PERSPECTIVES ON PROPULSION FOR FUTURE SPACE MISSIONS

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By
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First Task: Earth to Orbit

(1) Existing Expendable Launch Vehicles: Atlas-V, Delta-4


(3) New Reusable Vehicle: Rocket, Rocket-based Combined Cycle

(4) Advanced Concepts: Tethers, Laser-powered rockets, Guns, etc.
Basic Problem: Achieve Orbital Speed (~7.5 km/s)

- $V = V_e \ln \frac{M_o}{M_f} - \text{gravity} - \text{drag}$
- Best $V_e \sim 3.5 - 4.0$ km/s
- Hence $M_o/M_f > 9$
  ($> 89\%$ expendables)
Shuttle-Derived Vehicles: A Launch Option for Space Exploration
A New Beginning?

Change Factors:
- China in Space
- Columbia Tragedy
- Shuttle Orbiter being phased out
- Space Station operational
- Orbital Space Plane: Dead
- Project Constellation

Basic change in space philosophy since 1981.

Now have “destination” in LEO, Orbiter phasing out, new competition.
What is a Shuttle-Derived Vehicle (SDV)?

- New vehicle using major components of NASA’s Space Transportation System (STS).

- Modified and/or replaced:
  - Orbiter
  - Solid Rocket Boosters
  - External Tank
  - Engines (SSMEs)

- May be Piloted or Unpiloted
STS Components

• Orbiter
  – Crew, cargo, engines
  – 1.5 M-lb thrust
• Solid Rockets
  – Main liftoff thrust (5.2 M-lb)
  – “Pillars” on launch pad
• External Tank
  – 2 tanks: LOX, LH2
  – STS structural backbone
  – Brought almost to orbit, discarded
Why an SDV?

• New missions
  – Cargo to LEO and beyond
  – New piloted-vehicle launcher
  – Large lunar/planetary missions

• Cargo versions: 2x-3x Orbiter
  – 80 to 150 klb to LEO
  – Shuttle Orbiter: 50 to 65 klb

• Reduced development costs

• Use of STS infrastructure
  – Launch facilities
  – Ground support and processing
  – Design and production heritage
Some SDV Approaches

- **Shuttle-C, Shuttle-Z, Shuttle-B**
  - Replace Orbiter with cargo module, upper stage, etc.
- **Inline HLLVs (e.g. Ares)**
  - Adapt engines, tankage, solids for new launch vehicle
- **New Booster Rockets**
  - Liquid, Flyback, Hybrid
- **Wingless Orbiter**
  - ET reaches orbit with non-returning piloted vehicle
- **SRB-X**
  - All-solid launcher using Shuttle Solid Rocket Boosters
Shuttle-C

- Cargo canister replaces Orbiter
  - 2-3 SSMEs in Orbiter “boat-tail”
  - Engines, canister destroyed on re-entry

- 100 – 150 klb to LEO

- Closest SDV to reality
  - NASA-funded 1987-91
  - Killed by other Space Station Freedom needs
New Concept: Shuttle-B

- Use new expendable engines
  - Boeing RS-68, now used on Delta-IV
  - Northrop Grumman TR-106, ground tested

- Engines fixed to, discarded with ET

- Launcher-independent “payload vehicles”
  - Attached to ET above engines
    - Cargo Carrier
    - Space Exploration Vehicle
    - Payloads / Upper Stages

- Configuration shown is “schematic”
Shuttle-B Configurations

- Cargo
- Upper Stage
- Space Exploration Vehicle

NOTE:
Configurations, payloads shown are speculative.
Shuttle-B Expendable Engines

- **Boeing RS-68**
  - 750 klb thrust (vs 500 klb SSME)
  - Two RS-68s at 100% rated thrust match three SSMEs at 109% rated thrust
  - Some payload penalty: Isp 410 sec (vs 452 sec for SSME)
  - Reduced parts count, not man-rated.
  - Now flying, on Delta-IV Evolved Expendable Launch Vehicle (EELV).

- **Northrop Grumman (TRW) TR-106**
  - Pintle-injection (similar to LEM descent engine)
  - 650 klb thrust
  - Northrop Grumman claims one-half to one-fourth cost of RS-68 due to simplicity.
  - Limited test-firings in 2000; would require development, man-rating
Ares Launcher

• **Direct ascent for “Mars Direct”**
  – Robert Zubrin, David Baker, Owen Gwynne
  – Circa 1991, Lockheed Martin

• **Semi-Inline Concept**
  – Use ET, SRBs
  – Side-mounted engines
  – Top-mounted cryogenic upper stage and payload

• **Payload: 104,000 lb to Mars**
  – Earth Return Vehicle
  – Habitation Module & Crew
Wingless Orbiter

- General Dynamics, External Tanks Corp.
- Orbiter w/o wings lofted (no return)
- Connected to emptied External Tank
- Large-volume station with Orbiter crew cabin, payload bay
Liquid Rocket Boosters

• **Advantages**
  – Throttleable
  – Handling

• **Issues**
  – Complexity
  – Thrust
  – Cost
  – Reusability
Flyback Booster Concept

- Replace SRBs with liquid boosters that fly back to launch site.
- Jet engines for powered landing. Unpiloted.
- Flyback boost part of many early STS designs.
- Probably dead issue for STS following Columbia, Orbiter phase-out.
- May be an element in future SDV concepts.
SSTO: The “Holy Grail”

- Recent program: X-33 -> Venturestar
- Fully Reusable
- Propulsion: Hydrogen/Oxygen Aerospike Rocket
- Space Launch Initiative (NGLT): Two-Stage-to-Orbit (TSTO) using Kerosene and Oxygen
- Hyper-X; HyTech: Scramjet Technology
- No current large reusable LV development
Advanced-technology chemical rockets

- Solid/liquid hybrid rockets
- High thrust/weight, “Russian” cycles
- Gelled and metallized propellants
- High energy density materials
Generation-3 Technologies

- Combined-cycle engines
- Pulse-detonation engines
- Launch assist
- Gun launch
X-43C Hypersonic Flight Demonstrator
Once in Earth orbit, what next?

Space Exploration Vehicle (Project Constellation): Undefined; likely to be a modular set of Apollo-derived capsule-based vehicles

Project Prometheus: Nuclear-reactor powered electric thruster; new radioisotope powerplants for spacecraft

Nuclear thermal rocket: NERVA-based (solid-core reactor), particle-bed reactor, gas/plasma core, nuclear pulse (Orion)

Advanced concepts: Solar sails, laser-driven sails, tethers, M2P2, fusion-based rockets, antimatter propulsion, etc.
In-Space Propulsion—Currently Operational

– Chemical rockets (solid-propellant, liquid monopropellant, liquid bipropellant
– Arcjets
– Electromagnetic and electrostatic thrusters (all solar powered)
– Aerobraking and aerocapture (for planetary insertion)
Project Prometheus

Originally in Code S, Office of Space Science, now in Code T: Office of Space Exploration

(1) Performance upgrades to radioisotope power systems

(2) Development of a nuclear reactor, ca 100 kWe, to power an electric propulsion system and to provide large amounts of onboard power for scientific and exploration spacecraft.

(3) Development of a 100 kWe electric propulsion system

(4) Does not include nuclear thermal propulsion
Prometheus Heritage

(1) Current RTG powerplants (Galileo, Cassini): ca 250 We

(2) SP-100 reactor-powered thermoelectric: canceled 1992

(3) SNAP program (1950s, 1960s, 1970s):
   - SNAP-8: 30,000-hr test
   - SNAP-10A orbited 1964 (500 We SERT)
   - SNAP-20 design: 20 MWe

(4) Electric thrusters for Deep Space 1; long-term testing at GRC; XIPS at Hughes
Prometheus Isotope Power Research

(1) Thermoelectric Conversion
   - MIT: SiGe nanocomposites
   - Hi-Z Technology: Quantum-well thermoelectrics
   - Teledyne: segmented BiTe/PbTe-BiTe/TAGS/PbSnTe
   - Teledyne: superlattice BiTe-PbTe/TAGS

(2) Thermophotovoltaic Conversion
   - Creare, EDTEK, Essential Research

(3) Stirling-Cycle Conversion
   - Sunpower, Cleveland State University (microfabrication)

(4) Brayton-Cycle Conversion
   - Creare: Microfabrication and Demo
Prometheus Nuclear-Electric Power/Propulsion System Development

(1) Reactor Development: U.S. Department of Energy (Los Alamos)

(2) Power Conversion System and JIMO Spacecraft: ($50-million contracts awarded May 2003):
   - Boeing Phantom Works
   - Lockheed Martin
   - Northrop-Grumman

(3) Ion Propulsion Thruster: JPL and NASA-GRC
Blueprint for 21st Century Space Travel

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From the Nuclear Rocket Technologies web site.
Launching
with laser light
In-Space Propulsion: “Breakthrough” Concepts

• Nuclear fusion
• Interstellar ramjet
• Antimatter
• Breakthrough physics:
  - Wormholes
  - Warp drive
  - Antigravity
Ram-Scoop

H, H2
186,000 miles per second is not only a good idea...

IT'S THE LAW!