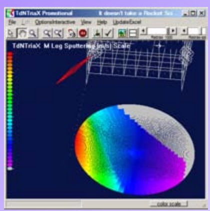
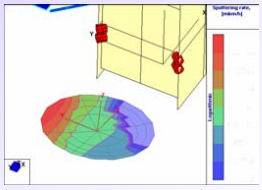
## 19th SPINE meeting

# Electric Propulsion Plume Impingement Tool TdNTriaX

**ESTEC, Noordwijk the Netherlands 19th March 2013**



***Christophe R. Koppel***







# Summary

# Introduction

- For the satellite prime, all interactions between any devices and other parts of the S/C shall be assessed
- Appropriate counter measure or change of design shall be undertaken in order to provide a reliable product in flight.
- Regarding the implementation of the Electric propulsion on a GEO bird (at an intermediate stage of its definition), the interactions are dealing with :
  - Force and moment perturbations
  - Heating by thruster ion jet
  - Sputtering on every S/C surface
  - Redeposition of sputtering products or of thruster erosion products if any
  - Radio frequency interactions





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# Introduction

- With any simulation tool there are some potential risks of getting wrong results:
  - the tool itself and the equations or data used inside the tool or the resolution methods or any other software bug.
  - In order to enhance the simulation results, the validation process of a tool is a mandatory task.
- When only **one tool** is available, even validated, it is not excluded to get wrong results.
  - For example: when simply a wrong input data has been taken into account.
  - ………………Sometime impossible to discover before the flight.
  - The main reasons are linked to the complexity of the analyses coming from 3D objects.
  - Absence of any cornerstone result of reference.
  - Even with the source files of the inputs, one single error can be hidden by the large amount of input data.
- When only **one tool** is available, other errors are dealing with the manual synthesis.
  - Such errors are even much more difficult to be trapped.
- Thus in order to get robust results, the plume impingement on the S/C surfaces are recommended to be conducted with **two different tools** .





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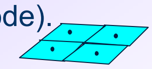
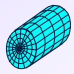
# TdNTriaX: Modelling tool for EP plume impingement

- Thruster simulated by a “Point source” (model simplification)
- Thruster plume described with tables of
  - ion current density (A/m²) distribution versus the divergence angle $\delta$, for every distance by using 1/R² law
  - ion energy distribution versus $\delta$
  - distribution versus $\delta$ of the type of ions (simple or double charges given by the ratio Xe+/total)
- Simplification of the spacecraft model by discretisation of any **surfaces** (primitive) into matrix of small quadrilateral **plane** elements, and the computations are performed in the centre point of each element (node).



  - Used for sputtering speed, forces, momentum, heat interactions
- The spacecraft model can include **volumes** (like cylindrical beam from antenna reflector)
  - Used for direct computation of RF phase shift angle and mean ion density



- Options
  - Shadow process: to set if the nodes are in the shadow of the plume or are directly impacted.
  - Automatic rotations (solar array for example) around any axes can be performed (the results for sputtering speed are averaged over one complete turn).
  - Spectrum analysis: computation automatically performed by ranges of divergence angles





# TdNTriaX: Heart of the Modelling tool

- **The heart of the tool for Forces, Moments, heat flows is based on the rarefied gas equations**

$$\vec{P} = \rho_i V^2.(p.\vec{n} + \tau.\vec{t})$$

$$Q = \rho_i V^3 q/2$$

$$p = (2-\sigma_n).\cos^2\theta + \sigma_n/2 \cdot \sqrt{\pi V_{pS}^2 / V^2}$$

$$\tau = \sigma_\tau .\sin\theta.\cos\theta$$

$$q = \sigma_\varepsilon .\cos\theta.\left(1 - 2V_{pS}^2 / V^2\right)$$

- **For the Sputtering rate** (m/s)

$$S = Y_{material}(eV,\theta).\cos\theta.J(r,\delta).M_{mol} / e.N_{av}.\rho_{material}$$

with $\theta^\circ$ : incidence on the surface

- **For the re-deposition rate** (m/s)

$$R = \cos^\beta(\delta_S).S.A.(\beta+1) / 2\pi.r_S^2$$

with $\delta_S$ and $r_S$ divergence and distance from the surface

- **Thrusters described with their**
  - **Current density *J(r,δ)*** (A.m^-2)
  - **Ion energy *eV(δ)*** (eV)
  - **Species density ratio Xe+/Xe total*(δ)***

- Interface: Excel **without add-in**
  - **Spacecraft model: Excel**
  - **Thruster database: Excel**
  - **Material database: Excel**

  **All with “Table-in-cell” feature**
- TdNTriaX Tool freely available at www.kopoos.com

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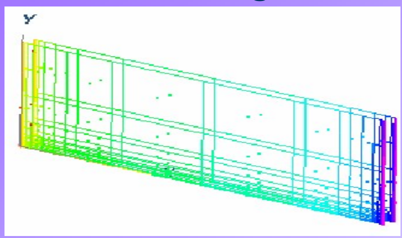
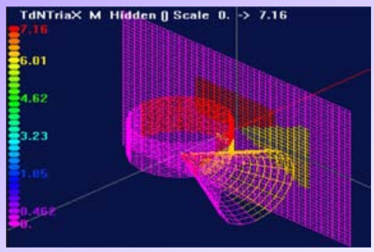
# TdNTriaX : Examples

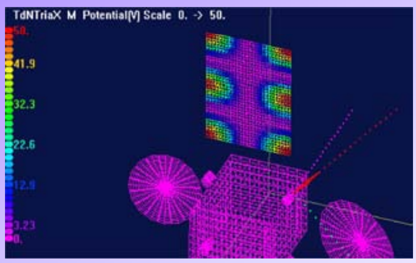
- Primitive rectangle 2 sides



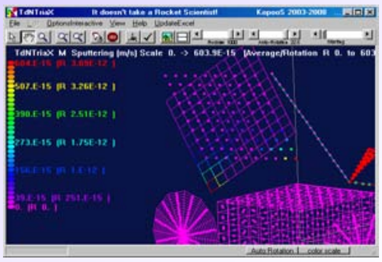
- Shadowing managed




- Surface potential distribution




- Automatic rotations managed







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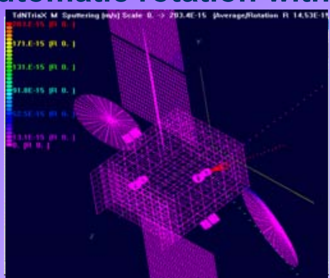
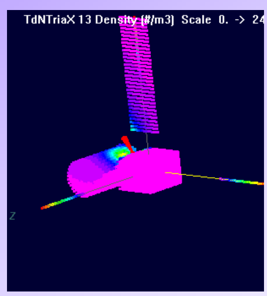
# TdNTriaX : Examples

- Automatic rotation with sputtering






- Other features of TdNTriaX
  - **Accuracy of results depends on the database**
    - and on the theoretical model used for the simulation
  - **Main advantage: tool accessible to every engineer**
  - **Traceability up to a** "self sustainable traceability" **included in reports**
    "one can re-run a case only with its report opened in Excel"





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# TdNTriaX : Management of Automatic rotations

- Example of model (T=translation; R=rotation)

| | |
|---|---|
| ThruterType | EP1 thr .05 .5 Cells 5 5 T 1 0 0 R Y 45 |
| Material1 | Name1 Rect 1 2 Cells 10 20 T 1 0 0 R Y 45 |
| Material2 | Name2 Rect 1 2 Cells 10 20 T 1 0 0 R X 30 |
| Material3 | **SADM** Rect 1 2 Cells 10 20 T 1 0 0 **Automatic** Z R X 30 |

- For the model above, the primitive **SADM** will rotate automatically in the following manner
- Main program

  **Sputtering or Forces & Moments computations asked**
  - **Start a loop on the SADM angle = 0° to 359.99 step 10**

    **Substitute the primitive definition "SADM Rect 1 2 Cells 10 20 T 1 0 0 Automatic Z R X 30" by**

    (with for example SADM angle =150°) : **"SADM Rect 1 2 Cells 10 20 T 1 0 0 R Z 150 R X 30"**

    **Run the module Geometrical**

    **Run the module thruster plume computations**

    **Run the module of Shadowing if requested**

    **Run the module sputtering or Forces & Moments computation for individual primitive**

    **Save tabulated results for the primitive**
  - **End of loop**

  **Perform averages, min, max worst cases computations**

  **End of Sputtering or Forces & Moments**

  **Reports saved; Open GL visualisation**
- Main program stand by





# TdNTriaX : Re-depositions with Automatic rotations

- Main program:

  **Re-deposition computations asked (or sputtering-cleaning or net-deposition)**
  - **Process Sputtering computations for all the primitives, <u>all rotations</u> of the rotating primitives, all bi-material primitive (rotating or not)**

    Save the material sputtered **M** and the Sputtering rates in a matrix
  - **Start a loop for each node A of each primitive and for <u>each rotation</u> of rotating primitive**
    - **Start a loop for each node B of each primitive and for <u>each rotation</u> of rotating primitive**

      **Process the Re-Deposition computation from A to B according to equations.**

      Accumulate for B in a re-deposition rate matrix the true resulting re-deposition rate of the material **M** sputtered from A.
    - **Loop on B**
  - **Loop on A**

  **End of Re-deposition**

  **Reports saved; Open GL visualisation**
- Main program stand by

- Note: for rotating primitives, the true rates values take into account a constant or variable rotation rate.
- Note: the process of Re-Deposition described here above involves
  - the deposition rates <u>from fixed nodes</u> A toward the <u>rotating nodes</u> B
  - the deposition rates <u>from rotating nodes</u> A toward <u>fixed nodes</u> B.
- Note: Second order of re-deposition rate of re-deposited materials that are further again sputtered is not managed.

## TurboDESIGN: Modelling tool for EP plume impingement

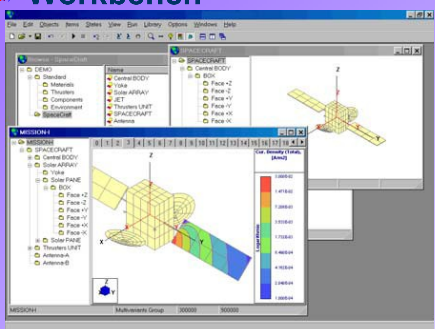
- **The tool TurboDESIGN, made by Moscow Aviation Institute (MAI), is a development of its version 1.0 and of ISP-2001 software package**
- **Rely on geometrical core and object orientated database**
- **Perform multi-variant calculations and analysis of the results : limit, mean or integral values for all variants.**
- **Thrusters description based on conical multi-component jet model according to the probes' measurement for 10-30 points over the divergence angle for flow density and energy.**
- **Includes smoothing and calibration procedures for integral parameters of the thrusters**
- **Spacecraft geometry is set by primitives: surfaces 1st and 2nd orders**
- **Also it is possible to set an arbitrary triangulated surface for complicated geometrical objects: frames or platforms**
- Computations duration from 20-30 minutes up to 1-2 hours
  - Except for deposition rate : 0.5 up to 3-5 hours



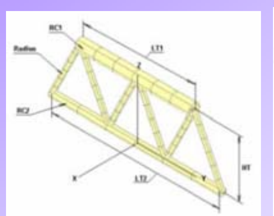


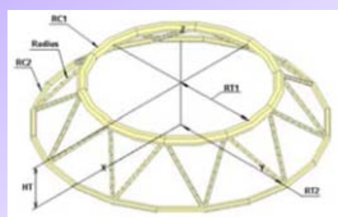
## TurboDESIGN : Examples

- **Workbench**

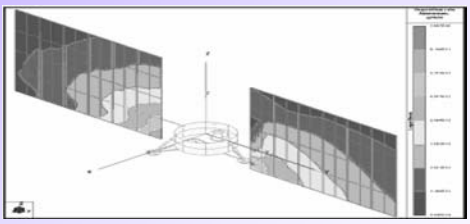


- **Structures and frames**





- **Sputtering map**



## Analyses performed with each tool

- Force and moment perturbations
- Heating by thruster ion jet
- Sputtering on every S/C surface
- Re-deposition of sputtering products or of thruster erosion products if any
- Radio frequency interactions
- Each tool was used independently.
  - Most of the time the results were in agreement
  - Sometime discrepancies were discovered and appropriate checks performed before finally getting similar results





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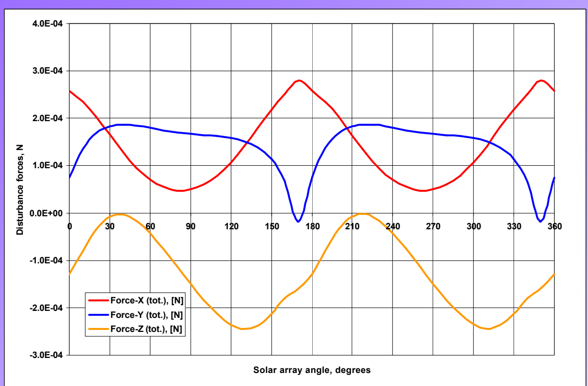
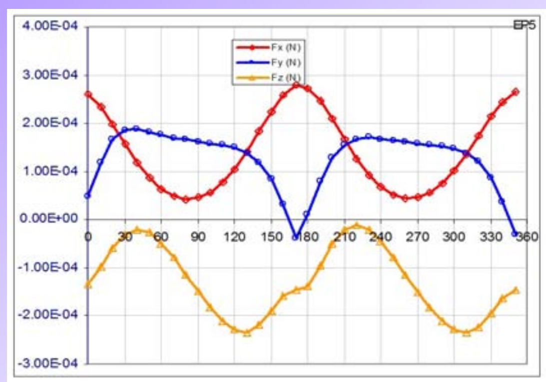
## Example : Impingement forces on rotating solar arrays




- The similitude of the results in shape and in magnitude is obvious
  - Even if not totally identical.
  - The minor differences are the result of the integral model taken into account (all the impinged surface for the TurboDESIGN and the most impinged surface for TdNTriaX (without yokes).





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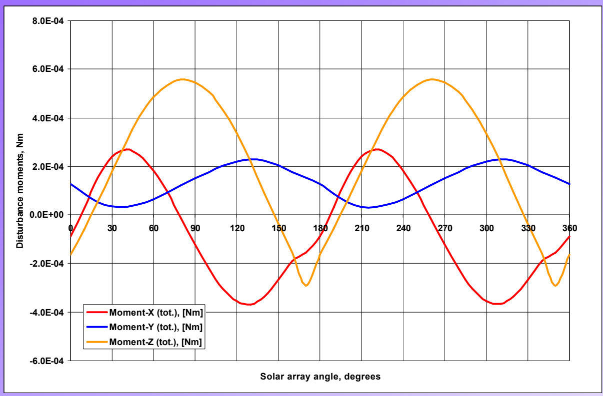
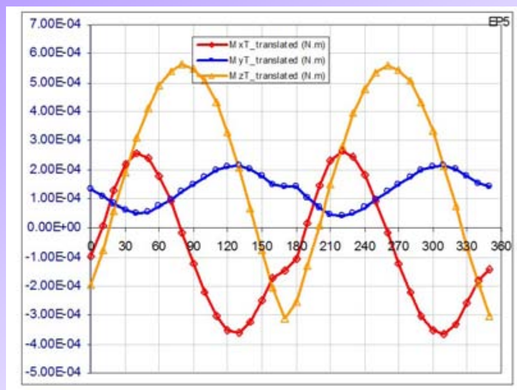
# Example : Impingement moments on rotating solar arrays



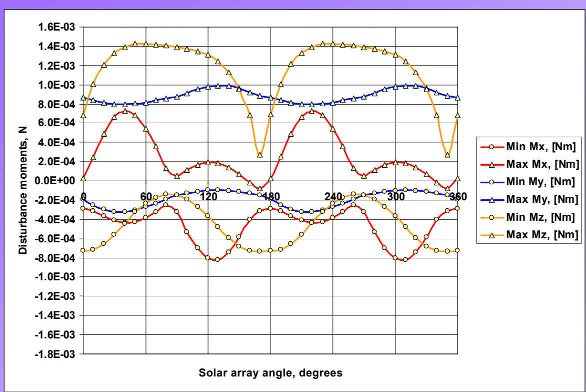



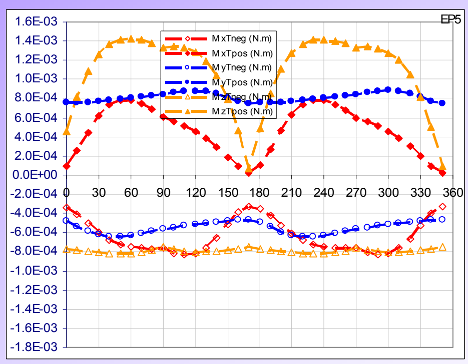

- The similitude of the results in shape and in magnitude is obvious
  - Even if not totally identical.





# Example : Worst case moments on rotating solar arrays



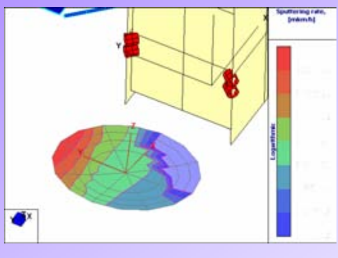



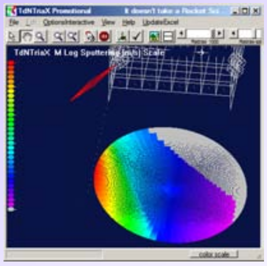

- The similitude of the worst cases results in shape and in magnitude is obvious for most of the moment components
  - For some component there are some noticeable discrepancies.
  - This come from the differences of the strategies used to compute the worst cases
    - **The approach for getting the worst case moments is slightly different between the tools TurboDESIGN and TdNTriaX: TdNTriaX compute the negative parts and positive parts of the moments.**
  - Because the results are however in the same range, one can be assured that the corresponding computations are valuable. And worst cases are subjective…

# Example : Heating, Sputtering

- Impingement Heat flux (W/m²)
  - For the Antenna Reflector-X: TurboDESIGN= 6.9 TdNTriaX= 6.6
  - The similitude is obvious

- Sputtering rate (m/s)
- For the antenna reflector-X





  - The similitude (shape) is obvious
- For the Silver interconnector (for one full rotation of the solar array)
  Maximum sputtering rates : TurboDESIGN=4.75E-13 TdNTriaX =4.75E-13
  - The similitude is obvious, even equal for this synthetic result





# Example : Redeposition , Radio frequency phase shift

- **Redeposition**
  - The redeposition of sputtered materials on other surfaces have been computed by the two tools.
  - The tool TdNTriaX was always providing more robust (i.e. higher rate) results than TurboDESIGN
  - But because the **order of magnitude were quite similar** no further investigation was performed

- **Radio frequency phase shift**
  - The ion jet passing into the RF beams produces a phase shift
  - Computed by the two tools.
  - The tool TdNTriaX was always providing slightly less pessimistic results than TurboDESIGN
  - But because the **order of magnitude were very similar** (discrepancy up 10%) no further investigation was performed

# MAIN LESSONS LEARNT

- **Accuracy of the input data**
  - When a model involves a large amount of input data (ex. plume impingement computations)
  - It has been proven to be very efficient to perform a double check with independent tools.
- **Accuracy of the synthesis computations**
  - The complexity of the computations needed to get some synthetic results can be sometime quite high.
  - Such synthesis may be considered as a minor task with respect to the tool computations themselves.
  - But it has been found to be very efficient to perform a double check with independent synthesis performed from results of independent tools.
- **Mutual improvements**
  - The performance of a double check need to use simulation tools having similar capabilities.
  - This was the case for example for the worst case of perturbing moment computations: the tool TdNTriaX has been updated in the course of the tasks in order to output worst cases results not identical, but similar to the one of the TurboDESIGN
  - Other example: the radio frequency phase shift that has been updated in TurboDESIGN tool while it was already available in TdNTriaX.





# Conclusion

- **Two plume impingement tools have been presented**
  - **TdNTriaX**
  - **TurboDESIGN**
  - **Two independent multi-functions tools.**
- **Those tools can be used independently for solving assessment tasks that are not easily achievable with other means.**
- **The improvements of the tools results have been proven to be very efficient when a double check can be performed independently:**
  - **Reduction of the risk of wrong input data**
  - **Reduction of the risk of wrong synthetic data.**

# Thanks for your attention