ATV JULES VERNE MISSION MANEUVER PLAN

P. Labourdette, E. Julien, F. Chemama, D. Carbonne

Centre National d'Etudes Spatiales
18, Avenue E. Belin, Toulouse, 31401, Cedex 9

On 03/09/2008, the first ESA Automated Transfer Vehicle (ATV), so-called Jules Verne, lifted off from Kourou aboard the Ariane 5 launcher towards the International Space Station (ISS). After several phasing, parking and rendezvous demonstration days, the ATV autonomously completed its docking to ISS with success on 04/03/2008. On 09/05/2008, the ATV undocked ISS, then performed maneuvers to re-phase with the ISS and finally initiated its reentry over Pacific Ocean on 09/29/2008. This paper deals with the description of the actual maneuver and attitude plans computed by the CNES Flight Dynamic Team all along the mission.

1. INTRODUCTION

ATV is a European Space Agency (ESA) funded program: the spacecraft is designed and built by EADS ASTRIUM Space Transportation and operated at ATV Control Centre (ATV-CC) by the French Space Agency (CNES).

ATV is an unmanned vehicle contributing to the servicing of the International Space Station by delivering pressurized cargo, providing ISS refueling, ensuring ISS re-boost and attitude control and, eventually, removing the general waste no longer used on the station.

In spite of the autonomy of many subsystems, for ATV-JV mission, many maneuver plans were calculated by the Trajectory team (TRA) and up-loaded to contribute to the success of the mission.

This paper will focus on the description of the maneuver plan designs and the solutions that have been set to cope with the Jules Verne mission, including the non nominal situations that have been met during the flight (debris avoidance, maneuver postponements). The detailed maneuver values have been described in [1].

This paper will also describe the FDS/TRA activities to compute the attitude profiles for forecasting and monitoring purpose and to generate the reference on-board frames.

1.1. Mission features

ATV generic mission. The generic ATV mission covers five phases:

- Launch and Early in-Orbit Phase (LEOP)
- Phasing to Rendezvous interface
- Rendezvous and Docking (RDV&D)
- Attached Phase
- Departure / Re-entry

Control Center. Despite the fact that many ATV vehicle subsystems are autonomous, for all the phases (except the attached phase), many Flight Dynamics activities are nevertheless performed on ground. The Flight Dynamics Subsystem (FDS), one of the ATV-CC components is mainly in charge of ATV trajectory thanks to activities like ATV Orbit Determination (OD), maneuvers computation and checking of their realization, attitude profiles forecasting and checking, operational forecasting, GNC monitoring, debris collision analysis [2].

On the other side, the ISS absolute trajectory is provided by the Moscow Mission Control Center (MCC-M) and the Houston Mission Control Center (MCC-H).

The accurate debris collision probability is also provided, when needed, by MCC-H (TOPO) based on the ATV trajectory provided by ATV-CC (FDS).

Rendezvous and docking overview. A sketch of the RDV phase is depicted in Figure 1. One important point is the one that makes the interface between “On-ground control” and autonomous phase is called the RDV interface (named $S_{-1/2}$).

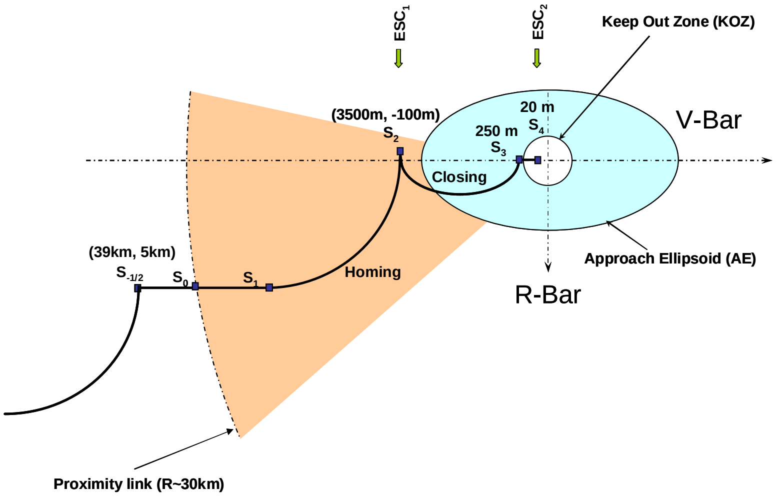

Figure 1. Rendezvous Phase Overview

This RDV interface with the non autonomous phases is a point located on an ISS co-elliptic orbit, 5km below and 39km behind the station. This point, tuned at mission analysis level, is the result of a trade-off between the minimization of the RDV phase duration and the necessary time for the convergence of the Relative GPS navigation filter. This point must be reached with a prescribed accuracy, to be compliant with the on-board algorithms (GNC and ISS safety monitoring).

ATV propulsion. The ATV engines locations are presented in the vehicle overview showed in Figure 2. The propulsion is composed of:

4 main engines (OCS - Orbital Control System, isolated by pairs 2x2x503.6N) that can be used during Phasing, Post-escape and Re-entry and for maneuvers exceeding 5 m/s. This kind of maneuvers required a vehicle orientation (slew maneuver) along the required maneuver direction.

28 engines (ACS - Attitude Control System, on the rear part 4 pods of 5 ACS, on the front part 4 pods of 2 ACS) to perform guidance maneuvers less than 5m/s, attitude maneuvers and attitude control.

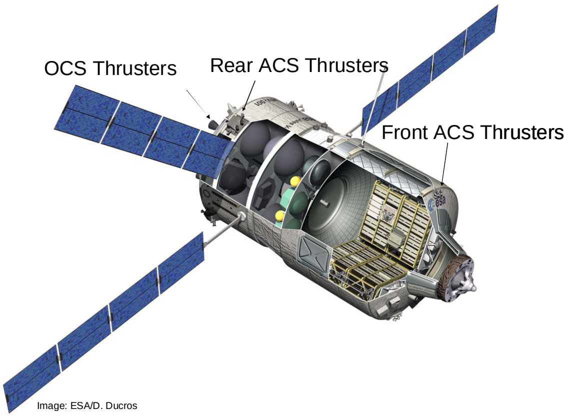

Figure 2. ATV Overview

For the design of the maneuver strategy, propulsion dispersions are in Table 1:

Table 1. Propulsion errors for scenario design

OCS (along-track)	OCS (cross-track)	OCS (slew)	ACS (along-track)	ACS (cross-track)	Thrust Duration
±3%	±3%	±2*0.2 m/s	±9%	±5%	±4.3%

1.2. ATV specific first flight

The first ATV mission, so-called Jules Verne (ATV-JV), differed from the generic mission:

- It involved the demonstration of the ATV capability to safely undertake rendezvous (DemoDay 1 and DemoDay 2 both ending the proximity operations with an escape maneuver), and the three successive approaches before Docking needed two ISS fly-around, “Post-Escape 1 (PE1)” or “Transfer to DD2” with a duration of about 48h then “Post-Escape 2 (PE2)” or “Transfer to Docking” with a duration of about 72h, (Figure 1 and Figure 3)
- it had to demonstrate the capability to perform a Collision Avoidance Maneuvers (CAM) with the ISS (performed during the phasing),
- it required a dedicated ACS test maneuver (AT) to check a long propulsion as it is performed for the escape maneuvers (ESC1, ESC2),
- as the Shuttle STS-123 mission was scheduled during the nominal phasing period, in order to comply with flight rules of vehicles servicing ISS and to be robust to Ariane 5 launch delay, a Parking Point was targeted after the phasing, waiting for the “GO Decision” to start the proximity operations,
- the Reentry phase required an ATV undocking on the 5th of September (before the scheduled Progress 30P docking), as well as to target a reentry area in eclipse optimizing the airplane observation; this implied a 3 weeks in-flight duration up to the reentry instead of one or two days for the generic mission,
- the Reentry phase required an ATV re-phasing with ISS allowing the astronauts to observe this phase thanks to FIALKA experiment [1], [2].

The Rendezvous proximity operations during the DemoDays 1 and 2 as well as the mission design implication required by the ISS safety have been described in previous papers [1], [2], [3], [4].

2. OVERVIEW OF THE MISSION PHASES

The overview of the whole mission is depicted in the Figure 3.

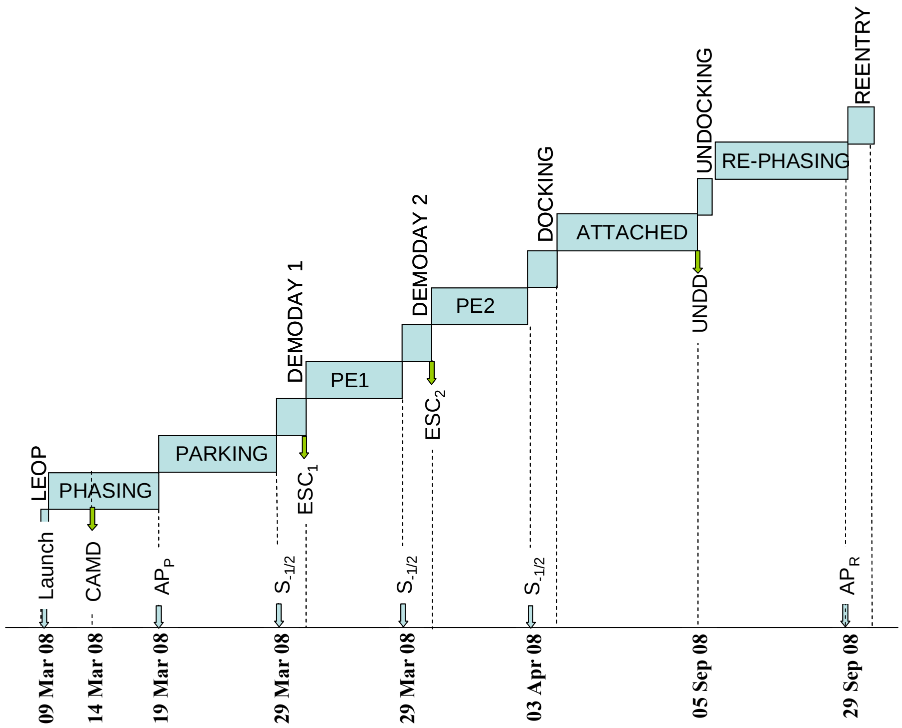

Figure 3. Mission Phase Overview

ATV-JV was launched to the ISS from the European spaceport in French Guiana by an Ariane 5 launcher on 9 March 2008 at 4:03:04*. The launcher placed the spacecraft into a 260km circular orbit at 5:09:43. The ISS orbited on a 355km circular orbit. The orbital period (T) was about 90 minutes.

The LEOP phase lasted around 2 revolutions encompassing several vehicle operations to get ready for the first transfer of the phasing period. The injection parameters were inside the 3σ expected dispersions.

3. PHASING

3.1. Phasing duration

The phasing duration depended at first order on the differential altitude and on the phase angle between ISS and ATV. Moreover, there was only one launch opportunity each day as the launch had to be performed on time.

In order to be robust to a launch delay and to the uncertainty of the docking day, maneuver schemes had to fit with any phasing angle. Furthermore, these schemes had to target the same Aimed Point (AP) in case of a launch delay up to 3 days. In order to save fuel, nominal drifting orbit below injection orbit had to be avoided. The aimed point arrival time had to comply with constraints as Russian Ground Segment visibilities and no dazzling of the sensors. All these constraints led to a minimum phasing duration of about 10 days.

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* All times in the document are given in UTC time

The traffic of spacecraft in the period of the ATV docking opportunities led to aim at a parking point (AP_P), instead of the nominal $S_{-1/2}$. The Parking Point was chosen as a stationary point located 2000km in front of ISS. This point permitted to comply with ISS safety constraints and necessitated few Station Keeping (SK) maneuvers. As there was no constraint for the AP_P then the arrival time was fixed on the 03/19/08 at 12:00:00 (phasing duration~10.3days)

Indeed for operational simplicity and robustness (procedure, training of operators), it was decided to keep the same phasing duration and maneuver schemes.

3.2. Phasing maneuver plan:

The phasing period was composed of several orbital transfers to catch-up the phasing angle and differential height. The standard 4-impulse strategy (2 Hohman transfers) had to be split into additional transfers to include test maneuvers and to be robust to perturbations.

The transfers included:

- maneuvers to reach the drift orbit (TP),
- test maneuvers (AT, CAM),
- Mid-course maneuvers (MC_1, MC_2),
- Three transfers TIV that allow to reduce mainly height difference, absorbing gradually the errors,
- the last transfer IF targeting the Interface to RDV point ($S_{-1/2}$).

The nominal maneuver scheme is presented in Figure 4.

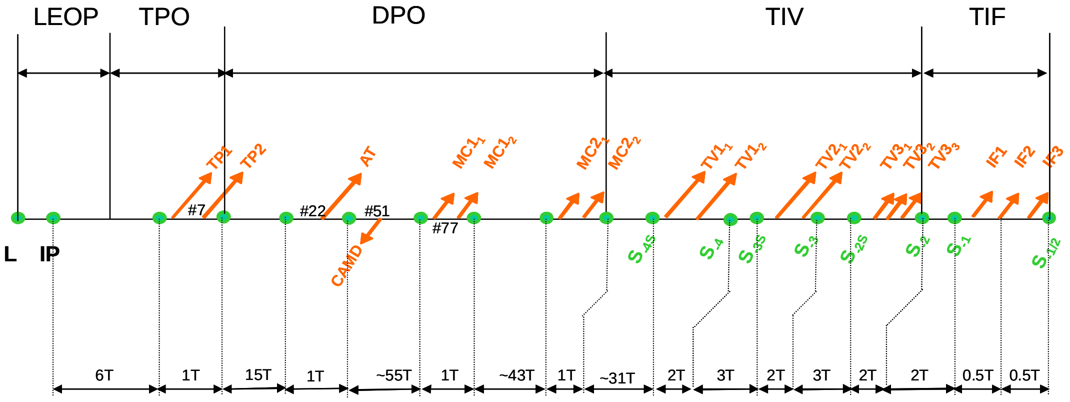

Figure 4. Nominal Maneuver Scheme

The maneuver cycle “Transfer to Phasing Orbit” (TPO) placed the ATV onto a phase angle catch-up orbit. The out of plane corrections were performed at this level to compensate for the offset (mainly inclination) that could not be fitted by launch time adjustment and to compensate for the injection errors.

At each maneuver cycle computation level, the whole remaining maneuver cycles were included in the optimization process, targeting the $S_{-1/2}$ point.

Then, the sub-phase DPO (Drift on Phasing Orbit) started. During this phase, an ACS test maneuver (AT) was required (within [3m/s, 4m/s]), to check the in-flight further Escape maneuver capability. A Collision Avoidance Maneuver (CAMD) had to be performed during DPO phase to demonstrate the further safety capabilities during the RDV phase. This maneuver was automatically performed on-board and set the vehicle in a survival mode, then ATV-CC reconfigured the vehicle to perform the next phasing maneuvers. Nominally, 2 Mid-Course cycles were foreseen to absorb all the dispersions accumulated up to their computation.

Approximately one day before $S_{-1/2}$ arrival started the transfer to the interface to RDV (TIV). To insure the good compensation for errors (in particular the specified maneuver errors) several steps were required depending on the differential height between DPO orbit and ISS orbit to catch-up. The principle adopted for TIV transfers was the “Sliding maneuvers”: maneuvers were performed, sooner or later within their authorized interval, permitting to maintain their values around their nominal values in order not to get maneuvers that can endanger the station. It is to be noted that the sliding is not symmetrical compared to the nominal location because of the simultaneous correction of the δa dispersions which are correlated (see Figure 5).

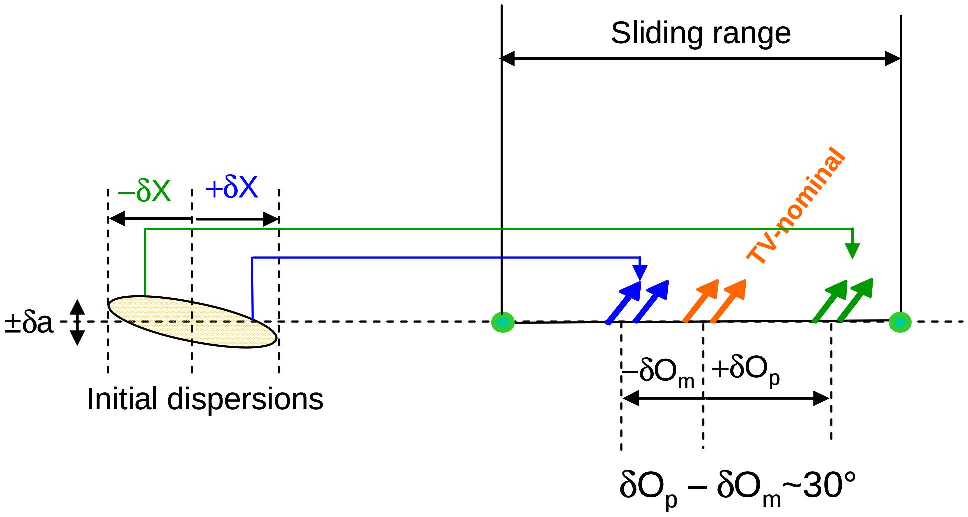

Figure 5. Sliding Maneuver Principle

At last, the transfer TIF was performed (see Figure 6). This transfer targeted the $S_{-1/2}$ point with 3 maneuvers (IF_1, IF_2, IF_3) separated by half a revolution (0.5T).

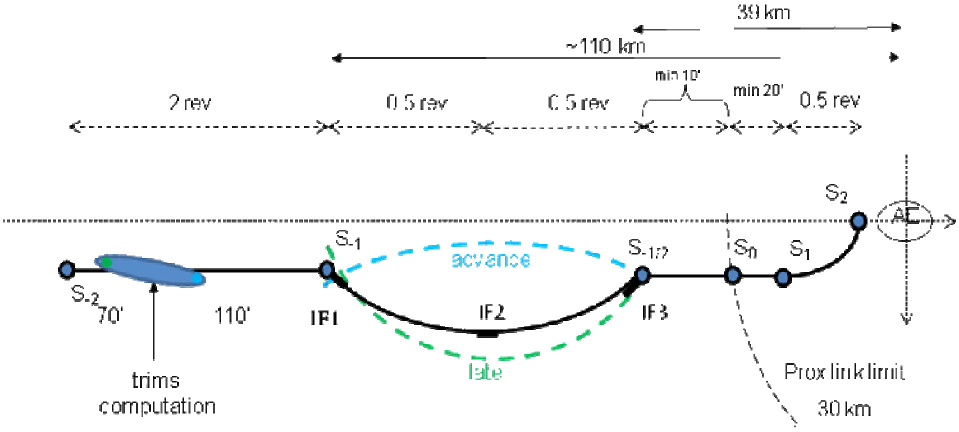

Figure 6. Interface RDV maneuver principle

This transfer had been designed in collaboration with EADS because there was a strong link at this level with the RDV phase. In particular, IF values had to be maintained within prescribed range (see

Table 2) to insure the good functioning of the on-board Flight Control Monitoring (ISS safety) and the resulting dispersions errors at $S_{-1/2}$ had to be within small range as well (Table 3).

Table 2. Maneuver IF Range Limits.

Maneuver	Nominal (m/s)	Min (m/s)	Max (m/s)
IF1 tangential	0	-1.88	1.88
IF2 tangential	0	-0.43	+0.42
IF3 tangential	1.2	-0.41	2.82
IF3 radial	0	-1.16	1.11

Table 3. $S_{-1/2}$ Accuracy

	Δa (m)	aΔex (m)	aΔey (m)	ΔX (m)	Δh (deg)
Aimed Point	5000	0	0	39000	0
Accuracy	480	480	480	3300	0.005729

Δa, aΔex, aΔey are the mean differential ISS/ATV values, DX along Vbar in the classical LVLH frame, Δh the relative orbital angular momentum.

The Table 2 and Table 3 were not requirements for the aimed point AP_P (not nominal Aimed point) but only for initiating the Demo Days 1 & 2 (DD1 & DD2) and Docking.

3.3. First non-nominal situations

First of all, during LEOP, a failure at ATV Propulsion Drive Electronic (PDE) level entailed the delay of the TPO transfer and the delay of the maneuvers AT, CAM, MC11 and MC12. The delay of the phasing transfer led to the cancellation of the cycle TV1. Furthermore, the propulsion experts required OCS test maneuvers of around 6 m/s, so a double TPO (TE/TP) cycle was performed.

Then a MC11/MC12 maneuver increase was due to the survival exit perturbation after the CAM realization that was not simulated for the mission plan computation.

The cycle MC2 was cancelled thanks to the good realization of the previous maneuvers and the low level of the atmospheric density.

The dedicated out of plane TV32 maneuver was cancelled because it was not fuel-optimal to correct the out of plane deviations at the Parking Point arrival.

At last, the retrograde IF1 maneuver allowed to catch-up a 2km along-track delay. The aimed point AP_p was reached within less than 200m. The Parking phase could start 2000km in front of ISS.

4. PARKING

Waiting for the opportunity to reach the next aimed point ($S_{-1/2}$ for DD1), scheduled on the 03/29, the station keeping maintained the ATV inside a box of 2000km ± 250km. This box was sized to comply with ISS safety requirements and to perform a control maneuver cycle every 2 days at maximum whatever the drag effects or the maneuver realization were. During operations, only two maneuvers were performed before transferring the ATV to the DD1 interface (03/21, ΔV's < 9cm/s).

The Parking phase lasted around 8 days during which occurred ISS trajectory perturbations such as "water dump effect" and STS undocking, then when the transfer to DD1 started the ATV was located around 1820 km in front of the ISS.

5. TRANSFER TO DD1

5.1. Nominal plan

This phase consisted in transferring the ATV from the Parking point to the $S_{-1/2}$ point interface to start the DD1 phase.

The nominal maneuver scheme is presented in Figure 7.

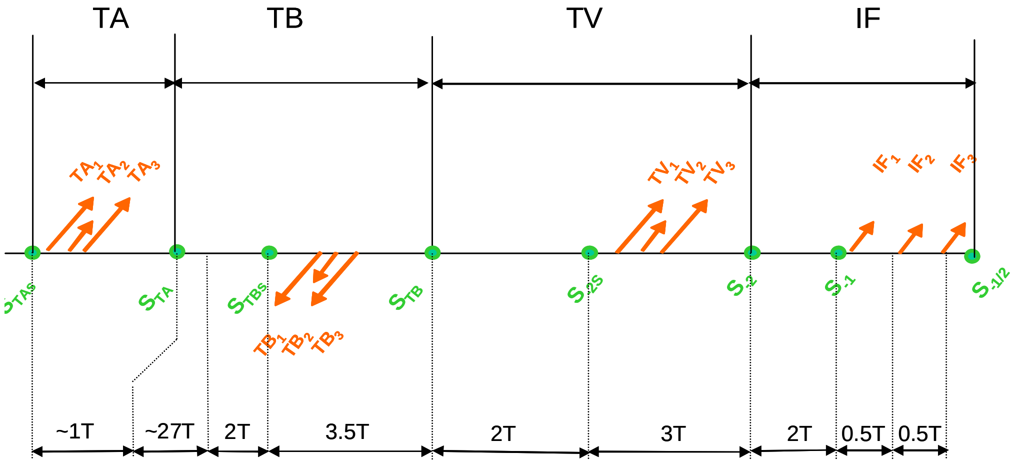

Figure 7 Nominal Maneuver Scheme

The nominal re-phasing trajectory is presented in Figure 8.

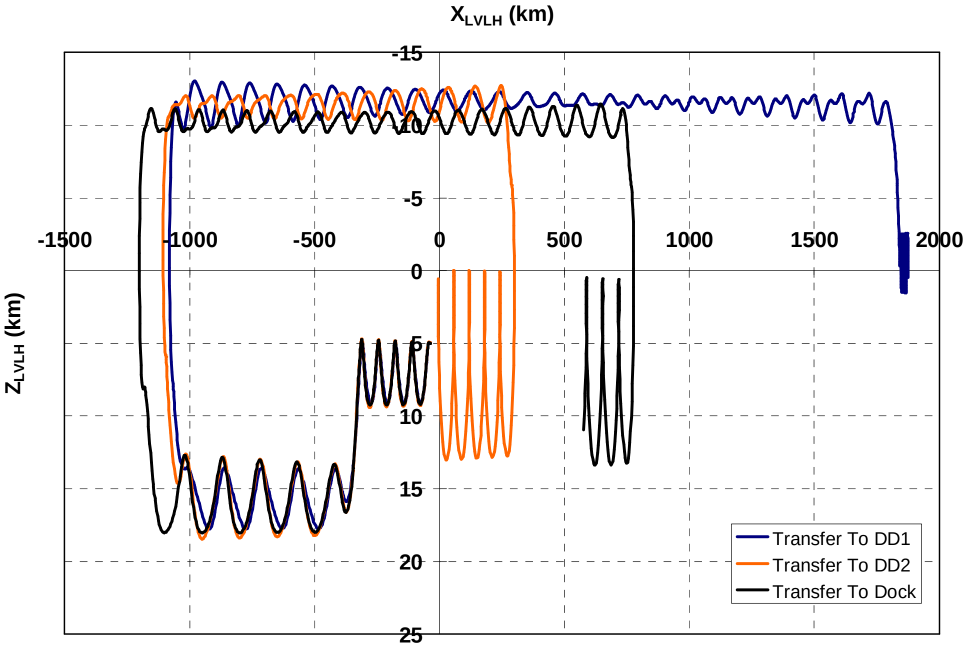

Figure 8. Transfer to DD1/DD2/Dock – Nominal relative trajectory

The targeted Aimed Point ($S_{-1/2}$ for DD1) was eventually scheduled on 03/29/08 at 14:18:37.

The re-phasing trajectory altitude was targeted around 11km above the ISS (co-elliptic with ISS) as recommended by mission analysis (a trade-off between maneuver dispersions recovering and duration of the transfer).

A 3-maneuver transfer (TA) was up-loaded, TA1 targeting an intermediate height of 5km above ISS (24h-ISS safety requirements). The "Sliding maneuver principle" (see Figure 5) was used for the TB and TV transfers. The TB sliding range was of 3.5T and the TV sliding range was of 3T. The TV2 maneuver was dedicated to correct out-of plane dispersions if necessary.

5.2. Another non-nominal situation

All maneuvers up to TV1 were performed with a very good accuracy.

Unfortunately, a new PDE alarm rose during TV execution leading to cancel the on-going cycle after the TV1 realization. A contingency procedure was activated to reconfigure the vehicle. A contingency 2-maneuver plan (TV2-TV3) targeting the point $S_{-1/2}$ was up-loaded (IF1=IF2=IF3=0m/s) to decelerate the ATV (the plan had to be computed and checked within 15 minutes to avoid the plan jump to the costly post-escape re-phasing and then to miss the first RDV opportunity). The probability to insure an $S_{-1/2}$ arrival within the required accuracy became less than 3σ. Thanks to the very good TV2/TV3 realization and the accurate OD of ATV/ISS, the IF cycle was within the prescribed values and the nominal process was re-activated. $S_{-1/2}$ was reached with an accuracy along X of about -2km (limit of ±3.3km – see Table 3), this dispersion was mainly due to the residual ΔV's of the slew maneuver for PDE re-integration just before the IF cycle.

The vehicle was within the allowed limits; the DD1 phase could start.

6. POST-ESCAPE – TRANSFER TO DD2 AND TRANSFER TO DOCK

The autonomous DD1 phase, not depicted in the frame of this paper, was performed nominally and stopped at the point S_2 (see Figure 1) with the triggering of the Escape maneuver (-4m/s on the 03/29 at 17:30:10). The Post-escape phase could start performing several maneuvers to bring the ATV back to the next $S_{-1/2}$ point, 48hours later, on the 03/31 at 12:26:08. Then the autonomous DD2 phase drove the ATV up to the S_4 point where the second escape was triggered (-4m/s on the 03/31 at 16:52:20) for a 72 hours fly-around (the next $S_{-1/2}$ was on the 04/03 at 10:31:56) to let enough time for the ground team analysis. The maneuver design is similar to the one depicted for the phase "Transfer to DD1" (see Figure 8).

The maneuver TA1 was performed at the relative periapsis after the Escape maneuver (4.5T for "Transfer to DD2", 11.5T for the "Transfer to docking") and it targeted a relative apoapsis of about 5km above the ISS.

The $S_{-1/2}$ point at DD2 interface was reached with a very good accuracy (Δa~7m, ΔX~131m).

The $S_{-1/2}$ point at "RDV to docking" interface was reached with a very good accuracy (Δa~0.5m, ΔX~3m).

The ATV docking successfully completed on 04/03 at 14:55.

From the injection, the ATV consumed around 1900kg of fuel and ATV-CC computed and up-loaded around 50 maneuvers.

7. ATTACHED PHASE

The attached phase is not described in this paper. The FDS/TRA team was not fully involved during the various operations except for up-loading regularly the ATV Orbital Control Frame in case of an on board contingency. From 04/03 to 09/05, the ATV contributed to six ISS re-boost maneuvers (for a total of 15.8 m/s), to a Debris Avoidance Maneuver (DAM, -1m/s) and several ISS attitude maneuvers.

8. UNDOCKING AND RE-PHASING

8.1. Nominal Plan

The undocking / departure sequence is an automatic sequence during which a 4m/s retrograde maneuver is performed one minute after the hook opening. ATV drifts away in front of the ISS waiting for the required conditions to perform the re-entry sequence in general the day after.

8.2. Jules Verne Plan

The docking port where the ATV was mated had to be freed before the arrival of the Progress 30P initially scheduled on the 09/12. The undocking was followed autonomously by a retrograde departure maneuver (-4m/s), one minute later. The Departure maneuver occurred on 09/05/08 at 21:30:14. As aircraft observations of the ATV re-entry was planned, the last part of the re-entry trajectory had to be in eclipse. This constraint added to the safety requirements (impact point in South Pacific over uninhabited areas) led to target the impact point on the 09/29/08, which was the first opportunity within the window. Furthermore, the observation by ISS crew with the Russia experiment FIALKA was claimed as well, that necessitated an ATV re-phasing trajectory to obtain a common on-ground projected trajectory with the ISS during the last part of the re-entry.

The Figure 9 shows a scheme of the maneuvers envisaged from the undocking to the reentry.

The transfers TV and IF used the “Sliding maneuvers strategy”. The maneuvers IF were located the day before deorbitation/reentry operations for sake of operational simplicity and because accuracy required at AP_R was not very tight (43km along track). Other re-phasing maneuvers were performed around mid-day for sake of operational simplicity. The date of the maneuvers TR was a trade-off between fuel consumption and minimal value for the TV maneuvers. The reentry maneuvers were separated by 2 revolutions. The MC cycles were optional.

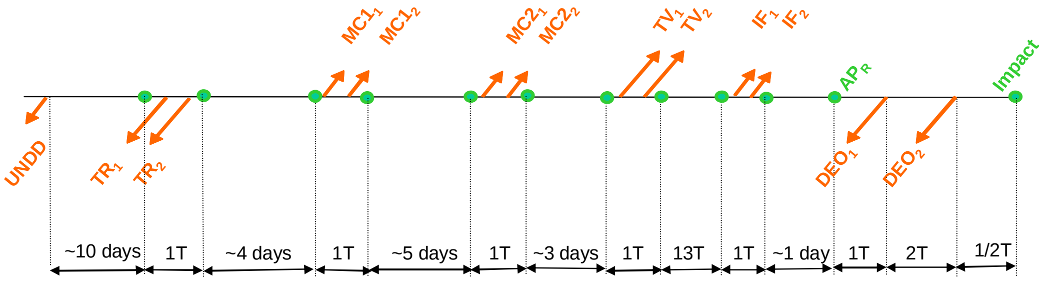

Figure 9. Re-phasing / Re-entry nominal scheme

8.3. Last non nominal situation

On the 09/10, in order to increase the margins for the TV maneuvers, it was decided to postpone them to the 09/17. The fuel increase by this delay was compliant with the consumption dedicated to the re-phasing. On the 09/10, a close conjunction with the debris #33257 (Cosmos 2421) was confirmed by the Mission Control Center at Houston (MCC-H). This conjunction, because of the orbit of the debris should have occurred on the 09/12 at 04:04 then 05:35. The best strategy to get out of the exclusion area was to perform a maneuver N_{rev}*T/2 before the conjunction. Furthermore, because of the hurricane threatening over Houston area and MCC-H closing, leading to a possible interruption of the debris screening support, it was decided to perform a DAM (-1.7 m/s to insure a nominal height separation of about 5km) a long time in advance (N_{rev}=4). The maneuvers MC11 and MC12 were cancelled thanks to the good realization of the previous maneuvers.

The aimed point for the reentry interface (AP_R) was eventually fixed on 09/29 at 08:30:38 for the computation of the last cycle IF (at the time of the undocking computation, it was estimated about 8 minutes later).

The point AP_R was reached with an along-track accuracy of 15 km, inside the mission analysis requirements (43km) for the further observation from ISS.

9. RE-ENTRY

The purpose of the deorbitation is to make the ATV enter into the atmosphere falling into the ocean without any risk of damages for population and goods.

As ATV has a low thrust level/mass ratio (1007N for 13t at time of the re-entry) and its engines are restricted to burn less than 30mn, the deorbitation has been performed with 2 manoeuvres separated by 2 orbits. The first one set the apsidal line orientation in order to be phased with the targeted impact point and targeted an osculating perigee altitude of 220 km, the second one targeted a 0 km perigee altitude.

The timing of the manoeuvres depended on the nominal targeted impact point (latitude=~-40°, longitude=~207°). Numerous Monte-Carlo simulations have been conducted during the mission analysis to set a location of the nominal impact point, inside the South Pacific Ocean Uninhabited Area (SPOUA), considering several perturbations (altitude of fragmentation, explosion, deorbitation manoeuvre accuracy, drag, debris) and leading to an acceptable risk level.

The ground track during the deorbitation maneuvers as well as the impact footprint due to the fragmentation are presented in Figure 10. The impact area or Declared Re-entry Area (DRA) delimits an area where the debris must be enclosed with a probability of 99% given the delivery accuracy (also called 10^{-2} contour). This area were provided to the Safety Authorities before the re-entry in order to warn maritime and air traffic (NOTAM emission).

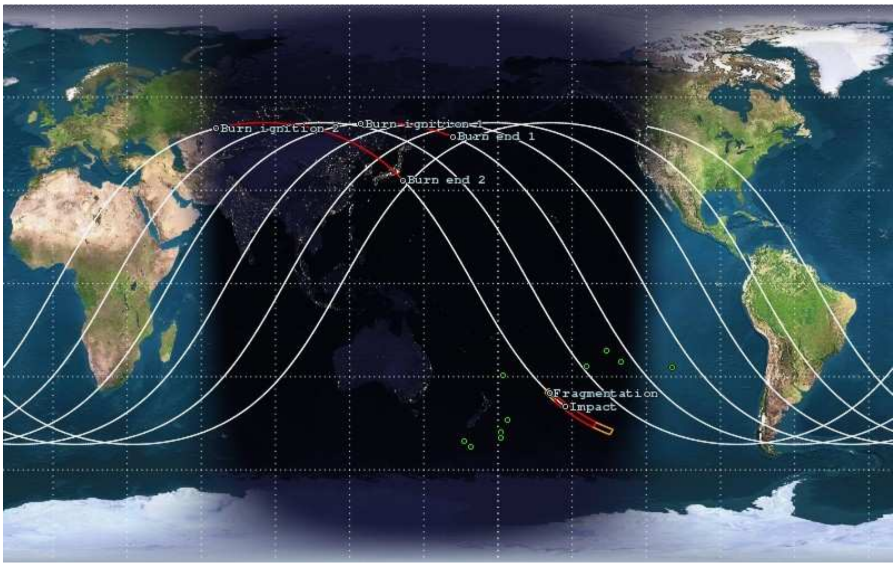

Figure 10. Deorbitation/Reentry ground track and footprint

10. ATTITUDE PROFILE AND REFERENCE FRAME

10.1. Orbital Control Frame

On-board, the attitude was computed thanks to the Orbital Control Frame (OCF) defined in the Figure 11. There is no on-board absolute navigation based on the GPS measurement, then ATV-CC had to compute and to up-load OCF's in order to provide the required accuracy.

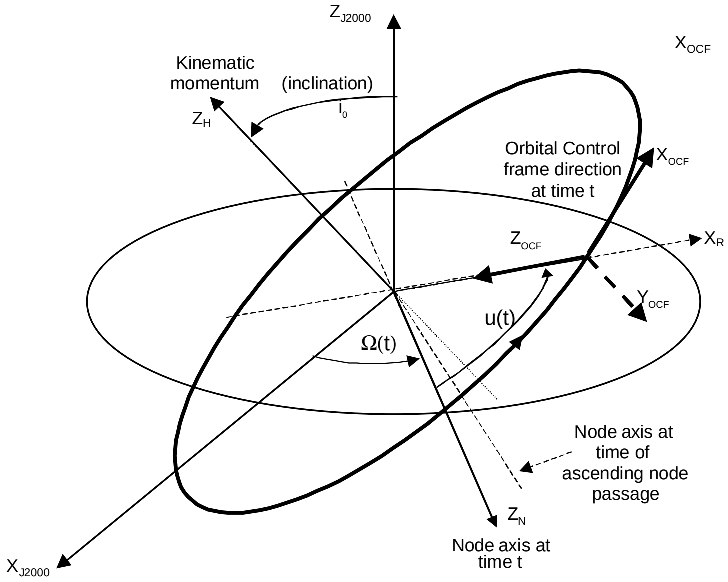

Figure 11. Orbital Control Frame Definition

On-board, the frame parameters were propagated by a simple linear law:

$i(t_{current}) = i0$

$\Omega(t_{current}) = \Omega_0 + \omega_\Omega \cdot t_{current}$

$u(t_{current}) = u_0 + \omega_u \cdot t_{current}$

ω_{Ω}: mean rate of longitude of the ascending node (around Z_{J2000})

ω_u: mean rate of the argument of latitude (around Z_H)

Due to this simple law the OCF parameters had to be uploaded (based on FDS/TRA computations), several times especially during the manoeuvre sequences, in order to fit with the real trajectory. There were accuracy constraints to assure visibility requirements or to perform accurately the maneuvers. There were also constraints on the OCF parameters gap to be compliant with the dynamic stability of the on-board attitude control (see Figure 12).

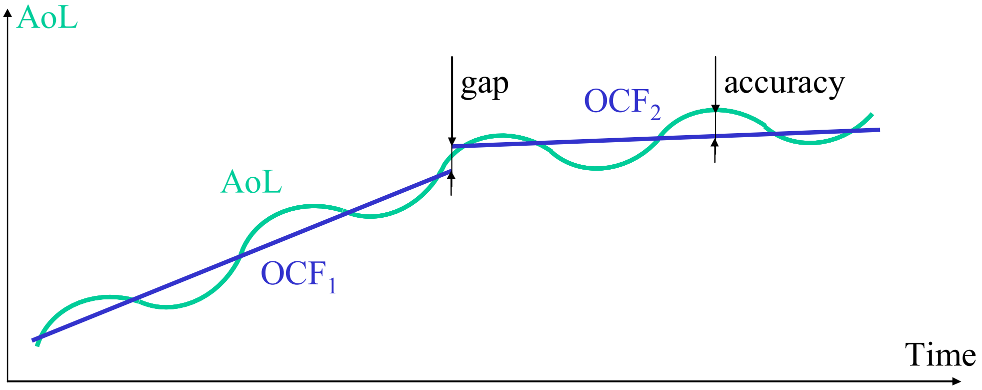

Figure 12. OCF's and real trajectory

Each OCF were computed independently. The algorithm was an example of a quadratic programming problem and used a Linear Constrained Least Squared method (routines DLSEI from SLATEC library, [5]); the constraints were half of the allowed gap at each end of the range. The mission analysis defined the validity ranges depending of the mission phases. On-ground procedures checked the resulting computed OCF gaps and accuracies. The resulting accuracy (mainly for pitch angle) comparison for the 2 first maneuvers (TE) after the LEOP phase (sequence in the Figure 15) is presented in the Figure 13.

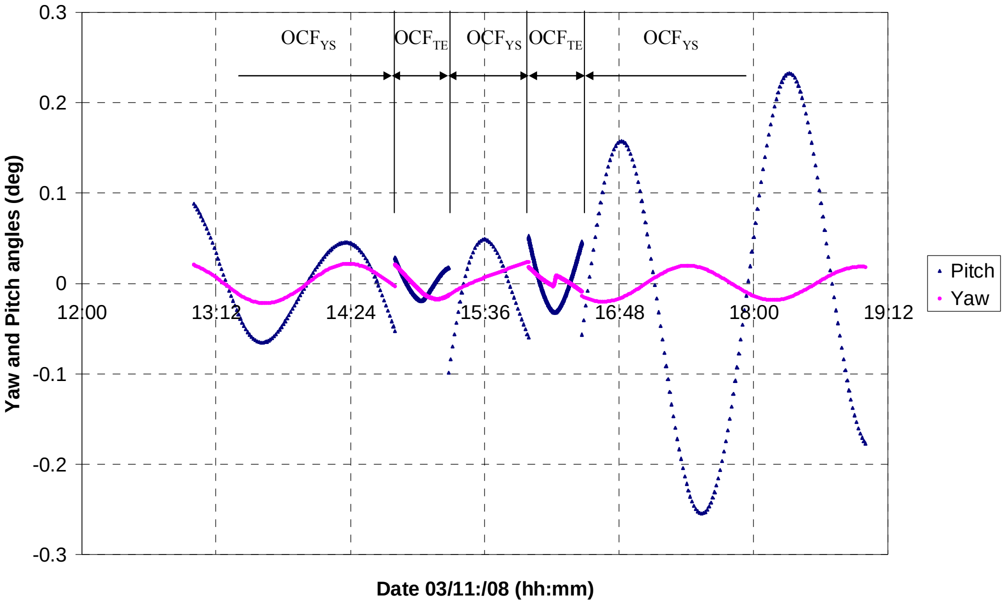

Figure 13. OCF accuracy

10.2. Attitude Profile

Except specific parts of the mission (LEOP, RDV, Attached phase, …) and for maneuvers performed with OCS engine, the ATV attitude followed a Yaw-Steering law (YS) to optimize the solar panels orientation towards the Sun. For monitoring and forecasting purposes the FDS/TRA team generated attitude profiles during YS and during the ATV re-orientation maneuvers (Slew) to perform the OCS maneuvers.

The YS law necessitated only an ATV rotation around the axis Vehicle/Earth center (Yaw, Ψ) and 4 rotations of the solar panels (SGS) around their sole rotation axis. The theoretical optimal yaw angle law is governed by the equation:

$$\tan\Psi = \tan\left(\frac{\tan\beta}{\sin\theta}\right)$$

where β is the solar elevation (see Figure 14) and θ is the orbital position from local noon.

In order to avoid a large rotation dynamic for small β, the Ψ law was approximated by a third order polynomial law in θ. The Yaw angle range was [β, π-β].

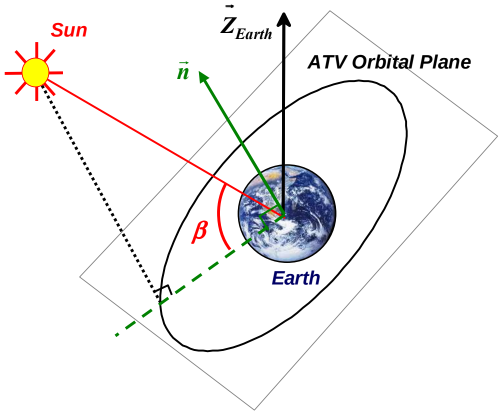

Figure 14 Solar Angle Definition

The slew maneuvers, computed by ground, were rotations from YS to OCS maneuver thrust direction. The slew maneuvers were 3 dimensional rotations composed of an acquisition velocity phase (<10s), of a constant velocity rotation (duration depending on the rotation to perform <10 min) and of a deceleration phase (<10s). On-board and on-ground algorithms are similar. The sequence that was obtained for the 2 first maneuvers (TE) after the LEOP phase is presented in the Figure 15.

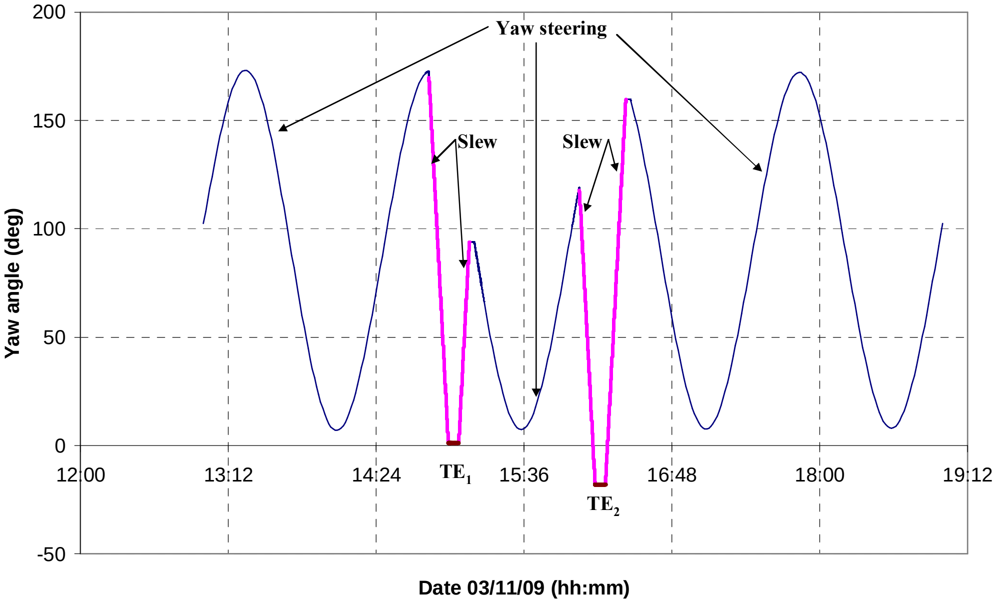

Figure 15. Two First Slew-Boost-Slew In-flight Sequence

Yaw angles during the OCS maneuvers were not null because out-of-plane components were uploaded to correct the orbital plane for the rendezvous phase. The FDS team was in charge of computing the timeline sequence and the quaternions to be targeted by on-board algorithm.

11. CONCLUSION

The First ATV mission - Jules Verne - was successful. It was a long and unusual mission as far as the Flight Dynamics System is concerned, because of the need of the demonstration days and the rephasing phase before the re-entry.

Sixty maneuvers were up-loaded and several maneuver plans were investigated to recover the contingency situations as the debris avoidance and the TV abort cycle during transfer to DD1.

The operational tools and teams demonstrated their robustness to analyze nominal and alternative maneuver plans which led to arrival at “Aimed points” on-time and with the prescribed accuracy.

Despite the late need for an ascent phase including the Parking and for an observation of the ATV re-entry, mission analysis had been conducted on time and the good operational organization led to a perfect observation gathering fruitful data to improve the knowledge of this part of the mission.

The next ATV mission duration will be shorter and will take the benefit of the lessons learned for Jules Verne flight.

[1] P. Labourdette & al., “Maneuver Plans for the First ATV Mission”, AAS 09-172, *19th AAS/AIAA Astrodynamics specialists Conference*, February 9-12, 2009, Savannah, Georgia.

[2] H. Cottet, L. Francillout, J.J. Wasbauer, “Overview of ATV Flight Dynamics Operations”, AAS 09-207, *19th AAS/AIAA Astrodynamics specialists Conference*, February 9-12, 2009, Savannah, Georgia.

[3] J.F. Goester and al., "Maneuver Computation at ATV-CC", ISTS-2006-g-02, *25th International Symposium on Space Technology and Science* , 4-11 June., 2006, Kanazawa, Japan

[4] P. Labourdette, D. Carbonne, J.F. Goester, “ATV Phasing and Post-Escape”, *European workshop on space mission analysis*, ESOC, December 10-12, 2007.

[5] SLATEC Common Mathematical Library, http://www.netlib.org/slatec

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