FAME Mechanisms

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Mechanisms Subsystem

• Top Level Requirements

• Interstage-Spacecraft Separation System
  - Marmon Clamp
  - Kick-off Spring Canisters

• Trim Tab System

• Trim Area System

• Trim Mass System

• Backup Slides
Top Level Requirements

• 1st Priority: Maximize Reliability of Mechanism Design
  - Simplification / Redesign to Rigid Solar Array
  - Maximize Use of Heritage Hardware

• 2nd Priority: Minimize Cost of Mechanism Design
  - Simplification / Redesign to Rigid Solar Array
  - Maximize Use of Heritage Hardware

• 3rd Priority: Minimize Mass of Mechanism Design
  - Lightweighting Design Iteration Remains to Be Done
  - Potential for Weight Savings As Program Matures
Top Level Requirements

- **Interstage-Spacecraft Separation System**
  - Provide a Highly Reliable Interstage-Spacecraft Separation System
    - **Marmon Clamp**
      - Structurally Hold Spacecraft to Interstage During Launch and Orbit Transfer Maneuvers
    - **Kick-Off Spring Canisters**
      - Provide a System and Interface That Will Separate the Spacecraft From the Interstage Cleanly (No Contact)
      - Assure No Re-Contact of Spacecraft to Interstage by Providing Minimum 3 inch/sec +/- 10% Delta V Between Vehicles

- **Trim Tab System**
  - Provide Three (3) Tabs Located 120° Apart Along the Circumference of the Electronics Deck to Provide a Solar Radiation Control Torque Range of +/- 1 Micro-N-m
    - Flowdown Requirement to Tab Sizing = a Minimum Area of 384 In²
    - Flowdown Requirement to Tab Motion = One (1) DOF, Such That Upon Deployment, the Tab Pitches up and Down W.R.T. the Electronics Deck -40° to +40° in <0.5° Increments
Top Level Requirements

• Trim Area System
  - Provide Three (3) Pairs Located $120^\circ$ Apart Along the Circumference of the Electronics Deck to Provide Center of Pressure Control Authority Within a 0.8-Inch Radius About the Spin Axis
    - Flowdown Requirement to Area Sizing = Trim Area Pair Area of 0-402 in$^2$
    - Flowdown Requirement to Area Motion = One (1) DOF, Such That Upon Deployment, the Areas Rotate in Plane of the Electronics Deck From $0^\circ$ to $90^\circ$ in $<0.5^\circ$ Increments

• Trim Mass System
  - Provide Two (2) Trim Mass Mechanisms Parallel to the Z-Axis to Adjust $I_{xz}$ and $I_{yz}$
  - Size the Trim Mass Mechanisms Such That $I_{xz}$ and $I_{yz}$ Can Change Spin Axis Misalignment up to 30 Arcsec
    - Flowdown Requirement to Trim Mass Sizing = 2 Mechanisms With 6.5 lb Mass, $+/-$ 9 Inch Travel in $<0.004$ in Step Increments
Interstage Separation / Marmon Clamp

- **Clementine** Flight Heritage Marmon Clamp Planned
  - At Satellite / Solid Rocket Separation Plane (Z=0 in)
    - FAME Required Preload = Pending Analysis - Should Be Less Than **Clementine** Qualification
    - Marmon Clamp Qualified to Preload of 3600 lb, Line Load N=240 lb/in
    - Thermal Conductance Test Planned to Refine Predicted Clamp Temps
    - If Temps Beyond Previous Qualifications Will Perform TVAC Delta Qual Test

For FAME This Will Be Part of the Satellite Structure

For FAME This Will Be an Interstage
Note: the SOLID ROCKET Will Be Attached to This Side

Clementine Marmon Clamp Shown
Interstage Separation / Kickoff Springs

- **TIPS Heritage Spring Cartridge Planned**
  HM-ME-0040
  - Flight Heritage, No Design Changes
  - Use 64Around Interface
  - Same Spring: LC-125-6SS
  - Delta V = 3-5 inch/sec (Adjustable)
  - TBR May Need to Delta Qualify for Temperature or Other FAME Test Criteria
  - Weight: 0.50lb Each
    - 4X = 2.0 lb
  - Size: 6.0in x 1.6in x 1.6in
    - Including Spring Force Adjustment Screw and Piston Retention Screw
  - Stroke: 1.0 in
Trim Tabs (1 of 2)

1 of 3 Trim Tabs Shown in Stowed Position

Launch Lock Pin Puller Detail
- Tab panel
- Lug
- Pin puller
- Bracket
- E-deck

Trim Tab Panel

Motor Drive

Snubber (3)

Hinge

Position Potentiometer
Trim Tabs (2 of 2)

1 of 3 Trim Tabs Shown in Deployed Position

Launch Snubber (3 total)

Launch Lock Pin Puller

30 in

14 in
Trim Areas (1 of 2)

Cable Driven Trim Area Design
(1 of 3 Trim Area Pairs Shown in Stowed Position)

Launch Lock
Pin Puller

Trim Area Panels

Guide Snubbers

Motor/
Pivot Hinge

Position Potentiometer/
Pivot Hinge

Cable Anchor
Trim Areas (2 of 2)

Cable Driven Trim Area Design
(1 of 3 Trim Area Pairs Shown in Fully Deployed Position)

- Launch Lock Pin Puller
- Motor/Pivot Hinge
- R 16 in
- Guide Snubbers
- Trim Area Panels
- Position Potentiometer/Pivot Hinge
Trim Areas (3 of 3)

Trim Area Pin Puller Launch Lock Detail

- Pin Puller
- Area Edge Retainer (Double Shear)
- Lug
- Pin Puller Stand-off
Trim Area / Trim Tab Pin Puller

Non-Explosive Pin Puller Launch Lock
(Model P25-810-1.5R)

The Pinpuller model P25-810-1.5R was first used to deploy the ATEX (Advanced Research Experiment) built by the Naval Research Laboratory (NRL). This embodiment uses TiNi’s patented trigger mechanism to retract the engagement pin with 25 lbs of force and 0.50" of stroke*. Fast actuation times are achieved by passing current directly through the Nitinol (Shape Memory Alloy) wire. The actuation time curve shown below is accurate for either of the two firing circuits incorporated. The fatigue life of the actuator is in the 100’s of cycles allowing numerous pre-flight firings. Reset is achieved by manual re-extension of the pin. Optional additions that may be incorporated in the P25-810-1.5R are: custom mounting configurations, built in enclosure and connector, and integrated shut-off switches (as shown).

* Custom configurations as to pull force and stroke are readily attainable.

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**Specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Pull Force</td>
<td>110 N (25 lb-f)</td>
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<tr>
<td>Pull Stroke</td>
<td>1.27 cm (0.5 in)</td>
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<tr>
<td>Operational Current</td>
<td>2 to 6 Amps</td>
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<tr>
<td>Minimum Operating Temp.</td>
<td>&lt;=50 °C (&lt;=58 °F)</td>
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<tr>
<td>Maximum Operating Temp.</td>
<td>&lt;=70 °C (158 °F)</td>
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<tr>
<td>Actuator Resistance</td>
<td>1.2 Ohms</td>
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<tr>
<td>Mass</td>
<td>110 gm (0.25 lb)</td>
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**Features:**
- Redundant SMA Circuit
- Reusable
- Auto Shut-Off Switch
Trim Masses

- Design Layout Similar to Lockheed Martin Gravity Probe B Design
- FAME Trim Mass: 6.5 lb
- Stroke: +/- 9 in, Step Resolution: <0.1 mm
- Gravity Probe B Trim Mass: 20 lb
- Stroke: +/- 12 in, Step Resolution: 0.2mm
- Difference in FAME Mass/Stroke Requirements Dictates New NRL in-House Design - Design/Layout Similar to Gravity Probe B
- Will Prototype Early ’02 to Reduce Development Risk
# Long Lead Items / Schedule

<table>
<thead>
<tr>
<th>Mechanism Component</th>
<th>Date</th>
<th>Delivery</th>
<th>Cost</th>
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<tr>
<td>Marmon Clamp</td>
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<td>- Pyro Bolts, Pyros</td>
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<td>- Motors</td>
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<td>- Pin Pullers</td>
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<tr>
<td>- Motors</td>
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<td>- ACME Screw, Nut &amp; Rail</td>
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Note: Cost Based on Vendor ROM Quotes
Note: Not All Necessary Hardware Is Listed
Summary

• Mechanisms Design Utilizes Many Heritage Components

• Designs Which Are New Are Relatively Simple/Low Risk

• Internal/External Peer Review Held on 10/11/01
  - No Major Actions/Deficiencies Found

• Additional / Detailed Design Information Is Available Upon Request
  - Brian Whalen  202-404-2619
   whalen@space.nrl.navy.mil
  - Steve Koss    202-767-0696
   skoss@space.nrl.navy.mil
Mechanisms Backup
Peer Review

• Internal/External Peer Review Held on 10/11/01
  - No Major Actions/Deficiencies Found
  - Actions/Suggestions:
    - Use Potentiometers for Position Feedback vs Cams & Microswitches
    - Revisit Motor Winding Redundancy vs $25K * 2lb Extra Electronics
    - Revisit Number of Microswitches for Telemetry on Trim Tabs/Areas/Masses
    - Add Subrequirement to Minimize Impact of Trim Area/Tab Movement on Dynamic Balance (Tolerances on Trim Tabs & Counterbalance Trim Area)
    - Consider Adding Center Position Indication Switch on Trim Masses
    - Consider Tapered Pins for Pin Pullers
    - Try to Use Single Guide Rail for Trim Mass to Reduce Tendency to Bind
    - Try to Lightweight Mechanisms in General, Especially Trim Tabs & Areas
    - Revisit Delta V Separation Requirements With Jim Barnds As Program Matures
    - Revisit # of Thermistors & Microswitches Used As Telemetry on Mechanisms
    - Get Better Traceability on Requirements Flowdown From Error Budget Document

• Attendees
  - Outside Reviewers: Ed Devine/Swales, Rodger Farley/NASA/GSFC, Joseph Bolek/NASA/GSFC, Alphonso Stewart/NASA/GSFC (Sent Slides to)
  - Various Internal NRL Personnel, Management, & Consultants Such as Russell Barnes, Bill Purdy
Trades - Marmon Clamp

Selected Implementation: Marmon Clamp
Separation Devices in Two Places (Clamp Will Separate If Either or Both Devices Fire)

- Best Load Path (Cylinder to Cylinder)
- Significantly Lighter Than a 4 or 8 Separation Nut/Joint Systems
  - WRT Mechanisms Weight, Structure Weight, & Ordnance System Weight
- Reduces Required Ordnance From 16 Lines to 4 Lines (Maximum)
- Inherently Redundant

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<td>(Cylinder-to-Cylinder)</td>
<td>(Cylinder-to-Square)</td>
<td>(Cylinder-to-Hexagon)</td>
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<td>Poor</td>
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<th>Ordnance Required</th>
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<tr>
<td>Good (2-4)</td>
<td>Fair (8)</td>
<td>Fair (12)</td>
<td>Poor (16)</td>
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Trades - Kick-Off Spring Cartridge

• **ATEX Spring Cartridge**
  AX-ME-0026
  - Flight Heritage
  - Use 6 Around Interface
  - Change Spring to LC-135L-8SS
  - Delta V = 14.2 in/s (19% Margin)
  - Will Need to Delta Qualify With New Spring and Any Modified Parts
  - Weight: 0.45 Lb Each
    - 6 X = 2.4 lb
  - Size: 12 in X 2 in X 1.5 in
    Including Piston Retention Screw
  - Stroke: 2.5 in

• **TIPS Spring Cartridge**
  HM-ME-0045
  - Flight Heritage
  - Use 6 Around Interface
  - Same Spring: KH75034-3
  - Delta V = 14.2 in/s (18% Margin)
  - May Need to Delta Qualify for Temperature or Other FAME Test Criteria
  - Weight: 0.55 Lb Each
    - 6 X = 3.3 lb
  - Size: 9.9 in X 1.6 in X 1.6 in
    Including Spring Force Adjustment Screw and Piston Retention Screw
  - Stroke: 2.7 in

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**Note:** Trade Open Until Design Finalized W.R.T. Access to Inside of Structure, Available Volume and Mass Constraints; Tips Has Been Baselined in Interim
Trades - Trim Areas

**Sector Gear**

- Slightly Heavier (2 lb Al, 1 lb PEEK for 6 Sector Gears)
- Slightly More Hardware Costs
- Requires Backlash Compensation (TBR)
- Less Prone to Thermal Error
- More Robust Design and Predictable Behavior (TBR)

**Cables**

- Requires Higher Torque From Motor (Extra Motor Gearing)
- Slightly Lighter
- Slightly Less Hardware Cost
- TBD Position Accuracy/resolution
- More Prone to Thermal Errors (?)

Note: While Cables Have Been Baseline This Trade Remains Open Until Further Design Work Can Be Completed, Compatibility With Other Subsystems Is Established (ACS, Thermal); a Prototype of the Cable Design Will Be Built & Tested in Early ‘02
Trade Study - Trim Masses

New Trim Mass Design

• Optimized for FAME

• Lighter (Current Estimate =11.4 lb)

• Does Not Yet Have Contamination Cover

• Motion Verification Using Leadscrew Mounted Potentiometer and 3 Microswitches (Middle & Ends of Travel) for <.1 mm Linear Motion Resolution Verification

Lockheed MTM

• Overdesigned for FAME

• Heavy (40 lb As Is)

• Needs Significant Modification to Make Compatible With the FAME Requirements and Bus Design

• Should Be Used As a ‘Lessons Learned’ Example

• No Telemetry for Motion Verification

Selected Implementation: New Trim Mass Design
(A Prototype of the Trim Mass Mechanism Will Be Built & Tested in Early 2002)
Trade Study - Motors

• Brushless vs Brush Trade
  - Brushless Chosen for Reliability Although Brush Motor @ Low Life Might Have Worked

• Type of Brushless Trade
  - Unipolar Stepper Chosen for Simplicity/Lowest Cost
  - Redundant Windings Chosen for Maximum Reliability
    - Electrical Redundancy Vs 30% Torque Penalty w/ Redundant Windings

• Vendor Trade
  - CDA Intercorp (Formerly Astro Instrument) Chosen Based on Good Previous Heritage W/NRL & On-Hand Qual Trim Mass Motor (ATEX Flight Spare)
  - Other Vendors’ Reputations Are More Blemished or No Experience
Trade Study - Position/Motion Verification

• None
  - Does Not Meet ACS Requirement to Verify Motion and Reduce Risk for Slow Spacecraft Reaction to Trim Mechanism Motion

• Potentiometers
  - Higher Hardware Costs
  - Have Troublesome History of Failures/Problems in Space/Vacuum
  - Fine Position Resolution
  - Absolute Position Capability for Trim Area & Trim Tabs

• Cams and Switches
  - Low Hardware Costs
  - Requires External Cam to Motor, Motor Change for Trim Tab
  - Cams Can All Be Made Identical
  - Coarser Position Resolution Than Potentiometers
  - Incremental Position Only

• Cams and Sensor
  - Hall Effect Sensor or LED/Diode Require More Electronics

Selected Implementation: Potentiometers With End of Travel Switch
Trade Study - Pin Pullers

• 25 Lb TiNi Pin Puller
  - Higher Margin on Loads
  - Larger Size, Weight (.25 lb)
  - Qualified on WindSat Program, in-House Knowledge of Mechanism
  - Resettable

• 5 Lb TiNi Pin Puller
  - Low Margins on Loads
  - Compact and Lightweight (0.5 oz)
  - No in-House Knowledge of Design
  - Resettable

• Pyro Pin Puller
  - High Margins
  - Compact and Lightweight
  - Not Resettable
  - Safety Issues

• Paraffin Pin Puller
  - High Margins
  - Compact, but 2 X Weight of TiNi Pin Puller
  - Resettable

Selected Implementation: 25 lb TiNi pin puller
Test Flow
IS/SC Separation System

Marmon Clamp

Thermal Gradient Test on Qual Unit → Delta Qual to FAME Criteria
- • Tvac W/ Hot Functional Test → Flight and Spare Assay

Acceptance Test
- • Vibe W/ Functional
- • Tvac W/ Hot/cold Functionals

FAME System Level Pyroshock

Spring Cartridge

Test and Group Springs → Qual Unit Assy → Delta Qual to FAME Criteria (If Necessary)
- • Tvac W/ Hot Functional Test?

Flight and Spare Assay* → Acceptance Test
- • Vibe W/ Functional
- • Tvac W/ Hot/cold Functionals

* May Be Able to Use Qual Spring Cartridge Units As Flight or Spare
Test Flow
Trim Tabs and Trim Areas

Prototype w/ Non-Flight Motors

-> Qual Panel/ Deck Inspection

-> Qual Unit Assy

-> Qual Unit Ambient Atmosphere Functional Tests and Inspections
  - Range of Motion (Deployment)
  - Angle Tolerance (Motion)
  - Position Feedback
  - Deployment Angle (ACS Error Budget)
  - Position Knowledge (Command V. Feedback V. Actual)

-> Qual Tests
  - Vibe w/ Functional Tests & Inspections
  - Tvac w/ Hot/cold/mid Functional Tests
  - Thermal w/ Hot/cold Inspections (Flatness)

-> Flight and Spare Assy

-> Flight & Spare Unit Ambient Atmosphere Functional Tests and Inspections
  - Range of Motion (Deployment)
  - Angle Tolerance (Motion)
  - Position Feedback
  - Deployment Angle (ACS Error Budget)
  - Position Knowledge (Command vs Feedback vs Actual)

-> Integrate to Spacecraft EM

-> Qual Life Cycle Test

-> Acceptance Tests
  - Vibe w/ Functional Tests & Inspections
  - Tvac w/ Hot/cold/mid Functional Tests
  - Thermal w/ Hot/cold Inspections (Flatness)

-> Flight Mechanism Integration to Flight Vehicle

-> Spacecraft System Level Acceptance Tests
**Test Flow**

**Trim Masses**

- **Prototype w/ ATEX Motor**
- **Qual Unit Assy**
  - Qual Unit Ambient Atmosphere Functional Tests and Inspections
    - Range of Motion (+/- 9.0 In)
    - Motion Tolerance (0.5 Mm)
    - Position Feedback (0.1 Mm)
    - Verify No Backlash or Backdrive
    - Position Knowledge (Command vs Feedback vs Actual)
- **Qual Tests**
  - Vibe W/ Functional Tests & Inspections
  - Tvac W/ Hot/cold/mid Functional Tests
- **Integrate to Spacecraft EM**
- **Qual Life Cycle Test**
- **Flight and Spare Assy**
- **Flight & Spare Unit Ambient Atmosphere Functional Tests and Inspections**
  - Range of Motion (+/- 9.0 In)
  - Motion Tolerance (0.5 Mm)
  - Position Feedback (0.1 Mm)
  - Verify No Backlash or Backdrive
  - Position Knowledge (Command vs Feedback vs Actual)
- **Acceptance Tests**
  - Vibe W/ Functional Tests & Inspections
  - Tvac W/ Hot/cold/mid Functional Tests
- **Flight Mechanism Integration to Flight Vehicle**
- **Spacecraft System Level Acceptance Tests**