GNC challenges for heavy active debris removal using blow effect to process or de-tumble debris

P.BRUN - 29/05/2013

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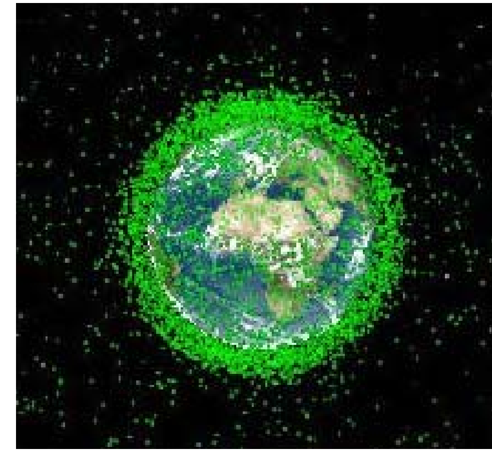
De-tumbling and processing by blowing
Context of the study



- "Kessler cascade effect" : evolution of debris population in Low Earth Orbit will increase due to collisions of objects

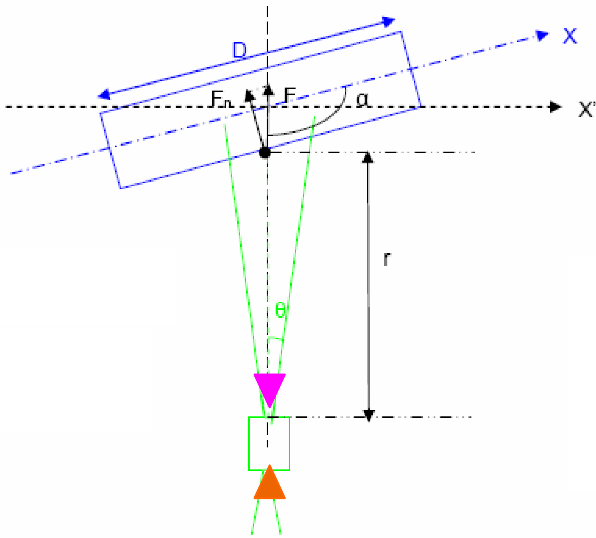
=> The active removal of 5 to 10 debris per year from Low Earth Orbit would reverse this cascade effect

- Many initiatives to cover the subject of Heavy Active Debris Removal at Astrium level :
  - CNES OTV – from 2010 on-going
  - ESA VAC project – 2012
  - Astrium internal R&T HADR – from 2012 on-going
  - CNES EASE – 2013 on-going

- GNC design of the spacecraft mainly driven by capture mean
  - Rigid link (e.g. use of clamps / robotic arm)
  - Flexible link (e.g. use of harpoon / net / bag / tether gripper)
  - Contactless solution (e.g. use blowing effect)

De-tumbling and processing by blowing
Context of the study

- Blowing effect = use of blow of thrusters existing in chaser propulsive architecture to process (modification of orbit) or de-tumble (modification of angular rate) a target => contactless method
- During the maneuver, a balance thruster is used to compensate the effect of the blowing thruster on the chaser
- The blowing effect can be either created by
  - a classical engine (e.g. Thrust = 220 N / Isp = 280 s)
  - or an electrical engine (e.g. Thrust = 0.1 N / Isp = 2500 s)
- Idea of the study is to have a “rule of thumb” to size mass to be allocated to such systems

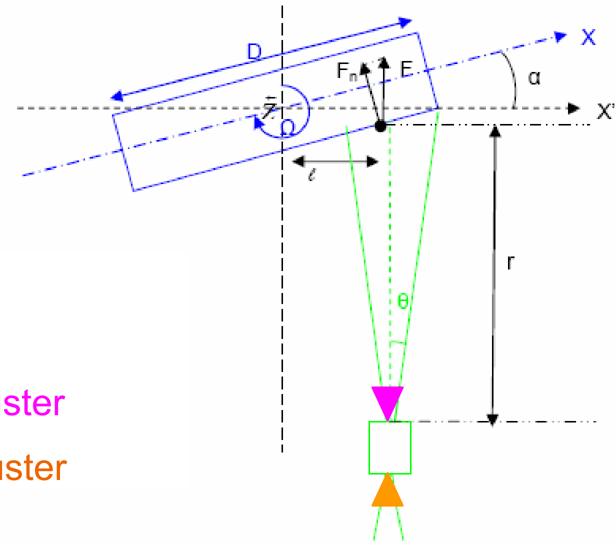


Target

Chaser

Blowing thruster

Balance thruster



Processing a target

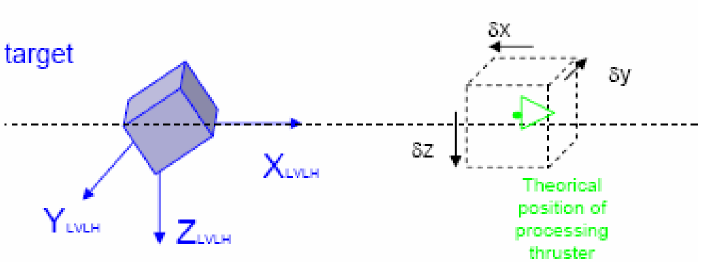
De-tumbling a target

De-tumbling and processing by blowing

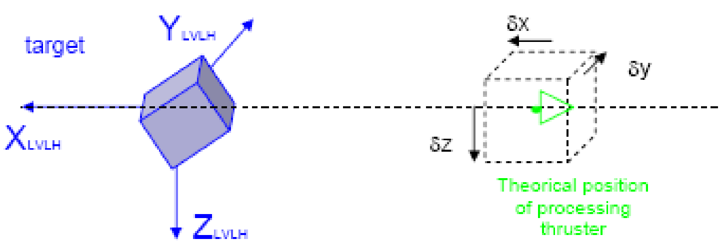
- Context of the study
- **Description of the processing maneuver**
- Description of the de-tumbling maneuver
- Estimation of consumption during maneuvers
- Application cases to a given architecture
- Conclusion

De-tumbling and processing by blowing
Processing with blow effect

- The processing maneuver with blow : modifying the orbit of a target by blowing on it with particles generated by engines of the chaser.
  - From the chaser point of view, this maneuver consists of reaching a station keeping box with coordinates (δx +/- X_{mean},δy,δz) in LVLH frame.
  - During this station keeping point, the blow direction should be constant with regard to LVLH attitude, oriented towards the aimed direction of DV



De-orbitation



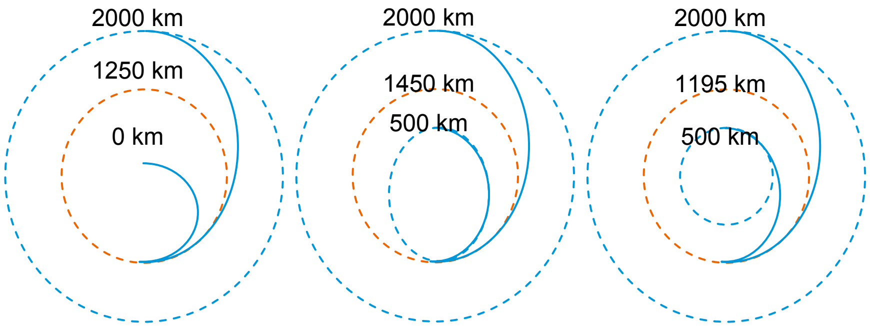
Re-orbitation

De-tumbling and processing by blowing
Processing with blow effect

- **Different scenarios for processing:**
  - **Controlled de-orbitation**
  - **Re-orbitation to graveyard orbit (2000 km altitude)**
  - **Uncontrolled de-orbitation (perigee at 500 km of altitude)**

Processing with classical engines

Processing with electrical engines



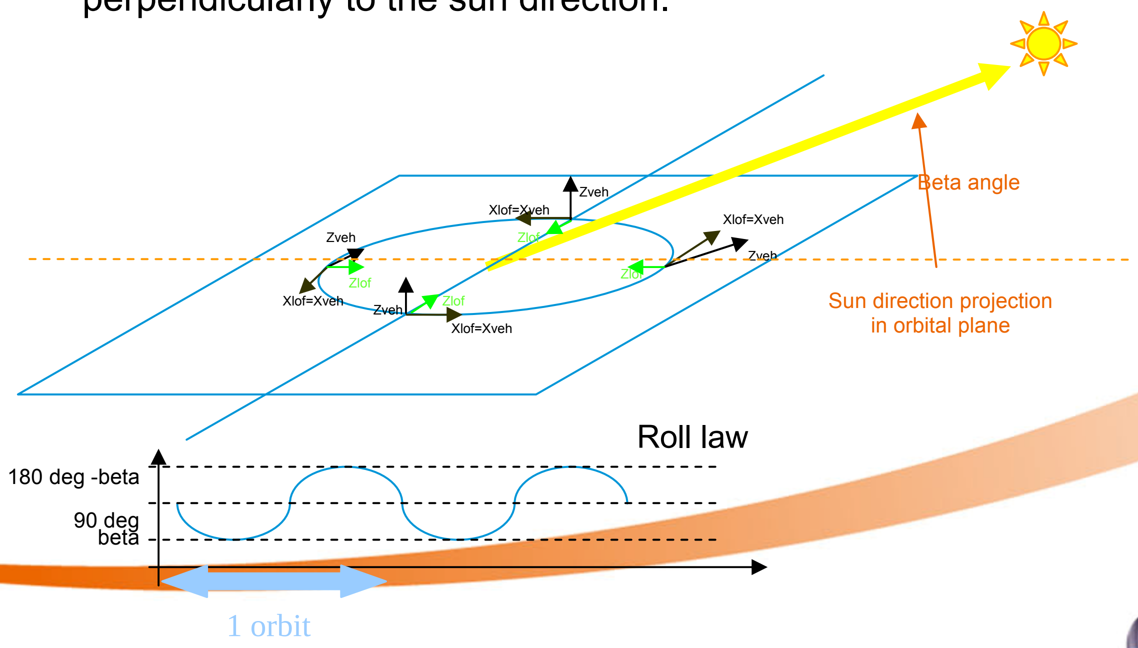
Scenario for target above limit	Re-orbitation	Re-orbitation	Re-orbitation
Scenario for target below limit	Controlled de-orbitation	Uncontrolled de-orbitation	Uncontrolled de-orbitation
Maximal DV budget	330 m/s	240 m/s	360 m/s
Hypothesis on the type of thrust	Quasi impulsional transfer	Quasi impulsional transfer	Low thrust transfer

De-tumbling and processing by blowing
Processing with blow effect

- GNC attitude strategy due to long duration of processing (up to 1 year, in case of electrical propulsion) :
  - X direction of the vehicle constrained by aimed direction of the DV (+/- X_{LVLH})
  - Need of optimized attitude from power point of view

= > « Roll steering » attitude (need of 1 degree of freedom for solar arrays) :

- $X_{vehicle}$ (direction of blowing of the vehicle) has to be aligned with +/-X_{LVLH}
- $Z_{vehicle}$ is oriented to have Sun in {$X_{vehicle}$, $Z_{vehicle}$} plane
- Solar arrays are supposed to have degree of freedom around $Y_{vehicle}$. As $Y_{vehicle}$ is perpendicular to the sun direction, the solar arrays can be oriented perpendicularly to the sun direction.



Drawback of this attitude : not optimized from communication point of view

De-tumbling and processing by blowing

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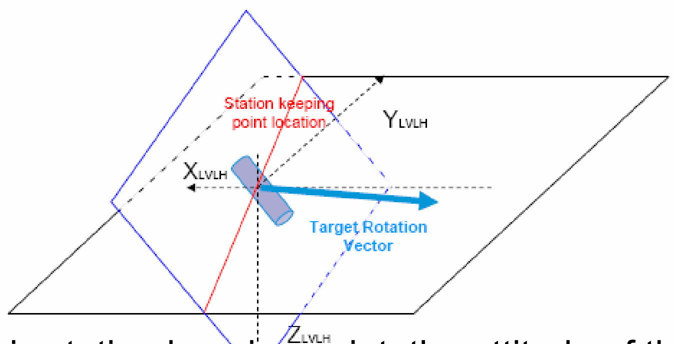
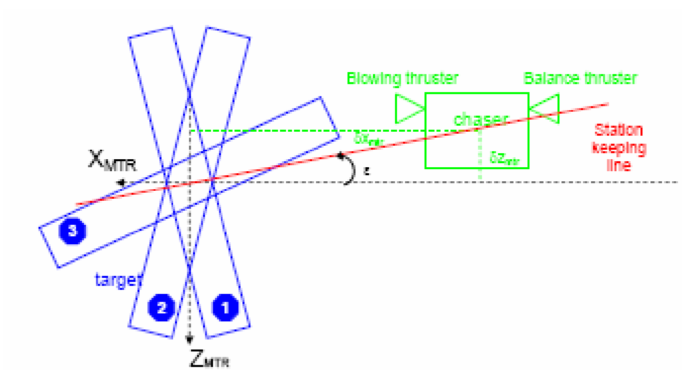
De-tumbling and processing by blowing
De-tumbling using blow effect

- The de-tumbling maneuver with blow : modifying the angular rate of a target by blowing on it with particles generated by engines of the chaser.
  - From the chaser point of view, this maneuver consists of reaching a station keeping box in LVLH frame. The station keeping point is chosen to minimize consumption (intersection of Xlvlh/Ylvlh plane and rotation plane of the target):



$$0 = \gamma_x$$
$$\omega^2 Y = \gamma_y$$
$$-3\omega^2 Z = \gamma_z$$

  - During this station keeping point, the attitude of the chaser should be correctly oriented towards the target.



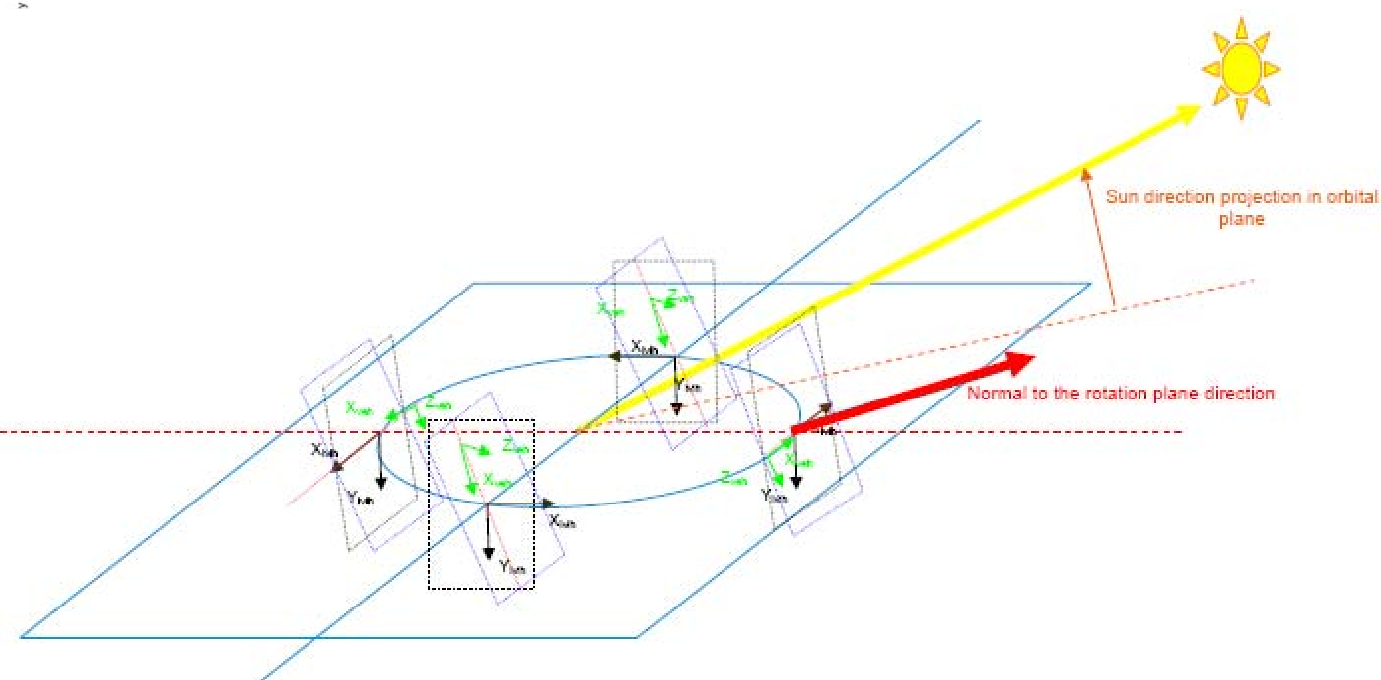
Distance and orientation of the target wrt chaser during de-tumbling maneuver derived from OTV study

De-tumbling and processing by blowing
De-tumbling using blow effect

- GNC attitude strategy due to long duration of processing (up to 2 weeks, in case of electrical propulsion) :
  - X direction of the vehicle constrained by aimed direction of the blow
  - Need of optimized attitude from power point of view

=>Attitude derived from "roll steering" attitude (need of 1 degree of freedom for solar arrays)

- $X_{vehicle}$ (direction of blowing of the vehicle) is perpendicular to direction of rotation **N** of the target and oriented to form an ε angle with station keeping point location line.
- $Z_{vehicle}$ oriented to have Sun in $\{X_{vehicle}, Z_{vehicle}\}$ plane.
- Solar arrays are supposed to have degree of freedom around $Y_{vehicle}$. As $Y_{vehicle}$ is perpendicular to the sun direction, the solar arrays can be oriented perpendicularly to the sun direction.



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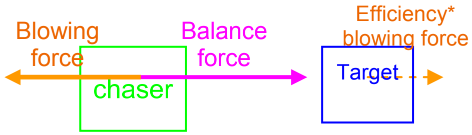
De-tumbling and processing by blowing
Consumption during processing or de-tumbling phases

Processing and balance thrusters budget



$$\Delta m = \frac{2m_T + \eta \cdot m_C}{\eta} \cdot \left[1 - \exp\left(\frac{-\Delta V_T}{g_0 Isp} \right) \right]$$

Mass chaser / Mass target / Efficiency of blowing / DV of the maneuver

Theoretical station keeping consumption

Station keeping point location chosen to minimize propulsive acceleration needed using CW equations

$$0 = \gamma_x$$
$$\omega^2 Y = \gamma_y$$
$$-3\omega^2 Z = \gamma_z$$

$$\Delta m = \frac{m_c * \omega^2 Y * \Delta t}{\varepsilon * g_0 * Isv}$$

Mass chaser / Duration of maneuvre / Efficiency of propulsive configuration

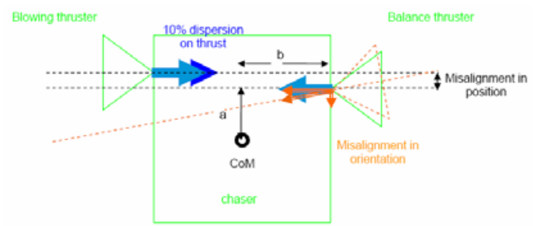
Position control consumption around theoretical trajectory

Consumption around a station keeping point derived from ATV consumption on S3 and S4 points

$$consumption_{vehicle2} = \frac{mass_2 DV_{vehicle2}}{g_0 Isv_{vehicle2}} = \frac{F_{MIB2}}{F_{MIBATV}} \frac{Isv_{ATV}}{Isv_{vehicle2}} consumption_{ATV}$$

MIB level chaser / Mass chaser / Isv chaser / Duration of maneuvre

Blowing thrusters performances and misalignment budget



Force disturbance due to dispersion on thrust level

Torque disturbance due to dispersion on thruster location and thruster orientation

Dispersion on blowing thrust at steady state / Position of blowing and balance thrusters

Attitude control consumption

Reaction wheels to be used for blowing with electrical thrusters (due to long duration). Attitude profile chosen to have mean null acceleration over one orbit. Only de-saturation effects due to perturbations => order of magnitude neglected for this study

MIB level chaser / Inertia of chaser / Duration of the maneuver

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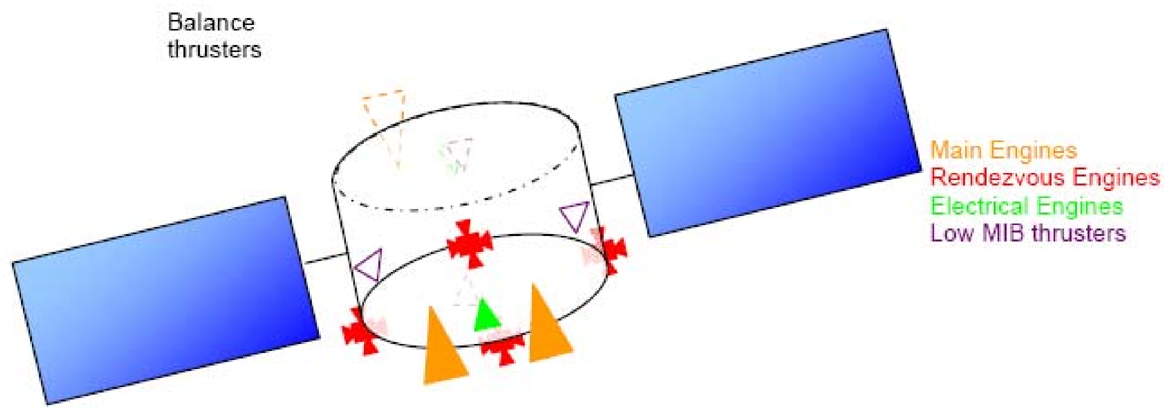
De-tumbling and processing by blowing Application case

- Additional propulsive architecture
  - Addition of a balance thruster with same characteristics as phasing thruster
  - For electrical blowing : Addition of 4 low MIB thrusters to control position during the maneuvre

Chaser Class	Light vehicle
Mass	1500 kg
Inertia	1100 kg.m^2
Available power level	5 kW

Target class	Medium (H10 like)
Mass	2000 kg
Inertia	28000 kg.m^2



Chaser Class	Main Engine	Electrical Engine	Rendez-vous engine	Low MIB thrusters
Light vehicle	500 N Isv = 300s	0.06 N Isv = 2500s	22 N Isv= 280s MIB 0.5Ns	Isv = 3000s MIB 0.004 Ns

De-tumbling and processing by blowing
Application case

		Processing chemical	De-tumbling chemical
Chaser		**Light Vehicle**	**Light Vehicle**
Target mass	**kg**	**2000**	**2000**
Processing duration		65 mn	84 s
Processing and balance thruster	kg	1623	4,12
Theoretical station keeping point	kg	0	0,00
Position control	kg	15	0,33
Misalignment torque compensation	kg	43	0,11
Misalignment force compensation	kg	440	1,13
Total consumption	**kg**	**2121**	**5,70**

- Major contributor is balance & processing thruster
- Processing : Level of magnitude of the consumption ~ mass of the target
  => Limitation of the method to small debris
- De-tumbling : reasonable consumption and duration of the maneuver

De-tumbling and processing by blowing
Application case

		Processing electrical	De-tumbling electrical
Chaser		**Light Vehicle**	**Light Vehicle**
Target mass	**kg**	**2000**	**2000**
Processing duration		166 days	79 hours
Processing and balance thruster	kg	95	0,20
Theoretical station keeping point	kg	0	0,16
Position control	kg	42	0,89
Misalignment torque compensation	kg	2	0,00
Misalignment force compensation	kg	19	0,04
Total consumption	**kg**	**159**	**1,30**

- Main contributors : Processing & balance thrusters / position control
- Propulsive architecture complexity is increased
- Processing :
  - too long duration of the processing maneuvers can discard some configurations mass target/ mass chaser
  - Consumption for the phase ~ 10 to 20% mass of the target
- De-tumbling :
  - Duration and consumption reasonable during those phases

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De-tumbling and processing by blowing
Conclusion

- Some GNC attitude strategies allow performing de-tumbling and processing maneuvers with classical or electrical engines
- Adaptation of existing propulsive architectures is mandatory to be able to process or de-tumble with blow effect
- The order of magnitude of additional masses to add to a given architecture has been estimated.
  - The most promising application case for use of blowing effect is de-tumbling with classical or electrical engines.
  - De-tumbling with classical engines seems feasible without any heavy modifications of an architecture already dedicated to rendezvous.
  - De-tumbling with electrical thrusters leads to more complex propulsive architecture.