ANTENNA DEPLOYMENT AND POINTING ASSEMBLY DEVELOPMENT

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ABSTRACT

This paper presents the Antenna Deployment and Pointing Assembly (ADPA) developed as a successor to the successful Eurostar 3000 Antenna Deployment and Trimming Mechanism (ADTM).

Astrium UK has been actively involved in the study, design, development, manufacture and test of ADTMs for 15 years. Today, over 40 ADTMs across 18 spacecraft programs have been launched and are failure free operated in orbit for deployment and trimming.

The need for larger antenna reflectors, 2 axes deployments, greater pointing accuracy, continuous operation over the spacecraft lifetime for Radio Frequencies (RF) sensing applications, as well as increased manoeuvrability has lead to the design of the ADPA presented here.

1. INTRODUCTION

1.1. Acronyms List

ADPA Antenna Deployment and Pointing Assembly
ADTM Antenna Deployment and Trimming Mechanism
E3000 Eurostar 3000
ESTL European Space Tribology Laboratory
MLI Multi Layer Insulation
Pot Potentiometer
PTP Peak to Peak
RA Rotary Actuator
RF Radio Frequency
SMG Stepper Motor Gearbox

1.2. History

Table 1: ADMs Technologies

	Damper	Pot	Spring motor	Gearbox	SMG
ADM	X		X	X	
E2000 ADTM	X		X	X	X
Stability Boom	X			X	
Artemis	X			X	
Skynet	X	X		X	
E3000 ADTM	X	X	X	X	X
ADPA		X	X	X	X

Figure 1 presents the historical evolution of the Antenna Deployment and Trimming Mechanism (ADTM), from the initial deployment-only mechanism developed for the Orion program, to today's Eurostar 3000 (E3000) ADTM family.

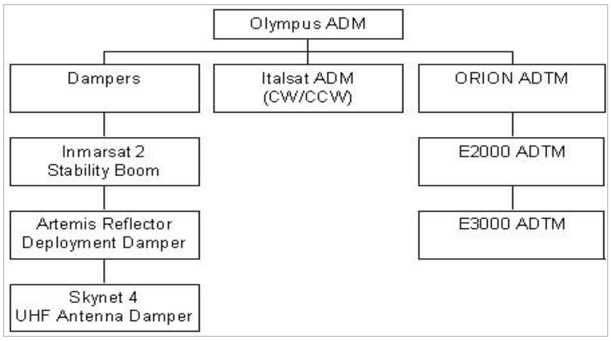

Figure 1: ADTM heritage tree

The E3000 ADTM devices are used to deploy large antenna reflectors stowed on the spacecraft walls during launch. It is composed of an active trunnion (motive source for pitch deployment and trimming) and a passive trunnion (passive pitch deployment follower + motive source for the roll trimming).

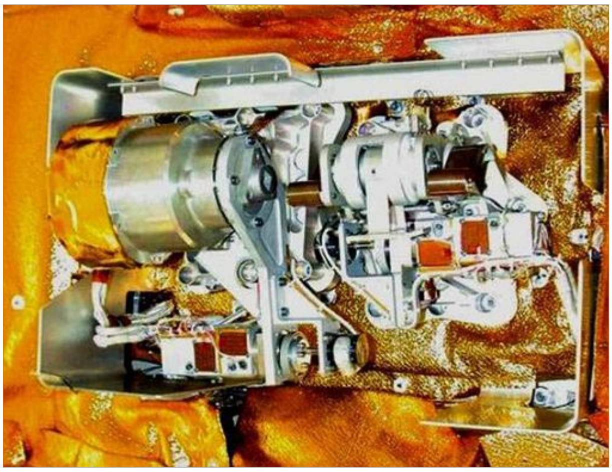

Figure 2: E3000 ADTM mounted on a spacecraft wall

Table 2 below summarises the E3000 ADTM characteristics.

Proc. '12th Euro. Space Mechanisms & Tribology Symp. (ESMATS)', Liverpool, UK, 19–21 September 2007 (ESA SP-653, August 2007)

Table 2: ADTM performances

Weight:	< 6 kg
Size:	214x229x124 + 176x161x129
Axes:	1 deployment axis 2 trimming axes
Deployment Range:	60° to 90° deployment
Trimming Range:	pitch: +/- 1.5° roll: +/- 2.3°
Trimming step size:	pitch: <0.046° roll: <0.007°
Minimum output torque:	12 Nm
Operating temperature range:	-25°C to +100°C

1.3. Evolution: ADPA

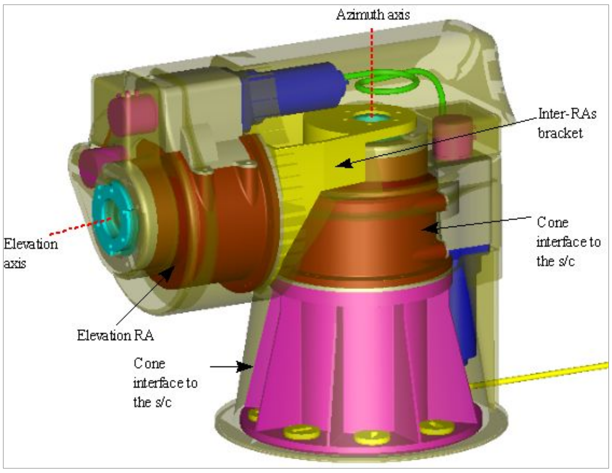

Figure 3: ADPA Elements Definition

Allowing greater flexibility with the end user requirements, the newly developed Antenna Deployment and Pointing Assembly (ADPA) uses 2 identical RA (rotary actuators), 1 actuator per axis providing deployment and trimming of that axis. The combination of the 2 RA therefore provides the 2 axes deployment + trimming / pointing mechanism.

The ADPA characteristics are:

Table 3: ADPA / RA performances

Weight:	< 6 kg (include 2 Rotary Actuators (RA), 1 adjustable height cone (s/c) interface, 1 inter-RAs bracket, 1.5m harness + connectors, MLI
Size:	214x229x124 + 176x161x129
Axes:	2 deployment axes 2 trimming / pointing axes
Deployment Range:	90°
Trimming Range:	pitch: +20° / - 90° roll: +20° / -90°
Trimming step size:	0.0017°
Minimum output torque:	12 Nm backlash free, 50Nm with backlash
Operating temperature range:	-50°C to +85°C

2. ADPA DESIGN

The ADPA has been designed as a full assembly, including 2 axes deployment and pointing Rotary Actuators (RA), adjustable height spacecraft interface, antenna interface, thermal control and its own Multi Layer Insulation (MLI) with connections points for antenna and spacecraft MLIs.

2.1. Main ADPA Elements

2.1.1. Cone Interface

Allows the ADPA to be attached to the spacecraft side wall / torsion box.

The cone is attached to the spacecraft wall using 8x M5 bolts, these bolts pass through slotted conical bushes in the foot of the cone. These bushes facilitates the position adjustment of the ADPA on the s/c wall at integration level. They are conical to match the corresponding holes on the cone base flange. They can be rotated freely through 360degrees, thus the slots can be oriented in any directions. Combining the 8 slotted bushes, horizontal Y / Z positional adjustment on the spacecraft wall is possible, the maximum allowance being defined by the slot length. The slots are also convenient for misalignment compensation between the s/c wall tapped holes and the cone holes.

The cone is made of aluminium to limit its mass whilst retaining strength and stiffness.

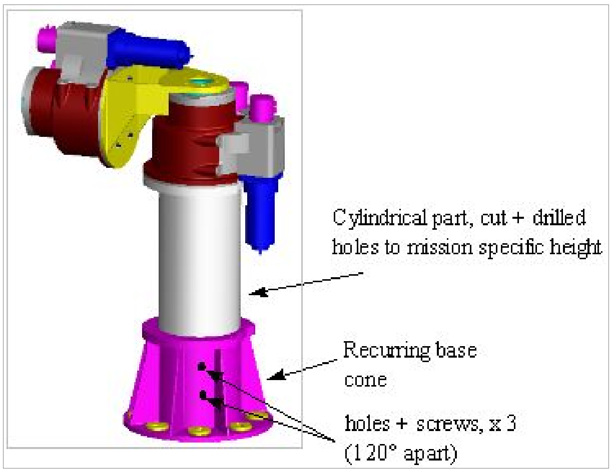

Figure 4: Cone Interface, Height Expansion

The ADPA being a recurring product, its design was emphasised on minimising the number of mission specific parts. This applies in particular to this cone interface because its height is adjustable between 175mm and 350mm from the cone bottom plane. An additional cylindrical tube can be added to the base cone to elevate the elevation axis. This cylindrical tube is procured at the maximum length for all ADPAs, and then cut to the desired project specific height. It is inserted in the base cone; drilled taped holes at 2 heights x 3 position (120° apart) are used to connect the cylinder to the cone. Additional bonding between these parts may be added for even better structural support.

2.1.2. Azimuth RA

The azimuth RA provides the azimuth axis motion, i.e. the antenna roll, through a selectable range of 0° to 55° or 0° to 110°. The RA may be positioned and then re-pointed or finely trimmed at any position within this range.

2.1.3. Inter-RAs Bracket

The inter-RAs bracket connects the azimuth and elevation actuators. This bracket is adjustable to specific RAs positions: up to +/-75mm offset for non-concurrent axes. It is made of aluminium alloy, and design includes webs to ensure its stiffness.

2.1.4. Elevation RA

The elevation RA provides the elevation axis motion, i.e. the antenna pitch, through a selectable range of 0° to 55° or 0° to 110°. The RA may be positioned and then re-pointed or finely trimmed at any position within this range.

2.1.5. Antenna Interface

Cf. RA section 2.2.4.

2.1.6. Harness

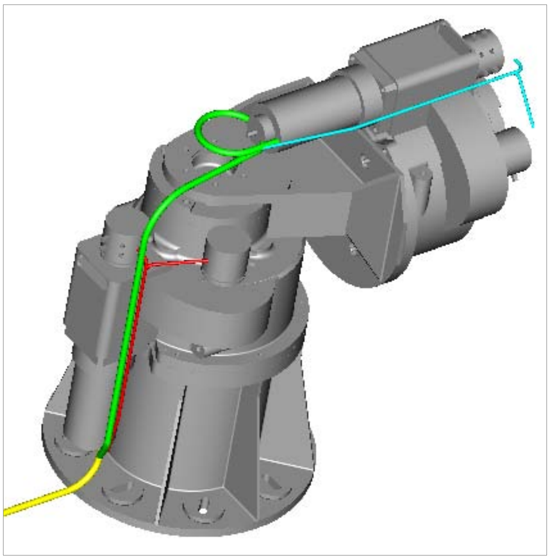

Figure 5: ADPA Harness Routing

Harness management is important on the ADPA. Because the 2 RA are connected together, the elevation RA, including its harness, is rotating around the azimuth actuator. The wires from the heaters, thermistors, potentiometers and stepper motor are routed to form a harness from the back of the elevation stepper motor, along the azimuth axis and joining the azimuth axis harness, to finally deliver an additional 1.5m long harness.

Azimuth movements amplitude are up to 45° + 10°ptp. This movement is composed of beginning of life long strokes (deployments during ground tests, then in-space deployment after up to 6 years ground storage), and then small movements over the lifetime (15 years in-orbit). These small movements are daily continuous for Radio Frequencies (RF) sensing applications.

Due to the length of the missions (>10 years), degradation of the harness flexibility is taken into account in the harness design. Over time, wires in the harness become stiffer, especially where they have been submitted to repeated bending (occurs during motion), or if exposed to direct solar radiation. This transfers the requested motion to other location in the harness, up to the attachment extremities (back of the stepper motor for instance). At this point, repeated motion of the rigid wires could yield the core conductor to a breaking point, or create cracks in the wire insulation (kapton in particular).

Therefore the elevation harness routing has been carefully designed so that no fatigue occurs at its extreme junctions; an effective and compact manner to achieve this is to reinforce the extremities junctions of the harness, and form the wire to a pig tail shape during build. This pig tail is designed to distribute the azimuth rotational angle along the bending radius of the pig tail, ensuring low harness torque load during azimuth movements, and minimum load at the harness junctions extremities.

2.1.7. MLI / Thermal Design

MLI is fitted on the ADPA via bonded studs (therefore maintaining its shape), to allow a minimum gap between the inner layer and the hardware, to maximise the effectiveness of the MLI and minimise the ADPA temperature gradient inside.

MLI is a very light material (measured at 340g/m^2 including grounding wire). Delrin studs bonded on the ADPA to support this MLI are also very light.

2.2. RA Main Elements

The RA is designed around simple, familiar and well understood components (bearings, spur gears, stepper motor, spring motor), therefore ensuring low risks (expected performances / schedule) during the qualification campaign, and yet delivers state of the art performances (cf. Table 3).

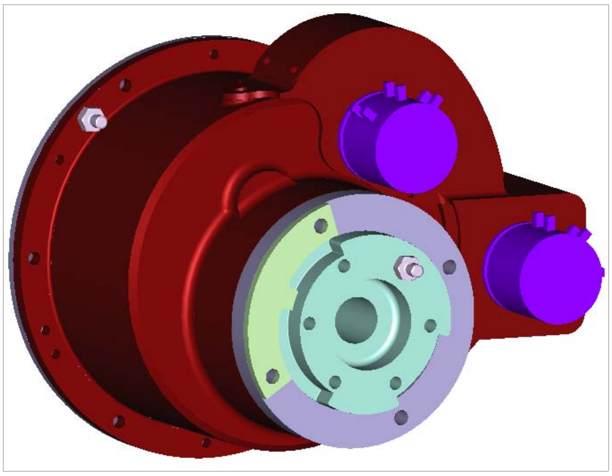

Figure 6: RA CAD Model

The RA consists of a stepper motor+gearbox coupled to an additional gearbox, including an anti-backlash spring motor.

2.2.1. Stepper Motor+Gearbox

Figure 7: RA Stepper Motor Gearbox (SMG)

The Stepper Motor Gearbox (SMG) is used for both the deployment and pointing functions of the RA. The SMG used in the RA is the same than on the E3000 ADTM.

Exposed environment temperature extremes are -50°C to +85°C. Therefore heater mats are required to ensure optimal performances of the stepper motor gearbox (lubrication). Heater mats used on the E3000 ADTM were 440Ω kapton heaters. For the RA, the heater mats (prime + redundant) will be bonded directly onto the curved gearbox profile, using alu-back kapton heaters and tack bond at the heater corners. These heaters are much easier to handle and bond than the RTV bonded heaters currently used on the E3000 ADTM, and are commonly used on spacecraft hardware.

In series with each (prime and redundant) heater line a thermistor is bonded on the flat edge of the stepper motor (therefore 1 prime and 1 redundant thermistors)

2.2.2. Spring Motor

Cf.Figure 8 below.

The springs are attached to the central torque drum with screws and are naturally wound around the storage drums due to their curling treatment. When the torque drum is rotated CCW, the springs follow and wind themselves around the torque drum. This action applies a constant CW torque on the torque drum.

This spring motor was used as the motive source of the E3000 ADTM, and is now used as an anti-backlash device for the ADPA RA gears trains. It will ensure that there is no backlash in the mechanism for an applied torque on the RA output shaft of up to 12Nm load.

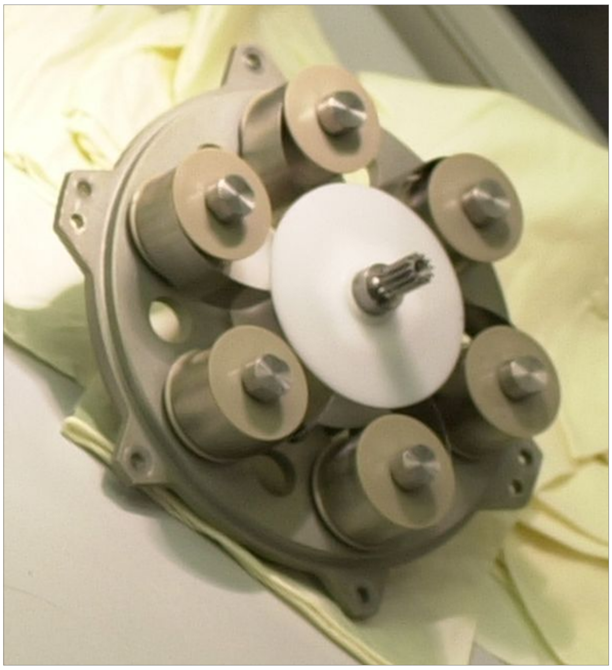

Figure 8: RA Spring Motor

2.2.3. Gear Trains

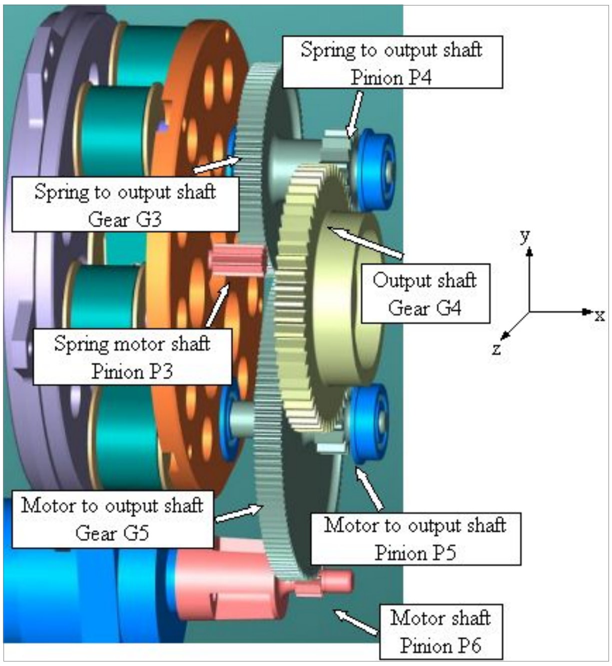

Figure 9: RA Gear Trains

The gear train is decomposed in 2 functions: power transmission from the stepper motor to the output shaft, and anti-backlash using the spring motor load through the output shaft and back to the stepper motor.

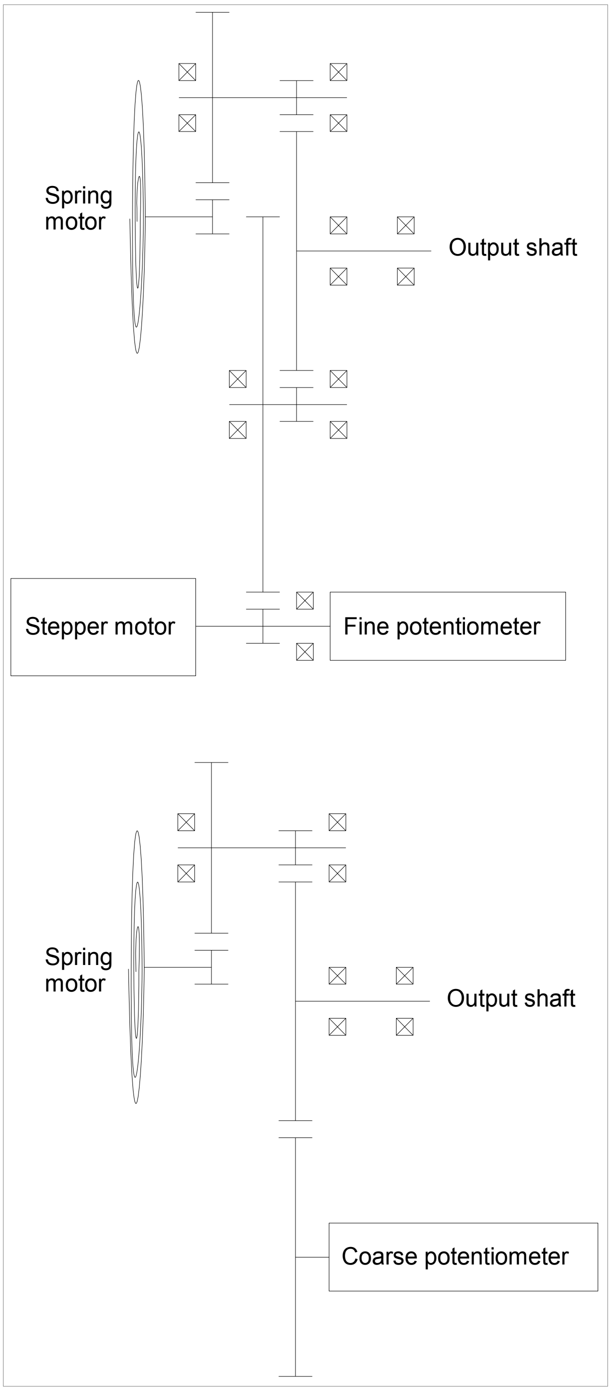

Figure 10: RA Gearbox Diagram

Lubrication used in the E3000 ADTM active trunnion is Braycote 601. This lubricant has been qualified for the trimming activities on the E3000 ADTM (Qualification Model stepper motor gearbox has performed 6,989,184 steps made from 105,810 cycles +/-0.5°). As the design of the gearbox in the RA is essentially similar to that used in the E3000 ADTM active trunnion, Braycote 601 is the baseline. Some further investigations in this area with the European Space Tribology Laboratory (ESTL) expert Emyr Roberts have been initiated and will be pursued during the detail design to rate braycote lubricant against other technologies such as lead plating and/or MoS2 coating for dither movements over an extended 15 years life time.

2.2.4. Output Shaft

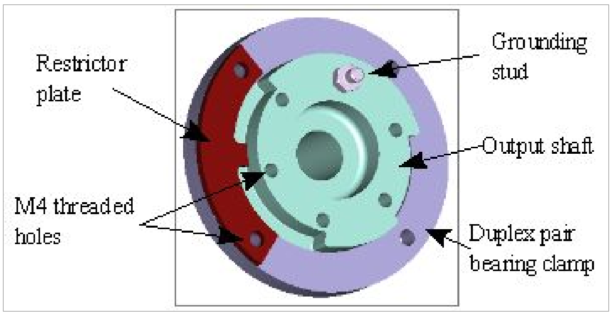

Figure 11: ADPA Antenna Interface

The output shaft interface design has been improved from the E3000 ADTM design by adding 2 separate grooves allowing either 50° TBC movement (azimuth) or 120° TBC (elevation) respectively, and increasing the number of interface M4 tapped holes from 3 to 6. One of these 6 holes is used with a grounding stud. This grounding stud is also used as one of the 6 attachment bolt for the interface on the RA output shaft.

The rotational movement of the RA output shaft is limited to the groove length thanks to a restrictor plate; the 50° TBC groove is used for the azimuth RA and the 120° TBC groove is used for the elevation RA. Design of the restrictor plate will be qualified for 300 shocks at full speed, and continuous drive into mechanical stop.

2.2.5. Potentiometers

The RA uses a fine and a coarse potentiometer, each having a prime and a redundant track. The potentiometer technology is the easiest to implement at system level as a voltage divisor, thus not requiring specific and sensitive signal processing electronics.

The reason for using 2 potentiometers is that the potentiometer technology is not able (for reasonable track resistance and physical dimensions) to directly read the absolute RA output shaft position down to 1 step resolution of 0.0017°. The coarse (RA output shaft) potentiometer is therefore used to distinguish in which rev the RA stepper motor gearbox is, and the fine (stepper motor output shaft) multi turn potentiometer to monitor every step.

2.2.6. Grounding Studs (rotor and stator)

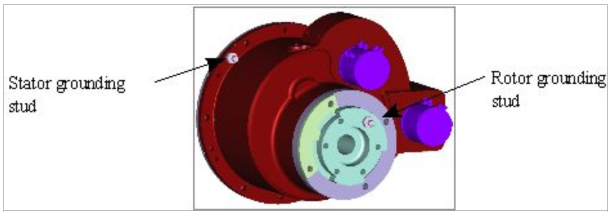

Figure 12: Grounding Studs

The RA is equipped with 2 grounding studs: one on the rotor, and one on the stator. Both surfaces on which the grounding studs are implemented are Al alloy + Alocrom 1200 (equivalent to the US trade name Alodine 1200)

2.3. Redundancies

<u>Stepper motor</u>: The stepper motor has redundant windings with fully independent lead wires. Windings are insulated to 50MΩ.

<u>Heater mats</u>: 2 heater mats per stepper motor are provided (prime + redundant).

<u>Potentiometers</u>: Both coarse and fine potentiometers have a prime + redundant set of track and wipers, both mounted on the same shaft.

<u>Screws</u>: All mating parts that are clamped together using screws are using several screws, which distribute the load between them and is tolerant to screws failure (yield / break)

<u>Note</u>: gears in the gearbox housing are not redounded, therefore can be considered as single points failure. Redundancy of the gears is not practical (weight, size, etc.), but they have been designed using the standard ECSS safety margins and therefore no failure is expected over the life time of the mechanism.

All items are covered by structural analysis with MoS >1

3. QUALIFICATION

3.1. Qualification Philosophy

2 Qualification Model RA will be build, assembled to form the ADPA, and tested to qualification levels TBD.

The qualification campaign will include a life test that will qualify the ADPA for deployments and continuous trimming operations for the lifetime of the spacecraft (15 years in-orbit).

The qualification sequence is summarised in Figure 13 below.

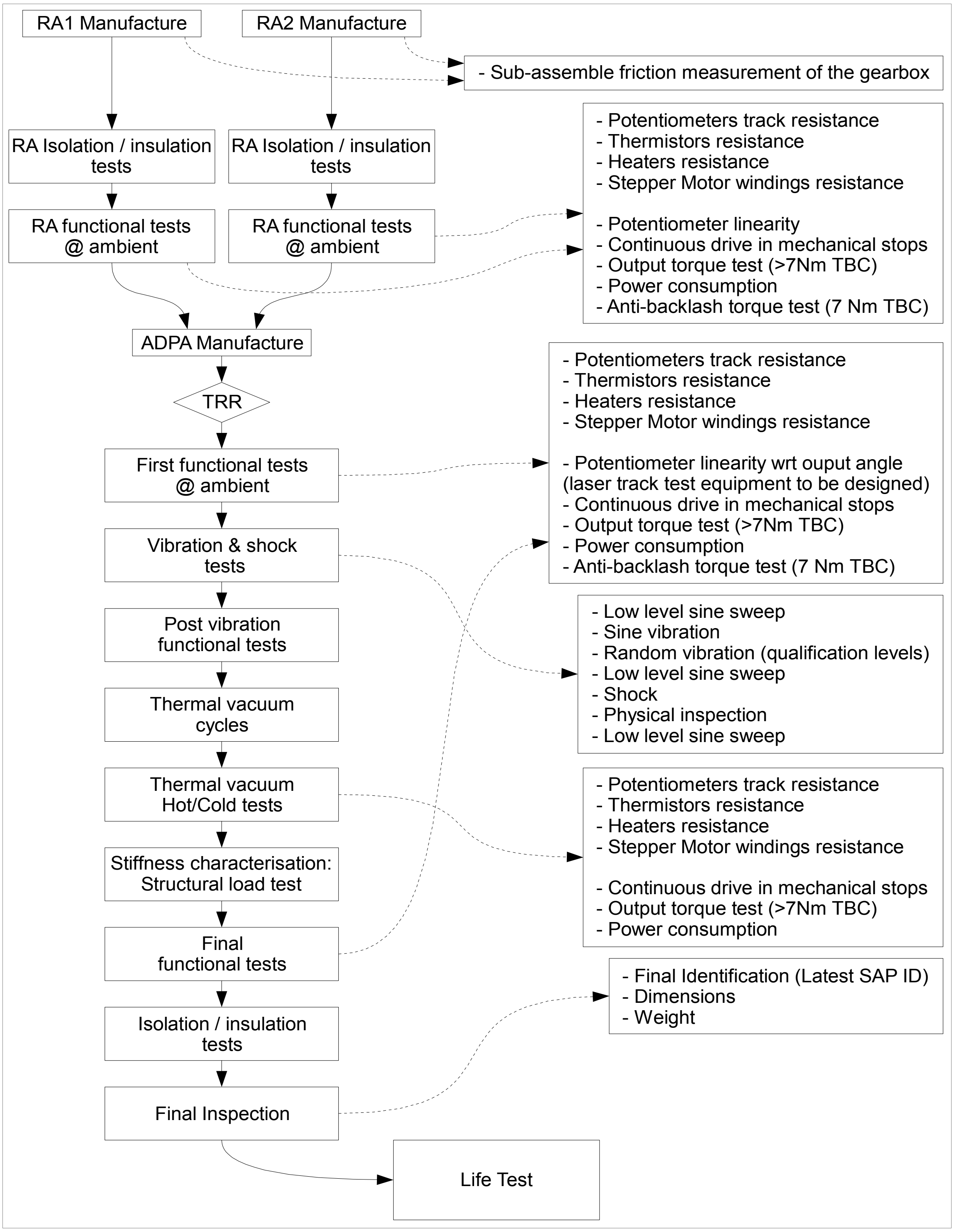

Figure 13: Qualification Philosophy

4. CONCLUSION AND RISK ASSESSMENT

The Rotary Actuators (RAs) are an evolution of the E3000 ADTM active trunnion. Design is emphasised on simplicity and well mastered technologies to ensure minimum risks during the qualification campaign.

The ADPA presented here is a complete assembly incorporating 2 RAs, structural brackets and the thermal hardware. Improvements from the previous model (E3000 ADTM) are:

- Total solution with deployments actuators but also structural brackets, antenna and spacecraft interfaces, thermal hardware + shield.
- 2 deployment axes instead of one
- Extended pointing / trimming capability, so that antenna coverage can be re-pointed to any part of the world.
- Mass saving: one complete ADPA weighs < 6 kg and does not require a complex mounting structure on the spacecraft wall, which represents at spacecraft level for 2 dual deployments (4 antennas) a total saving of 18.4kg compared to solution with our previous E3000 ADTM.

The solution utilises many components from the ADTM programmes (SMG, spring motor, output shaft, some of the gears trains etc), maximising upon the heritage and experience from that equipment offering a low risk solution, yet offering better pointing / trimming performances and allowing RF sensing missions.

The solution has sufficient flexibility to accommodate variations in height (cf. 2.1.1) for the elevation axes as well as offsets (cf. 2.1.3) from the azimuth axis.

The route to qualification will encompass the full range of build permutations negating the need re qualify the assembly for different installation configurations.

The ADPA has been chosen as the next generation antenna deployment and trimming / pointing mechanism for the Eurostar 3000 spacecraft family.