AE 240 COURSE PROJECT

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Proton-K/17S40, Iridium 28

Objective: To launch Iridium 28 satellite with another Iridium satellite in their LEO orbits.

IRIDIUM SATELLITES

The Iridium satellite constellation is a system of 66 active communication satellites and spares around the Earth. It allows worldwide voice and data communications using handheld devices. The Iridium network is unique in that it covers the whole earth, including poles, oceans and airways. The satellites used are frequently visible in the night sky as short-lived bright flashes, known as Iridium flares. The Iridium satellites orbit at an altitude of approximately 483 miles above the earth (and travel at approximately 16,689 mph resulting in a complete orbit of the earth approximately every 100 minutes).

Satellite: Iridium 28
Launch Vehicle: Proton-K/17S40
Launch date: September 14, 1997
Source: United States (US)
Launch Site: TYURATAM MISSILE AND SPACE COMPLEX (TTMTR), Baikonur Cosmodrome, Kazakhstan
Orbit type: Low Earth Orbit (LEO)
Mission succeed.

ORBITAL PARAMETERS

Perigee height: 778.2 km
Apogee height: 781.2 km
Inclination: 86.3997 °
Period: 100.3 minutes
Semi-major axis: 7150.7 km
Average Speed: 7.47 km/s
Reaction Control System (RCS): 4.0828 m^2 (large)
Eccentricity: 0.0002051
The right ascension of ascending node: 52.0811°
The argument of perigee: 77.5128°
Revolutions per day: 14.35757281
Mean anomaly at epoch: 282.6298°
Perigee passage time: 78.7 min
Ascending node: 230.9°
Orbit number at epoch: 23797
Apoapsis: 7152.2 km
Periapsis: 7149.2 km

Given mean anomaly at epoch = 282.68298°

$$n = \sqrt{\frac{\mu}{a^3}} = \frac{1}{a}\sqrt{\frac{\mu}{a}}$$

$$= \frac{1}{7150.7\times10^3}\sqrt{\frac{3.986\times10^{14}}{7150.7\times10^3}}$$

$$= \frac{7.46611\times10^3}{\cancel{7}\,7150.7\times10^3}$$

$$n = 1.04411\times10^{-3}\ s^{-1}$$

$$\overline{M} = n\,\overline{T}_0$$

$$\overline{T}_0 = \frac{\overline{M}}{n} = \cancel{1.04411\times10^{-3}}\quad \frac{282.6298\times\frac{3.14}{180}}{1.04411\times10^{-3}}$$

$$\overline{T}_0 = 4722.03\ sec$$

$$\boxed{\overline{T}_0 = 78.7\ min}$$

* Time period:

$$\cancel{T = 2\pi a\sqrt{\frac{a}{\mu}}}\qquad T = 2\pi a\sqrt{\frac{a}{\mu}}$$

$$\cancel{T = \frac{2\pi}{M}}\qquad T = \frac{2\pi}{n}$$

$$= \frac{2\times3.14}{1.04411\times10^{-3}}$$

$$\boxed{\begin{aligned} T &= 6014.692\ sec \\ T &= 100.3\ min \end{aligned}}$$

IRIDIUM 28

Payload: Iridium s/n SV028
Mass: 689 kg (1,518 lb)
Nation: USA
Agency: Iridium
Manufacturer: Lockheed, Motorola
Program: Iridium
Class: Communications
Type: Civilian communications satellite
Spacecraft: LM 700

LAUNCH VEHICLE: Proton-K/17S40

Status: Retired 2002
First Launch: 06/06/1997
Last Launch: 17/10/2002
Number: 6
Payload: 6,000 kg (13,200 lb)
Thrust: 8,847.00 kN (1,988,884 lbf)
Gross mass: 708,410 kg (1,561,770 lb)
Height: 59.00 m (193.00 ft)
Diameter: 4.15 m (13.61 ft)
Span: 7.40 m (24.20 ft)
Apogee: 1,500 km (900 mi)
LEO Payload: 6,000 kg (13,200 lb) to a 1,500 km orbit at 63.00 degrees.
Launch Price $: 70.000 million in 1994 dollars.

Stage Data - Proton 8K82K / 17S40

Stage 1. 1 x Proton K-1:
- **Gross Mass:** 450,510 kg (993,200 lb)
- **Empty Mass:** 31,100 kg (68,500 lb)
- **Thrust (vac):** 10,470.158 kN (2,353,785 lbf)
- **Isp:** 316 sec
- **Burn time:** 124 sec
- **Diameter:** 4.15 m (13.61 ft), **Span:** 7.40 m (24.20 ft), **Length:** 21.20 m (69.50 ft)
- **Propellants:** N2O4/UDMH
- **No Engines:** 6, **Engine:** RD-253-11D48, **Status:** In Production

Stage 2. 1 x Proton K-2:
- **Gross Mass:** 167,828 kg (369,997 lb)
- **Empty Mass:** 11,715 kg (25,827 lb)
- **Thrust (vac):** 2,399.216 kN (539,365 lbf)
- **Isp:** 327 sec
- **Burn time:** 206 sec
- **Diameter:** 4.15 m (13.61 ft), **Span:** 4.15 m (13.61 ft), **Length:** 14.00 m (45.00 ft)
- **Propellants:** N2O4/UDMH
- **No Engines:** 4, **Engine:** RD-0210, **Status:** In Production

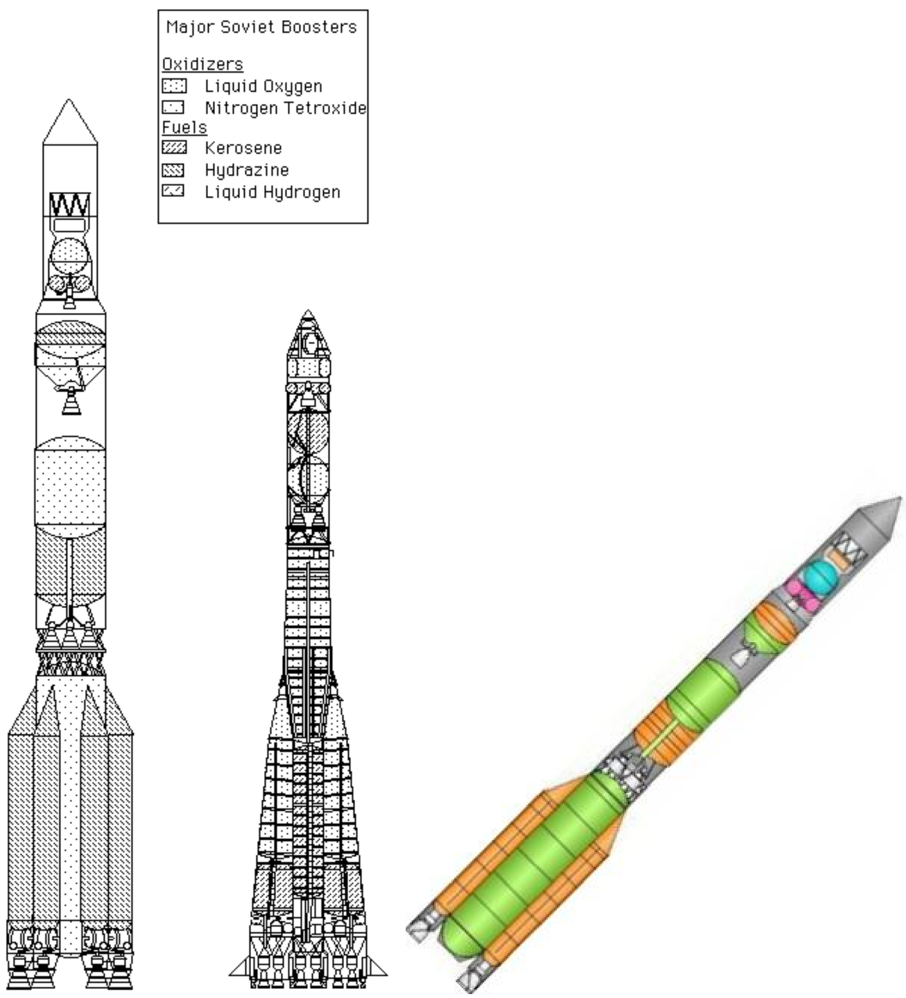
Stage 3. 1 x Proton K-3:

- **Gross Mass:** 50,747 kg (111,877 lb)
- **Empty Mass:** 4,185 kg (9,226 lb)
- **Thrust (vac):** 630.170 kN (141,668 lbf)
- **Isp:** 325 sec
- **Burn time:** 238 sec
- **Diameter:** 4.15 m (13.61 ft), **Span:** 4.15 m (13.61 ft), **Length:** 6.50 m (21.30 ft)
- **Propellants:** N2O4/UDMH
- **No Engines:** 1, **Engine:** RD-0212, **Status:** In Production

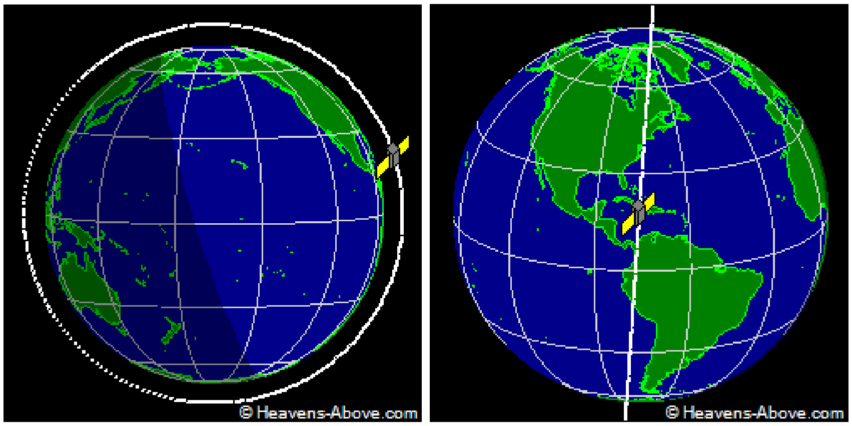
Stage 4. 1 x Proton 17S40:

- **Gross Mass:** 14,600 kg (32,100 lb)
- **Empty Mass:** 3,300 kg (7,200 lb)
- **Thrust (vac):** 85.020 kN (19,113 lbs)
- **Isp:** 352 sec
- **Burn time:** 450 sec
- **Diameter:** 3.70 m (12.10 ft), **Span:** 3.70 m (12.10 ft), **Length:** 7.10 m (23.20 ft)
- **Propellants:** Lox/Kerosene
- **No Engines:** 1, **Engine:** RD-58M, **Status:** In Production.

Also known as Block DM-5. The commercial version is Block DM2, with an Iridium dispenser, designed for the insertion of multiple LM 700 (Iridium) spacecraft into medium earth orbit. With guidance unit, modification of 11S861 stage for heavier payloads and with different payload adapter.



(Proton 8K82K / 17S40 Launch vehicle)



(Iridium satellite orbit view)

How the nature of the orbit/trajectory is connected with the objectives of the mission?

Communication occurs through a constellation of LEO satellites; global coverage requires a large number of spacecraft. Low-Earth-orbit (LEO) satellites typically communicate through inter-satellite links, but some may operate independently. Iridium satellites are communication satellites and our satellite iridium 28 is also a communication satellite that needs to be an LEO satellite.

Trajectory:

Pg.No:
Date: / /20

Stages Information from internet,

	1	2	3	4
m_s	31100	11715	4185	3300
m_p	419410	156113	46562	11300
Thrust (kN)	10470.158	2399.216	630.170	85.020
I_{sp} (sec)	316	327	325	352
t (sec)	124	206	238	450

Now if we assume constant mass flow rate, $\dot{m} = \beta$

$$\beta = \frac{\text{Thrust}}{g_0 I_{sp}}$$

$$t_b = \frac{m_p}{\beta} = g_0 \left(\frac{m_p I_{sp}}{\text{Thrust}}\right)$$

Putting values of m_p, I_{sp} & Thrust for each Stage we got almost experimented time value

$$t_B \text{ for stage 1} = (9.81)\left(\frac{419410 \times 316}{10470.158 \times 10^3}\right)$$

$$= 124.177 \text{ sec.}$$

Pg.No: ____ Date: / /20

t_B for stage 2 $= \dfrac{(9.81)\ (156113) \times 327}{2399.216 \times 10^3}$

$= 208.731$ sec.

t_B for stage 3 $= \dfrac{(9.81)\ (46562) \times 325}{630.170 \times 10^3}$

$= \cancel{232.54\ \text{sec}}\ 235.57$ sec

t_B for stage 4 $= \dfrac{(9.81)\ (11300)\ 352}{85020}$

$= 458.95$ sec.

→ We can see that as stage no. increase error between theoretical time and experiment time is increases.

→ Seems it to be good to assume constant burn rate profile for mission.

→ Now for constant burn rate β, the ascent misson formulae are,

$$m(t) = m_0 - \beta t \qquad t_b = \frac{m_p}{\beta}$$

$$V_b = g_0 I_{sp} \ln \frac{m_0}{m_f} - \tilde{g}\left(\frac{m_p}{\beta}\right) \qquad m_f = m_0 - m_p$$

→ Here I made following assumptions:

① There is not curvilinear motion
② There is no drag
③ I have used vaccum thrust values.

→ Now if V_0 is ~~burn~~ burnout velocity of previous stage and h_0 is height obtained from previous stage, burnout velocity and height obtained in next stage are,

$$V_b = g_0 I_{spi} \ln \frac{m_{oi}}{m_{fi}} - \tilde{g}\left(\frac{m_{pi}}{\beta_i}\right) + V_0$$

$$h_b = \frac{m_{oi} g_0 I_{spi}}{\beta_i}\left[(1-d_i)\ln(1-d_i) + d_i\right] - \frac{1}{2}\tilde{g}\left(d_i \frac{m_{oi}}{\beta_i}\right)^2 + V_0 d_i \frac{m_{oi}}{\beta_i} + h_0$$

where $d_i = \frac{m_{pi}}{m_{oi}}$

a_i = repective parameters of ith stage.

→ V_0 and h_0 for 1st stage is zero.

→ Now if we put all values in formulas, we get final stage burnout velocity and height obtained.

I took help of google spreadsheet to do all calculations.
Link for sheet:
https://docs.google.com/spreadsheets/d/1Y-bPju38DYMivrVUaWK42p-iIz5sPLb_z-VH9KZ4HP8/edit#gid=0

Table:

Stage		1	2	3	4
		450510	167828	50747	14600
ms(kg)		31100	11715	4185	3300
mp(kg)		419410	156113	46562	11300
Thrust(N)		10470158	2399216	630170	85020
Isp(sec)		316	327	325	352
time(sec)		124	206	238	450
mi(kg)		708410	257900	90072	39325
mf(kg)		289000	101787	43510	28025
beta(kg/s)		3377.513903	747.9155951	197.6538854	24.62121212
time(Theorically)		124.177135	208.7307726	235.5734111	458.9538462
lambda		0.5920441552	0.6053237689	0.516942002	0.2873490146
h1(km)	0	71.48630208	383.526788	622.206064	762.5386886
g_h1(m/s^2)	9.81	9.593502871	8.727590497	8.142008784	7.824816751
g_bar1(m/s^2)	9.81	9.701751436	9.160546684	8.43479964	7.983412767
h2(km)	0	71.48630208	381.1145361	609.5264801	729.9976389
g_h2(m/s^2)	9.81	9.593502871	8.733827627	8.1716143	7.896697124
g_bar2(m/s^2)	9.81	9.701751436	9.163665249	8.452720963	8.034155712
V burnout(m/s)	0	1574.677074	2644.261261	2972.854805	455.3390882
h burnout(km)	0	72.32089639	392.8363497	629.1668148	772.1931835
g_h burnout	9.81	9.591017766	8.703582191	8.125824508	7.803679537

Burnout velocity came out is 455.34 m/s and height obtained is 772.19 km.

Now, for our ~~sa~~ satellite,

$h_a = 781.2$ km $\quad R_e = 6371$ km

$h_p = 778.2$ km $\quad \mu = 3.986 \times 10^{14}$ m^3/s^2

$r_a = a(1+e) = 7152.2 = h_a + R_e$

$r_p = a(1-e) = 7149.2 = h_p + R_e$

$a = 7150.7$ km

$$\frac{V_a^2}{2} = \frac{\mu}{r_a} - \frac{\mu}{2a}$$

$V_a = 7464.9$ m/s for $h_a = 781.2$ km

$V_p = \frac{r_a v_a}{r_p} = 7468.035$ for $h_p = 778.2$ km

$V_b = 455.34$ m/s $\quad h_b = 772.19$ km

→ We will have to increase velocity of our vehicle from 455.34 m/s to 7464.9 m/s. It can be done in 5th stage. Our rocket have additional stage if we want.

→ Also if we apply curvilinear motion we may have required velocity.

Parameters achieved theoretically after ascent mission:

Burnout velocity 455.34 m/s direction radially outward(θ=0°) at height 772.19 km.

Parameters we need for satellite:

Burnout velocity = speed of orbiting satellite = 7464.9 m/s at apogee or 7468.035 m/s at perigee and direction local horizon(θ=90°).

Reason for error:

- We ignored drag force and used vacuum thrust for value.
- We don't applied curvilinear motion. (If we apply curvilinear motion we may get desired velocity at desied height)

One applicable solution is we can apply another extra stage in our rocket name DM-5 block to achieve desired velocity and height. It is typically used for heavy payload in Proton-K/17S40.

References:

http://www.astronautix.com/p/proton-k17s40.html
https://www.n2yo.com/satellite/?s=24948
http://www.astronautix.com/l/lm700.html
https://heavens-above.com/orbit.aspx?satid=24948&lat=0&lng=0&loc=Unspecified&alt=0&tz=UCT&cul=en