Autonomous Navigation Flight Demonstration Results for the New Millennium Program EO-1 Mission

by
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SHORT ABSTRACT

The New Millennium Program's Earth Orbiter-1 (EO-1) spacecraft was launched on 21 November 2000. EO-1 flys in a one minute trailing formation with the Landsat 7 spacecraft to validate an advanced land imaging instrument. Autonomous onboard navigation was also flight validated to demonstrate possible reductions in mission operations resources. Navigation here, is defined as the process of determining and controlling the orbit of a spacecraft. Orbit determination was provided by an onboard Global Positioning System (GPS) receiver; while, a simple empirical approach was used to provide orbit control. Flight results and lessons learned are presented.

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EXTENDED ABSTRACT

WHAT: Flight validation of autonomous navigation/formation flying technology

WHY: Demonstrate autonomous maintenance of a one minute along track separation between EO-1 and Landsat-7 (within six seconds) to obtain co-registered images for EO-1 camera validation

WHEN: Launch November 2000, flight validation July-September 2001

HOW: Use a simple algorithm that takes advantage of onboard GPS positioning to determine orbital maneuvers needed to maintain orbital formation between EO-1 and Landsat-7

Introduction

A key technology flight validated on the New Millennium Program's Earth Orbiter 1 (EO-1) mission is autonomous navigation. In the context of this paper it is defined as autonomously determining and controlling the orbit of a spacecraft. Autonomous formation flying is a type of autonomous navigation that for EO-1 and Landsat-7 involved maintaining a one minute along track separation to within six seconds. A simple algorithm developed at NASA's Jet Propulsion Laboratory (JPL) was flight validated and the results are present here.

Lessons Learned

Several findings became apparent: Two to three days of GPS observations required to converge on an accurate solution; Consider more advanced outlier editing for GPS outage case; Add maneuver magnitude scaling factor to accommodate alternate maneuver strategies. Maneuver implementation interface should have been tested more; EO-1 co-maneuvers should be performed as soon after Landsat-7 maneuvers as possible to reduce along track runoff.

Conclusions

Flight validations were completed from July 18 - September 19, 2001. Six maneuvers were performed (3 co-maneuvers, 2 formation maintenance maneuvers, see figure 1). All onboard planned burn durations were within one second of ground plans (see table 1).

Benefits of autonomous navigation are: Ground tracking network for navigation not required; Reduces mission operations ground team effort and size; Applicable to many future Earth science missions

Benefits of the JPL algorithm are: Minimal memory and onboard processor requirements (<100kB RAM); Simple, relies on GPS onboard navigation solutions (position only); No numerical integration required; No navigation (Kalman) filtering required; Autonomous, Landsat-7 maneuvers are only routine data transmitted to EO-1.

Acknowledgements

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References

[1] Guinn, J.R., and others, "Autonomous Spacecraft Navigation for Earth Ground Track Repeat Orbits Using GPS," presented at the AAS/AIAA Space Flight Mechanics Meeting, Austin, TX., 12-15 February 1996

[2] Folta, D. and others "Foundations of formation flying for Mission to Planet Earth and New Millennium," presented at the AIAA/AAS Astrodynamics Specialists Conference, July 29-31, 1997.

[3] Guinn, J.R. and R.J. Boain, "Spacecraft Autonomous Navigation for Formation Flying Earth Orbiters Using GPS," presented at the AIAA/AAS Astrodynamics Specialists Conference, July 29-31, 1997.

[4] GPS Tensor™ Brochure, Space Systems/Loral.

Figure 1. - Flight Validation Results

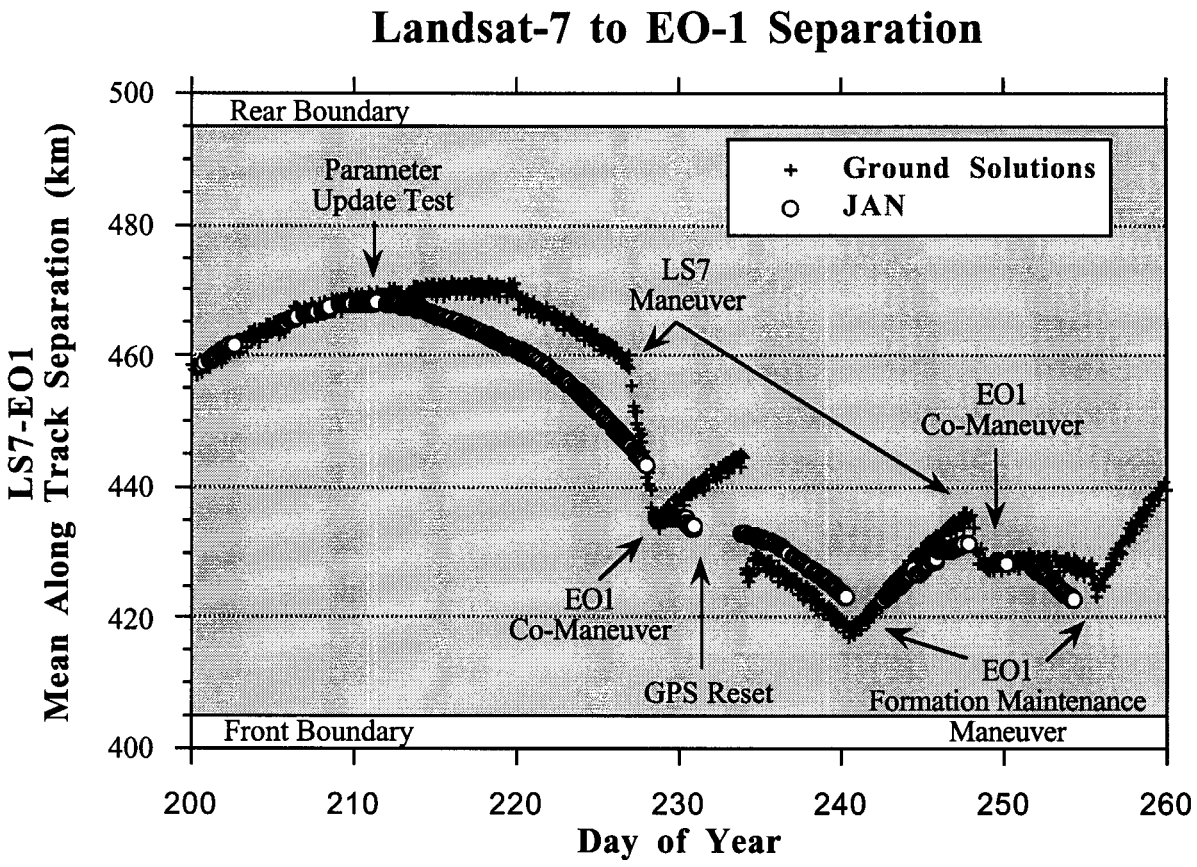

Table 1. - Flight Validation Results

Maneuver Type & Date	Onboard Plan **Burn duration / Magnitude**	Ground Plan **Burn duration / Magnitude**	Comments
Co-maneuver **16 Aug 2001**	23 sec / 61.1 mm/s	22sec / ~58 mm/s 2 sec / ~3 mm/s	Manual Mode **2 maneuver ground plan used**
Formation Maintanence **28 Aug 2001**	9 sec / 23.8 mm/s	9 sec / ~24 mm/s	Semi-Autonomous **Success: but bad table parameters required re-initialization after maneuver**
Co-maneuver **5 Sep 2001**	16 sec / 43.5 mm/s	16 sec /~43 mm/s	Semi-Autonomous **Manually patched to complete successfully**
Formation Maintenance **12 Sep 2001**	10 sec / 26.6 mm/s	10 sec / ~27 mm/s	Fully-Autonomous **Ops procedure error: terminated prematurely**