Vehicle Reusability

• The concept
• The promise
• The price
• When does it make sense?
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
Flyback Booster and Winged Upper Stage
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
Early Shuttle Design Concept

PROPOSED
NASA / MSC DC-3 (MSC-001)
CIRCA 1970

Reusability
Launch and Entry Vehicle Design
“Triamese”, “Biamese” Shuttle Concepts

PHASE A
LOCKHEED
VEHICLE STACKING OPTIONS

Two-Stage Concept

Orbiter Internal Arrangement (common to both concepts)
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
Why Launch Vehicles are Expensive