COBRA: CONTACTLESS METHOD FOR DETUMBLING SPACE DEBRIS OBJECTS

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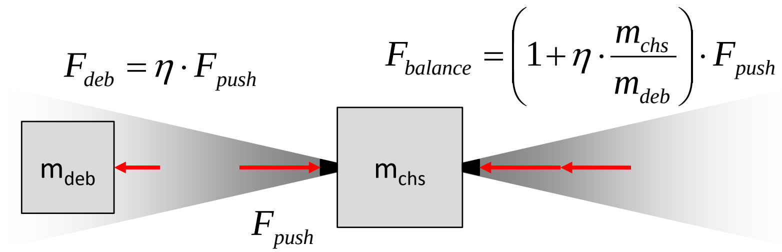
INNOVATING SOLUTIONS

INTRODUCTION

- COBRA overview
- COBRA context
- Plume modeling
- Despinning control strategies
- Envisat & PROBA 2 test cases
- Simulation

COBRA OVERVIEW

- Momentum exchange between chaser and target through plume impingement
  - Chaser fires thruster in direction of target
  - (Part of) plume intercepted by target
  - Plume pressure generates force and torque on target
- COBRA initially developed for orbit modification
  - Found to be expensive in terms of ΔV, **but:**
  - Rotation state modification feasible and fairly cheap
- COBRA concept requires no additional payload apart from what is already present for performing rendezvous
  - At least one thruster needs to point in the direction of the relative sensors



COBRA CONTEXT: DEBRIS REMOVAL

- Removal options
  - – Removal of tiny & small debris not practical
  - – Removal of large objects removes potential sources of fragments in case of collision
- Conclusion: remove large objects
- Recent interest in removing Envisat in particular
- Trial mission could focus on smaller target, such as PROBA2

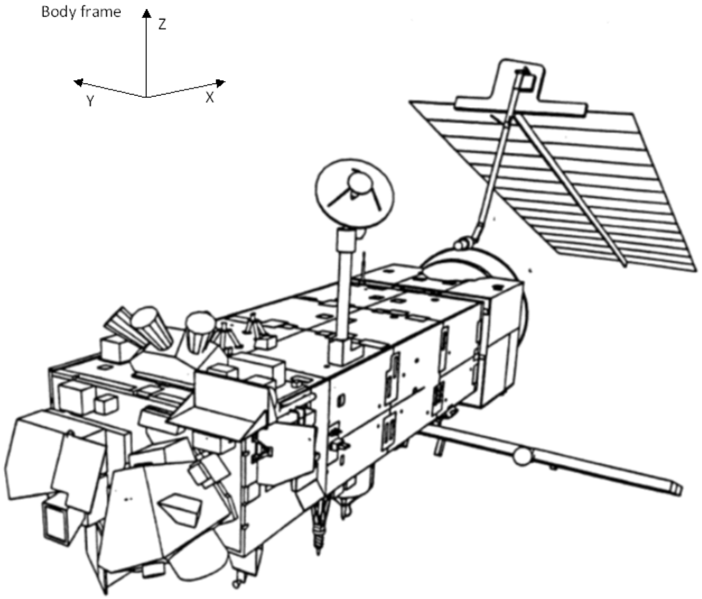
Type	Characteristics	Hazard
Tiny	Not tracked, <1 cm	Shielding exists, damage to satellites may occur
Small	Not tracked, diameter 1 – 10 cm, 98% of lethal objects, ~400.000 objects in LEO	Too small to track and avoid, too heavy to shield against
Medium	Tracked, diameter >10 cm, <2 kg, 2% of lethal objects, ~24.000 objects in LEO, > 99% of mass (incl. large objects)	Avoidance manoeuvres performed most often for this category
Large	Tracked, >2 kg, <1% of lethal objects, > 99% of mass (incl. medium objects)	Primary source of new small debris, 99% of collision area and mass

ENVISAT

- An ADR mission is being studied to de-orbit Envisat
  - Robotic arm concept requires risky and expensive (ΔV) synchronization manoeuvre
- Detumble Envisat using plume impingement
  - Reduce risk of collision by easing / removing need for attitude synchronization
  - Synchronization ΔV ~20 m/s
  - S.K. ΔV ~2.2 m/s/min

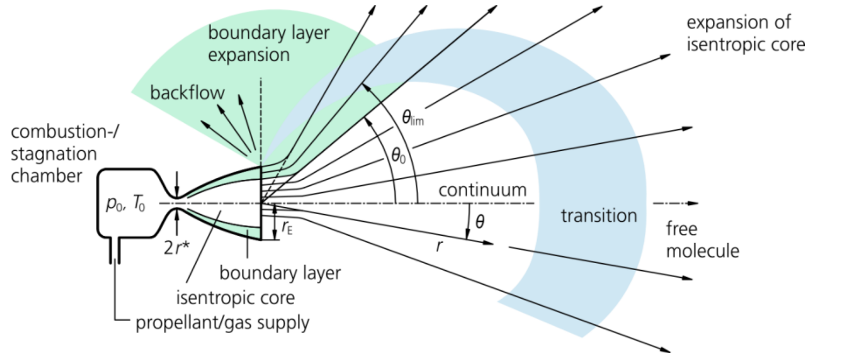
Envisat rotation state

- Spin rate of 3.5 °/s, around body z-axis
  - Possibly around y-axis or intermediate axis
- Spin rate of 5 °/s around y-axis assumed for simulation

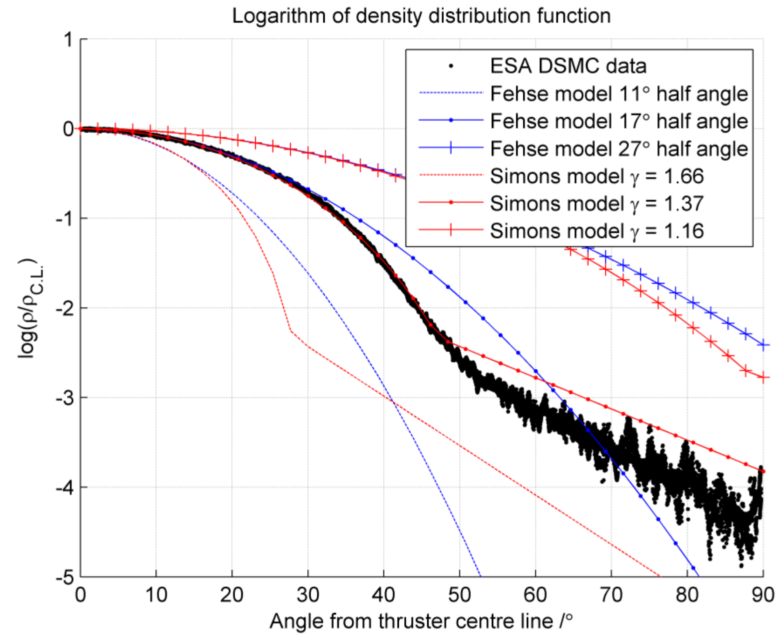


PLUME MODELING

- Plume model based on work by G. A. Simons
  - High-power cosine law in isentropic core
  - Exponential decay in boundary layer
  - Analytical & fast model
- Verification and parameter settings
  - ESA DSMC data available for 1 N thruster
  - Analysis of experimental data in literature ongoing
- Interaction with target assumed to occur in free molecular flow regime
  - Transition is estimated to occur (Flow “freezes”) at about 0.3 m to about 2 m

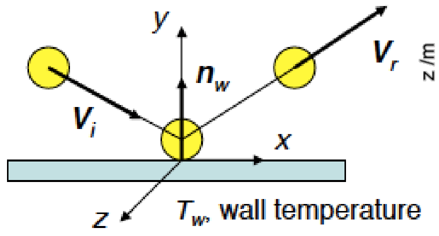


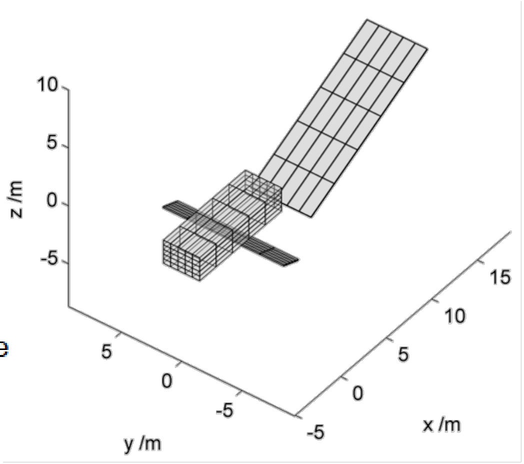
From: Dettleff, Georg and Grabe, Martin (2011) Basics of Plume Impingement Analysis for Small Chemical and Cold Gas Thrusters. In: RTO Educational Notes Models and Computational Methods for Rarefied Flows. RTO/NATO. pp. 1-40. ISBN 978-92-837-0129-3



SURFACE INTERACTION

- Simplifying assumptions made for speeding up calculations
  - Few special functions to limit number of function evaluations
  - Coarse, low detail model of target
- Assumptions
  - Simplify Schaaf & Chambré model
    - Collisions of gas molecules assumed Maxwellian
  - Thermal motion negligible compared to flow velocity (hyperthermal flow) (in reality up to 20%
  - Zero wall temperature (in reality flow velocity up to 20% of incoming flow velocity

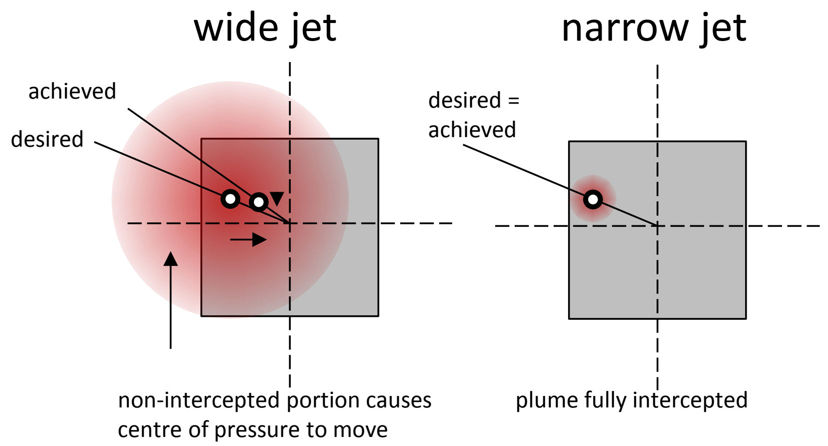


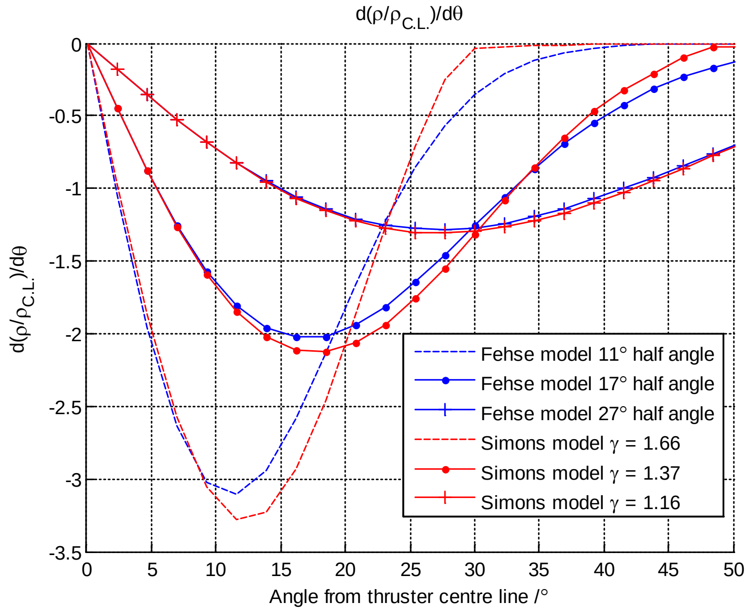


- Simplifying assumptions reduce fidelity but reduce computation time
  - Full model should be used to check results
  - Still, force components will be present in the direction of panel normal and direction of incoming flow

EFFECT OF PLUME OPENING ANGLE ON CONTROLLABILITY

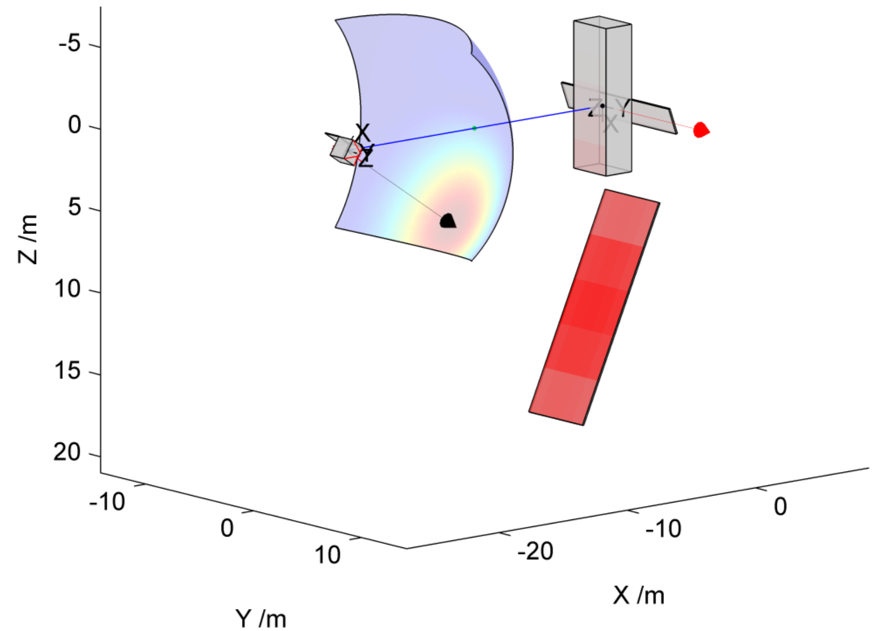
- Narrower plume desirable
  - Larger operating distance possible (larger portion of jet intercepted)
  - Torque depends on
    - Dynamic pressure variation (depending on dρ/dθ) so the narrower the plume, the higher the torque
    - Part of plume intercepted
  - Narrow plume behaves more like force application at single point instead of over an area
    - Less “unexpected” behaviour if a single force application point is used in control model

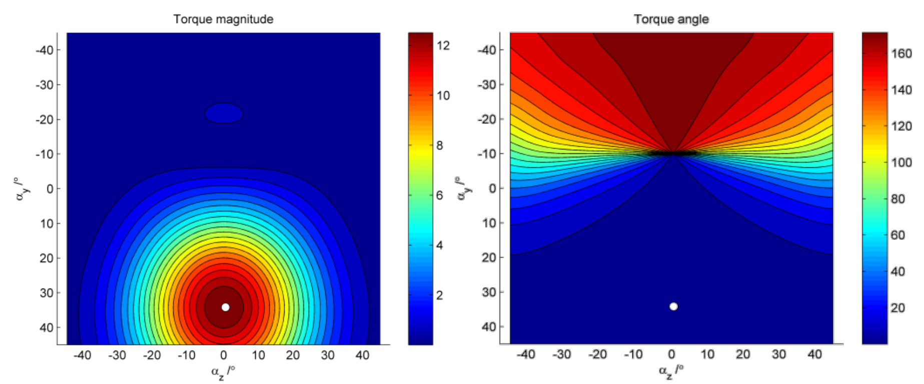




CONTROL STRATEGY 1 / 2

- Two effects
  - Target object asymmetry
    - chaser imparts torque on target even if gas jet is directed at centre of mass
  - Gas jet pointing away from centre of mass
    - pressure distribution is non-symmetrical with respect to centre of mass (even if target is symmetric)
- Envisat panel causes large asymmetry
- Control strategy
  - Based on pointing and switching
  - Can control two axes at a time





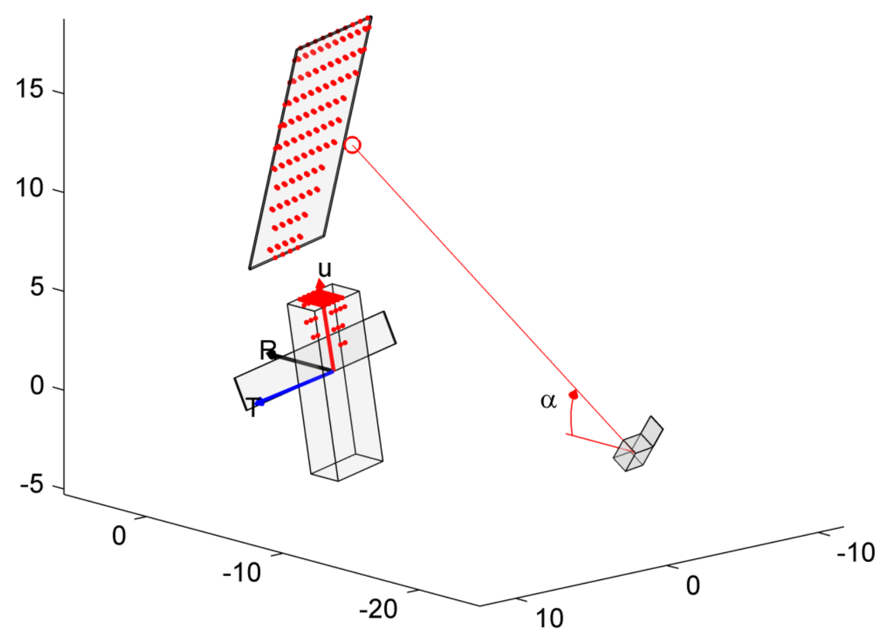
CONTROL STRATEGY 2 / 2

Direction calculation

- Step 1: desired torque on target is computed based on target angular momentum
- Step 2: direction u of force application is calculated
  - Perpendicular to torque and direction to target
- Step 3: off-centre angle α is calculated based on target shape
  - i.e., a sufficiently large portion of plume must be intercepted

Switching calculation

- Check whether desired torque is close to perpendicular to direction to target (threshold)



SIMULATION CASES

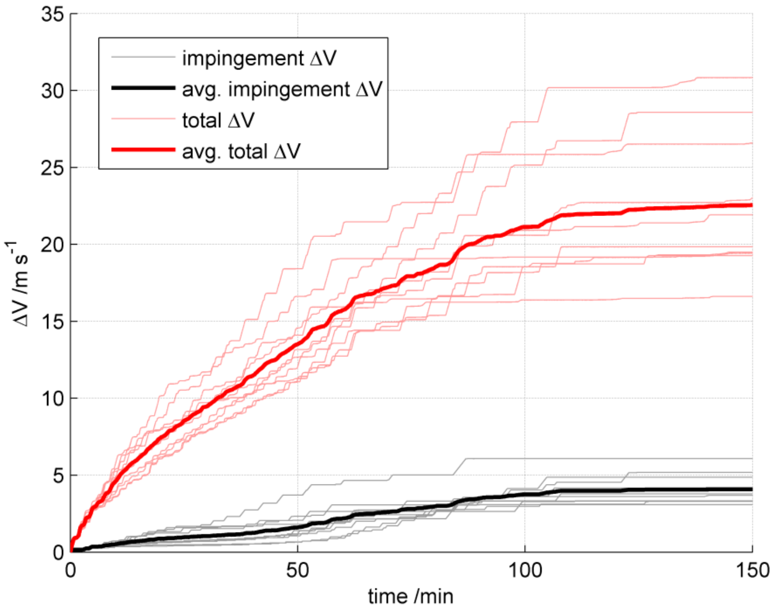
Simulations performed

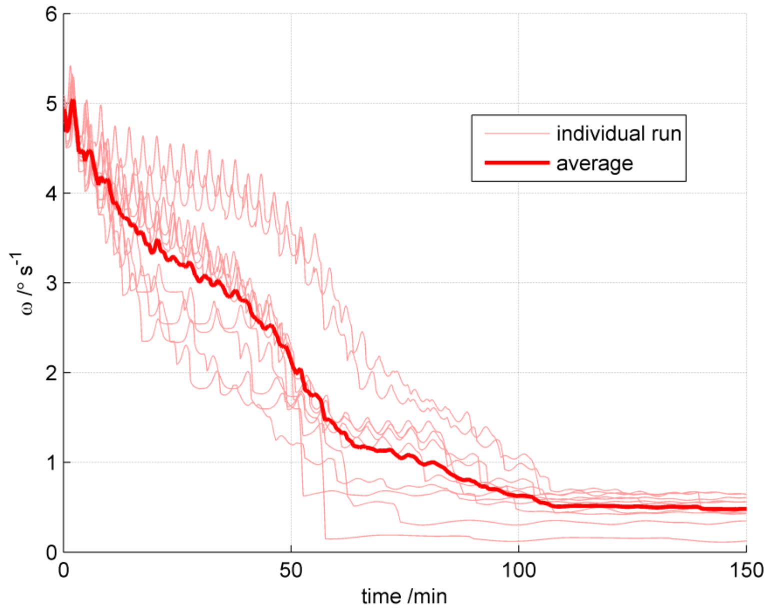
- To establish detumbling ΔV and duration
- To check sensitivity to model parameters

Case #	Description	Distance [m]	Wall temperature [K]	Ratio of specific heats	Tangential accommodation factor	Normal accommodation factor
1	nominal	22	300	1.37	0.97	1
2	rotation around z	22	300	1.37	0.97	1
3	low wall temperature	22	0	1.37	0.97	1
4	high γ	22	300	1.66	0.97	1
5	low accommodation	22	300	1.37	0.5	0.5
6	high distance	30	300	1.37	0.97	1

SIMULATION RESULTS 1: NOMINAL

- ΔV ~23 m/s
- 50 – 100 min to despin below 1°/s
- Variability in de-spin rate due to rotation around intermediate inertia axis

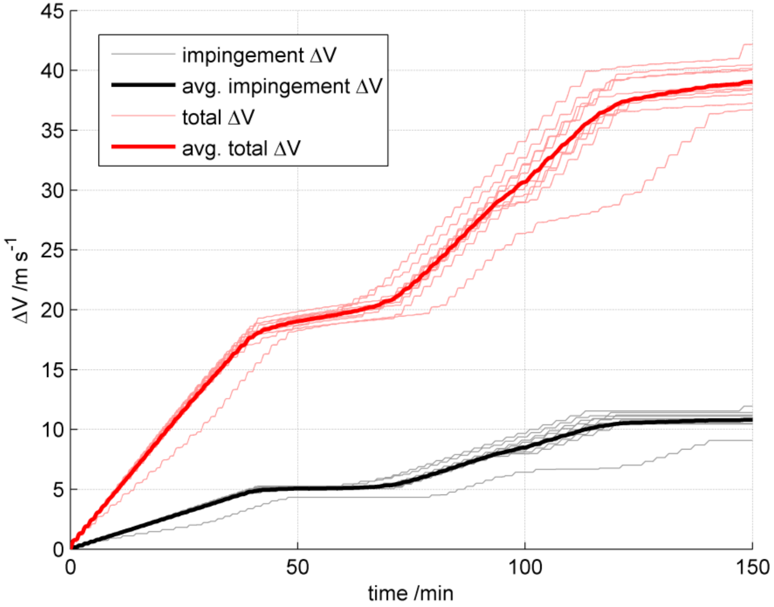


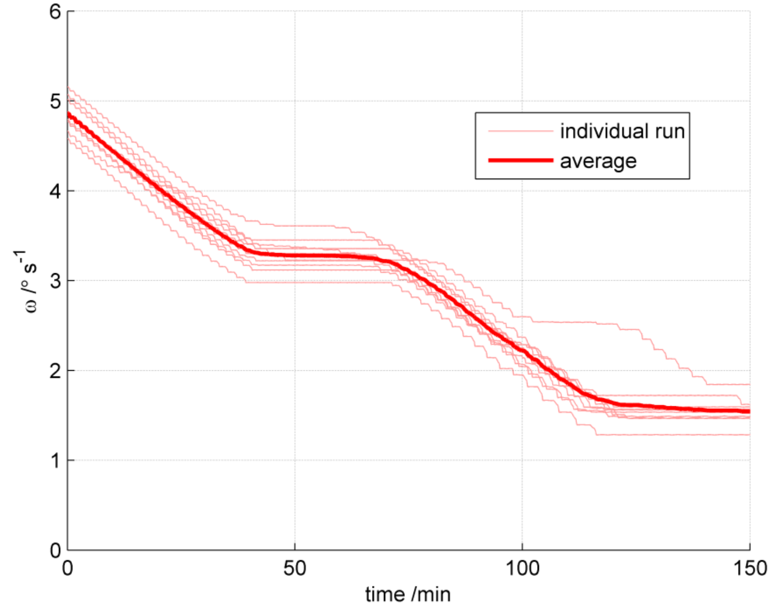


ΔV ~23 m/s, 50 – 100 min to despin below 1°/s

SIMULATION RESULTS 2: ROTATION AROUND Z

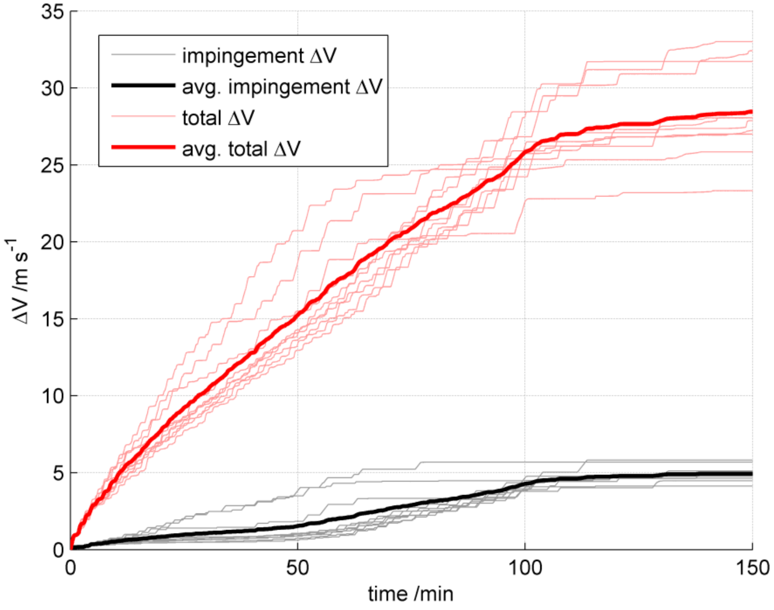
- Higher ΔV (~37 m/s)
- Longer duration
- More constant de-spin rate
  - Envisat rotating around stable inertia axis

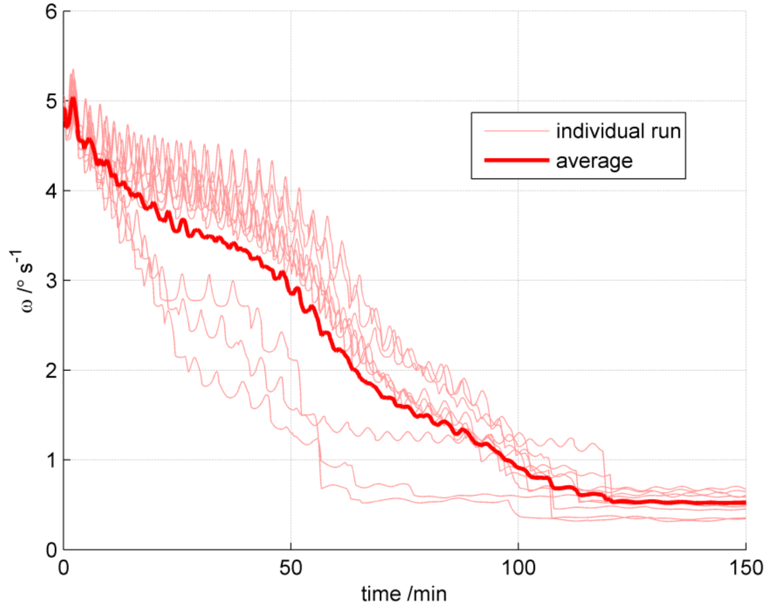




SIMULATION RESULTS 3: LOW WALL TEMPERATURE

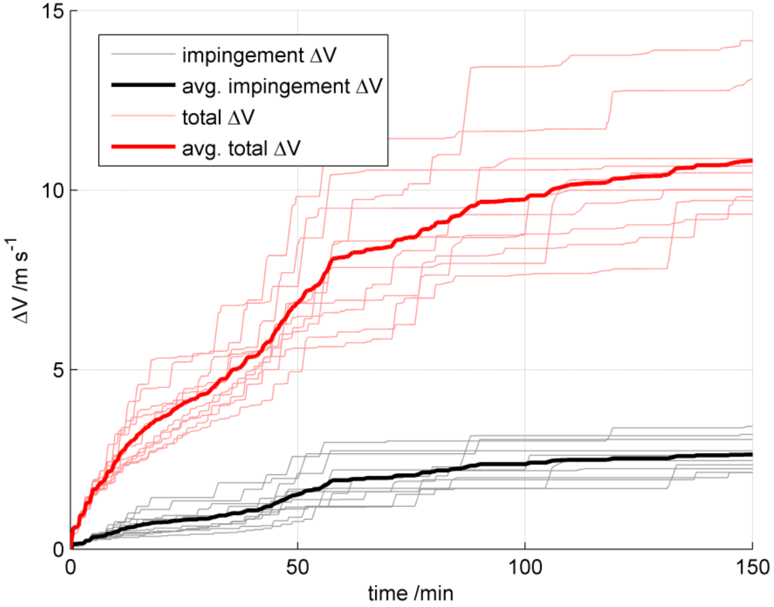
- Higher ΔV ~27 m/s
- Longer duration
- Zero wall temperature removes impulse due to thermal motion for molecules leaving surfaces of Envisat

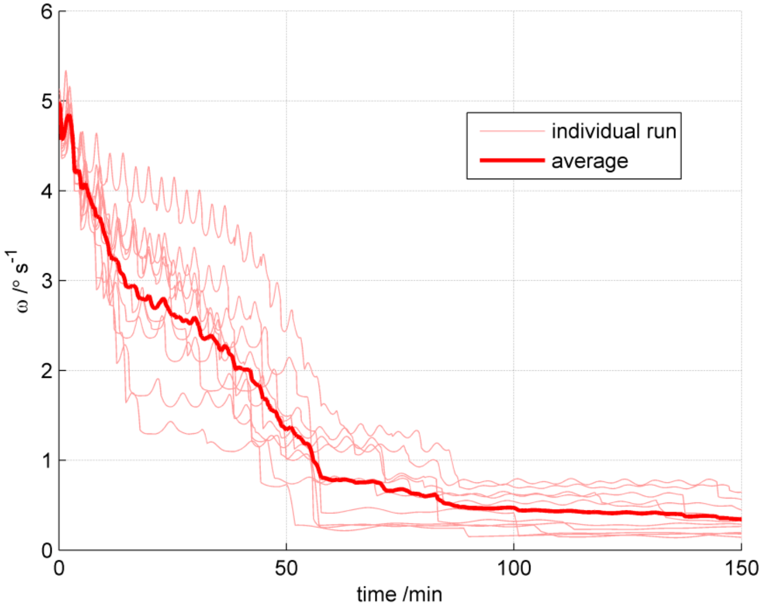




SIMULATION RESULTS 4: HIGH RATIO OF SPECIFIC HEATS

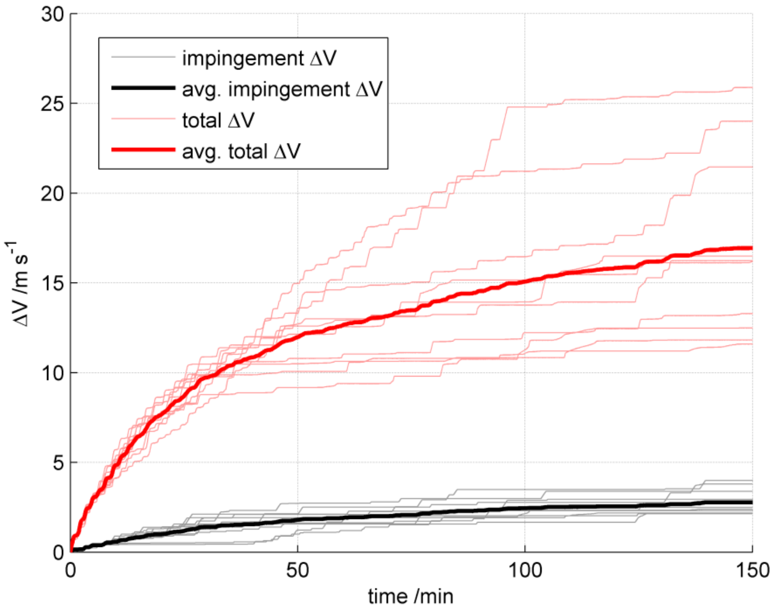
- Much lower ΔV ~10 m/s
- Shorter duration
- Narrower plume leads to higher portion of plume to be intercepted and better controllability

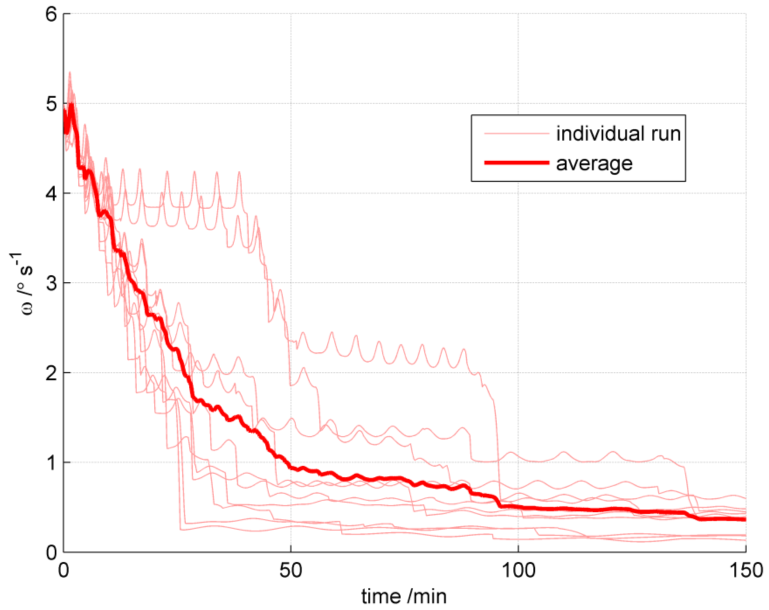




SIMULATION RESULTS 5: LOW ACCOMMODATION

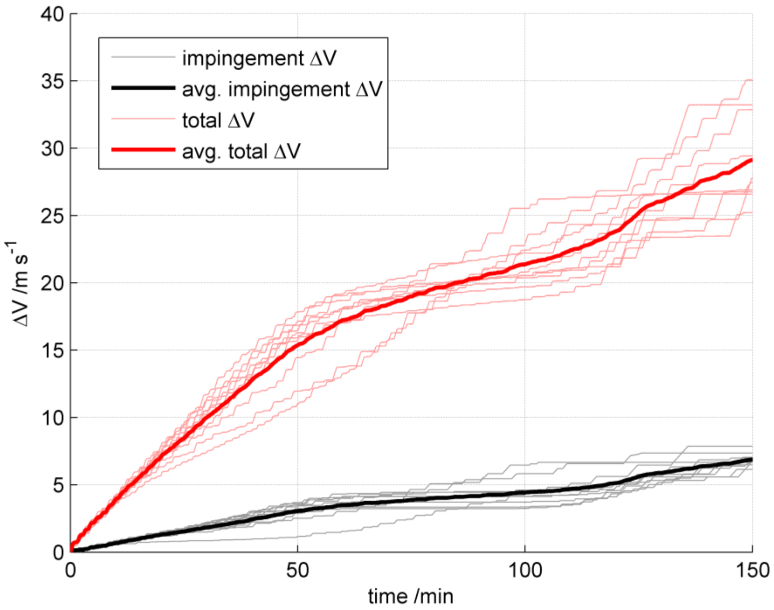
- Lower ΔV ~16 m/s
- Shorter duration but greater spread
- More specular reflection leads to higher force on target, but also to undesirable variation in direction of force

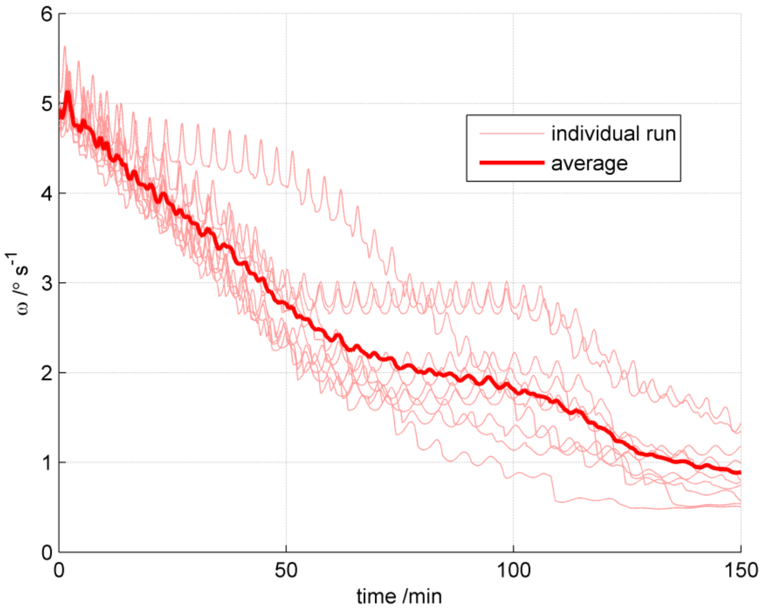




SIMULATION RESULTS 6: HIGH DISTANCE

- Higher ΔV ~30 m/s
- Longer duration
- Smaller portion of plume intercepted; however, detumbling still possible at safer distance of 30 m





CONCLUSION

- COBRA de-tumbling satellites is promising technique for de-tumbling space debris objects.
  - No additional equipment on chaser apart from equipment already there for performing rendezvous with the object
    - Configuration of thrusters can be optimised (adding pushing + compensating thrusters)
  - Detumbling Envisat can be performed within 1 – 2 orbital revolutions, with a ΔV of ~23 m/s
    - further optimisation is possible
- Improved models
  - Improved plume model
  - more realistic (albeit highly simplified) model of surface interaction of plume exhaust gases with surface of target object
  - Variation of model parameters shows that COBRA detumbling works even for large uncertainty in plume impingement behaviour
- Simulations have shown that de-tumbling by means of plume impingements is possible
  - Even if target object is in unfavourable rotation state
  - Even if inter-satellite distance is large (30 m)

Thank you

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