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

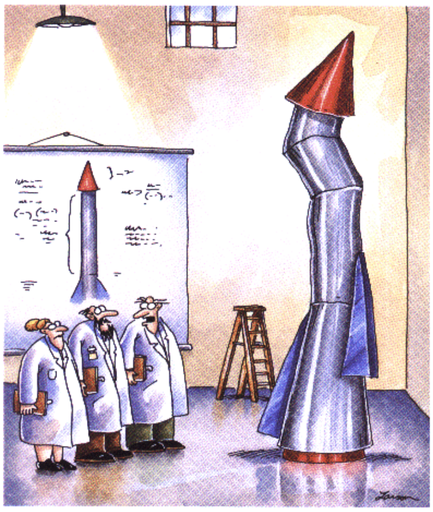
No. 2

- **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

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Rocket Equation

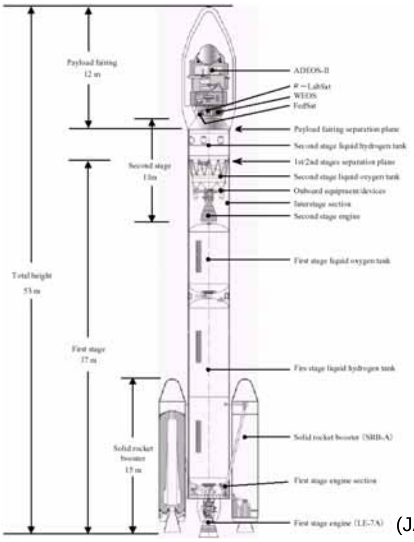
$$\Delta p_{\text{exhaust}} = dM(u+v)$$
$$\Delta p_{\text{rocket}} = (M - dM)\,du.$$
$$dM\,(u+v) = (M - dM)\,du \approx M\,du.$$
$$M\,du + dM = 0 \quad \text{if} \quad u \ll v$$
$$du = -v\frac{dM}{M}$$
$$\int_{u_0}^{u} du = -v\int_{M_0}^{M}\frac{dM'}{M'},$$

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

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)



(JAXA)

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				
	1st stage	Solid Rocket Booster (SRB)	2nd 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	

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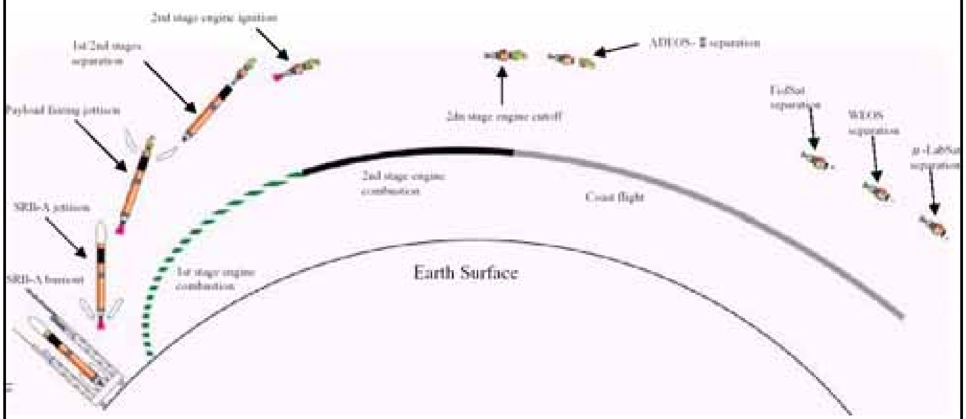
Rocket Equation

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



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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/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 1st/2nd 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

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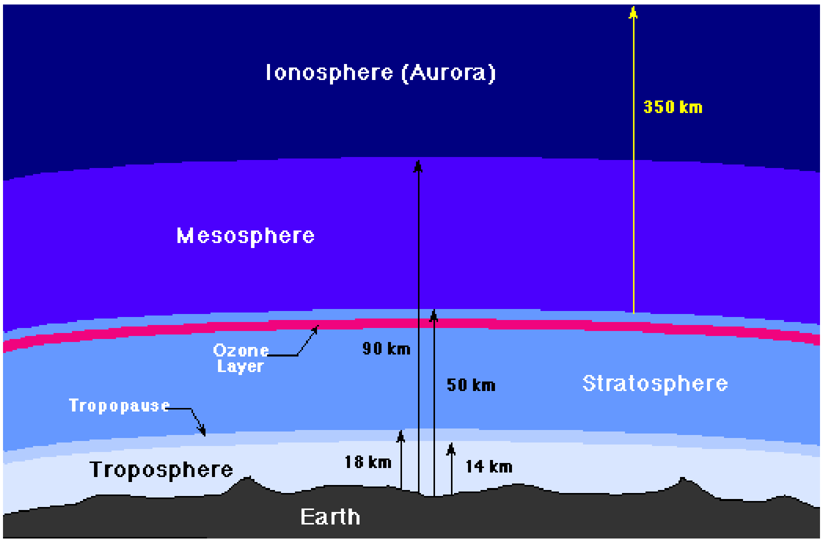
Rocket Equation
HII-A F4 Launch
No. 10

(movie)

Earth's Atmosphere

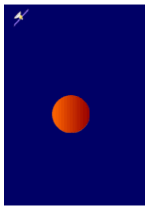
No. 11



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.

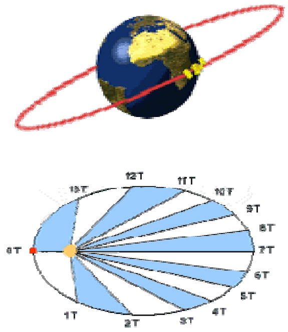
$$F = ma$$

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.

Kepler's Laws

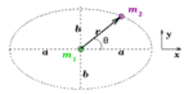
No. 13

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.)

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



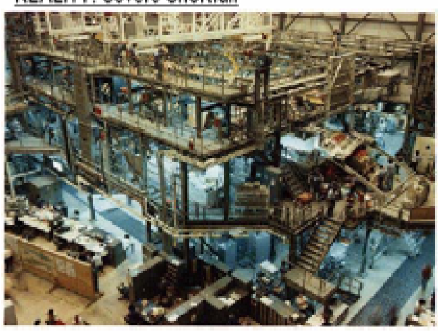
Example

Vision versus Reality

No. 14

VISION: Simple Hangar Operations

REALITY: Severe Shortfall



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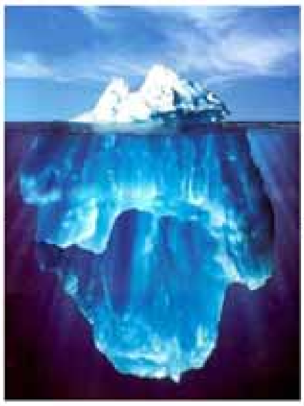
Example
Cost Estimates

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

STS Budget "Pyramid" (FY 1994 Access to Space Study)

	Generic Operations Function	Total $M FY94	Total (%)	
Direct (Visible) Work "Tip of the Iceberg"	Elem. Receipt & Accept	1.4	0.0%	~10%
	Landing/Recovery	19.6	0.6%	
	Veh Assy & Integ	27.1	0.8%	
	Launch	51.5	1.5%	
	Offline Payload/Crew	75.9	2.3%	
+	Turnaround	112.3	3.3%	
Indirect (Hidden)	Vehicle Depot Maint	237.5	7.1%	~20%
	Traffic/Flight Control	196.4	5.8%	
+	Operations Support Infra	316.8	9.5%	
Support (Hidden)	Concept Unig Logistics	842.7	25.1%	~70%
	STS Ops Planning & Mgmnt	1477.4	43.9%	
Recurring Ops $$s	Total ($M FY94)	3363.4	100.0%	
	Percent	100.0%		

Only Examining the Tip of the Iceberg

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