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Space Rider re-entry – ground station adaptations to cope with vehicle trajectory dispersion

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Abstract

In orbit operations and safe return from space to Earth is one of the most challenging topics Europe is facing in the last decade in the space domain. The European independent capability to return from space has been demonstrated through the successful flight of the Intermediate eXperimental Vehicle (IXV) in 2015. The IXV program was focusing on the atmospheric re-entry from LEO, achieved through the implementation of an end-to-end European suborbital mission with a splashdown in the Pacific Ocean. Strengthened by the knowledge acquired with IXV, Europe continues to exploit the next challenges in the space transportation domain with Space Rider. Space Rider will provide Europe with an affordable, autonomous, reusable end-to-end integrated space transportation system, facilitating routine access and return from space. The present paper focuses on the technical implementation solution of a ground station able to cope with the most critical phase of the vehicle mission: re-entry after blackout zone and landing.
Keywords: Ground station, re-entry phase, trajectory dispersion, acquisition aid, antenna tracking

Acronyms/Abbreviations

AAA (Acquisition Aid Antenna)
ACU (Antenna Control Unit)
AOM (AVUM Orbital Module)
AOS (Acquisition of Signal)
ARD (Atmospheric Re-Entry Demonstrator)
ARIA (Advanced Range Instrumentation Aircraft)
AZ (Azimuth)
CSG (Centre Spatiale Guyanais)
EIP (Entry Interface Point)
EL (Elevation)
ESA (European Space Agency)
ESTRACK (ESA's tracking station network)
GNC (Guidance Navigation Control)
IOD/IOV (In-Orbit Demonstration and Validation)
IXV (Intermediate eXperimental Vehicle)
LEO (Low-Earth Orbit)
LEOP (Launch and Early Orbit Phase)
LHCP (Left Hand Circular Polarization)
LNA (Low Noise Amplifier)
NASA (National Aeronautics and Space Administration)
PVC (Polyvinyl Chloride)
RHCP (Right Hand Circular Polarization)
SR-RM (Space Rider – Re-entry Module)
TC (Telecommand)
TDRS (Tracking and Data Relay Satellite)
TM (Telemetry)
TT&C (Telemetry, Tracking, and Command)
XAA (X-band Acquisition Aid)
XEL (Cross-Elevation)

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1. Introduction

A ground station able to track vehicles re-entering from space has to deal with specific constraints, mainly related to the uncertainties of the information of the position of the target, both in space and time.
It is worth to mention that ESA has prior experience with re-entry vehicles.

The first ESA Atmospheric Re-Entry Demonstrator (ARD) was launched in 1998 and achieved a controlled sub-orbital flight, from launcher separation through atmospheric re-entry to splashdown.

Anyhow, in this case the tracking during the re-entry phase was not under ESA responsibility: the transmitting radio signals were sent to a NASA TDRS satellite and to one of the two Advanced Range Instrumentation Aircraft (ARIA) waiting in the re-entry zone. The ARIAs are special KC-135 aircraft equipped for receiving telemetry data from re-entry vehicles.

The Intermediate eXperimental Vehicle (IXV), launched in 2015, was consolidating the knowledge necessary for the development of any future European re-entry system. The vehicle was splashing down into the water after a flight of 100 min, in this case tracked by a dedicated ESA antenna installed on a boat waiting for it in the Pacific Ocean.

Despite the successful results of both missions, finding and recovering a relatively small object floating in the sea is an extremely difficult and risky undertaking. For the recovery itself, the main problem is that, if the landing on the water takes place far from the coast, helicopters cannot reach the landing zone and fixed-winged aircraft cannot land on the water. It is therefore mandatory to pre-position one or more ships in the target area. Additional ships are required in order to allow for an accidental landing outside of the nominal area. In the case of a manned vehicle, it is important to reach the landing point rapidly. Moreover, securing the vehicle in the water and lifting it aboard a recovery ship under all possible weather conditions is an additional challenge[2].

Space Rider will take a significant step forward by landing on the ground, eliminating the need for aircraft or naval antennas. Instead, it will rely on precise remote manned landing. In this context, the ground station and control from the ground are extremely critical. The terrestrial station must address the challenges of trajectory dispersion of the spacecraft and operate in an electromagnetically noisy and populated environment, whether it is landscapes or nearby cities. The horizon profile determined by the landscape also plays a crucial role. The goal is to face these challenges validating a ground station concept to be re-used for any future vehicle re-entering from space at the given frequency band. The proposed solution is the output of a trade-off study in terms of performances, cost, efficiency and implementation time. The idea comes from the analysis of the main ground station mission requirements characterizing the Space Rider re-entry phase, which are basically related to trajectory dispersion on one side and the signal level on the other. Unfortunately, the laws of physics present us with a compromise: as the beamwidth of an antenna increases, its gain decreases, and vice versa. An antenna with a large beamwidth, provides the necessary field of view to locate a target with an uncertain position, but the signal level may not be sufficient to retrieve data. Conversely, a larger antenna dish, with its smaller beamwidth, will not be able to easily find the target, but once correctly pointed, it will have a signal level sufficient to retrieve the telemetry data. With that in mind the attention was then turned to the landing site.

The initial Space Rider maiden flight selected landing site was located in Kourou, French Guyana, at the European Spaceport, where ESA owns the Diane ground station, equipped with a 15-m Cassegrain antenna. Further project development are now indicating Santa Maria, Azores island, as possible final Space Rider landing site. The Teleport of Santa Maria, Portugal, is equipped with several antennas, among which, a relocated former ESTRACK 15-m antenna previously operational in Perth. What do the Kourou and Santa Maria sites have in common? An existing infrastructure and an ESTRACK 15-m antenna. The primary goal is to evaluate the capabilities of these 15-meter antennas and determine the necessary modifications to meet all mission requirements.The assessment of all inputs resulted in the development of a so called acquisition aid antenna specifically designed to that purpose and being at the same time adaptable with different existing 15-m ESTRACK stations. Its implementation in the frame of Space Rider project will consolidate and strengthen the ESA know-how in supporting all future missions dealing with the critical phase of vehicles re-entering from space.

The first section of this paper will indeed provide an overview of the Space Rider project, with a special focus on the most critical phase from a ground station perspective, which is the re-entry through the atmosphere after the blackout.

A brief description of the already existing 15-m ESTRACK antennas will follow, explaining their limits to track re-entry vehicles but also the advantages to be reused for that purpose.

The third section is dedicated to the description of the developed acquisition aid antenna highlighting its most innovative aspects, as well as all challenges to be faced considering the installation environment and integration aspects.

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Finally, the outcomes of the design interfacing the ESTRACK 15-m with the acquistion aid antenna will prove of the validity of the proposed implementation solution for a successful Space Rider – Re-entry Module (SR-RM) acquisition strategy.

2. The Space Rider mission

Space Rider project aims at developing an affordable, autonomous, reusable end-to-end integrated space transportation system for routine access to and return from low earth orbit. Space Rider seeks at serving multiple un-crewed, profitable and institutional applications (microgravity, IOV/IOD, Earth observation, science, robotic exploration, etc.) and aims at performing in-orbit payloads operations, de-orbit, re-enter, land on ground and be relaunched after limited refurbishment.

With respect to the IXV project, the complexity of the mission increases significantly due to the introduction of new flight phases (orbital, deorbiting, and landing) and modified ones (launch, descent).

The orbital mission phase is one of the most innovative, defining the "use cases" of the Space Rider vehicle and the overall scope of the program. Among the modified ones, the descent phase introduces new elements (e.g. parafoil) to achieve the required landing accuracy. Because of that, differences on the ground segment are also present.

Fig. 1 gives an overview of all main events and phases: ascent, orbital and return.

The main objective of the ascent and return phases is providing routinely access and return from orbit while the main objective of the orbital mission phase is the capability to perform applications in Low Earth Orbit, targeting in-orbit experimentation and demonstration.

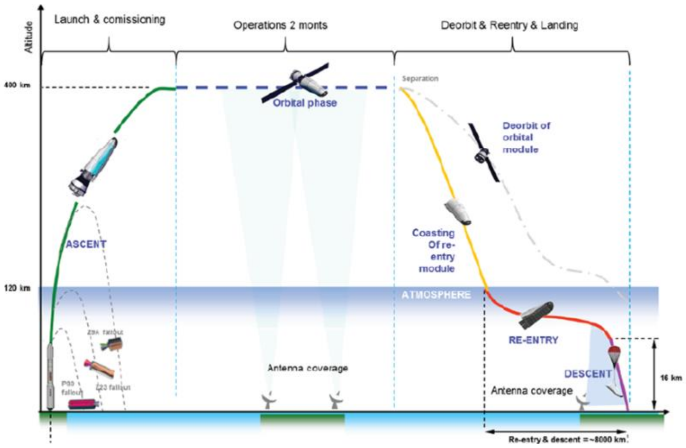

Fig. 1. Space Rider mission overview, main Events and Phases

The ground station adaptations, focus of this paper, are specifically designed to deal with the last part of the return phase following the black-out zone. The scope of the de-orbit boost is to separate the orbital module (AOM) from the Re-entry module (RM) and put the Re-entry Module in a safe re-entry trajectory. Therefore, it has to target certain parameters, such as altitude, velocity, latitude, longitude, heading and flight path angle, that allow the RM to manoeuvre from orbit to the selected landing site. The complete set of these parameters, which comes from the re-entry trajectory design, defines the entry gate. By definition, if the RM crosses the entry gate with the correct conditions, a safe re-entry, descent and landing can be performed.

Space Rider shall perform a high precision soft ground landing, with 150-m accuracy. With respect to IXV, that performed a water landing, reusability implies landing on ground in order to recover the Space Rider in the best possible conditions (e.g. avoiding salt water contaminations) for the post-landing operations and the preparation of a subsequent flight, minimizing the complexity of the post-flight operations. High accuracy landing also implies the definition of a Descent and Landing subsystem and the Guidance Navigation Control (GNC) with better landing accuracy performance than the passive parachutes sequence implemented in IXV. The system will allow a controlled re-entry by means of a parafoil ending with a very precise and safe landing, ensuring experiments return from the orbit back to the Earth.

With respect to the IXV, the design of the return mission requires to design a robust solution that would allow performing a safe deorbit manoeuvre, separate and re-enter to reach the desired landing site taking into account the uncertainties associated to the vehicle's mass, deorbit maneuver and the flight environment – the atmosphere, wind. For example, the deorbit strategy needs to consider possible NO-GO situations (e.g. due to weather conditions at the landing site) that would require the possibility of counting on multiple de-orbit opportunities.

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Deorbiting gates have been defined for all the main reference return scenarios, associated to the cross-range interval compatible with the performance IXV-based re-entry guidance, maximizing the heritage and the reliability of the solution. Wider gates are available for all cases that would allow more de-orbit opportunities, but would also very likely demand a significative consolidation of the entry guidance and navigation control solution with respect to the IXV one.

The re-entry into the atmosphere starts at the Entry Interface Point (EIP), when the atmospheric layer is dense enough so that the aerodynamic forces acting on the vehicle become non negligible. The standard interface between the orbital and atmospheric phases of the re-entry is set at an altitude of 120 km.

It has been noticed there is a strong dependency of the ground track on the EIP location within the deorbit gate (Fig. 2), which requires to be considered for the acquisition of signal (AOS).

AOS mean azimuth will be a function of the deorbit gate position, and it is known *a priori* before the deorbiting. What really matters to assess the deorbit and re-entry scenario compatibility are the dispersions at the EIP.

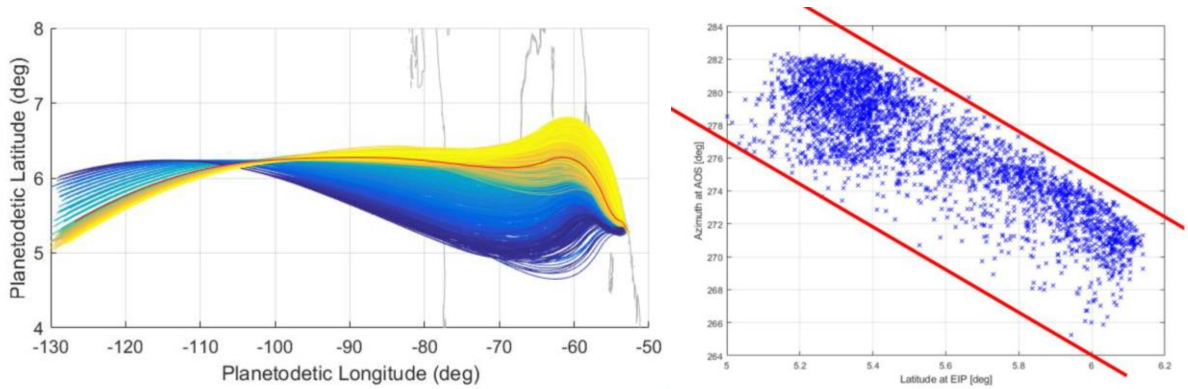

Fig. 2. Correlation between the EIP location and the ground track for the Monte Carlo trajectories (Left), Correlation between EIP location (latitude) and the azimuth at AOS as seen from the ground station (Right) (Courtesy of TASI)

From a ground station point of view these information are reflected into the AZ and EL dispersions over time. Fig. 3 is an example of the Montecarlo simulation run for the Kourou landing site.

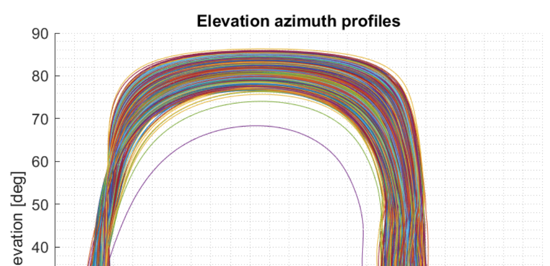

Fig. 3. Montecarlo simulation of dispersed trajectories, AOS is on the left side, landing on the right side (Courtesy of TASI)

The trend over time is better explained in Fig. 4, where the black dots represent all the possible vehicle position in AZ and EL, at a given instant of time. The corresponding power flux density of the received signal is given in Fig. 5, showing how the most critical phase remain the acquisition of signal when the vehicle is appearing at the horizon, where, in addition to the uncertainty due to the dispersion, the antenna has to cope with a power flux of signal at its minimum.

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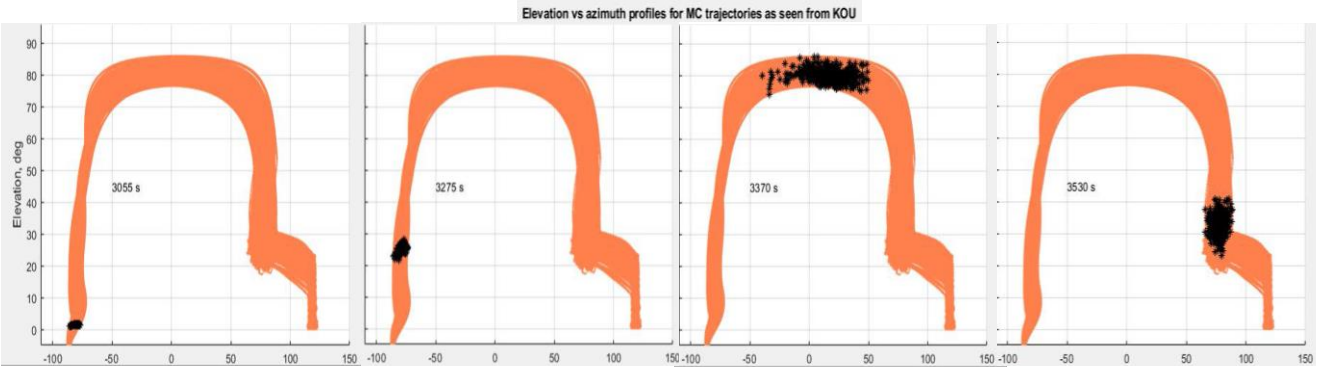

Fig. 4. Trajectories dispersion over time (Courtesy of TASI)

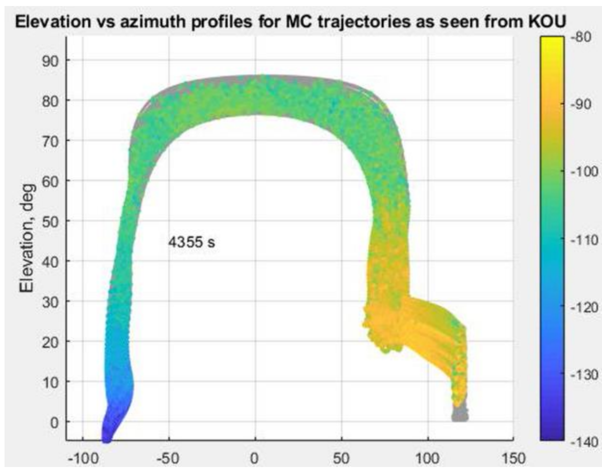

Fig. 5. Power flux density of dispersed trajectories in dBW/m2 (Courtesy of TASI)

3. The ESTRACK 15m antennas

ESTRACK is the ESA's tracking station network, a global system of ground stations providing links between satellites in orbit and ESOC, the European Space Operations Centre, Darmstadt, Germany. The core ESTRACK network comprises seven stations – some with multiple antennas – in seven countries: three 35-m-antennas and four smaller dishes between 4.5 and 15 meters antenna diameters. The common task of all ESA ground-based tracking stations is to communicate with spacecraft – to transmit commands and receive scientific data and spacecraft status information.

The 15-m antennas, part of ESTRACK, provide routine support for satellites in low-Earth orbits (LEO) during their routine phases, and specialised support during the Launch and Early Orbit Phase (LEOP).

In particular, the station of Kourou is located 27 km from the town of Kourou and 90 km from Cayenne, the capital of French Guiana, in South America. The station site is 19 km from the Centre Spatiale Guyanais (CSG), Europe's Spaceport. It hosts a 15-m dish antenna that transmits and receives signals in S- and X-bands, plus facilities for tracking, telemetry, telecommand and radiometric measurements. There is also a 1.3-m dish mounted on the side of the 15-m dish (Fig. 6) as an X-band acquisition aid (XAA). The acquisition aid was designed to provide a wider X-Band beam than the large 15-m dish during the first critical acquisition phase after orbit injection of satellites. Unfortunately, it cannot be reused for Space Rider because of its frequency range, not compatible with the S-band antennas on board the re-entry vehicle. Anyhow it provides the basic approach followed for the design of the new S-band acquisition aid antenna, as it will be further shown in the next section.

The Santa Maria 5.5m antenna station, also known as 'Montes das Flores' (Hill of Flowers), is located 5 km from the town of Vila do Porto on the Portuguese island of Santa Maria, in the Azores some 1500 km from Lisbon. Santa Maria is one of the first ESTRACK stations with launcher tracking capability. It is used to receive real-time telemetry from

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launches originating from ESA's spaceport in Kourou, in S-band and provides as well an X-band capability to receive scientific data from Earth observation satellites.

Since few years the Santa Maria teleport is also hosting a former 15-m ESTRACK ground station, now belonging to the Portuguese Space Agency. This high-performance TT&C (Telemetry, Tracking and Command) antenna is intended for control and command of satellites and space missions in the S-band and X-band.

Both 15-m antennas of Kourou and Santa Maria, have in principle all the characteristics to fulfil the requirements to receive the vehicle telemetry with enough margin on signal to noise ratio, even during the most critical phase of the mission, when the vehicle is low at the horizon and the signal power flux is at his minimum. Unfortunately, due to the diameter dimensions, the corresponding antenna radiation pattern is not able to cover the AZ and EL dispersion presented in the previous section. It definitely needs to be "aided" by a smaller antenna with a larger beamwidth which, once found the target, can provide the pointing information to which the 15-m can be finally locked too.

Fig. 6. ESTRACK-15m antenna at Kourou, French Guyana

Fig. 7. Former ESTRACK-15m antenna in Santa Maria, Azores

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3. S-Band Acquisition Aid (SAA)

In order to better understand the design of the SAA a brief summary of the overall driver requirements is given hereafter.

3.1 Driver requirements

The general goal is to provide the 15-m station with a wider acquisition Beamwidth (Az and EL) in S-band, when the Space Rider -Re-Entry Module (SR-RM) becomes visible at the horizon and ensure Telemetry (TM), Telecommand (TC) and Tracking capability during the descent phase in both polarisations.
The TM acquisition shall go ahead till the end of the mission, after landing, when the ground station shall be also able to send the switch-off command to the re-entry module.
The telemetry reception shall occur in polarization diversity, so the antenna shall be able to simultaneously receive signals at the same frequency but at different polarization (right circular polarized - RHCP and left circular polarized – LHCP), while in transmission the polarization shall be selectable (RHCP or LHCP) .
The antenna performance shall be such that it can support all mission scenarios described in section 2, including all dispersed trajectories and worst case in term of slant range, on board antennas orientation and horizon profile.
This has been calculated to be satisfied with a G/T greater than 2.0 dB/K at 0°EL and an acquisition range, intended as the angular area centred on the Antenna Boresight axis where the spacecraft can be acquired, greater than ±5°. This range guarantees the successful acquisition during the most critical phase: AOS after blackout zone. The red circle in Fig. 8 shows the 10x10 degrees coverage in AZ and EL. At the moment the vehicle appears at the horizon, all the black spots, i.e. all possible vehicle positions, are falling inside it. Once the signal has been acquired, the antenna autotrack system will keep the lock on the target. Later, if for any reason the lock is lost, there will be a point at which the dispersion is too high to stay inside the acquisition window of ±5°. Anyhow, thanks to the trajectory information gained with the initial acquisition, the overall dispersion is now significantly reduced, without need of a larger acquisition range. Furthermore, enlarging the acquisition range translates in a decrease of the antenna gain, and consequently reduces the capability to retrieve a low signal. Taking into account the criticality of the AOS phase, and the expected power flux density at horizon (Fig. 5), the ±5° was finally target as the best compromise.

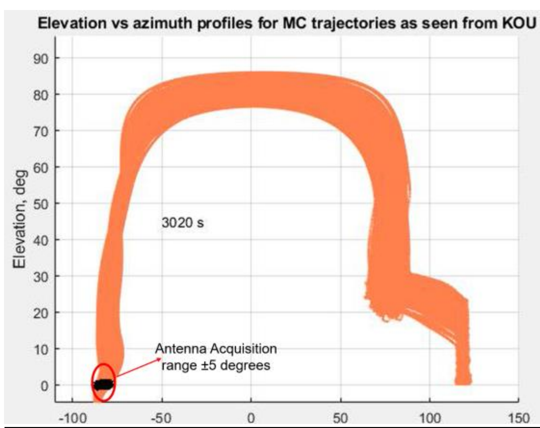

Fig. 8. Acquisition range and vehicle dispersions

Regarding the autotrack system, a Monopulse Tracking is required to maintain the necessary robustness and pointing accuracy due to the expected signal level and its fluctuations (autotrack error (3σ) shall be lower than ±0.3°under worst case wind condition). Within the 3σ tracking error a cross polarisation better than 25 dB guarantees the needed polarization discrimination.
Moreover, once the SAA has been characterized, it is essential to confirm that it possesses the required functionality to pass the pointing information to the main 15-m dish. Additionally, it shall be done within a certain required time and, considering the physical mounting on top of the main reflector, with a specific mechanical alignment.
The required time to achieve handover to the main antenna and achieve stable lock being the target within the acquisition aid tracking range shall be less than 5 s (including main antenna move to target).
The SAA antenna RF Tracking null has been calculated to be mechanically aligned to the 15-meter S-Band Tracking null with an accuracy ≤ 0.03° in far field.
In this way the existing Antenna Control Unit (ACU) can drive the 15-m antenna based on the input coming from the SAA RF system tracking system. The switchover between the antennas is managed by the ACU to enable the best

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acquisition strategy during the different operational phases of the mission: exit from blackout zone, descent, parachute and parafoil opening, landing, switch-off. The SAA shall be able to ensure the first acquisition, slave the 15-m for telemetry reception, secure tracking and re-acquisition in case of loss of signal, send the switch-off command to end the mission.

3.2 SAA Antenna Design

The basic idea of the antenna design comes from the already existing X-band acquisition aid of Kourou 15-m antenna. It gives a valuable example of the basic concept to be further developed for the S-band Acquisition Aid Antenna. The idea is straightforward: just as the purpose of XAA is to provide a wider X-band beam than the large 15m dish during the first critical acquisition phase after orbit injection of satellites, so the SAA has to provide a wider beam in S-band during the critical acquisition phase after re-entry vehicles exit the blackout zone. A very similar goal, at different frequencies and in different direction to/from space.

Similar to the XAA, the SSA shall consist of a box and small reflector mounted on the side of the main 15-m dish.

The box, shown in Fig. 9, houses the outdoor front-end equipment, which includes filters, diplexers, and low-noise amplifiers (LNAs) for both the telemetry and tracking chains.

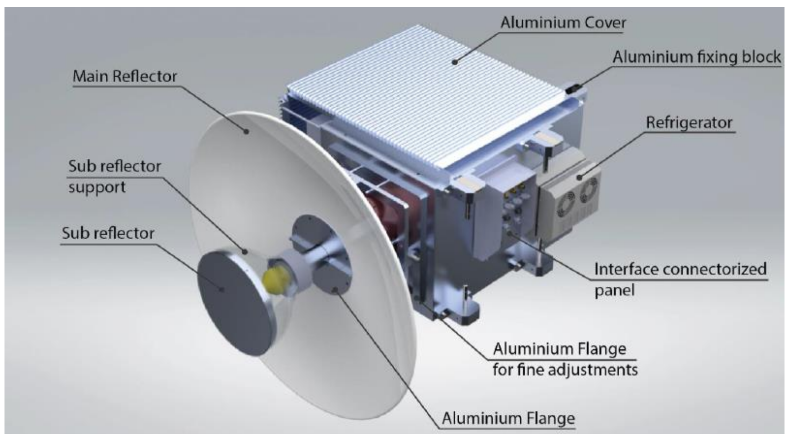

Fig. 9. SAA Antenna configuration

The S-band reflector antenna design is based on a dual reflector optics of ring focus type illuminated by a dielectric-based feed radiator. The characteristics of the reflector surface profiles, in combination with the radiator, allow to achieve a high efficiency antenna maintaining an increased acquisition range.

The feed radiator is based on a specially shaped dielectric core, with rexolite as dielectric material, which guarantees a stable relative permittivity, that is 2.53, over frequency as well as a reduced loss. Such dielectric material represents a good dielectric solution in terms of electrical and mechanical characteristics stability as well as workability. The relative permittivity and the shaping of the reflectors' surfaces allowed to make possible the design of a compact feed system which efficiently illuminates the antenna from the secondary focus.

The shape of the dielectric core for the feed radiator is specially designed to achieve high illumination efficiency of the reflectors' surfaces as well as good cross-polarization performances.

The active surface diameter of the main reflector is 1.15 m. The use of ring focus optics (Fig. 10) provides beneficial effects in terms of blockages compared to the feed placed in front of the reflector in the prime focus optics, including the added value to have no cables running over the struts. Moreover, to completely avoid the use of the struts themself the sub reflector has been anchored to the feed by using of a low loss dielectric cone (a sort of radome indicated as sub-reflector support in Fig. 9). This will give as well the flexibility in the placement of the feed components since the feed extends from the secondary focus of the antenna towards the antenna box.

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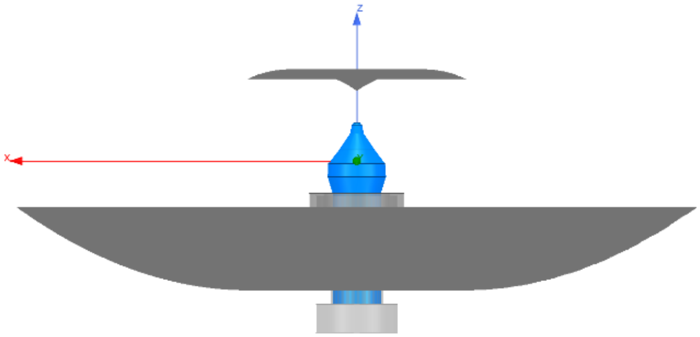

Fig. 10. SAA Ring Focus Reflector Antenna

In Fig. 11 the design of the dielectric Radome, in Teflon material, is shown added as a support for the sub-reflector and as a protection for the antenna radiator. The main reflector, in combination with its sub-reflector and feed system, is optically designed to yield high efficiency (better than 70%).

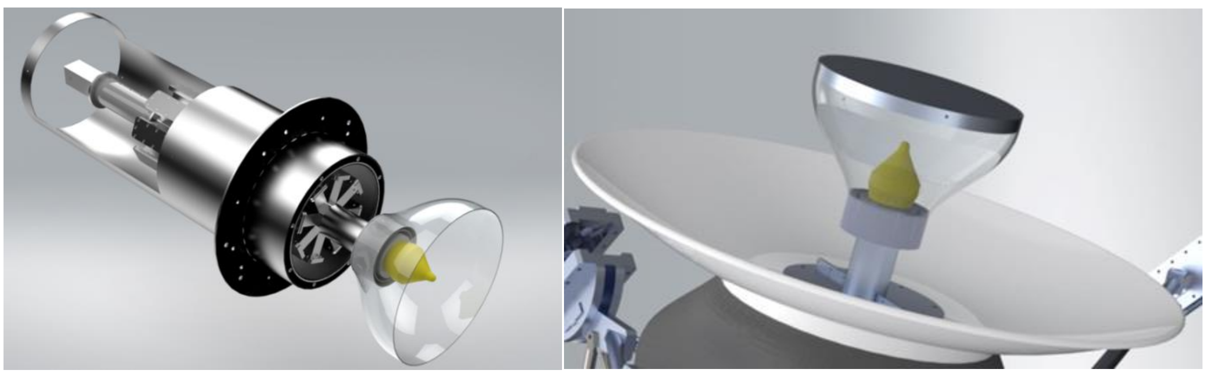

Fig. 11. SAA Feed Horn (left) and Teflon protection system (right)

This antenna design is fully in line with the G/T requirements. The active surface diameter of 1.15m, at 2200 MHz is indeed providing a calculated maximum gain of 27.02 dBi, with an efficiency of 71.73%.

$$G = \xi \left(\frac{\pi D}{\lambda}\right)^2 \qquad (1)$$

The achieved G/T is then calculated knowing the selected LNAs noise figure and feed losses (Table 1. and Table 2.) and the estimation of the antenna noise temperature T_{ant}.

The estimation of T_{ant} is done considering that the noise captured by the antenna consists of noise from the sky and noise due to radiation from the earth [1].The antenna noise temperature is thus given by:

$$T_{ant} = T_{sky} + T_{ground} \qquad (2)$$

T_{sky} is the sky noise contribution in the direction of the antenna boresight determined by the cosmic background noise T_{cosm} plus the effect of the atmosphere contributing with its own atmospheric temperature T_{atm}.

The atmosphere is modelled as a passive device, behaving as an attenuator with a loss L due to atmospheric absorption and a temperature T_m which is the mean thermodynamic temperature of the meteorological formations.

$$T_{atm} = T_m \left(1 - \frac{1}{L}\right) \qquad (3)$$

$$T_{sky} = \frac{T_{cosm}}{L} + T_{atm} \qquad (4)$$

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T_{ground} is the effective noise temperature from the ground (~ 290K, worst case [1]) captured by the side lobes of the antenna radiation pattern and partly by the main lobe when the Elevation angle is small.

The overall estimation of T_{ant} is then done considering that T_{sky} and T_{ant} are respectively weighted by the average gain of the antenna, computed respectively within the solid angle subtended by the sky or by the ground.

$$T_{ant} = \frac{\Omega_{sky}\overline{G_{sky}}}{4\pi}(T_{cosm} + T_{atm}) + \frac{\Omega_{ground}\overline{G_{ground}}}{4\pi}\mathrm{T}_g \quad (5)$$

Table 1. and Table 2. summarize the G/T estimation made at 5° and 0°EL, showing the fulfilment of the minimum required G/T, including an additional 5% margin on the antenna efficiency.
It is worth to mention that the estimation of the antenna temperature at 0°EL is not straightforward. It has to include the information of the approximated brightness temperature of the ground [1] and the antenna gain pattern [5].

Table 1. G/T evaluation at 5°EL and 2.2GHz

	Value	Unit
Antenna Diameter	1.15	m
Antenna Efficiency	66.63*	%
Gain	26.7	dBi
Tant	70	K
Feed losses	0.7	dB
LNA Noise Figure	0.63	dB
Tsys	22.52	dBK
G/T	4.18	dB/K

* 71% reduced by 5% margin

Table 2. G/T evaluation at 0°EL and 2.2GHz

	Value	Unit
Antenna Diameter	1.15	m
Antenna Efficiency	66.63*	%
Gain	26.7	dBi
Tant	111	K
Feed losses	0.7	dB
LNA Noise Figure	0.63	dB
Tsys	23.41	dBK
G/T	3.28	dB/K

* 71% reduced by 5% margin

With the G/T satisfying the requirements we can then proceed with the verification of the acquisition range. As mentioned in the previous section, the acquisition range is intended as the angular area centred on the antenna boresight axis where the vehicle signal can be acquired. For signal acquisition it is intended the capability of the ground station to blindly (no information on the trajectory) lock onto the incoming signal and move the antenna towards the target.

The implemented Monopulse Tracking system is based on a 8 branches tracking coupler extracting the TE21 modes to generate the delta channel. The obtained tracking slope in Fig. 12 is showing a clear linear working region between ±4 degrees, matching with the expected approximation of the tracking range with the half power beamwidth (HPBW). Whenever the target is falling in this region the modulo and angular offset information given by the tracking receiver will reflect the actual boresight displacement error.

Conversely, the acquisition range, usually estimated as:

$$acquisition\ range \simeq 1.5 \times HPBW \quad (6)$$

is an angular range for which, even if the tracking receiver is not able to generate the exact error information, it is still able to provide the correct direction of the antenna movement to get closer to the maximum incoming signal, therefore eventually enabling the lock.

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Fig. 13 shows that the acquisition range is close to ±6°, therefore complying to the requirement for SR-RM (≥±5°). This proves that the selected antenna diameter of 1.15m is a good compromise between the G/T figure and the acquisition range, two design choices that inevitably move in opposite directions.

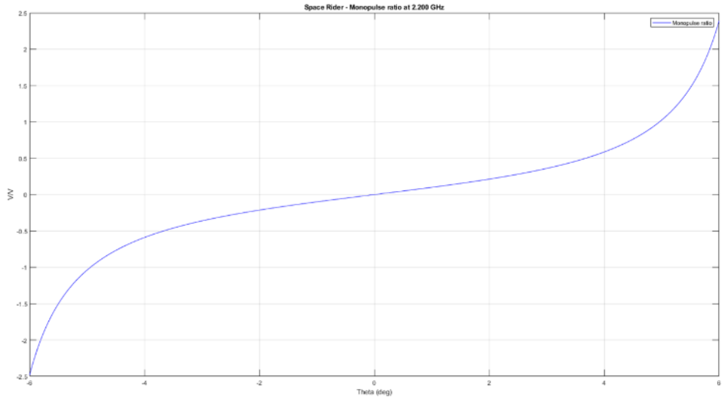

Fig. 12 Tracking Slope at 2200 MHz

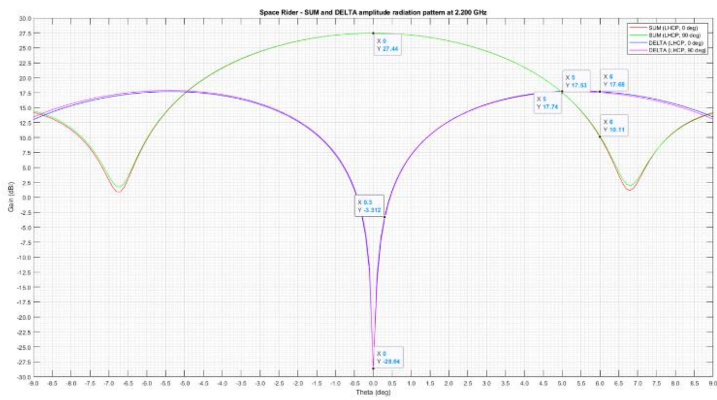

Fig. 13 SUM and DELTA patterns

The Space Rider Re-entry Module has the added challenge to suffer from trajectory dispersion, which affects the signal level depending on the "selected trajectory". A worst case and best case scenarios have been considered, in terms of power flux density at Kourou ground station site, as result of selected trajectory slant range and vehicle orientation. The capability to lock and stay locked to that signal will then depends on the minimum supported Carrier to Noise density at tracking receiver input. This has been calculated for the worst case in terms of minimum flux/slant range and leads to the need of a so called LNA switching matrix, i.e. a selectable path including (or not) an additional amplification for very low signal levels.

Such an antenna will then guarantee the fulfilment of the requirements needed to cope with the trajectory dispersions described in section 2. At this point is anyway worth to remember that a well characterized SAA antenna itself is not enough to cover all mission goals. Once the target is within the SAA tracking range, the final aim is to achieve the handover to the main antenna in less than 5 s (including main antenna move to target), to allow the telemetry reception with the correct signal level.

Considering the acquisition at the edge of the possible range (6°) and that the antenna max speed is 5°/sec, the maximum time required to move to the target is 1.2 sec. In reality the tracking loop will slow down the antenna as far as it gets close to the target. Therefore the overall time can be estimated to be around 1.7 sec. Prior to that, 1 sec for the tracking receiver acquisition time for the selected PLL bandwidth shall be accounted. Additionally, some overshoot (estimate 0.5 sec) on the move to the target will determine an additional delay for a stable lock onto the signal. All in all the SAA will achieve the target in ca. 3.2sec.

At this point the main Antenna Control Unit (ACU) simultaneously receives the tracking error voltages (carrying the information about the antenna mis-pointing to the target) from the 15-m and the SAA tracking receivers

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respectively. Now the switch-over from one system to the other is allowed. The remaining acquisition time shall take into account the maximum alignment error between SAA and main antenna of 0.03°, which is negligible compared to the 15-m HPBW (±0.3°). The overall added time is then only the one of the main antenna tracking receiver, again around 1 sec. This leads to an overall acquisition time of 4.2 sec.

Taking all the above into account, the final acquisition strategy will be formulated based on the various mission phases. The initial AOS phase will be covered by the SAA antenna. The task to retrieve the telemetry data will be then passed to the 15m depending on the link budget constraints. The SAA will support tracking and re-acquisition whenever needed and especially during the parachute and parafoil phase. The end of the mission is marked by the switch-off command, to be sent by the SAA at 0°EL.

3.3 Implementation aspects

Proved that the behaviour of the SAA together with the 15-m antenna is achieving the required RF performances, this section wants to provide an overall overview of some of the implementation aspects which have been considered during the design phase, to demonstrate the feasibility of a 15-m antenna adaptation also from this point of view.

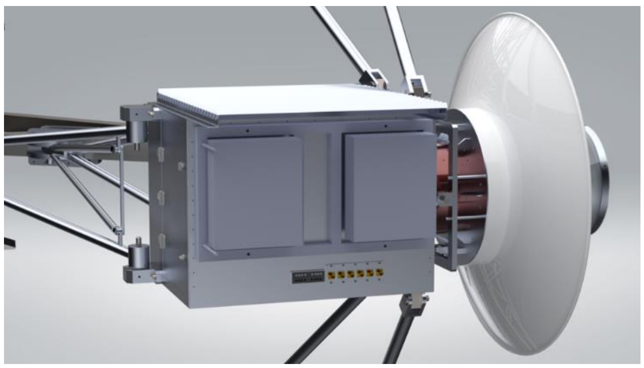

Fig. 14. SAA box with the two outdoor power amplifiers

The proposed solution is a metallic house which allow to host the S-band Feed, coaxial diplexers, coaxial filters, coaxial switches for RX chain, S-band LNAs, S-band Power Amplifiers and the thermo-cooler.

In order to cope with different environmental conditions all the internal walls of the SAA box are coated with isothermal panel Vaku Isotherm. This is a very high-quality insulation with limited density and extraordinarily low thermal conductivity values. This allows to have a thickness 8/10 times lower than a conventional insulation material.

The thermoelectric cooling system is then dimensioned taking into account several parameters, including: the overmentioned insulation material, the estimation of the surface exposed to the solar radiation, the thermal power produced by the internal equipment, a delta temperature of 15° between the external temperature (max at 45° C) and the internal one (max of 30°). The thermoelectric cooler is not using any liquid refrigerant, and considering the moving of the antenna, has no constraints to be installed in any possible position, it is compact and small and obviously resistant to adverse environment conditions.

On top of the heat dissipation, another crucial aspect strongly affecting the antenna performances is the condensation. Applying positive pressure of dry air can reduce performance-impacting moisture. A well design pressurization system is of paramount importance especially in the harsh environment conditions of French Guyana or on an island in the middle of the Atlantic Ocean, as Santa Maria. For space constraints, the pressurization equipment will not be installed inside the SAA box, but in the main antenna APEX. The interconnection between the APEX and the SAA will be done via a PVC air supply pipe (approximately 15-m long), at the end of which a manifold will be installed to divide the flow of air between the two sensitive parts (SAA Feed and LNA box), plus a pressure sensor and manual drainage valve. The valve aim is to work during the first ignition phase to let out the unfiltered air present inside the tube or during any maintenance activity.

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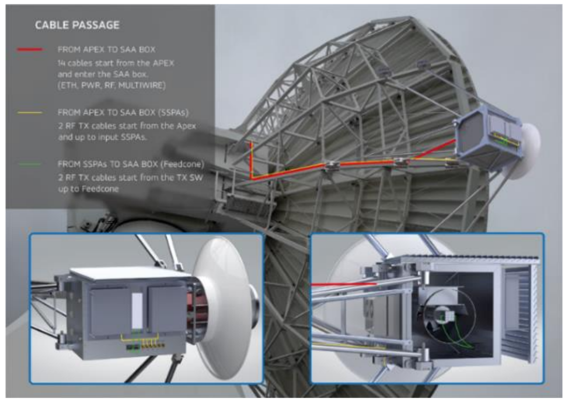

Fig. 15. Routing of cables form APEX to SAA box

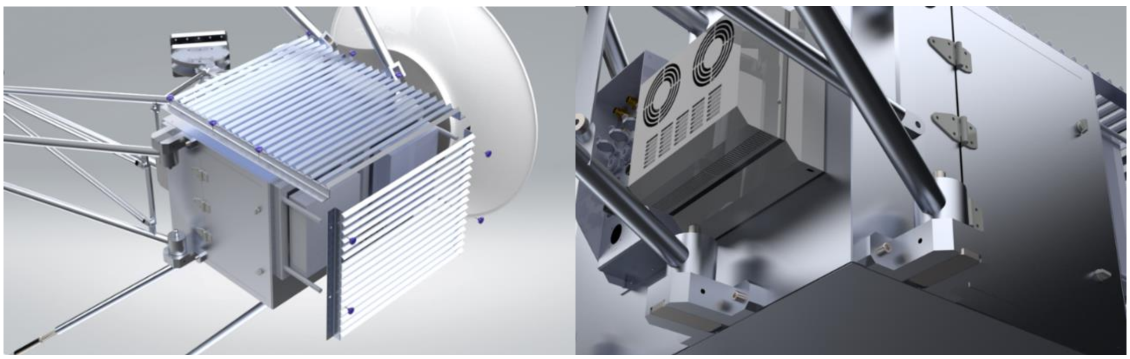

Fig. 16. Details on the sun shutters and outdoor thermo-cooler

3.4 SAA Mechanical interfaces to main antenna

Beside all overmentioned aspects, so far specifically related to the SAA itself, there is an essential element to be taken into account, which is the interface to the main 15-m antenna from a mechanical point of view.

As already mentioned in the previous sections, the alignment and joint work between the two antennas is playing a key role in the acquisition of signal. It is therefore important to evaluate the integration aspect in a way that it is possible to meet the Space Rider requirement on one side, and not degrade the current 15-m antenna performances on the other. The existing backup structure of the 15-m antenna is modelled in Fig. 17 showing the 6 anchor points for the SAA box.

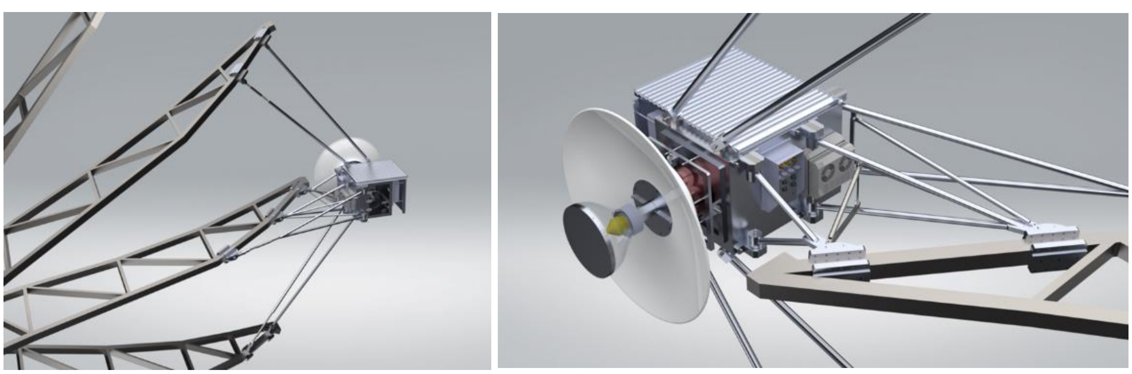

Fig. 17. SAA anchor points to the 15m antenna

The implementation idea is coming from the XAA mounting of the ESTRACK Kourou antenna, trying to replicate in a symmetric way what done on the other side of the dish. The estimated total weight, including the anchoring structure and the SAA box, is close to 500 kg.

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The additional weight of the SAA antenna system installed at the reflector will results in an unbalancing of the antenna system. This unbalance needs to be aligned via inserting of additional ballast plates at the main counterweight of the 15-m antenna reflector.

The feasibility of the installation of those steel plates is depending on the mechanical construction of the concrete tower, as this could collide with the new tuning plates. For the analysis done for Kourou a maximum of 70 additional plates can be installed out of the needed 116. The proposed solution is a concept that includes the existing steel plates in combination with a new ballast plate made of lead material. A total tuning mass of 6100 kg can be achieved via using 150 given steel-plates in combination with 150 new plates made of lead material.

This gives a rough idea of the mechanical impact on the existing antenna.

4. Conclusions

Re-entry through the atmosphere is the most critical phase of the Space Rider mission from a ground station perspective. The capability to rely on a consolidated communication link during this phase has a pivotal role in the ESA know-how development for future European re-entry system.

This paper gave an overview of a technical implementation solution of a ground station able to lock to a re-entry vehicle after the blackout zone and to support TT&C until its landing and switch-off.

The already existing 15-m ESTRACK antennas are able to provide the needed signal over noise feature, tracking capability and antenna servo speed to follow the Space Rider re-entry module, together with an already validated infrastructure and monitoring and control system. Despite that, the small beamwidth does not allow to cover the expected dispersion in AZ and EL which is affecting the vehicle trajectory at the acquisition of signal. A fast acquisition is, in the case of Space Rider, even more crucial than it was for its predecessor IXV, due to the final landing on ground instead of a splashdown in the ocean. This is why adaptations works are needed to make the 15-m antenna compatible with the mission specific requirements. The design of an S-band acquisition aid antenna (SAA) demonstrate the fulfilment of all RF performances, including the evaluation of all challenges to be faced considering the installation environment and integration aspects. The similarities between the 15-m ESTRACK antennas make the SAA suitable to be easily interchangeable between different ESA sites, profiting of the already existing infrastructure, although accepting some degree of cost and risk impact. Depending on the final site selection, the step forward will be then to work at the best acquisition strategy which will be the result of a careful balancing of several different factors: trajectory dispersion at the foreseen entry interface point, power flux density range, time dispersion, target velocity compared to tracking system reaction, weather conditions at landing, safety aspects.

The final goal being the consolidation of a "re-usable" re-entry vehicle, "re-using" already existing antennas to be adapted with a "re-used" approach already implemented in the past for other purposes (XAA) and different frequencies.

This reusability concept together with the SAA new design aspects constitute an example of how the future ESA growth in the space transportation domain can be pursued in a way that promotes efficiency and innovation at the same time.

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