Collision Avoidance with Multiple Pulsing Manoeuvres

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ABSTRACT

ISRO operates a fleet of Low-Earth-Orbit (LEO) satellites for various applications like remote sensing, weather forecasting, oceanography, scientific applications etc. Space Object Proximity Analysis with Resident Space Objects is regularly carried out for all operational satellites to assess close approach risk with other space objects. Critical conjunctions are closely monitored, and a Collision Avoidance Manoeuvre is planned based on predefined limits on close approach distance and maximum probability of collision. This paper presents the collision avoidance methodology adopted for ISRO's LEO satellites with constraint on maximum firing duration. CAM design for IRS-P6 is presented as a case study.

1 INTRODUCTION

The growing numbers of objects in space pose a serious collision hazard to operational satellites. Hence, space situational awareness towards collision risk mitigation is an important responsibility of all space faring nations. Execution of Collision Avoidance Manoeuvre (CAM) mitigates collision risk and protects an operational satellite from catastrophic mission failure and also avoids creation of new space debris. ISRO follows IADC guidelines [1] for space debris mitigation to ensure safe and sustainable space operation and takes all necessary efforts to avoid on-orbit collision.

The Flight Dynamics Group (FDG) at ISRO Telemetry Tracking and Command Network (ISTRAC) carries out Orbit Determination(OD) of all operational LEO satellites. The sources of orbit determination are tracking data measurements and the measurements from on-board GPS receiver. In IRS-P6 orbit determination is done using range and range-rate measurements from various tracking stations across the globe. In addition to orbit determination and prediction, FDG carries out periodic analysis and planning of orbit manoeuvres to maintain the satellite in mission specified orbit with ground track within predefined limits.

After regular orbit determination, the state-vector (SV) is sent to Applied Mathematics Division of Vikram Sarabhai Space Centre (VSSC) for Space Object Proximity Analysis (SOPA) [2]. Every Orbit Manoeuvre (OM) plan is also subjected to SOPA screening before execution to prevent any post OM conjunction threats.

Conjunction alerts with minimum Close Approach Distance (CAD) less than 1 km are reported after the daily SOPA analysis. The trend in close approach distance is closely monitored for objects having CAD of less than one kilometre. Repeated orbit determination with fresh data sets is carried out for the assets displaying monotonically decreasing close approach distance on successive days. Conjunction analysis is then repeated using the updated orbit information of the primary object and latest available orbit information of the risk object. Conjunction data messages from CSpOC of 18th SPCS are also analysed with the latest SV from OD solution. Collision Avoidance Manoeuvre is planned if the close approach distance is less than 100 meters and maximum collision probability is more than 10^{-3}. The manoeuvre plan is generated based on the station support availability and the existing payload plan. The direction of the burn is decided so as to cause minimum impact on the ground track pattern. The manoeuvre plan is cleared for execution if: a) It mitigates the present conjunction threat and b) Does not result in any other conjunction post manoeuvre for next seven days. The CAM is re-planned if any of the said conditions are not met. The ground track shift may exceed mission limits after executing the Collision Avoidance Manoeuvre. Hence another manoeuvre may be required for maintaining the ground track shift within limits. Refer Figure 1 for SOPA and related activities in ISRO.

Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office
Ed. T. Flohrer, S. Lemmens & F. Schmitz, (http://conference.sdo.esoc.esa.int, May 2021)

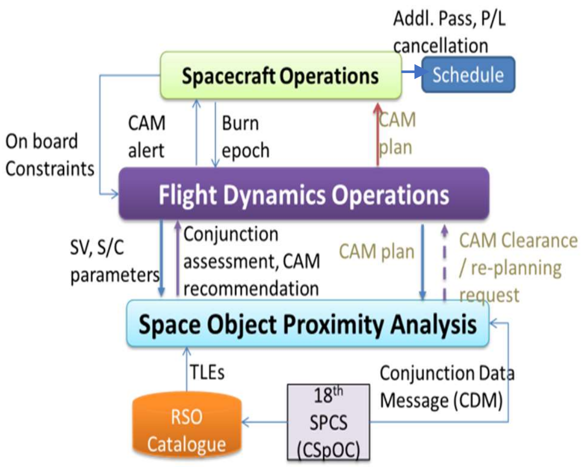

Figure 1: SOPA and Related Activities in ISRO

2 CONJUNCTION BETWEEN IRS-P6 AND METEOR 2-5 RIS

Minimum close approach distance between IRS-P6 and Meteor 2-5 Deb (NORAD ID: 31404) was observed below 1 km from SOPA of 23rd July 2019 onwards and the predicted Time of closest approach (TCA) was on 25th July 2019, 01:08:48.857 UTC. The close approach distance was 778 meters and collision probability was 1.86e-05. Conjunction analysis was also carried out with latest five space track TLEs of Meteor 2-5 Deb [3]. The analysis indicated a decreasing trend in close approach distance. Refer Table 1 for trend analysis.

Meteor 2-4 Deb TLE Epoch (UTC)	CAD (km)	
	IRS-P6 SV 24-07-2019	IRS-P6 SV 23-07-2019
12 Jul 2019 13:02:32.155	2.240	2.241
14 Jul 2019 12:16:53.254	1.880	1.882
18 Jul 2019 02:00:44.181	1.267	1.267
19 Jul 2019 01:36:09.255	1.104	1.104
21 Jul 2019 04:38:45.477	0.778	0.777

Table 1: Trend of CAD between IRS-P6 and different TLE of Meteor 2-5 Deb

The CSpOC report on 24/07/2019 was showing conjunction on 25th July 2019, 01:08:48.857 UTC with close approach distance of 166 m and collision probability 4.07e-04. Analysis was carried out on 24 July 2019, with the latest state vectors of IRS-P6 and CSpOC state vector of Meteor 2-5 Deb. Analysis results confirmed that the close approach distance was 61 m and collision probability 3.03e-03. The analysis was then repeated using the updated state vectors of IRS-P6. The computed CAD and maximum collision probability were 53 m and 4.04e-03, respectively. As the CAD and the maximum collision probability were beyond threshold, operations team alerted for CAM. The alert information was given to spacecraft operations team. Refer Table 2 and Figure 2 on SOPA of IRS-P6 SV and Cspoc SV of Meteor 2-4 Deb.

Different cases for trend analysis	CAD	Maximum collision probability
Conjunction Data Message from CSpOC	166	4.07e-04
SOPA using P6 SV of 24/07/2019 and CSpOC SV of Meteor 2-5 Deb	61	3.03e-03
SOPA using updated SV of P6 on 24/07/2019 and CSpOC SV of Meteor 2-5 Deb	53	4.04e-03

Table 2: Trend of CAD based on IRS-P6 SV and CSpOC SV of Meteor 2-5 Deb

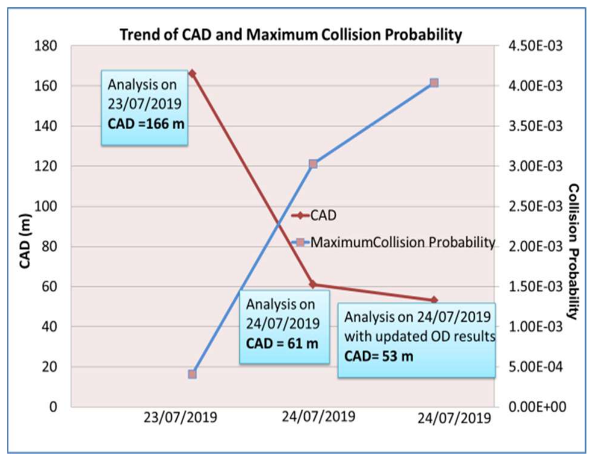

Figure 2: Trend of CAD and maximum collision probability

3 COLLISION AVOIDANCE MANOEUVERS STRATEGY DEVISED

IRS-P6 was launched on 17th October 2003, and has been in orbit past the design life of five years. The subsystems have degraded over a period of time. The spacecraft is operated with updated operation guidelines and still serves the remote sensing community.

The mission directives for IRS-P6 mandate the orbit manoeuvres to be executed in station visibility and by operating thrusters in pulse mode. The typical pass duration and the allowed thruster duty cycle result in limiting the maximum number thruster pulses to 12 per visibility. In other words the maximum Δv that could be imparted was limited to 0.028 m/sec per pass. The required Δv of 0.1 m/s would take about 48 pulses, hence Δv requirement had to be split over multiple visibilities. Additional ground support was taken for executing the manoeuvres. The net CAM was planned over successive orbits. The predicted satellite state vector based on the first manoeuvre design was used in the next manoeuvre design and so on. The spacecraft state vector after the final manoeuvre was analyzed for close approach distance and was found that with the post OM trajectory the CAD would be beyond 1 km. Hence the CAM plan was cleared for execution. Refer Table 3 for CAM details.

CAM plan	Mid-Burn (UTC)	Delta V (m/sec)	Delta a (km)	Burn duration (sec)
1	16:25:30.000	0.028	0.054	11.928
2	18:06:00.000	0.028	0.054	11.928
3	19:34:00.000	0.028	0.054	11.928
4	21:48:00.000	0.028	0.054	11.928

Table 3: CAM Details of IRS-P6 on 24/07/2019

The planned manoeuvres were flawlessly executed in four consecutive orbits, and a Δv of 0.112 m/sec (each 0.028 m/sec) was achieved as planned resulting in successful conjunction risk mitigation. The operation was carried out by ISTRAC with support of other teams SOPA/VSCC and Directorate of Space Awareness and Management (DSSAM) ISRO. Refer Figure 3 and Figure 4 for visualization of scenario before and after CAM. In the visual the uncertainty ellipsoids are overlapping at TCA (Time of Closest approach) before OM, while post OM, they are well separated.

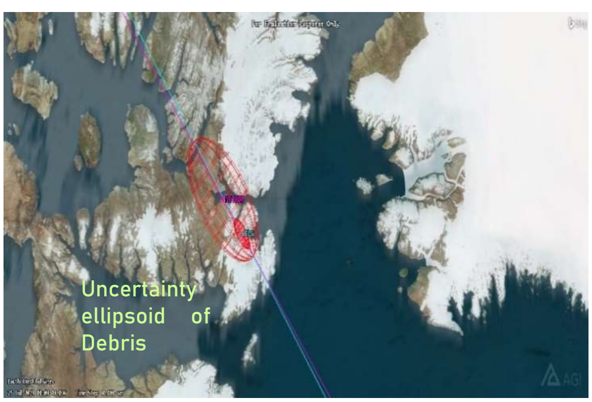

Figure 3: Close conjunction before CAM at TCA


Figure 4: Close conjunction before CAM at TCA

4 CONCLUSION

In this paper we presented the operational strategy followed to mitigate conjunction risk for ISRO satellites, and described in detail one such CAM execution for IRS-P6 where the maximum firing duration and no. of pulses were constrained.

5 ACKNOWLEDGMENT

The authors thank Dr. Manikantan Ramadas, Mr. Ajit Bhandari, Mr. Leo Jackson and Mr. R. Srinivasan, of Spacecraft Operations Area ISTRAC/ISRO towards their contribution in this operation. We acknowledge Ms. Pooja Dutt and Mr. Deepak Negi, of Applied Mathematics Division, VSCC/ISRO for analysis and support in completing this operation. We thank Ms. Bulbul Mukherjee and Dr. A. K Anil Kumar, Directorate of Space Awareness and Management (DSSAM) ISRO for guidance and constant encouragement.

6 REFERENCES

1. *IADC, 2007. Space Debris Mitigation Guidelines. https://www.iadc-online.org/index.cgi?item=docs_pub*
2. *Space Debris Activities in India – UNOOSA https://www.unoosa.org/*
3. *www.space-track.org*