OCCAM:
Optimal Computation of Collision Avoidance Maneuvers

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Introduction

- Increasing number of close encounters between active satellites and other bodies
  - 2010: **Every week an average 190 conjunctions and 3 collision avoidance maneuvers** were reported
  - 2011: **Envisat alone** reported **4 collision avoidance maneuvers**.

- Software tools are needed to plan the execution of these maneuvers in an optimum way and with:
  - Versatility
  - Efficiency
  - Capability to explore a wide parameter space
  - Modularity

What OCCAM can do

- **Accurately** predict the outcome of a collision avoidance maneuver (CAM)
- **Globally** optimize the direction of the maneuver $\boldsymbol{\Delta v}$ for minimum collision probability or maximum miss distance
- Finding the **global** minimum Δv to reduce the collision probability to a given threshold

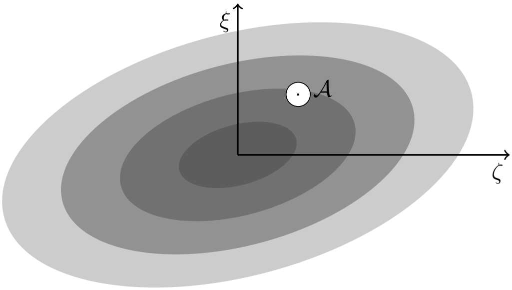
Scenario

- A maneuverable satellite S_1 and a non-maneuverable body S_2 experience a close encounter and may collide
- What do we know? (Input)
  - S_1 and S_2 nominal positions and velocities at close encounter
  - S_1 and S_2 covariance matrices at close encounter
  - S_1 and S_2 spherical envelopes
- What do we want to know (Output)
  - Collision probability
  - Best way to reduce it (if critical)

Calculating Collision Probability

- Short-term encounter scenario
- Encounter plane $(\xi - \zeta)$ projection
- 2D integral over combined cross-section area

$$P_c = \iint_{\mathcal{A}} f\left(\boldsymbol{r}\right) \mathrm{d}\boldsymbol{r}$$



Calculating Collision Probability

OCCAM supports six collision probability calculation methods (from the fastest to the slowest method):

1. García-Pelayo & Hernando-Ayuso method (JGCD, in press)
2. Serra et al. method (JGCD, 2016)
3. Chan's method
4. Alfano's method
5. Patera's method
6. Foster's method

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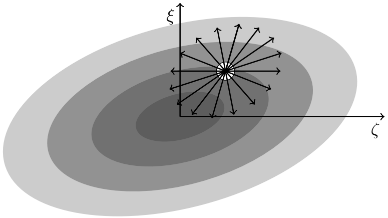
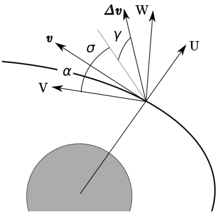


- Displace the conjunction point away from the high P_c area
- Find the optimum orbital maneuver orientation and timing

Maneuver and conjunction geometry

- Impulsive maneuver in UVW (Local Horizontal Local Vertical) $\boldsymbol{\Delta v} = (\Delta v_U, \Delta v_V, \Delta v_W)^\top$

$$\Delta v_U = \Delta v \cos\gamma \sin(\sigma + \alpha),$$
$$\Delta v_V = \Delta v \cos\gamma \cos(\sigma + \alpha),$$
$$\Delta v_W = \Delta v \sin\gamma.$$



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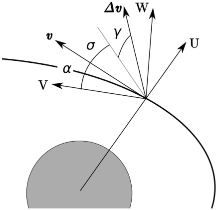
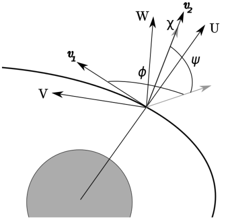


- $\boldsymbol{v_2}$ is related to $\boldsymbol{v_1}$ by:
  - a S_1 in-plane rotation ϕ
  - a S_1 out–of-plane rotation ψ
  - a scaling $\chi = v_2/v_1$



Impulsive collision avoidance dynamics

Linear impulsive maneuver approximation:

$$\boldsymbol{r} \simeq \boldsymbol{r_e} + M\boldsymbol{\Delta v}, \quad M = R\,K\,D$$

- R: Rotation matrix
- K: Kinematics matrix
- D: Dynamics matrix (error state transition matrix)

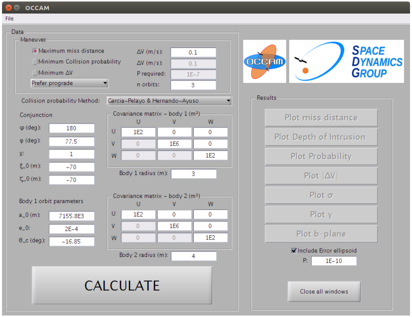
M is a function of ϕ, ψ, χ, e_0, θ_c, θ_m and $\sqrt{\frac{a_0^3}{\mu}}$

- e_0 eccentricity of unperturbed orbit of S_1
- a_0 semimajor axis of unperturbed orbit of S_1
- θ_c, θ_m true anomaly of S_1 at conjunction and maneuver
  Maneuver anticipation angle: $\Delta\theta = \theta_c - \theta_m$

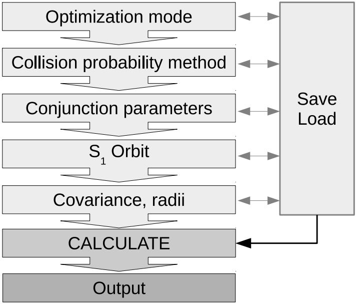
Maneuver Optimization

- In general: non-linear, non-convex optimization problem
- Computationally heavy
- To solve it, two **relaxations** are introduced:
  1. Linear dynamics $\boldsymbol{r} = \boldsymbol{r_e} + M\boldsymbol{\Delta v}$
  2. Constant P_c when $\boldsymbol{r}$ lays on a constant pdf ellipse. Good approximation if the bodies are large with respect to the uncertainty
- The problem is transfomed into a Quadratically Constrained Quadratic Program equivalent to a convex problem
- **Finally reduced to an eigenvalue and eigenvector problem + 1D non-linear equation**
- Extremely fast

OCCAM (Input)

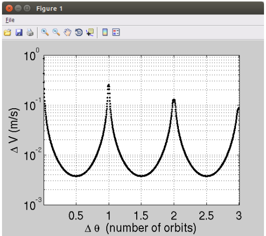


OCCAM user interface

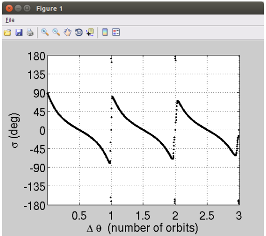


OCCAM input diagram flow

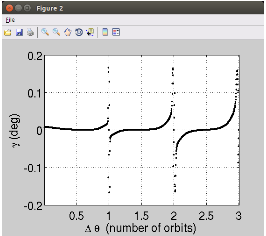
OCCAM (Ouput)



required Δv



In-plane maneuver orientation angle

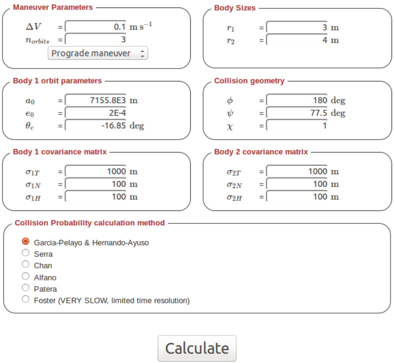


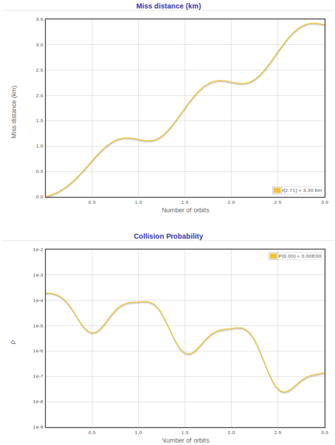
Out-of-plane maneuver orientation angle

OCCAM lite (Try it online!)

Reduced number of features

Online web-app





http://sdg.aero.upm.es/index.php/online-apps/occam-lite

(or Google: “OCCAM lite”)

OCCAM

- OCCAM was developed at the Space Dynamics Group (UPM)
- Submitted to the Copyright Registry Office of Madrid and presented at UPM Innovatech 2014 (technology commercialization seminar)
- OCCAM allows satellite operators to rapidly analyze a wide range of possible strategies
- Its graphical user interface makes it easy to learn and use, while retaining a high design flexibility
- It can be used as a standalone tool, or in conjunction with other satellite operation planning frameworks
- A customized integral service could be offered to each partner

Thank you

Questions?