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Class Agenda

- Basic launch vehicle considerations
- Launch system selection process
- Determining the spacecraft design envelope and environments

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Payload Planners Guides

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Launch Systems

- Launch process severely constrains spacecraft design
  - Lift capacity
  - Environment during ascent
- Launch system
  - Alters velocity to place spacecraft in orbit
  - Creates severe ascent environment
  - Protects spacecraft from its surroundings
  - Places payload into desire orbit with a functional spacecraft attitude
- Payload – all hardware above launch vehicle-to-spacecraft interface (not fairing)

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Steps in Selecting a Launch System

1. Collect requirements and constraints, which depend on mission operations concept. Consider deployment strategy
   - Number of spacecraft per launch
   - Spacecraft dry weight
   - Spacecraft dimensions
   - Mission orbit
   - Mission timeline
   - Funding constraints

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Steps in Selecting a Launch System

2. Identify and analyze acceptable configurations for the launch system
   - Include following information for each potential configuration
     - Weight of spacecraft propellant
     - Orbit-insertion stage weight, if required
     - Weight of booster adaptor
     - Performance margin available
     - Boosted weight capability
     - Reliability

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Steps in Selecting a Launch System

3. Select launch systems for spacecraft design. During conceptual design, identify several potential launch systems to make the launch more likely
   – Criteria based on following parameters
      • Boosted weight capability
      • Cost
      • Performance margin available
      • Reliability
      • Schedule vs. vehicle availability
      • Launch availability

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Steps in Selecting a Launch System

4. Determine spacecraft design envelope and environments dictated by launch system selected
   – Include following information
      • 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

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Steps in Selecting a Launch System

5. Iterate to meet constraints on performance, cost, risk, and schedule
   – Document and maintain criteria, decision process, and data to support program changes

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Basic Launch Vehicle Considerations

- Space launch system unique – only systems that accelerate continuously throughout their performance envelope
- Velocity – fundamental measure of performance for launch systems
- Launch system's ability to achieve orbital velocity comes from
  – Propulsion efficiency
  – Vehicle weight and drag acting against it

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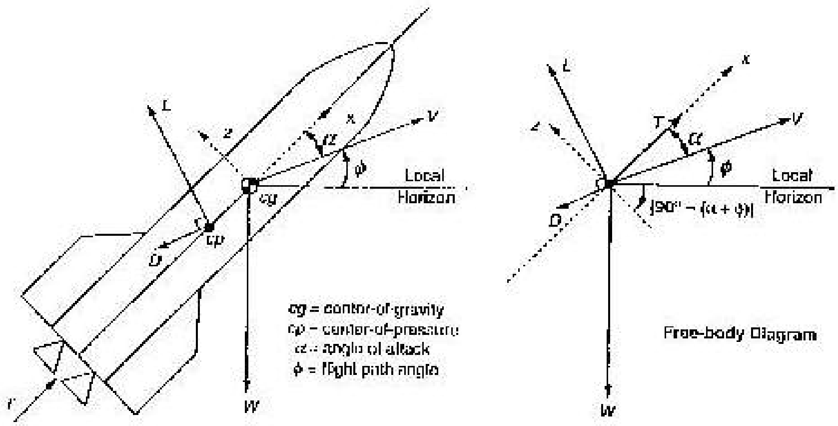
UAH Basic Launch Vehicle Considerations



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UAH Basic Launch Vehicle Considerations

- From free body diagram – we can develop expressions for acceleration
  - Axial acceleration, a_x

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

  - Lateral acceleration, a_z

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

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Basic Launch Vehicle Considerations

- Can estimate the velocity a launch vehicle should provide

$$\Delta V_{design} = \Delta V_{burnout} + \Delta V_{gravity} + \Delta V_{drag}$$

- Have to account for velocity losses from thrust vector control for trajectory shaping and other performance variables
  - Solid rocket motor bulk temperature causes thrust level variations

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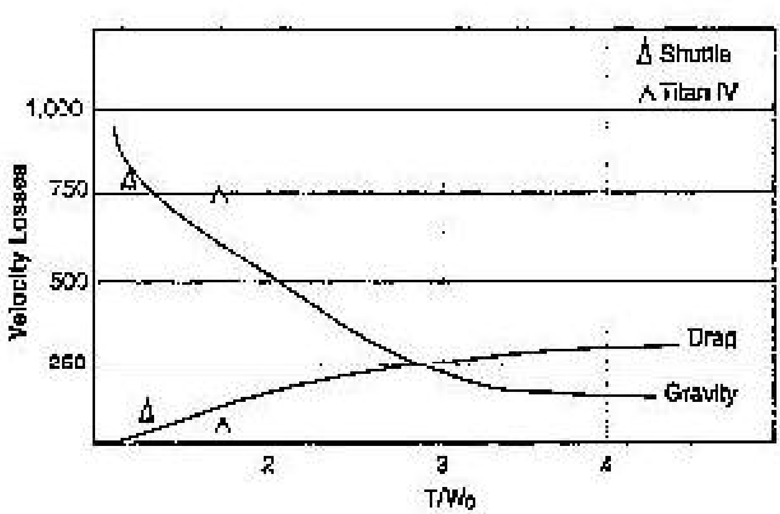
Basic Launch Vehicle Considerations



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Basic Launch Vehicle Considerations

- If there were no atmosphere and no topographical variations, an optimum launch trajectory would be very similar to a Hohmann transfer and gravity losses would be minimized by thrusting normal to the radius vector
- Velocity losses due to gravity are between 750 – 1500 m/sec
- Aerodynamic drag forces acting on launch vehicle are function of shape and size of vehicle, speed, and angle-of-attack, α

$$\frac{D}{W} = C_d\left(\frac{A}{W}\right)q$$

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Basic Launch Vehicle Considerations

- Current expendable launch vehicles – velocity losses due to drag are less than 3% (20 – 40 m/sec)
- Percentage decreases as size of vehicle decreases
- Once ΔV_{design} is known, can find mass of propellant needed

$$m_p = m_f\left[e^{\left(\Delta v / Isp*g_O\right)} - 1\right] = m_O\left[1 - e^{-\left(\Delta v / Isp*g_O\right)}\right]$$

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Basic Launch Vehicle Considerations

- Flight vehicle mass – sum of propellant mass, structure mass, including mass of fairing, and mass of everything above the launch vehicle interface, including mass of spacecraft bus, payload, and any upper stage
- Mass fraction – portion of flight vehicle devoted to certain sections
  - Propellant mass fraction – mass of propellant divided by total flight vehicle mass, typically 0.85
  - Structure mass fraction or deadweight fraction – structure mass, including mass of fairing, divided by total flight vehicle mass, typically 0.14
  - Payload mass fraction typically 0.01

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Launch System Selection Process

- 1st step – establish mission needs and objectives – dictate performance, trajectory, and family of vehicles which can operate from suitable sites
- Mission need should be stated in terms of specific return desired
- Clear understanding of real mission need is extremely important since it can dictate launch strategy

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Launch System Selection Process

- Another issue – whether spacecraft will use a dedicated or shared launch system
- Dedicated systems may cost more, but lessens chances that a problem with another spacecraft will adversely affect launch
- Shared launches are usually less expensive per spacecraft
- Consider launching multiple spacecraft if their desired orbital altitudes and inclinations are compatible

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Launch System Selection Process

- After mission need – determine specific mission requirements
  - For LEO – orbit altitude, inclination, estimated payload weight, dimensions
- Mission concept specifies
  - Number of spacecraft
  - Anticipated lifetime
  - Replacement strategy
  - Method of data retrieval and management
  - Required launch date – affects schedules and vehicle and launch site availabilities

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Launch System Selection Process

- Allocate mission requirements as functional requirements between launch vehicle and payload
- “What specific functions or operations must payload accomplish, and which must launch vehicle perform?”
- Two functions affected
  - Propulsion
  - GN&C

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Launch System Selection Process

- Assess each function required to achieve mission objective
  - Allocate functions based on cost, reliability, and risk
- Knowing mission requirements, constraints, and required information – decide which launch system configurations can deliver spacecraft to its mission orbit
  - Selected systems should satisfy mission’s performance requirements and minimize program risk
- Need to select launch system early in process
- May need to redesign spacecraft and its interfaces with change in launch vehicle

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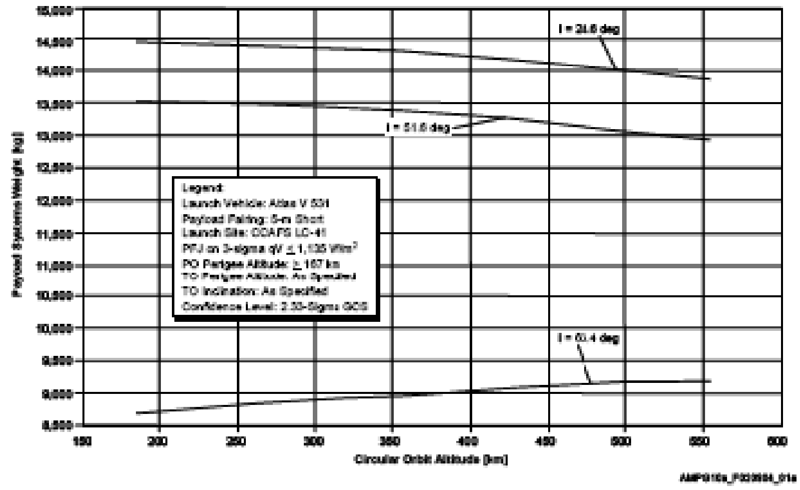
Atlas V 531 LEO Performance Curve

Figure 2.6.5-2a: Atlas V 531 Low-Earth Orbit Performance - CCAFS



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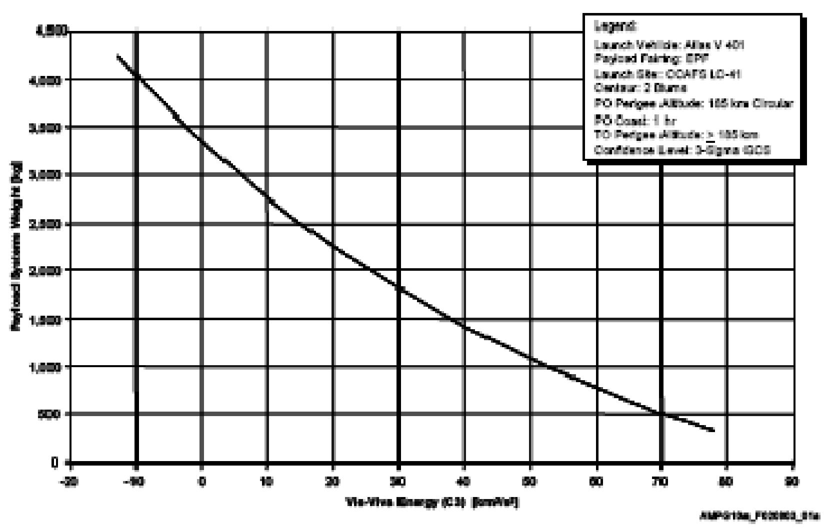
Atlas V 401 C3 Curve



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Launch System Selection Process

- Criteria to selection
  – Performance capability
  – Vehicle availability
  – Compatibility
  – Cost
- Performance margin – difference between payload performance by launch vehicle and the projected boosted weight

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Weight Parameter Definitions

- Spacecraft dry weight – weight of all spacecraft subsystems and sensors
- Propellant – weight of propellant required by spacecraft to perform its mission when injected into its mission orbit
- Loaded (wet) spacecraft weight = spacecraft dry + propellant
- Upper stage weight – weight of any apogee or perigee kick motors and stages
- Injected weight = loaded spacecraft + upper stage weight

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Weight Parameter Definitions

- Booster adapter weight – adapter fitted between upper stage of launch vehicle and spacecraft
- Boosted weight = injected weight + booster adapter – total weight that must be lifted by launch vehicle
- Payload performance capability = boosted weight + performance margin

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Launch System Selection Process

- If launch vehicle does not have required performance – "options" can be added
  - Might have to redesign spacecraft/mission
- Next step – payload fairings
- Fairings must be physically large enough to house and protect spacecraft during ascent, and interfaces to spacecraft, both structural attachment and other services such as cooling must be acceptable to spacecraft

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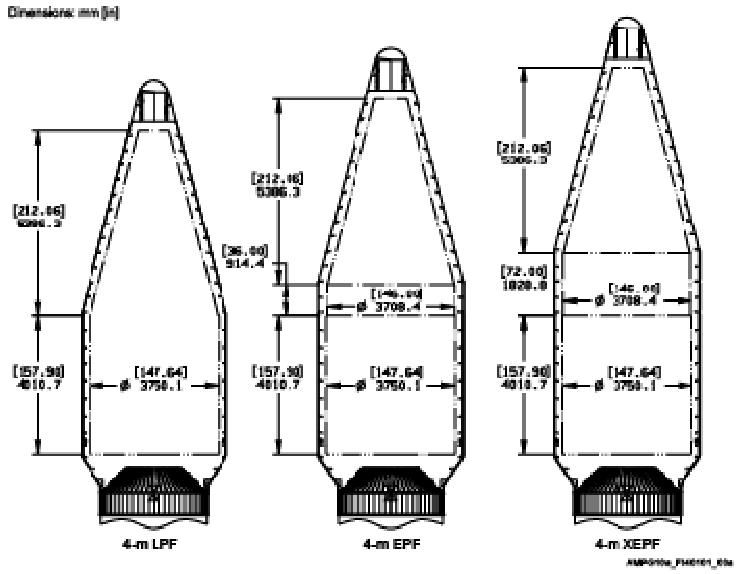
Atlas V – 4 m Shrouds



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Launch System Selection Process

- Must consider launch schedule and whether preferred launch system will be available
- Given required launch date and window – discuss availability
- Must consider launch site's availability
- Three options for ascent
  - Direct injection by launch system
  - Injection using various launch and stage vehicle combinations
  - Injection using an integral propulsion system

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Launch System Selection Process

- Small payloads usually use launch vehicle to insert directly into LEO
- For GEO, typically need to augment launch vehicle with upper stage
- Integral propulsion allows insertion and maintenance of spacecraft in its orbit and control its attitude with a single propellant system in spacecraft

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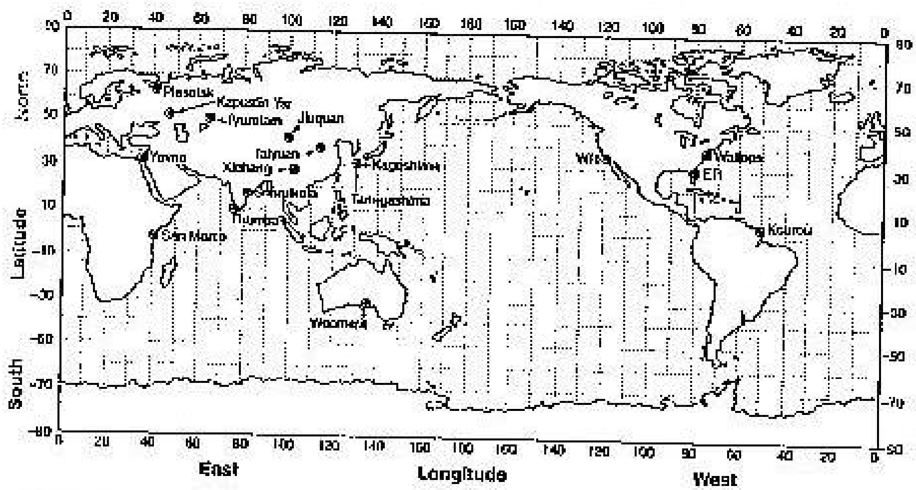
Launch Sites



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Launch Sites

- Get best performance from launch vehicle into a direct orbit by locating launch site at equator to take advantage of easterly velocity of Earth's rotation
- Launch sites at higher latitudes cannot directly access orbit inclinations much below their latitude and trajectory profiles that go to higher inclinations sacrifice velocity and payload mass
- Inclination change of 1 degree requires ~ 208 m/sec in LEO

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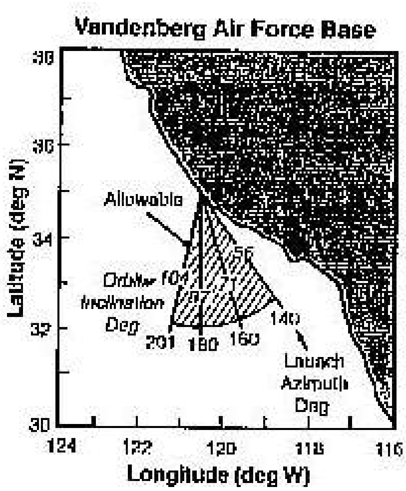
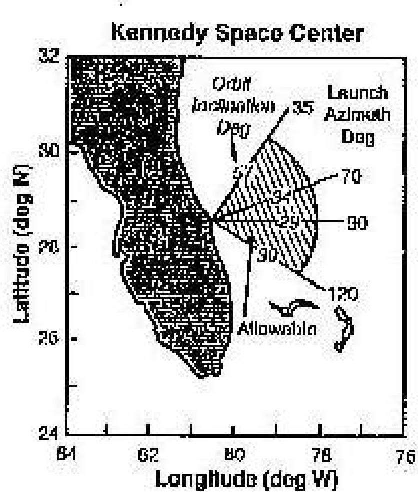
Launch Sites





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Launch Sites

- Must consider weather – look at where we mostly launch from!
- Bad weather can severely restrict chances to launch – costing time and money

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Design Envelope and Environments

- Payload integration – management, program support, and analysis required to integrate spacecraft with launch vehicle
- Payload design must address launch environments and interfaces
- Payload integration must meet specific requirements of program review – includes ICDs
- Must consider payload environment as time payload leaves vendor's facility until it completes mission

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Design Envelope and Environments

- In many areas, combination of high accelerations and vibrations coupled with thermal environment and rapidly changing local pressures result in environmental conditions more severe than it would experience on orbit
- Three areas to evaluate
  – Usable payload volume
  – Structural and electrical interfaces
  – Payload environments

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Fairings

- Mission designer must ensure spacecraft will fit within allowable envelope
- Fairing protects payload from aerodynamic loads – also provides benign environment
- Generally fairing is jettisoned late in ascent when dynamic pressure and heating rate are below acceptable levels specified by launch vehicle

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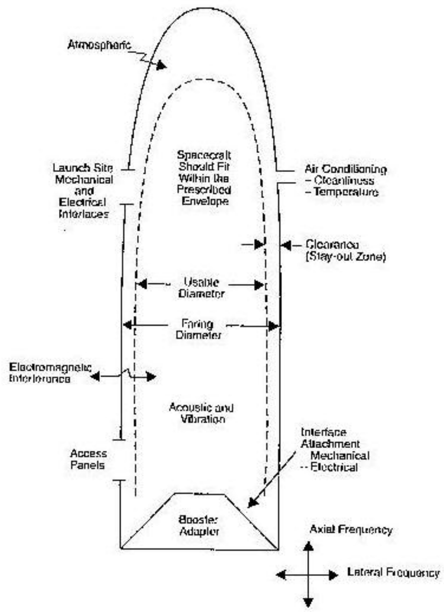
Fairings



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Structural and Electrical Interfaces

- Need to ID interfaces between payload and launch system early in design process
- Launch vehicle adapters are important
  - Usually provided by launch vehicle
- Launch vehicle provides physical, electrical, radio frequency, and optical access to payload while fairing encloses it
- Manufacturers wire launcher to command and safe spacecraft
- Provide mechanisms that separate payload from launch vehicle in orbit

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Structural and Electrical Interfaces

- Launch system and payload must match desired communications architecture for launch operations
- Communications requirements depend on combined demands of entire space mission
  - Ground stations
  - Payload
  - Launch vehicle
  - Range safety
  - User

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Payload Environments

- Need to pay attention to predicted payload environments – protect payload during ground transportation aircraft take-off and landing, hoisting operations, launch, and ascent
- Need to control handling of particles and molecules from launcher's out-gassing materials
  - Can degrade performance of solar panels, optical sensors, thermal control surfaces
- Electrical signals must be compatible among spacecraft bus, payload, launch vehicle, launch site

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Payload Environments

- Analysis of ascent environments concentrate on discrete events (can drive design)
  - Ignition and shutdown events
  - Periods of maximum dynamic pressure
  - Maximum acceleration
  - Peak heating rates
  - Heat loading
- Thermal environment
  - Radiant heat from payload fairing
  - Thermal environment in parking orbit
  - Thermal environment in cruise

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Payload Environments

- Static and dynamic loads affect structure of payload, adapters, and launch vehicles
- Loads either aerodynamic or depend on acceleration and vibration
- Aerodynamic loads are function of total pressure place on vehicle moving through atmosphere
  - Static (ambient) pressure and dynamic pressure (pressure component experienced by a fluid when brought to rest)
- Pressure differential between inside and outside of fairing during ascent – need to vent trapped air

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Payload Environments

- Acceleration loads (called load factors)
  - Static (steady state)
  - Dynamic (vibration)
  - Need to consider axial and lateral load
- Need to design for several loads
  - Launch vehicle acceleration
  - Variable combustion flows in engines
  - Aerodynamic drag and shear
  - Acoustic pressures from engines
  - Mechanical response of vehicle to any of these
- Use pyrotechnic devices to separate from launch vehicle, deploy components (shock load associated with them)

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Payload Environments

- Acoustic environment function of
  - Physical configuration of launch vehicle
  - Acceleration time history
  - Configuration of propulsion system
- Near launch pad acoustic environment depends on reflected sound energy from launch pad structures and facilities

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Processing and Integration

- Flow depends on specific processing requirements, configuration of propulsion, ordnance elements, and available facilities
- Typical functions
  - Mating spacecraft with a stage vehicle
  - Spin tests
  - Loading propellants
  - Mating with launch vehicle
  - Prelaunch testing of all systems (integrated test)
- Two methods for integration
  - Vertical
  - Horizontal

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Example Problem

- Calculate the axial and lateral acceleration on a 4 meter shroud launch vehicle
  - Thrust = 3,000,000 lbf
  - Weight = 1,000,000 lbf
  - Velocity = 1000 mph
  - $C_L = 1.8$
  - $C_D = 0.8$
  - Atmospheric density = 0.163 kg/m^3
  - Flight path angle = 45°
  - Angle of attack = 15°

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