# Vehicle Reusability

- The concept
- The promise
- The price
- When does it make sense?

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**Sir Arthur C. Clarke:**

"We're moving from the 'beer can' philosophy of space travel towards the 'beer keg' approach."

- Discussion about recent Congressional approval of the Space Shuttle program (1972)

**Wernher von Braun:**

"The Apollo program is like building the Queen Elizabeth II ocean liner, sending three passengers on a trip from New York to London and back, and then sinking it."

# "Common-Sense" Rationale:

- Launch vehicles are really, really expensive.
- If we could use them more than once, we could reduce the costs for each payload.
- Airplanes represent an "existence proof" that reusability provides lower costs
- If the costs become low enough, we can make space transportation a commercial endeavor like air transportation.

# Airline Economics (from first lecture)

- Average economy ticket NY-Sydney round-round-trip (Travelocity 1/28/04) ~$1300
- Average passenger (+ luggage) ~100 kg
- Two round trips (same energy as getting to low Earth orbit = $26/kg
  - Factor of 60x electrical energy costs
  - Factor of 250x less than current launch costs

☆ So all we have to do is fly the launch vehicle 250 times and we're there?

# Expendable --> Reusable?

What are the additional capabilities required to make a vehicle reusable?

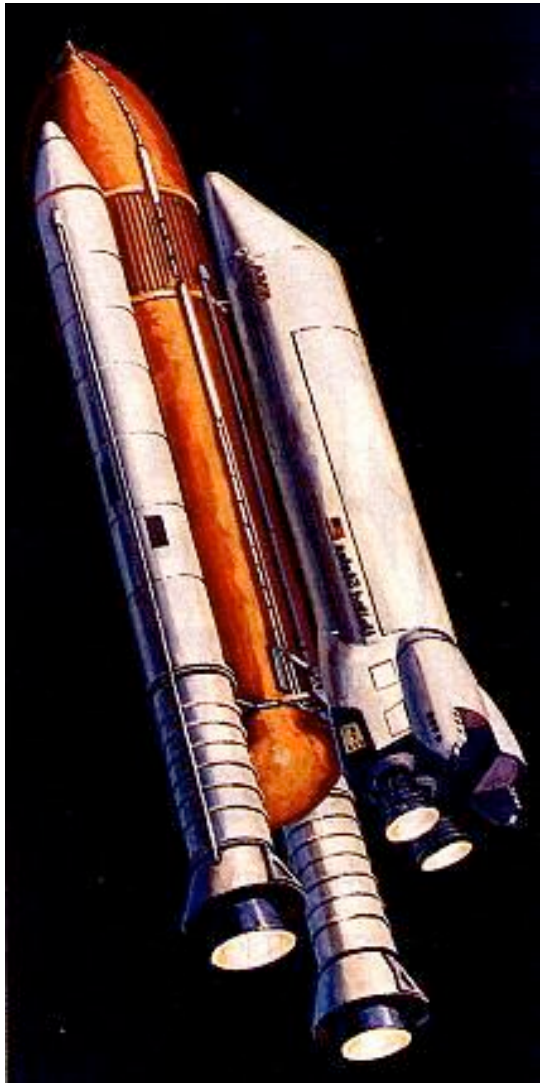
- Atmospheric entry and descent
  - Additional mass
- Targeting to desired landing point
  - Additional complexity
- Terminal deceleration and landing
  - Additional mass
- Robustness and Maintainability
  - Additional mass and complexity

# Impact of Reusability

- ELV upper stage generally lighter than payload
  - Delta IV Heavy stage 2 inert mass 3490 kg
  - Delta IV Heavy payload mass 25,800 kg
- RLV upper stage generally much heavier than payload
  - Shuttle orbiter mass 99,300 kg
  - External tank mass 29,900 kg
  - Shuttle payload 24,400 kg

# Side Issue - Heavy Lift to Orbit?

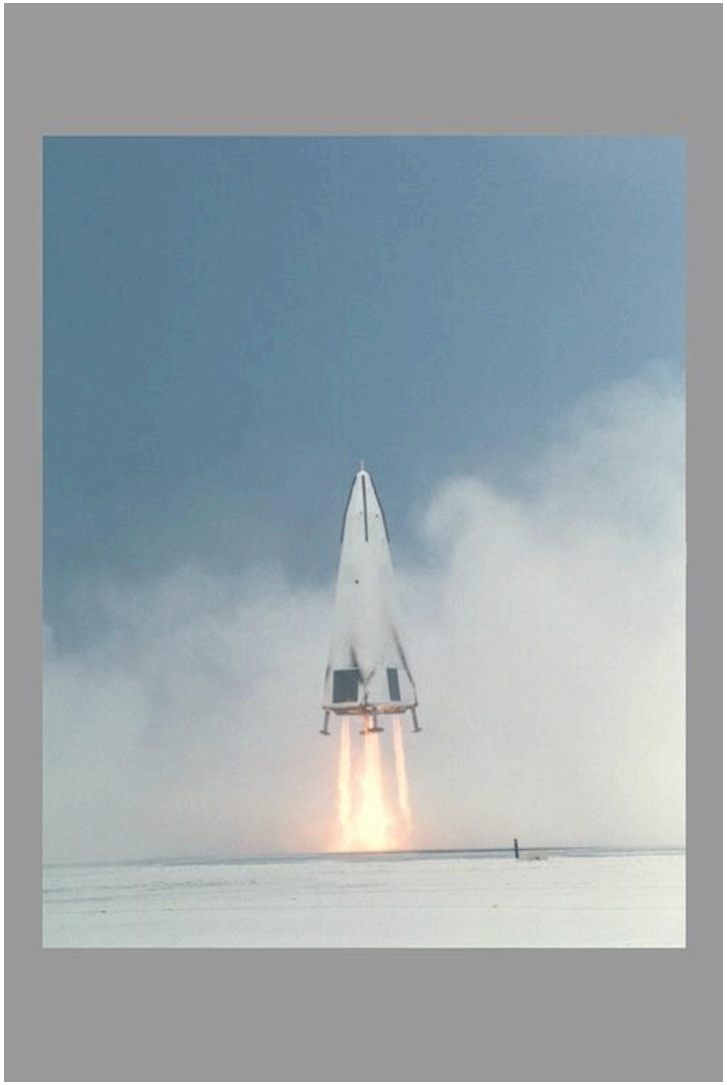
- Total Saturn V mass delivered to LEO = 131,300 (118,000 kg payload)
- Total Shuttle mass delivered to LEO = 153,600 kg (24,400 kg payload)
- Genesis of "Shuttle -C(argo)" concepts to eliminate orbiter in favor of payload

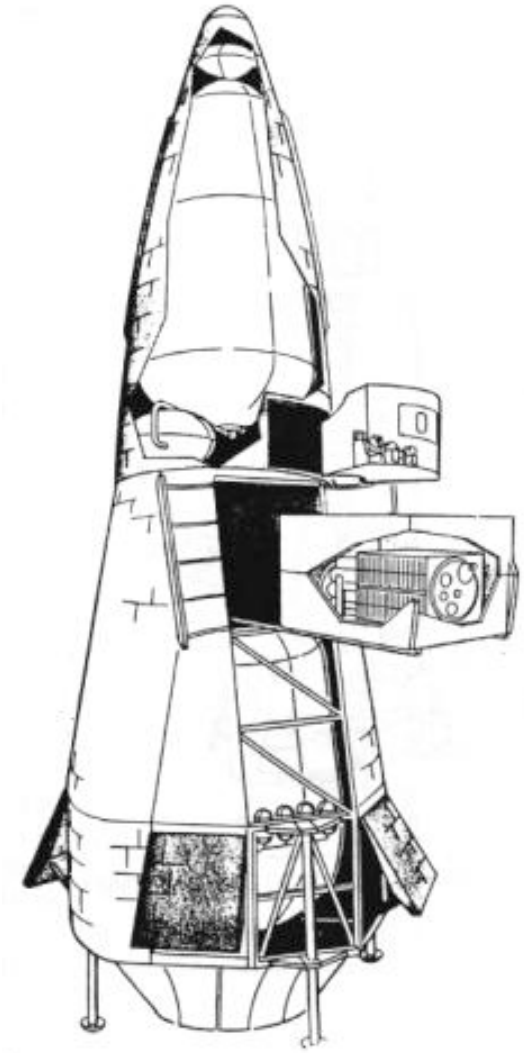


# Performance Issues of RLVs

- Large ratios of orbited inert mass/payload mass degrades mission performance
- Atlas V payload capabilities
  - 27,550 lbs to 28° LEO
  - 23,700 lbs to polar orbit
- Shuttle payload capabilities
  - 53,800 lbs to 28° LEO
  - 19,000 lbs to polar (requires augmentation)

# Ballistic Vehicle

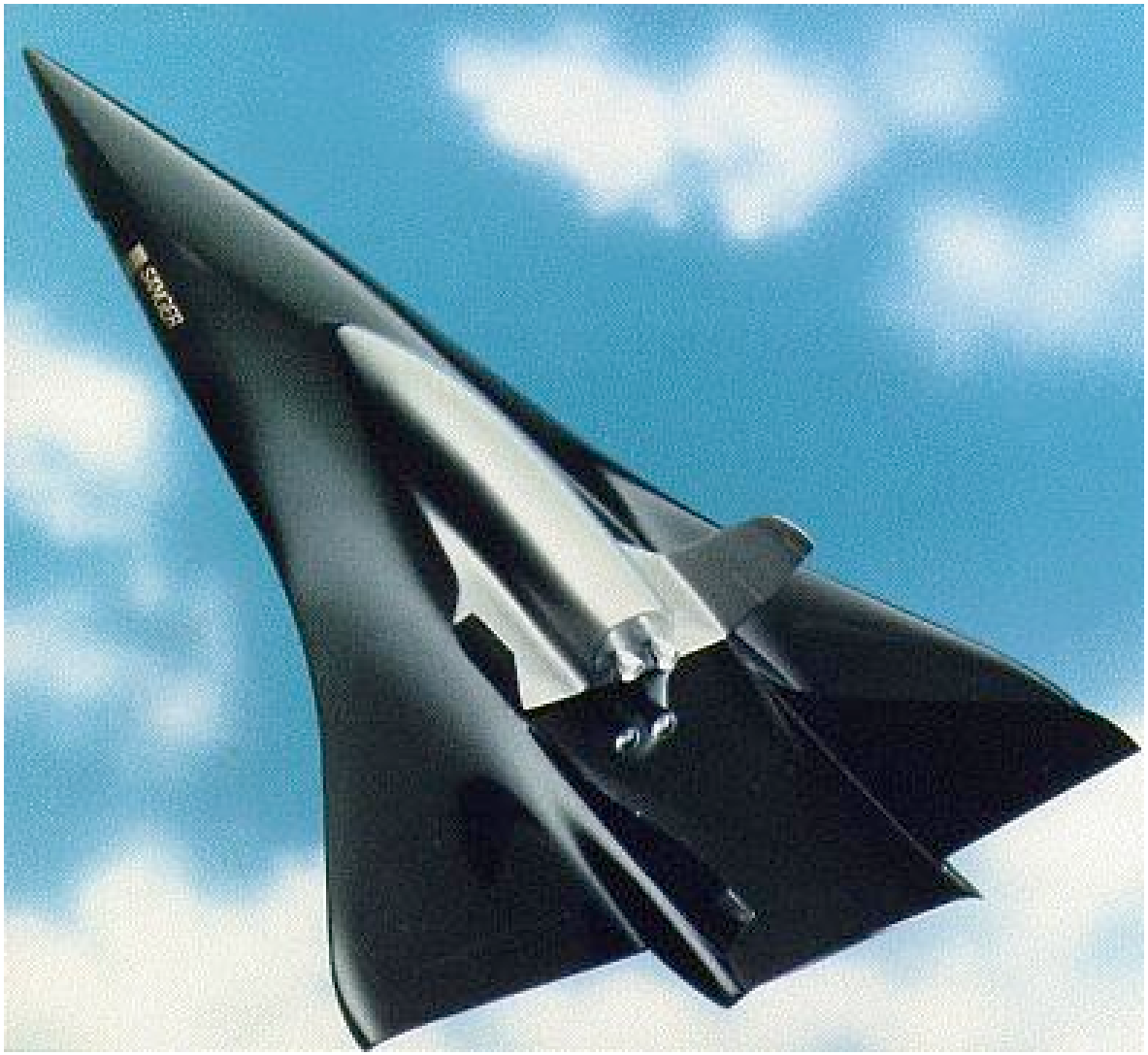




# SSTO - Winged (VTOHL)

# SSTO - Lifting Body (VTOHL)

# Airbreathing First Stage (HTOHL)



# Flyback Booster and Winged Upper Stage

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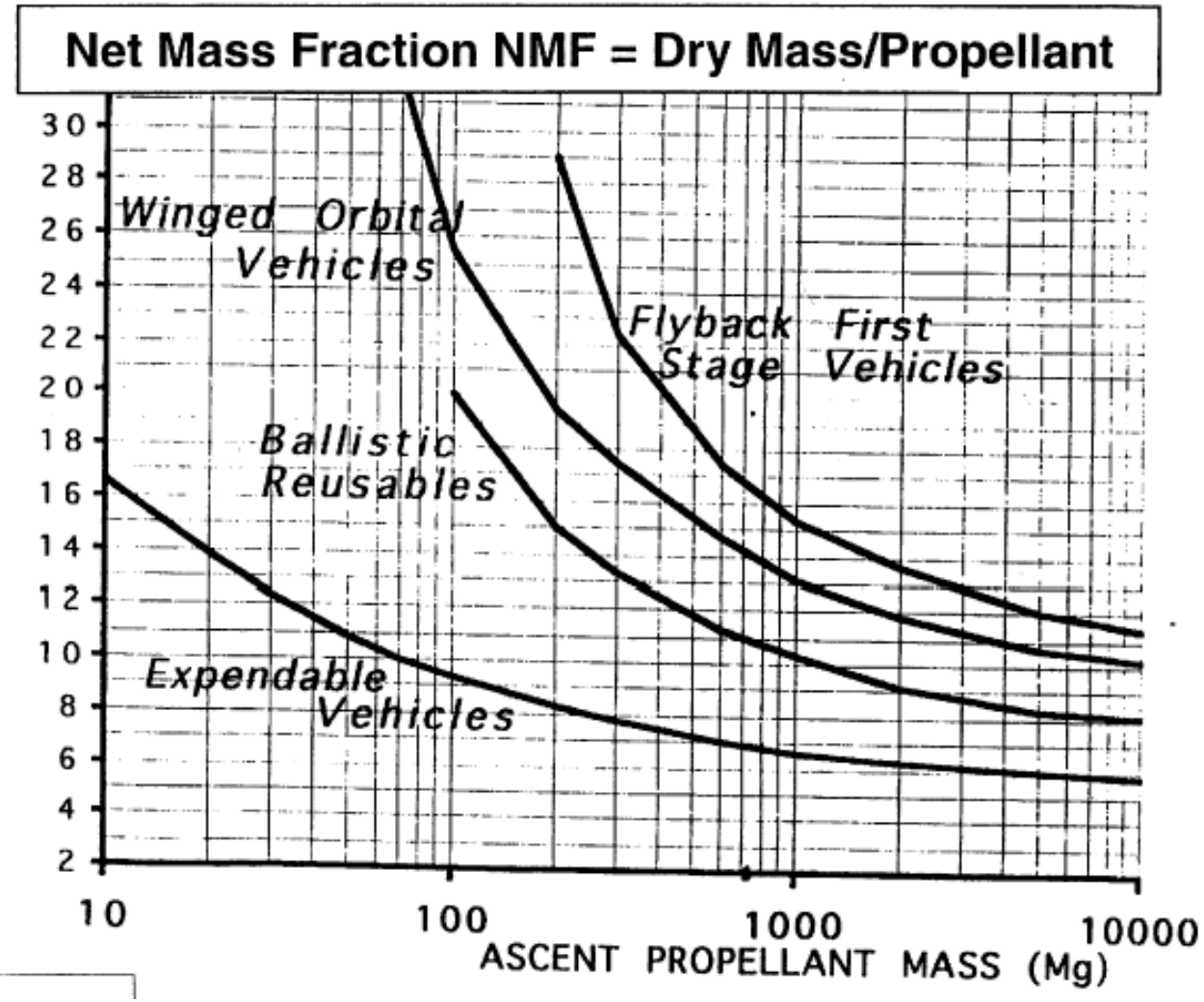
# Flyback Booster and Winged Upper Stage

# Air Launch and Winged Upper Stage

# Air Launched and Winged Upper Stage

# Mass Effects of Reusability




from Dietrich Koelle, Handbook of Cost Engineering (TRANSCOST v.7)

# Orbital Entry (the Cliff's Notes version)

- Mass of thermal protection system ~ 20% of mass of vehicle protected
- Add ~300 m/sec (minimum) for maneuvering and deorbit
- Additional per-flight operating costs for maintaining orbital maneuvering system, thermal protection system

# Landing Taxonomy

- Vertical landing
  - Rockets
  - Rotors
  - Parachutes
    - Land
    - Water
- Horizontal landing
  - Wings
  - Lifting body
  - Parafoils

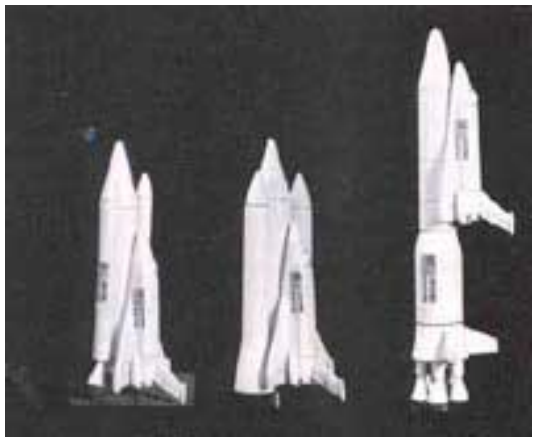
# Landing (the Cliff's Notes version)

- Mass of wings ~20% of mass supported
- Mass of parachute/parafoil ~3% of mass supported
- Mass of landing gear ~ 5% of mass of vehicle landed
- Best landing velocity attenuation ~3-4 m/sec vertical impact velocity

# RLV and Cost Savings (Shuttle Version)

- Shuttle was intended to reduce payload costs from ~$5000/lb (Saturn V) to~$500/lb
- Cost savings predicated on high flight rates
  - Shuttle: 10 yr program, 550 flights
  - One flight/week; two-week turnaround between flights of individual orbiter
- Had to cancel all other launch systems (single-fleet approach)

# Shuttle Design Concepts

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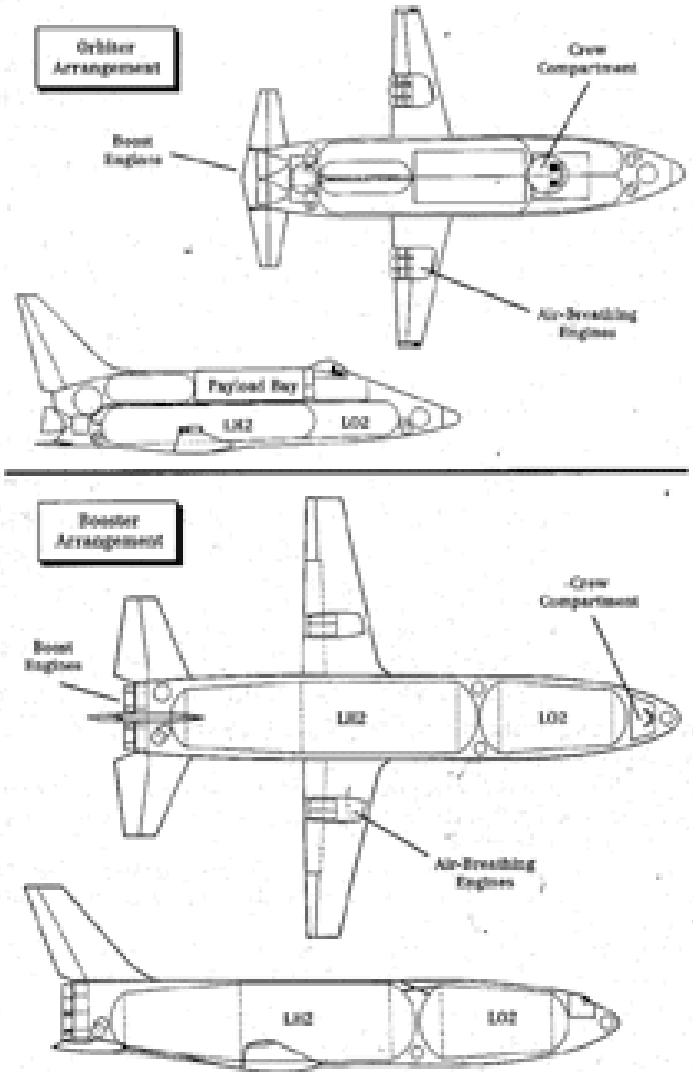
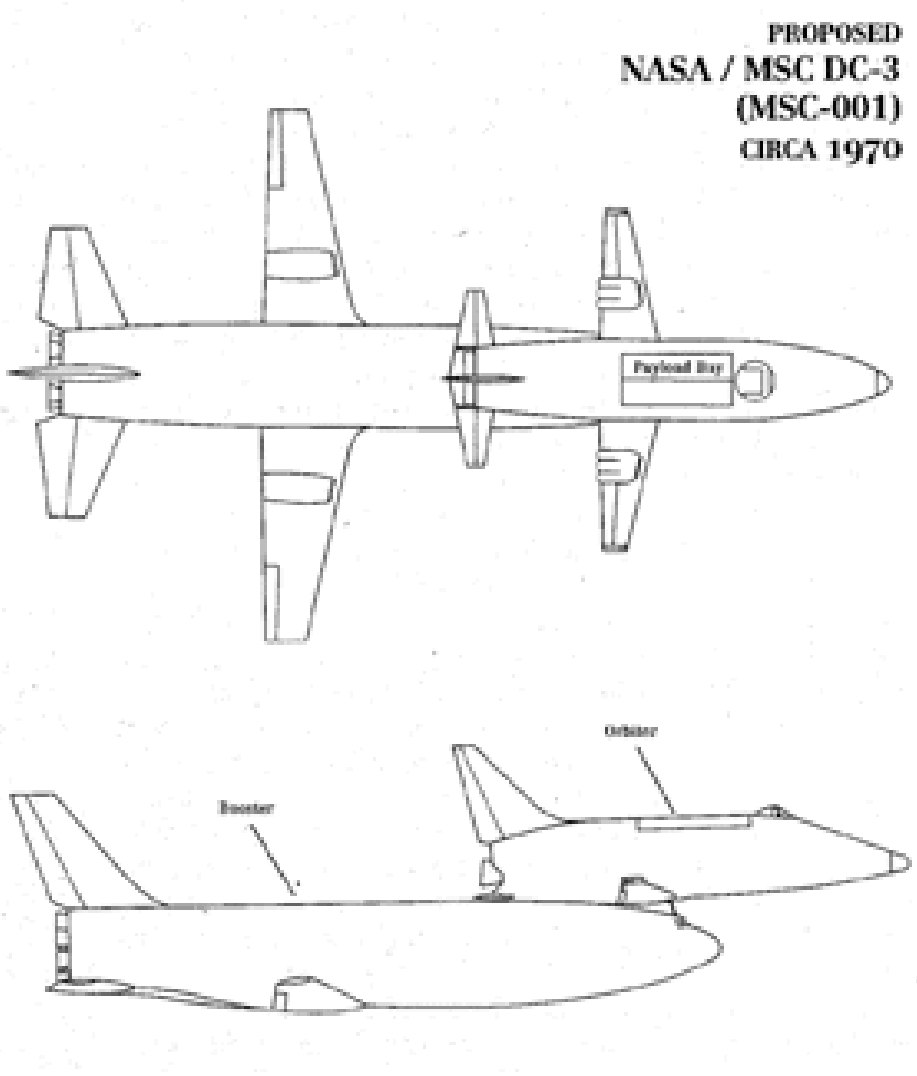
Reusability
Launch and Entry Vehicle Design

# Early Shuttle Design Concept

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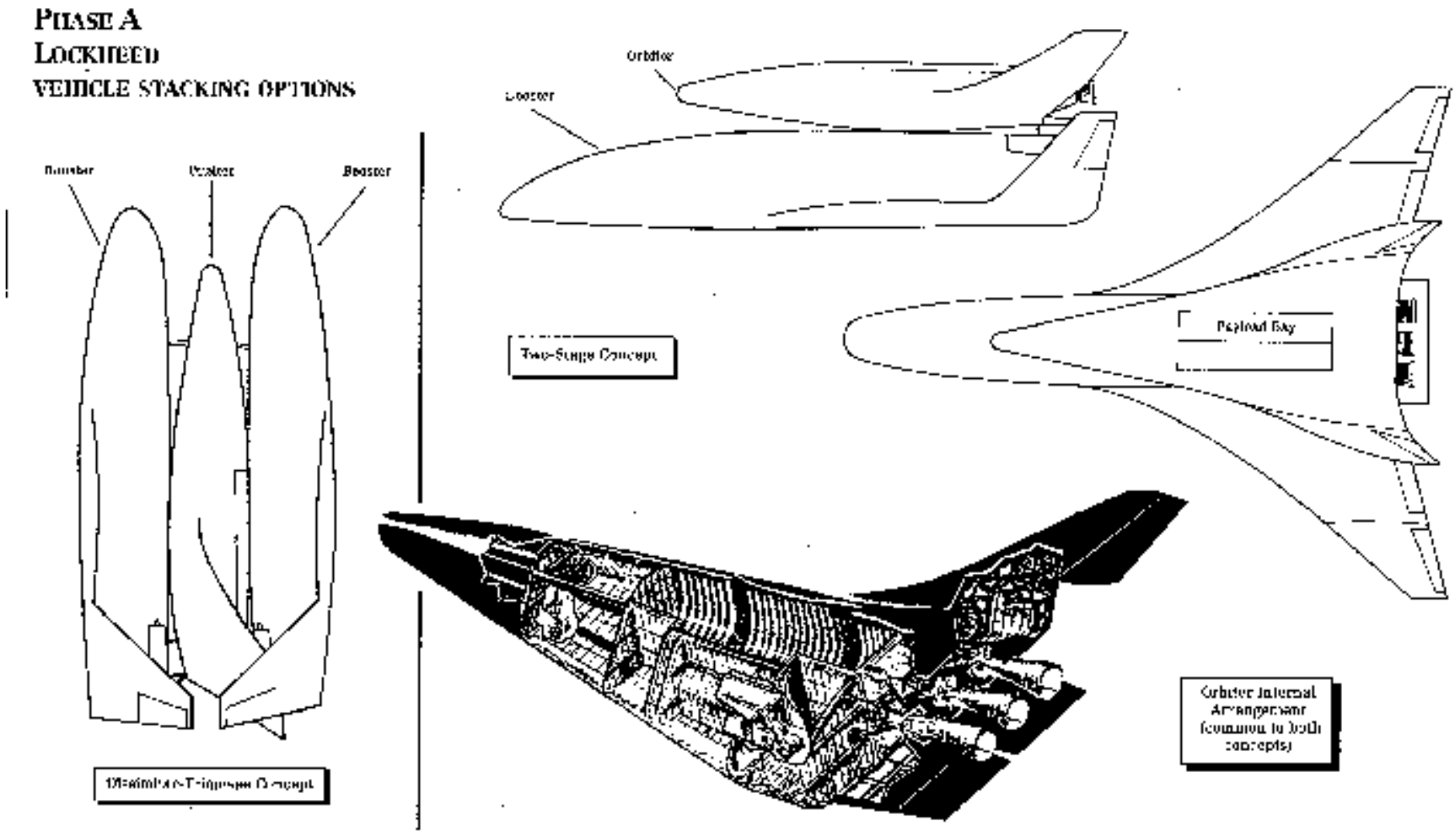
Launch and Entry Vehicle Design

# "Triamese", "Biamese" Shuttle Concepts

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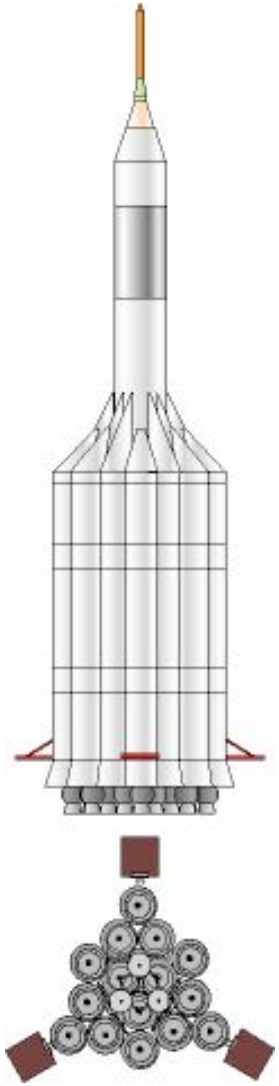
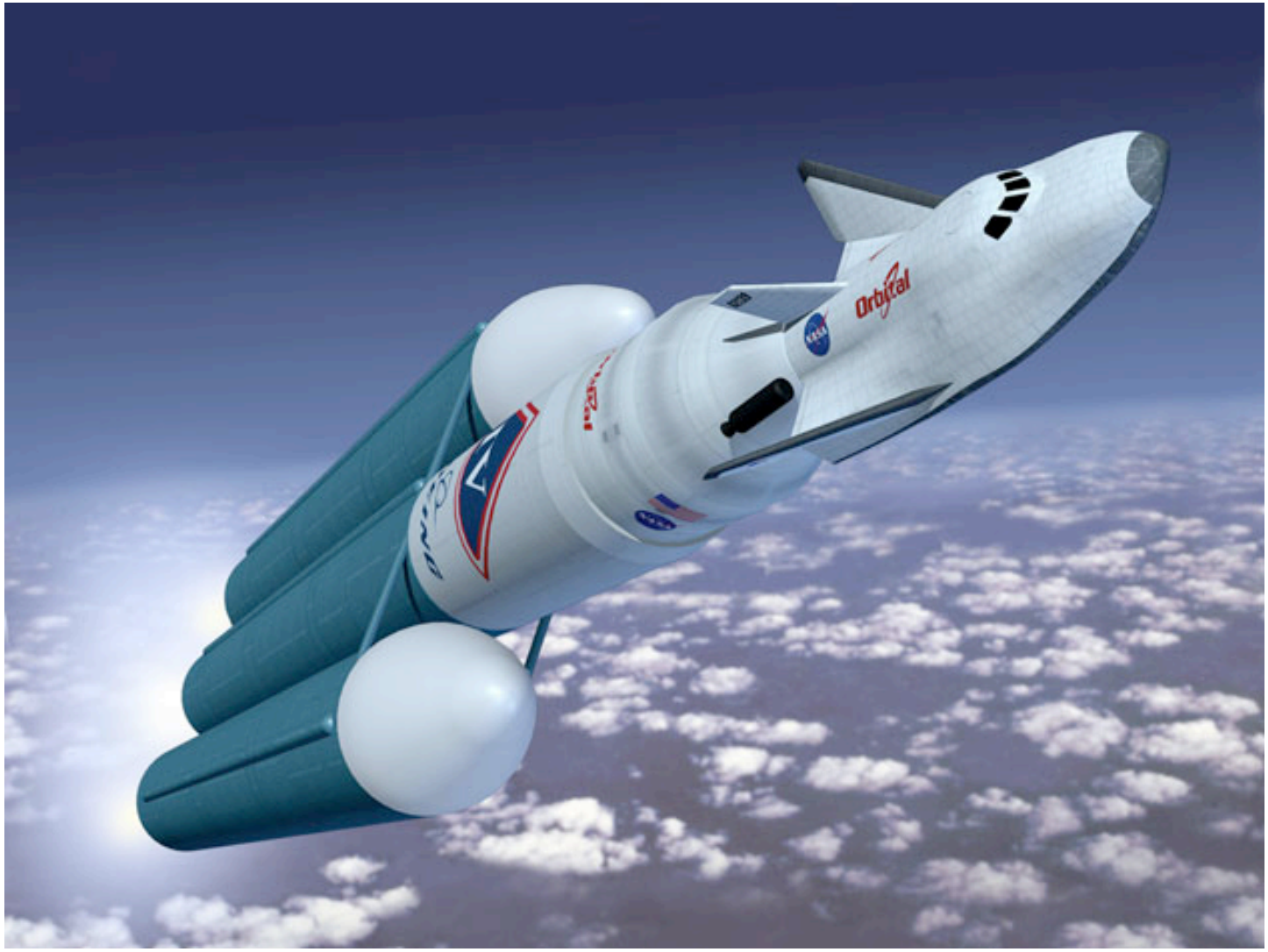
# Shuttle Costs Savings: What Went Wrong?

- 160 hr turnaround --> 2000 hr turnaround
- 1% refurbishment --> 10-15% refurbishment
- Not everyone wants to be human-rated
- Why fly humans on missions where you don't need them?
- Why fly reusable stages on missions where nothing comes down?

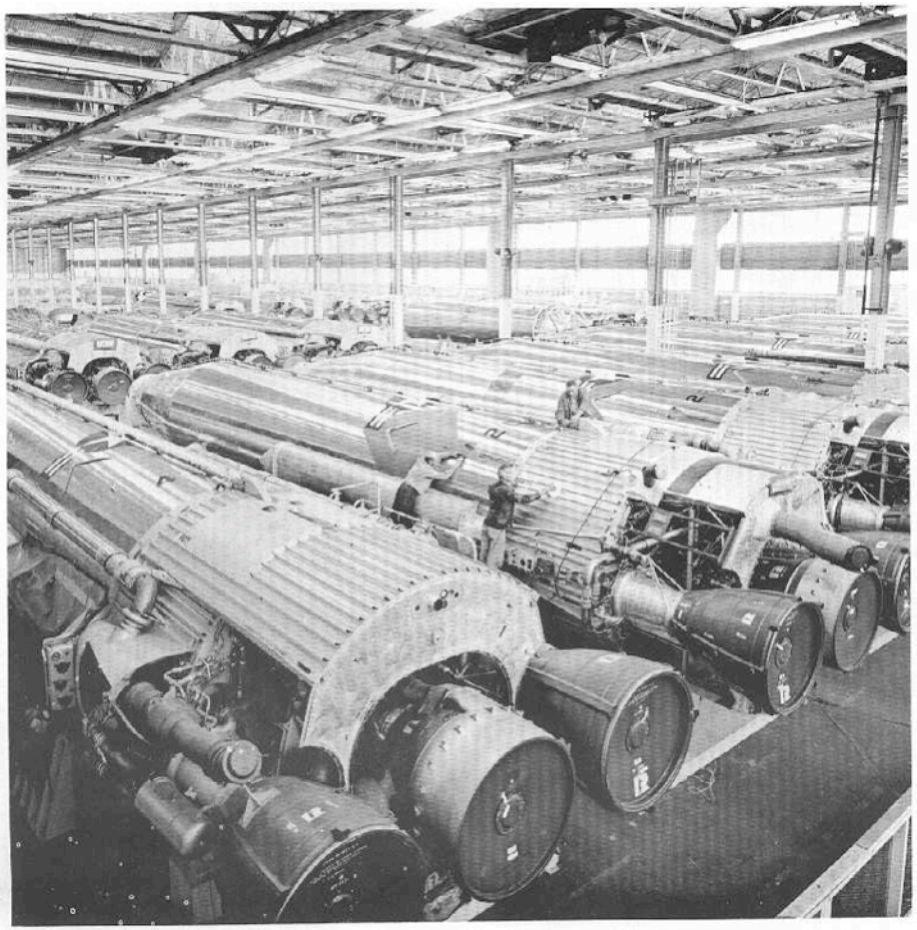
# Cost Reduction: Modular Launch Vehicles



# Crew Rotation Vehicle on Delta IV Heavy



# Cost Reduction: Mass Production



OUT OF RETIREMENT - Atlas ICBMs in storage are slated for refurbishment and launch for ABRES (Advanced Ballistic Re-Entry Systems) and Nike Target program launches for the U.S. Air Force. Twenty-three Atlas series E and F ICBMs will be updated under a contract awarded to the Convair division of General Dynamics by the Air Force Ballistic Systems Division. Fifteen of the twenty-three are shown here in storage at San Diego. The other eight of the twenty-three to be refurbished are in storage at Norton AFB, Calif. and will be taken to the Convair division's Kearny Mesa plant at San Diego for the updating work. The "retired" missiles were produced originally for service in the strategic missile deterrent force at eleven Air Force bases across the nation. (General Dynamics photo)

# Why Launch Vehicles are Expensive