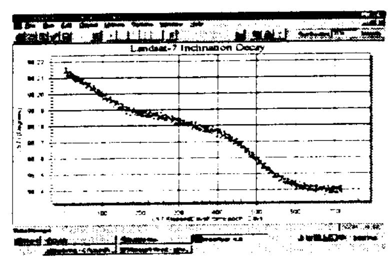

Figure 7

The next inclination maneuver, for Landsat-7 is planned for mid-October 2000. Flight operations management has agreed to two significant maneuver goals. The first is to schedule inclination maneuvers once per year (fall quarter). Secondly, a target inclination has been determined such that in one year, the inclination will decay to a value slightly above the initial inclination. Planning this sequence is identical to the steps outlined earlier. The only difference is that the target inclination is 98.22 degrees, 0.005 degrees above the value targeted in the first Δi, and the maneuver duration has increased to about 18 minutes.

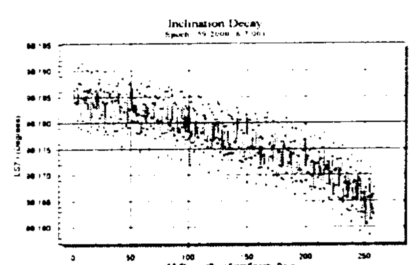

Figure 8