GNC CHALLENGES FOR HEAVY ACTIVE DEBRIS REMOVAL USING BLOW EFFECT TO PROCESS OR DE-TUMBLE DEBRIS

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Abstract: *This paper presents the Flight Control analysis of the use of the alternative blowing method on both processing phase (modification of orbit) and de-tumbling phase (modification of angular rate) for heavy debris. This paper details the constraints implied on the maneuver by the choice of blowing method and the drivers for Guidance, Navigation and Control design. A sizing method for consumption contributors has been applied to have first rough estimation of consumption during the maneuver. An application to a study case of the method is presented to show the impacts on the design of the spacecraft in terms of propulsive architecture and constraints on mission.*

Keywords: *Active Debris Removal, Blow effect, De-tumbling, Processing*

1. Context of the study

In the next 150 years, the “Kessler cascade” effect explains that the population of objects in space will increase due to collisions between already existing large objects with other objects. Large objects are identified as major contributors to debris creation because of their fragmentation through collisions and explosions. It has been predicted that the active removal of 5 to 10 large objects per year from Low Earth Orbit would reverse this cascade effect. The research and development of technologies related to active debris removal is therefore essential for heavy debris.

Astrium has investigated different spacecraft solutions for heavy active debris removal. Through these studies, the main driver identified for GNC design is the choice of the nature of the capture mean. The latter can be:

- a rigid link in case of capture with clamps or robotic arm,
- a flexible link, in case of capture with net or tether,
- or no link at all in case of contactless solution such as blowing effect described in this paper.

Solutions for spacecraft design including capture with a link between target and the spacecraft, can lead to strong constraints on the mission but also on the design of the vehicle. Therefore, in the search for optimal solutions for heavy active debris removal, alternative technologies without contact have been studied. In particular, the use of proximity blow effect of thrusters of the existing propulsive architecture of a spacecraft can be used during de-tumbling (to decease capture difficulty in case of highly rotating target) or during processing.

1.1 Description of the blowing effect

Blowing effect is the effect that modifies angular rate or velocity of the target from the interaction of the plume engine at close range with the surface of the target. The impingement of the beam of the thruster on the surface creates torque and force on it, by transfer to the target of the momentum carried by the particles of the beam. A balance thruster has to be used at the same time as the blowing thruster to compensate the effect of the blowing thruster on attitude and position of the chaser.

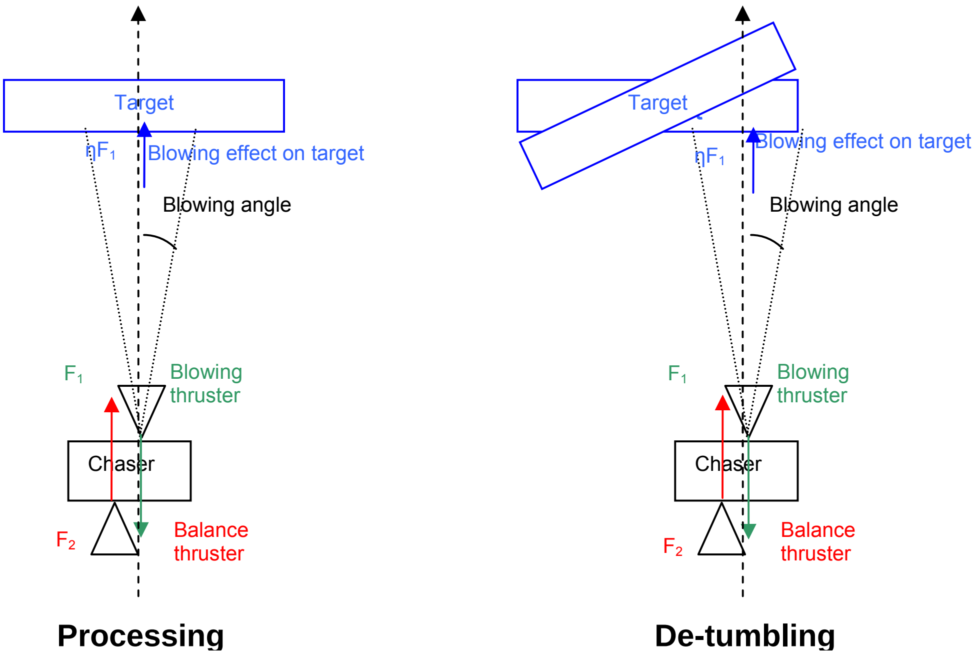


Figure 1. Blowing effect for processing and de-tumbling

The blowing effect on the target is considered parallel to the velocity of the particles in the beam and independent on the shape and the orientation of the target. To take into account the loss due to uncertainties in the interaction of the plume with the chaser and the fact that all particles in the beam do not impinge the target, an efficiency coefficient η shall be introduced to express the force applied on the target by the beam.

For chemical propulsion, the value of this efficiency coefficient η has been evaluated for different values of relative position wrt. the target and different blowing angles. The evaluation of force and torque created by the particles on the target has been performed with a simplified model of the plume effect on the surface of the target (software previously developed to assess the impact of ATV thrusters on ISS during the docking). The values used in this study correspond to a distance between target and chaser of 10 m and a blowing angle of 15 deg.

For electrical propulsion, the value of the efficiency coefficient used is a theoretical value, as no return of experiment was available to determine it.

1.2 Assumptions

The following assumptions have been used to perform this study:

- For de-tumbling cases, the target motion is a “flat spin” motion, which can be modeled by a rotation around one of the transversal axis of the target (angular velocity is taken equal to 6.5 deg/s)

- The blow effect can be created either by chemical or electrical propulsion. Application cases presented in this study correspond to the following characteristics of engines:

Table 1: Characteristics of blowing thrusters used for this study

	Chemical	**Electrical**
Isv	250 s	2500 s
Thrust level	220 N to 1750 N	0.02 N to 0.1 N
Efficiency of the blowing	34 %	80 % *
Power/thrust ratio	-	20 kW/N

- This study is limited to the de-tumbling and processing of “H10 like” targets (cylindrical shape). Different classes of target are evaluated in this study :

Table 2: Characteristics of target

Target class	**Light**	**Medium (H10 like)**	**Heavy**
Mass	700 kg	2000 kg	5000 kg
Inertia	4100 kg.m²	28000 kg.m²	110000 kg.m²

Different classes of chaser are considered in this study :

Table 3: Characteristics of chaser

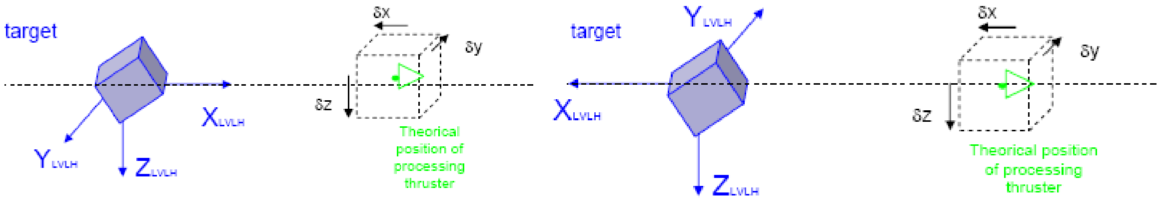
Chaser Class	**Kit**	**Light vehicle**	**Medium vehicle**
Mass	500 kg	1500 kg	5000 kg
Inertia	250 kg.m²	1100 kg.m²	8200 kg.m²
Available power level	2 kW	5 kW	20 kW

2. Description of the processing maneuver

2.1 Principle of the maneuver

The aim of such a maneuver is to modify 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 in reaching a station keeping box with an accuracy (δx,δy,δz) in Local Vertical Local Horizontal (LVLH) frame. During this station keeping point, the attitude of the chaser should be constant with regard to LVLH attitude, oriented towards the aimed direction of DV to be applied on the target and processing thruster should be oriented towards the target. The activation of the processing thruster should be balanced to ensure that the attitude of chaser is constant in LVLH, therefore a balance thruster is used to counter the action of the processing thruster. The modification of orbit of the target is realized while the blowing thruster and balance thruster are activated, which results in modifying the velocity of the target.

The most efficient direction to modify orbital parameters of the target is +/- X_{LVLH} (direction of the velocity vector of the target). Depending on the processing scenario (de-orbitation or re-orbitation), the processing device is located in front or behind the target, along X_{LVLH}.



De-orbitation of the target **Re-orbitation of the target**

Figure 2: Station keeping point location for processing of the target

2.2 Different scenarios for processing

The DV budget for the processing of a target depends on the initial altitude of the target and the hypothesis taken for transfer of DV. Indeed, different strategies can be envisioned for processing a target:

- Controlled de-orbitation (reentry orbit being defined with 0 km perigee) - NOTA: this strategy cannot be used in case of processing with electrical engines
- Re-orbitation to graveyard orbit (graveyard orbit being defined as orbit with 2000 km altitude)
- Uncontrolled de-orbitation (perigee of the uncontrolled reentry orbit being defined at 500 km of altitude)

The DV budget for the processing maneuver will depend on the processing method and the initial altitude of the target. Comparison of DV budget has been performed for the different strategies. The following table summarizes the maximal DV needed for a pair of strategies and the limit of altitude which defines the domain in which a strategy is more optimal than the other.

Table 4: Comparison of processing strategies

Limit of altitude between both strategies	1250 km	1450 km	1195 km
Scenario for target above limit of altitude	Re-orbitation	Re-orbitation	Re-orbitation
Scenario for target below limit of altitude	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 transfer associated to DV budget computed	Quasi impulsional	Quasi impulsional	Low thrust

2.3 Attitude strategy

As the processing phase can last up to one year (if electrical thrusters are used), the vehicle should stay in proximity of the target during the whole phase. During this station keeping phase, the attitude should be optimized from power point of view. As the axis of blowing needs to be constantly directed towards the target, a “roll steering” strategy is proposed to allow orientation of Solar Array towards the sun during the maneuver.
Such orientation is described below:

- $X_{vehicle}$ (direction of blowing of the vehicle) has to be aligned with $+/-X_{LVLH}$
- $Z_{vehicle}$ is oriented to have Sun direction 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.

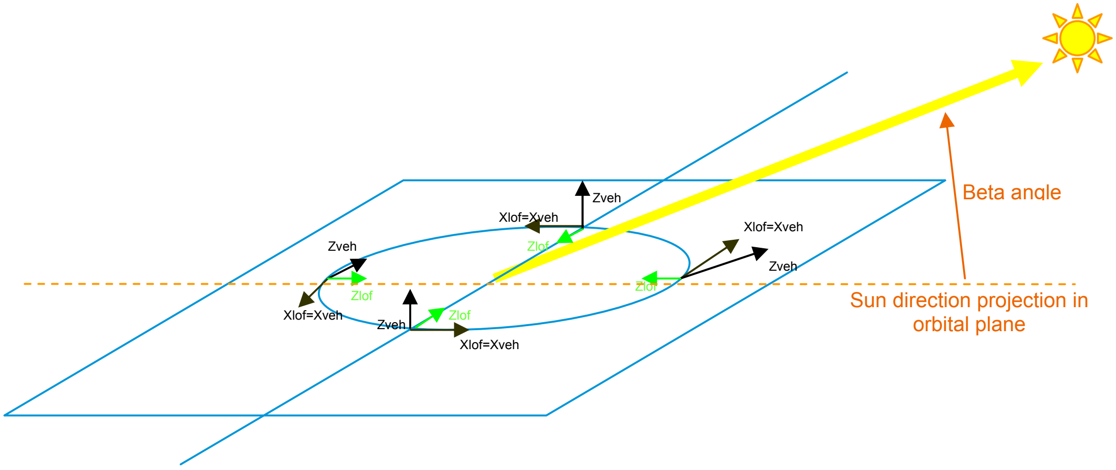


Figure 3: “Roll steering” attitude during processing maneuver

2.4 Duration of the maneuver

The acceleration of the target resulting from the effect of the blowing engine is $\frac{\eta F_1}{m_{T\arg et}}$ with notations of Figure 1.
The duration of the processing maneuver ΔT can be computed as follows:

$$\Delta T = \frac{m_{T\arg et} * \Delta V}{\eta F_1}$$

The level of thrust for blowing and balance thrusters in case of an electrical chaser is considered to use ½ of the available level of power.

3. Description of the de-tumbling maneuver

3.1 Principle of the maneuver

The de-tumbling maneuver begins with estimation of the angular rate of the target. A fly-around in and out of plane could be performed to achieve that goal. The distance at which the fly around is performed will depend on the sensor chosen, its field of view and the level of accuracy needed. Once the angular rate of the target has been estimated with a sufficient accuracy, the de-tumbling maneuver itself can begin. The de-tumbling maneuver with the use of blow effect consists in 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 in reaching a station keeping point and maintaining an attitude such that de-tumbling thruster is oriented towards the target and in target rotation plane.

3.2 Position of station keeping point

The station keeping point is chosen to minimize consumption, on intersection of X_{LVLH}/Y_{LVLH} plane and plane normal to angular rate of the target (if both planes are parallel, the station keeping point will be chosen along X axis to minimize the consumption):

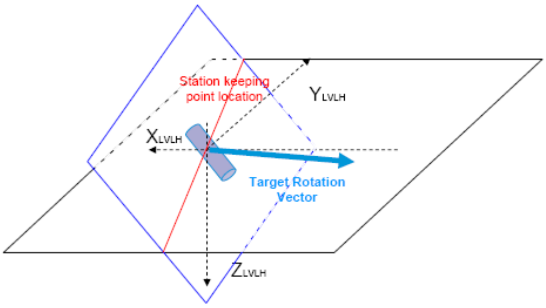


Figure 4: Definition of station keeping line minimizing consumption during de-tumbling maneuvre

The de-tumbling of the target is realized while the blowing thruster and balance thruster are activated, which results in slowing the tumbling motion of the target.

3.3 Attitude strategy

The Mean Target Referential frame (MTR) is used to describe this attitude

- The origin of this reference frame is the centre of mass of the target
- Y_{MTR} is parallel to the target rotation vector and with the same direction.
- X_{MTR} is parallel to the blowing thruster and has the same direction
- Z_{MTR} completes the trihedron

The blowing thrust is oriented to be aligned with rotation plane of the target and it is used only when it is efficient to create a torque to slow down the target. Therefore, the blowing is limited to a given sector of relative attitude (taken equal to [+/-10 deg] for angle between main axis of the target and Z_{MTR}). On Figure 5, the blowing thrust is activated between attitude 1 and 2 for the target and de-activated when target attitude is out of this domain as on attitude 3.

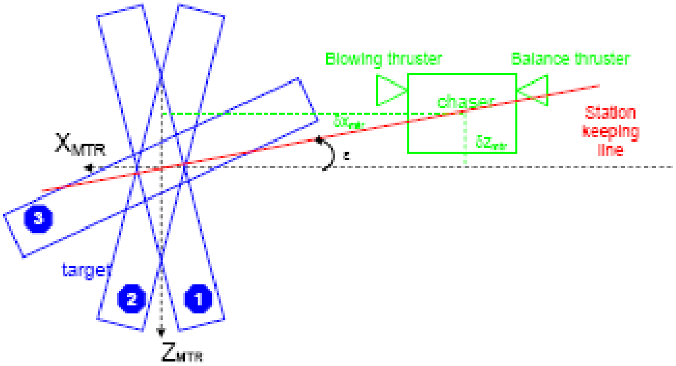


Figure 5: De-tumbling maneuver from Mean Target Referential frame

As the de-tumbling can last up to two weeks, in case of electrical propulsion, a dedicated “roll MTR steering” strategy has to be defined to optimize attitude from power point of view (with assumption that the vehicle has one degree of freedom for solar arrays around $Y_{vehicle}$).

This attitude strategy is defined as follows:

- $X_{vehicle}$ (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 (which defines the roll angle around X_{MTR} axis)
- 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.

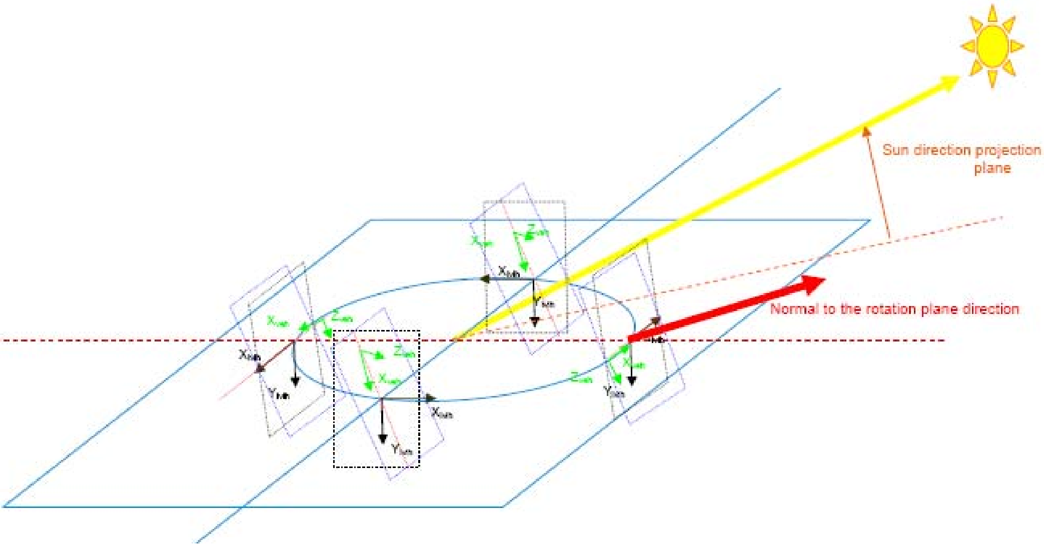


Figure 6: “MTR roll steering” attitude during de-tumbling maneuver

3.4 Duration of the maneuver

The torque created by blow effect can be sized as $\Gamma_{bloweffect} = \eta * F_1 * l$ with l mean lever of arm during blowing phase estimated at around 2 m in simulation of plume effect. Duration of the blowing phase of de-tumbling is then equal to:

$$\Delta T_{blow} = \frac{I_{t\arg et} * \Delta\Omega}{\Gamma_{bloweffect}}$$

Total duration of the maneuver (including both blowing and non-blowing phase) is then equal to:

$$\Delta T = \frac{360}{2 * 20} * \Delta T_{blow}$$

The level of thrust for blowing and balance thrusters in case of an electrical chaser is considered to be equal to ½ of the available level of power.

4. Consumption estimation during the maneuvers

The consumption budget during the de-tumbling and processing maneuvers is roughly estimated via the sizing of its different contributors:

- Processing and balance thrusters budget
- Theoretical consumption computed from:
  - Theoretical acceleration needs based on the trajectory.
  - And efficiency of the propulsive architecture (i.e. ratio between controlled force and sum of thrust of the opened thrusters)
- Position control consumption around theoretical trajectory
- Attitude control consumption
- Budget for misalignment of thrusters compensation

Total consumption of the maneuver can be evaluated for a first estimation via sum of those different contributors.

4.1 Blowing and balance thrusters budget

The evolution of mass for the chaser can be expressed as $\frac{dm_{chaser}}{dt} = -\frac{F_1 + F_2}{g_0 Isv}$

As the chaser is in station keeping point wrt the target, the acceleration of the chaser is equal to the one of the chaser. Therefore: $\frac{F_2 - F_1}{m_{chaser}} = \frac{\eta F_1}{m_{t\arg et}}$, which leads to :

$$F_1 + F_2 = \frac{\eta m_{chaser} + 2m_{t\arg et}}{m_{t\arg et}} * F_1$$

$$\frac{dm_{chaser}}{\eta m_{chaser} + 2m_{t\arg et}} = -\frac{F_1}{m_{t\arg et} g_0 Isv} dt$$

Integrating previous equation, the consumed mass Δm during the maneuver can be expressed wrt initial mass of chaser m_{chaser} and mass of target m_{target}:

$$\ln\left(\frac{\eta(m_{chaser} - \Delta m) + 2m_{t\arg et}}{\eta m_{chaser} + 2m_{t\arg et}}\right) = -\frac{\eta F_1 \Delta T}{m_{t\arg et} g_0 Isv}$$

i.e. $\Delta m = \frac{\eta m_{chaser} + 2m_{t\arg et}}{\eta}(1 - \exp(-\frac{\eta F_1 \Delta T}{m_{t\arg et} g_0 Isv}))$

In the case of processing, this can be expressed as:

$$\Delta m = \frac{\eta m_{chaser} + 2m_{t\arg et}}{\eta}(1 - \exp(-\frac{\Delta V}{g_0 Isv}))$$

In the case of de-tumbling, ΔV << g_0Isv low, then

$\Delta m = \frac{(\eta m_{chaser} + 2m_{t\arg et}) F_1 \Delta T}{m_{t\arg et} g_0 Isv}$, with ΔT the duration of the blowing phase only

4.2 Theoretical consumption budget

Both processing and de-tumbling should be performed minimizing the consumption of the chaser. As the distance between the target and the chaser is only a few meters and the eccentricity is low Clohessy-Wiltshire equations apply to this system. Therefore, for a station keeping point with null acceleration and null velocity with respect to the target, the propulsive acceleration is given hereafter.

$$0 = \gamma_x$$

$$\omega^2 Y = \gamma_y$$

$$-3\omega^2 Z = \gamma_z$$

One can note that to reduce this propulsive acceleration to perform the station keeping point, one should minimize the Z position in LVLH frame. That is why in the case of processing maneuver, the station keeping point is chosen on X_{LVLH} axis, in the front or behind the target, and in case of de-tumbling the target, the preferred station keeping location is on the intersection of rotation plane and $X_{\text{LVLH}}Y_{\text{LVLH}}$ plane.

On processing maneuvers, the theoretical consumption associated to the station keeping phase is then null. For de-tumbling the propulsive acceleration due to position of station keeping point is always lower than ω²*L with L distance between target and chaser during the de-tumbling phase (considered at 10 m in this study). This leads to consumption lower than:

$$m_{chaser}(1-\exp(-\frac{\omega^2 L \Delta T}{g_0 Isv}))$$

NOTA: To take into account that thrusters are not available on all directions, an efficiency factor of the propulsive architecture should be applied to this consumption (a typical value of 0.3 for efficiency is used in this study).

4.3 Position control budget

The “Position control budget” represents the consumption due to MIB level activations to maintain the chaser around the station keeping point dealing with the disturbances. A rough estimation of this consumption is derived from the consumption values observed on ATV. Indeed, ATV is performing three station keeping points (S3 at 250 m, S4 at 20 m and S41 at 12 m) in the vicinity of the station along X_{LVLH} axis. Those station keeping points have a theoretical Clohessy-Wiltshire consumption that is null as they are located along X_{LVLH} axis. Practically, the consumption to maintain the position in the vicinity of the theoretical point is far from being null (see Table 5).

Table 5: Consumption table of ATV during station keeping points

	3 sigma consumption rate
S3 Station Keeping	0,047 kg/s
S4 Station Keeping	0,0135 kg/s

The values given in Table 5 have been computed for ATV which is a heavy vehicle of 20 tons with a MIB level of 6Ns. For smaller vehicles or other class of MIB, the value of consumption rate should be re-evaluated. One can consider that the dynamic around station keeping point is driven by the minimal level of acceleration of the system (ratio F_{MIB}/mass). In fact:

- the heavier the system, the less impulse there will be to manage the station keeping point.
- the smaller the MIB is the less impulse there will be to manage the station keeping point.

Given a DV for a maneuver performed with ATV, it is therefore possible to estimate the same maneuver with an other vehicle (given the assumption that both propulsive architectures can be compared / have the same efficiency level).

$$DV_{vehicle2} = \frac{F_{MIB2}}{mass_2} * \frac{mass_{ATV}}{F_{MIBATV}} * DV_{ATV}$$

Consumption rate for station keeping point can therefore be estimated via the formula:

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

In order to minimize the impact of this contributor on consumption, especially when the duration of the phase is important as it is the case with electrical blowing maneuvers, it is necessary to find a propulsive architecture ensuring the station keeping with a MIB level as low as possible.

The tuning of the controller has strong impacts on both accuracy and the consumption results. It is proposed to use the worst case for sizing position control budget.

4.4 Attitude control consumption

In order not to disturb position control by activations of thrusters due to attitude control, it is proposed to perform the attitude control with reaction wheels to be de-saturated by the existing thrusters.

The instantaneous angular rate of the vehicle is the combination of the angular rate due to LOF angular rate w.r.t inertial frame and the roll angular rate due to roll steering around LOF frame.

- The roll steering attitude around LOF frame will lead to a mean null angular acceleration due to symmetrical roll motion on the orbit. Therefore it will lead to marginal thrusters de-saturation if the reaction wheels are well sized.
- The LOF angular rate wrt inertial frame will vary in norm due to increase or decrease of semi major axis. This is a small variation that can be coped with reaction wheels.

The sizing of the reaction wheels and of the consumption linked to attitude control is then only due to the wheels de-saturation because of perturbing torques:

- The roll steering attitude is close to the unstable equilibrium of gravity gradient, therefore, the contribution of gravity gradient will be marginal.
- Last point to size the reaction wheels is to evaluate the aero-dynamical forces on the vehicle, which depends on the design chosen. For other studies, with a vehicle of ATV size at 400 km, those aero-dynamical torques have been evaluated to 0.1Nm at maximum with a profile that can have a null angular acceleration mean if the control law is well chosen.

Propellant used for attitude control will then be neglected for this study.

4.5 Misalignment budget

The error budget associated to blowing and balance thruster can lead to overconsumption. Classical values for misalignment have been taken into account:

- Dispersion on thrust < 10%
- Error on thruster position $\delta a < 12$ mm
- Error on thruster alignment $\mu < 1$ °

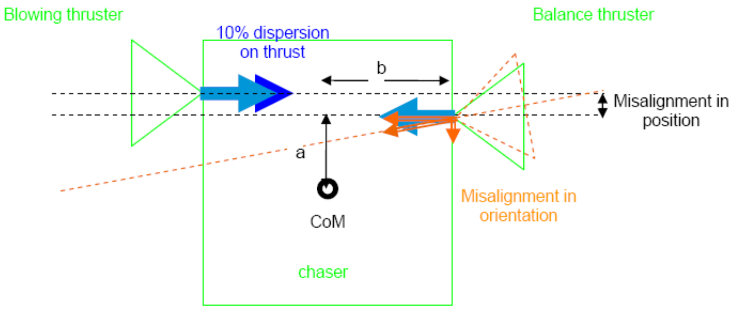


Figure 7: Effects of misalignment of blowing and balance thrusters

Dispersion on thrust of blowing and balance thruster can lead to a 2*10%*F1 force to be countered by the architecture of thrusters used for position control. That will lead to an overconsumption to maintain the required station keeping position of:

$$\Delta m = \frac{\frac{1}{\alpha} 2 * 10\% * F_1}{g_0 Isv}$$

with α the propulsive architecture efficiency of the thrusters used for position control, and Isv the specific impulse of those thrusters.

Torques to be countered during this phase will be mainly due to misalignment effect of balance and blowing thrusters. Indeed, the torque of one blowing or balance thruster is nominally equal to F*a. However, due to misalignment effect:

- this torque can be increased up to $F(1+10\%)*((a+\delta a)*\cos\mu + b*\sin\mu)$
- this torque can be decreased up to $F(1-10\%)*((a-\delta a)*\cos\mu - b*\sin\mu)$

Worst case to compensate with attitude control system would be to compensate a maximal torque on one side and a minimal torque on the other side. The maximal torque to compensate is then with a and b expressed in meters:

$$F*(2\delta a*\cos\mu + 2b*\sin\mu + 0.1*(2a)*\cos\mu)$$

5. Application cases to a given architecture

An application of this consumption sizing for a blowing phase has been done on several configuration of target and chaser to see in which cases this method can be applied. The numerical application for a medium size of target and medium size of chaser is given hereafter. The vehicle considered is represented in Figure 8. The blowing effect is performed either with the use of main engine for application of blowing with classical propulsion or with the use of electrical engine for application of blowing with electrical propulsion. The characteristics used for application case are described in Table 6.

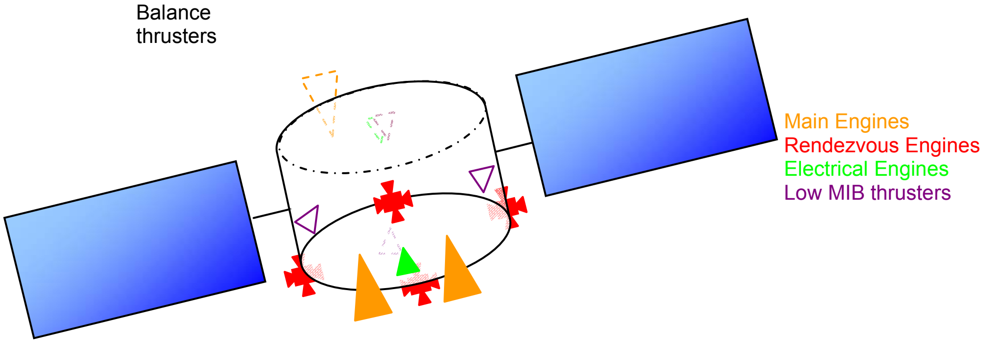


Figure 8: Architecture of the vehicle used to apply blowing method

Table 6: Characteristics of chaser used for application case

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

5.1 Application to a vehicle using classical propulsion

In case of blowing maneuvers with classical propulsion, the propulsive architecture of the vehicle should be modified to add a balance thruster on the opposite side to compensate the effect of the blowing thruster. The forces necessary to maintain the station keeping point is realized via thrusters used during rendezvous, and therefore it does no impact the existing architecture.

For processing maneuver with chemical propulsion, consumption has been evaluated for different configurations of chaser and target (the values obtained for application case are given in Table 7). This consumption is mainly due to the consumptions of blowing and balance thrusters and its level of magnitude is in average the one of the mass of the target to be processed. This method will then be limited to small debris removal.

Table 7: Evaluation of consumption during processing with chemical propulsion

Chaser		Light Vehicle
Target mass	**kg**	**2000**
Processing duration	mn	65
Processing and balance thruster	kg	1623
Theoretical station keeping point	kg	0
Position control	kg	15
Misalignment torque compensation	kg	43
Misalignment force compensation	kg	440
Total consumption	**kg**	**2121**

The estimation of the consumption of the de-tumbling of a target with chemical propulsion has also been computed (see Table 8). This consumption is mainly due to the consumption of blowing and balance thrusters. Duration of the maneuver and level of consumption computed make this maneuver very attractive.

Table 8: Evaluation of consumption during de-tumbling with chemical propulsion

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

5.2 Application to a vehicle using electrical propulsion

In the case of blowing with electrical engine, the propulsive architecture of the vehicle should be modified to add an electrical balance thruster on the opposite side to compensate the effect of the blowing thruster. In addition, some low MIB thrusters should be added to the architecture to allow reasonable consumption during the long station keeping phases. The equipments to be added to allow blowing with electrical propulsion are therefore more important than in the case of blowing with chemical propulsion.

The consumption of processing maneuver with electrical propulsion has been evaluated for the application case (see Table 9). Blowing and balance thrusters consumption and position control consumption are the two main contributors to consumption during this maneuver. Total value of consumption for processing is more attractive than for the case of processing with classical thrusters (consumption represents only 10 to 20 % of the target mass). However, the duration of the maneuver can lead to discard some configurations of target and chaser masses and it introduces design complexity.

Table 9: Evaluation of consumption during processing with electrical propulsion

Chaser		**Light Vehicle**
Target mass	**kg**	**2000**
Processing duration	days	166
Processing and balance thruster	kg	95
Theoretical station keeping point	kg	0
Position control	kg	42
Misalignment torque compensation	kg	2
Misalignment force compensation	kg	19
Total consumption	**kg**	**159**

The consumption of the de-tumbling maneuver with electrical thrusters has been evaluated (see Table 10). Duration of such maneuvers is more reasonable than for processing with electrical thrusters. Use of electrical propulsion leads to lower consumptions than the ones obtained with chemical propulsion and the concept seems attractive.

Table 10: Evaluation of consumption during de-tumbling with electrical propulsion

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

6. Conclusion

GNC attitude strategies can be found to fulfill the requirements of de-tumbling and processing with classical or electrical engines. Some adaptations can be found to adapt the foreseen vehicles for debris removal to the blowing method. Consumption associated to these new phases has been evaluated for both electrical and chemical propulsion. The concept proves to be not so attractive for processing heavy target with chemical thrusters. The duration of processing with electrical thrusters is also a point that may have strong impacts on the design of the vehicle. However, the concept of de-tumbling using blow effect seems very attractive given these first results. Further system analysis including this concept will be studied to see how it can be integrated in Heavy Active Debris Removal vehicles.