CENTRE NATIONAL D'ÉTUDES SPATIALES

A5ES-ATV : Challenges and results of the first European controlled deorbitation for the upper composite of a launcher

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Contents

Generalities

- **1995, participation of Europe to the International Space Station Program → launch of ATV vehicle with Ariane 5.**

- **1999, vote of the Ariane 5 adaptation program → adaptation of launcher upper stage for multiple ballistic phases and ignitions.**

  Delegation of project activities by ESA to CNES

- **2008, ground qualification of A5ES-ATV and first flight on 9th of March**

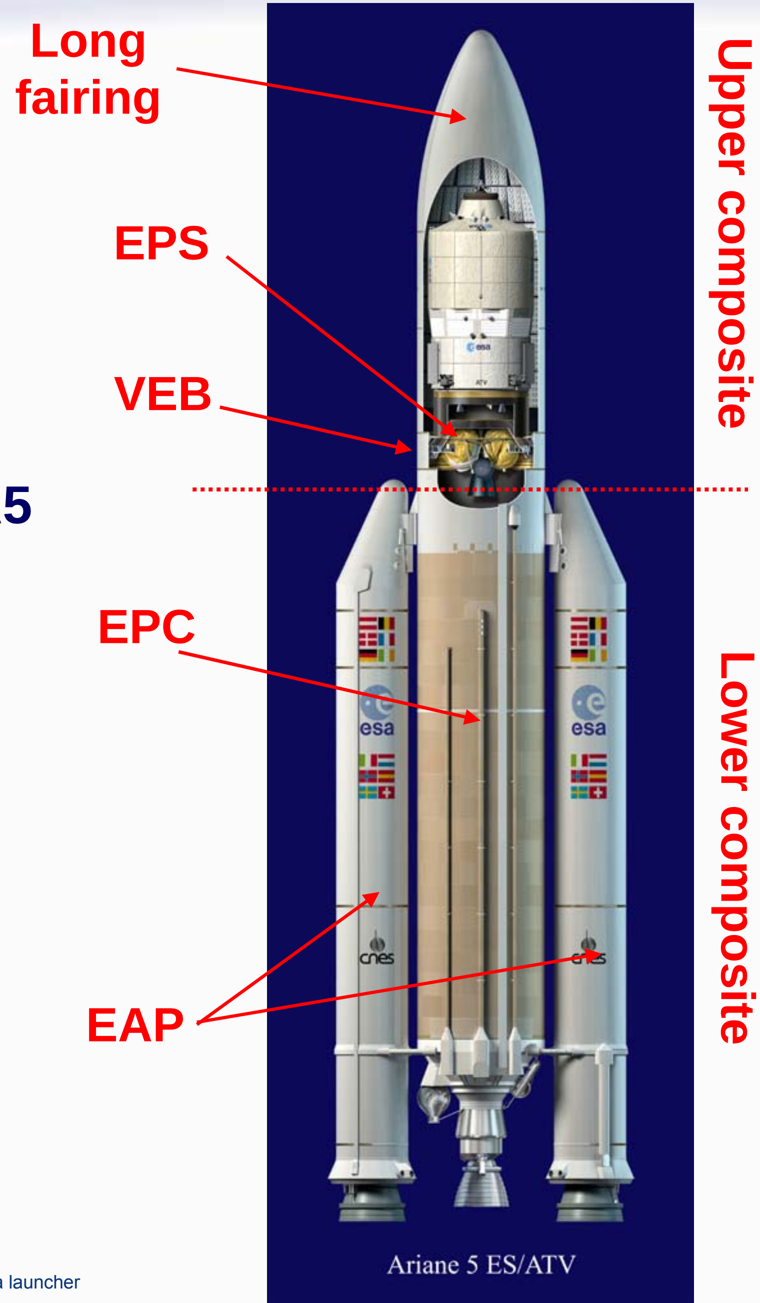
1996 – 2008 – 2005

A5GS – A5ES – A5ECA

Generalities

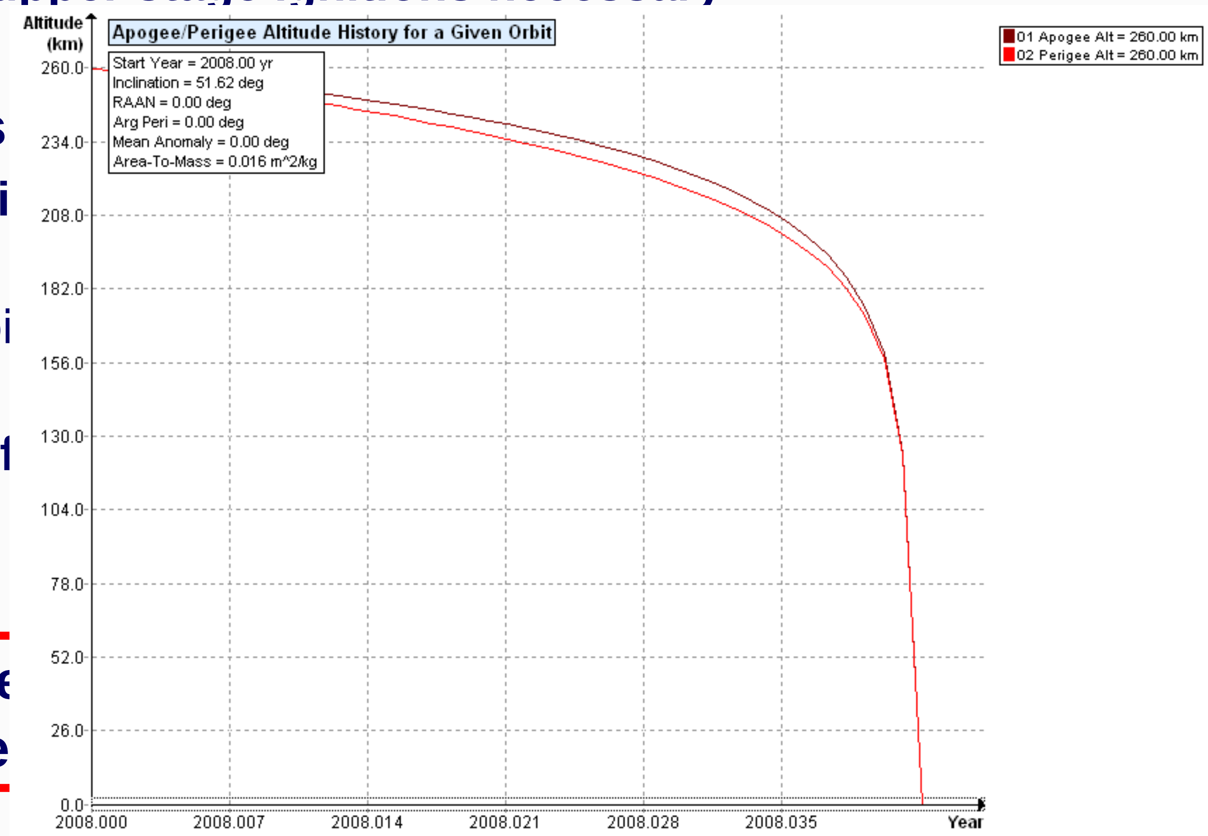
Ariane 5 ES launcher :

- Same lower composite as Ariane 5 ECA
- Adapted upper composite from generic A5
  - reinforced VEB (Vehicle Equipment Bay) equipped with 6 hydrazine tanks for the adapted ACS (Attitude Control System)
  - Underloaded EPS stage (Etage à Propergol Stockable) at 50%, with baffles
- Long fairing



- A5ES-ATV launcher mission
  - To place the vehicle ~20 tons directly onto a circular orbit at 260 km inclined at 51,62° → two upper stage ignitions necessary

- **Sensitiveness** of the miss
  - Inclination of 51,62° → flyi Europe or Asia
  - Intermediate and final orbi very short time
  - Operational re-ignitions of final orbit

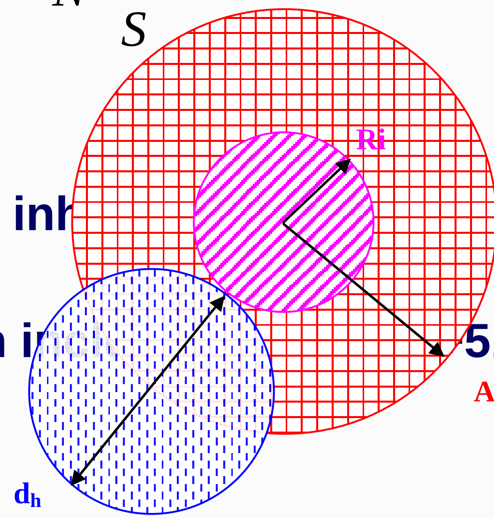


Decision to evaluate
because

Risk evaluation

■ **Equiprobability of casualties repartition with the longitude :**

$$p_{natural}^{EPS} = N\,\frac{A_C}{S}$$



- **where :**
  - **N represents the number of inh… limited by +51,6° and -51,6° of latitude**
  - **S is the surface of the Earth i… 51,6° and -51,6°**
  - **And Ac is the casualty area**

$$Ac_i = \pi\left(\frac{d_h}{2}+R_i\right)^2 = \left(\sqrt{\pi}*\frac{d_h}{2}+\sqrt{\pi}*R_i\right)^2 = \left(0,6+\sqrt{S_i}\right)^2$$

Risk evaluation

- A5ES-ATV mission : no specification in the CNES safety rules (considered as stable orbit) ; nevertheless compliance with Code of Conduct achieved

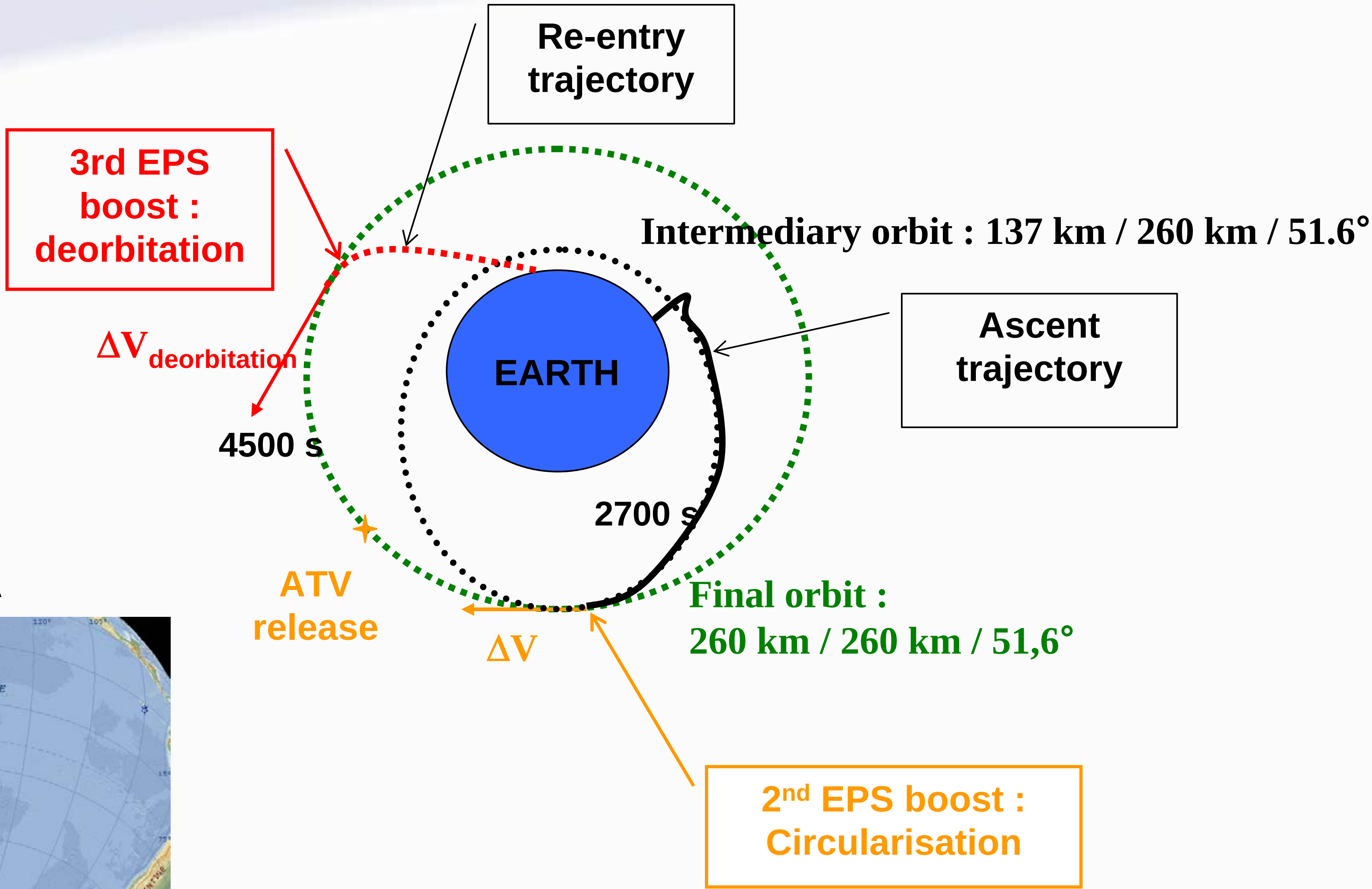
- Preliminary assessment for value of the risk (random re-entry) with different methods included between :

  4.10^{-4} and 7.10^{-4}

- So risk judged too high compared with the global risk specification for Ariane launch missions

ESA/CNES project decision to realise a controlled atmospheric re-entry of the launcher upper composite, ensuring all safety objectives

Deorbiting manoeuvre



SPOUA

Deorbiting manoeuvre

- Management of EPS propellant exhaustion risk + fixed time and duration boost

  → use of ACS boost to complete the nominal EPS one :

  - ΔV = 145 m/s in all dispersed cases
  - velocity flight path angle at 120 km and speed value of
    γ = - 2° and V = 7490 m/s

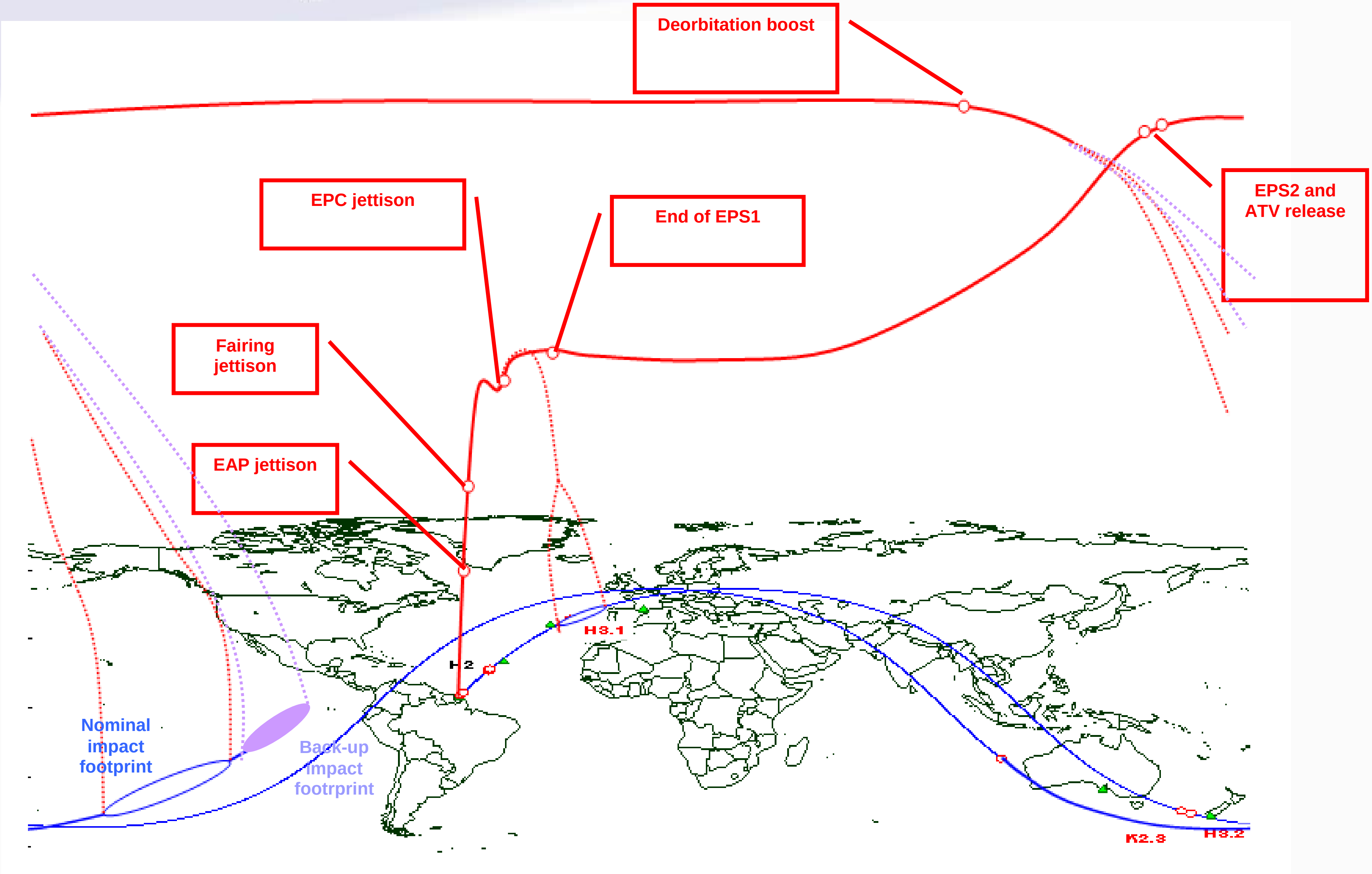
- Management of degraded cases (sensors, actuators, …)

  → necessity to be able to perform all the boost with ACS

  → 2 hydrazine tanks were added

  - ΔV = 80 m/s with a boost of ~350s long
  - γ = - 1,4° and V = 7540 m/s

Deorbiting manoeuvre

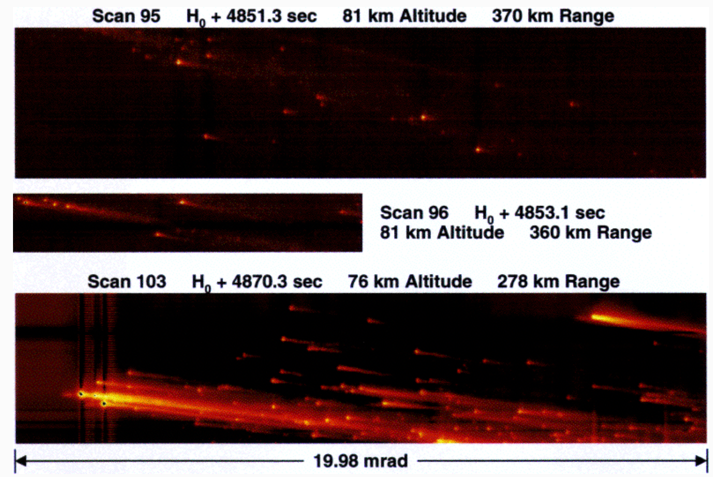


Impact footprint computation

- Determination of the fragmentation scenarii :
  - Experience → initiation of re-entry by thermal fluxes
  - Monte-carlo analysis → worst thermal fluxes on upper composite structures (EPS + VEB + SDM remaining part) → physical properties evolution and integrity limits for several composite orientations

- Case of SDM (separation and distancing module):

  • mechanical integrity not guaranteed between 110 and 105 km, whatever the composite orientation
  → computation of 2 independent pieces (SDM and EPS+VEB)
  • Similarity of material between SDM and SPELTRA → break up into several pieces and melting at reentry



- Case of tanks (N2O4, MMH and N2H4) :
  - Determination of orientation which protects as long as possible → angle of attack of 70° for a fragmentation altitude equal to 85 km
  - But still overheating of the tanks → study of different scenarii, with associated rupture altitude and debris ejection velocity

Impact footprint computation

N2O4 tanks	- Aluminium tank inner surface fusion - Hot point on the tank surface with contact with N204 liquid - N204 vapour pressure increase - N204 chemical decomposition
MMH tanks	- Aluminium tank inner surface fusion - Hot point on the tank surface with contact with MMH liquid - MMH vapour pressure increase - MMH chemical decomposition
N2H4 tanks (hydrazin)	- Titanium tank inner surface fusion - Nitrogen pressure increase (tank bursting) - N2H4 chemical decomposition (tank bursting)
He tank	- He pressure increase due to temperature increase

Results :

- **MMH and hydrazine tanks burst at high altitude (around 100km)**
- **N2O4 explosion below 100 km**

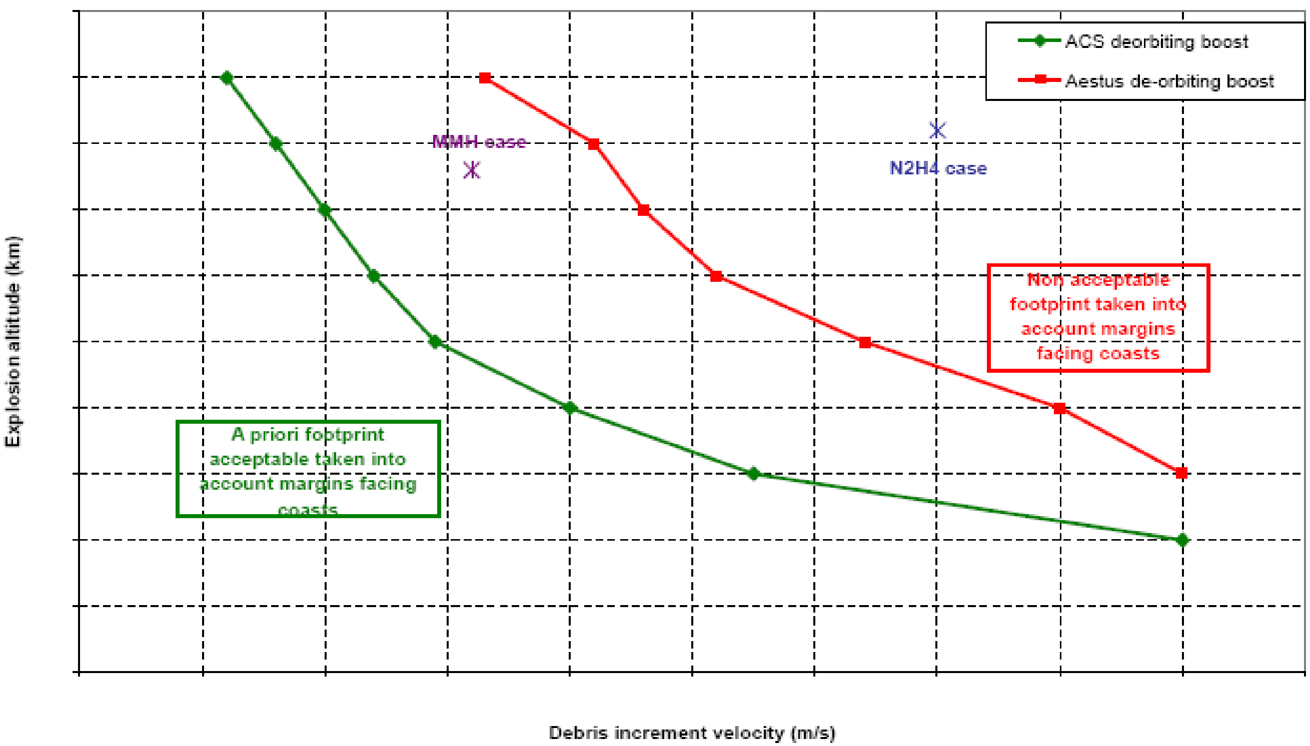
→ 2 sizing cases : burst due to propellants decomposition of MMH and N2H4

Determination of debris increment velocity :

- **Use of 2 different tools based on PYRO project (dated of 1968)**
- **Margin policy with use of most important values (few hundreds of m/s)**

Impact footprint computation

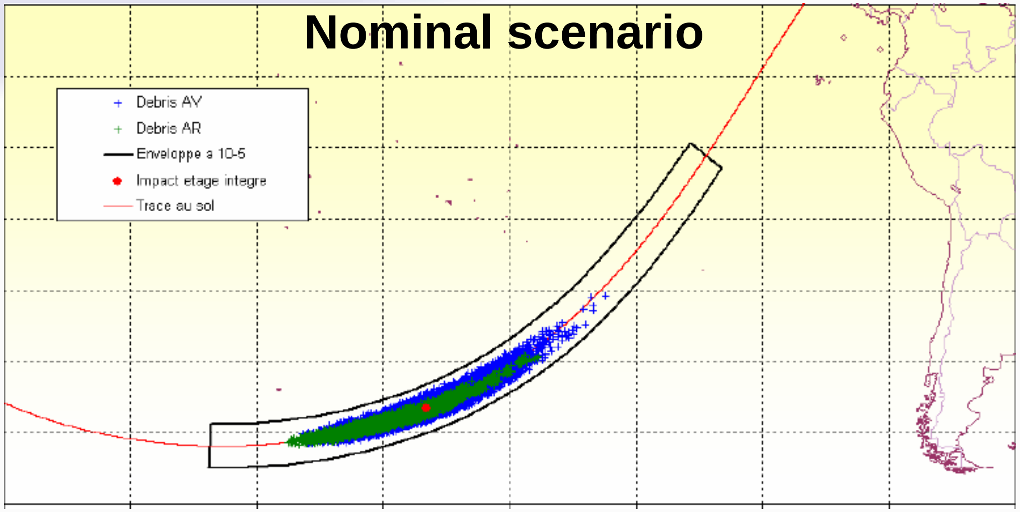
Sensibility of the impact footprint to the explosion altitude and to the debris increment velocity

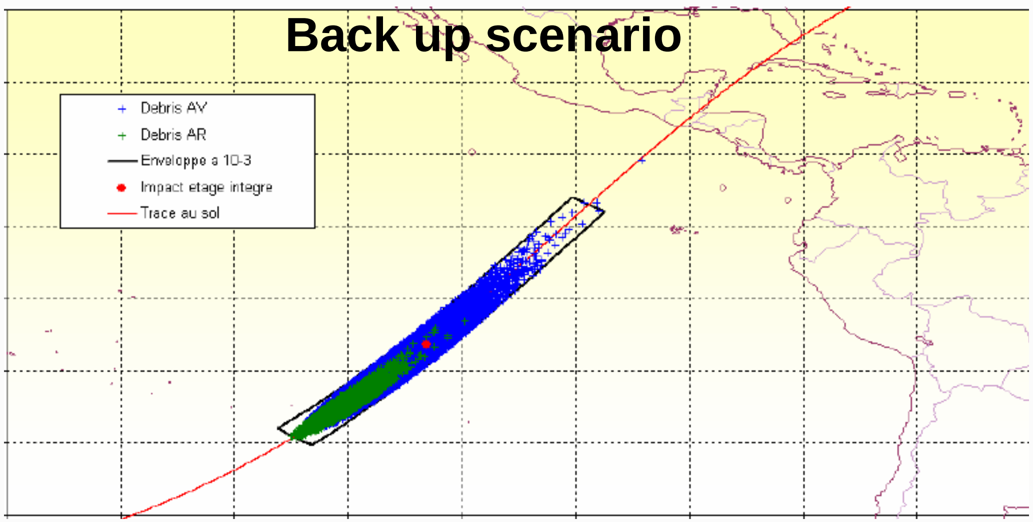


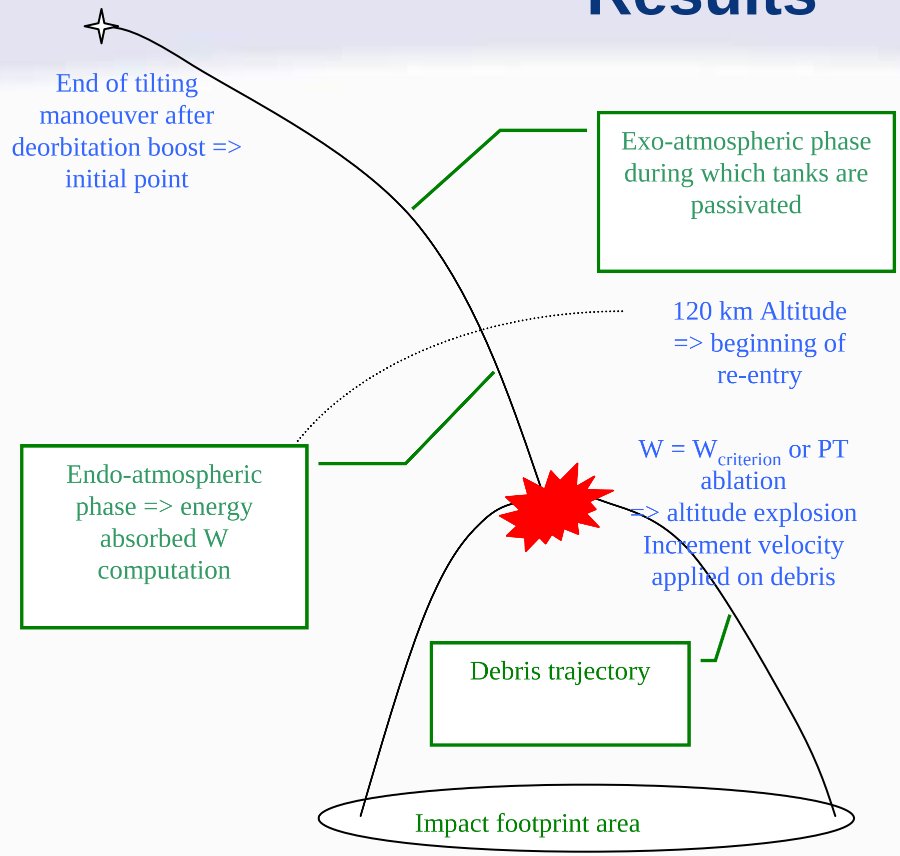
- Necessity to reduce altitude of the N2H4 scenario
  → addition of thermal protection on each N2H4 tank (a few mm of PROSIAL 2000)
  → decrease the altitude lower than 85 km
  → first burst = MMH tank

- Final results :
  determination of 1 unique criterion for explosion altitude / scenario / tank
  - MMH tanks explosion under energy absorbed during the re-entry
  - N2H4 tanks explosion after complete ablation of the thermal protection

Results







	Nominal scenario 99.999%	Back-up scenario 99.9%
Total length	~8780 km	~4510 km
Total width	~660 km	~425 km

The day of launch

- **Authorization of deorbitation** by all the successive onboard controls
- **Perfect tilting manoeuver** just after the deorbitation boost
- Perigee altitude of -178 km at the end of the boost
- Correct tanks passivation, consistent with forecast analysis
- At 120 km, loss of telemetry

Conclusion

- **Very good consistency between A5ES Upper Composite deorbitation observed in flight and forecast analysis.**
- **Successful European challenge for this first controlled deorbitation,**
  - **with a frozen design and dealing with all failure cases (even main propulsion failure)**
  - **Assuming all the consequences on the launcher qualification**
    material design adaptations, update of GNC algorithms, modification of fight software to implement controls before authorize the deorbitation, developpement and qualification of an other telemetry ground station…

The success of the A5ES-ATV flight and of the ATV mission afterward was the best award of this European initiative