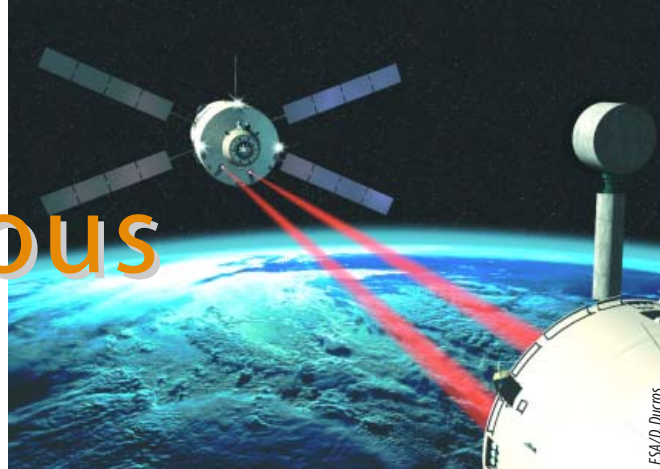


ATV: Rendezvous with ISS



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Introduction

One of ESA's most ambitious contributions to the International Space Station (ISS) will culminate in 2 years, when the Automated Transfer Vehicle (ATV) is launched by Ariane-5 and, after 5 days, performs an automatic rendezvous and docking with the ISS.

From a total launch mass of up to 20.5 t, ATV will deliver up to 9 t of supplies, payloads, crew items and propellant. During its stay of 6 months, ATV will also provide reboost and attitude control for the Station. On departure, ATV will take up to 5.5 t of waste (including up to 840 kg of liquid wastes), for destructive reentry into the atmosphere.

The first mission (named 'Jules Verne') will be a premiere for Europe in more than one sense: it will be the first rendezvous and docking ever by a European spacecraft, it will be the first automated rendezvous with a space station using optical sensors, and the first ever where the target's attitude motion is compensated for by the chaser. Ensuring the safety of the ISS crew was an essential design driver.

The Rendezvous Scenario

Ariane-5 will inject ATV into a 51.6° orbit at an altitude between 200 km and 300 km, 50-150 km below the ISS, depending on the Station altitude at the time. On separation from Ariane, the essential ATV subsystems are automatically activated and ATV stabilises its attitude, establishes radio communication with its Control Centre (ATV CC) in Toulouse via the NASA TDRSS and ESA Artemis data relay network, and deploys its solar array.

Altitude Raising and Phasing

A sequence of orbital manoeuvres brings ATV

to an intermediate orbit 10-15 km below the Station, where the natural drift due to orbital dynamics corrects the relative phase angle. When ATV is 200 km behind the ISS, trim manoeuvres then position it in exactly the same orbital plane as the ISS, still at a slightly lower altitude, so that the relative drift

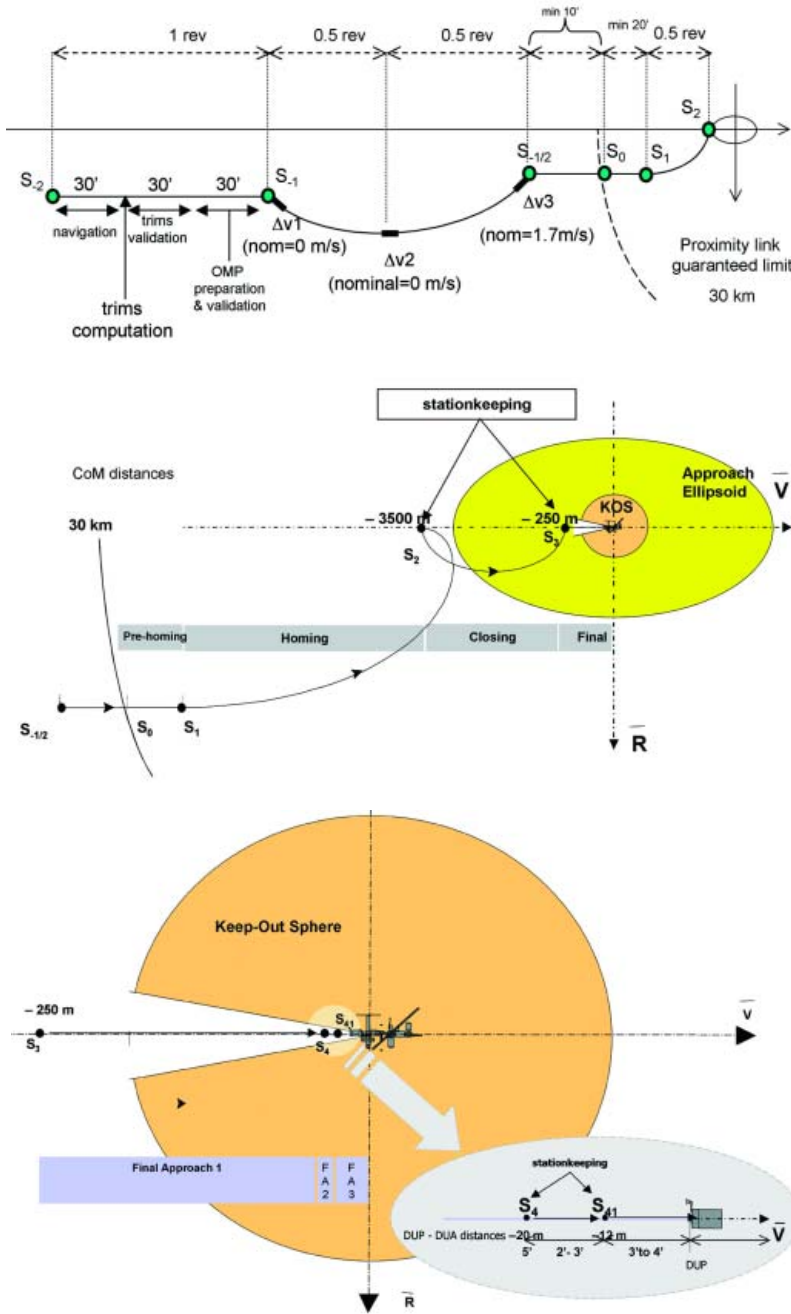
When the Automated Transfer Vehicle docks with the ISS, it will be a first for Europe ...

brings them closer and closer. At 30 km out (point S0), direct ATV-ISS radio communications are established, allowing ATV to initiate relative navigation to the Station using GPS data from both ATV and ISS receivers, processed by ATV.

Homing

At point S1, about 20 km behind the Station, the ATV CC commands ATV to begin its homing manoeuvre, which consists of a two-boost transfer lasting 45 min. It brings ATV to point S2 on the same orbit and about 3.5 km behind the ISS, still outside the ISS 'Approach Ellipsoid' (an ellipsoid of 4000 x 2000 x 2000 m centred on the ISS centre-of-mass, with the long axis along the velocity vector, or V-bar). All ATV operations inside the Approach Ellipsoid are 'combined operations' and involve the mission control authorities in Houston, Moscow and Toulouse. S2 is the first stable hold point of ATV with





Top: the series of orbital manoeuvres. (OMP: Onboard Mission Plan.)
 Centre: the homing approach from point S1.
 Bottom: the final approach from point S3.
 (Illustrations: EADS)

respect to the ISS; ATV stays there for up to 90 min, in preparation for final approach.

Closing

Once the Mission Control Centre in Houston gives the go-ahead for Approach Initiation, the ATV CC commands the vehicle to enter the Approach Ellipsoid. The Closing manoeuvre brings it to point S3, 250 m behind the ISS. It must not enter the ISS 'Keep Out Zone' – a safety sphere of radius 200 m, centred around the ISS centre-of-mass. This exclusion is guaranteed by using an 'eccentricity increase' manoeuvre to get from S2 to S3: two burns perpendicular to the orbital tangent bring ATV to S3 in half an orbit (45 min). If the braking

burn fails at S3, then ATV naturally returns to S2 in another half-orbit.

Final Approach and Docking

Between S3 and docking, ATV approaches on a 'forced' translation along the ISS velocity vector to the docking port at the aft end of Zvezda. 'Forced' means that, in addition to the 220 N thrusters propelling ATV towards the ISS, perpendicular thrusters are firing towards Earth to stop the orbit rising.

To ensure proper capture and acceptable docking loads, ATV's docking probe has to meet Zvezda's docking cone within a radius of 10 cm and a lateral velocity of less than 2 cm/s. To meet these conditions, the relative navigation during final approach is based on ATV's optical sensors, with corresponding passive target patterns close to Zvezda's port. While measurements from the Videometer primary sensor are used in the active guidance, navigation & control (GNC) loops to control ATV's motion, the information provided by the Telegoniometer secondary sensor is provided to the Flight Control Monitoring (FCM) system to supervise the performance of the active loop.

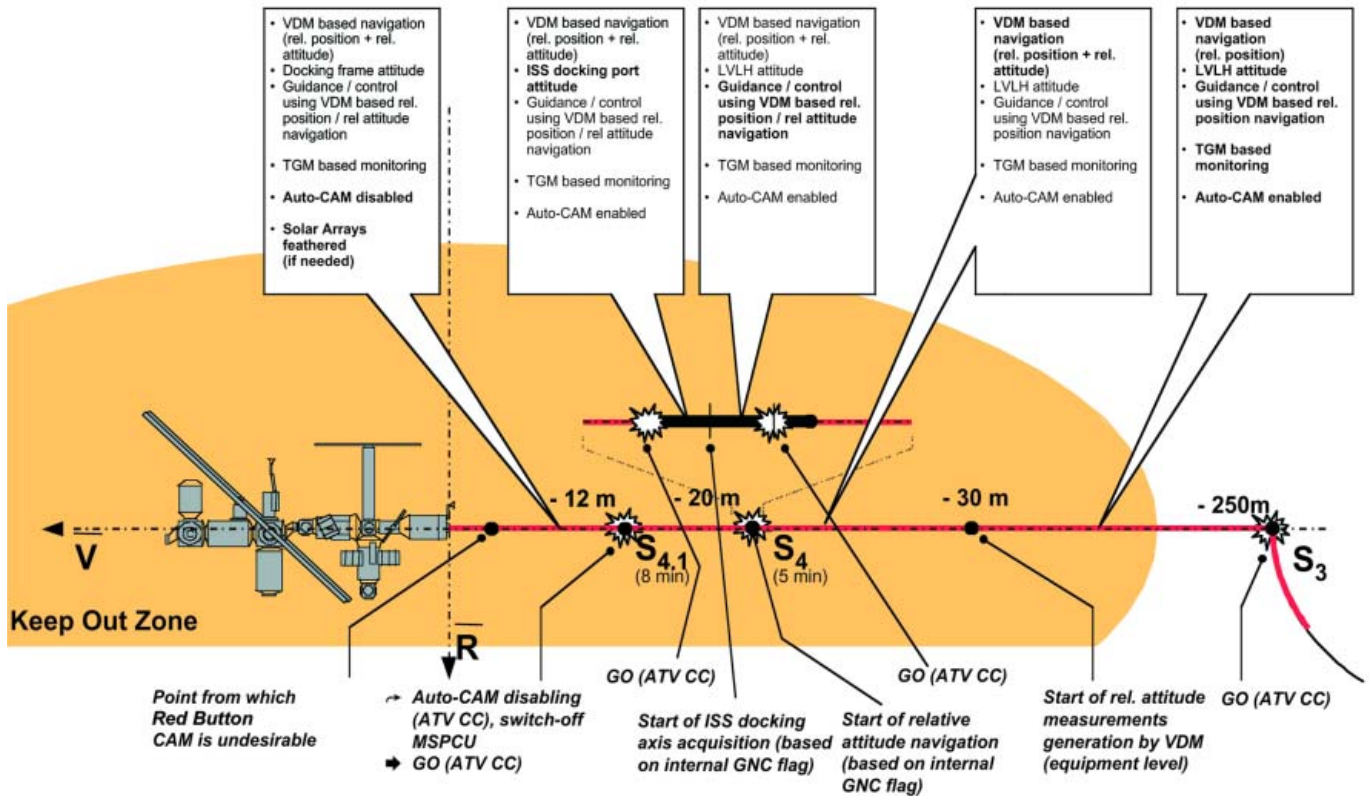
Principle of the Videometer

The Videometer delivers range and line-of-sight angles to the GNC system, and, from within 30 m, relative attitude angles, based on triangulation. A diverging laser beam emitted by diodes on the ATV front cone towards Zvezda is returned by a pattern of reflectors, imaged by a CCD. The pattern size provides the range, its position on the CCD yields the line-of-sight angles, and its apparent shape gives information about the relative attitude angles.

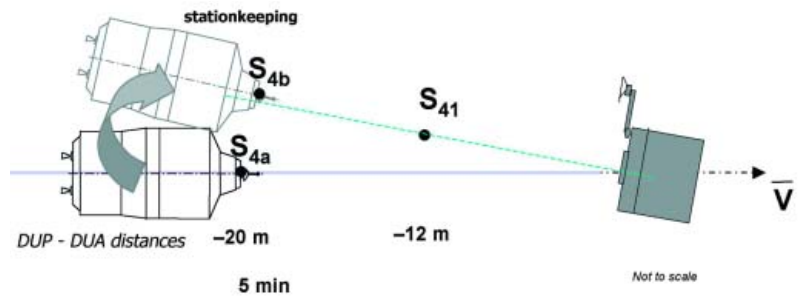
Principle of the Telegoniometer

The Telegoniometer delivers range and line-of-sight angles to the FCM, based on time-of-flight measurement. Collimated laser pulses from a diode scan the ISS vicinity and are returned by three reflectors on Zvezda. The light-pulse travel time provides the distance, and the positions of two beam steering mirrors give the two line-of-sight angles.

Once the rendezvous sensor relative navigation is properly acquired, the ATV CC commands ATV to leave S3 and enter the Keep-Out Zone. This final approach is performed in several steps, each initiated by ATV CC command for ATV to proceed automatically to the next hold point:



- S3 to S4, 20 m from docking. ATV stays on the V-bar and controls its motion relative to the ISS based on range and line-of-sight information from the Videometer.
- S4 to S41. Before reaching S4, the sensor mode changes to relative attitude measurement. From then on, ATV's docking port always aligns with Zvezda's, thereby tracking any movements of the ISS.
- S41 to docking. At S41, about 12 m out, ATV performs a last hold, for the crew and ground to confirm that all is ready for docking. It resumes the approach on command from the ATV CC; there are no more mode or configuration changes. The crew closely monitors this last part of the approach using information independent of ATV's onboard systems (Zvezda video camera visual image, and range and range-rate readings from the Russian Kurs rendezvous system on Zvezda).



by executing a safe departure from the Station (ESCAPE manoeuvre).

During rendezvous, the independent Flight Control Monitoring system, which runs in parallel with the active GNC loop, permanently supervises vehicle performance and triggers corrective actions in case of discrepancy.

To ensure ultimate safety, and to cover any 'unforeseen' problems (such as a crash of the onboard flight software), the Proximity Flight Safety (PFS) system continuously monitors the approach trajectory. In the event that safety thresholds are violated, it triggers a Collision Avoidance Manoeuvre (CAM), which propels ATV into a safe trajectory far away from the Station.

An additional safety layer on top of the onboard resources is provided by the ATV CC, which during rendezvous is in continuous contact with ATV and can interrupt the mission at any time. During final approach, the Station crew will visually monitor ATV and can command it to stop or fly away by using the ESCAPE or RED BUTTON CAM command.

Top: the approach from S3. (CAM: Collision Avoidance Manoeuvre. LVLH: local-vertical, local-horizontal. TGM: Telegoniometer. VDM: Videometer.) Above: from S4, ATV matches the ISS motion. (DUA: Docking Unit Active. DUP: Docking Unit Passive). (Illustrations: EADS)

How Safety is Ensured

In accordance with the principle of two-fault tolerance (2FT) against failures that could endanger crew safety, all ATV onboard functions involved in the rendezvous and docking operations are designed 2FT. A first failure will in general be recovered by the onboard FDIR (Fault Detection, Isolation and Recovery) function without interrupting the mission. After a second failure in the same functional chain, ATV performance may be degraded, but the FDIR will still ensure safety