

Part 3

No. 1



C.O.S.T ENGINEERING II™

Economics of Satellites, Rockets and Space Organizations

Lecture Series given by Dr.-Ing. Robert Alexander Goehlich



- Part 3: Basics about Rocket Science
and Space Transportation Systems -

Content

No. 2



- **General**
- **Rocket Science**
 - Ideal Rocket Equation
 - Earth's Atmosphere
 - Newton's Laws
 - Kepler's Laws
- **Definition**
 - Cost Engineering (Practice V)
- **Requests from Audience for Lectures**

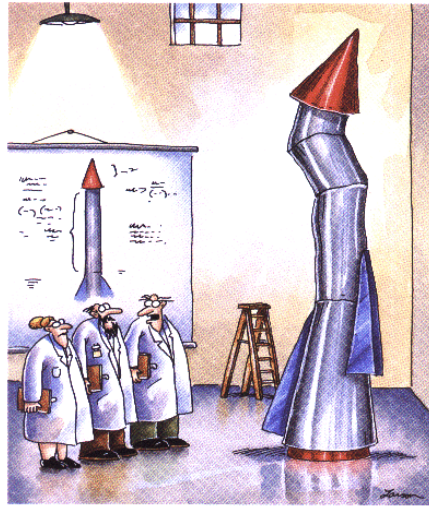
General

Goal of Today's Lecture

No. 3



„You will learn about basics of rocket science and do some exercises with selected examples.“



"It's time we face reality, my friends. ... We're not exactly rocket scientists."

General

Contact

No. 4



Dr.-Ing. Robert Alexander GOEHLICH
Mobile: +81-(0)90 1767 1667
Fax: +81-(0)45-566-1778
Email: mail@robert-goehlich.de
Internet: www.robert-goehlich.de



Mr. Akihiko Hara (Teaching Assistant)
Mobile: n.a.
Email: chicago@doi.ics.keio.ac.jp



Mr. Sindharta Tanuwijaya (Webmaster)
Mobile: n.a.
Email: zaraasran@yahoo.com



Keio University
Department of System Design
Engineering
(Space System Engineering)
Office 14-609/14-620
3-14-1 Hiyoshi
Kohoku-ku
Yokohama 223-8522
JAPAN

Rocket Equation

No. 5



$$\Delta p_{\text{exhaust}} = dM(v_e + v)$$

$$\Delta p_{\text{rocket}} = (M - dM) dv_e$$

$$dM(v_e + v) = (M - dM) dv_e \approx M dv_e$$

$$M dv_e + dM = 0 \quad \text{if } v_e \ll v$$

$$dv_e = -v \frac{dM}{M}$$

$$\int_{u_0}^u dv_e = -v \int_{M_0}^M \frac{dM}{M}$$

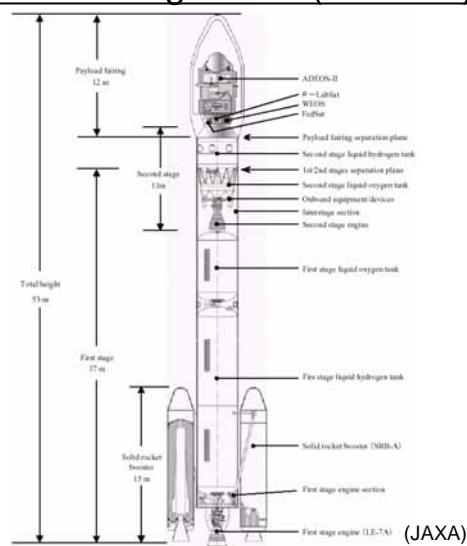
$$u = v \ln \left(\frac{M_0}{M} \right) + u_0.$$

where u is the final rocket velocity, v is the velocity of the exhaust gases, M_0 is the starting mass, M is the ending mass of the rocket and u_0 is the initial rocket velocity prior to the fuel burn. This equation was published by [Tsiolkovsky](#) in 1903.

Rocket Equation

Launch Vehicle Configuration (HII-A F4)

No. 6





Rocket Equation

Launch Vehicle Characteristics (HII-A F4) No. 7

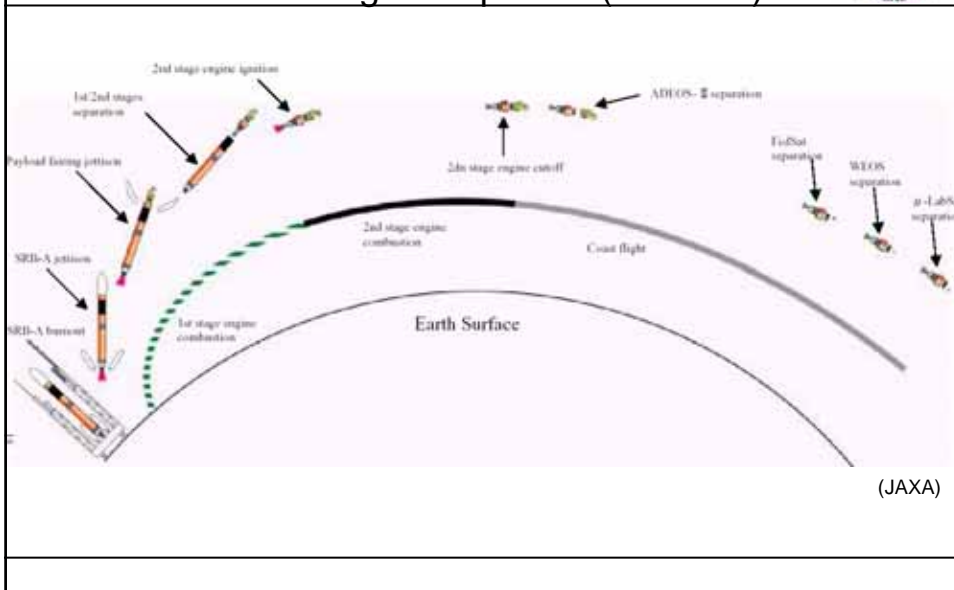
Name	H-IIA Launch Vehicle No.4 (H-IIA F4)			
Height (m)	53			
Total mass (t)	286 (without payloads)			
Inertial method	Inertial guidance system			
Each stage				
	1 st stage	Solid Rocket Booster (SRB)	2 nd stage	Payload Fairing
Height (m)	37	15	11	12
Outside diameter (m)	4.0	2.5	4.0	5.1
Mass (t)	114	150 (for two)	20	1.7
Propellant mass (t)	101	130 (for two)	17	
Thrust (KN)	1,100 ^{*1}	4,520 (for two) ^{*1}	137 ^{*1}	
Combustion time (s)	390	100	530	
Propellant type	Liquid oxygen/hydrogen	Polybutadiene composite solid propellant	Liquid oxygen/hydrogen	
Propellant supply system	Turbo pump	—	Turbo pump	
Impulse to weight ratio (s)	429 ^{*1}	280 ^{*1}	447 ^{*1}	

(JAXA)



Rocket Equation

Launch Vehicle Flight Sequence (HII-A F4) No. 8



Rocket Equation

Launch Vehicle Flight Plan (HII-A F4)

No. 9



Event	Time passed after liftoff			Distance on earth		Altitude		Inertial velocity
	hour	min.	sec.	km	km	km	km	km/s
1 Liftoff	0	0		0	0			0.4
2 Solid Rocket Booster (SRB-A) burnout	1	40		20	50			1.3
3 SRB-A jettison	1	47		23	57			1.3
4 Payload fairing jettison	4	20		153	202			1.8
5 1st stage engine cutoff	6	35		404	390			3.6
6 1 st /2 nd stages separation	6	43		426	405			3.6
7 2nd stage engine ignition	6	49		443	416			3.5
8 2nd stage engine cutoff	15	38		2662	808			7.4
9 ADEOS-II separation	16	28		2995	808			7.4
10 FedSat separation	30	55		8764	824			7.4
11 WEOS separation	32	40		9462	826			7.4
12 μ - LabSat separation	34	30		10193	828			7.4

(JAXA)

Rocket Equation

HII-A F4 Launch

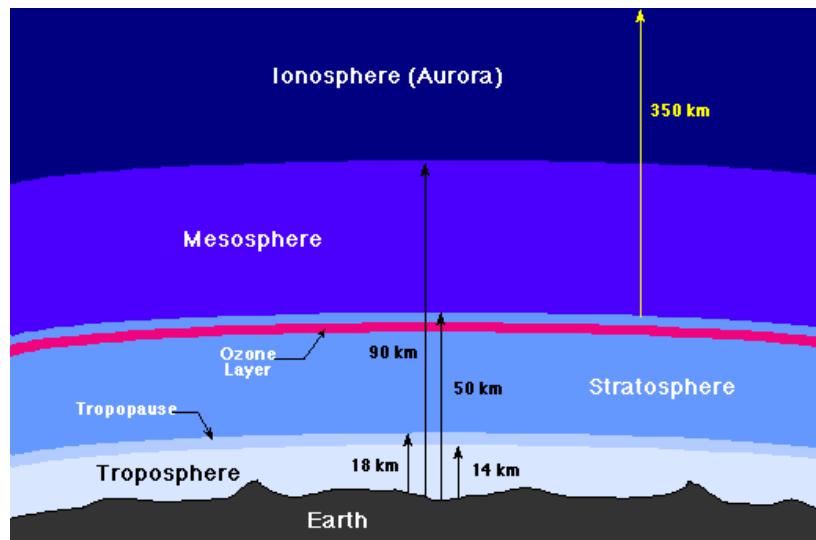
No. 10



(movie)

Earth's Atmosphere

No. 11

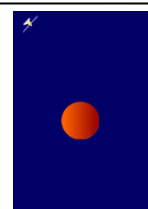


Newton's Laws

No. 12



1. Every body continues in a state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.
2. The change of motion (linear momentum) is proportional to the force impressed and is made in the direction of the straight line in which that force is impressed.
3. To every action there is always an equal and opposite reaction; or, the mutual actions of two bodies upon each other are always equal, and act in opposite directions.



$$F = ma$$

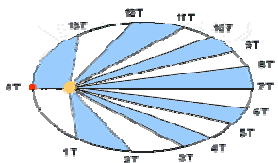
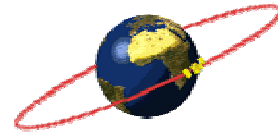


Kepler's Laws

No. 13

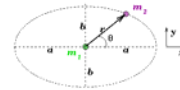


1. If two bodies interact gravitationally, each will describe an orbit that is a conic section about the common mass of the pair. If the bodies are permanently associated, their orbits will be ellipses. If they are not permanently associated with each other, their orbits will be hyperbolas (open curves).
2. If two bodies revolve around each other under the influence of a central force (whether or not in a closed elliptical orbit), a line joining them sweeps out equal areas in the orbital plane in equal intervals of time.
3. Stating that the ratio of the square of the revolutionary period (in years) to the cube of the orbital axis (in astronomical units) is the same for all planets



T = any unit of time (hour, day, week, etc.)

$$T_a^2 / T_b^2 = R_a^3 / R_b^3$$



Example

Vision versus Reality

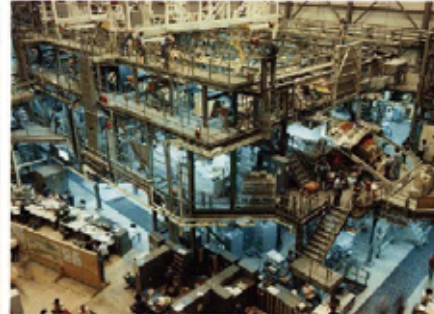
No. 14



VISION: Simple Hangar Operations



REALITY: Severe Shortfall



(SpaceWorks Engineering)

Example Cost Estimates

No. 15



Mass and cost estimates only reveal some characteristics, need to look beyond direct costs

The **true value** for a space system includes additional analysis from multiple other disciplines, including safety and operations assessments to find all indirect effects

Hours required to turnaround United States Space Shuttle:
Direct: 600,000 – 700,000 hours
Indirect: 140,000,000,000 hours

Direct (Visible) Work
"Tip of the Iceberg"

-
-
-
-

Indirect (Hidden)

-
-
-
-

Support (Hidden)
Recurring Ops \$\$\$

STS Budget "Pyramid" (FY 1994 Access to Space Study)		
Generic Operations Function	Total \$M FY94	Total (%)
Learn, Record & Record	110	0.8%
Landing Recovery	100	0.8%
Post-Entry & Entry	27	0.2%
Launch	513	1.5%
Crew/ Payload/Crew	250	2.3%
Turnaround	1125	3.3%
Vehicle Depot/Maint	3370	7.0%
Traffic/Flight Control	1000	5.0%
Operations Support Infra	3100	9.0%
Concept/Eng/Logistics	8627	25.1%
STS Ops/Maint & Mgmt	14774	43.9%
Total (\$M FY94)	33624	100.0%
Percent	100.0%	

↑ -10%

↓ -20%

↓ -70%

Only Examining the Tip of the Iceberg

(SpaceWorks Engineering)



Dr.-Ing. Robert Alexander GOEHLICH
 Keio University
 Department of System Design Engineering
 Space System Engineering
 3-14-1 Hiyoshi, Kohoku-ku
 Yokohama 223-8522, JAPAN
 email: mail@robert-goehlich.de
 Mobile: +81-(0)90-1767-1667
 Fax.: +81-(0)45-566-1778
 Internet: http://www.robert-goehlich.de