6th IAASS Conference

DEBRISK,

CNES TOOL FOR RE-ENTRY SURVIVABILITY PREDICTION: VALIDATION AND SENSITIVITY ANALYSIS

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MONTREAL CANADA

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- LITERATURE TEST CASES COMPARISON
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- SENSITIVIY ANALYSIS
  - Convective heat flux
  - Break-up altitude
  - Orbit inclination
  - Atmospheric density
- CONCLUSIONS

CONTEXT

- The "French Space act" has been approved by French parliament in 2010, one main goal of this law is re-entry safety.
- Operators have to evaluate the risk during re-entry. CNES will provide tools to do so. One of these, is dedicated to prediction of debris reentry after breakup in the upper atmosphere.
- Such tools exist: SCARAB, DRAMA (ESA), ORSAT, DAS (NASA) … but they are "black boxes": no knowledge of inner workings … and there is no possibility to extend these tools according specific needs. CNES needs to have technical control of the codes.

  ➔CNES has decided to develop its own engineering tool DEBRISK.
- DEBRISK first release was distributed internally in April. Some phases of the validation process will be presented in this presentation.

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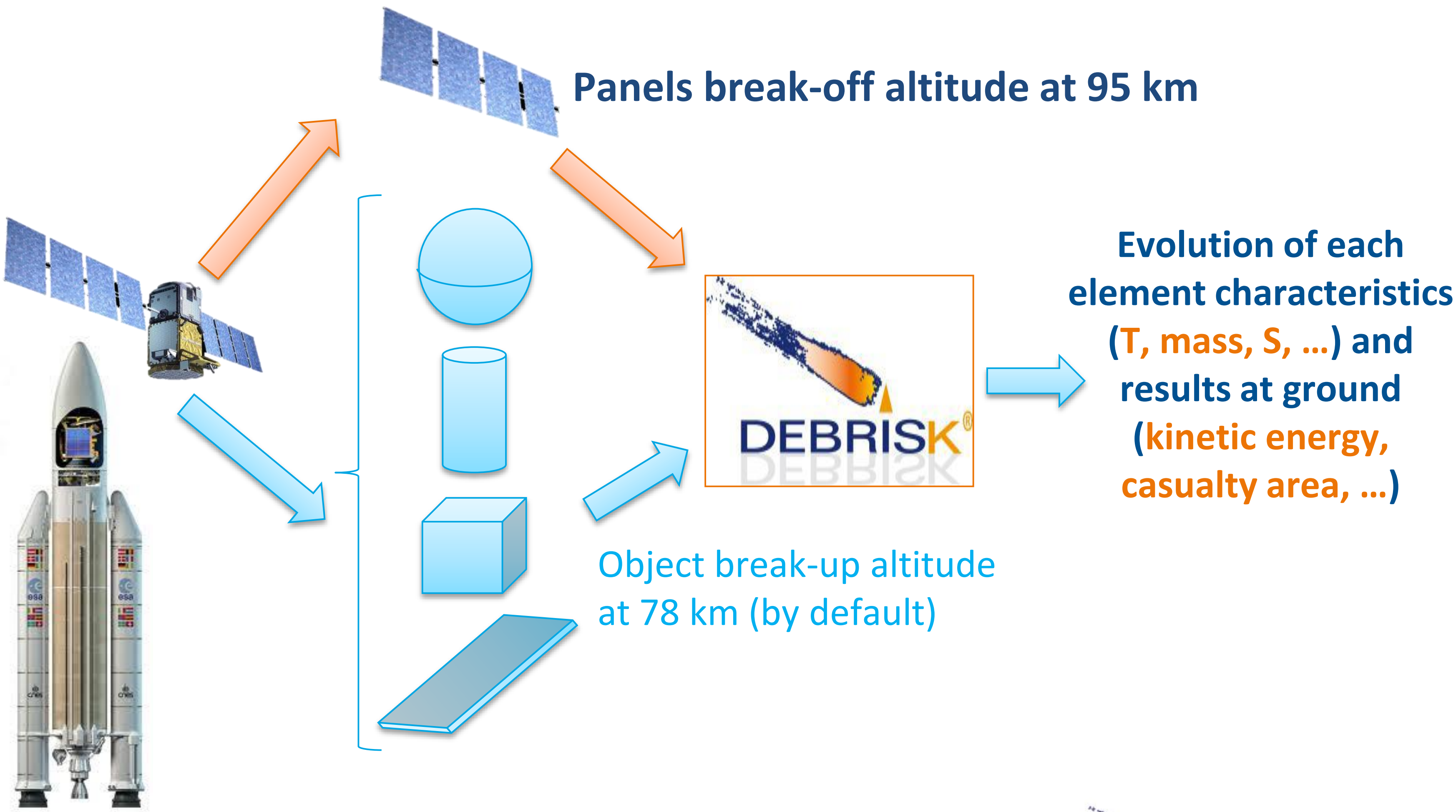
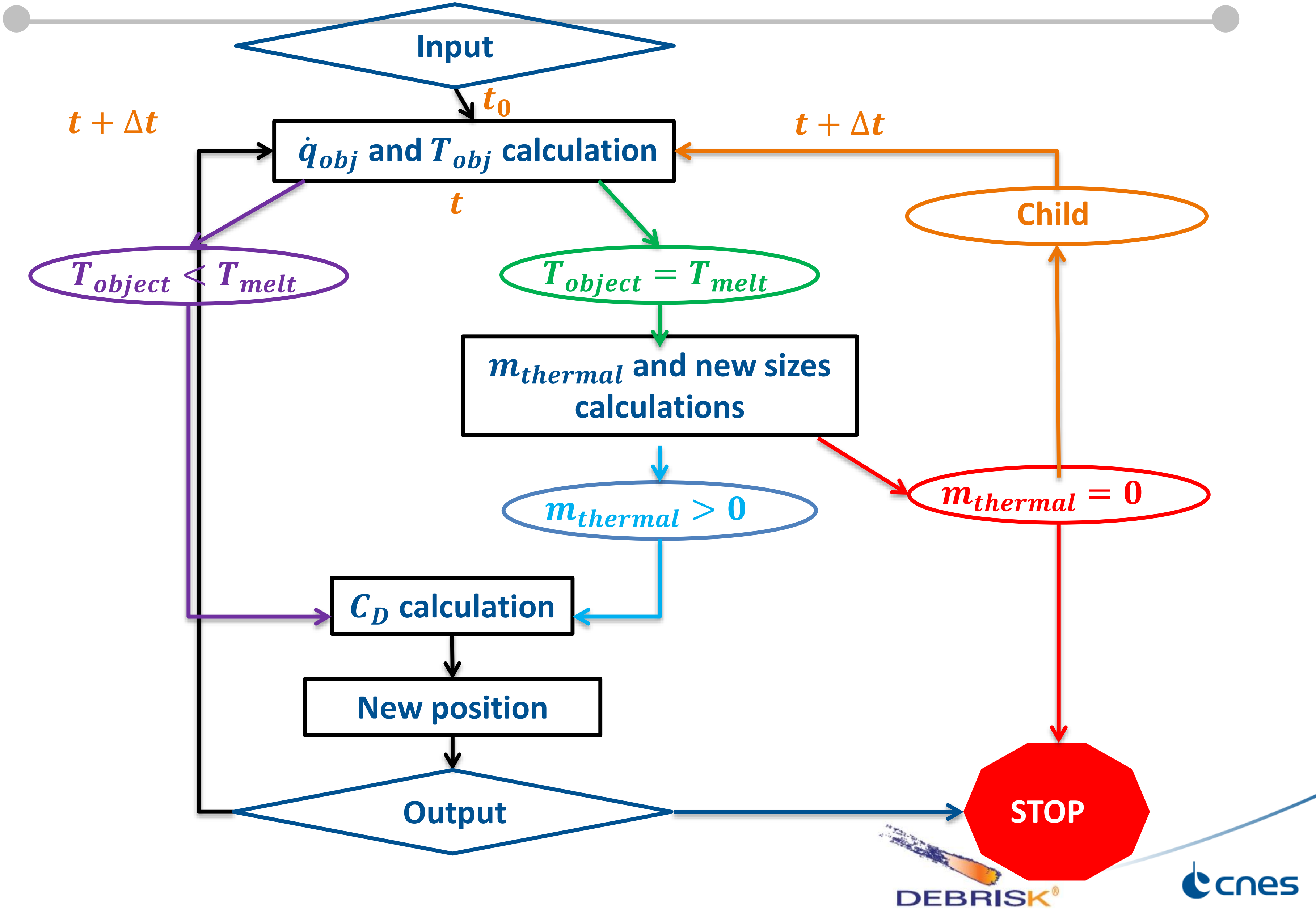
INTRODUCTION



ALGORITHM


Input
t_0
$t + \Delta t$
$\dot{q}_{obj}$ and T_{obj} calculation
$t + \Delta t$
t
Child
$T_{object} < T_{melt}$
$T_{object} = T_{melt}$
$m_{thermal}$ and new sizes calculations
$m_{thermal} > 0$
$m_{thermal} = 0$
C_D calculation
New position
Output
STOP
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LITERATURE TEST CASE COMPARISON

2ND STAGE OF THE DELTA II ROCKET

Previous comparisons with ORSAT results presented in literature have been done for 5th IAASS and differences were assigned to a difference in thermal modeling.

These comparisons were based on the paper :

<u>DELTA II second stage</u>

"SPACECRAFT ORBITAL, DEBRIS RE-ENTRY AEROTHERMAL ANALYSIS "

Wm. C. Rochelle, Robin E. Kinsey, Ethan A. Reid,and Robt C. Reynolds,Nicholas L. Johnson

Focused on the Steel Tank

Simulation use the same initial conditions and try to share the same assumptions:

- Atmosphere US76
- Material properties A410
- Initial temperature 300K

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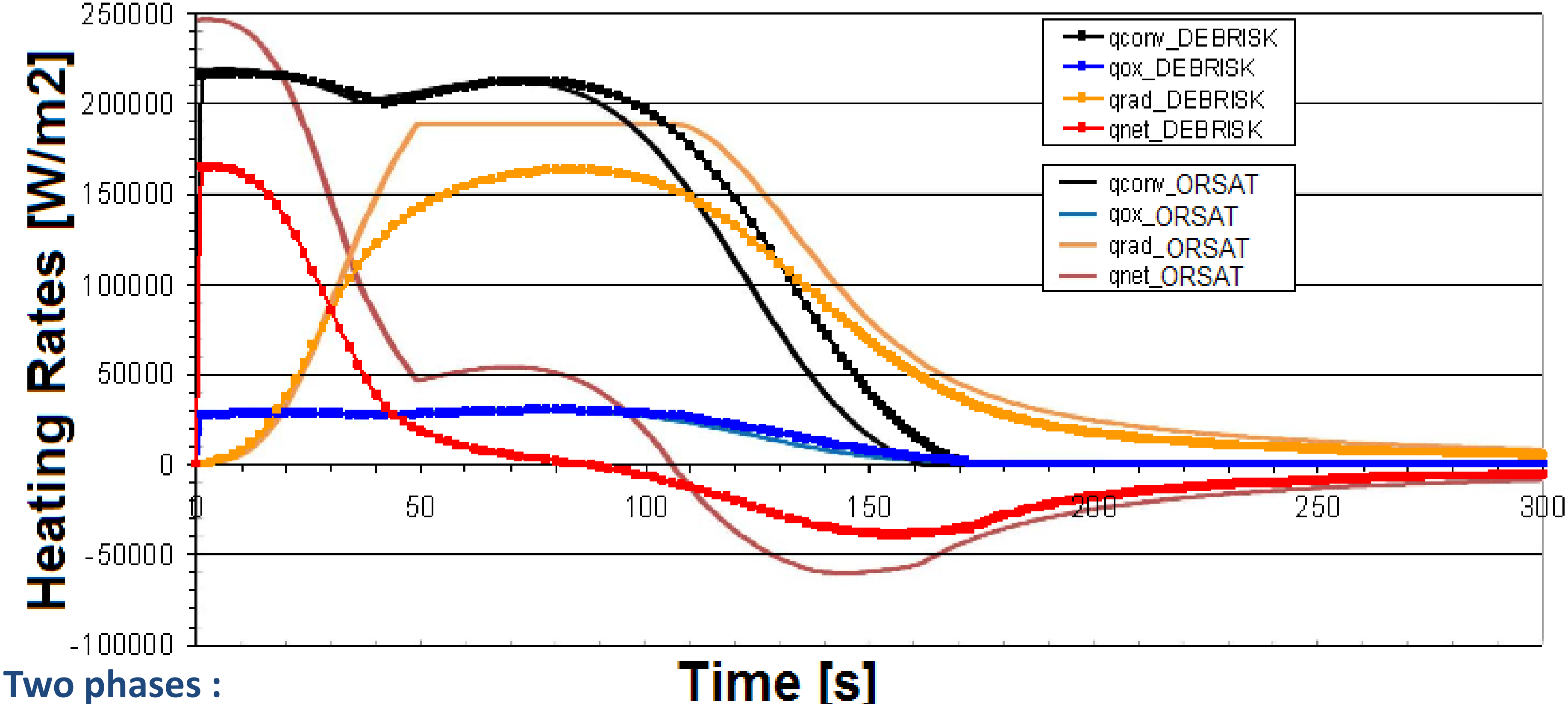
LITERATURE TEST CASE COMPARISON

2ND STAGE OF THE DELTA II ROCKET



Two phases :

- **First 45s all the fluxes except $\dot{q}_{net}$ (application surface) are exactly the same**
- **After 45s ablation starts in ORSAT so masse change and trajectory change in comparison to DEBRISK. That explains differences in heat fluxes at the end on the simulation.**

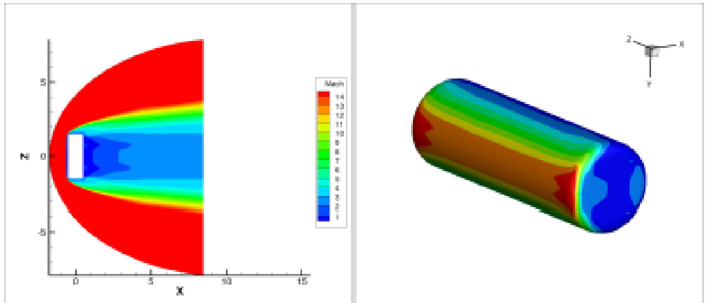
This study leads to a good understanding of the differences in the modeling, between ORSAT and DEBRISK.

CFD COMPARISONS - TEST CONDITIONS

- 3 cylinders
- 4 boxes
- 7 angles of attack
- 3 laminar flow conditions
- Drag coefficient and Heat fluxes are compared

	Spheres	Cylinders			Boxes			
N°	S1	C1	C2	C3	B1	B2	B3	B4
Lenght [m]	/	3	1	0,1	3	1	3	1
Width/ Diameter [m]	1	1	1	1	1	1	1	1
High [m]	/	/	/	/	1	1	0,1	0,1

Computations performed with Mistral code, used in various European re-entry projects



	Inflow Conditions		
Variables	A1	A2	A3
Altitude [km]	40	58	70
Density [kg/m3]	0,0037	0,00036	9,5E-05
Velocity [m/s]	2888	4769	5959
Temperature [K]	256	250	220
Wall Temperature [K]	700	700	700
Pressure [Pa]	272,72	26, 3	6,2
Mach	9	15	20
Re/L [1/m]	656275	98573	34557

CFD COMPARISONS - RESULTS

	Sphere
$\varepsilon_{C_D S_{aero}}$	[-5%,+5%]
$\varepsilon_{q_{conv} S_{th}}$	+20%

	Cylinder	
	$\frac{L}{D} > 1$	$\frac{L}{D} < 1$
$\varepsilon_{C_D S_{aero}}$	+10%	[-15%;-80%]
$\varepsilon_{q_{conv} S_{th}}$	+25%	[+5%;+20%]

	Boxes	
	$\frac{L}{W} > 1$	$\frac{L}{W} = 1$
$\varepsilon_{C_D S_{aero}}$	[-5%;-10%]	-20%
$\varepsilon_{q_{conv} S_{th}}$	[+35%;+45%]	[+20%;+30%]

	Plates	
	B3	B4
$\varepsilon_{C_D S_{aero}}$	-20%	-35%
$\varepsilon_{q_{conv} S_{th}}$	+30%	[+5%;+10%]

Discrepancies could be explained by:

- **CFD computations are done under laminar assumption**
  ➔ lower convective heat rate.
- **Analytical formulas have been established for design to protection (shuttles, …)**
  ➔ Higher convective heat rate.

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SENSITIVIY ANALYSIS

Uncertain Parameters:

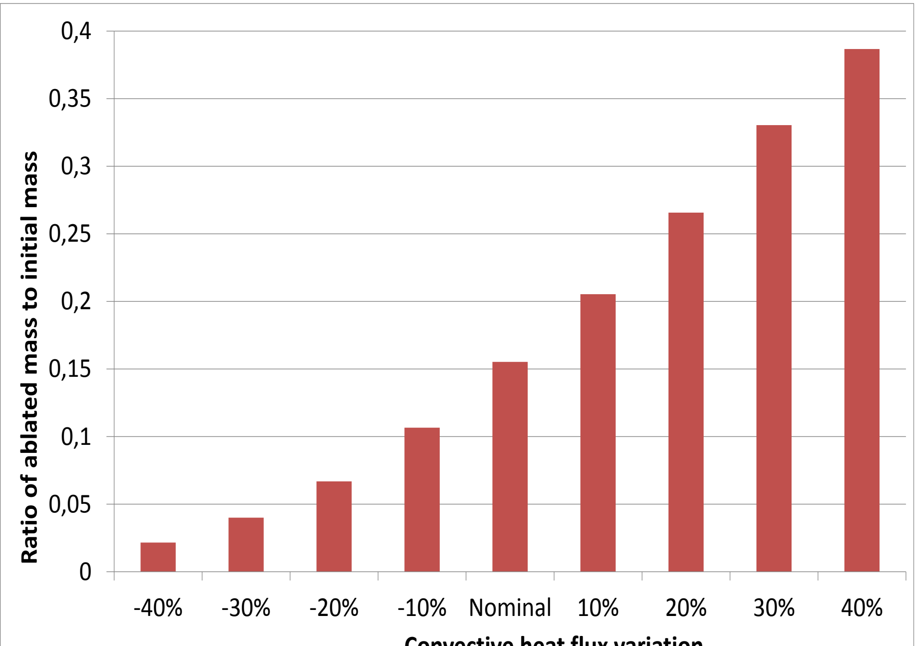
- convective heat flux
- spacecraft break-up altitude
- orbit inclination
- atmospheric density

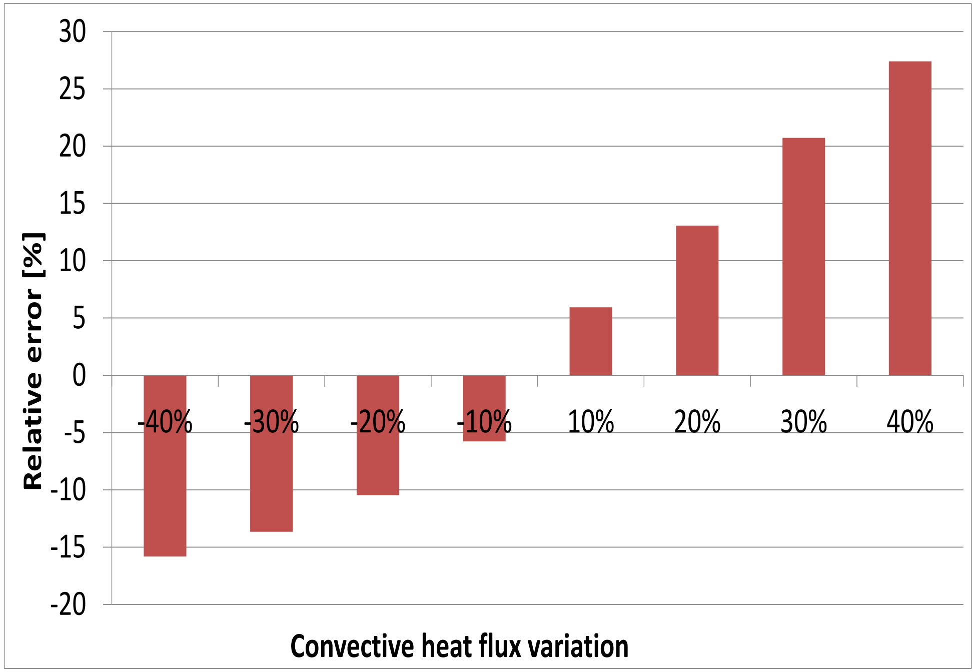
Tested Objects:

69 objects in aluminium spheres, cylinders, boxes and plates. Objects are hollow-shaped except plates.

Uncertain parameters	Variation regime
Break-up altitude	[70 km, 100 km], step size of 5 km included 78 km break-up altitude.
Orbit inclination	[0°, 180°], step size of 30°.
Atmospheric density	[-40%, +40%], step size 10%.
Convective heat flux	[-40%, +40%], step size 10%.

SENSITIVIY ANALYSIS - CONVECTIVE HEAT FLUXES

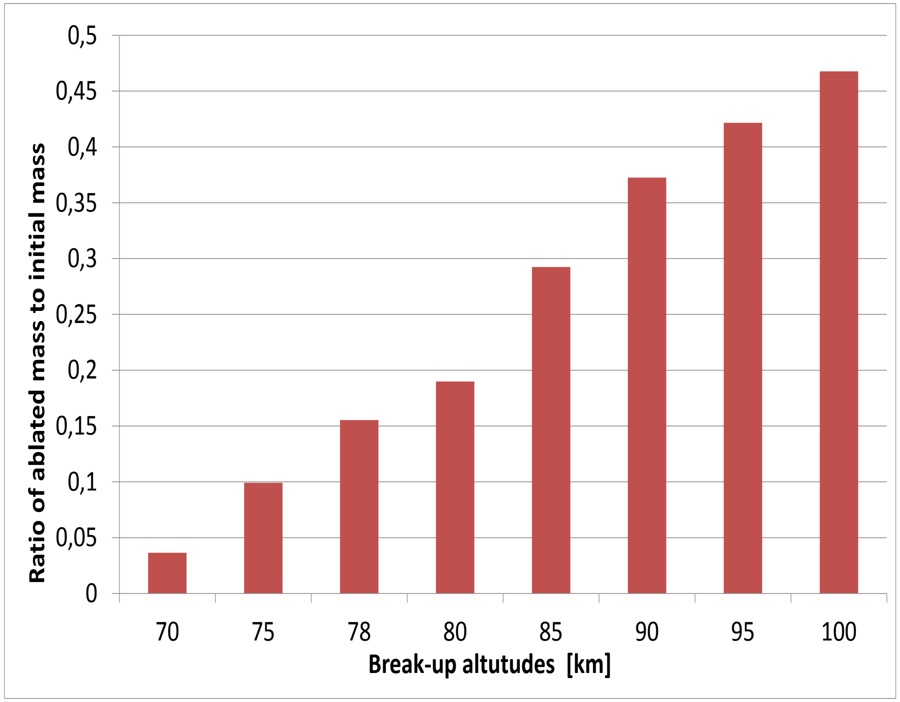


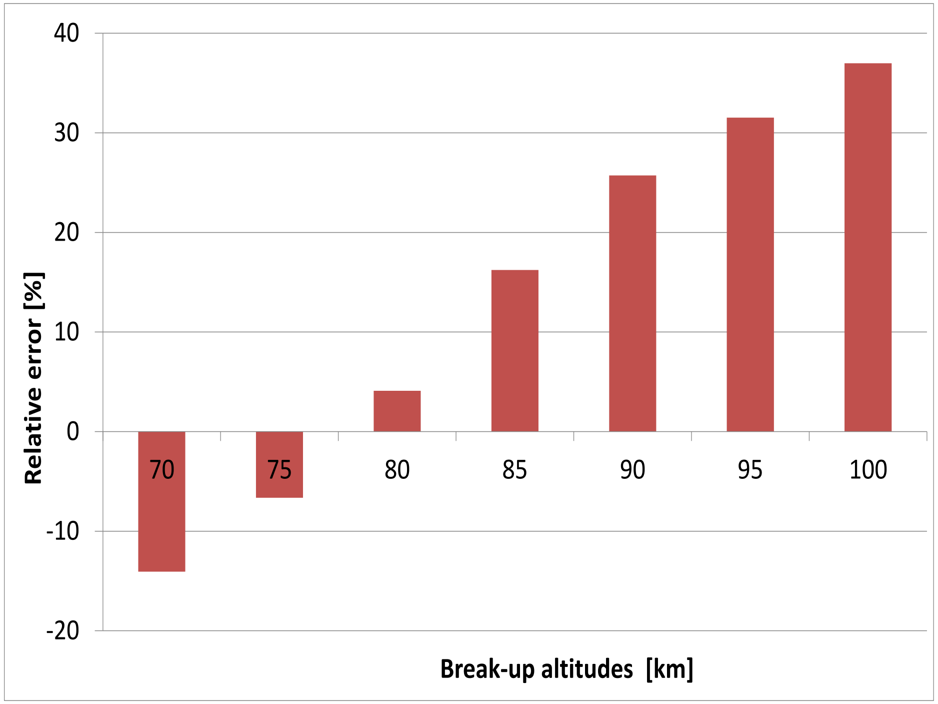


$$Error = \frac{End\ mass\ of\ nominal\ case - End\ mass\ of\ present\ case}{Initial\ mass\ of\ present\ case}$$

Higher convective fluxes ➔ A lower survivability

SENSITIVIY ANALYSIS - BREAK-UP ALTITUDE

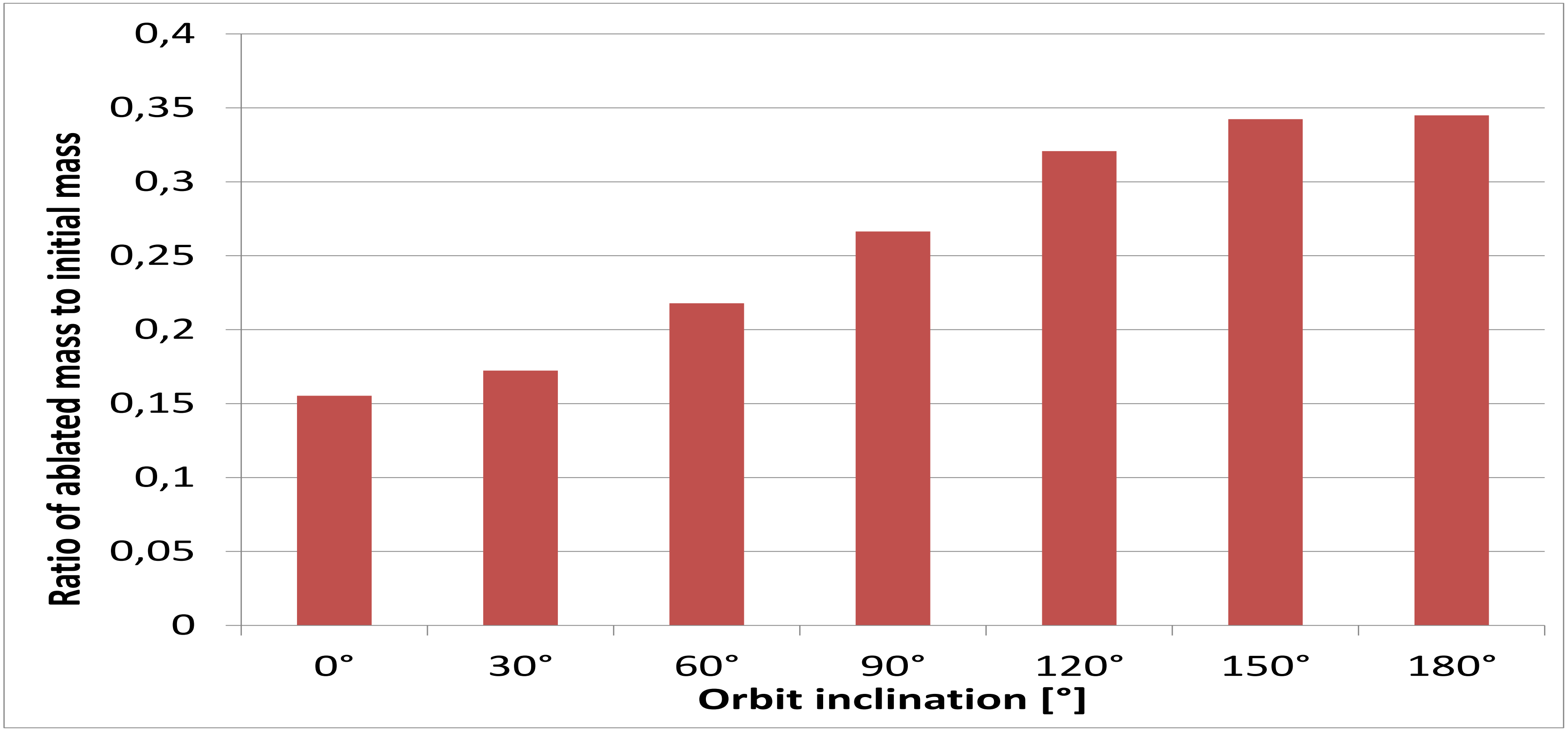




Higher break-up altitude

➔ Higher time exposition to fluxes.
➔ A lower survivability (less surviving mass and objects).

SENSITIVIY ANALYSIS - ORBIT INCLINATION

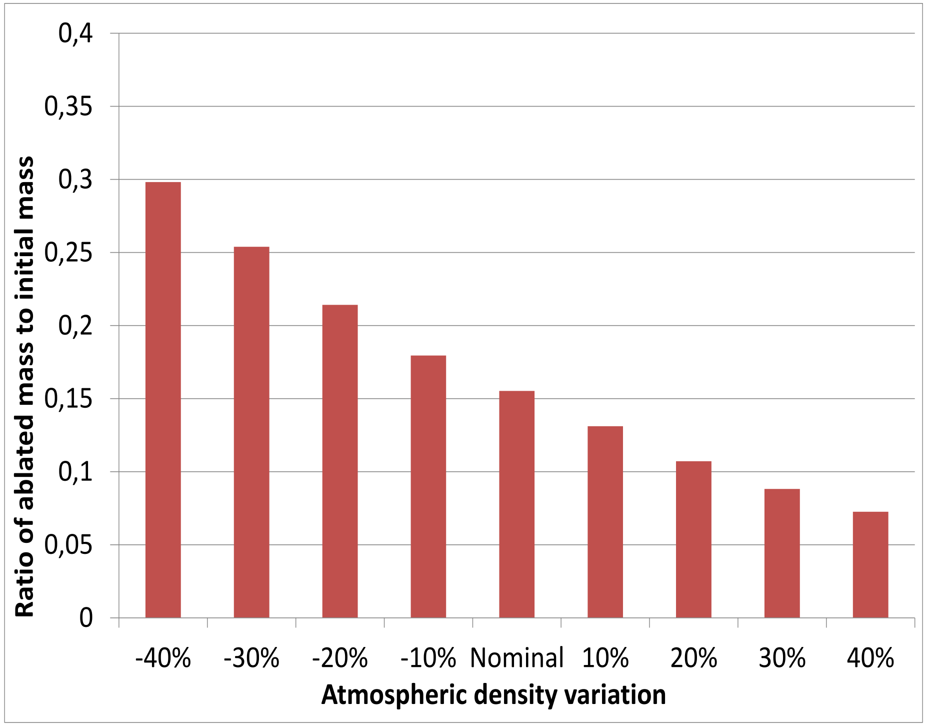


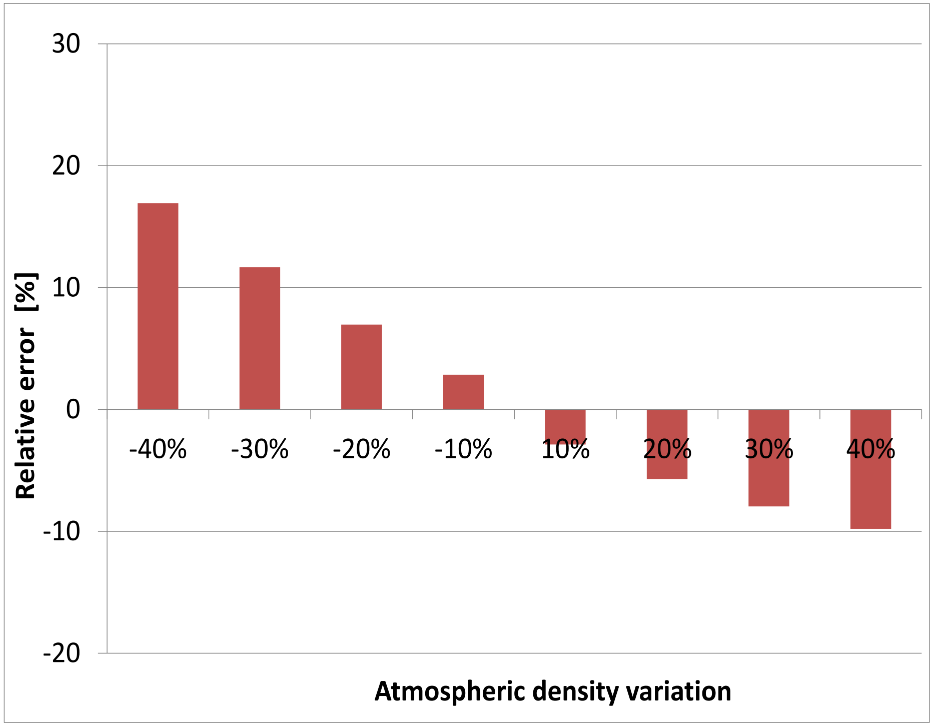
Increased orbit inclination

➔ Higher relative velocity between spacecraft and atmosphere.

➔ A lower survivability.

SENSITIVIY ANALYSIS - ATMOSPHERIC DENSITY





Lower density

➔ Lower deceleration ➔ higher velocity ➔ higher fluxes

➔ A lower survivability.

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SENSITIVIY ANALYSIS

	Relative errors		
Variation	Atmospheric Density	Convective Heat Flux	Break-Up Altitude
10%	-3%	6%	(85,8km) 17%
-10%	3%	-6%	(70,2km) -13%
40%	-10%	27%	(109,2) ~40%
-40%	17%	-15%	/

Relative errors between end mass and initial mass in comparison to the nominal case.

➔ The parameter that most influence the mass ablation during the re-entry is the break-up altitude

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CONCLUSION

- **DEBRISK is validated in comparison with ORSAT literature results.**
- **CFD results ➔ future efforts will be done for improvement/revision of analytical formulas (CFD and experiments campaign tests).**
- **Sensitivity results ➔ Fragmentation process (break-up altitude) will be analysed (CREATES project).**

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