In-Orbit Fluid Transfer for Satellite Servicing

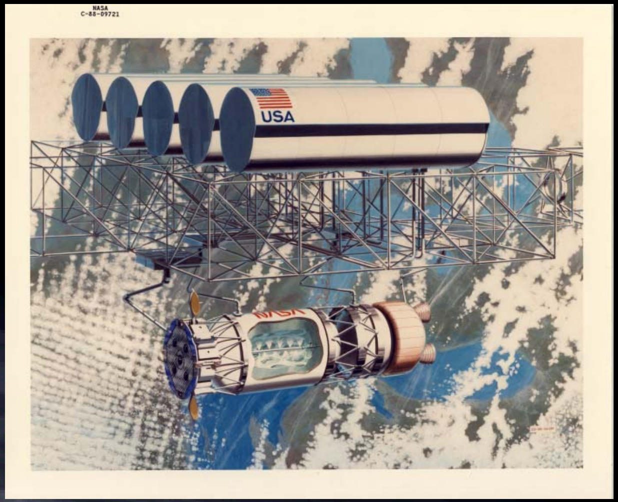
Dr. David J. Chato
NASA Glenn Research Center

Purposes of this Presentation

- Acquaint the Satellite Servicing Community with the rich history of In-orbit propellant transfer technology development
- Show that in-orbit propellant transfer is “game changing” technology
- Show that in-orbit propellant transfer of hypergolic propellants has been demonstrated and is done routinely
- Show that in-orbit propellant transfer of cryogenic propellants with appropriate development and flight demonstration can be taken to the same level of technical maturity as hypergolic propellants

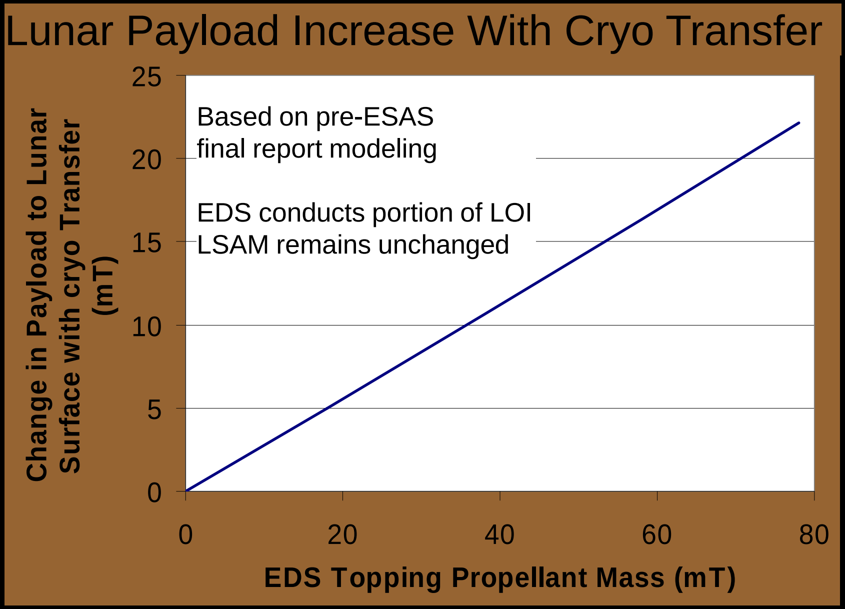
Challenges

- Technology developed for hypergolic propellants
- Techniques for single phase transfer which work well for storable not directly applicable to cryogens
  - Elastomers have poor cycle-life
  - Metals become brittle and crack
  - Large scale of systems makes any in-tank structure large and complex.



Benefit of Cryogenic Transfer

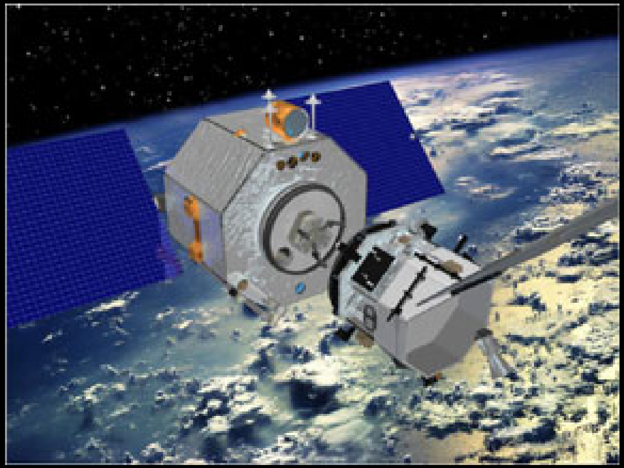
- Lunar Exploration can realize significant benefit from cryo transfer
  - Increase in mission performance through the "topping off" of the Earth Departure Stage (EDS)
  - Enables commercial launch involvement
    - Catalyst for private sector investment
  - Opportunity for alternative architectures
    - Launch EDS on CLV
    - Deferral of large heavy lift requirement
    - Deferral of large in-space engine
  - In-space stage simplification
    - Fill stages on orbit from EDS
    - Lofting stages empty reduces weight
    - Minimizes long duration requirement



22 mT increase in Lunar Delivered Payload with Cryo Transfer For ESAS Baseline Architecture

Presented at MDSCR Final Review B. Kutter L-M

Examples of In space Propellant Transfer



- In-orbit flight experiments (SHOOT, VTRE, FARE I, FARE II,) have proven the basic feasibility of zero-g liquid transfer and are applicable to both cryogens and earth storables using surface tension
- Freon used to simulate cryogen
- All necessary modes of transfer demonstrated; filling, venting GHe, transfer from tank

- Orbital Express performed successful mating and in-orbit transfer of hydrazine using surface tension devices
  - Automated Rendezvous & Docking (AR&D)
  - flowmeter
  - automated coupling,
  - surface tension device,
  - ullage gas recompression

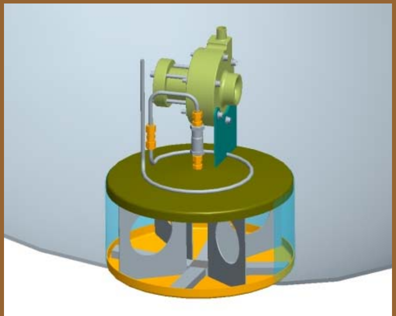
- Progress transfers up 3800 lbms of UDMH and NTO from bellows tanks to the ISS Service Module

SHOOT - Superfluid Helium On Orbit Transfer
VTRE - Vented Tank Resupply Experiment
FARE - Fluid Acquisition and Resupply Experiment

Key Cryogenic Transfer Technologies

ETDP CFM
project funded

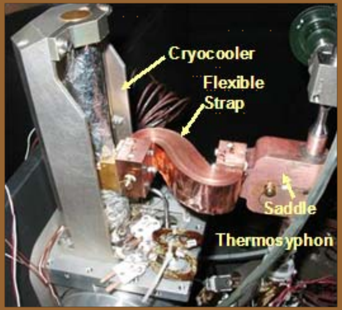
Liquid Acquisition



Automated Couplings and Disconnects

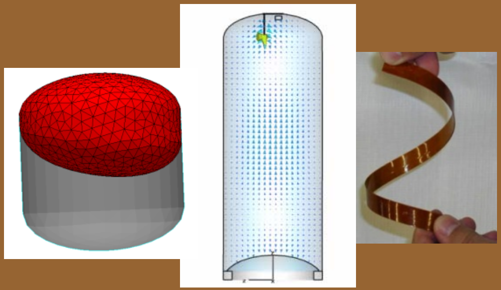
Pressure Control

Passive Storage



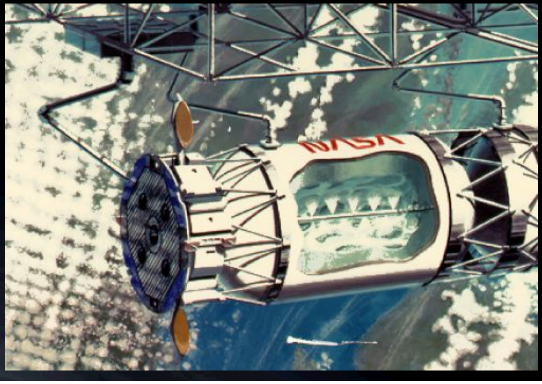
Active Cooling

Mass Gauging



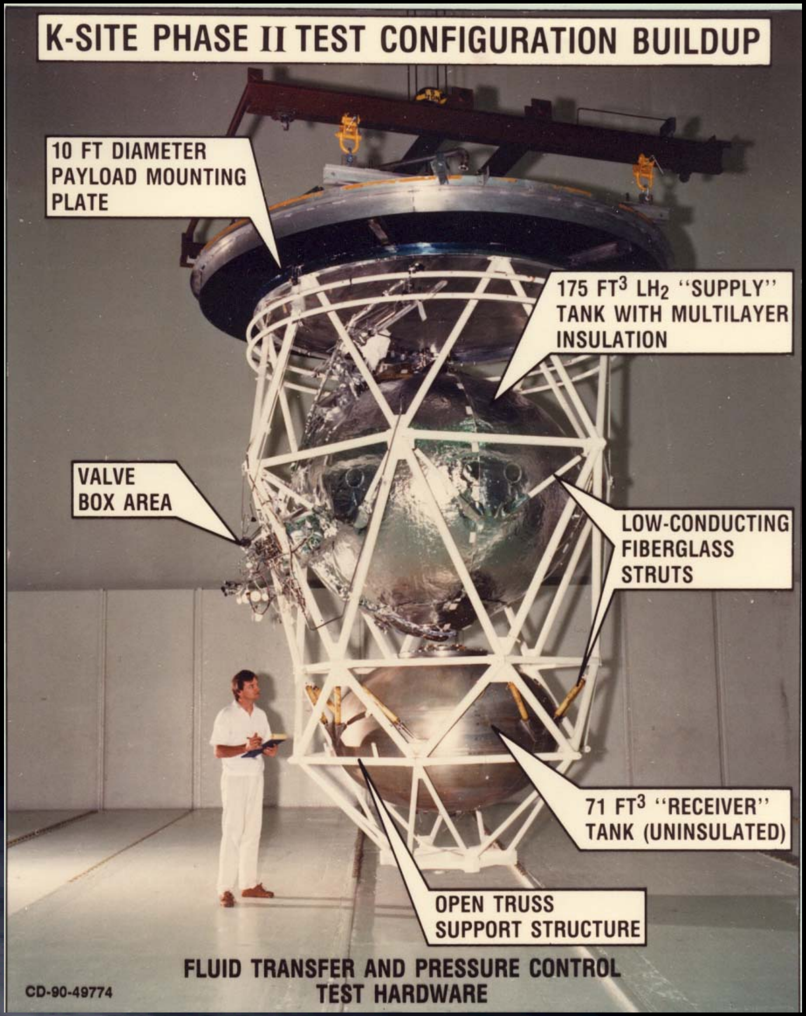
Thermodynamic Vent System

Tank Chill and Fill



Tank Chill and Fill Technologies

- No Vent Fill
  - Uses evaporative cooling and sub-cooling to chill cryogenic tank and transfer fluid with out venting
  - Demonstrated in 1990's at GRC-PB
- Rapid Chill & Fill
  - Uses evaporative cooling and sub-cooling to rapidly chill and fill a cryogenic tank with minimum venting
  - Demonstrated in 1990's GRC and 2000 MSFC
- Models validated with ground based test data



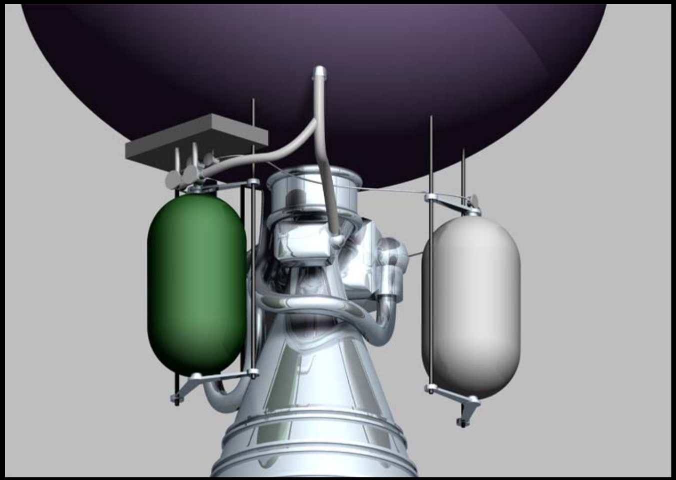
Achievable Transfer for 22 Metric Ton Top-Off

- K-Site Fastest Transfer is 534 Kg/hr using a 6.35 cm diameter Pipe
- If this is assumed to be the maximum tank can be filled in 42 Hours
- Flow rate increases as the square of pipe diameter so a 20 cm pipe would cut the transfer time to 4 Hours
- Using Rapid Fill Rate of 16,000 Kg/Hr in a 10.2 cm diameter Pipe Fill Time would be 1.4 Hours

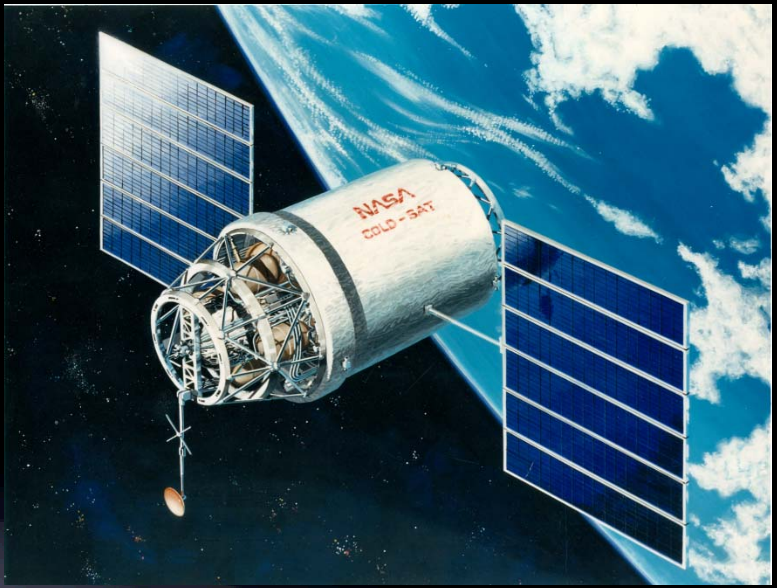
Notes: for Reference Purposes STS Main Feed is 43.2 cm Diameter

Currently there are no constraints on Depot fill time but desires tend to recommend a single shift (8 hours or less)

Cryogenic Fluid Management Technology Low Gravity Demonstration



Low Cost Secondary Payload Demonstrator



Flagship Class Demonstrator (Historical Concept)

Summary – In-Orbit Propellant Transfer SOA

- Historically – A steady effort since the 1960's
  - More than 6 U.S. flight experiments of varying scope
  - Over 30 design studies
  - 100s of papers
- Today – Propellant(earth storable) and life support gasses are transferred regularly on the ISS but gaps exist for a Depot application
- All essential elements have been demonstrated
  - Resupply is an applications engineering problem, not a physics problem
  - An integrated large scale prototype demonstration is needed to bring risk within acceptable levels for a large scale mission
    - Ie Orbital Express with Cryogens

BACKUP

Key Questions for Transfer

- What flow rates can be achieved?
- How much cryogen will be lost?
- How much does the transfer hardware weigh?
- How does the process change in low-gravity?
- Does the benefit justify the added complexity?

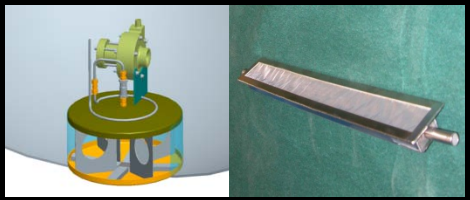
Issues of Transfer

- Additional Hardware is required
  - Flight rated transfer couplings need development
  - Unmanned tankers will require autonomous rendezvous
- Requires additional launch for tanker vehicle
- Low gravity behavior verification may require flight test
- Flow rates comparable to those required for flight systems not yet demonstrated

Summary: In-Orbit Propellant Transfer State-of-the-Art

- **Summary**
  - Operational systems and prototypes have proven high TRLs for certain propellants and tank designs
    - TRL 8, 9 for hydrazine,
      - Orbital Express, Orbital Resupply System(ORS), ..
    - TRL 9 for NTO/UDMH using metal bellows tanks (ISS)
      - Note: metal bellows not practical for exploration spacecraft, landers, etc
  - In-orbit flight experiments (SHOOT, VTRE, FARE I, FARE II,) have proven the basic feasibility of zero-g liquid transfer and are applicable to both cryogens and earth storables using surface tension
    - TRL 4 for Cryogenic Systems
    - TRL 4/5 for NTO/MMH systems using surface tension devices for acquisition, filling and liquid free venting of ullage gases as necessary
  - As of yet, the schedule and cost of a TRL 6/7 **Flight Demonstration** of the technologies has not been committed to, so it is difficult for a program to accept the risk of a depot
    - Would Need to target specifically MMH/NTO and Cryogenics using surface tension devices and all critical functions
    - This is primary reason for programs not to accept the risk

Liquid Supply Options for In Orbit Fluid Transfer



Objective: Provide thermally efficient, delivery of a single phase fluid to depot tanks and propulsion stages.

Method	Advantages	Disadvantages
Settled via thrusters: Use RCS to settle propellants prior to transfer	- Close to procedures used on existing launch vehicles	- Consumes RCS propellant - Disturbs orbit.
Settled via Rotation: Rotate tanks to produce preferential	-Less RCS than linear thrust -Preliminary tests done for Air Force	- Consumes RCS propellant - Complicates control of spacecraft and docking.
Build Two Phase Flow tolerant systems	- Simplifies acquisition	- Risks vapor lock in transfer line - NOT ACCEPTABLE for turbo pump equipment
Screen Channel Liquid Acquisition Devices: Use fine mesh screen to act a capillary barrier for gas flow	- Proven technology for hypergols -Definitely feasible for RCS systems	- Requires hardware in tanks. - Challenging to size for high flow rates without extensive internal structure.
Vane Propellant Management Devices; Use metal sheets to create structures with preferential locations for liquid in low gravity	-Proven technology for hypergols - More tolerant of bubbles and manufacturing flaws than screens	- Requires hardware in tanks. - Poor retention at high thrust accelerations
Other devices: Bladders, Pistons, Spinning Vanes, Magnets Electro-Static Devices	-May offer better separation than above systems	-Heavy and complex -Low Technical Maturity (especially in cryogens)

Automated couplings and disconnects

Current State-of-Art

- Commercial Ground Cryogenic Coupling available as large as 14” diameter
- Several Flight Storable Couplings Bench Tested
- Flight Superfluid Helium Coupling Designed
- No Flight Qualified Coupling Available

Suggested Approach

•Contract with current coupling manufacturer for flight rating of existing design

•Conduct Flight Demo in conjunction with other technologies