IRNSS-1H/PSLV-C39 Orbit Evolution and Re-entry Analysis

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ABSTRACT

IRNSS-1H was launched onboard PSLV-C39 on 31st August, 2017 from Shriharikota (India). Due to failure of payload fairing separation, spacecraft could not attain its intended sub-GTO orbit. Orbit determination was carried out using 2 hrs and 36 min of available tracking data. A very low orbit was achieved with 164 km perigee height and 6585 km apogee height with 19.2 deg inclination. The orbit period was 2 hr 39 min. Liquid engine firings using onboard LAM engine, were attempted to help s/c come out of the payload fairing and to passivate the propellants. IRNSS-1H trapped inside the payload fairing along with the dry PS4 stage is considered as object for study.

Detailed orbit evolution and decay analyses were carried out since September 2017 till 2nd March 2019. In this paper, different case studies have been presented and results are discussed. Orbital decay prediction strongly depends on the cross-section area normal to velocity vector, mass of the object and space weather in the low-Earth environment. In the absence of attitude information of the object, the exact cross section area for drag was not available. For the prediction of earliest date of decay, analysis was carried out with maximum area to mass ratio. The dry mass of PS4 and satellite was 873 kg and 597 kg respectively. The payload fairing mass was 1182 kg. Two cases were considered for total mass of object: 2675 kg which also accounts for the residual propellant and 3480 kg which includes 828 kg of propellant. The maximum and average cross section area considered is 23.42 m^2 and 16 m^2 respectively. Latest available solar flux and geomagnetic index data have been considered in the analysis. Re-entry start is assumed when perigee height is near 120 km.

As per results posted by JSpOC on www.space-track.org the final re-entry prediction was at 19:23 UTC on 2nd March 2019 at -19.1° latitude and 174.3° longitude. In comparison, the final re-entry prediction provided in this paper was at 19:27 UTC on 2nd March 2019 at -19.0° latitude and 168.2° longitude. The same orbit was monitored to check the latitude and longitude predicted by JSpOC, and it was observed that the same condition was achieved at 19:28:30 UT when perigee height was 119.4 km.

1. INTRODUCTION

IRNSS (NAVIC) is the Indian Regional Navigation Satellite System which will provide high accuracy navigation service for the Indian region. IRNSS-1H was launched onboard PSLV-C39 on 31st August, 2017 from Shriharikota (India) as replacement of IRNSS-1A in the constellation series. Due to failure of payload fairing separation, spacecraft could not attain its intended sub-GTO orbit.

After the non-nominal separation, orbit determination was carried out using 2 hrs and 36 min of available tracking data. A very low orbit was achieved with 164 km perigee height and 6585 km apogee height with 19.2 deg inclination. The orbit period was 2 hr 39 min. Liquid engine firings using onboard LAM engine, were attempted to help s/c come out of the payload fairing and to passivate the propellants. IRNSS-1H was being also tracked by NORAD. After the maneuver, NORAD has catalogued three objects associated to this mission which is provided in Table-1. IRNSS-1H trapped inside the payload fairing along with the dry PS4 stage is the main object (A). Other two objects B & C are reported to be very small in size.

No communication could be established with satellite after depletion of onboard battery. Detailed orbit evolution and decay analyses were carried out for the main object (A) since September 2017 till 2nd March 2019. In this paper, different case studies have been presented and results are discussed.

Table-1: Three object tracked by NORAD

Object	NORAD ID	Orbit		
		Perigee Ht. (km)	Apogee Ht. (km)	Inclination (°)
A	42928	176	6554	19.16
B	42929	188	6523	19.16
C	42930	177	6470	19.14

2. ORBIT EVOLUTION AND DECAY ANALYSES

Orbital decay prediction strongly depends on the cross-section area normal to velocity vector, mass of the object and space weather in the low-Earth environment. In the absence of any attitude information of the object A, the exact cross section area for drag is not available. For the prediction of earliest date of decay, analysis is carried out with maximum area to mass ratio. The dry mass of PS4 and satellite is 873 kg and 597 kg respectively. The payload fairing mass is 1182 kg. Total mass of object A is 2675 kg which also accounts for the residual propellant. The maximum cross section area considered is 23.42 m^2. Two more cases are studied with an average cross section area of 16 m^2 and mass with and without the satellite propellant (828 kg). Three different cases of area/mass ratios considered are provided in Table-2. The re-entry start is assumed when perigee height is near 120 km.

Table-2: Different area/mass cases

Case #	Area (m^2)	Mass (kg)	Area/Mass
1	23.42	2675	0.00876
2	16.0	2675	0.00598
3	16.0	3480	0.00460

2.1 Prediction-I: (13 September, 2017)

As on 13th Sep, 2017, there were 42 TLE sets available in NORAD catalogue. Fig.1 and 2 provide the orbit evolution with these 42 TLE sets as a function of date. It can be observed that the apogee height is decreasing due to the atmospheric drag effect. The initial relatively higher decay in apogee height and semi-major axis can be attributed to the high solar activity in first few days of September. As per the TLE, the semi-major axis is decreased by 70 km over a period of 12 days. Considering the latest TLE orbit with proper area, mass and solar flux data; the orbit is propagated with full force model for over 10 months. Perigee and apogee evolution over the lifetime is shown in Figure 3. The predicted re-entry details are tabulated in Table-3. The earliest and latest re-entry date predicted was on 13th June 2018 and 7th March 2019 respectively.

Table-3: Predicted re-entry date (I)

Case #	Area/Mass	Date/Lifetime
1	0.00876	13th June 2018/285 days
2	0.00598	27th Oct 2018/421 days
3	0.00460	7th March 2019/552 days

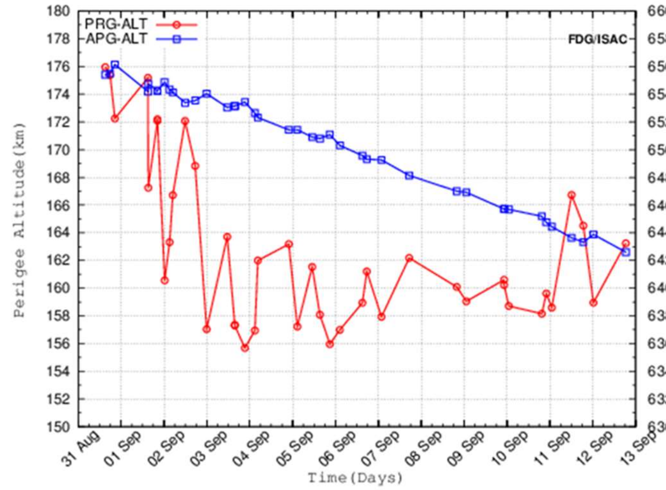

Fig. 1: Perigee & Apogee variation from TLE

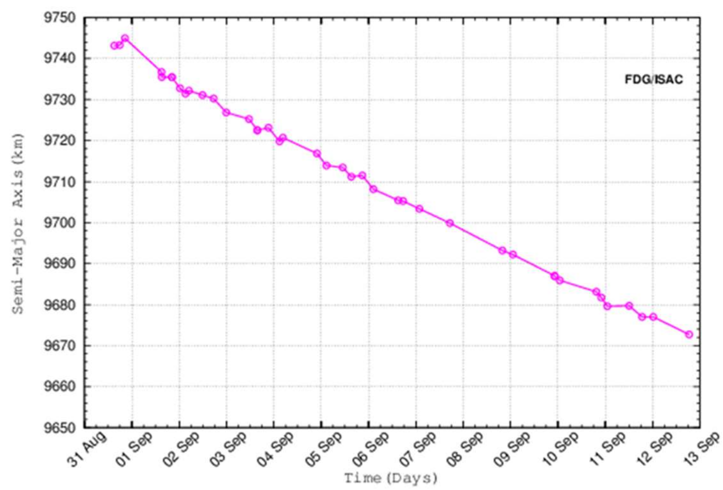

Fig. 2: Semi-major axis variation from TLE

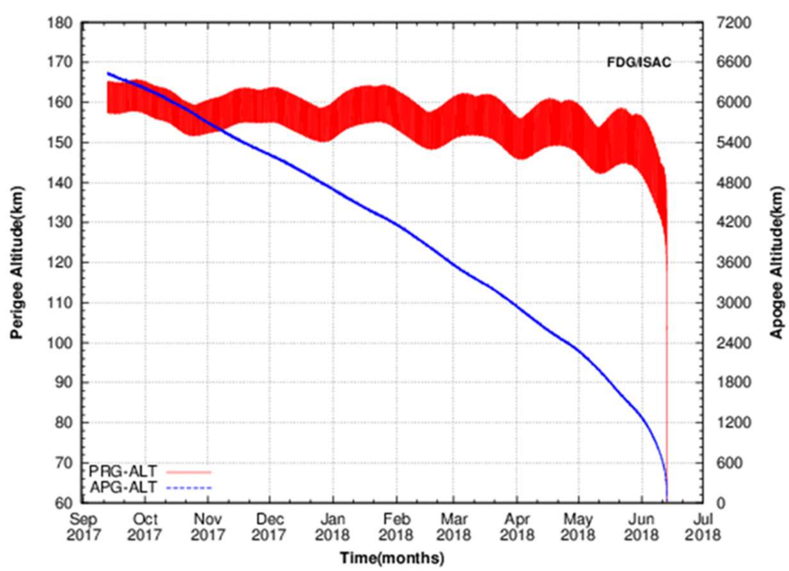

Fig. 3: Perigee & Apogee variation over the lifetime

2.2 Revision-I: (20th July, 2018)

As on 20th July, 2018, there were 838 TLE sets available in NORAD catalogue. Fig.4 provide the orbit evolution with these 838 TLE sets as a function of date. It can be observed that the perigee altitude is oscillating around 160 km and the apogee altitude is decreasing due to the atmospheric drag effect. As per the TLE, the apogee altitude has decreased by 2865 km over a period of 322 days in orbit. The semi-major axis has decreased by 1443 km over same period. Full force model propagation with the latest orbit, yields predicted earliest and latest re-entry date on 13th June 2018 and 27th February 2019 respectively. The predicted re-entry details are provided in Table-4. Revised perigee and apogee variation is shown in Figure 5.

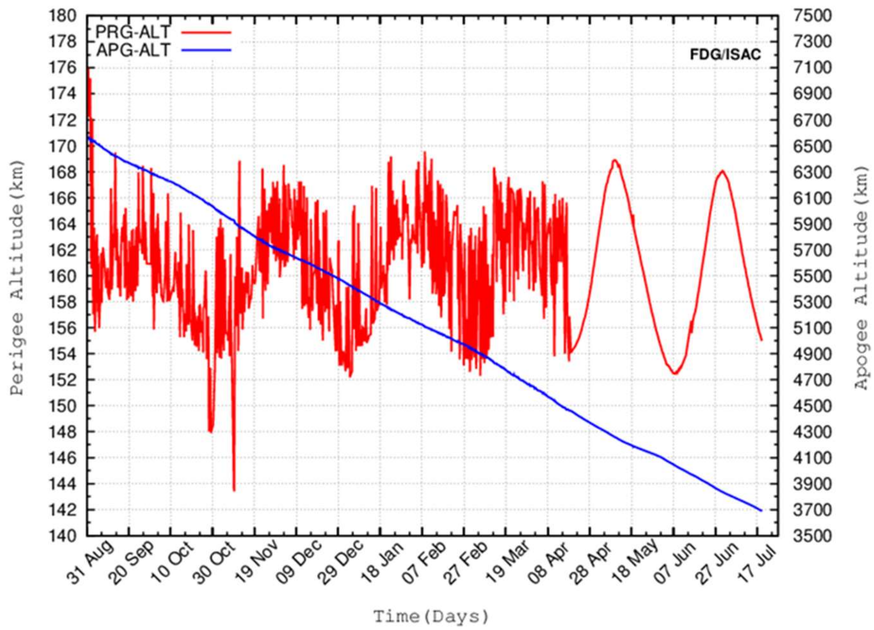

Fig. 4: Perigee & Apogee variation from TLE

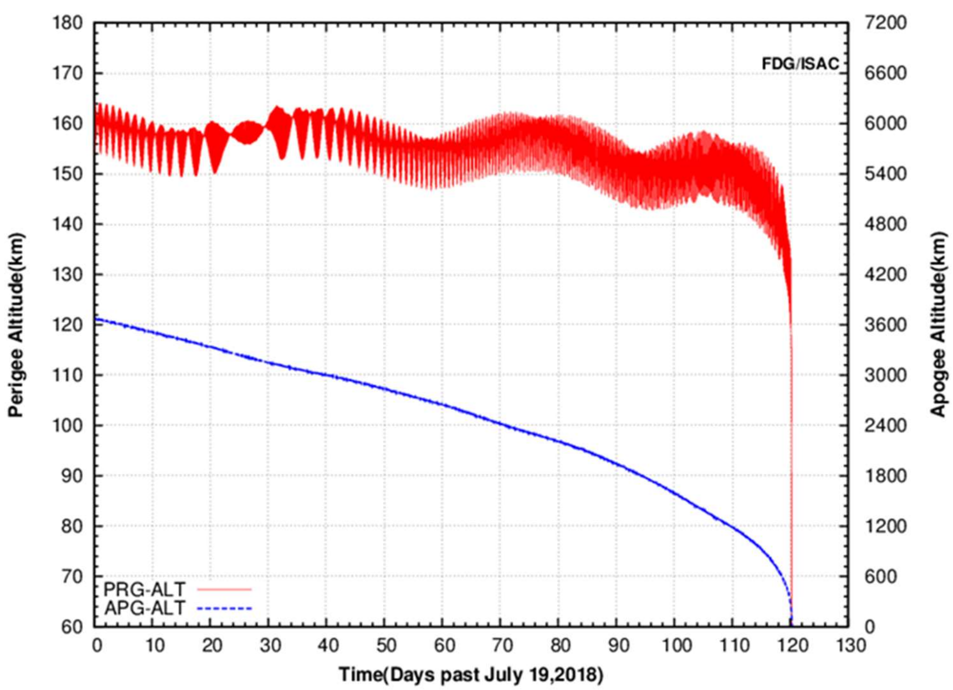

Fig. 5: Perigee & Apogee variation over the lifetime

Table-4: Predicted re-entry date (II)

Case #	Area/Mass	Date/Lifetime
1	0.00876	16th November 2018 442 days
2	0.00598	4th January 2019 491 days
3	0.00460	27th February 2019 545 days

2.3 Revision -II: (15th February, 2019)

As on 15th February, 2019, there were 1306 TLE sets available in NORAD catalogue. Fig.6 & 7 provide the orbit evolution with these 1306 TLE sets as a function of date. It can be observed that the apogee altitude and semi-major axis are decreasing due to the atmospheric drag effect but perigee altitude is oscillatory in nature due to the Moon's perturbation. As per the TLE, the apogee altitude has decreased by 5600 km over a period of 532 days in orbit. The semi-major axis has decreased by 2808 km over same period. Full force model propagation with the latest orbit, yields predicted earliest and latest re-entry date on 25th February 2019 and 4th March 2019 respectively. Revised perigee and apogee variation is shown in Figure 8. The predicted re-entry details are provided in Table-5.

Table-5: Predicted re-entry date (III)

Case #	Area/Mass	Date/Lifetime
1	0.00876	25th February 2019 543
2	0.00598	1st March 2019 547
3	0.00460	4th March 2019 550

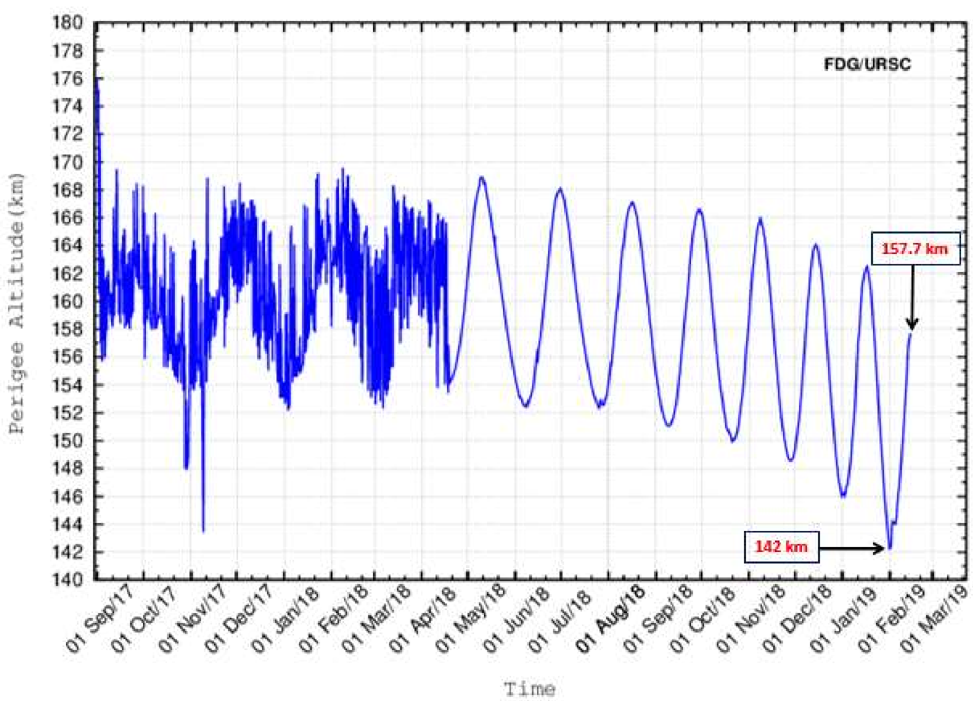

Fig. 6: Perigee variation from TLE

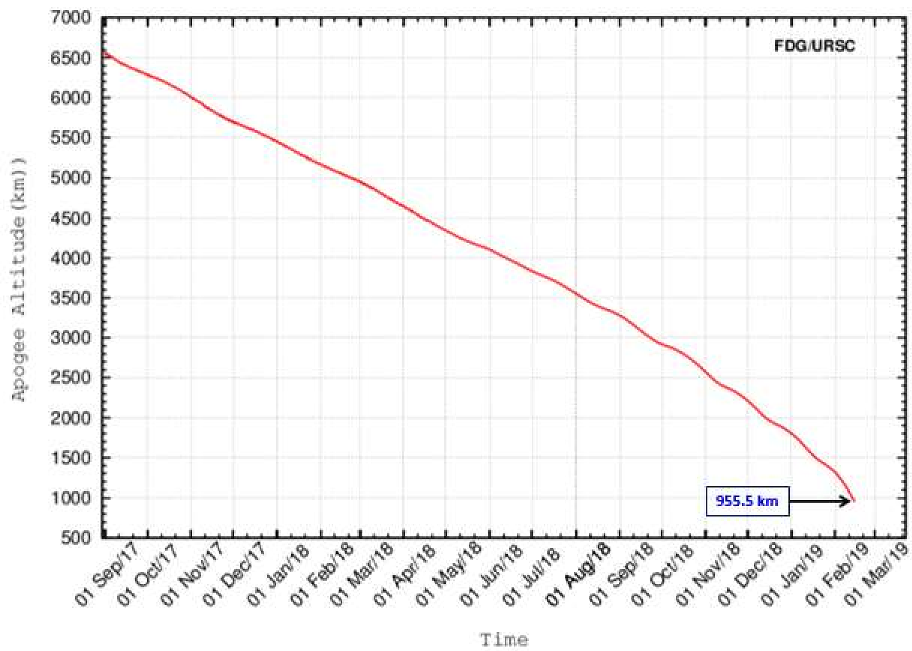

Fig. 7: Apogee variation with TLE data

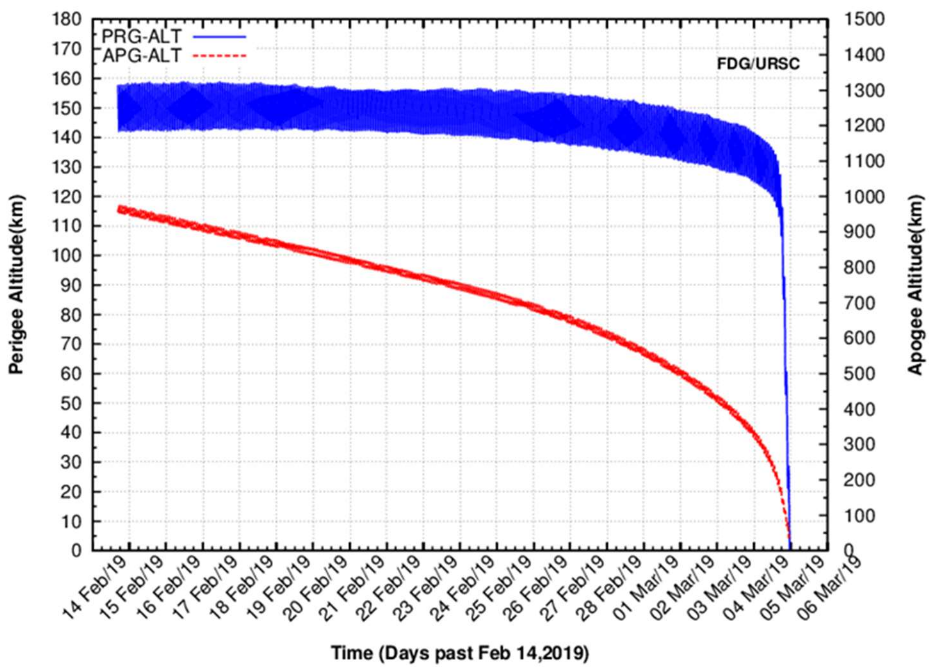

Fig. 8: Perigee & Apogee variation over the lifetime

2.4 Revision -III: (01 March 2019)

As on 1st March, 2019, there were 1348 TLE sets available in NORAD catalogue. Fig.9 & 10 provide the orbit evolution with these 1348 TLE sets as a function of date. As per the TLE, the apogee altitude has decreased by 6072 km over a period of 546 days in orbit. The semi-major axis has decreased by 3058 km over same period. Full force model propagation with the latest orbit, yields predicted earliest and latest re-entry was between 1st March 2019 and 2nd March 2019 respectively. Revised perigee and apogee variation for case#3 near re-entry is shown in Figure 11. The predicted re-entry details are provided in Table-6.

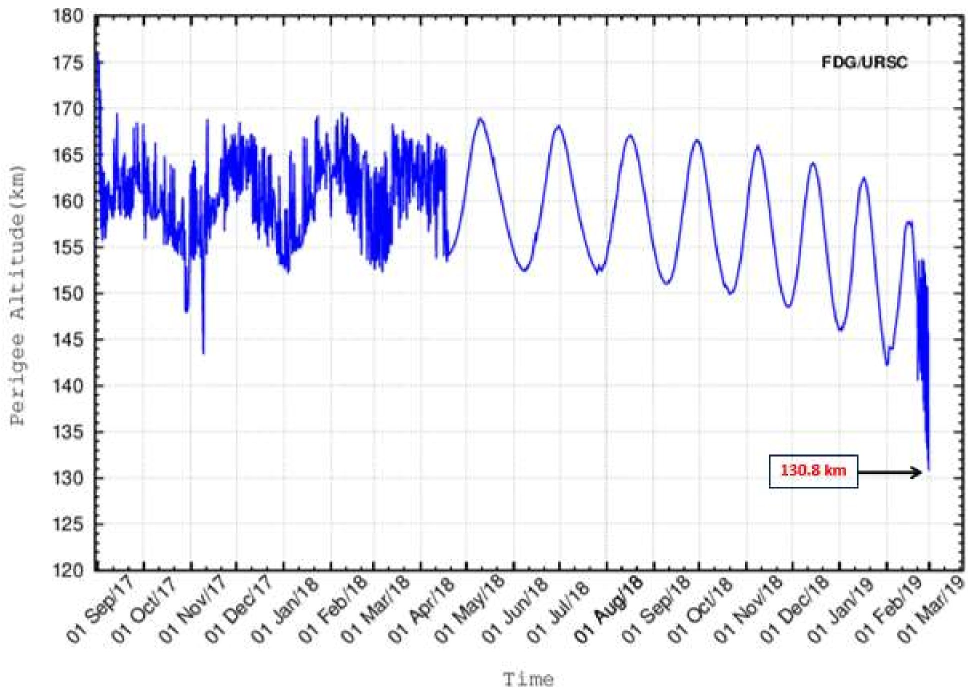

Fig. 9: Perigee variation from TLE

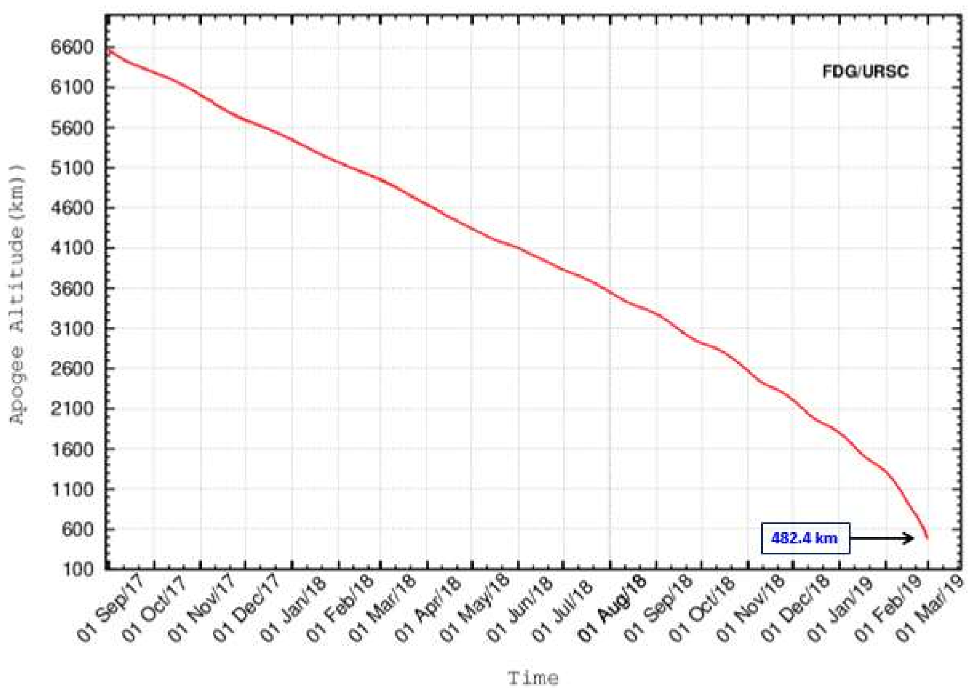

Fig. 10: Apogee variation with TLE data

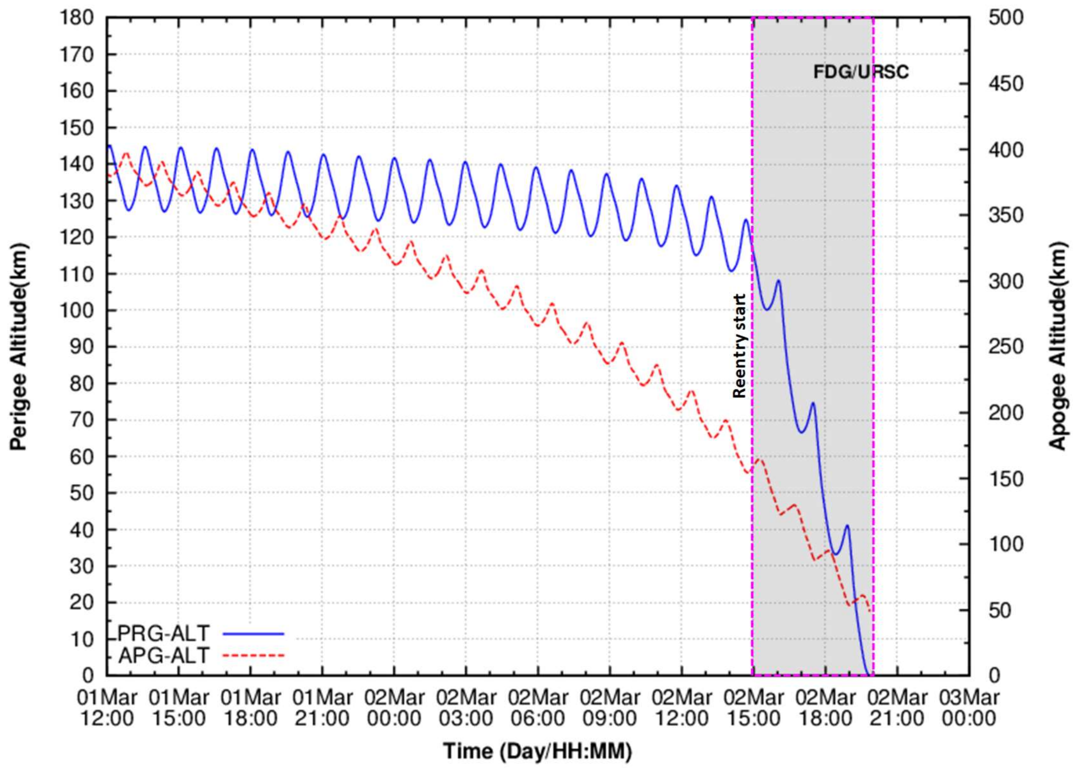

Fig. 11: Perigee and Apogee variation towards the end of lifetime (case#3)

Table-6: Predicted re-entry date (IV)

Case #	Area/Mass	Epoch
1	0.00876	2019-03-01 16:27 UT
2	0.00598	2019-03-02 04:13 UT
3	0.00460	2019-03-02 14:51 UT

2.5 Revision -IV: (02 March 2019)

As per the last TLE update from NORAD, the perigee and apogee altitudes are 128.9 km and 342.5 km respectively. Considering the latest orbit (suitably converted from TLE) with proper area, mass and solar flux data; the orbit is propagated with full force model. The revised predicted reentry details are provided in Table 7. The re-entry predictions posted by JSpOC at (www.space-track.org) are provided in Table-8. It can be observed from Table-7 and 8 that, the re-entry predictions are very close the JSpOC. The same orbit was monitored to check the latitude and longitude predicted by www.space-track.org, and it was observed that the same condition was achieved at 19:28:30 UT when perigee height was 119.4 km. The predicted re-entry point coordinates are shown in Figure 12 and 13. The consolidated re-entry predictions are tabulated in Table-9. It can be observed that the predictions for Case#3 were very consistent right from September 2017 to last prediction on 2nd March 2019. And the last prediction for Case#3 is very close to update provided by JSpOC. For other two cases, the inputs for analysis like solar flux data and geomagnetic index were identical at the time of analyses. The only difference was in area-to-mass ratio.

Table-7: Predicted re-entry date (V)

Area/Mass (m^2/kg)	Predicted Reentry Epoch /Lifetime	Lat, Long at Reentry start **(120 km)**
0.00460	2019-03-02 19:27 UT, 548 days	-19.0°, 168.2°

Table-8: JSpOC re-entry predictions

Predicted Reentry Epoch	Lat, Long at Reentry start
2019-03-02 19:23 UT	-19.1°, 174.3°

Table-9: Consolidated re-entry predictions

Analysis date	Predicted Reentry date		
	Case#1	Case#2	Case#3
13th Sep, 2017	13th June 2018	27th October 2018	**7th March 2019**
20th July, 2018	16th Nov 2018	4th January 2019	**27th Feb 2019**
15th Feb, 2019	25th Feb 2019	1st March 2019	**4th March 2019**
28th Feb, 2019	1st March 2019 16:27 UT	2nd March 2019 04:13 UT	**2nd March 2019 14:51 UT**
2nd March 2019	2nd March 2019 11:54 UT	2nd March 2019 16:13 UT	**2nd March 2019 19:27 UT**

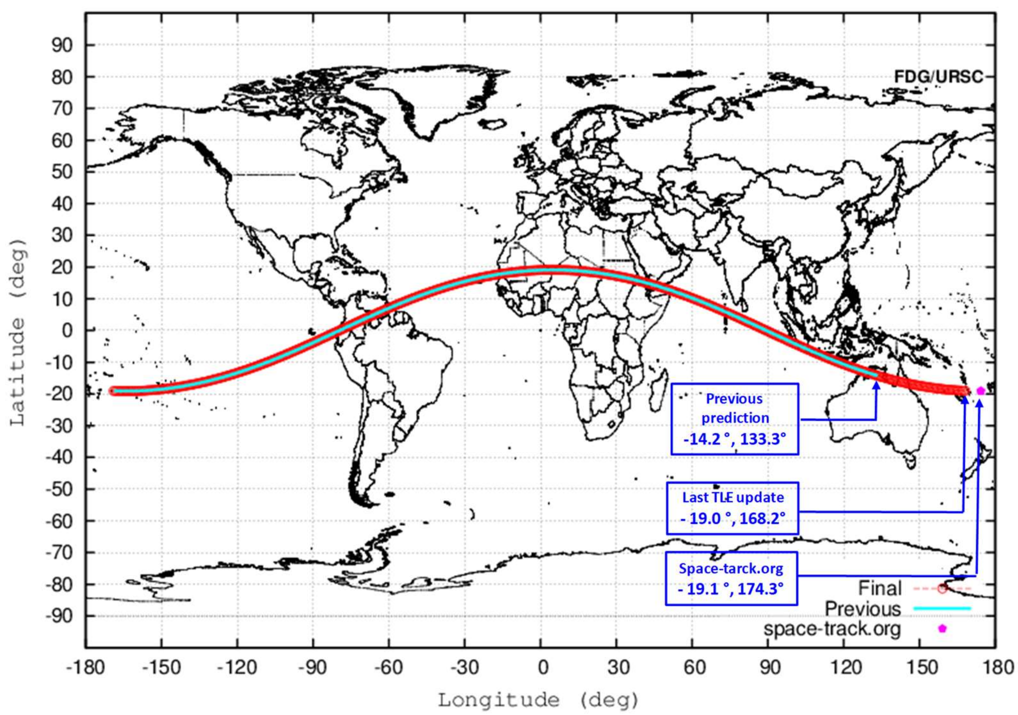

Fig. 12: Predicted re-entry point

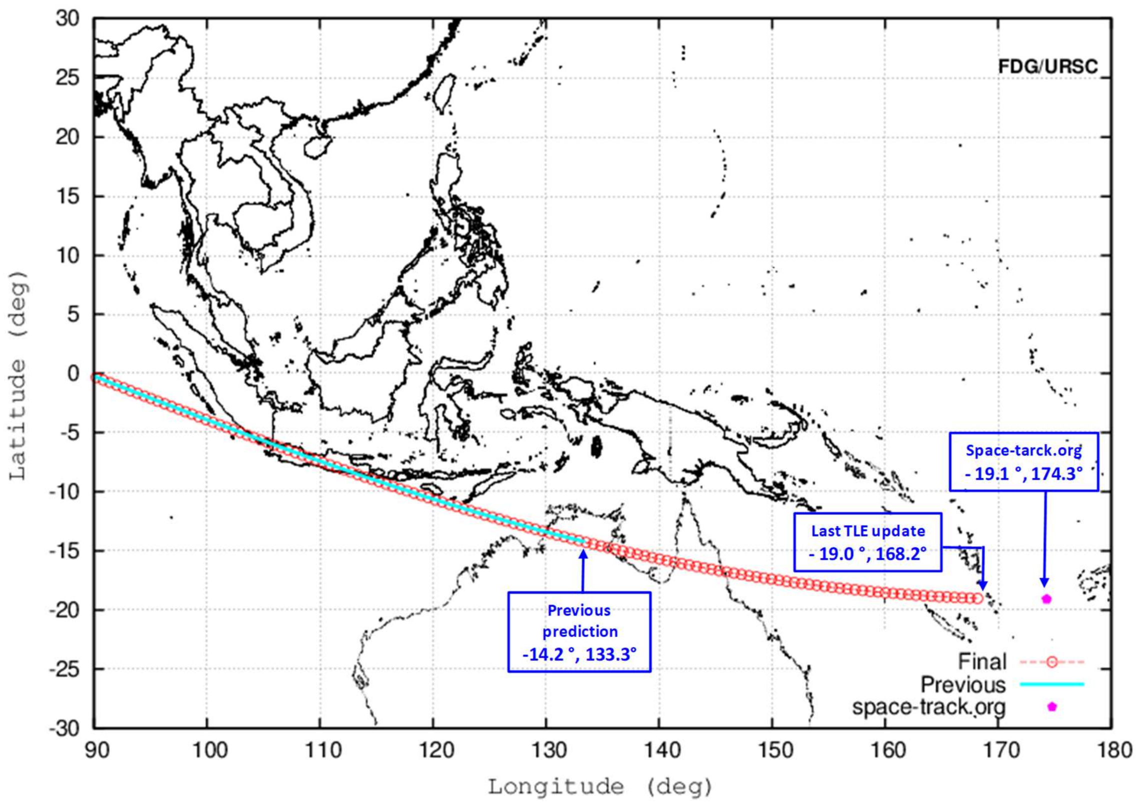

Fig. 13: Predicted re-entry point (zoomed view)

3. CONCLUSION

Due to various associated uncertainties, accurate re-entry prediction is very challenging for any re-entering object. In this paper, detailed orbit evolution and re-entry prediction analysis has been presented. The re-entry predictions provided in this paper, are very closely matching with JSpOC both in re-entry epoch and location. This shows that based on the available information of physical parameters of IRNSS-1H spacecraft, PS4 upper stage of launch vehicle and payload fairing, the assessment of area to mass ratio of whole object was precise. Also, the full force model propagation is of very high fidelity.

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