

## ARIANE 5 DUMMY SATELLITES AND STRUCTURES

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### Abstract

The paper summarizes the design and performance of Kayser-Threde's satellite dummies and goes in more detail of the recent realized structures flown in 2002 on ARIANE 5. For the test flights of ARIANE 502 and 503 three different dummy satellites – one with instrumentation and autonomous telemetry system – were delivered by Kayser-Threde. The structures should simulate typical spacecraft physical and dynamic characteristics. The MAQSAT (MAQuette SATellite) spacecraft structure models allowed the tuning of mass properties and fundamental modes by attachment of trim masses at several locations. In addition to that, Kayser-Threde was contracted for six Modular Fitting Dummies (MFD), which are a kind of raising cylinders between launcher and payload adapter, in order to fit launch mass and payload CoG and to attenuate shocks for sensitive payloads. In total KT produced up to now around 11 tons of GTO-hardware for ARIANE 5.

MAQSATB and MAQSATH were used for the first qualified flight of ARIANE 5 basic version in 1997. MAQSATH e.g. consisted of an aluminum structure with a total mass of 2300 kg, an overall diameter of 2.7 m and a height of around 4 m. The design, manufacturing and qualification testing (vibration, static, acoustic tests) of payloads MAQSATB and MAQSATH was completed within eight months.

For ARIANE 503 in 1998 a spacecraft Dummy had to be delivered within 3 months as replacement for a real payload. The mass properties and dynamic characteristics of MAQSAT 3 had to be identical to EUTELSAT W2, which was damaged shortly before launch. The design concept was totally open. Finally the spacecraft model consisted of an aluminum structure (welded flanges, riveted skins and internal platforms) with a total mass of 2600 kg and an overall diameter of 2.0 m with 3.5 m height. The tuning of mass properties and fundamental modes were required within  $\pm 5\%$  to  $\pm 10\%$  accuracy and reached. Also significant damping could be realized.

For ARIANE flight 513 (A5-basic) and ARIANE flight 517 (A5-ECA), Kayser-Threde was contracted for the design, manufacturing and test for six MFD. The modularity of the MFD enables

the Customer ARIANESPACE to adjust the final weight to the specific mass requirement and a certain flexibility of ARIANE to possible payloads with respect to mass, CoG and dynamic behavior and to lower the effort for the launch configuration analyses. Each MFD has a mass of around 650 kg and has an outer diameter of around 2.6 m and a height of 500 or 325 mm. The first set of two MFD 500 could be delivered only 9 weeks after kick-off and have been used for flight 513. For the first flight of ECA-version, the total payload capacity should be proved using the MFD 325. These "mass dummies" complemented the mass of the primary payloads to the total lift-off capacity of the new ARIANE 5. Because of the positive experiences made with the MFD, the MFD shall be used also for future flights due to their modularity.

### The MAQSAT family

For the test flights of Ariane 502 and 503 three different dummy satellites, one with instrumentation and autonomous telemetry system were delivered by Kayser-Threde. The models should simulate the typical spacecraft physical and dynamic characteristics. The missions of all three MAQSATs were successful.

### MAQSAT H and B for Ariane 502

The launch of Ariane 502 with the structure models MAQSATB and MAQSATH took place in 1997 under contract to CNES. MAQSATH consists of an aluminum structure with a total mass of 2300 kg, an overall diameter of 2.7 m (outer hole diameter:  $\varnothing$  2624mm), and a height of around 4 m (without stand-offs). The project comprised also an acoustic simulation panel from CFRP sandwich with  $\varnothing$  2.7 m and stand-off structures for e.g. acoustic sensors.

A complete autonomous instrumentation, developed and delivered also by Kayser Threde, performed during launch mainly shock, vibration, and acoustic measurements and send the data via its own telemetry to ground. The MAQSAT spacecraft structure models allowed the tuning of mass properties and fundamental modes by attachment of trim masses at several locations. The design, manufacturing, and extensive qualification testing of the two payloads MAQSATB and MAQSATH was completed within eight months. For MAQSATH a vibration test, for MAQSATB (1800 kg) a static load test was performed, both at IABG, Munich. After transportation to CSG in French Guyana, MAQSATH was finally assembled and tested.

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Figure 1: Structural verification of MAQSATH



Figure 2: Instrumentation Platform of MAQSATH with power, amplifiers and telemetry



Figure 3: Ariane 502 (left) with dummy payloads MAQSATB (middle) and MAQSATH during integration onto the launcher

Launch	October 1997
Launcher	ARIANE 502
Delivery time	8 months
Diameter (max., without instrumentation)	2630 mm
Height (max. without instrumentation)	3630 mm
Mass	2322 kg
Center of gravity (above interface plane)	1360 mm
Moment of Inertia (x)	2016 kgm <sup>2</sup>
Moment of Inertia (y, z)	4010 kgm <sup>2</sup>
1 <sup>st</sup> longitudinal eigenfrequency (hardmounted)	93 Hz
1 <sup>st</sup> lateral eigenfrequency (hardmounted)	17.5 Hz
Number of Sensors (acceleration, vibration, shock, temperature)	36
Telemetry	Recording - playback
Data transmission	S-band
Power	2 NiCd battery packs
Commanding	Timer

Table 1: Data sheet for MAQSATH

### MAQSAT 3 for ARIANE 503

For ARIANE 503 a new spacecraft structure model had to be delivered within 3 months as replacement for a real payload. Several months before launch, EUTELSAT W2 was lost by an accident. In order to be able to keep the launch date and to avoid repetition of the complete overall coupled load analysis, the idea of MAQSAT 3 was created. Contracted now by ARIANESPACE, the mass properties and dynamic characteristics of MAQSAT 3 had to be identical to EUTELSAT W2. The design concept was totally open.

A simple design has to be found that fulfills all requirements and provides the possibility to accommodate the dynamic characteristics at the end of the qualification testing to meet modified requirements. In order to simplify the design and verification process, MAQSAT 3 has been designed to behave like a single DOF system for lateral and longitudinal frequencies. No significant local modes/eigenfrequencies occurred.

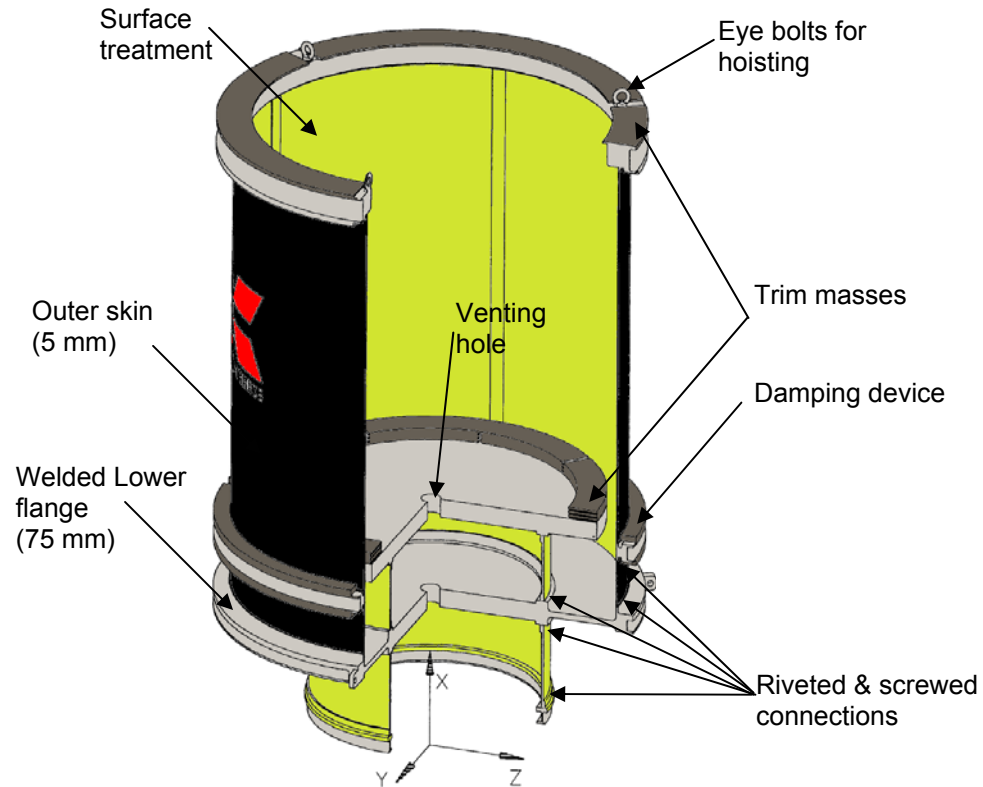


Figure 4: Design of MAQSAT3 for ARIANE 503

The spacecraft model consisted of an aluminum structure (welded flanges, riveted skins and internal platforms) with a total mass of 2600 kg and an overall diameter of 2.0 m with 3.5 m height. The I/F to the launcher was provided by a typical ACU 1194 V clamp band interface. An overview of the MAQSAT 3 design and its components is given in Figure 4.

The outer cylinder is tuned to meet the mass property requirements. It is designed to carry a set of trim masses. The trim mass can be shared between the lower and upper frame such, that the mass properties can be adjusted within the required range. Additional trim masses can be placed on top of the inner cylinder, having no significant impact on both, center of gravity and eigenfrequencies.

Most of the mass is accommodated on the upper frame of the outer cylinder. Correspondingly the upper frame has been designed with a solid section, to provide a high mass and a good stiffness in order to avoid local modes.

The design of MAQSAT 3 was strongly influenced by the accompanying straight forward structural analyses to meet the very tight schedule. Due to the fact, that no significant design iteration were allowed, a sensitivity analysis was performed in the frame of the feasibility analysis in order to reveal any critical areas. The results of the sensitivity analysis were used to design the amount of trim masses required to compensate for deviations, to

define specific design solutions and tuning possibilities as well as to define the necessary spares of critical parts which might have to be replaced in case of major deviations.

The final characteristics of MAQSAT 3 are listed in Table 2. The tuning of mass properties, fundamental modes, and damping were required within  $\pm 5\%$  to  $\pm 10\%$  accuracy, and reached.

The following verification tests has been performed: a modal survey test to determine eigenfrequencies and a dynamic test to demonstrate the quasi-static load capability. For test prediction the impact of the test set-up on the dynamic characteristics has been accounted for implementing a model of the test adapter with a simulation of the clamp band, a model of the base plate and a model of the test facility ground into the overall Finite Element Model. This experience has already been gained from the previous MAQSAT B and H program.

On completion of the test program there was satisfaction on the one hand, because all specified requirements have been achieved, but there was also some disappointments about the achieved damping. Based on experience gained from MAQSAT B and H a damping around 0.5 % was expected, but only 0.1 % in lateral direction and 0.4 % in axial direction was achieved. Taking benefit of the particular structural concept of MAQSAT 3 it was possible to implement a simple passive

damping device. The device, based on an elastomeric layer at the proper location, was implemented within 1 day. At the same time a redistribution of trim masses was performed to slightly reduce the lateral eigenfrequency. The modified configuration was verified by a repeated modal and loading test with a limited program. The efficiency of the damping device was higher than expected having at the end 0.8 % lateral and 2.2 % axial.



Figure 5: MAQSAT 3 during integration to ARIANE 503

After delivery to CSG, integration support to ARIANESPACE during launcher integration was given. Ariane 503 was launched successfully in 1998.

Launch	21.10.1998
Launcher	ARIANE 503
Delivery time	14 weeks
Diameter (max.)	2,290 mm
Height (max.)	3,215 mm
Mass	2,730 kg
Center of gravity (above interface plane)	1,343 mm
Moment of Inertia (x)	1,834 kgm <sup>2</sup>
Moment of Inertia about separation plane (y, z)	7,993 kgm <sup>2</sup>
1 <sup>st</sup> longitudinal eigenfrequency (hardmounted)	48.1 Hz
1 <sup>st</sup> lateral eigenfrequency (hardmounted)	15.4 Hz
Effective mass, longitudinal	46.9 %
Effective inertia, lateral	80.6 %
Longitudinal damping (flight level)	2.1 %
Lateral damping (flight level)	0.9 %

Table 2: Data Sheet for MAQSAT 3

### **Modular Fitting Dummy (MFD)**

For ARIANE flight 513 and the first launch of the new version of ARIANE 5 (flight 517), Kayser-Threde was contracted for the design, manufacturing and test for six modular adapters. These “mass dummies” complemented the mass of the primary payloads to the total lift-off capacity of the new ARIANE 5. The modularity of the Modular Fitting Dummies (MFD) enabled the Customer ARIANESPACE to adjust the final weight to the specific mass requirement and a certain flexibility of ARIANE to possible payloads with respect to mass, CoG and dynamic behavior.

Each MFD has a mass of up to 650 kg and an outer diameter of around 2.6 m and a height of 500 or 325 mm. The design followed the experience of the previous MAQSATs. The raising cylinder out of a rolled metal sheet was riveted to the upper and

lower interface ring having the typical diameter of 2624 mm with 244 interface bolts. To achieve the dedicated requirements given by ARIANESPACE a heavy internal platform at the middle of the MFD height was introduced and riveted to the outer skin. As parameters for trimming the structure to the required performances the dimensions of the internal platform (plate thickness and inner hole diameter) and location and distribution of the trim masses mounted on the internal platform has been used. Due to the tight schedule a minimum test program has been performed to verify the structural characteristics. The test program consisted of a modal survey test and a balancing test. The structural characteristics of the MFD 325 and 500 are listed in Table 3 on next page.

The first set of two MFD 500 could be delivered only 9 weeks after kick-off. A second set was delivered in spring 2002 and a set of two MFD 325 was delivered in summer 2002.

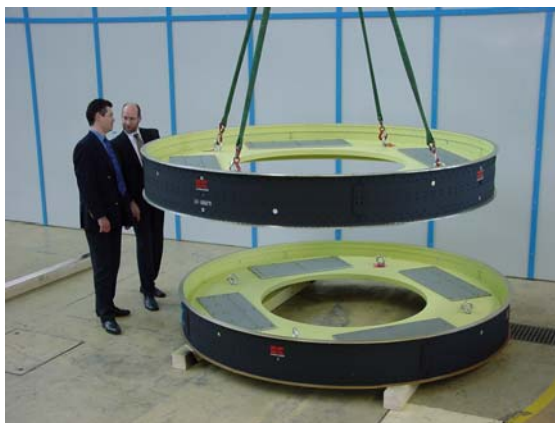


Figure 6: MFD500 (height 500 mm, nominal weight 600 kg) (left) and MFD325 (height 325 mm, nominal weight 575 kg) (right)



Figure 7: Integrated MFD500 for Flight 513 (left) and two integrated MFD325 for Flight 517 (right)

Value	MFD500	MFD325
Minimum Mass	550 kg	530 kg
Capacity of Trim Mass incl. Screws	50 kg, 100 kg, 150 kg	50 kg, 100 kg, 150 kg
Moments of Inertia (Ix) 700 kg configuration (MFD500) / 680 kg (MFD325)	771 kgm <sup>2</sup>	738 kgm <sup>2</sup>
Moments of Inertia (Iy,z) 700 kg configuration (MFD500) / 680 kg (MFD325)	389 kgm <sup>2</sup>	370 kgm <sup>2</sup>
Total Height	500 mm	325 mm
Center of Gravity 700 kg configuration (MFD500) / 680 kg (MFD325)	258 mm	170 mm
Static Unbalance	< 1 mm (at 3 $\sigma$ )	0 mm (calculated)
Dynamic Unbalance	< 0,007° (at 3 $\sigma$ )	0° (calculated)
Dynamic Behavior (2 MFDs + 1000kg):	F <sub>MFD</sub> = 11.79 Hz (lat.)	F <sub>MFD</sub> = 11.87 Hz (lat.)
Dynamic Behavior Internal Platform simply supported: - 1 <sup>st</sup> longit. Mode - 2 <sup>nd</sup> longit. Mode	F <sub>1 lo pl</sub> = 38,3 Hz F <sub>2 lo pl</sub> = 421 Hz	F <sub>1 lo pl</sub> = 38.3 Hz F <sub>2 lo pl</sub> = 421 Hz
Damping (platform mode at flight level)	0,66 %	Similar to MFD500

Table 3: Data Sheet for MFD500 and MFD325

### Summary

Kayser-Threde has developed and manufactured a series of dummy satellites and structures for ARIANE 5 flights. Each structure was realized fulfilling dedicated requirements, in one case including complete instrumentation and telemetry system, in another case simulating a real passenger, which was not available for the launch. The success of all of these projects was based on keeping very stringent and tight schedules, that no launch date has passed due to missing payload. Up to now Kayser-Threde delivered 11,5 t of GTO hardware.