LAUNCH SYSTEMS

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Outline

- Launch systems characteristics
- Launch systems selection process
- Spacecraft design envelope & environments.

Lesson Objectives

- Each student will
  - Understand launch system characteristics, sizing and trade-offs.
  - Estimate launch system sizes, staging requirements.
  - Be able to select appropriate launch system for a given mission from available systems.
  - Be able to estimate spacecraft requirements driven by launch vehicle induced environments.
  - Determine costs of launch systems.

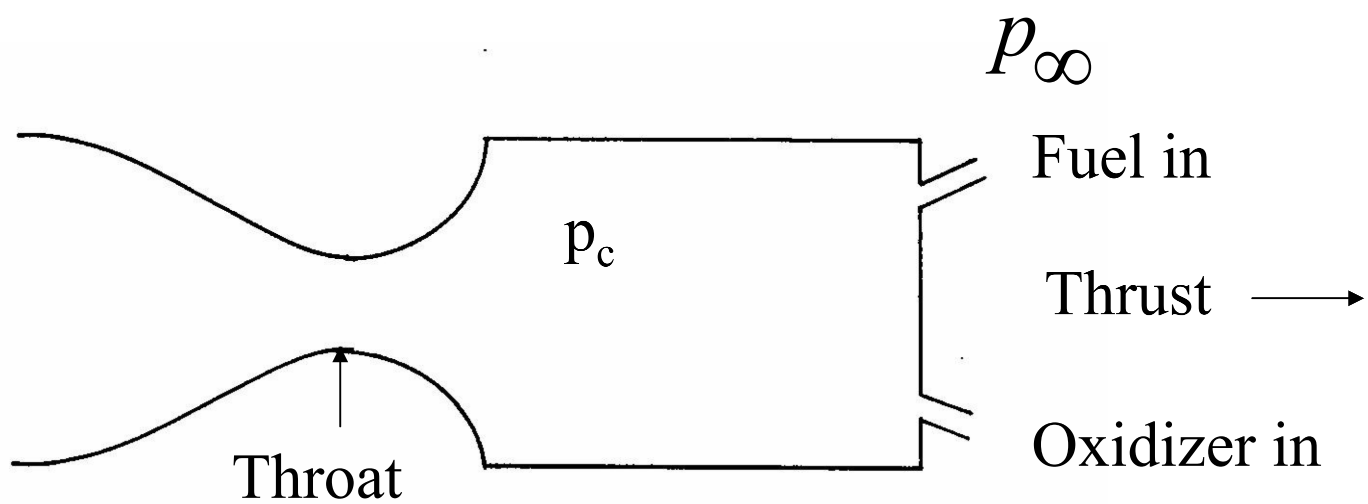
Rocket Basics

m_e

V_e

P_e

A_e



Thrust

$$F = \dot{m}_e V_e + A_e (p_e - p_\infty)$$

Specific impulse

$$Isp \equiv \frac{F}{\dot{m} g}$$

$$Isp = K \sqrt{\frac{T_c}{M}}$$

where K depends on γ and the engine pressure ratio

Rocket Equation

$$a = \frac{F}{M_{veh}} = \frac{\dot{m}\, Isp}{M_{veh}}\, g \qquad M_{veh} = M_o - \dot{m}t$$

$$\Delta V = \int a\, dt = Isp\ g \int_{t_o}^{t_f} \frac{\frac{dm}{dt}dt}{M_o - \frac{dm}{dt}t}$$

$$\Delta V = g\ Isp\ \ell n\left(\frac{M_o}{M_o - M_{propellant}}\right) = g\ Isp\ \ell n\left(\frac{M_o}{M_f}\right) = g\ Isp\ \ell n\left(R\right)$$

Where $R = \frac{M_o}{M_f}$ is the mass ratio

(Assumes zero losses due to drag and gravity)

Rocket Equation (Cont.)

$$M_p = M_f \left[e^{\left(\frac{\Delta V}{Isp\ g}\right)} - 1 \right] = M_o \left[1 - e^{\left(-\Delta V / Isp\ g\right)} \right]$$

M_p = mass of propellant

M_o = initial mass

M_f = final mass

ΔV = vehicle velocity change

M_{veh} = vehicle mass

Staging

- Near burnout, rocket acceleration is diminished because payload mass includes entire launch systems structure.
- Staging removes lower stage structural weight

$$\Delta V_i = g\, Isp\, \ell n \left(\frac{M_{oi}}{M_{fi}} \right)$$

M_{oi} = initial mass of rocket including all upper stages and payload.

M_{fi} = final mass after stage has burned before separation.

i = stage number

$\Delta V = \sum \Delta V_i$

Staging (Cont.)

λ = payload fraction = $\dfrac{M_{payload}}{M_o}$

or $\lambda_i = \dfrac{M_{payload\, i}}{m_{oi}}$

$M_{payload\ i}$ = mass of payload plus all upper stages

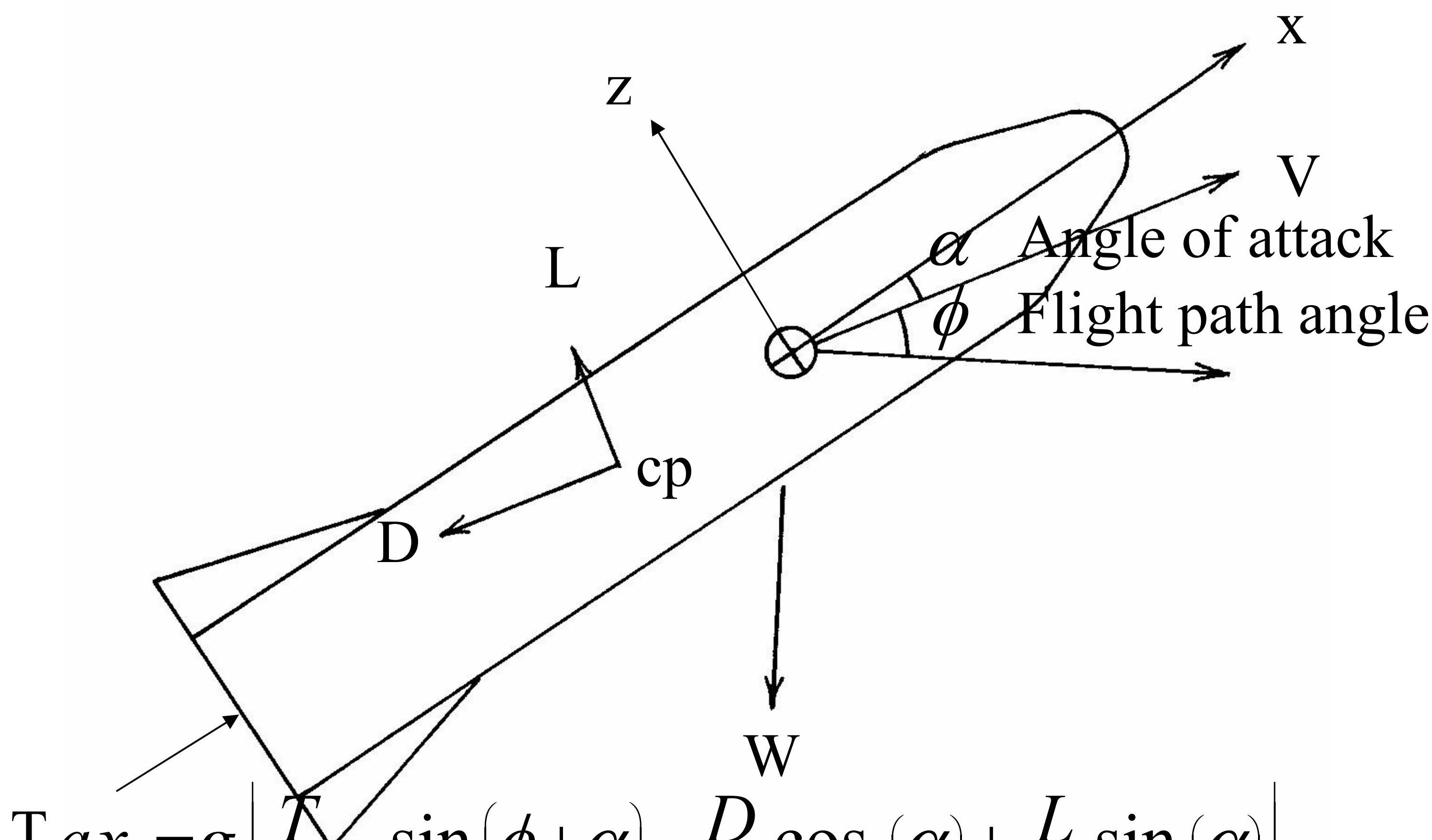
$$\lambda = \prod_{i=1}^{n} \lambda_i$$

Structure fraction $\varepsilon_{si} = \dfrac{M_{si}}{M_{oi}} = \dfrac{M_{si}}{M_{pi} + M_{si} + M_{payload\ i}}$

M_{si} = mass structure for stage i

M_{pi} = mass propellant for stage i

Launch Vehicle Forces



$$ax = g\left[\frac{T}{W} - \sin(\phi+\alpha) - \frac{D}{W}\cos(\alpha) + \frac{L}{W}\sin(\alpha)\right]$$

$$az = g\left[-\cos(\phi+\alpha) + \frac{D}{W}\sin\alpha + \frac{L}{W}\cos\alpha\right]$$

Launch System Selection Process

- Mission needs and objective
- Mission requirements
  - Altitude
  - Inclination
  - Right ascension of ascending node (RAAN)
  - Payload dimensions
- Launch system performance, availability, cost, reliability
- Fairings
- Upperstage

Example Launch Systems

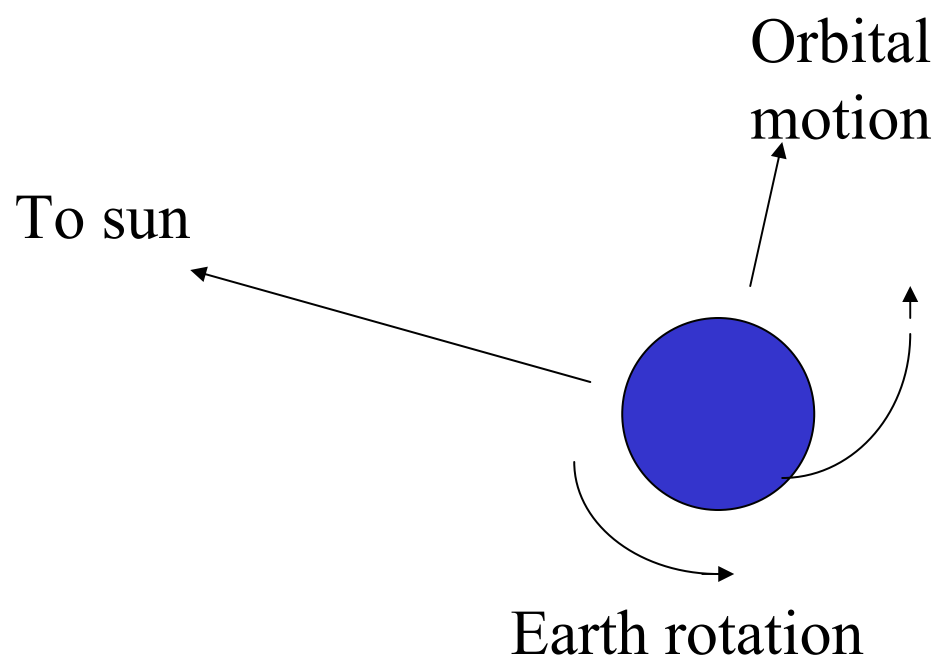
Launch System	**Upper Stage**	**LEO (kg)**	**GTO (kg)**	**GEO (kg)**	**Polar (kg)**
Atlas IIAS	Centaur 2A	8640	3606	1050	7300
Delta II 7920/25	PAM-D	5089	1840	910	3890
Pegasus XL		460			345
Shuttle	- IUS	24,400	 5900	 2360	
Taurus	Star 37	1400	450		1060
Titan IV	- Centaur		 8620	 4540	14,110

Example Orbit Transfer Vehicles

Characteristics	**PAM-D**	**IUS**	**Centaur**
Length (m)	2.04	5.2	9.0
Diameter (m)	1.25	2.9	4.3
Mass (kg)	2180	14,865	18,800
Thrust (N)	66,440	200,000	147,000
Isp	292.6	292.9	442
Structure mass	180	1255	2100
Propellant mass	2000	9710	16,700
Airborne support equipment mass	1140	3350	4310

Launch Sites Criteria

- Minimum inclination
- Launch azimuth
- Weather



US Launch Sites and Launch Systems

- Western range (Vandenberg AFB):
  - LMMS Titan II, IV-B, Athena
  - Boeing Delta II, III, EELV
  - OSC Taurus, Minotaur, Pegasus
- Equatorial launch site:
  - Boeing SeaLaunch
- Alaska Spaceport
  - OSC Minotaur

US Launch Sites and Launch Systems (continued)

- Eastern Range (Cape Canaveral Air Station, Kennedy Space Center):
  - STS
  - LMMS Titan IV; Atlas II, IIA, IIAS; EELV
  - Boeing Delta II, III, EELV
  - Orbital Pegasus XL, (Taurus, Minotaur)
  - Coleman/TRW/IAI Shavit
- Wallops Island
  - Pegasus XL, Minotaur

Typical Launch Vehicle Integration Tasks

- Mission Orbit Planning
  - Effect of launch delays, launch window definition
- Launch vehicle and spacecraft performance analyses
  - LV performance variations vs mission impacts
- Defining, implementing mission unique requirements
  - Ground processing, ground testing
  - Launch vehicle interfaces - power, command, telemetry, etc.
  - Critical s/c commands: self-generated, booster provided, backup timers?
- Flight safety systems - range destruct protocols: installation and test of range destruct packages
- Developing multi-agency day-of-launch launch ops procedures
  - Example: Go/No-Go limits

Launch Services - Scheduling

- LMMS Atlas Commercial template
  - @ 36 months, select a 3 month window
  - @ 12 months, select a 30 day slot
  - @ 6 months, select a launch day
- STS templates:
  - 36+ months for a Primary payload
  - 24 months minimum for secondary payloads

Payload Integration

- Fairing size and shape
- Maximum accelerations
- Vibration frequencies and magnitudes
- Acoustic frequencies and magnitudes
- Temperature extremes
- Air cleanliness
- Orbital insertion accuracy
- Interfaces to launch site and vehicle

> Ground handling, ground and airborne transportation, and launch environment may be more severe than space operating environment

Fairings

- Protection from aerodynamic loading
- Diameter and length constraint
- Acoustic environment
- Jettison Altitude

Structural & Electrical Interface

- Physical support adaptors
- Separation/deployment system
- Kick motor/Spin tables
- Electrical interface
- Access
  - Physical
  - Electrical
  - Optical
  - Radio frequency

Payload Environments

- Thermal
  - Pre-launch
  - Ascent fairing radiant
  - Aero-heating (Free molecular heating)
- Electromagnetic
- Contamination
- Venting
- Acceleration
- Vibration
- Acoustics
- Shock

Acceleration Load Factors

	Lift off		Max Airloads		Stage 1 shutdown		Stage 2 shutdown	
Vehicle	Axial	Later al	Axial	Lateral	Axial	Later al	Axial	Later al
Titan 34D/IUS steady Dynamic	+1.5 ±1.5	± 5.0	+2.0 ± 1.0	± 2.5	0 - +4.5 ± 4.0	± 2.0	0 – +2.5 ± 4.0	± 2.0
Atlas II steady dynamic	+1.3 ±1.5	±1.0	+2.2 ± 0.3	+0.4 ± 1.2	+5.5 ± 0.5	± 0.5	+4.0 ± 2.0	0.5
Delta steady dynamic	+2.4 1.0	2 to 3					+6.0	
Shuttle IUS steady Dynamic	+3.2 +3.5	+2.5 +3.4	+1.1 to 3.2	+0.25 to –0.59			+3.2	+0.59

Vibration Environments

- Caused by
  - Launch system propulsive dynamic acceleration
  - Unsteady aerodynamic effects
  - Acoustic pressure from engines
  - Amplified mechanical response of vehicle structure
- Includes ground and airborne transportation
- Yields structural stiffness requirement on payload and adaptor/interface.

Shock Loads

Caused by pyrotechnic devices used to separate from launch.

Staging, engine starts and shut down.

Acoustic Environments

- Caused by
  - Reflected sound energy from launch pad structures and facilities.
  - Maximum dynamic pressure (max q) aerodynamics.
- Affected by fairing design

Injection Accuracy

- Final stage guidance and propulsion performance determines injection accuracy.
  - Apogee, perigee, inclination
  - Payload's Attitude Determination and Control System must capture and correct linear and rotational tip-off rates, and injection errors.

Payload Integration Procedures

- Mating spacecraft to launch vehicle.
- Spin tests.
- Propellant loading.
- Pre-launch test of all subsystems.

Payload Processing

- Receiving inspection
- Payload & ground support equipment
- Installing hardware (batteries, guidance systems)
- Pressure checks
- Communication and payload functional test

Launch System
Cost Estimate

- Determined from supplier.
- Should include integration and check out costs, launch support systems and launch integration costs.
- Small payloads may ride as a secondary payload.
- Example launch system costs.

References

- Launch system user handbooks.
- Lockheed Martin, Boeing, Orbital, etc. (or www)
- AIAA Launch Vehicle Summary (in Library)
- International Space Industry Report
- Reducing Space Mission Costs. Wertz and Larson