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GEO COMMUNICATION SATELLITES WITH EP

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ABSTRACT

In this study, the advantages of using EP (Electric Propulsion) compare to using CP (Chemical Propulsion) in GEO (Geostationary Orbit) satellites were investigated in terms of the mass of the launch, dry and propellant. Calculations were performed for the GEO satellites with CP and EP, having a 15-year mission life (2019-2033), for Proton M Breeze 5 Burn and Zenith 3SLB launchers.

INTRODUCTION

EP:

In EPS (Electric Propulsion System) electrical energy, provided by solar panels and stored in batteries, is used to accelerate particles producing thrust in a spacecraft [Goebel and Katz, 2008].

Depending on the process used to accelerate the propellant, EP thrusters are classified in three categories (Table 1) [Mazouffre, 2016].

Table 1: EP thruster properties.

EP Thruster Type	EP Thruster Name	Specific Impulse (s)	Thrust (mN)
Electrostatic	Ion	2500-6000	0.01-200
	Hall	1500-2000	0.01-1000
Electro-thermal	Resistojet	300	2-100
	Arcjet	500-600	2-700
Electromagnetic	Pulsed Plasma	850-1200	0.05-10

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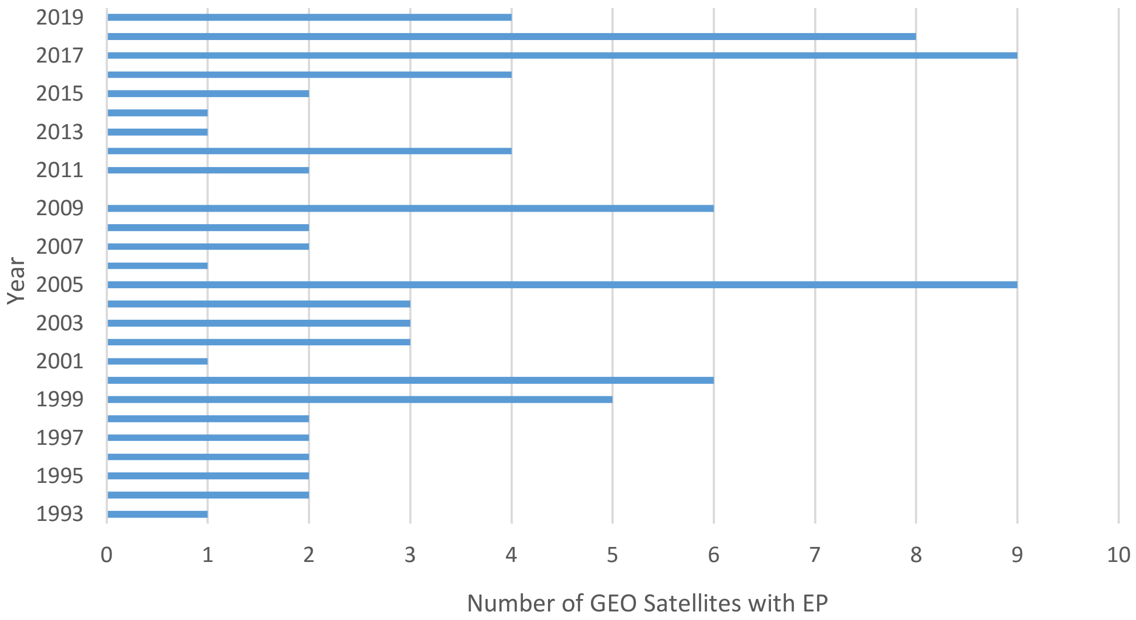
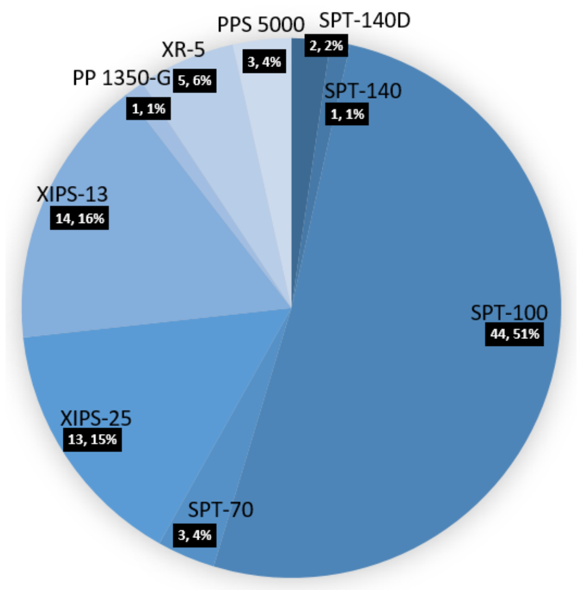
GEO Communication Satellites with EP:
Since the first GEO communication satellite with EPS was launched in 1993 (Telstar 401), more than 250 satellites with EPS have been launched, 87 of them are GEO communication satellites (see Figure 1). Traditionally, EP is used to perform S/K maneuvers of GEO satellites. Two Boeing all-electric satellites performed for the first time EOR to the GEO in March 2015 [Boeing, 2015]. Details of the some of the GEO communication satellites with full EPS given in Table 2.



a) Number of GEO communication satellites with EPS.



b) EP thruster types used in GEO communication satellites.

Figure 1: GEO communication satellites with EPS (between 1993 and as of 20/07/2019). [https://space.skyrocket.de].

Table 2: GEO communication satellites with full EPS.

Launch Year	Satellite	Platform	Launcher	Launch Mass(kg)	EOR	S/K	Thruster
2015	Eutelsat 115 West-B	BSS-702 SP	Falcon-9 v1.1(ex)	2205	√	√	4xXIPS-25
2015	ABS 3A	BSS-702 SP	Falcon 9 v1.1	1954	√	√	4xXIPS-25
2016	Eutelsat 117 West-B	BSS-702 SP	Falcon-9 v1.2	1963	√	√	4xXIPS-25
2016	ABS 2A	BSS-702 SP	Falcon-9 v1.2	2000	√	√	4xXIPS-25
2017	Eutelsat 172B	Eurostar 3000EOR	Eurostar-3000EOR	3500	√	√	4xPPS 5000
2017	SES 12	Eurostar 3000EOR	Falcon-9 v1.2(ex)	5300	√	√	4xPPS 5000
2017	SES 14/GOLD	Eurostar 3000EOR	Ariane-5ECA	4200	√	√	4xPPS 5000
2017	SES 15	BSS-702SP	Soyuz-ST-A Fregat-M	2300	√	√	4xXIPS-25
2018	SES 12	Eurostar 3000EOR	Falcon-9 v1.2	5300	√	√	?xSPT140D
2019	Eutelsat 7C	SSL-1300	Ariane-5ECA	3400	√	√	4xSPT100

METHOD

Propellant consumption can be calculated using the ideal rocket equation [Goebel, 2008]:

$$m_p = m_0 * (1 - e^{\frac{-\Delta V}{I_{sp} * g_0}}) \qquad (1)$$

where m_p is propellant used (kg), m_0 is the total mass of the satellite (kg), ΔV represents change in the velocity of the satellite (m/s), I_{sp} is the specific impulse of thruster (s) and g_0 is the gravity of the Earth at sea level, 9.8067 m/s^2.

We used the SPT-100 Hall thruster in EP propellant calculations. The properties of thrusters used in our calculation are given in Table 3.

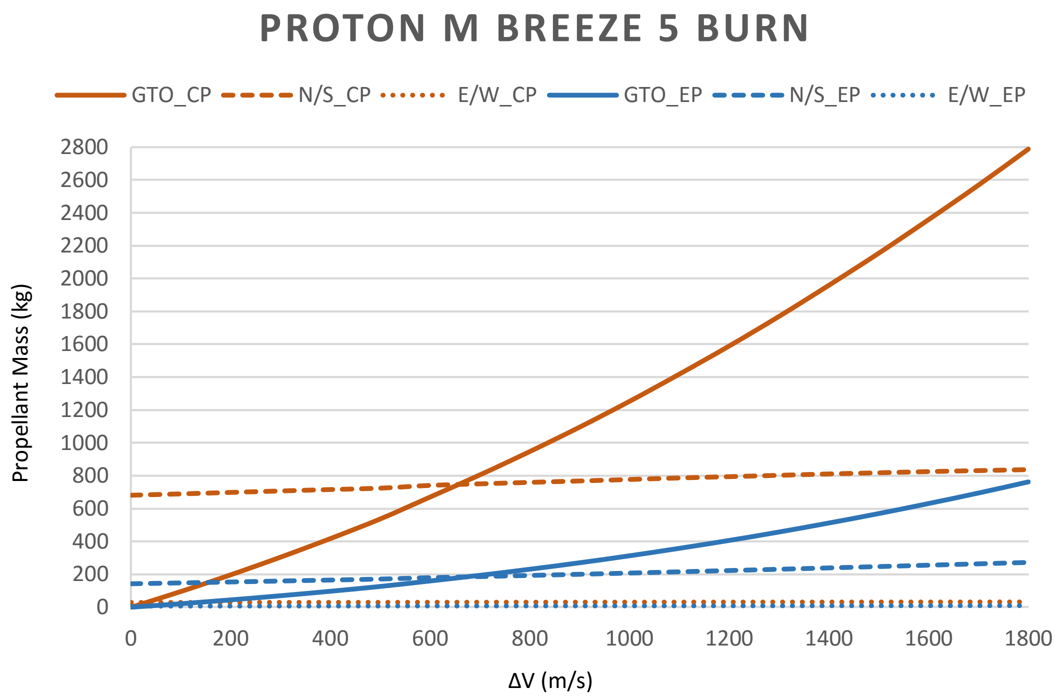
Table 3: Properties of thrusters used in calculations.

CP			
	GTO	N/S	E/W
Isp(s)	320	286	277.5
F(N)	400	10	10

EP			
	GTO	N/S	E/W
Isp(s)	1600	1600	1600
F(mN)	0.83	0.83	0.83

Calculations were made for a GEO satellite located at 42° E longitude having 15 years of satellite lifetime (2019-2033). Proton M Breeze 5 Burn and Zenith 3SLB launch vehicles were considered in this study [PROTON, 2009; ZENIT-3SLB, 2019].

The total propellant requirement of the GEO satellites is mainly the sum of the propellant required for GTO (Geostationary Transfer Orbit) and S/K. The major contribution of the propellant consumption is due to the ΔV needed for GTO. Usually, GEO satellites require ΔV around 50 m/s per year for N/S (North/South) and 5 m/s per year for E/W (East/West) maneuvers [Soop,1983]. We calculated propellant requirements and dry mass capabilities of GEO satellites with EP and CP for Proton M Breeze 5 Burn and Zenith 3SLB launchers performance (see Figure 2 and Figure 3).



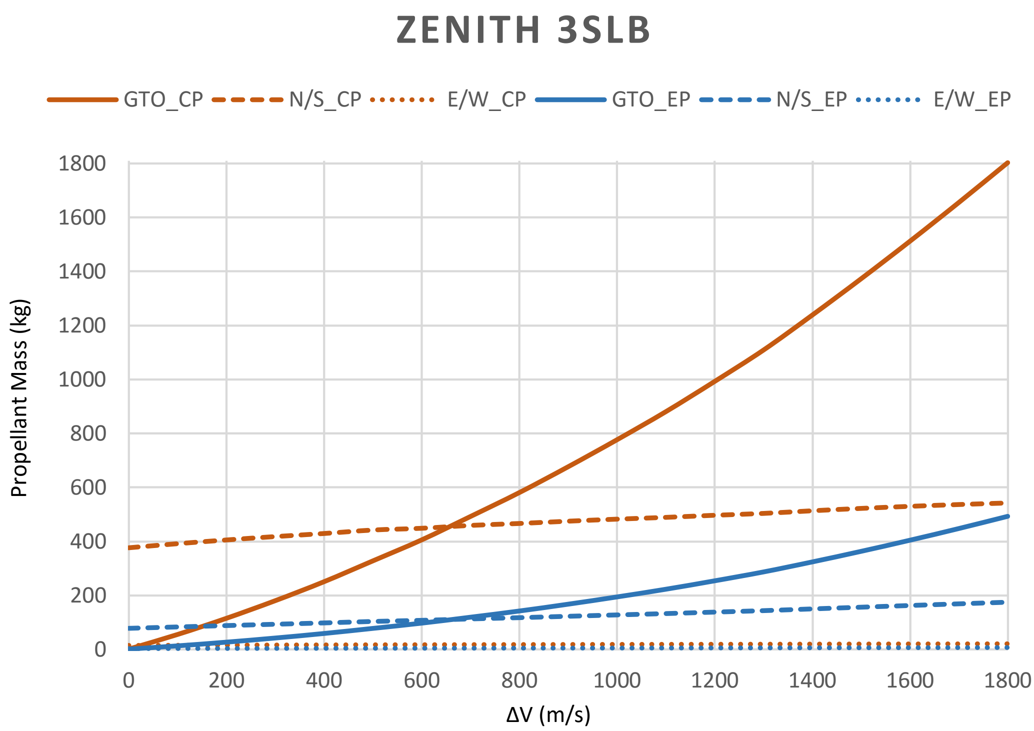
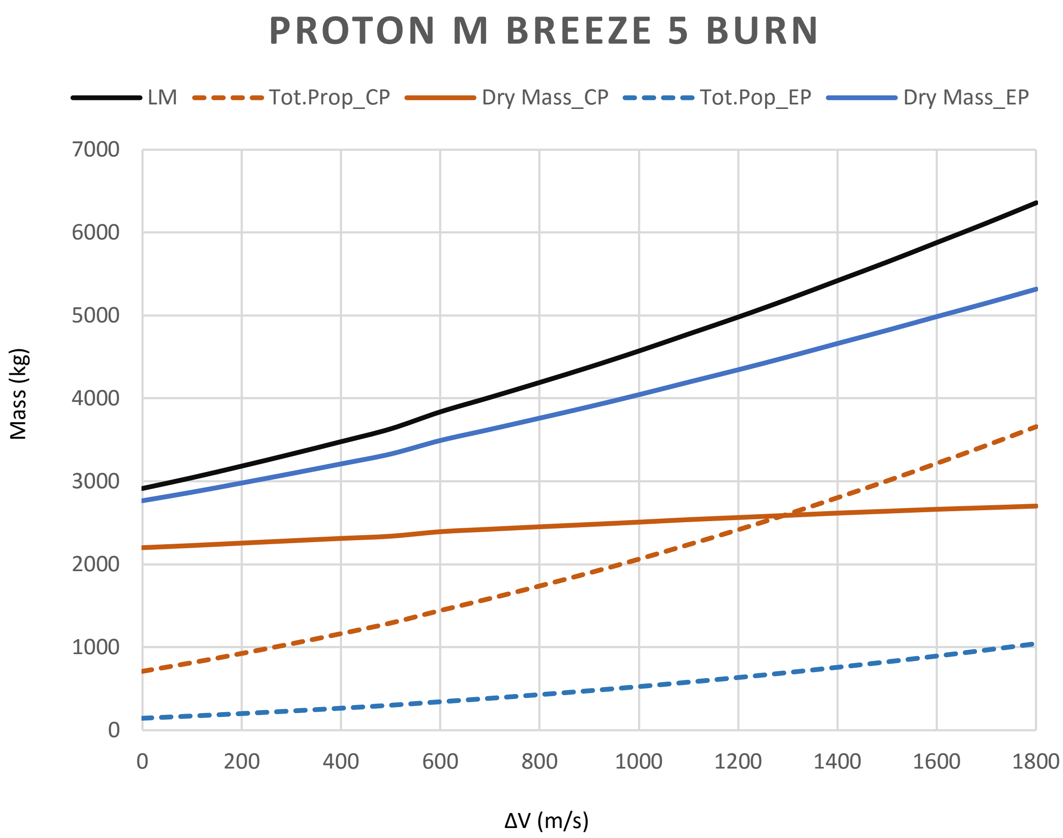


Figure 2: Propellant requirements of GEO satellites with CP and EP for Proton M Breeze 5 burn and Zenith 3SLB launchers.



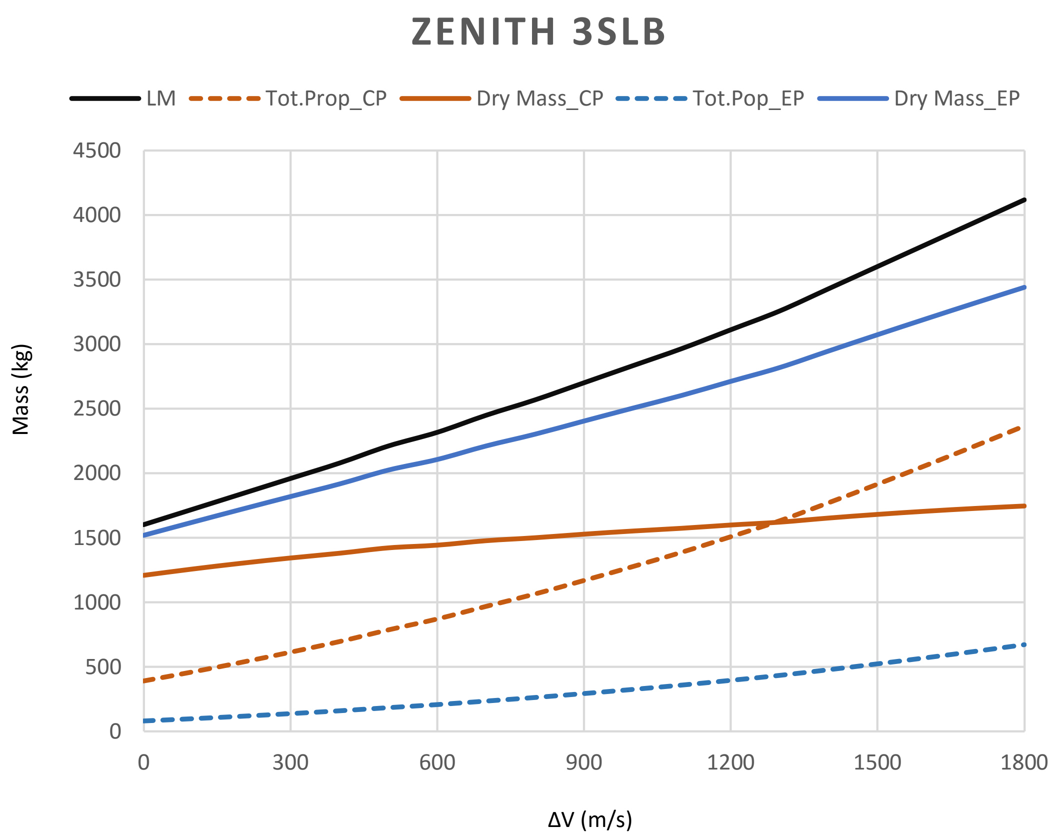


Figure 3: Satellite dry mass (kg) vs launcher ΔV performance (m/s) for CP and EP.

It is seen from Figure 2 and Figure 3 that, for example, Proton M Breeze 5 Burn launcher can insert satellite having a launch mass of 2910 kg directly into GEO. The dry mass of the satellite with CP is 2200.13 kg while 2763.93 kg with EP, i.e. 563.81 kg increase in dry mass and 146.07 kg of propellant is required for GEO satellite with EP while it requires CP propellant of 709.87 kg for 15-year mission life. i.e. for the same satellite LM of 2910 kg, CP propellant mass/LM is 24.39% while EP propellant mass/LM is 5.02% and CP dry mass/LM is 75.61% while EP dry mass/LM is 94.98%, see Fig 4.

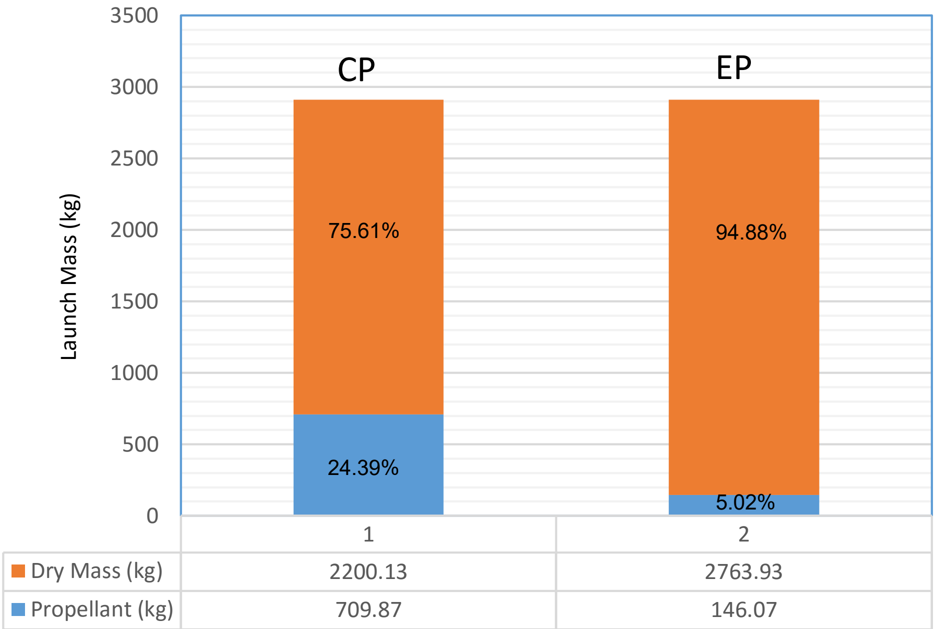


Figure 4: Satellite dry mass (kg) vs Propellant mass (kg) for CP and EP when Direct Injection to GEO (DI) using Proton M Breeze 5 Burn launcher with LM=2910 kg.

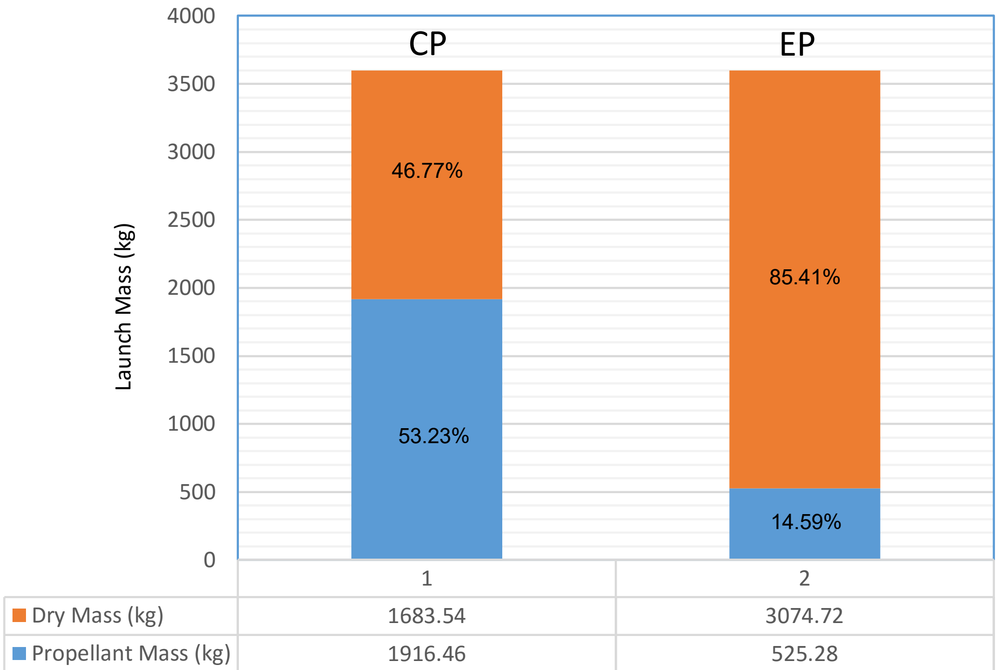


Figure 5: Satellite dry mass (kg) vs Propellant mass (kg) for CP and EP when GTO to GEO using Zenith 3SLB launcher with LM=3600 kg and ΔV=1500 m/s.

When Zenith 3SLB is used, satellite having a launch mass of 3600 kg requires ΔV of 1500 m/s to reach GEO, see Fig 3. The dry mass of the satellite is 1683.54 for the satellite with CP while 3074.72 kg for the satellite with EP, i.e. 1391.18 kg increase in dry mass. In this case, required propellant for a 15-year mission life is 525.28 kg for EP while 1916.46 kg for CP. i.e. for the same satellite LM of 3600 kg, CP propellant mass/LM is 53.23% while EP propellant mass/LM is 14.59% and CP dry mass/LM is 46.77% while EP dry mass/LM is 85.41%, see Fig 5.

For the satellites having a same dry mass of 1684 kg, the launch mass of the satellite would be 3600 kg and requiring ΔV of 1500 m/s to reach GEO with CP while it would be 1793 kg and requiring ΔV of 160 m/s to reach GEO with EP (i.e. 50.2% decrease in satellite LM), see Fig 6.

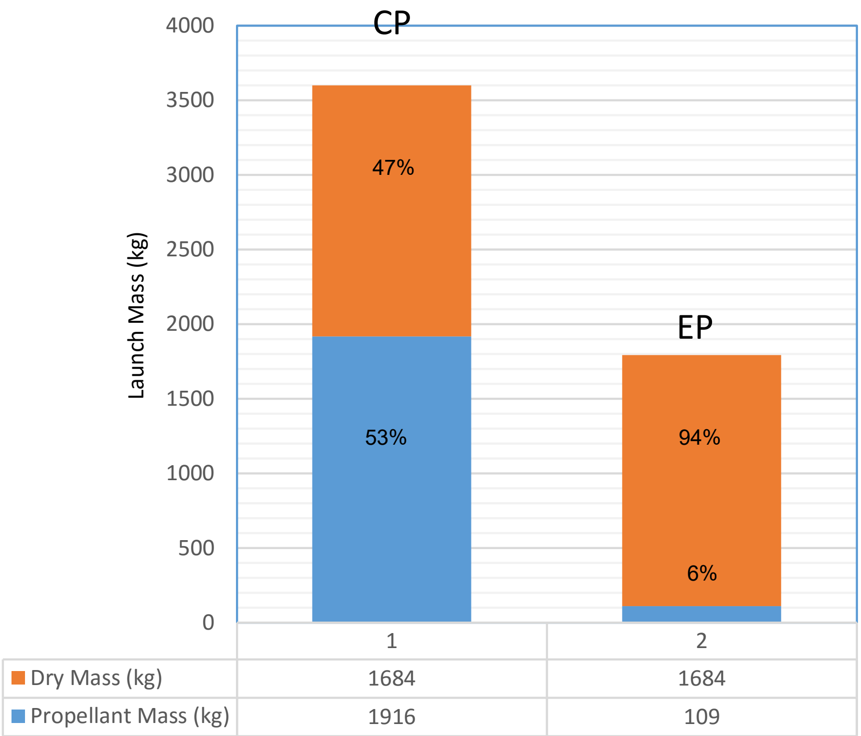


Figure 6: Satellite launch mass (kg) vs Propellant mass (kg) for CP and EP when GTO to GEO using Zenith 3SLB launcher with same Dry Mass=1684kg.

CONCLUSION

The primary aim for communication satellite operators is to minimize the launch mass while to maximize payload mass. CPS (Chemical Propulsion System) constitutes almost 55% of LM of the GEO satellite having a 15-year mission life. EP can significantly reduce the satellite mass since the specific impulse of EP is higher than CP, i.e. having high propellant efficiency, resulting an important amount of increase in payload mass or satellite lifetime since satellite lifetime is determined by the amount of S/K propellant it can store. EP also reduces LM and the launch cost significantly since it enables using smaller and cheaper launchers (or dual launch with half of the launch cost).

The full benefits of EP can be obtained when DI method is used. Since thrusters will be used only for S/K hence the lifetime of the satellite will be increased more, time to transit to GEO will be drastically reduced and risks in GTO will be eliminated.

In conclusion, since EP is cost efficient than CP, the usage of EP in GEO satellites will be more and more.

References

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