H-II A 202, IGS-Optical 7

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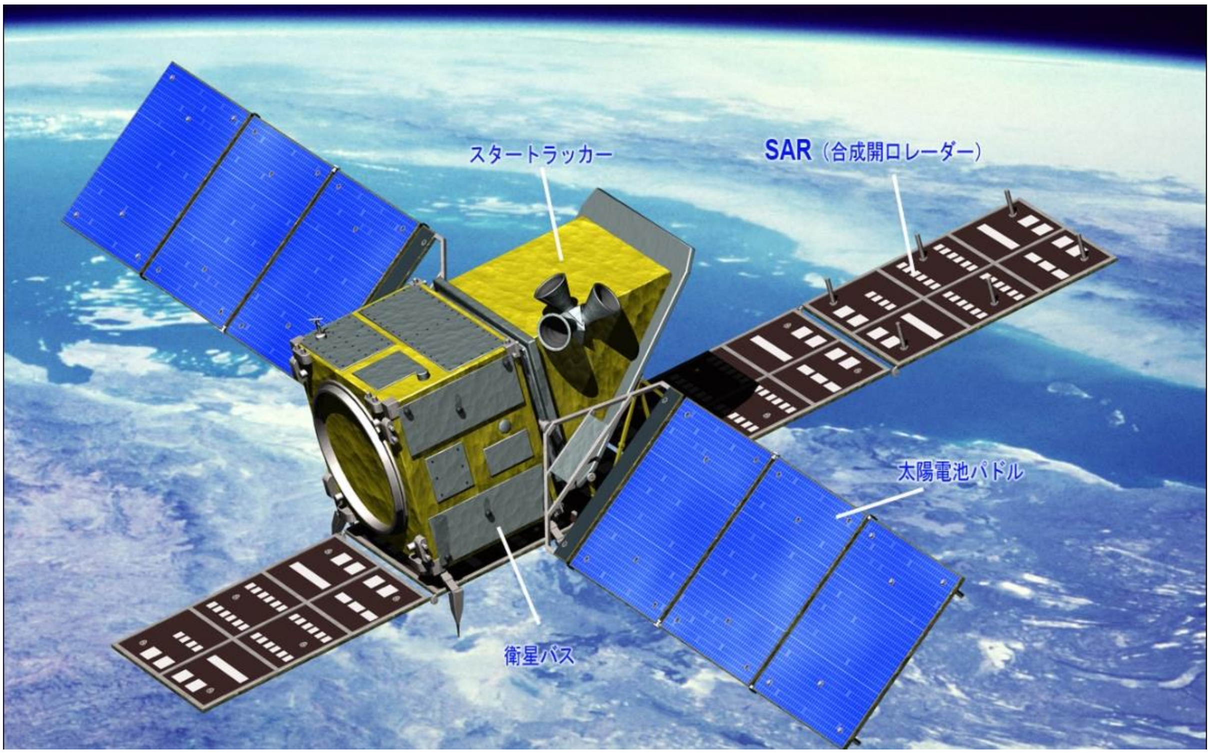
Launch Vehicle: H-II A 202
Payload: IGS-Optical 7

Mission Objective

IGS Optical 7 is part of the Information Gathering Satellite (IGS) or Joho Shushu Eisei (JSE) system, consisting of spacecraft collecting optical and radar images of the Earth for surveillance with the primary mission being the development of an independent reconnaissance capability to monitor future threats from North Korea. Repeated testing of North Korea's Taepo Dong missiles, some of them overflying Japanese territory, provided the political impetus for the project. The constellation can also be used for disaster monitoring and other civilian applications by the Japanese government.
IGS Optical 7 is the eighteenth IGS spacecraft to launch including the two satellites that failed to reach orbit.

IGS-Optical 7



General Information

Launch date:	9 February 2020
Launch site:	Tanegashima Space Centre, Pad 1 of the Yoshinobu Launch Complex 30.3749° N, 130.9576° E
Launch vehicle:	H-II A 202
Time of launch:	10:34 local time 01:34 UTC, during a five-minute launch window
Mission length:	NA
Mass:	1000kg*
Type of orbit:	Sun synchronous, Low earth orbit
Height:	515 km (apogee), 511 km (perigee) *
Orbit period:	94.4min*
Inclination:	97.5*
Eccentricity:	2.9 * 10 ^-4 (almost circular)
Resolution:	>30cm*
Status:	Operational

Launch objective

"Launch the satellite in January end, 2020 by H-II A 202 to a 515 km sun synchronous low earth orbit"

Reason for the chosen orbit : The constellation of satellites collect optical and radar images of the earth using various instruments which require power to function. Since they have a mission length of about 1-2 years they require a continuous supply of power which is provided from the sun using solar panels. To avoid solar panels facing away from the sun for large time intervals a sun synchronous orbit is chosen.

A LEO orbit could be chosen -
1 - Because of the limit of launch vehicle
2 - The specifications of the instruments used

* The spacecraft's specifications, including its imaging performance, are kept secret by the Japanese government. The Information Gathering Satellites are operated by the Cabinet Satellite Intelligence Centre, which reports directly to the Japanese government's executive leadership. The above specifications are assumptions based on data from other satellites in the constellation.
Proof: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/displayTrajectory.action?id=2020-009A

H-II A 202

General Information

Type	H-IIA 202
Manufacturer	Mitsubishi Heavy Industries
Height	53m
Diameter	4m
Launch Mass	285,000kg
Stages	2
Boosters	2
Mass to LEO	11,000kg
Mass to SSO	3,600-4,400kg
Mass to GTO	4,100kg

1st stage propulsion details

Diameter	4m
Length	37.2m
Propellant	Liquid Hydrogen
Oxidizer	Liquid Oxygen
Launch Mass	114,000kg
Propellant Mass	102,800kg
Tank Structure	Aluminum, isogrid
Guidance	From 2nd Stage
LOX Mass	87,100kg
LH2 Mass	15,700kg
Propulsion	1 LE-7A Engine
Engine Type	Staged Combustion
Propellant Feed	Turbopump
Total Thrust	1,078kN
Engine Length	3.4m
Engine Dry Weight	1,714kg
Burn Time	390sec
Specific Impulse	349s (SL) 446s (Vac)
Chamber Pressure	1,840psi (12.7MPa)
Nozzle Ratio	52:1
Restart Capability	No
Tank Pressurization	Helium (252 liters, 308bar)
Attitude Control	Engine Gimbaling, Auxiliary Thruster
Avionics	Guidance Computer, Gyro Package
	Flight Termination, VHF Telemetry
	Lateral Acceleration Unit

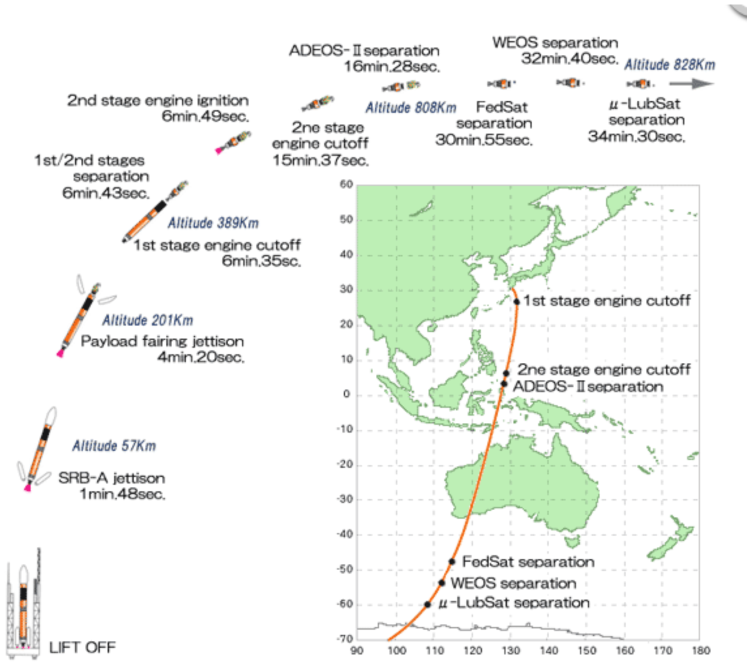
Solid Rocket Booster SRB-A (2 units)

Type	SRB-A
Diameter	2.5m
Length	15.1m
Mass	76,400kg
Propellant	Solid
Propellant Mass	65,040kg
Motor Case	Monolithic Carbon-Fiber-Reinforced Polymer
Thrust	2,260kN
Burn Time	100sec
Chamber Pressure	11.8MPa
Specific Impulse	280s

2nd stage propulsion details

Diameter	4m
Length	9.2m
Propellant	Liquid Hydrogen
Oxidizer	Liquid Oxygen
Tank Structure	Aluminum isogrid
Propellant Mass	16,600kg
LOX Mass	14,100kg
LH2 Mass	3,100kg
Propulsion	1 LE-5B
Engine Type	Expander Bleed (Chamber)
Total Thrust	137kN
Engine Diameter	2.49m
Engine Length	2.79m
Engine Dry Weight	269kg
Burn Time	530sec
Specific Impulse	447s
Chamber Pressure	519psi (3.58MPa)
Restart Capability	Up to 16 Starts
Throttle Settings	100%, 60%, 3% (Idle Mode)
Ignition System	Spark Ignition
Tank Pressurization	Helium (257liters, 130bar)
Avionics	Guidance Control Computer
	Inertial Measurement Unit
	Flight Termination
	UHF Telemetry, C-Band Tracking

Ascent Mission sequence



Ascent Mission calculations

The moment of launch for Japanese rockets is termed X-0

1. Two or three seconds before the countdown reaches this mark the LE-7A engine that powers H-IIA's first stage is ignited. AT X-0 the rocket's two SRB-A3 motors are ignited powering H-IIA F-41 away from its launch pad.

Vertical Lift Off

LE7A engine + 2 SRB motors firing - parallel staging, T = 1 min 39 sec

```
import math

M_payload = 1000
M_launch_vehicle_1stage = 114000
M_launch_vehicle_2stage = 20000
M_boosters = 76400          #2 units

g0 = 9.81
t1 = 99               #sec

#1 boosters
thrust_b = 2260000             #N
Isp_b = 280                    #sec
burn_rate_b = thrust_b/(g0*Isp_b)
Mp_burnt_b = burn_rate_b * t1

#LE-7A engine
thrust_LE7A = 1078000        #N
Isp_LE7A = 446               #sec
burn_rate_LE7A = thrust_LE7A/(g0*Isp_LE7A)
Mp_burnt_LE7A = burn_rate_LE7A * t1

Isp_effective = (burn_rate_b*Isp_b + burn_rate_LE7A*Isp_LE7A)/(burn_rate_b + burn_rate_LE7A)
burn_rate_effective = burn_rate_b + burn_rate_LE7A
```

```
Mp_burnt_total = burn_rate_effective * t1
M_i = M_payload + M_launch_vehicle_1stage + M_launch_vehicle_2stage + M_boosters
M_f = M_i - Mp_burnt_total

V0 = g0* Isp_effective * math.log(M_i/M_f) - g0*t1
Lambda = Mp_burnt_total/M_i
H0 = ((M_i*g0*Isp_effective)/burn_rate_effective) * ((1-Lambda)*math.log(1-Lambda) + Lambda)
- 0.5*g0*((Lambda*M_i)/burn_rate_effective)**2
X0 = 0

print(V0)
print(H0)
print(M_f)
```

```
1197.2100775247704
46935.8535786603
105553.06584229117
```

Without drag:

At T= 1min 39s V = 1.197 km/s H = 46.93 km X = 0

The burn rate is quite high ~1000kg/s. Assume Drag to be max at 15sec

Implimenting effect of drag

```
# for fast burn D is max at 15 sec
Mp_total_burnt15 = burn_rate_effective * 15
M_f15 = M_i - Mp_total_burnt15
Lambda15 = Mp_total_burnt15/M_i
V15 = g0* Isp_effective * math.log(M_i/M_f15) - g0*15
H15 = ((M_i*g0*Isp_effective)/burn_rate_effective) * ((1-Lambda)*math.log(1-Lambda) + Lambda)
- 0.5*g0*((Lambda*M_i)/burn_rate_effective)**2

print(V15)
print(H15)
```

```
99.165518419124
46935.8535786603
```

```
# at 976.85m
rho = 1.112
CD0 = 1
Sr = 3.14
D = 0.5* rho * V15**2 * CD0 * Sr
ad = D/(2*M_f15)

Vf = V0 - ad*t1
Hf = ((M_i*g0*Isp_effective)/burn_rate_effective) * ((1-Lambda)*math.log(1-Lambda) + Lambda)
- 0.5*g0*((Lambda*M_i)/burn_rate_effective)**2

print(Vf)
print(Hf)
print(ad)
```

```
1192.8600739175938
46935.8535786603
0.043939430375520894
```

Assuming buff nose of rocket: CD0 = 1
With drag:
At T= 1min 39s V = 1.1928 km/s H = 46.935 km X = 0

2. About 99 seconds after lift-off the two SRB boosters are burned out, depleting their solid propellant. For next nine seconds the rocket ascends using LE7A engine alone.

Boosters burned out

LE7A operates alone - Constant pitch rate, T=1 min 48 sec

```
t2 = 9
M_i = M_f
# Assume
q0 = 0.0046  #rad/s
theta0 = math.asin(q0*Vf/g0)
thetab = t2*q0 + theta0
V2 = g0*math.sin(thetab)/q0
H2 = g0*(math.cos(2*theta0)-math.cos(2*thetab))/(4*q0**2) + Hf
X2 = g0*(thetab-theta0 - math.sin(2*thetab)/2 + math.sin(2*theta0)/2)/(2*q0**2)

M_f = M_i*math.exp(-2*g0*(math.sin(thetab)-math.sin(theta0))/(q0*g0*Isp_LE7A))


print(V2)
print(H2)
print(X2)
print(thetab*180/3.14)
print(M_f)
```

```
1265.0038357116284
55973.54717796942
6377.284009151686
36.40088359230373
102128.90344419851
```

At T = 1 min 48 sec V = 1.265 km/s H= 55.973 km theta = 36.4 deg

Constant pitch rate is assumed to be of some small constant value since we want the inclination to start changing slowly.

3. After 9 secs boosters are jettisoned and the rocket ascends and changes inclination using LE7A engine.

Boosters jettisoned

LE7A alone - Constant specific turn maneuver, T = 6min 48 sec

```
import sympy
t3 = 5*60
M_i = M_f - 11360 #mass of booster structure
M_f = M_i - burn_rate_LE7A*(t3)
n0 = math.log(M_i/M_f)*Isp_LE7A/t3
theta0 = thetab
thetab = 1.2
k = V2 * math.sin(theta0)/ math.tan(theta0/2)**n0
V3 = k* math.tan(thetab/2)**n0 / math.sin(thetab)

k_ = V2/((math.tan(theta0/2))**(n0-1) + (math.tan(theta0/2))**(n0+1))
H3 = H2 +( (k_**2)/(2*g0) ) * ((math.tan(thetab/2)**(2*n0-2))/(n0-1) - (math.tan(thetab/2)**(2*n0+4))/(n0+2)
   - (math.tan(theta0/2))**(2*(n0-1))/(n0-1) + (math.tan(theta0/2))**(2*(n0+2))/(n0+2))


print(k)
print(n0)
print(V3)
print(H3)
print(t3)
```

```
12164.903456483245
2.503205475769579
5046.653520400299
398773.807753226
300
```

At T = 6min 48 sec V = 5.046km/s H = 398.773 km theta = 68.75 deg

4. Since the rocket is now well above the atmosphere where there is negligible drag the payload fairing is separated. This was the nose cone that encloses the IGS Optical 7 satellite during the first few minutes of the flight, protecting the satellite from aerodynamic forces as H-IIA ascended through the dense lower regions of the atmosphere. As soon as the fairing was no longer needed to protect the satellite, it was jettisoned to reduce the vehicle's weight.

Payload fairing is separated

```
Dia = 2.9     #m
A = 3.14*Dia**2/4
M_fairing = 4.95 * A**1.15
M_fairing
```

```
43.37312355205423
```

5. The first stage burns for about 6min and 48 sec. After shutdown of its LE-7A engine the second stage ignition occurs with the second stage firing its LE-5B engine for about eight minutes to place its payload into a parking orbit.

1stage is separated

LE5B operated alone - constant burn rate, T = 14min 48 sec

```
t4 = 8*60
Thrust_LE5B = 137000
Isp_LE5B = 447
burn_rate_LE5B = Thrust_LE5B/(g0*Isp_LE5B)
M_i = M_payload + M_launch_vehicle_2stage - M_fairing
M_f = M_i - burn_rate_LE5B*(t3)

theta0 = thetab
thetab = math.pi/2
theta_avg = (theta0 + thetab)/2

V4 = V3 + g0* Isp_LE5B * math.log(M_i/M_f) - g0*math.cos(theta_avg)*t1
Lambda4 = (M_i-M_f)/M_i
H4 = H3 +((M_i*g0*Isp_LE5B)/burn_rate_LE5B) * ((1-Lambda4)*math.log(1-Lambda4) + Lambda4)
- 0.5*g0*((Lambda4*M_i)/burn_rate_LE5B)**2 + V3*Lambda4*M_i/burn_rate_LE5B



print(V4)
print(H4)
print(t4)
```

```
7646.287294423863
1822959.7382618983
480
```

At T = 14 min 48 sec V = 7.646 km/s H = 1822.959 km theta = 90 deg
Time of injection into perigee of parking orbit = 14min 48sec

Parking orbit parameters:

Calculating orbit parameters

```
mu = 3.986 * 10**14
Re = 6378000
r = H4 +Re

a = mu/(2*mu/r - V4**2)
a/1000
```

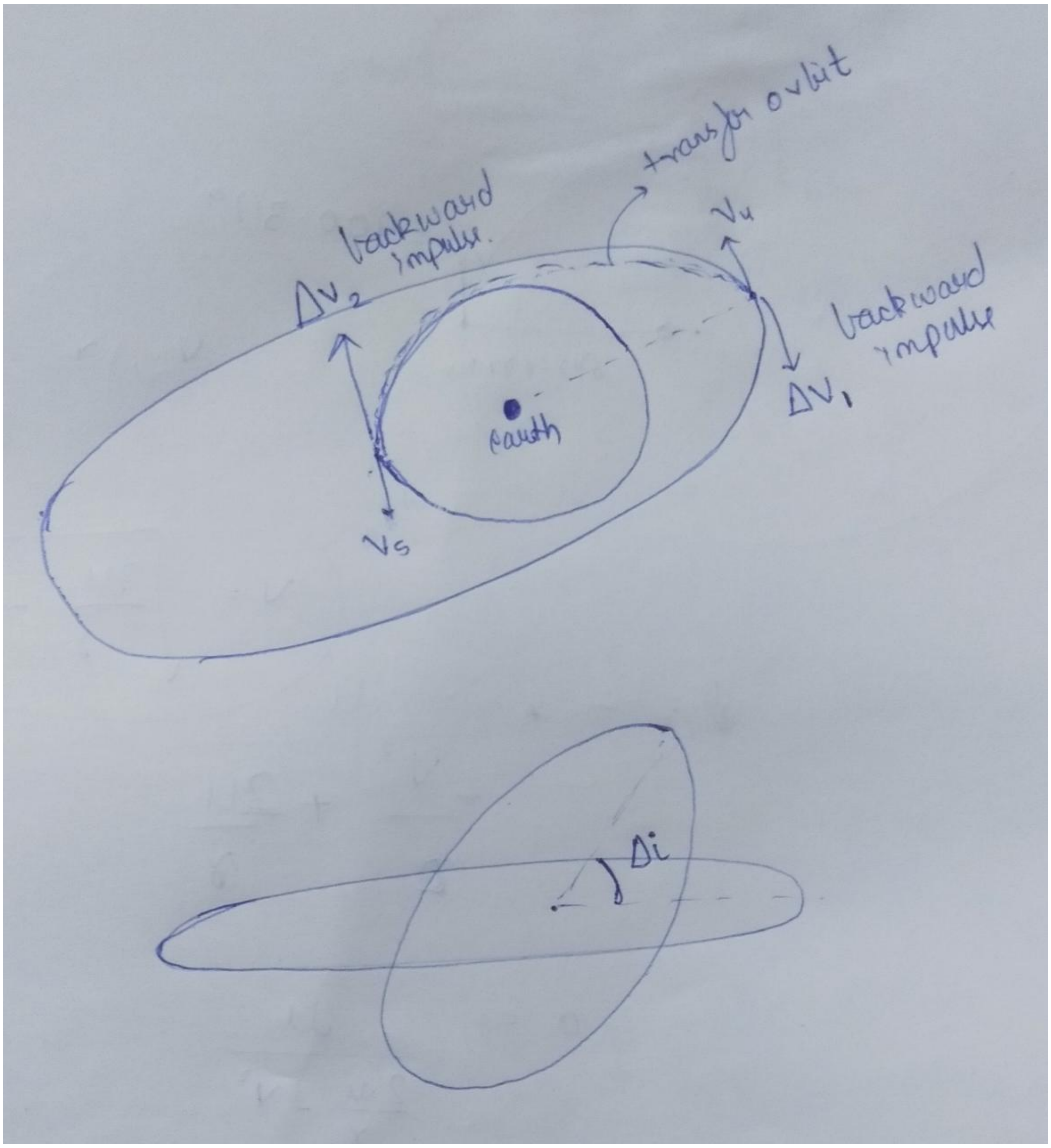
```
10288.46272340354
```

```
ap = 2*a - r
print(ap/1000 - Re/1000)
print(r/1000 - Re/1000)
e = 1 - r/a
print(e)
```

```
5997.965708545182
1822.9597382618977
0.20289746303819745
```

a = 10288.4627 km
apogee = Re + 5997.9657 km
perigee = Re = 1822.9597
e = 0.2028
True anomaly = 0 (it is injected at perigee)
Flight path angle = 90 deg (attained after ascent mission)
Inclination = 30 deg (obtained from the latitude of the launch site and from the assumption that the horizontal movement of the rocket in ascent mission happened along the 30 deg latitude in East direction which is most probable because of earth’s rotation)

Using orbital manoeuvre (Hoffmann transfer + inclination change) the desired orbit is attained



Hoffmann transfer

```
a1 = (515000+Re + r)/2
delV1 = V4 - (2*mu/r - mu/a1)**0.5
V_ap = V4 - delV1
print(delV1)
```

```
983.5321886564125
```

```
a2 = (515000+Re + 511000+Re)/2
delV2 = (2*mu/(515000+Re) - mu/a1)**0.5 - (2*mu/(515000+Re) - mu/a2)**0.5
V_appogee = (2*mu/(515000+Re) - mu/a2)**0.5
print(delV2)
print(V_appogee)
```

```
323.736842804311
7603.28859870124
```

```
V_perigee = (2*mu/(511000+Re) - mu/a2)**0.5
print(V_perigee)
```

```
7607.703340230461
```

Desired orbit parameters attained

delV1 = 983.5321 m/s
delV2 = 323.736 m/s
apogee = Re + 515 km
perigee = Re + 511 km
V apogee = 7603.2885 m/s
V perigee = 7607.703 m/s
e = 0.00029 (almost circular)
I = 30 deg

Inclination change maneuver

```
i_0 = 30
i_f = 97.5
delV3 = 2*V_appogee*math.sin(math.radians(i_f-i_0))
print(delV3)
```

```
14049.045432232995
```

delV3 = 14049.045 m/s
I = 97.5 deg (sun synchronous orbit)

REFERENCES

https://global.jaxa.jp/activity/pr/brochure/files/rocket01.pdf

https://www.nasaspaceflight.com/2020/02/h-iia-igs-optical-7-launch/

http://www.astronautix.com/i/igs.html#:~:text=Optical%2D3%20Verification%20Satellite%2C%20an,Japanese%20military%20optical%20surveillance%20satellite.

https://en.wikipedia.org/wiki/Information_Gathering_Satellite#External_links

https://global.jaxa.jp/projects/rockets/h2a/

https://www.engineeringtoolbox.com/standard-atmosphere-d_604.html

http://spaceflight101.com/members/wp-content/uploads/sites/54/2017/02/HIIA-202.pdf