AE280

Hypersonics

Introduction

Hypersonic Flow

- Flow regime where certain phenomena become progressively more important as the Mach number increases.

- Unlike the change from subsonic to supersonic aerodynamics, there is no clear Mach number at which these phenomena occur. It is generally accepted that lower limit of the hypersonic flow regime is:

$$M_\infty = 5$$

- Typical hypersonic aerothermodynamic phenomena include:

  - Very strong shock waves leading to high temperatures.
  - The gas may not be considered calorically perfect (variable c_p and γ).
  - Chemical reactions may occur as a consequence of the high temperatures.
  - Large surface heat-fluxes (aerodynamic heating).

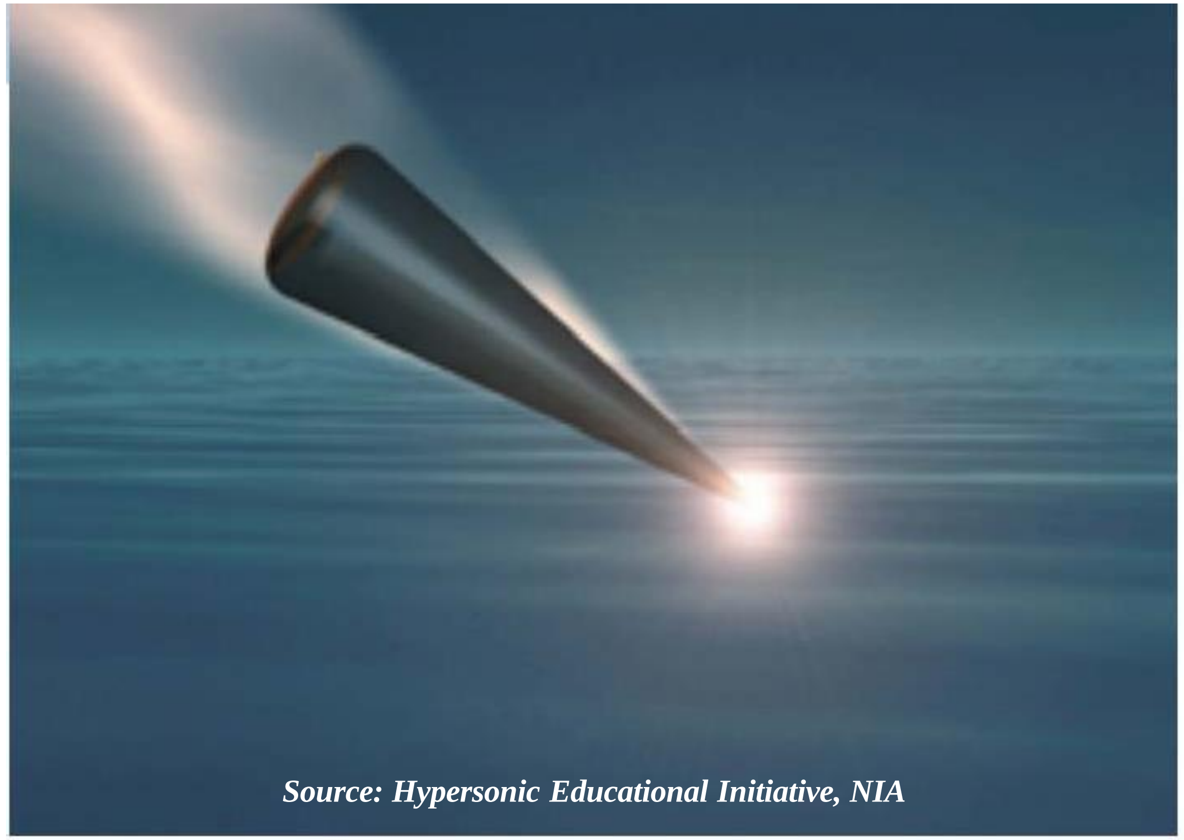
- Hypersonic vehicles configurations are strongly mission-dependent.

Hypersonic Aerodynamics vs Supersonic Aerodynamics

- Both aerodynamics and configurations of hypersonic vehicles are deeply different from those of supersonic vehicles.

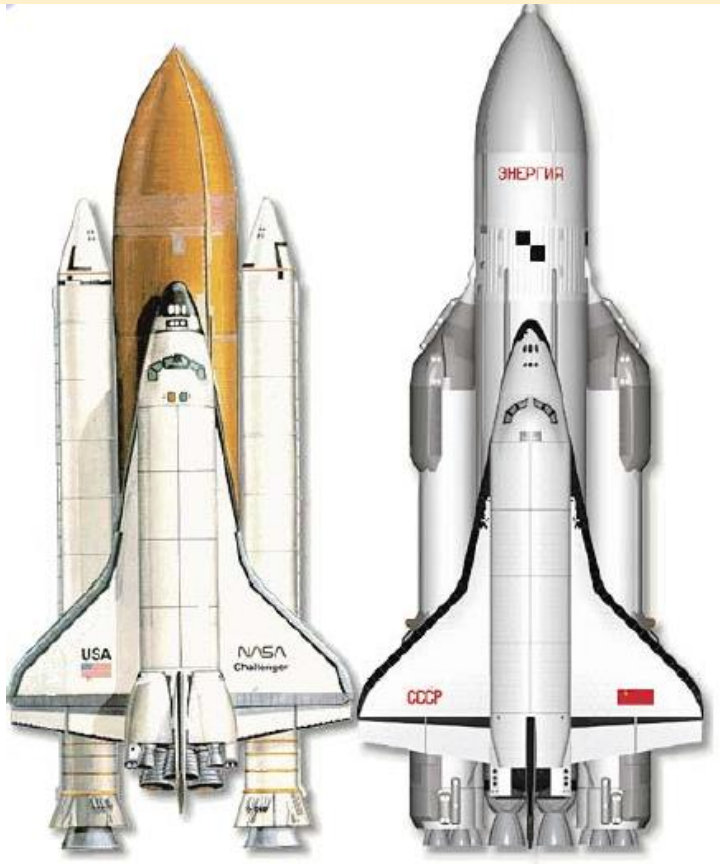
- The various subsystems (propulsion, aerodynamics, structures) are highly integrated in hypersonic solutions, forcing multidisciplinary design of each component.

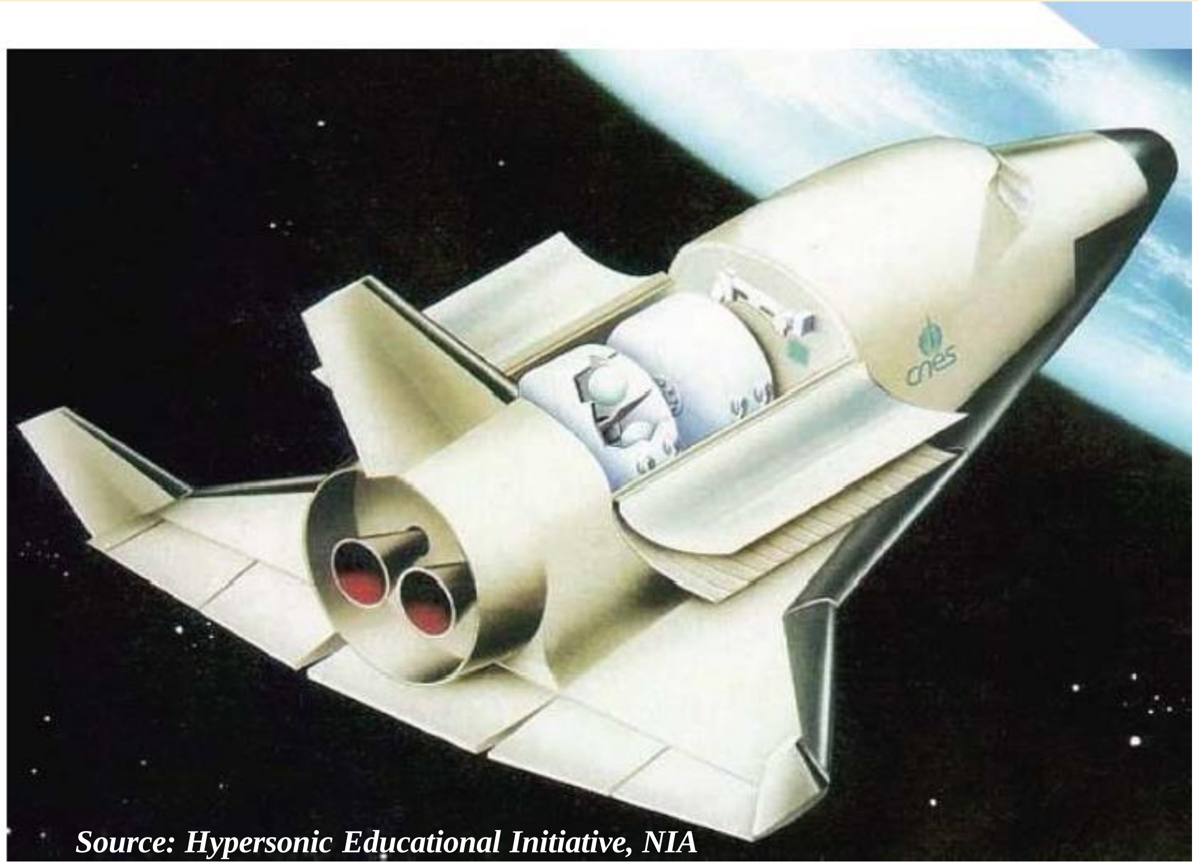
Hypersonic Vehicles I: Missiles



➢	Mission:	high-speed delivery of explosives
➢	Aerodynamics:	slender body with blunt noses
➢	Propulsion:	rockets, ramjets, scramjets
➢	Examples:	Patriot, HyFly

Hypersonic Vehicles II: Space Vehicles

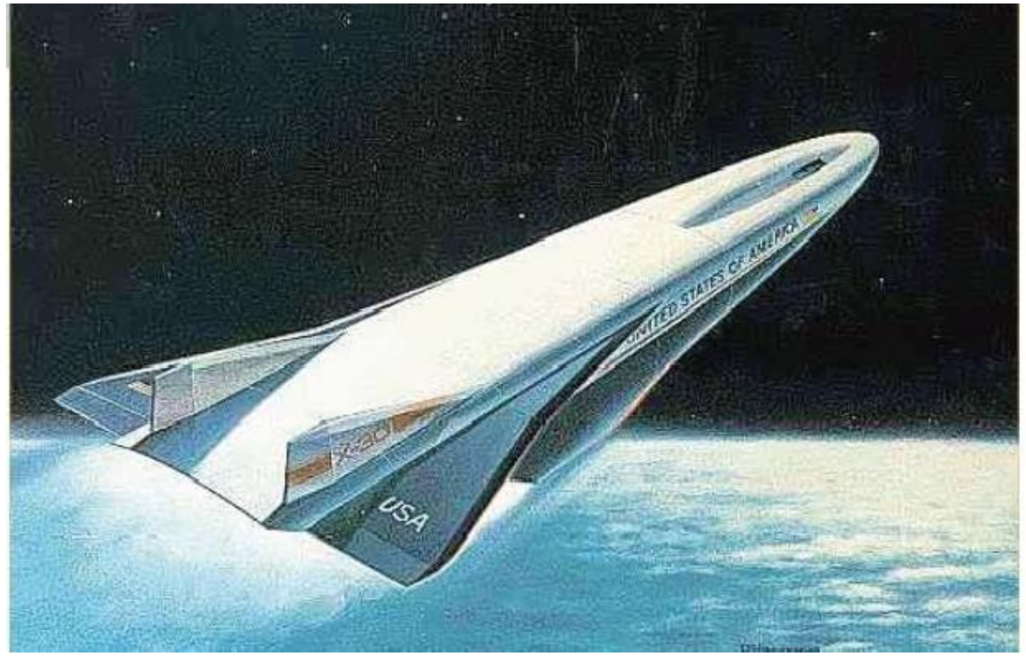


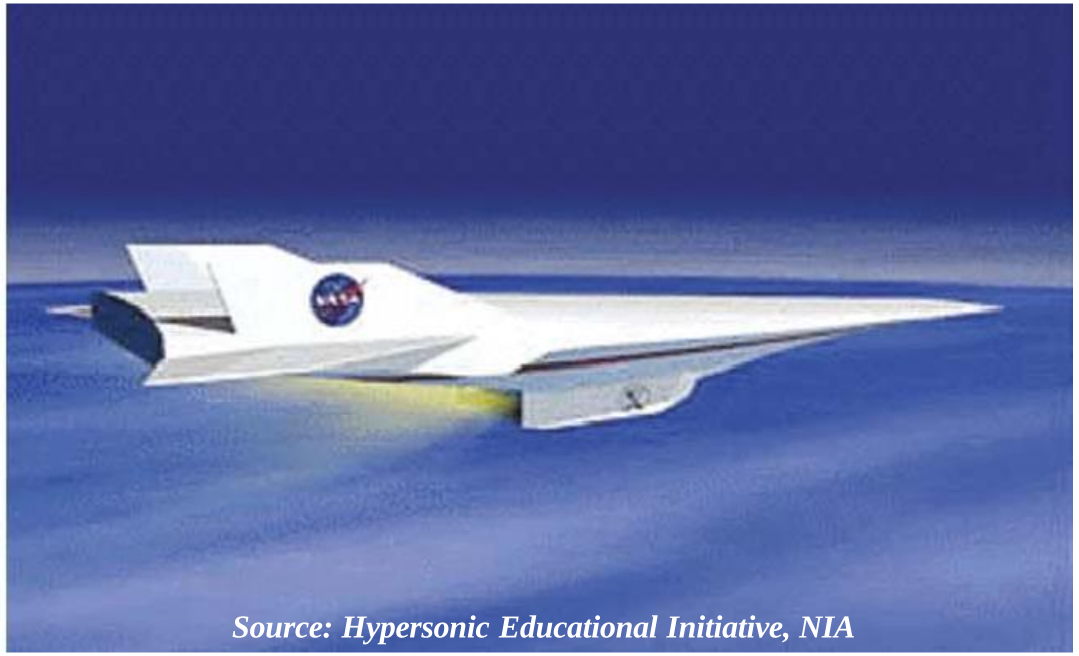


Source: Hypersonic Educational Initiative, NIA

- Mission: orbital re-entry
- Aerodynamics: gliders with thermal protection
- Propulsion: none (control thrusters only)
- Examples: Space Shuttle, Buran

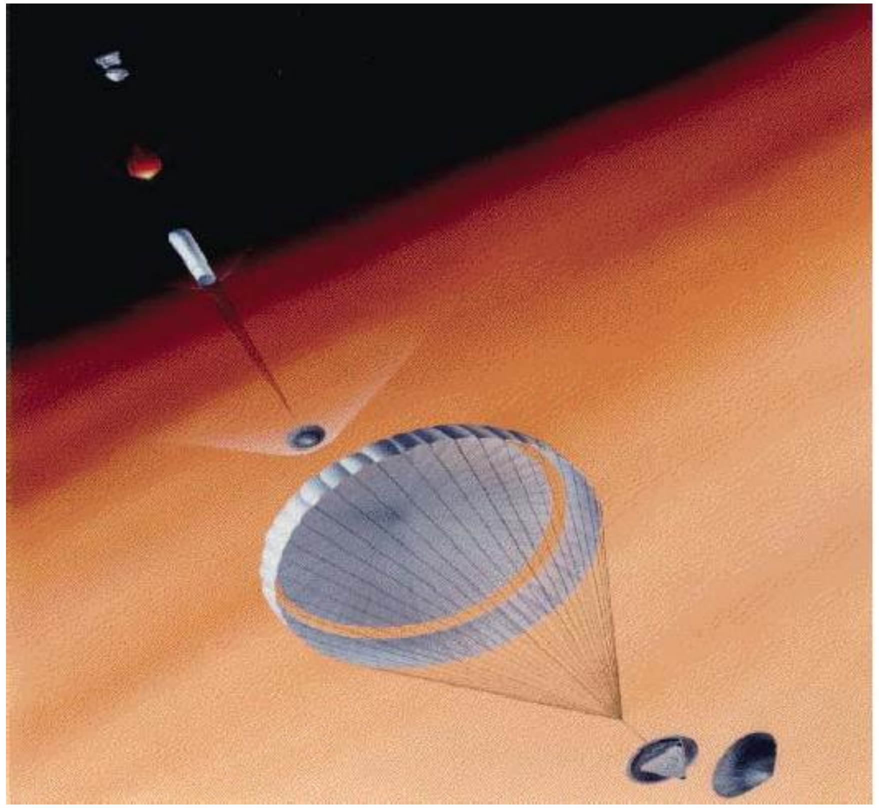
Hypersonic Vehicles III: Air-Breathing Systems




Source: Hypersonic Educational Initiative, NIA

- Mission: launch, cruise, re-entry
- Aerodynamics: Slender body, generally blunt leading edges, integrated propulsion
- Propulsion: Ramjet, Scramjet, Rockets, TBCC
- Examples: X-15, X-43, X-51

Hypersonic Vehicles IV: Planetary Entry



Source: Hypersonic Educational Initiative, NIA

- ➢ Mission: Entry-Descent-Landing (EDL)
- ➢ Aerodynamics: Very blunt
- ➢ Propulsion: None
- ➢ Examples: Apollo, Orion

Some Current Hypersonic Programs

Lockheed Martin [SR-72](#)

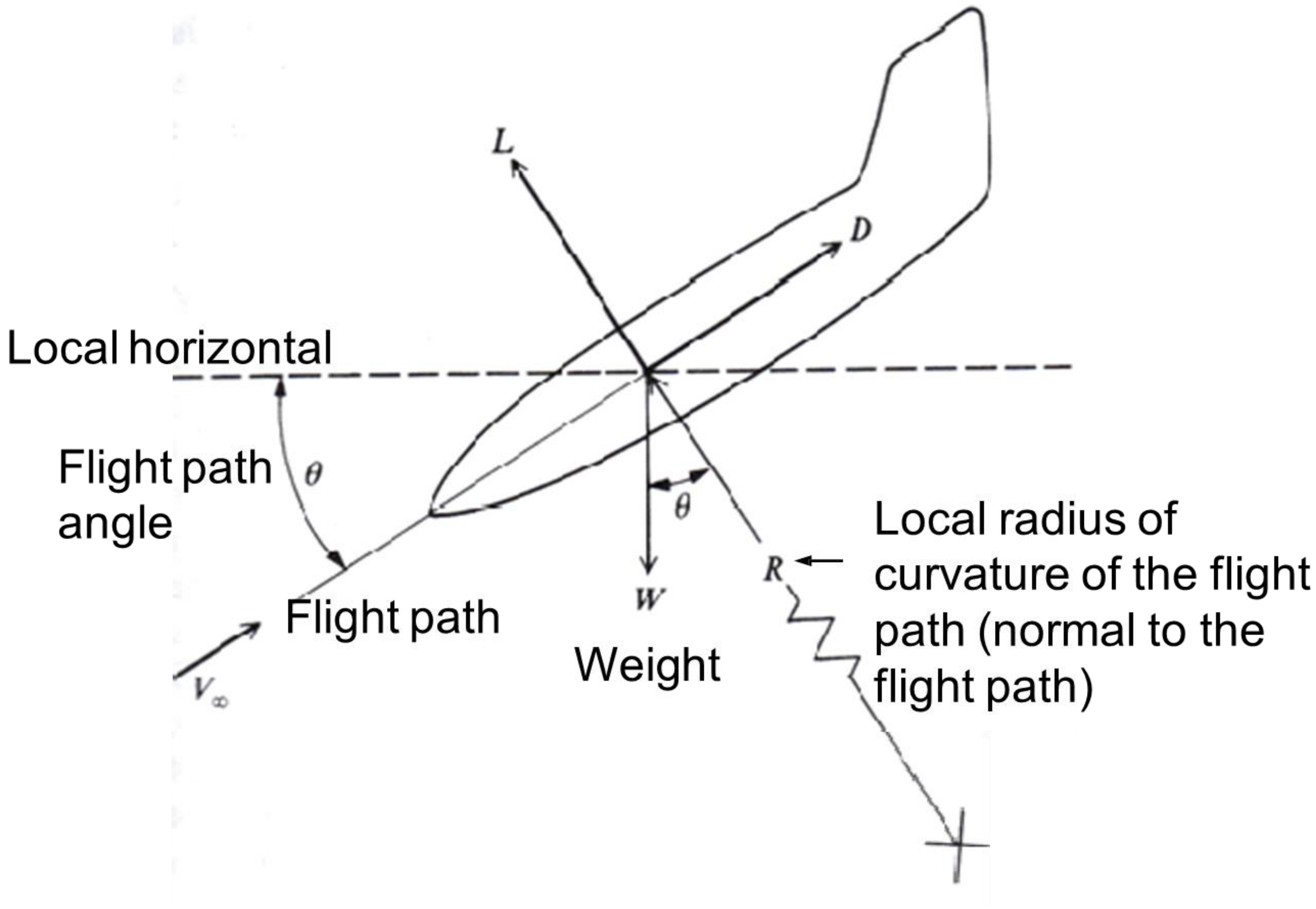
NASA [ORION](#)

DSTO/AFRL [HIFire Program](#)

Example of Unexpected Events Produced by Hypersonic Flight

- X-15 test flight with dummy scramjet installed.
  - Unexpected shock interactions generated
  - Burned holes in connection pylon

Re-Entry Trajectories



- Consider a hypersonic re-entry vehicle to derive the trajectory equations for Earth centered system.

- Assume constant flight path angle and no thrust.

Re-Entry Trajectories

$$\begin{cases} \sin\theta - \dfrac{1}{g}\dfrac{dV}{dt} = \left(\dfrac{W}{C_D S}\right)^{-1} \dfrac{\rho V^2}{2} \\ \cos\theta - \dfrac{1}{g}\dfrac{V^2}{R} = \left(\dfrac{W}{C_L S}\right)^{-1} \dfrac{\rho V^2}{2} \end{cases}$$

$\dfrac{W}{C_D S}$ ***Ballistic parameter***

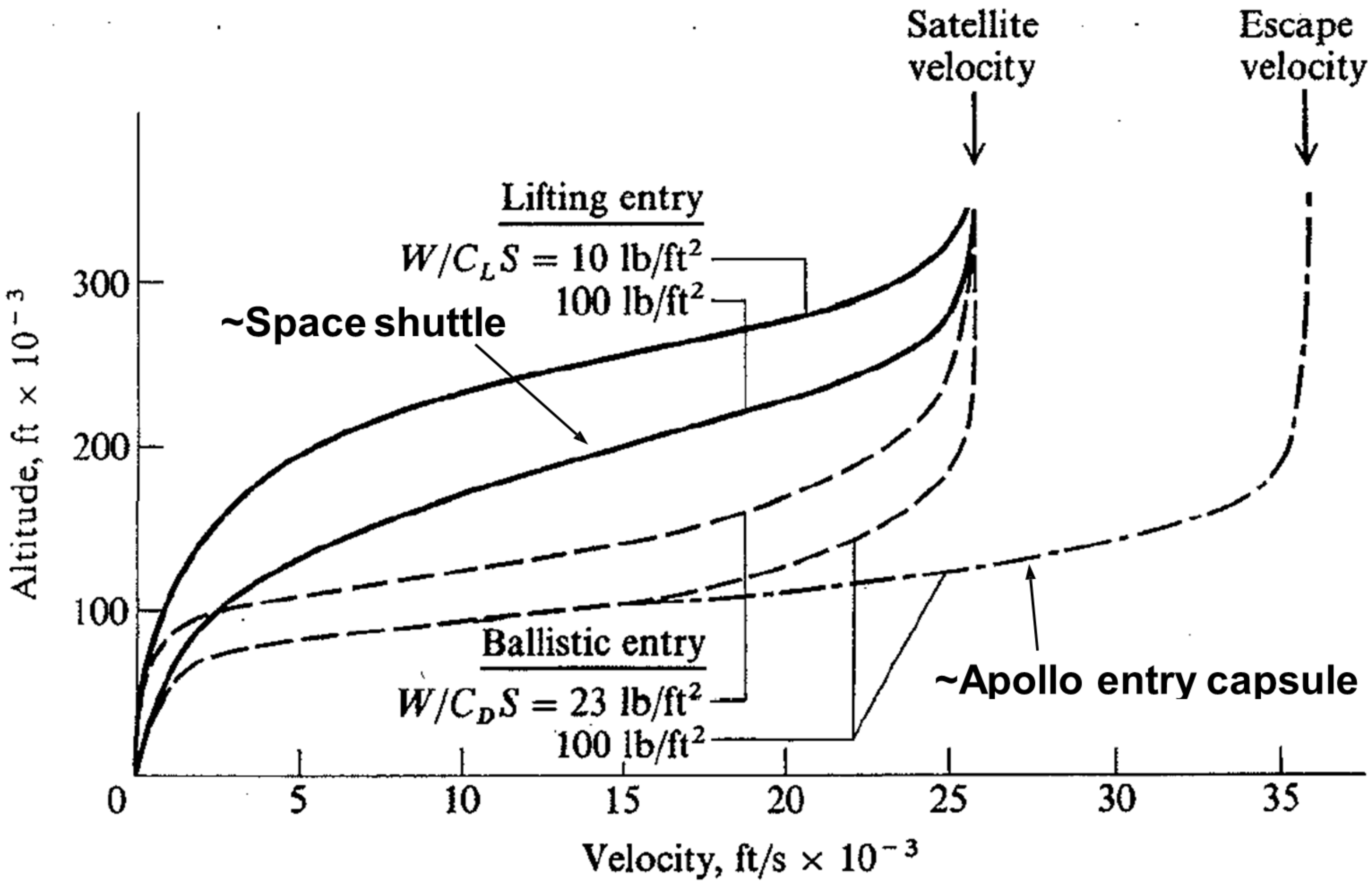
$\dfrac{W}{C_L S}$ ***Lift parameter***

For small re-entry angles:

$$\begin{cases} -\dfrac{1}{g}\dfrac{dV}{dt} = \left(\dfrac{W}{C_D S}\right)^{-1} \dfrac{\rho V^2}{2} \\ 1 - \dfrac{1}{g}\dfrac{V^2}{R} = \left(\dfrac{W}{C_L S}\right)^{-1} \dfrac{\rho V^2}{2} \end{cases}$$

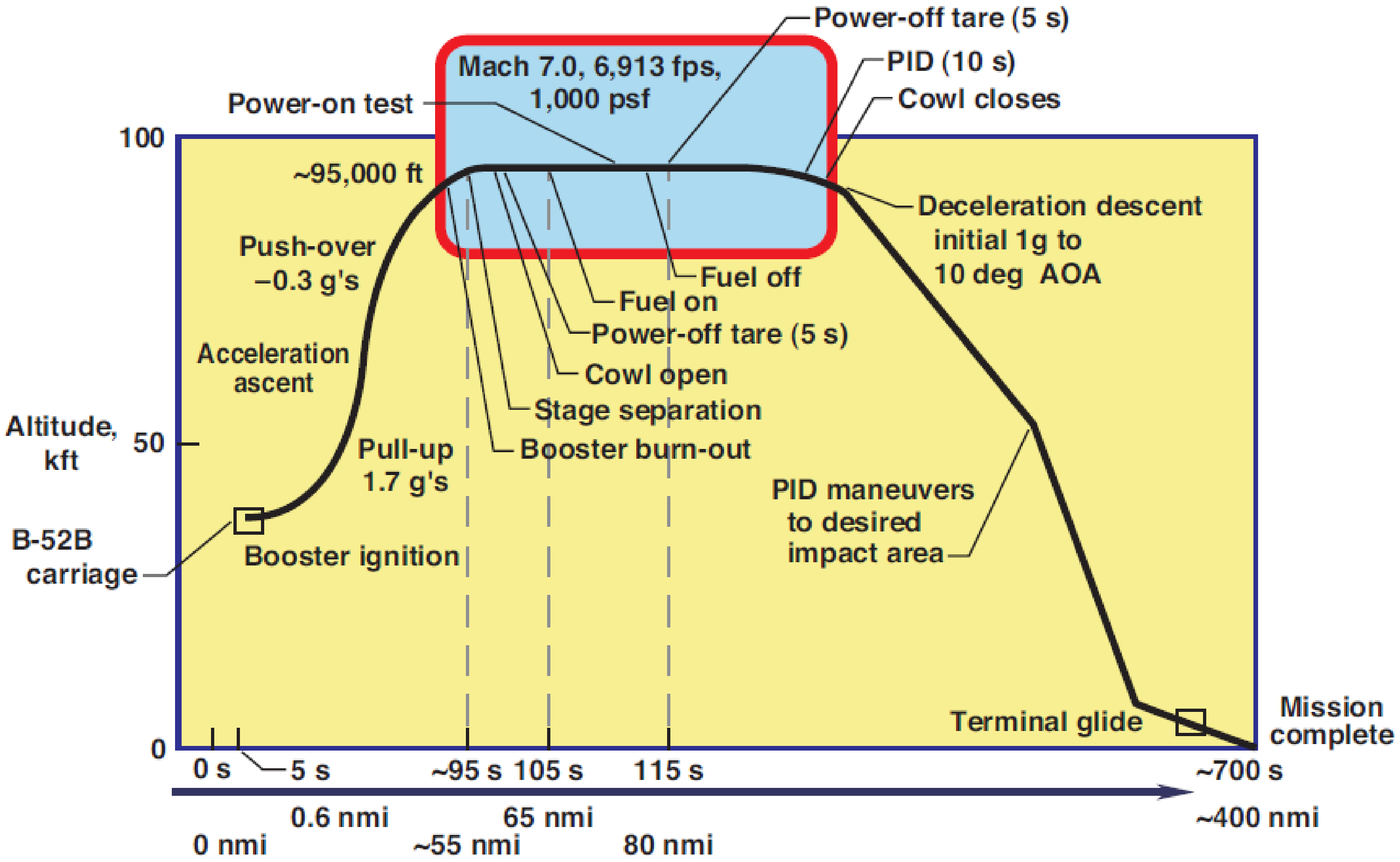
- Both ballistic and lift parameters affect the flight path of the entry vehicle.
- For a purely ballistic re-entry, L = 0 and ballistic parameter is the only parameter governing the flight path for a given entry angle.
- For high values of ballistic parameter and/or the lift parameter the vehicle can penetrate deeper into the atmosphere before slowing down.

Velocity-Altitude Maps for Re-entry Vehicles



Velocity-Altitude Maps for Ramjets and Scramjets

- In the case of air-breathing hypersonic vehicles, it is customary to operate the aircraft along a **constant dynamic pressure path** above Mach 2 or 3 for engine design constraints.



The X-43 Mach 7 mission profile.

Source: AIAA 2005-3332

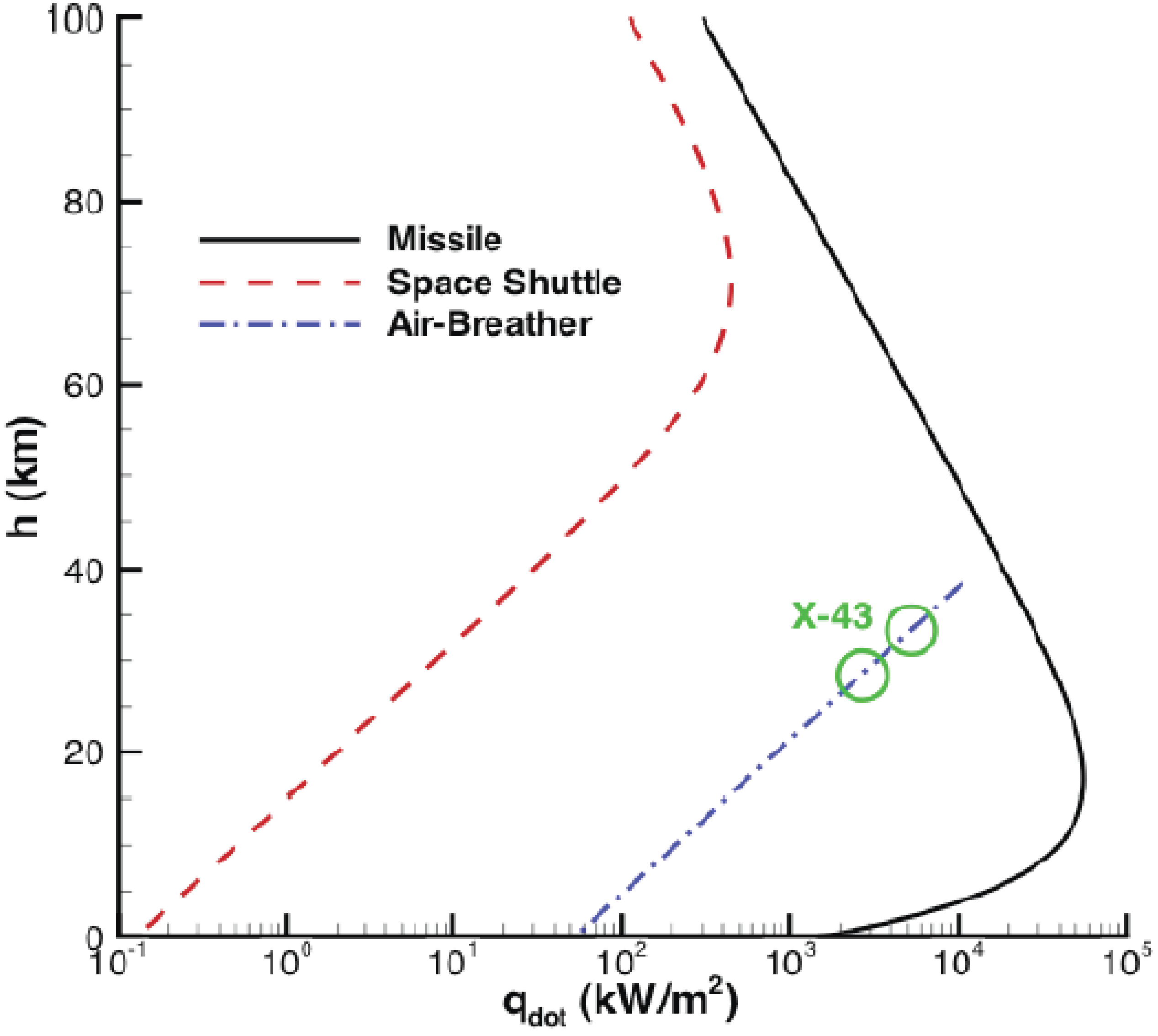
Re-entry Trajectories for various Hypersonic Vehicles

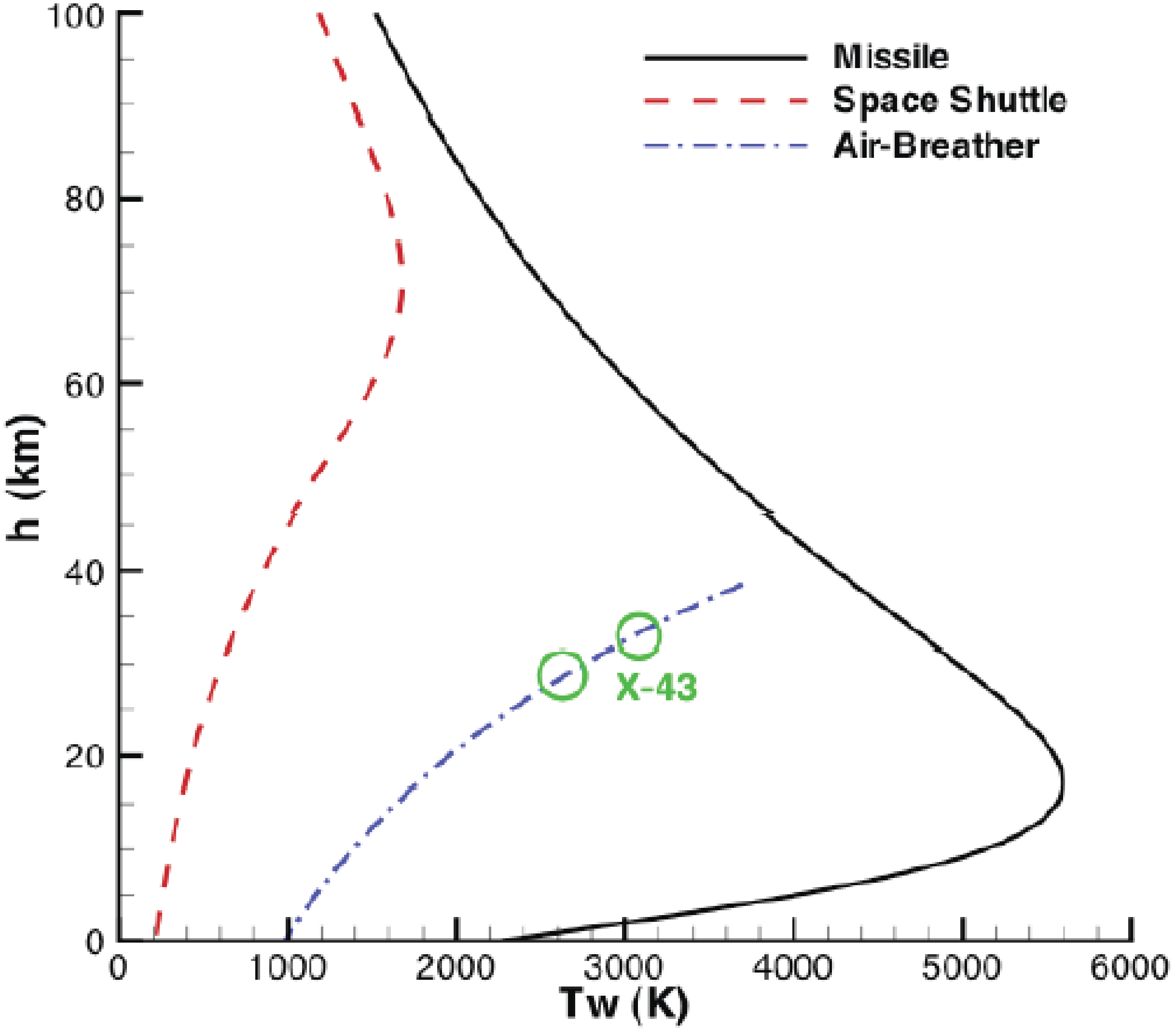
- Ballistic missiles:
  - Mission: short flight, fast impact
  - Rocket launch, ballistic entry
  - No thrust or lift during entry
  - Fixed flight path at large angle (θ=const.)

- Space Shuttle:
  - Mission: orbital return
  - Rocket launch
  - Lifting (glide) entry
  - No thrust, L / D ~ 1 and $\theta \sim 0$ (shallow entry)

- Air-breathing vehicle:
  - Mission: cruise, orbital return
  - Completely reusable
  - Powered take-off and entry

Stagnation Point Heat-Flux and Wall Temperature





Source: Hypersonic Educational Initiative, NIA