High Capability Actuator

Attitude agility and how HCA transforms SmallSat design and operations

This white paper presents the challenge of small satellite agility and proposes a solution to address it. While currently qualified solutions, such as Control Momentum Gyroscopes (CMGs), exist for larger satellites (typically above 750 kg), an equivalent flight proven range of actuators providing high levels of agility for the SmallSats (typically 100 - 500 kg) has not existed…until Airbus's High Capability Actuator solution presented here!

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Agility: why it matters

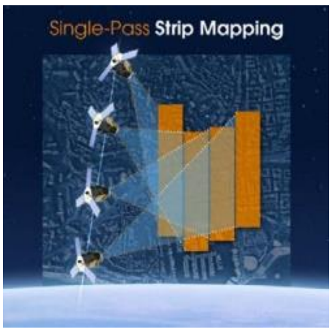
- **Higher quantity of data and use cases:** Agile satellites increase the amount of information collected, both by acquiring more images on a single path and being able to perform tactical imaging. There are several image collection scenarios described below (figures 1 to 6), some of them directly impacted by the satellite agility. Here agility is defined as the ability of a satellite to modify its attitude in order to collect images outside its ground track, and is a combination of the satellite inertia (geometry, weight) and its actuator performance, whether based on CMG or reaction wheels (RW).

Multiple close targets during the same pass, typically 20 targets over a 1,000 x 1,000 km area inside a +/- 30°corridor

Figure 1

Agile actuators enable a maximum number of acquisitions over a given area, typically ten images over an area of 100 x 200 km

Figure 2



Strip mapping over large areas, typically up to five contiguous strips of 150 km each

Figure 3

Stereo and Tri-stereo acquisitions for 3D applications

Figure 4

Corridor acquisition over linear targets (borders, roads, railways, pipelines…)

Figure 5

Persistent surveillance mode, for moving targets and/or improved photo-interpretation

Figure 6

- Currently most high performance/high resolution satellites (30 cm ground resolution) are in the >750 kg class. They can rely on flight-proven actuators* such as CMGs from different vendors. CMGs provide high torque and angular momentum together with a low power consumption, enabling demanding tasking missions to be undertaken.
- The SmallSat category (100 to 500 kg) simply does not have the same availability of suitable actuators as the market demand has been relatively low until recently.

(*) Airbus DS have an extensive portfolio of high torque actuators. The CMG 15-45 S is flight proven for 1000 kg class satellites, a radiation hardened version of CMG 15-45 S (CMG 15-45 R) for missions with severe radiation environment, and two larger models CMG 40-60 and CMG 75-75 for respectively 2000 and 3000 kg class satellites.

- The SmallSat segment is becoming increasingly important for EO constellations, and the demand for high performance actuators in this market is increasing.
- The current solution to use Reaction Wheels (RW) for SmallSats has some limitations as the RW torque and angular momentum are generally not high enough to fulfil agile missions; furthermore, RW require higher power level per unit torque delivered, a key issue as SmallSats usually have limited power resources.
- Some mini-CMGs are currently under development, not yet flight proven. While the comparison between a CMG and a RW is well known in terms of maneuver time improvement, CMGs require a more complex implementation, which can be a constraint for start-ups and business models requiring fast ROI.
- Considering this context, the challenge is then to find a smart actuator, less complex to implement than a small CMG, with improved maneuver time compared to a RW, and with a moderate power consumption.

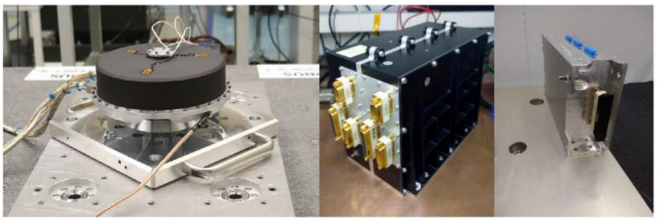
Airbus' Solution: High Capability Actuator

Building on our extensive CMG heritage, Airbus DS started the development of the high capability actuator, HCA, in 2015. Geared towards the small satellite market (200-500 kg), its performance of 4 Nms momentum and 1 Nm torque brings **high-speed maneuvers** and **enhanced pointing control** to this segment, whilst also providing **ease of use and cost efficiency**. Over 10 HCA FM have already been delivered and additional FM units are in production.

The HCA provides **strong differentiators** compared to both: RWs, with a **higher torque** and a **lower consumption,** and small CMGs, due to simplified integration on the satellite.

The HCA actuator is made up of 3 sub-assemblies:

- Mechanism
- Electronics
- Bank of Supercapacitors or BOSC



Mechanism Electronics BOSC

HCA Performances: A Comparison with Reaction Wheels

Torque capacity

Delivering 1 Nm at only 48 W, HCA has a significantly superior maximum torque to consumption ratio. This characteristic makes integration on small platforms possible and paves the way for wheel-based agility.

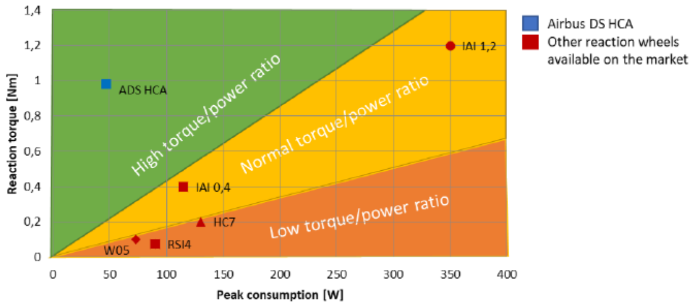


Figure 7 - HCA's positioning relative to RW. Energy recovery during braking limits HCA consumption for an unmatched effective torque.

Angular Momentum Accuracy

The HCA mechanism is equipped with an optical encoder derived from the CMG product line, delivering precise incremental position measurements. The HCA electronics compensate for known encoder discrepancies and processes a highly accurate speed estimation. This information is then used inside a speed loop to efficiently reject disturbance torques such as torque friction, zero-crossings, and power driver imperfections.

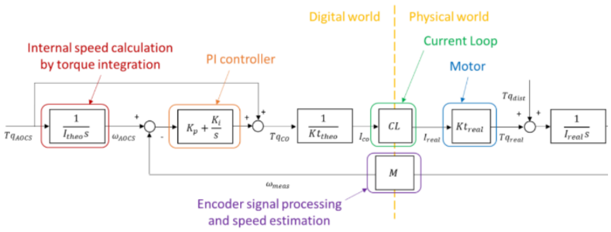


Figure 8 - Internal speed control loop architecture

The speed loop bandwidth is tuned to maximize the disturbance rejection without interacting with isolator modes. Precise synchronisation of the torque feedforward action and the internal speed calculation ensures accurate speed command tracking even after torque discontinuities

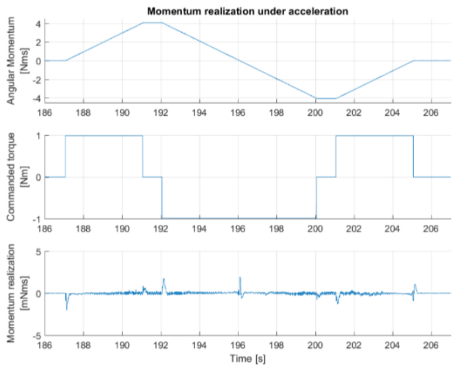


Figure 9 – Speed realization during the manoeuvre – Test result on FM

Additional Revenues for Satellite Operators

Due to the additional image collection, HCA offers the satellite operator potential for **additional revenue generation**.

HCA (in 4-1 configuration) **performs better** than the two other configurations (classic RW and Mini-CMG) in **collecting more images**.

Two use cases of multiple acquisition on a single path (see Figure 2 type) have been simulated and presented. Based on a 300 kg SmallSat (with typical inertia for that class, see Figure 10). The simulations compare the performances of HCA, a classic RW and a Mini-CMG (Figure 11).

$$I = \begin{pmatrix} 100 & 0 & 0 \\ 0 & 100 & 0 \\ 0 & 0 & 100 \end{pmatrix} \; kg.m^2$$

Figure 10 - Inertia matrix of a 300 kg satellite

Type	Name	Momentum (Nms)	Torque (Nm)
HCA	HCA 4-1	4	1
Classic RW	RW	4	0.2
CMG	Mini-CMG	2.8	3

Figure 11 – simulated actuators data

Use Case 1

The tasking plan (Figure 12), coming from a real case used as a benchmark by CNES, gathers 30 targets over a surface of 300 X 460 km². The simulation uses a guidance algorithm that searches to maximise the target acquisition, knowing the actuator cluster capabilities.

The number of acquired targets are:

- **HCA** configuration: **15** targets,
- **Classic RW** configuration: 8 targets,
- **Mini-CMG** configuration: 13 targets.

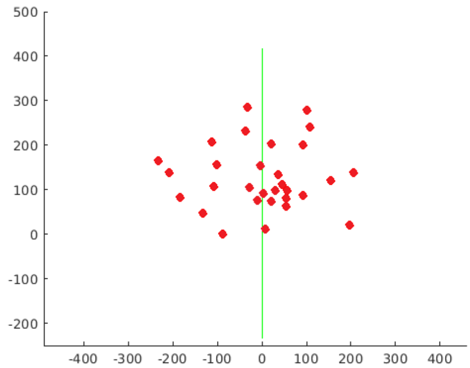


Figure 12 – Use Case 1

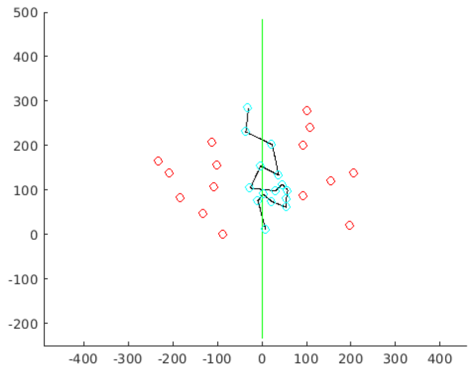


Figure 13 – Use Case 1 / HCA

Legend:

- Light green line: spacecraft ground path,
- Circles: designated targets (green if successfully imaged),
- Blue curve: line of sight ground path

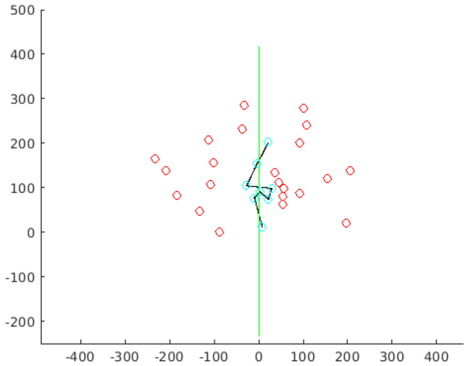


Figure 14 – Use Case 1 / RW

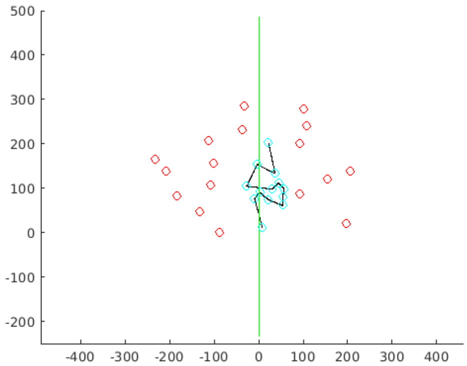


Figure 15 – Use Case 1 / Mini-CMG

For this first scenario, the HCA 4-1 yields **88%** more images compared to a RW, and **15%** more compared to a Mini-CMG.

Use Case 2

The tasking plan (Figure 16), coming from a real scenario used as a reference benchmark by CNES, gathers 30 targets over a surface of 500 X 700 km². Similar to the previous use case, the guidance algorithm optimizes efficiency for the actuators under study.

The number of acquired targets are:

- **HCA 4-1** configuration: 11 targets,
- **Classic RW** configuration: 7 targets,
- **Mini-CMG** configuration: 11 targets.

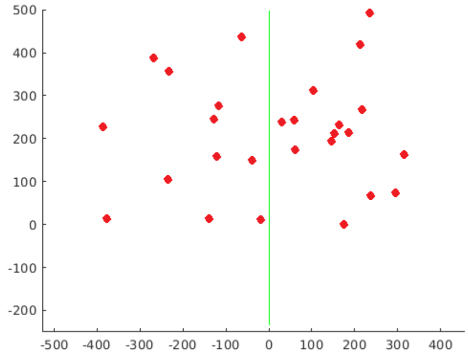


Figure 16 – Use Case 2

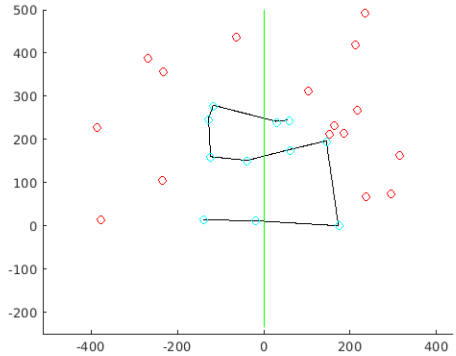


Figure 17 – Use Case 2 / HCA

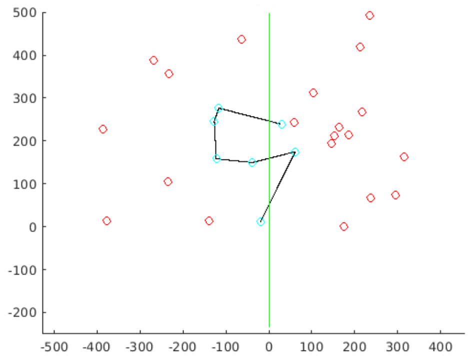


Figure 18 – Use Case 2 / RW

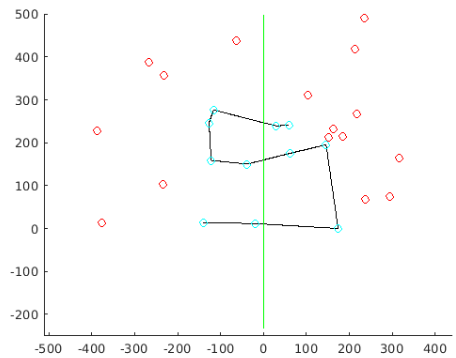


Figure 12 – Use case 2 / Mini CMG

For this second use case, the HCA 4-1 yields **57%** more images compared to a RW, and **the same** compared to a Mini-CMG.

Considering both scenarios, the average maneuver durations from one target acquisition to the next are the following:

- HCA: 11.4 seconds
- RW: 24.3 seconds
- Mini CMG: 12.8 seconds

HCA is thus faster than the two other actuator solutions.

Reduced Power Consumption

HCA configuration **needs less power** compared to the classic RW configuration. Thanks to the storage of mechanical energy, through a bank of supercapacitors, the equipment can recover the mechanical energy from the rotor during the braking phases and re-inject it during the acceleration phases. Only internal losses must be compensated by the satellite bus. This makes it possible to achieve unrivalled torque capability without affecting the power budget of the system.

Simplified Satellite Integration

The satellite platform integration is simplified with the HCA configuration. An HCA cluster, compared to a cluster of mini-CMG, is significantly easier to use**:**

■ No need for a complex algorithm or steering laws to control the cluster, in contrast to those used for CMGs, making the AOCS development of the spacecraft easier.

■ The embedded speed loop rejects any internal disturbances which do not need to be dealt with at AOCS level, further reducing the bus development efforts.

■The state-of-the-art, fully digital interface for TeleMetry (TM) and TeleCommand (TC) allows for seamless data handling integration.

■ Each actuator axis is composed of 3 smaller independent elements, facilitating their accommodation in the spacecraft bus.

Conclusion

Airbus' HCA is based on the proven heritage of our CMG product line. The HCA product is already qualified and the first units will fly Q2 / 2024. The recurring production is currently on going with HCA already delivered and additional units currently in production.

HCA is significantly more efficient than a RW and presents comparable or better performance compared to Mini-CMG for a fraction of the integration costs.

Simulations (Use case 1) screenshots highlighting HCA performances for the same mission plan:

HCA configuration | Small CMG configuration | RW configuration

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