Phase III Study of
Selected Tether Applications In Space

Contract: NAS8-36617
DPD 665 DR-3

☑ Mid-Term Review
July 10, 1986

Prepared for:
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National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

Approved by:
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Program Manager

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Introduction

- Guidelines For STS Payload Deployer Design  (Dan McMann)
  + Mini – OMV (MOMV)
  + Shuttle Tether Deployer System (STEDS)

- MOMV Design  (Dan McMann)

- STEDS Design  (Dan McMann)
  + STEDS Control Simulation  (John Glaese)

- Cost Modeling  (Tim Patton)

- Tethered Platform Analysis  (Cal Rybak)
  + Fuel Savings Analysis

- Tasks For Remainder of Program  (Dan McMann)
Guidelines for Shuttle Deployer Design

- STS Launch
  + Minimize Weight/Length
  + Meet All STS Safety Requirements
- Deployment/Retrieval In Less than 24 hrs Cumulative of Crew/STS Time
- Payload Weight Range 1,000 to 10,000 kg
- Transfer From 300 km STS Orbit to Maximum 600 km Dropoff
- Minimize Impact on Payload Design/Operation
- No Payload Retrieval Required
- MOMV/STEDS Returned By STS Between Missions
Rationale For MOMV vs OMV Trade

- Operational Cost Data Not Available For OMV
- MOMV Has Lower Launch Cost – lighter weight
- MOMV Takes Less Bay Space – actual launch cost driver
- MOMV Mechanisms Already Developed
- Our Mission Does Not Require Payload Retrieve Capability (No T.V. cameras or supporting software, equip., personell)
- Our Mission Does Not Require On – orbit Refueling Capability
- Want To Compare Systems With Approximately Equal Capabilities
MOMV Design
MOMV Derived Design Requirements

- Attachment to Payload Accomplished On-orbit
- Self-contained Subsystems
  + Power
  + Thermal
  + Attitude Control
  + Communications & Data Handling
  + Propulsion
- Mission Duration of 48 hours Minimum
- No Subsystem Redundancy
- Recovery by STS After Mission Completion
- Only Mechanical Interface to Payload
MOMV Design Summary

- Structure of Honeycomb and Truss Members
  + Weight: Empty 1400 kg  Hyd. 1112 kg = 2511 kg Total

- Hydrazine Propellant System
  + 3 TRDSS Tanks
  + 5 lbf Thrusters
  + Blowdown System

- Attitude Control System Similar to ERBS
  + Always in ERBS Orbit Transfer Orientation
  + Nadir Oriented/ 3 – axis Stabilized

- Communications & Data Handling Through TDRSS
  + Low Data Rate
  + Intermittent Operation Times

- Power System Uses Solar Arrays and Batteries

- Thermal Control Using MLI and Heaters

- Uses 3 MMS/FSS Berthing Latches for Payload Attachment
MOMV Features

- Optimized to Minimize STS Bay Length

- Uses Flight Proven Hardware & Mechanisms
  + Hydrazine Tanks — TDRSS Heritage
  + Berthing Latches — MMS/FSS Heritage
  + Subsystem Boxes — ERBS Heritage
  + Propulsion System — ERBS Heritage

- Structure is Fabricated from 6061-T6 Aluminum & HC Panel

- Designed for 25 STS Launches Including Fracture Considerations
  (Tanks and Trunions Replaced Once over 25 Missions for Fracture)

- Uses ERBS Proven Low-Thrust Concept for Orbit Raising

- Can Place Payloads Into Circular or Elliptical Orbits
MOMV Operational Sequence

STS Launch
  → Open STS Cargo Bay Doors
  → Perform Payload In-Bay Checkout If Necessary
  → Perform MOMV In-Bay Checkout
  → Attach RMS Arm To Payload

Remove Payload From STS Bay
  → Extend MMS-FSS Berthing Latch On MOMV
  → Position Payload Over MMS-FSS Latches for Attachment to MOMV
  → Activate MMS-FSS Latches
  → Use RMS to Remove MOMV/Payload Stack From Bay

Release RMS from Payload/MOMV and Clear STS To 2500 feet
  → Activate MOMV Propulsion System
  → Establish Comm. with MOMV via TDRSS
  → Initialize the MOMV Attitude Control System
  → Start Orbit Transfer

Update MOMV Thrust Vectors as Required from POCC
  → Stop Thruster Firing At Payload Dropoff Altitude
  → Release Payload From MMS-FSS Latches
  → MOMV Continues Ascent to 600 km If Dropoff Altitude Lower Than 600 km
  → Begin MOMV Descent to STS Altitude & Plane

MOMV Operates as a Free-flier

MOMV Approaches To Within TBD km Of STS
  → Safe MOMV for Restow In STS Bay
  → Retract MMS-FSS Latch
  → STS Rendezvous With MOMV and Attaches RMS
  → Replace MOMV In STS Bay

DRM MIDTRM4
MOMV Attitude Control System

- Sensors
  + Horizon Scanner
  + Triaxial Rate Gyro Package

- Actuation System
  + Hydrazine Reaction Jets

- Attitude Control Electronics
  + Process Horizon Scanner Data
  + Gyrocompass Implementation
  + Reaction Jet Control Logic
MOMV Thermal Requirements

- All Sun Angle Vehicle \((-90^\circ < \varphi < 90^\circ)\)
- 300 to 600 km Orbit
- Operate With/Without Payload Attached
- Maintain Hydrazine to \(+5/\, +55^\circ C\)
- Maintain Electronics to \(-10/\, +55^\circ C\)
- Maintain Batteries to \(-5/\, +25^\circ C\)
- Survive All STS Operational Attitudes
MOMV Thermal Design

- MOMV Completely Covered With MLI Blankets
  + 5 mil Silvered Teflon and .5 mil Aluminized Kapton Covers
  + 10 Layers .25 mil Aluminized Mylar and Dacron Netting Interior
- Solar Arrays Isolated From Structure
- 30 W Survival Heaters Provided for Each Hydrazine Tank
# MOMV Thermal Analysis Results

<table>
<thead>
<tr>
<th></th>
<th>W/O Payload</th>
<th></th>
<th>With Payload</th>
<th></th>
<th>STS Bay to Earth</th>
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<tr>
<td></td>
<td>Cold = 0°</td>
<td>Hot = 90°</td>
<td>Cold = 0°</td>
<td>Hot = 90°</td>
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<td>Elec. Mounting Panel</td>
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<td>Hydrazine Tank Frame</td>
<td>6.9</td>
<td>19.9</td>
<td>6.9</td>
<td>21.0</td>
<td>4.6 3.8</td>
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<td>Hydrazine</td>
<td>5.0 #</td>
<td>17.7</td>
<td>5.0 *</td>
<td>18.0</td>
<td>5.0** 5.0***</td>
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<tr>
<td>Battery</td>
<td>6.9</td>
<td>20.0</td>
<td>6.9</td>
<td>20.9</td>
<td>8.6 26.0</td>
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</table>

All Temperatures – deg C

# 7.2 W htr. power
* 13.0 W htr. power
** 8.4 W htr. power
*** 26W htr. power
COMMUNICATIONS CONCEPT FOR MOMV

TLM. ANTENNA SET

NASA STD. TRANSPONDER

TDU with Memory

DTU

TELEMETRY INPUT CHANNELS

DISCRETE COMMANDS

USES TDRSS S-BAND SINGLE ACCESS LINK AT 1 KBPS TLM & 125 BPS COMMAND.

MAX. RANGE = 44,600 KM.

Corrections to Thrust Direction are Telemetered Up From the Ground

PAYLOAD MINI-OMV

TOP SEMI-OMNI ANT.

BOTTOM SEMI-OMNI ANTENNA

POCC

OMVCOM1B.GEM R.S. 6/23/1986
Mini-OMV C&DH Component List

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<tr>
<th>#</th>
<th>COMPONENT NAME</th>
<th>Wt. (KG)</th>
<th>L (CM)</th>
<th>W (CM)</th>
<th>H (CM)</th>
<th>PWR (W)</th>
<th>% ON</th>
<th>AVERAGE POWER (WATTS)</th>
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<td>7</td>
<td>MISC. SW'S,CABLE,ET</td>
<td>4.0</td>
<td>8.0</td>
<td>8.0</td>
<td>4.0</td>
<td>0.0 SMALL STUFF</td>
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NOTE: TOTAL AVERAGE POWER 37.3

THIS COMPONENT LIST IS BASED ON A SYSTEM SIMILAR TO THAT USED ON ERBS AND CRRES WITH A LOT OF HERITAGE. WAYS TO CUT POWER WOULD BE TO USE A DIFFERENT COMMAND AND TELEMETRY SYSTEM DESIGNED WITH POWER CONSERVATION IN MIND. ALSO, ONE COULD CONSIDER PUTTING COMMAND RECEIVERS ON A STORED PROGRAM COMMAND TO COME ON AT SET INTERVALS. IT WOULD BE ADVISABLE, IN THIS CASE, TO HAVE A SEPARATE HI-REL SIMPLE RESET TIMER DESIGNED TO TURN THE RECEIVERS ON IF A RESET HAS NOT BEEN RECEIVED IN A FIXED INTERVAL (LIKE 24 HOURS).
MOMV Electrical Power System Concept

- Solar Arrays: 1.6 sq. meters active area
- GND, RTN, CMD
- 30% of circuits
  - Enable Rug Payload Interrogator
  - Typical
    - XPONDR, CDU, TDU
- Essential Bus: 28 +/- 4 VDC
  - Arm Plug
  - CMD
  - Propulsion System
  - ACE, IRU, Tank Heaters

DRM MIDTRM13
MOMV PROPULSION SUBSYSTEM

TDRSS TANKS (3)

SYSTEM FILTER

FILL AND DRAIN VALVES

GN₂ FILL AND DRAIN VALVES

N₂H₄ FILL AND DRAIN VALVE

LATCHING VALVES WITH POSITION INDICATORS

VALVE HEATER

THRUST CHAMBER HEATER

PRESSURE TRANSCLUDER

TEMPERATURE SENSOR/TERMISOR

(8) 5 lb THRUSTERS
MOMV MISSION TIME FOR 300 KM ROUNDTRIP IS TWO DAYS

SYNODIC PERIOD FOR MINIMUM TRANSFER TIME (TIME UNTIL MOMV AND ORBITER CELESTIAL LONGITUDES ARE AGAIN EQUAL)

\[ P_s \approx \frac{P_{450} \cdot P_{300}}{P_{450} - P_{300}} = 46.2 \text{ HOURS} \]

ASSUMES UNIFORM ASCENT, DESCENT AND VERY SMALL PAYLOAD DROP-OFF TIME

IF DROP-OFF ALTITUDE IS LESS THAN 600 KM THEN MISSION TIME WILL BE LONGER UNLESS MOMV COMPLETES ROUNDTRIP CIRCUIT TO 600 KM
\[\Delta V\] parallel to orbit normal is required at maximum declination, which rotates plane and changes \(\Omega\), but not \(i\).

Maximum plane change impulse is required when \(i = 45^\circ\).

For 300 km transfer to 600 km circular and back over two days with \(i = 45^\circ\), the differential nodal regression is \(0.86^\circ\) which requires a plane change of 0.61 degs and a \(\Delta V\) of 82 meters per second.
MOMV Propellant Manifest Sizing

- Low Thrust Spiral Transfers a la ERBS
- $m_{\text{payload}} = 10,000$ kg
- $I_{\text{sp}} = 215$ lbf⋅sec/lbf
- MOMV Dry Mass = 1400 kg (1100 kg $N_2H_4$)

Two Day Mission Sequence
1) Deploy and Ascend to $h_c$
2) Payload Dropoff at $h_c$
3) Ascend to 600 km for phasing
4) Descend to 300 km
5) Adjust Node
6) Restow
STEDS Design
STEDS Derived Design Requirements

- Attachment To Payload Accomplished On – Orbit
- Disposable Tether
- Use a Non – Swinging Release
- Self – Contained Payload Tether Release Mechanism
- Deployment Times Up To 24 Hours Acceptable
- Tether Line Must Clear STS Structure By TBD Meters
- Must Manage Energy of Deployment
STEDS Design Summary

- Lightweight Truss Structure (Total Wt. = 1290 kg inc. tether)
- Energy Dissipation Using Light Weight High Temperature Quartz Lamps
- Remote Mate/De-mate of Tether With Payload
- Active Cooling for Generator, Brake and Electronics Using STS Fluid Loop
- Design Minimizes STS Bay Length
  + Deployable Boom
  + Non-Standard Tether Canister Shape
STEDS Features

- Optimized to Minimize Weight & Bay Length
- Structure is Fabricated From 6061 – T6 Aluminum Stock
- Designed for 25 STS Launches Including Fracture Considerations
- Incorporates Boom to Allow Bay Positioning Flexibility
  - Deployed Using Torsion Springs in Boom Hinges
  - Located and Stowed with Small Motor, Cable
- Designed for One Time Use of Tether
  - No Reel, Level Wind or Motor Required
  - Tether is Cut at the STEDS as Deployment is Completed
- Tether End Effector (P/L Interface) is Remotely Mateable
  - Uses RMS
  - Autonomous from Payload
  - Independently Powered and 'Smart'
STEDS Features
(Continued)

- Tether Tension Control System
  + Generator – Aircraft Heritage, Electrodynamic Braking To Provide Tension
  + Gearbox – To Increase Generator Speed and Improve Performance
  + Clutch – Disengages Gearbox From Generator
    * Accommodate Low Tension Initial Deployment
  + Friction Wheels – Provides Friction Needed to Control Tether Tension
    * Designed to Handle Tensions Caused by 10,000 kg @ 70 km
  + Brake – Used at End of Deployment to Arrest Final Motion
  + Radiator Lamps – to Dissipate Generated Energy
SHUTTLE TETHER DEPLOYMENT SYSTEM (STEDS)

- Clutch
- Gearbox
- Generator
- 1600 W Radiator, Lamp (16)
- Cold Plate
- Replaceable Tether Spool
- Tether Launch Clamp
- Tether Guillotine
- Friction Wheel
- Brake
- Power Control Electronics
- Main Support Structure
- Bowannie Envelope

Specifications:
- STEDS Wt: 1920 lb
- Tether Wt: 929 lb
- Total: 2849 lb
- 872 lb
- 418 lb
- 1290 lb
STEDS - SIDE VIEW

- Tether Guides
- Boom Hinges / Torsion Springs
- Tether Deployment Boom (4 x DATUBES, 18 WALL)
- Diagonal Braces 2 x 4 x 10 WALL TUBE
- Boom Deployment Cable
- Boom Stowed Lock
- Motor/Reel - Boom Deployment Cable (Shown This View Only)
STEDS OPTIMALLY POSITIONED FOR TETHER FORCE ALIGNMENT THRU ORBITER CG
STEDS POSITIONED FOR MAXIMUM BAY LENGTH PAYLOAD CAPABILITY
STEDS TETHER DEPLOYMENT CONTROL CONCEPT

AMOUNT OF WRAP (RADIANS) = 

\[ \frac{\ln\left(\frac{\text{TENSION AFTER REEL}}{\text{TENSION BEFORE REEL}}\right)}{\text{FRICTION COEFFICIENT (TETHER,WHEEL)}} \]

3 DRIVEN WHEELS
TOTAL ANGULAR WRAP:
TETHER ON WHEELS = 800°.

ASSUMPTIONS:
TETHER-COATED WHEEL FRICTION \( \mu = 0.5 \)
TENSION IN = 1 LL.
TENSION OUT = 755 LL. (MAX. EXPECTED x1.2)
STEDS REMOTELY MATEABLE TETHER END EFFECTOR CONCEPT

SPACER CRAFT STRUCTURE

SPRING - ASSURES RELEASE

INTERFACE PIN

MATED BEFORE FLIGHT, SEPARATED AFTER DEPLOYMENT

CLAMP ASSY, NSI RELEASE (3)

BATTERY

ELECTRONICS-TIMER, PROCESSOR

LOAD CELL

TETHER CLAMP, SPRING COCKED COLLET

TETHER TERMINAL FITTING

TERMINAL LOCATING FIXTURE (NSI RELEASE (2))

STEDS BOOM

TETHER
STEDS Operational Sequence

1. STS Launch
2. Open STS Cargo Bay Doors
3. Perform Payload In-Bay Checkout
4. If Necessary, Activate STEDS Systems and Perform Check-Out
5. Attach RMS Arm to Payload
6. Remove Payload From STS Bay
7. Extend the STEDS Boom
8. Position Payload and Attach the Tether
9. Release RMS From Payload
10. Use STS RCS System to back away from Payload (approx. 1 m/sec)
11. Slow Separation Rate and Start Phase II of Deployment (exponential)
12. Start Phase III of Deployment (Constant Vel.)
13. Start Phase IV of Deployment (Const. Deceleration to Zero Velocity)
14. Send Command to Cut Tether at Both Ends (Payload Release)
15. Re-Stow the STEDS Boom
16. Shutdown the STEDS Systems Except for Survival Heaters
17. Mission Complete: Wait for STS De-Orbit and Landing

STEDS Performs Payload Deployment
STEDS Thermal Control Design

- STS Fluid Loop is Used to Cool the Generator and Electronics
- High Temperature Quartz Lamps Radiate Generator Power to Space
  + Same Type of Lamp Used for STS Bay Illumination
  + Ten 1600 Watt Quartz Lamps
  + Gold Plated Stainless Steel Reflectors Mounted Behind Each Lamp
- Exterior of Tether Container Covered With MLI
- Generator, Electronics and Brake Mounted on Fluid Cold Plate
  + Uses STS Freon Loop to Dump About 850 W
  + Up to 16 kW Radiated by Lamps
STEDS Thermal Control Concept

Heat Radiated To Space

Gold Reflector

Generator

Energy Input From Deploying Payload

Joule & Friction Heating (750 watts)

Friction Heating (750 watts max.)

Freon From STS Radiators

850W max.

STS P/L HTX

Pump Package

Control Electronics

Rotational Energy

Mechanical Brake

Friction Pulleys

Cold Plate

STEDS Freon Loop

Energy Input

STS/STEDS Interface

Freon To STS Radiators

850W max.

Freon From STS Radiators
STEDS Tension – Only Deployment Simulation Results

by

Dr. John Glaese
Control Dynamics Company
Cost Analysis

Approach & Preliminary Results

(Tim Patton)
Cost Analysis

- BASD'S LCC ANALYSIS APPROACH

- COSTING METHODOLOGY

- COST WBS FOR DEPLOYMENT CONCEPTS
  - MOMV
  - STEDS

- RCA PRICE MODEL
  - PARAMETRIC ESTIMATING
  - SAMPLE PRICE INPUT SHEET
  - SAMPLE PRICE OUTPUT

- GROUNDRULES & ASSUMPTIONS

- LIFE CYCLE COST MODEL
  - MOMV (PRELIMINARY)
  - STEDS (PRELIMINARY)
LCC Analysis Approach

Production

R&D

Ops

LCC Estimate

LCC Breakdown

Identify "Tall Poles"

Develop Cost Sensitivities

Cost Driver Determination

Schedule & Performance Requirements

Design Analysis

Design Alternatives

Design Trade Study

LCC Update

Design Selection

Documentation

Lowest LCC Design

Traceability

LCC Parameter Value

Cost Elements

$L$
BASD Costing Methodology

- HARDWARE CONFIGURATION
- RCA PRICE MODEL
  - DEVELOPMENT COSTS
  - PRODUCTION COSTS
- GROUNDRULES & ASSUMPTIONS
- OPERATIONS SCENARIO
- MAINTENANCE CONCEPT

- LCC ESTIMATE CURRENT YR $
- LCC ESTIMATE CONSTANT YR $
- TRADE STUDY ANALYSES
- FUNDING PROFILE (RCA PRICE A)
- DATA REQUIREMENT (DR6)

- LCC MODEL DOCUMENTATION

ID DAN2
Parametric Cost Estimating Process

RECORDS
- PRODUCTION COST
- DEVELOPMENT COST
- RESOURCES
- DESIGN INVENTORY
- TECHNOLOGY
- QUANTITY
- SIZE
- WEIGHT
- SCHEDULE
- CUSTOMER
- SPECIFICATIONS
- MAJOR SUBCONTRACTS
- LEVEL OF ECONOMICS
- DIFFICULTIES EXPERIENCED

NEW REQUIREMENTS
- PERFORMANCE
- CONCEPT CONFIGURATION
- QUANTITY
- SCHEDULE
- SPECIFICATIONS
- ECONOMICS

DATA
- CALIBRATED
- PARAMETRIC
- DATA BASE

PARAMETRIC
- COST
- MODELS

COSTS
Parametric Estimating Method

DISADVANTAGES

• BLACK MAGIC AURA

• NIH – CAN'T FIT

• LACKS DETAILS
  – MAN HOURS
  – WAGE RATES
  – OVERHEAD

• REQUIRES SPECIAL TRAINING

ADVANTAGES

• REQUIRES LITTLE INPUT DETAIL

• FAST/INEXPENSIVE

• TABLES FOR NORM PROVIDED

• CAN BE CALIBRATED
  – MANUFACTURE
  – VENDOR

• DISCIPLINED
  – NO OVERSIGHTS
  – NO DOUBLE ACCOUNTING
  – DISTORTION NORMALIZED

• PERPETUAL RETENTION OF EXPERIENCE
## PRICE HARDWARE MODEL

**MECHANICAL ITEM**

**INPUT FILENAME:** momv4  
**GLOBAL FILENAME:**  
**DECLARATION DATE:** 27-JUN-86 09:39  
**GLOBAL FILENAME:**  

### STRUCTURE-SUBSYSTEM PLATE

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**UNIT PROD COST:** 118.83  
**MONTHLY PROD RATE:** 0.00

### PROGRAM COST ($ 1000)

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**MANUFACTURING**

|                        | 119.        |            | 119.       |
| PRODUCTION             |            |            |            |
| PROTOTYPE              | 0.         |            | 0.         |
| TOOL-TEST EQ          | 10.        | 5.         | 15.        |
| **SUBTOTAL(MFG)**      | 10.        | 123.       | 134.       |

**TOTAL COST**

|                        | 962.        |            | 1141.      |

### DESIGN FACTORS

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<tr>
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**SCHEDULE**

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<td>JAN 88 (11)</td>
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<td>FIRST ITEM</td>
<td>OCT 87* (0)</td>
<td>NOV 88* (0)</td>
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<tr>
<td>FINISH</td>
<td>OCT 87* (10)</td>
<td>NOV 88* (11)</td>
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**SUPPLEMENTAL INFORMATION**

<table>
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<tr>
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<td>T. I. COST</td>
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**COST RANGES**

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<td>CENTER</td>
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<tr>
<td>TO</td>
<td>1114.</td>
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Groundrules and Assumptions

(GENERAL)

1) LIFE CYCLE COST ESTIMATE IS IN CURRENT DOLLARS
2) COST TRADE STUDY RESULTS ARE IN CONSTANT DOLLARS (1986)
3) THE LCC ESTIMATE IS FOR A QUANTITY OF 1 FLIGHT ARTICLE
4) 1 YEAR DEVELOPMENT PHASE
5) 1 YEAR PRODUCTION PHASE
6) 10 YEAR OPERATIONAL PHASE
7) NO REDUNDANT SUBSYSTEMS
Groundrules and Assumptions

(DESIGN AND DEVELOPMENT)

1) THE DEVELOPMENT SCHEDULE IS 1/87 TO 12/87 FOR BOTH MINI – OMV AND SHUTTLE TETHER DEPLOYER SYSTEM

2) THERE IS NO PROTOTYPE HARDWARE IN THE DEVELOPMENT PHASE

3) DEVELOPMENT COSTS ARE ESTIMATED USING THE RCA PRICE MODEL

(PRODUCTION)

1) PRODUCTION QUANTITY IS 1

2) NO NEW PRODUCTION FACILITIES ARE REQUIRED

3) PRODUCTION COST IS ESTIMATED USING THE RCA PRICE MODEL
Groundrules and Assumptions

(OPERATIONS AND SUPPORT)

1) 10 YEAR PERIOD OF SUPPORT

2) REFURBISHMENT OF THE DEPLOYMENT SYSTEM WILL BE DONE ON-SITE

3) FACILITIES ARE AVAILABLE ON-SITE FOR REFURBISHMENT ACTIVITIES

4) THE TETHER IS EXPENDABLE AFTER EACH MISSION

5) OPERATIONS WILL INCLUDE 25 MISSIONS OVER 10 YEARS

6) TETHER CANISTER WILL BE SENT TO TETHER VENDOR FOR TETHER REPLACEMENT AFTER EACH MISSION

7) MAINTENANCE TRAINING AND DOCUMENTATION FOR THE MOMV AND STEDS ARE ADDITIONAL COSTS AND ARE ACCOUNTED FOR IN THE LCC ESTIMATE
## Hardware Design & Development Cost

<table>
<thead>
<tr>
<th></th>
<th>Thermal</th>
<th>Structure</th>
<th>ACS</th>
<th>C&amp;DH</th>
<th>Propulsion</th>
<th>Electrical</th>
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### Support Equipment

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<tr>
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<tr>
<td>Tooling &amp; Equipment</td>
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<tr>
<td>Prototypes</td>
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<tr>
<td><strong>Subtotal</strong></td>
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### Design & Development Summary

- **Total**
  - Design: $3,195,000
  - Drafting: $1,158,000
  - Systems Engineering: $557,000
  - Program Management: $418,000
  - Data: $205,000
  - Tooling & Equipment: $95,000
  - Prototypes: $0
  - Design Integration: $1,731,000
  - Integration & Test: $2,755,000

  **Total**: $10,114,000
## Hardware Production Cost

### Mini-OMV

<table>
<thead>
<tr>
<th></th>
<th>Thermal</th>
<th>Structure</th>
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<th>C&amp;H</th>
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<th>Elect.</th>
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#### Sub Total

- **Design**: $598,000
- **Drafting**: $1,429,000
- **Program Management**: $1,685,000
- **Data**: $3,200,000
- **Tooling & Equipment**: $2,614,000
- **Propul.**: $1,895,000

**Total**: $11,421,000

### I&T Facilities

- **Facilities**: $1,485,000

**Total**: $12,906,000

### Support Equipment

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<th></th>
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<th>FSE</th>
<th>Subtotal</th>
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**Sub Total**: $0

### Production Summary

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<td><strong>I&amp;T</strong></td>
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<tr>
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**Total**: $12,906,000
## Hardware Design & Development Cost

**STEDS**

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<th>Teth Deploy</th>
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**Support Equipment**

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**Design & Development Summary**

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<td>Tooling &amp; Equipment</td>
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## Hardware Production Cost

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### Support Equipment

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</thead>
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<td>Program Management</td>
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<tr>
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### Production Summary

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<tbody>
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<tr>
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<tr>
<td>Program Management</td>
</tr>
<tr>
<td>Data</td>
</tr>
<tr>
<td>Tooling &amp; Equipment</td>
</tr>
<tr>
<td>Hardware</td>
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<tr>
<td>I&amp;T</td>
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<tr>
<td>Facilities</td>
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## MOMV/STEDS Cost Comparison

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<th>STEDS</th>
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<tr>
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</table>
Launch Cost Comparison

MOMV (48" length) 48" + 6" = 54"

\[
\frac{54"}{(720")(.75)} \times ($111.0M) = $11.1M/\text{launch}
\]
\[
\times 25 \text{ launches}
\]
\[
\frac{}{} \boxed{\$277.5M}
\]

STEDS (45" length) 45" + 6" = 51"

\[
\frac{51"}{(720")(.75)} \times ($111.0M) = $10.5M/\text{launch}
\]
\[
\times 25 \text{ launches}
\]
\[
\frac{}{} \boxed{\$262.5M}
\]
Tethered Platform Study

Analysis of Fuel Savings

Cal Rybak
Additional Fuel to Offset Tether Drag Less Savings Due to 10 km Higher Platform Altitude

\[ I_p = 215 \text{ lb}-\text{sec/lbm} \]
\[ C_A / m = 0.02 \text{ m}^2/\text{kg Nominal} \]
\[ h_p = 500 \text{ km (Space Station)} \]
\[ l_{TETHER} = 10 \text{ km} \]
Tether Diameter = 2.5mm

Supplemental Annual Fuel Consumption – kg

Tether Diameter – millimeters
## Error Sources Contributing to Fuel Usage

<table>
<thead>
<tr>
<th>Error Source</th>
<th>GPS Radial Position Error (3 $\sigma$, m)</th>
<th>GPS Tangential Velocity Error (3 $\sigma$, m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballistic Coefficient (D)</td>
<td>50%</td>
<td>0.3</td>
</tr>
<tr>
<td>Differential Error</td>
<td>(3 $\sigma$)</td>
<td>(3 $\sigma$, m/sec)</td>
</tr>
<tr>
<td>(3 $\sigma$)</td>
<td>21</td>
<td>(2)</td>
</tr>
</tbody>
</table>

(1) Rss of 15m, 3 $\sigma$ Each for Individual Space Station and Platform Determinations

(2) Rss of 0.2 m/sec, 3 $\sigma$ Each for Individual Space Station and Platform Determinations
Days to Drift 10 km From Nominal Separation Distance
Platform to Station Ballistic Coef. Difference $\epsilon_{\Delta \Phi}$, %

- Maximum expected drag differential
- Range of minimum expected drift times due to drag differential

$\Delta h = 500 \text{ km}$
$\epsilon = \frac{C_{\Delta \Phi}}{m} = 0.02 \text{ m/kg (nom)}$

Drift Time - Days

$1 \leq \frac{\epsilon_{\Delta \Phi}}{\epsilon_{\Delta \Phi}} \leq 10$

Initial Radial Position Error $\epsilon_{\Delta h}$, Meters

Initial Tangential Relative Velocity Error $\epsilon_{\Delta v}$, M/sec
Annual Fuel Required to Maintain Platform Within +/- 10 km Deadband Centered at Nominal Distance

\[ h_c = 500 \text{ km} \]
\[ m_{\text{platform}} = 10,000 \text{ kg} \]
\[ I_{tr} = 215 \text{ lbf-sec/lbm} \]

Includes Fuel for each Cycle
- To Arrest Motion
- Start & Stop Correction
- 20% Execution Error
Propellant Cost Savings Due To Tethering Platform

Min. Propellant Cost Savings - \( \frac{2000 \times 2.2}{(65000)(.75)} \times 111 \text{M} = 10 \text{M/yr} \)

Nom. Propellant Cost Savings - \( \frac{4000 \times 2.2}{(65000)(.75)} \times 111 \text{M} = 20 \text{M/yr} \)

Max. Propellant Cost Savings - \( \frac{9000 \times 2.2}{(65000)(.75)} \times 111 \text{M} = 45 \text{M/yr} \)
Results From Tethered Platform Studies

- Primary Cost Benefit of Tethered Platform is in Station Keeping Fuel Savings Which Can Range Between $100M and $450M Over The Initial 10 Years of Operation

- Other Areas of Potential Cost Savings (i.e. Power Tether, Comm.) are Small Compared to the Fuel Cost Savings

- Future Studies Should Evaluate the Cost Impact of Beefing up the Space Station Structure to Withstand the Tether Tension Loads
Tasks To Be Completed

- STEDS/MOMV Cost Analysis
- Tether Crawler Design and Costing
- LCC Cost Models & Documentation
- Final Report