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Changing Paradigms:

Manufacturing vs. Fabricating a High Volume

Hold Down and Release Mechanism

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Abstract

A detailed description of the Hold Down and Release Mechanisms designed for a 70+ constellation of spacecraft. The design is reviewed to understand the practical implications of severely constraining cost. Strategies for adapting the traditional aerospace design paradigm to a more commercial, cost driven paradigm are discussed and practical examples are cited.

Introduction

Starsys Research Corporation (SRC) manufactures caging, hold down and deployment mechanisms for spacecraft. SRC is providing the Hold Down and Release Mechanisms (HDRM) for a 70+ constellation of satellites scheduled for launch starting in 1996. SRC will be providing over 1000 HDRMs for this program. Prior to this our largest build of mechanisms was 12.

The large scale commercialization of space is introducing a new paradigm. Commercial manufacturing exists in a paradigm that is one or even two orders of magnitude different than current spacecraft manufacturing. A latch that cost $10,000 must be built for $1,000. Manufacturing times that were measured in weeks must now be measured in days yet, the constraints of reliability, mass, environment and structure remain every bit as rigorous and in some cases are even more demanding.

Design, development and manufacture of the HDRM mechanism practically illustrate the change in thinking SRC had to incorporate as we made this shift. The initial conceptualization of a mechanism typically includes layout drawings and analysis. To this we added a detailed costing and weight matrix. Every option was rigorously evaluated not only for its direct cost impact but for secondary impacts such as assembly time, inspection time, reject rate (non-conformances cost a lot of money), handling time, and testing required.

Qualification hardware have been delivered. Flight hardware will be delivered May 1995 . The first launch is scheduled for 1996.

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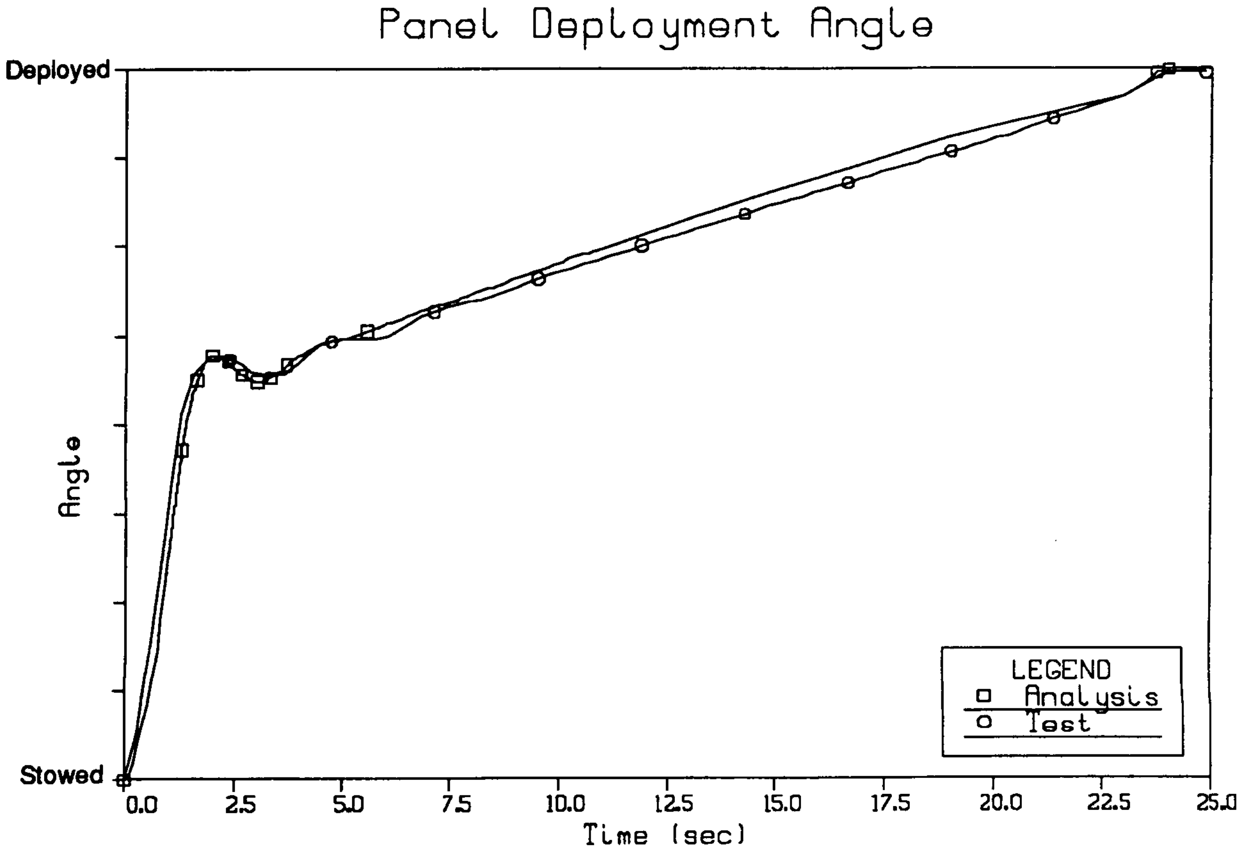
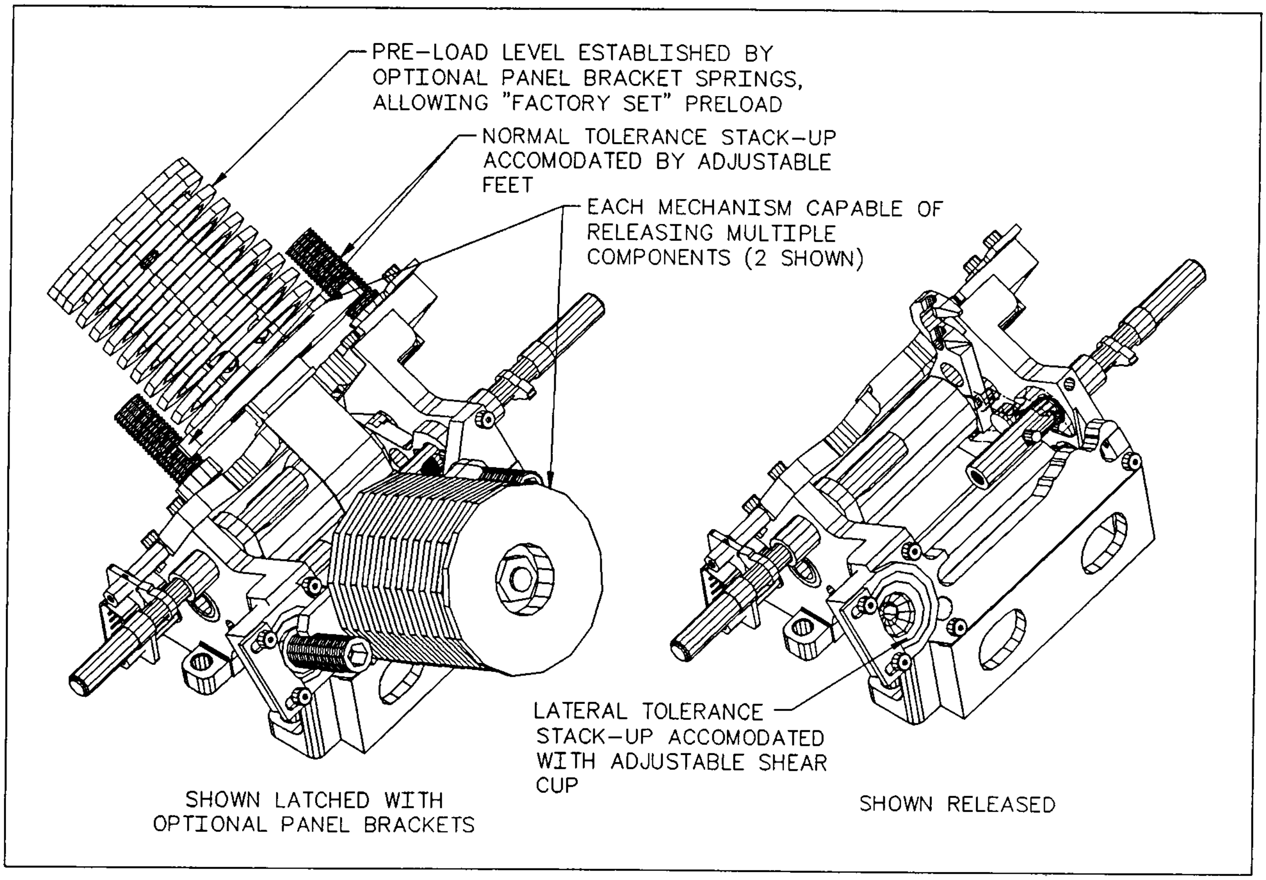
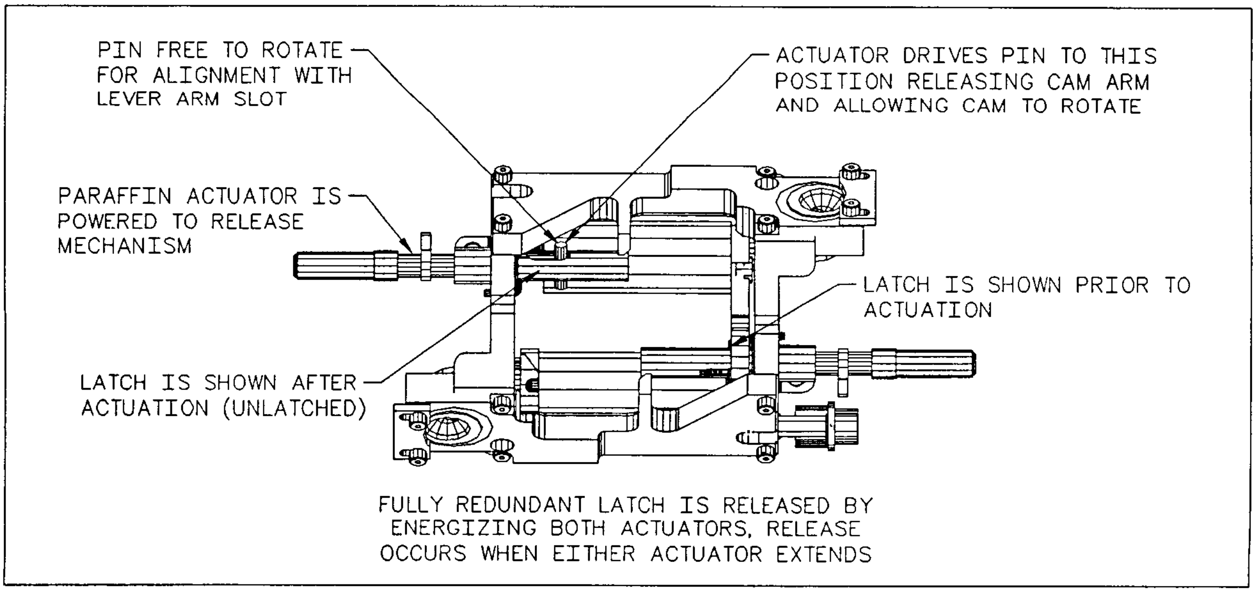
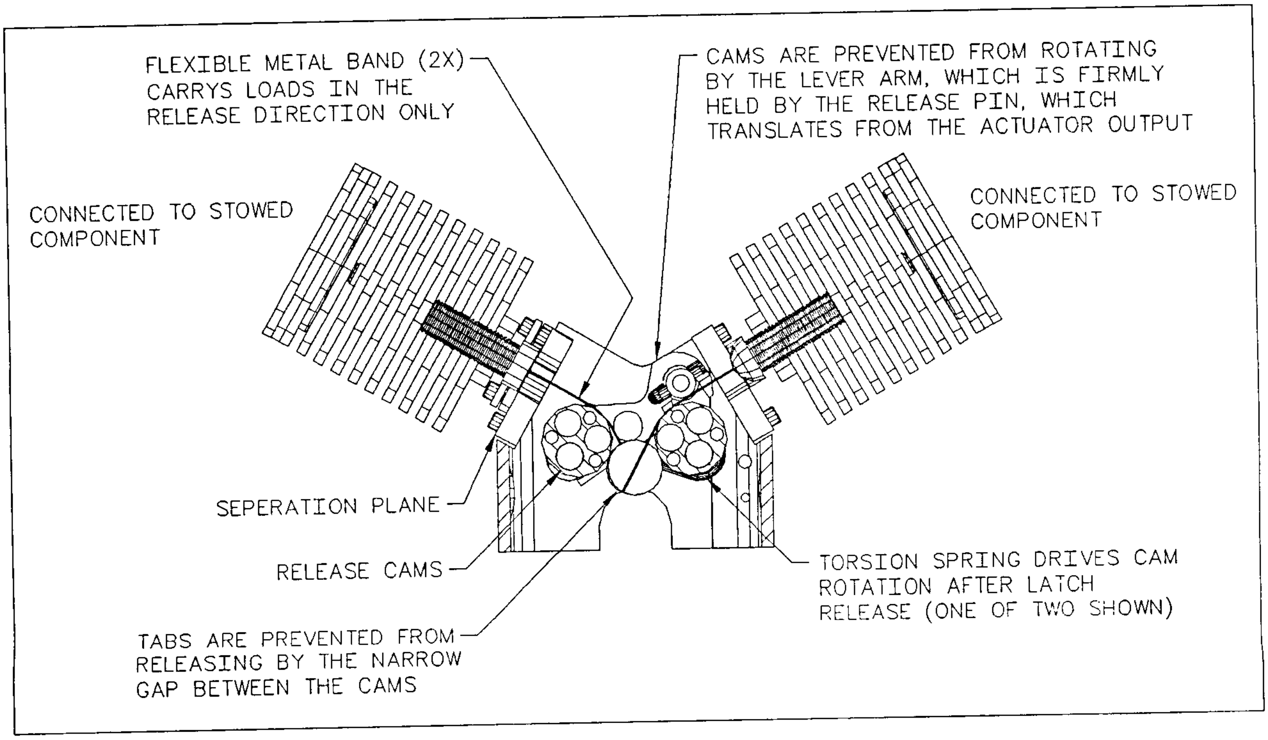


Figure 17. Solar Array Panel Deployment (Ambient)

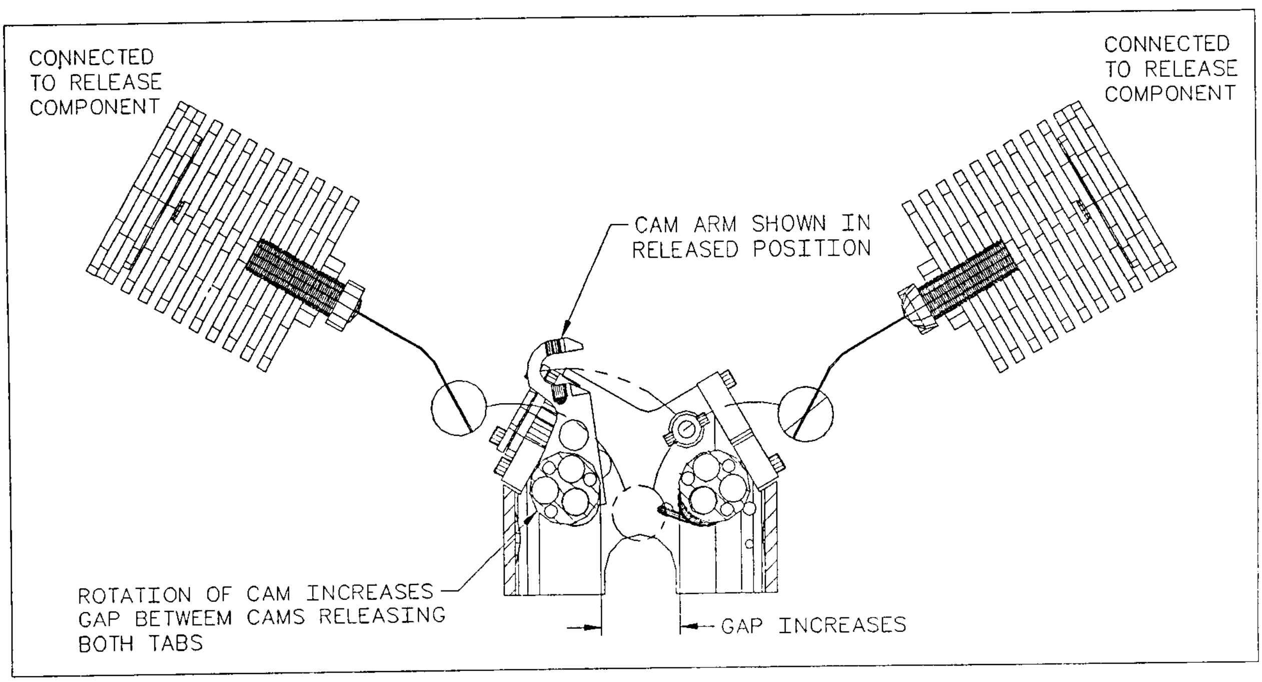
Hold Down and Release Mechanism (HDRM) Description







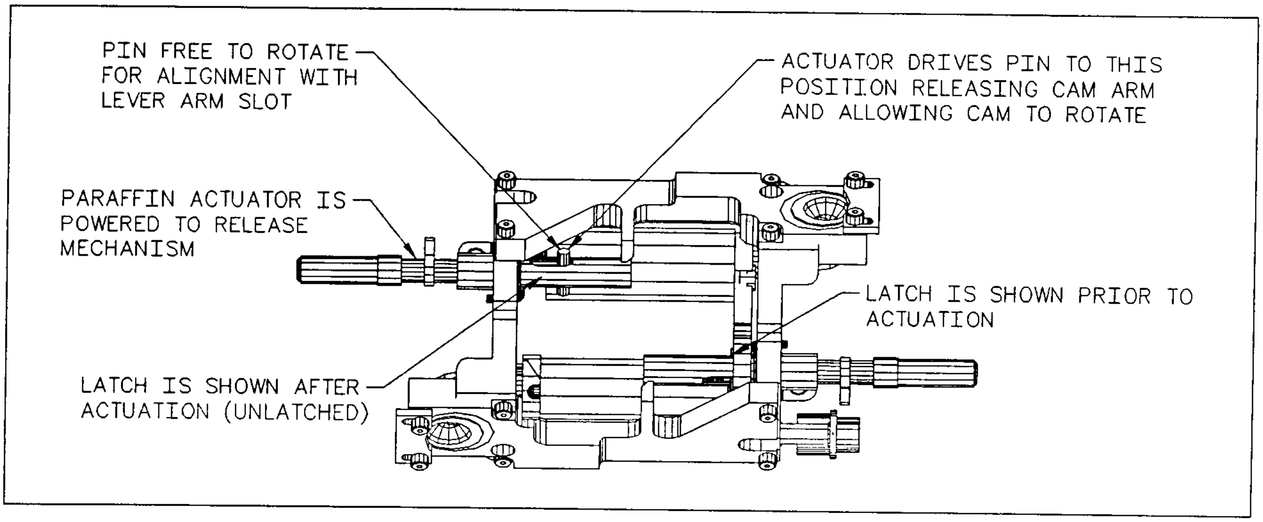
FLEXIBLE METAL BAND (2X)
CARRYS LOADS IN THE
RELEASE DIRECTION ONLY
CAMS ARE PREVENTED FROM ROTATING
BY THE LEVER ARM, WHICH IS FIRMLY
HELD BY THE RELEASE PIN, WHICH
TRANSLATES FROM THE ACTUATOR OUTPUT
CONNECTED TO STOWED
COMPONENT
CONNECTED TO STOWED
COMPONENT
SEPERATION PLANE
RELEASE CAMS
TABS ARE PREVENTED FROM
RELEASING BY THE NARROW
GAP BETWEEN THE CAMS
TORSION SPRING DRIVES CAM
ROTATION AFTER LATCH
RELEASE (ONE OF TWO SHOWN)

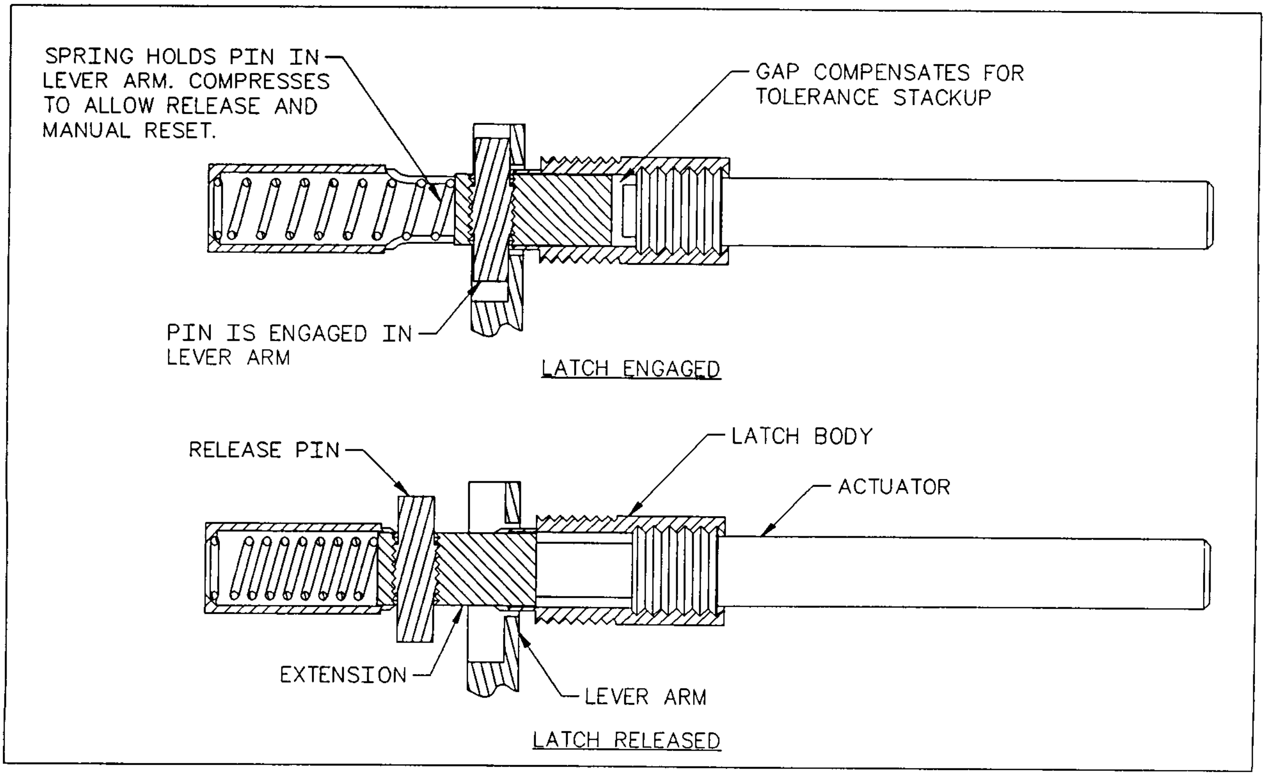


CONNECTED
TO RELEASE
COMPONENT
CONNECTED
TO RELEASE
COMPONENT
CAM ARM SHOWN IN
RELEASED POSITION
ROTATION OF CAM INCREASES
GAP BETWEEM CAMS RELEASING
BOTH TABS
GAP INCREASES

HDRM Subsystem - Latch

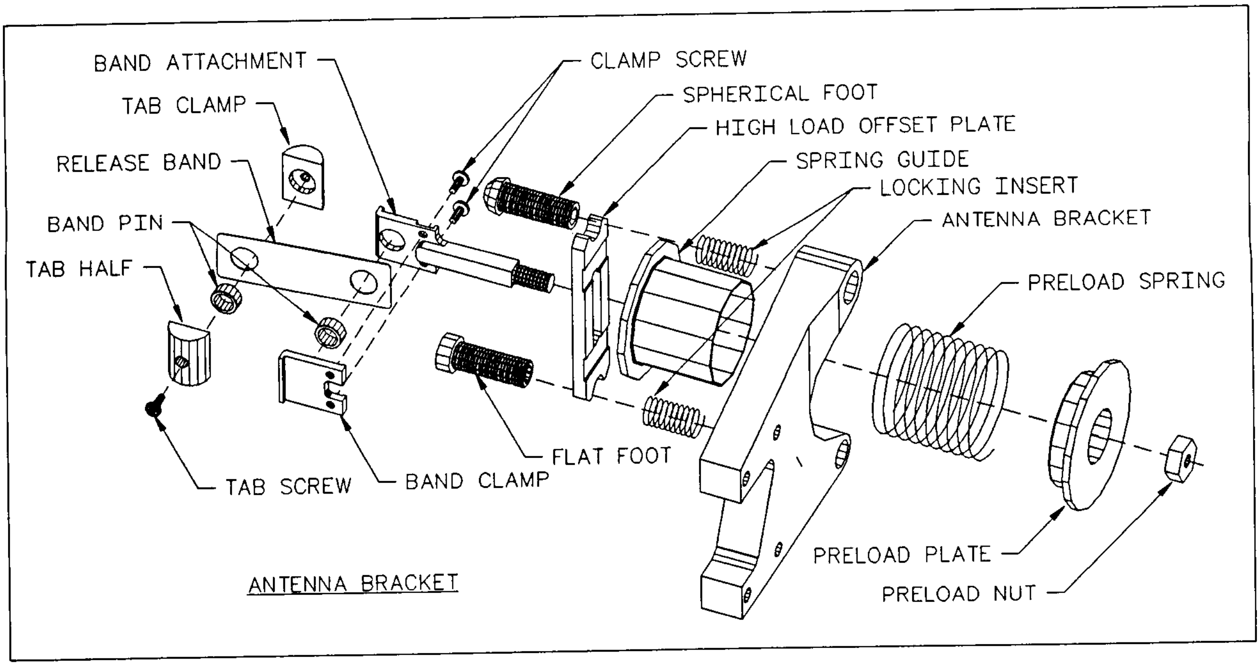
Actuator - SRC EH-1540, 445 N (100 lbf) maximum output, .64 cm (.25 in) stroke
Extension - Ultem 1000
Latch body - 6061 aluminum for low loads, 6AL-4V titanium with Tiodize for high loads
Release pin - Nitronic 60, Tiolube coating
Spring - 302 stainless steel
Lever arm - 6AL-4V titanium
Cam - 6061 aluminum for low loads, 6AL-4V titanium for high loads, Tiodize coating



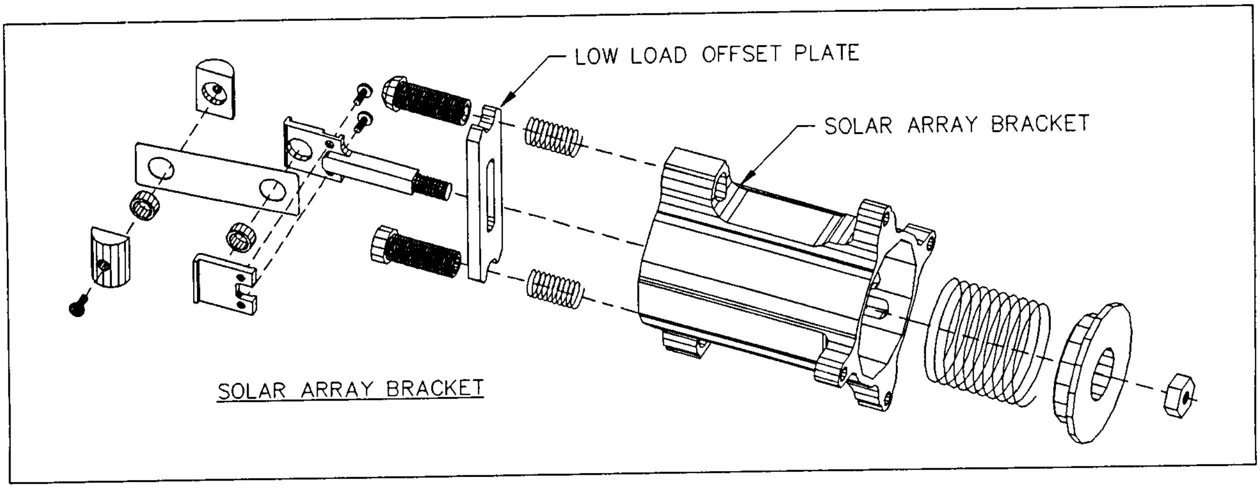


HDRM Subsystem - Bracket

Tab - 6061 aluminum for low loads, titanium for high loads, Tiodize & Tiolube coating
Band pin - 303 stainless steel
Release band - 254,000 psi Elgiloy
Band attachment - 6AL-4V titanium
Band clamp - 6061 aluminum
Preload plate - 6061 aluminum
Spring - 17-4 stainless steel
Spring guide - 6061 aluminum (antenna bracket assembly only)
Offset plate - 6061 aluminum for low loads, 6AL-4V titanium for high loads
Bracket - 6061 aluminum extrusion
Feet - 6AL-4V titanium Tiodize and Tiolube

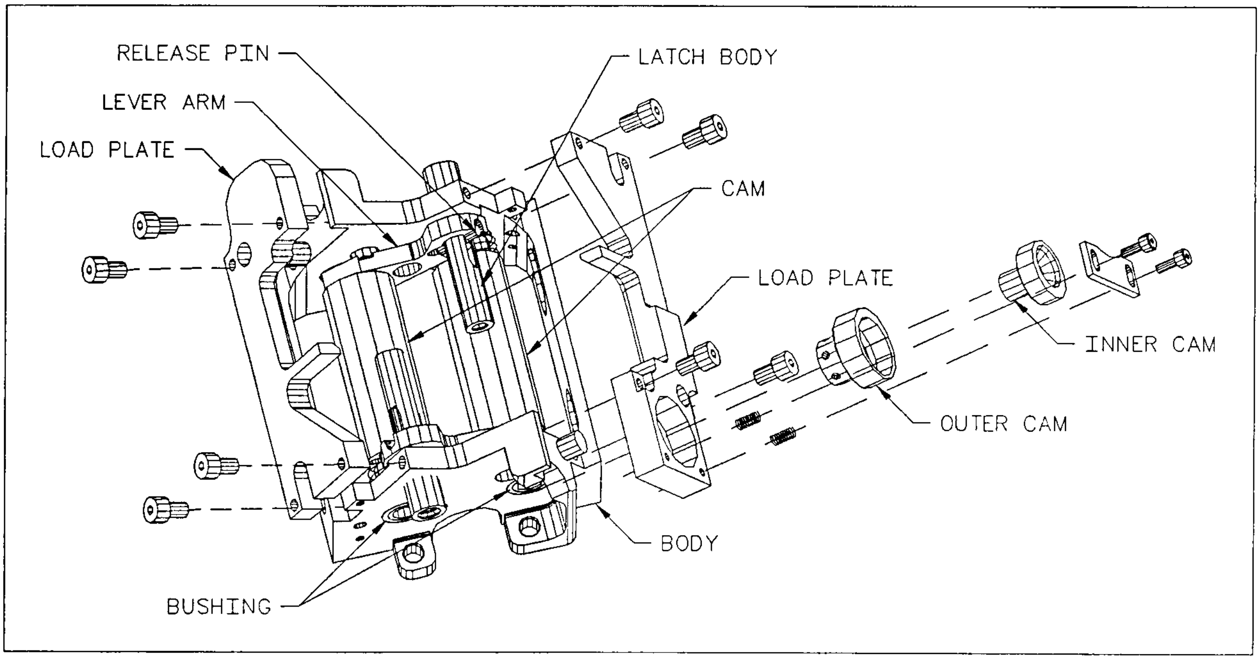


ANTENNA BRACKET



SOLAR ARRAY BRACKET

HDRM Subsystem - Body
Inner cam - 6061 aluminum, hard anodized
Outer cam - 6061 aluminum
Load plate - 6061 aluminum for low loads, 7075 for high loads, hard anodized
Body - 6061 aluminum extrusion
Bushing - 303 stainless steel, PTFE lined



HDRM Requirements

Interchangability
Provided by a design with minimal tolerance stack and a low spring rate. Bracket preload is set "at the factory" rather than on the spacecraft. Latches are inspected for final tab interface.

Positionability (± .15 cm (.060 in) lateral, ± .25 cm (.100 in) normal)
Provided by double-eccentric cams and screw adjustment of the interface spherical feet.

Kinematic freedom and restraint
Lateral restraint is provided by a spherical foot in a spherical socket. Normal restraint is provided by a flexible metal band with pivoting attachment points. A second foot restricts rotation in the axis normal to the spacecraft axis. The attachment is free to rotate about the normal and spacecraft axis.

Restraint - (3.18 KN (715 lbf) x2 axial, 3.09 KN (695 lbf) x2 lateral and 2.36 KN (530 lbf) x2 normal)
Motion and loads are restrained by a spherical foot in a hemispherical cup. The preload is restrained by redundant cams that capture multiple tabs allowing a single latch to restrain two brackets.

Release - (2.6 KN (585 lbf) x2 preload)
Provided by an HOP powered latch at the end of a lever arm attached to a moveable cam. The latch kinematics create approximately a 15:1 mechanical advantage thereby allowing a low input force to release a high force.

Multiple releases (20 minimum)
The cam and tab are round with the radii (.95 cm (.375 in) and (.71 cm (.281 in)) chosen to limit hertzian stresses. The latch pin and lever arm are made of high strength materials (Nitronic 60 and titanium) and have radiused interface points. Parts are coated with dry film lubricant (Tiolube).

Resettability
To reset the latch, the cams have a hex socket that allow a hex driver to return them to the latch position. The actuator spring resets the paraffin actuator and allows a ramped feature on the lever arm to rest the latch. To reset the bracket, a removable rest tools allow manual compression of the preload spring in the brackets and are removed after the bracket is engaged in the release latch.

Reliability (>.999)
100% of the components critical for release are redundant. Two actuators operate two release latches opening two cams. Rotation of either cam releases both tabs. All elements critical to restraint are limited to simple, high margin components.

Stiffness (3.85 KN/mm (22 klb/in) axial, 7.0 KN/mm (40 klb/in) lateral and normal)
Structural requirements are stiffness driven. Aluminum was chosen for it's stiffness to weight ratio and cost. FEA was used to optimize the shape of the structural elements.

Mass (14 kg (31 lbm) for 16 HDRMs)
The latch design is compact and uses a minimum of parts. The HOP actuator weighs 10 gm and provides 445 N (100 lbf) of force.
Strength driven parts are light-weighted extensively. The cams have 6 holes through them, the spherical feet are hollowed out, and the band pin is a tube.
Stiffness driven parts are 42% of the overall weight. The predominant material used is aluminum. Body and bracket shapes were chosen for stiffness and are optimized with FEA.
Load driven parts are 27% of the overall weight, titanium is used extensively for these parts. Metal bands provide a flexible couple at 1 gram each. Crest springs provide a 60% weight savings over die spring and 15% over belleville washers.

Fasteners

Fasteners are used only to secure parts, mechanical features carry loads. Uralane and Nylok are used to secure all permanently locked fasteners. Helicoils are used to secure user adjustable parts.

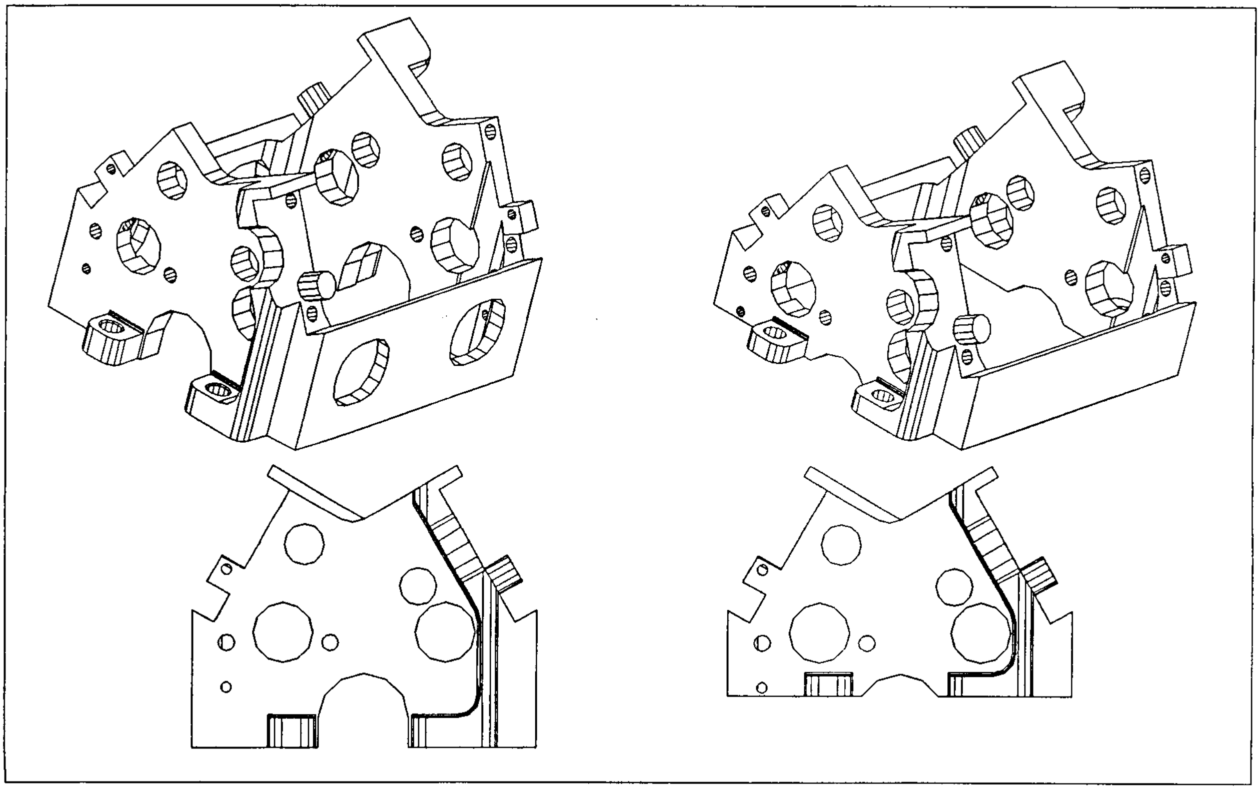
Cost strategies

Common elements

The initial goal was to have one latch for all requirements. As the customer's design evolved significantly different requirements forced a hybrid approach to commonalty.

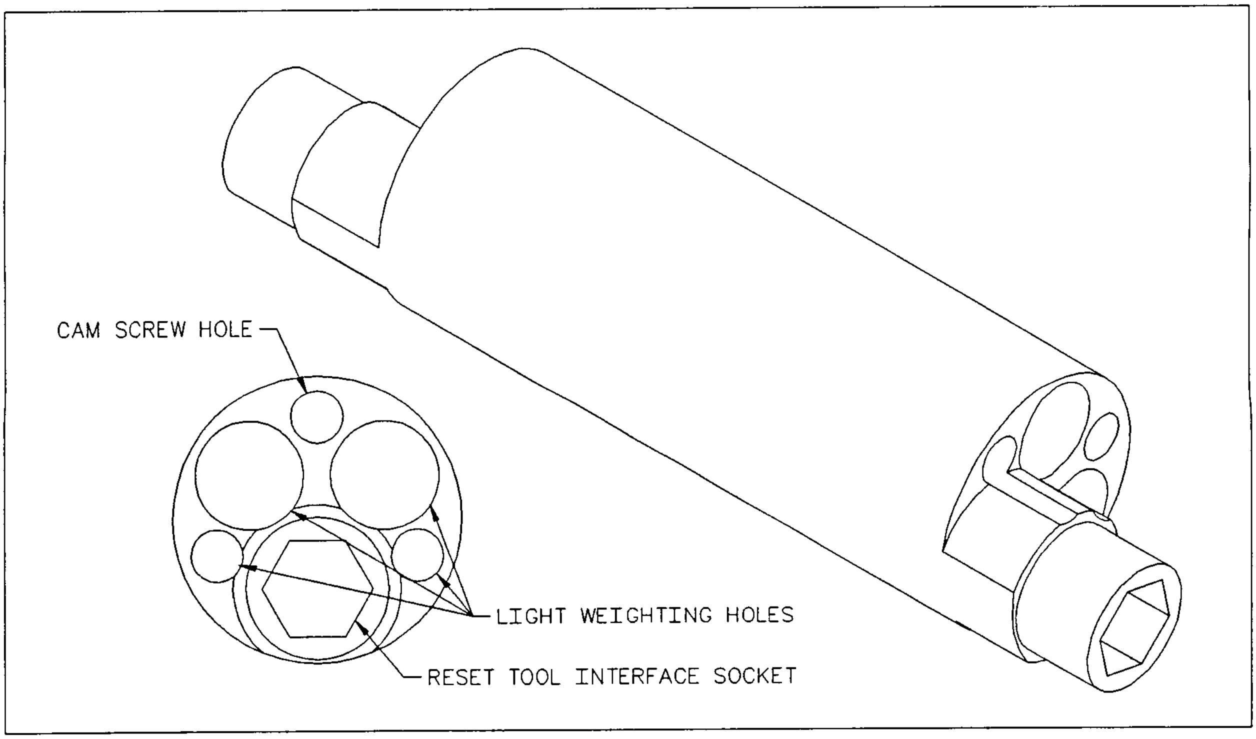
Latch body

Because the satellite design placed the solar panels over the antenna panels different latch heights were required. The same placements of components were used and the additional length was applied outside of the functional area. The height difference was further exaggerated to improve stiffness in the higher loaded and higher stiffness (shorter) antenna latch body.



Cams and tabs

The preload requirement for the solar array HDRM is 734 N (165 lb) and for the antenna panel it is 2600 N (585 lb) or three times higher. The strength of titanium is three times higher than aluminum. Therefore, the part design for the cam and tab in the higher load latch could be the same as for the low load latch with the only change in material, from aluminum to titanium.



Fabrication costs and methods

Traditionally mechanisms at SRC are built around precisely machined parts. We explored many other methods used for fabricating parts.

Supplier involvement

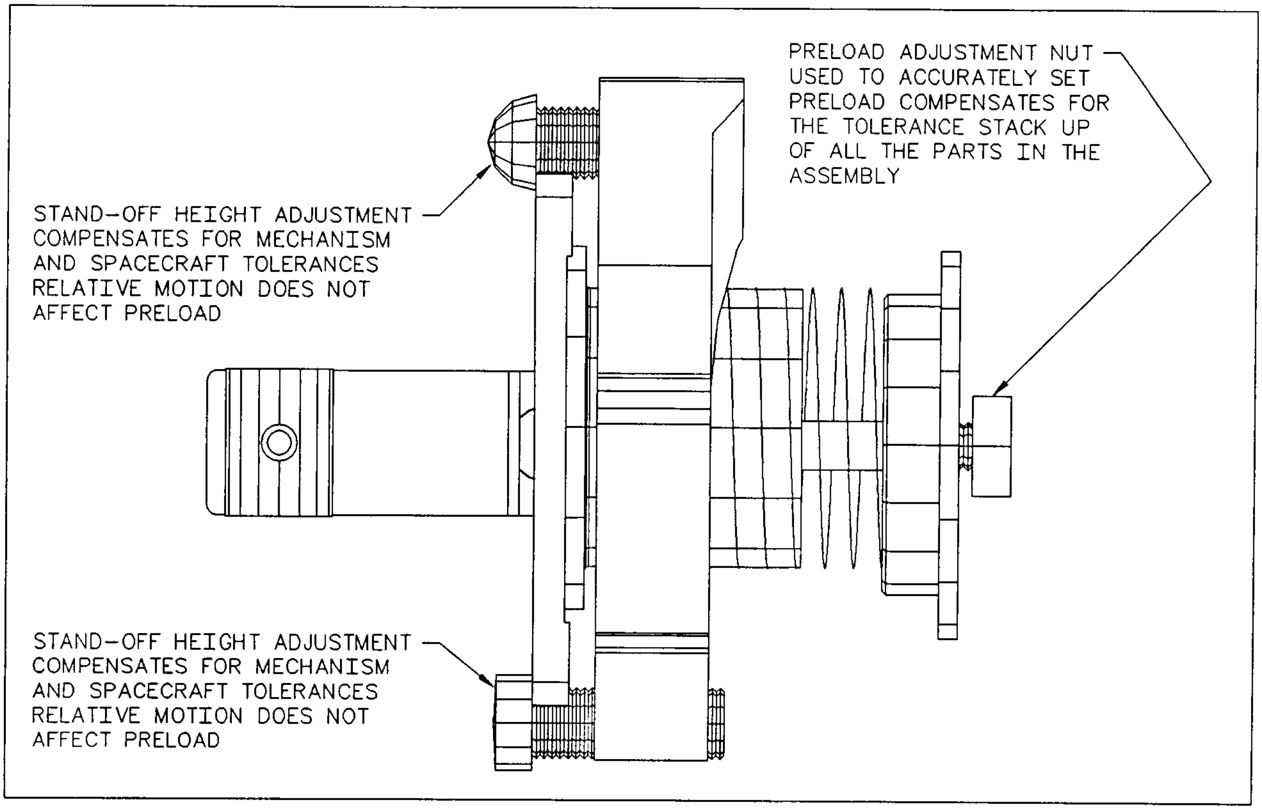
Our part designs were reviewed extensively by suppliers. Their comments and suggestions were employed whenever possible. This involvement started at the concept and layout stage so the design could evolve toward lower cost parts.

Customer involvement

In our relationship with our customer, requirements and design changes were reviewed for their cost implications. Dogmatic requirements were examined for their purpose and were frequently negotiated to reduce costs.

Tolerances

Lower tolerances directly lower cost and open the possibility of alternate methods of fabrication, such as using extrusions rather than machining from billets. Designing to limit the total number of parts in a stack up allows higher tolerances. Designing in an adjustable feature allows higher tolerances in associated parts.

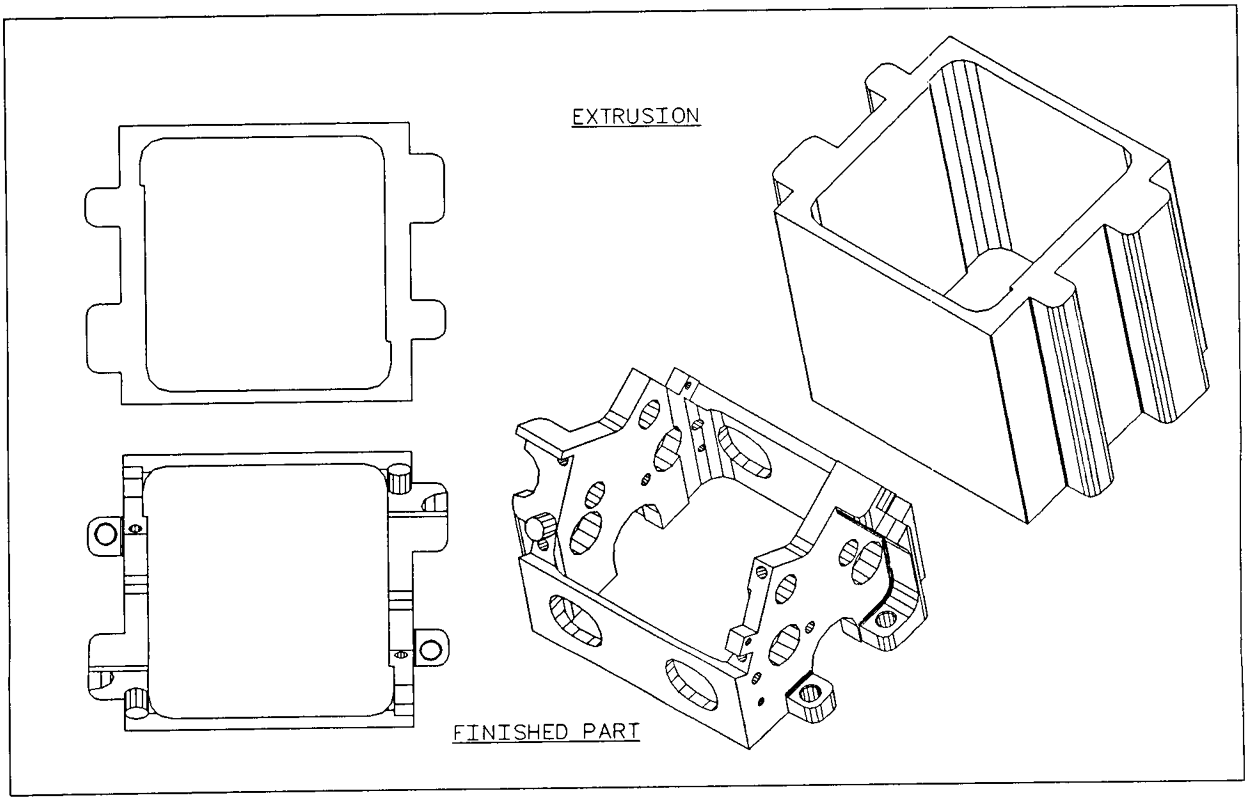


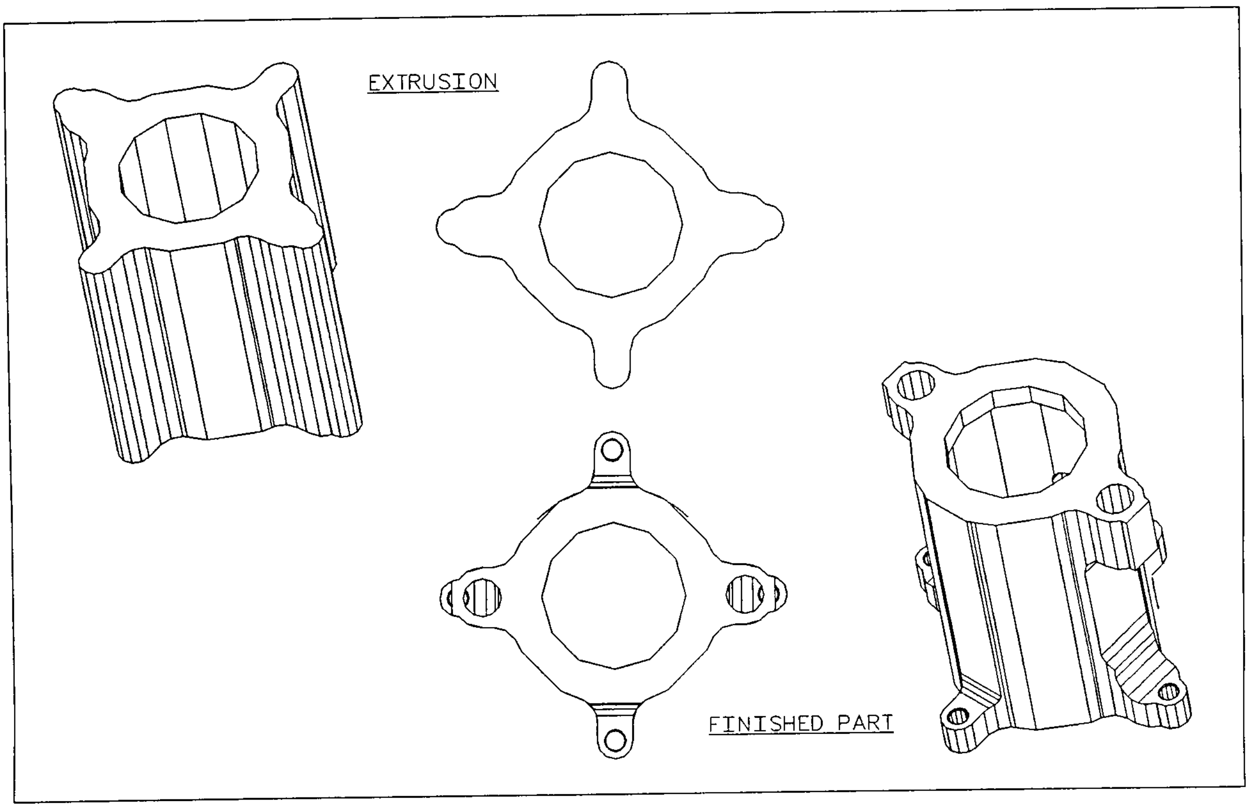
Materials

At SRC the first choice for a high strength plastic is Envex, which was initially specific for the Extension. Envex is very costly, after a careful review of properties and cost Ultem was specified at 1/2 the material cost.

Extrusions

From the beginning of the design major parts were examined for the feasibility of using extrusions. The cost of an extrusion die is under $1500. In quantities as low as 100 parts this cost can be recovered from just the material saved and of course the machining cost reduction is even higher.


EXTRUSION
FINISHED PART


EXTRUSION
FINISHED PART

Standard "off-the-shelf" parts and shapes
Other than fasteners we usually design and fabricate most parts. The Thomas Register and component catalogs were consulted extensively. Parts were designed to use available stock and standard stock tolerances. The initial actuator heater was custom and with high volume still cost $70. A thorough search of standard heaters identified a stock heater that would work with slight modification of the actuator design. It cost only $9.84. The electrical connector is mounted on a stock standoff that costs only 25¢.

Keeping it simple
Since simplicity and reliability have such a strong correlation we always try to keep it simple. The mechanism utilizes a flexible metal band attached at both ends with a pin that allows rotation. this system allows 5 degrees of freedom and restrains in one axis. An equivalent toggle system would required more parts, be more sensitive to dimensional variation and cost more.

Limiting part count is one way to keep it simple. But, to limit costs this approach had to be expanded significantly, all the way to total setup count and total feature count. The more setups a part requires, the more labor intensive it becomes. The more dimensions on a part, the more time it takes to fabricate. Eliminating sharp corners on the cam clamp eliminated a second machining setup and lowered the fabrication cost by 20%.

Price determines cost

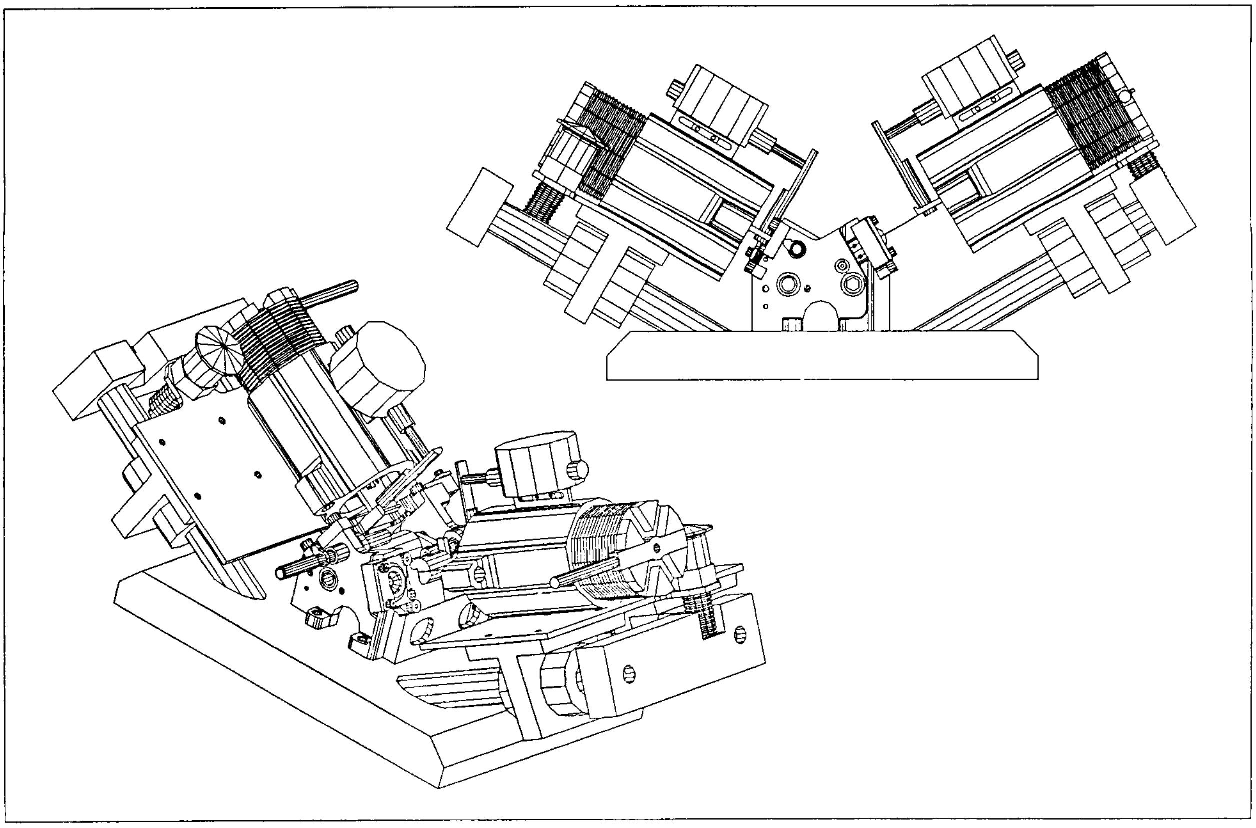
This is perhaps the biggest change in thinking required for ourselves and our industry. Traditionally we start with our costs add them up and come up with price. It is very different to start with the price and work backwards to determine the cost of each system and ultimately what the cost of each part must be. This seemingly backward approach to developing costs is what drives costs lower.

Negotiating
Setting a cost goal works. It worked for our customer with us and it worked with our suppliers. The cost goal set by our customer initially seemed impossible. But, after we accepted the challenge and applied our creativity amazing opportunities were identified. When we set aggressive cost goals with our vendors they surprised us with their solutions.

Understanding the source of costs
While we understood that some materials cost more than others and some materials are harder to machine than others we had to refine this understanding. We asked questions such as; Which features are harder to machine than others? What is the shape of a tolerance/cost curve?

Assembly
Assembly costs a lot and especially as part costs are lowered the percentage of cost attributed to labor becomes very significant. Designing parts for ease of assemble is critical. Extensive input from manufacturing was used in developing the design. In fact, our assembly documentation was developed concurrently with the design to allow assembly process to help dictate design.

Fixtures
Group discussion between engineering and manufacturing allowed us to identify operations where fixturing could significantly reduce assembly time. Discussions with suppliers identified tooling they could build to lower the unit part cost. Discussion with inspection personnel identified functional gages that could speed inspection. The use of actual parts in the fixtures lowered the cost to develop and build the fixtures.



Design evolution

Phase one - Concept
The original design concepts had numerous complex parts. Each part and each system was conceived without fully considering the whole device. This initial design proved the approach and created the structure to begin optimizing the design. In the metaphor of the forest and the trees each tree was planted and the forest created.

Phase two - Simplification
Now it was time to look at the forest as a whole and integrate it. The design was refined, part functions were combined, part interfaces simplified and the value added by each part or feature was evaluated. The design was finalized and prototyped. But, as initial testing begin we realized some problems had been overly simplified and others ignored entirely.

Phase three - Refinement (Complication)
Customer requirements changed, some for the better, most for the worst. Fortunately, experience had taught us to allow for this in the design and no major changes were required. However, new and varying requirments challenged our approach to commonality and required creative solutions.

Extensive testing pointed to problems that were not adequately resolved, structures that were overly lightweighted and new kinematic interactions identified. Materials had to be changed, webs added to strengthen weak sections and features added to parts to improve clearances. As a result, mass and cost were added back to the design. On the other hand, a better, more refined, understanding of the design and kinematics allowed some parts to be simplified further, reducing mass and cost.

Examples
The solar array bracket was originally made with a thinner walled extrusion and had a stiffening ring inserted in the end to stiffen the tubular structure. After, building a prototype and understanding the real costs involved in such an approach, the bracket wall thickness was increased to the ring inner diameter and then machined to remove the excess material. This approach was identified in the beginning but was assumed to be more costly, our experience taught us differently.

In order to lower weight and cost, a guide to keep the preload spring located on the antenna bracket was eliminated. As loads rose and envelope shrunk the position of the spring became an issue. A feature was added to the offset plate to locate the spring end and a spring tube was added to the antenna bracket assembly to eliminate "caterpillaring" of the spring.

A word about changes
Make changes carefully. Last minute changes to correct a local problem can sometimes have far reaching effects on a complex system. Changes should be thought out as carefully as the original design was thought out. We changed the length of the release band to reduce the stroke of the preload spring and thereby reduce the shock at release. This change altered the complex trajectory of the exiting tab allowing it to impact the latch body. This impact effectively bent the latch body on the high load latches.

What we learned about changing our paradigm to include cost

Lots of inputs
Designers are used to balancing varied requirements and evaluating trades. Adding unit cost to the list of requirements is not inherently difficult. However, creating and

evaluating cost input and developing experience with costs requires effort. On a large design effort, assigning support personnel to concurrently monitor cost, source suppliers and participate with the development team can be a practical solution.

Simple tools
Creating and maintaining a part level cost budget, much like a mass budget, is a simple practical tool for meeting cost objectives. A part information summary was maintained for each part. It listed all suppliers, their price quotes, lead times, issues and suggestions.

Elegance = Reliability + Low Cost
There might be a belief that lower cost means lower reliability. It is our experience that high reliability actually results in low cost if the approach to reliability is driven by simplicity. "Keeping it simple" supports both reliability and cost. An elegant design is one that accomplishes as much as possible with as little as possible. Therefore, an elegant design inherently costs less. Time invested in an elegant design will result in lower costs.

Conclusion

Adding severe cost constraints to mechanism design extends the demands placed on a designer. The proven approach of acquiring knowledge, conducting research and experimenting work with the requirement of cost as it does with all other requirements. For the accomplished designer cost is the final frontier.