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SPACE & NAVAL ENGINEERING

Novel Thrust Vectoring Mechanism

Design for Controlled De-Orbiting based on Solid Rocket Motor Propulsion

ESA Clean Space Industrial Days 23 October – 25 October 2018

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SPACE & NAVAL ENGINEERING

Almatech is a space engineering company with established expertise in four main fields

Integrated Systems | Ultra-stable structures | High precision mechanisms | Thermo-optical hardware

PROJECT OBJECTIVES

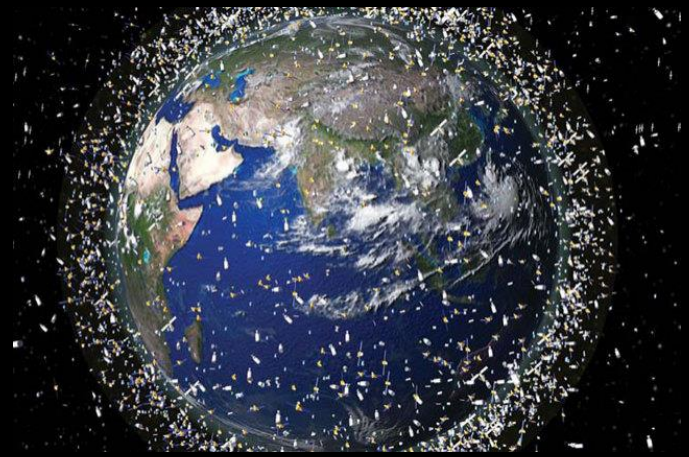
- Almatech was selected for the ESA Clean Space initiative to investigate, and design a Thrust Vector Control (TVC) mechanism as part of the Solid Propellant Autonomous Deorbit System (SPADES).

  (ESA Contract No. 4000112746/14/NL/KML)

- almatech is Prime with 2 Italian partners:

  D-ORBIT SITAEL

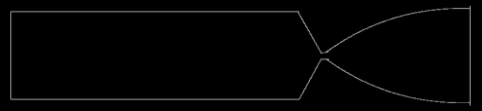
- **The objective of the activity** is to
  - identify vectoring solutions
  - trade-off of vectoring concepts
  - carry out detailed design on chosen concept



TRP UNDER ESA CLEAN SPACE INITIATIVE

Baseline scenario

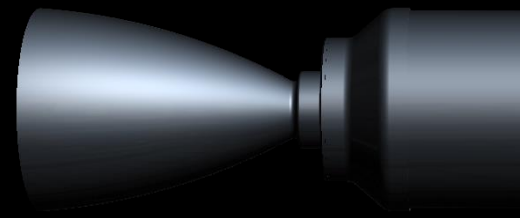
- **Large spacecraft** ~ 1500 kg
- **LEO** ~ 800 km altitude
- **Rocket motor clustering** - 4 motors required for deorbit
- **Rocket motor thrust level** – 3 classes, nominal 250 N
- **Long burning time** ~ 4.75 min, cigarette burning
- **Bell shaped nozzle**
- **High expansion ratio** ~ 450



$$Expansion\ ratio = \frac{Area_{exit}}{Area_{throat}}$$

VECTORING REQUIREMENTS

Nominal SRM thrust level	250 N ± 20%.
Thrust deflection target performance	±5°
Thrust deflection rate target performance	±10°/s
Pointing resolution	0.05°
In-orbit non-operational lifetime	15 years
Reliability	>0.9995 with 60% confidence



Main design drivers

Compactness

- low mass, volume
- low encumbrance for clustering

Performance

- thrust deflection angle > +/-5 deg
- thrust deflection rate > 10 deg/s

Cost-effectiveness

- minimized complexity
- standardized components and processes
- manufacturing and assembly reproducibility

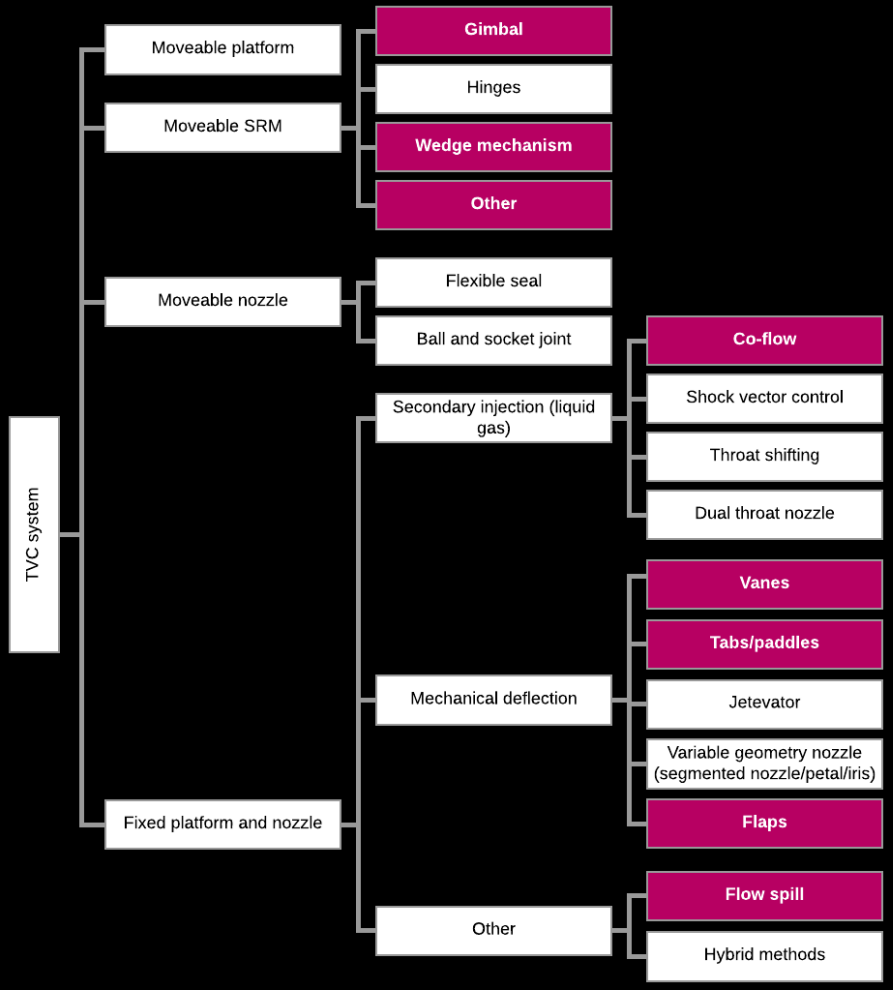
Reliability

- non-operational lifetime of 15 years in-orbit
- long SRM burn time

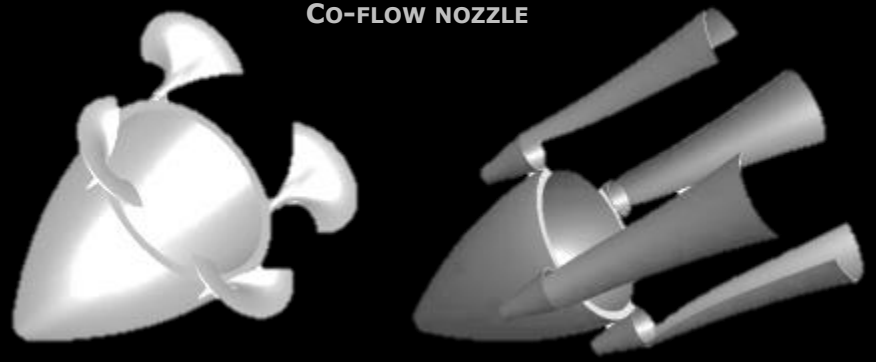
Integration

- interfaces
- ease of access and installation
- AIT activities
- cleanliness

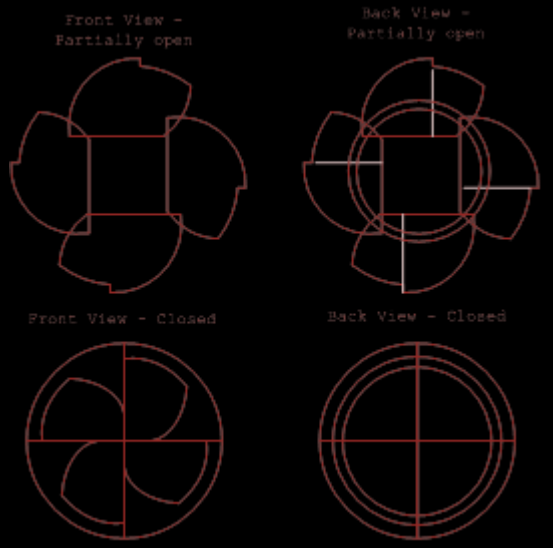
DESIGN EVOLUTION – CONCEPT GENERATION



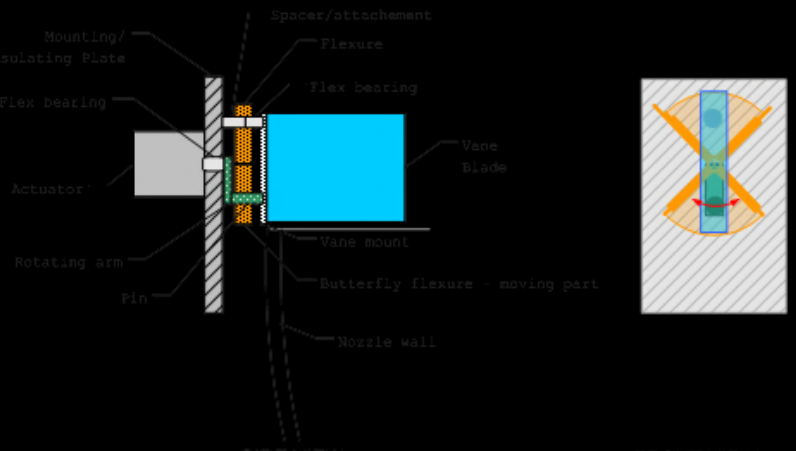
CO-FLOW NOZZLE



JET TAB IRIS MECHANISM



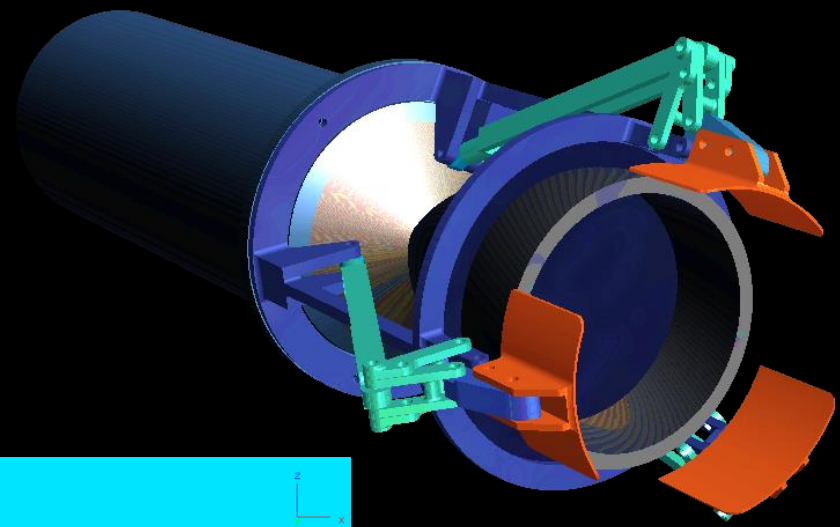
JET VANE MECHANISM

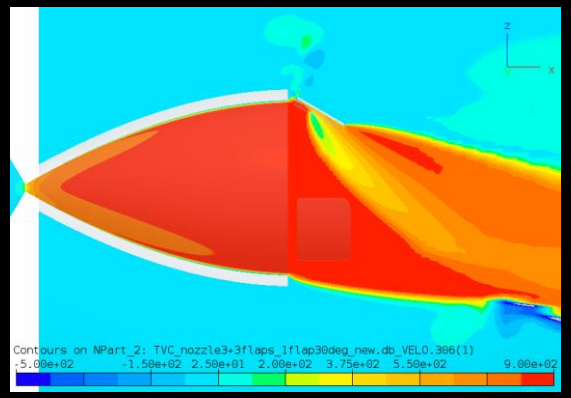


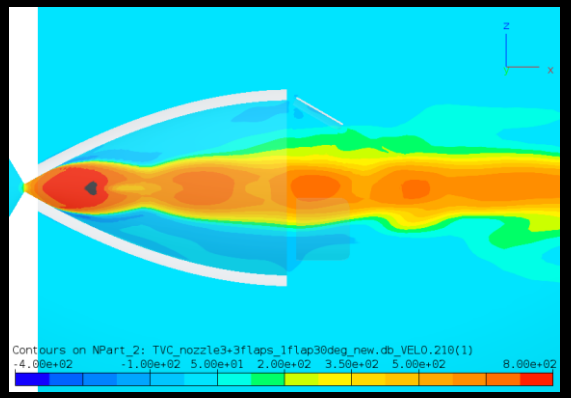
Design evolution – Initial tradeoff chosen concept

- Linkage mechanism
- Good performance characteristics
- Protected from environment
- No need for high temperature sealing
- Mechanism jamming risks greatly reduced

Jet Flap mechanism

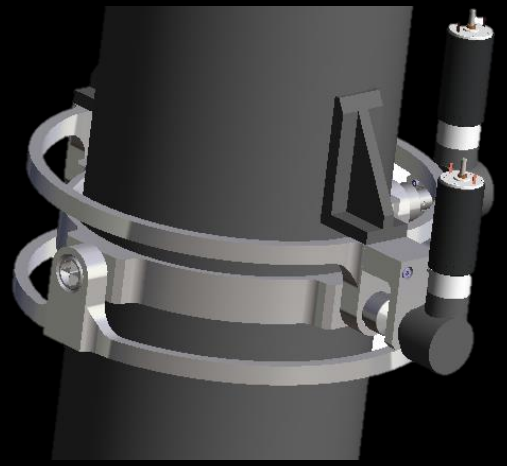






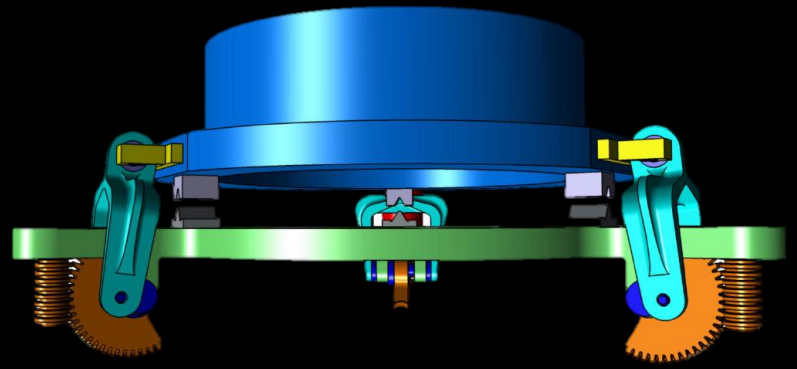
Flow velocity profile at 30 deg flap deflection
Model with 65 Pa and 6500 Pa ambient pressure

Design evolution – Mechanical system tradeoff concept generation



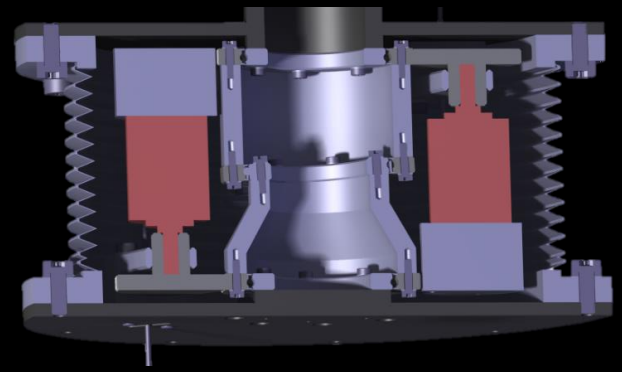
Flex-Gimbal Mechanism

with conventional geared stepper motors.



A-frame mechanism

a novel solution that encompasses redundancy and launch lock function.



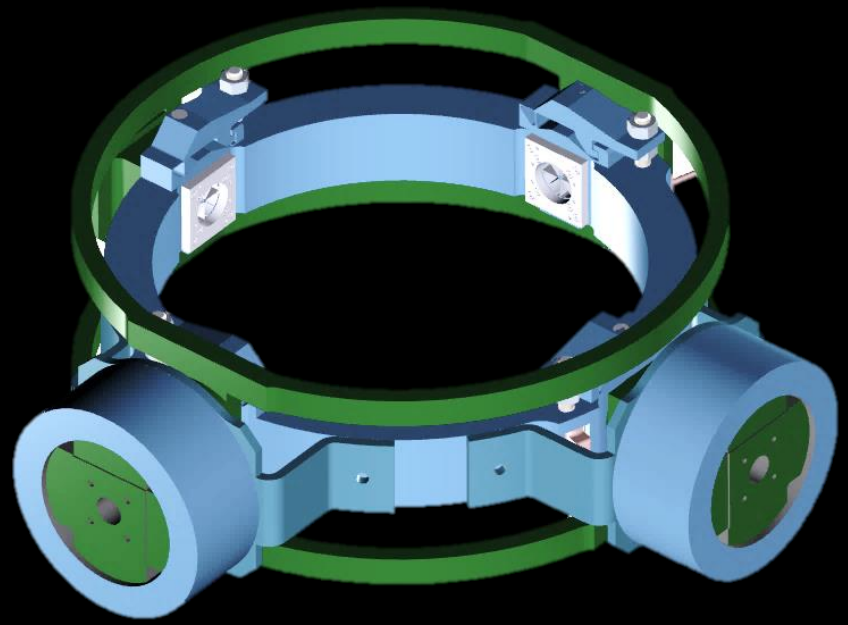
Wedge mechanism

sized for vectoring loads only, while launch lock development is to be considered.

Design evolution – Mechanical system chosen concept

- Gimbaling is achieved with the help of **flexure pivots**.
- Pivots are **directly driven** by two limited angle torque motors.
- The SRM is mounted within an **annular interface ring**.
- This ring is actuated by motor and connected to the **middle stage mobile ring** by two flexure pivots 180° apart.
- The middle stage ring is connected to an **identical interface ring** at the spacecraft side through another set of pivots.

Frictionless Flex-Gimbal mechanism



FRICTIONLESS FLEX-GIMBAL MECHANISM ADVANTAGES

Performance

- Improved performance at no additional developmental cost.

Design and Development

- Accelerated life testing is not of major concern.
- Simple analysis of motorization behavior
- Possibility to test with dummy SRM

Cost

- Low mechanical complexity
- Commonality of components
- No need of expensive /exotic materials or processes

Assembly complexity

- Low assembly complexity
- Simple interface provisions

Life / Reliability

- Number of active components is low
- Fully frictionless mechanism with high predicted reliability
- Integrated launch lock solution

Frictionless flex-gimbal mechanism pivots (1)

Custom flexure pivots (patent pending) allow for sizing the mechanism for minimal rotational stiffness, lower actuation torque and larger rotational angle capability than commercial options.

Custom flexure pivot advantages and benefits

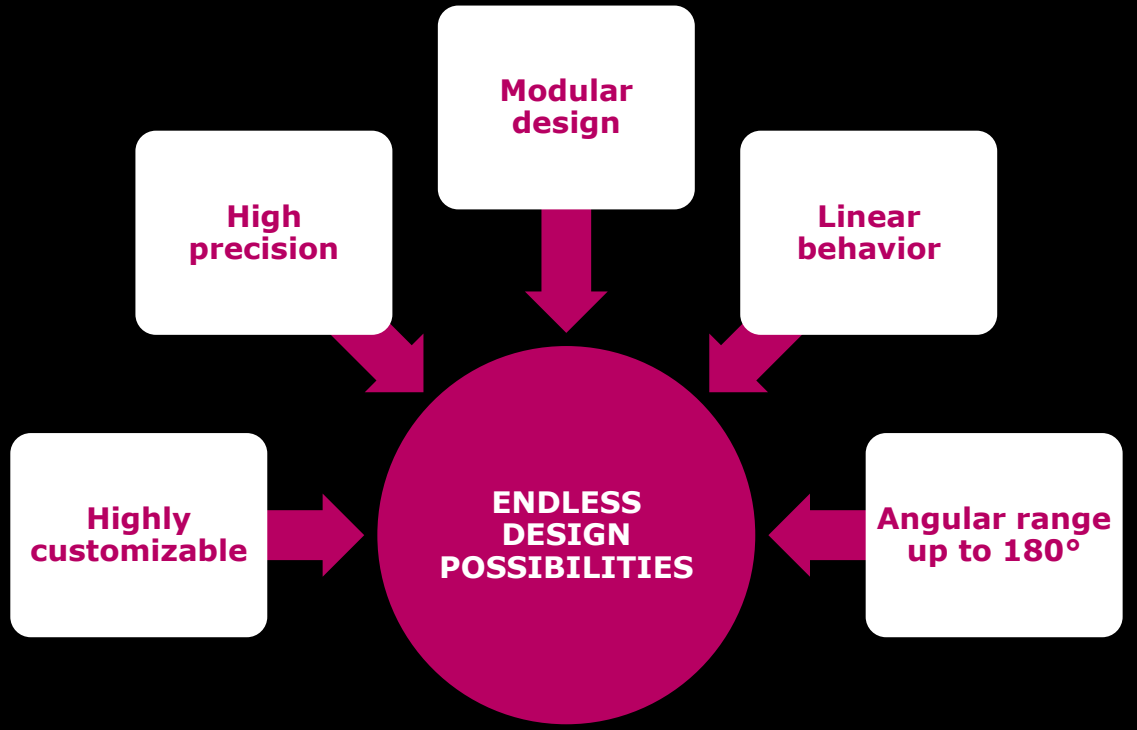
- Robustness to environmental conditions
- No wear, and lubricant-free
- Predictable life / infinite life
- Predictable, reliable performance
- No contamination
- Integrated movement limiters to ensure flexure protection during assembly and integration.

FRICTIONLESS FLEX-GIMBAL MECHANISM PIVOTS (2)

- Optimized blade profile, generous filler radii (to avoid stress concentrations)
- Fully symmetric design that minimizes center shift

In-house optimization for

- Angular range
- Stiffness
- Dimensioning
- Interface (inside/outside/through-hole)
- Material
- Configuration (no. of stages, blades)

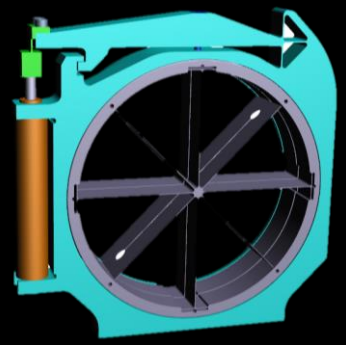


Global optimizer implementation with analytical models and integrated FE modeling and verification

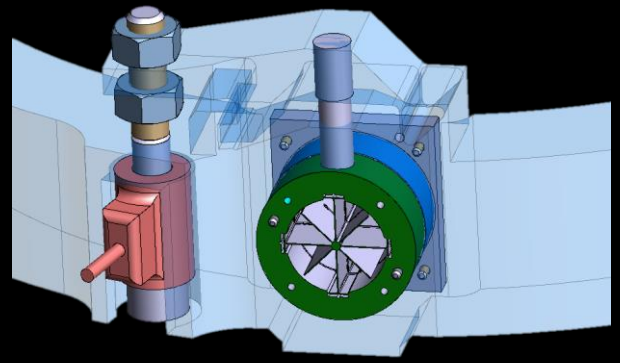
FRICTIONLESS FLEX-GIMBAL MECHANISM IN LAUNCH ENVIRONMENT

Integrated launch lock solution

- Pivots sized for operational and handling loads
- Compliant launch lock principle
- COTS actuators



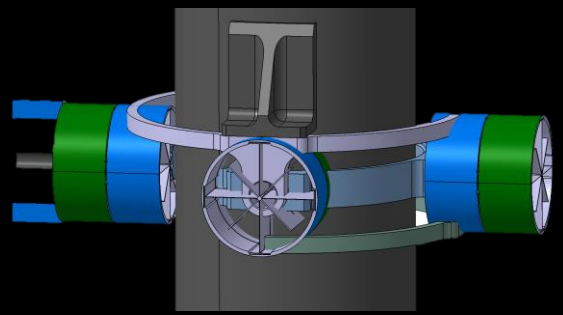
PIVOTS WITH INTEGRATED LAUNCH LOCK



Flexures designed to withstand launch loads

- Pivots sized for launch loads
- Performance 10x better than COTS with similar radial stiffness
- Encumbrance limitation

PIVOTS SIZED TO WITHSTAND LAUNCH LOADS



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FRICTIONLESS FLEX-GIMBAL MECHANISM UNDER DETAILED DESIGN

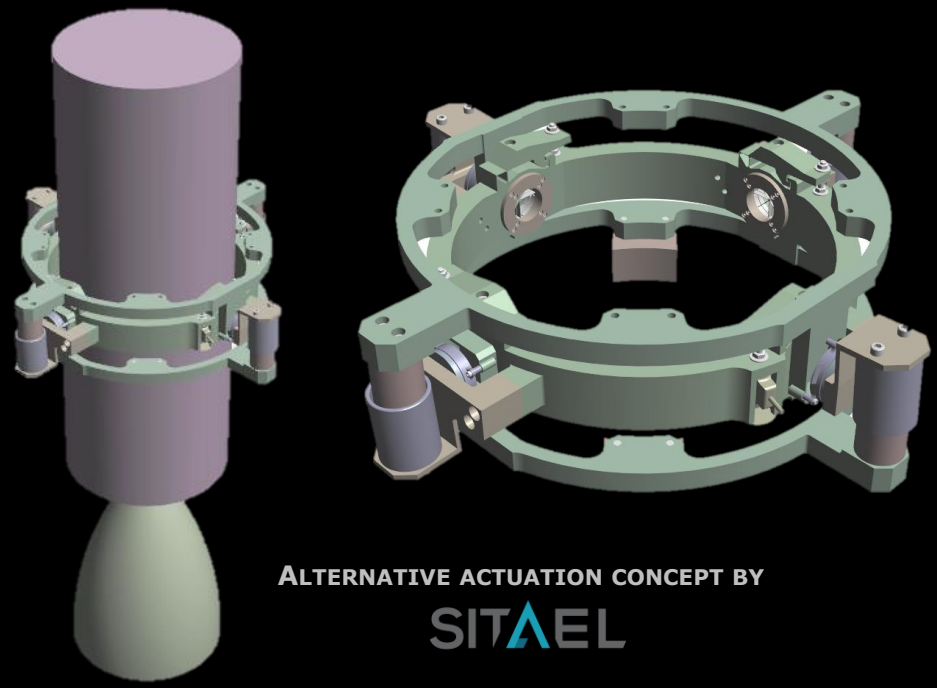
Almatech Mechanism concept underwent critical review and is currently under detailed design by SITAEL

Frictionless flex-gimbal mechanism with limited angle torque motor

TVCS DESIGN BY almatech

- ✓ **Direct drive**
- ✓ **Frictionless**
- ✓ **Simple control logic**

Frictionless flex-gimbal mechanism with custom voicecoil actuators



ALTERNATIVE ACTUATION CONCEPT BY SITAEL

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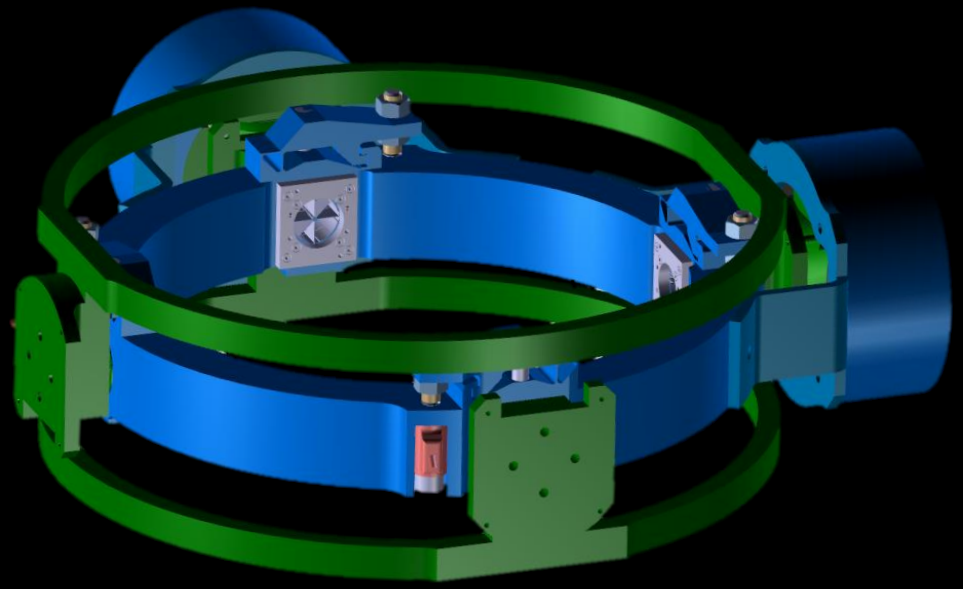
Frictionless flex-gimbal mechanism - Summary

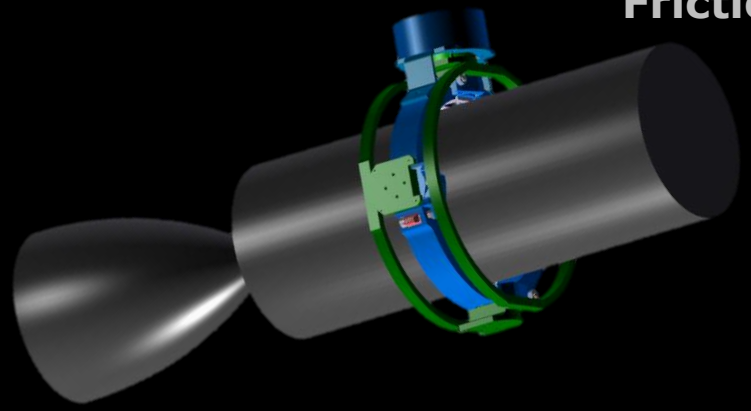
Frictionless Flex-Gimbal design combines **reliability, scalability, predictably, ease of integration and low-cost features** for a thrust vectoring system for end-of-life de-orbiting:

- Frictionless solution
- Long lifetime and high reliability are predicted
- No lubrication is required
- The number of active components is very low
- Direct drive
- Accelerated life testing is not of major concern
- Analysis of motorization behaviour is simple
- Compliant mechanism based launch lock



A NOVEL VECTORING SOLUTION: DEVELOPMENTS FOR SIMPLE, SUCCESSFUL DEORBIT

Frictionless flex-gimbal concept

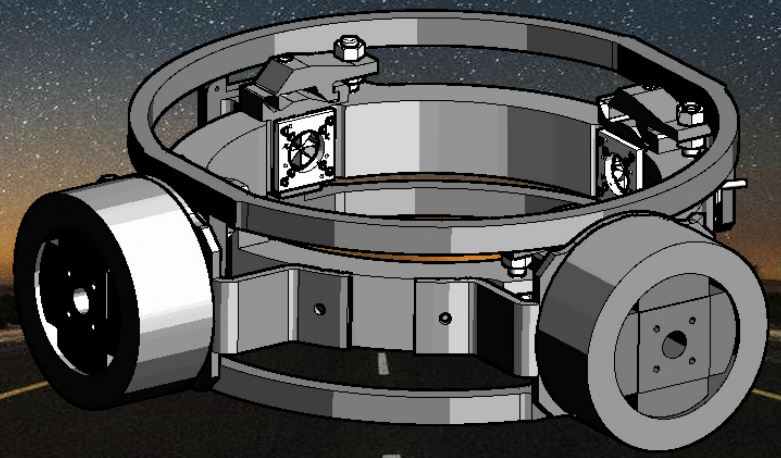


Innovative optimized pivot solutions

PATENT PENDING

Smart flex embedded encoder solutions

Questions ?



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