CENTRE NATIONAL D'ÉTUDES SPATIALES	**Communauté de Compétence Technique** **CCT ORB –** Orbital Mechanics	Centres de Compétence Technique http://cct.cnes.fr

Seminar:

RARE EVENTS, EXTREME VALUES, EXTREME IMPACTS APPLIED TO FLIGHT DYNAMICS

Monday, April 27th 2015 (09:20 – 18:10)

At ISAE-SUPAERO Amphitheater No. 4, Toulouse

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Flight dynamics and space missions have to deal with events which are rare but have significant consequences. These rare events are extreme values of a sample with a low occurrence but with an overriding importance, they are the so-called distribution tails. We can find laws and so we can compute these extreme values. But also the worst can result from a miscalculated or underestimated risk with an extreme impact. Such not expected rare event can be a disaster like the collision in space between Iridium-33 and Cosmos-2251 in 2009 or also the blast of a meteor over Tcheliabinsk in 2013, the two most notable space disasters in the past.
Firstly, the conference will introduce the fundamentals of extreme values theory as well as its practical aspects for estimating tail-related risks. Then, some algorithms will be shown like the branching splitting in EGNOS/Galileo project, like the estimation of the ionosphere magnetic storms occurrence. The conference topic will continue with collision of space debris, launch vehicle fallout, spacecraft reentry, and will end with risks from space associated to Near-Earth Objects.

For registration:

http://cct.cnes.fr/content/séminaire-rare-events-extreme-values-extreme-impacts-applied-flight-dynamics

The registration is mandatory.

Getting to ISAE-SUPAERO: see information at the end of the document

CNES — CENTRE NATIONAL D'ÉTUDES SPATIALES	**Communauté de Compétence Technique** **CCT ORB –** Orbital Mechanics	CCT — Centres de Compétence Technique http://cct.cnes.fr

Program:

09:20 – 09:50	***Welcome & Coffee***	
09:50 – 10.00	*Introduction*	C. Le Fèvre, A. Couhert, D. Hautesserres, CNES
10:00 – 10:30	*Extremes method*	Jean-Marc Azaïs, IMT/UPS
10 :30 – 11 :00	*The branching splitting algorithm for rare event analysis*	Agnès Lagnoux, IMT
11 :00 – 11 :30	*Coffee break*	
11:30 – 12:00	*Non integrity in corrections of an increase GPS SBAS*	Jean-Marc Azaïs, IMT/UPS
12 :00 – 12 :30	*Application of the branching splitting ALGORITHM to estimate the integrity/continuity of EGNOS/Galileo*	Agnès Lagnoux, IMT
12 :30 – 14 :00	*Lunch*	
14 :00 – 14 :30	*Ionosphere magnetic storms occurrence probability*	Malika Chassan, CNES
14 :30 – 15 :00	*Maximum residual error of the ionospheric corrections EGNOS compared to IGS delays*	Malika Chassan, CNES
15 :00 -15 :30	*Computation of IXV safety footprint boundaries*	Rodrigo Haya, DEIMOS
15 :30 – 16 :00	*AsteRisk - Risks from space associated to Near-Earth Objects*	Daniel Hestroffer, IMCCE
16 :00 – 16 :30	*Coffee break*	
16 :30 – 17 :00	*Estimation of a launch vehicle stage fallout zone*	Jérôme Morio, ONERA
17 :00 – 17 :30	*Space collision*	Juan Carlos Dolado Perez, CNES
17::30 – 18:00	*Round table*	Conducted by Jean-Marc Azaïs
18:00 – 18:10	*Conclusion*	C. Le Fèvre, A. Couhert, D. Hautesserres, CNES

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Abstracts:

PART I: THEORY

1) **EXTREMES METHOD,**
   (J.M. AZAÏS, IMT/UPS)

2) **THE BRANCHING SPLITTING ALGORITHM FOR RARE EVENT ANALYSIS**,
   (A. LAGNOUX, IMT)

The study of rare events is an important area in the analysis and prediction of major risks as earthquakes, floods, air collision risks, etc. Studying the major risks can be taken up by two main approaches which are the statistical analysis of collected data and the modeling of the processes leading to such events. The statistical analysis of extreme values needs a long observation time since the very low probability of the events considered and may require many simplifying assumptions. The modeling approach consists first in formalizing the system considered and then in using mathematical or simulation tools to obtain some estimates. Monte Carlo simulation is a practical alternative when the analysis calls for fewer simplifying assumptions. Nevertheless, obtaining accurate estimates of rare event probabilities, say about 10^{-9} to 10^{-12}, using traditional techniques require a huge amount of computing time.
Many techniques for reducing the number of trials in Monte Carlo simulation have been proposed, like importance sampling or trajectory splitting. In this technique, we suppose there exists some well identifiable intermediate system states that are visited much more often than the target states themselves and behave as gateway states to reach the rare event. The principle of the algorithm is at first to run simultaneously several particles starting from the current level; after a while, some of them have evolved "badly", the other have evolved "well" i.e. have succeeded in reaching the next threshold. Then "bad" particles are moved to the position of the "good" ones and so on until the level of interest is reached. In such a way, the more promising particles are favored. We then derive the optimal algorithm and study its properties.
To end with this presentation, we consider the performances of the navigation system EGNOS and we perform the branching splitting algorithm to evaluate its non-integrity.

PART II: APPLICATIONS

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3) NON INTEGRITY IN CORRECTIONS OF AN INCREASE GPS SBAS, (J.M. AZAÏS, IMT/UPS)

4) APPLICATION OF THE BRANCHING SPLITTING ALGORITHM TO ESTIMATE THE INTEGRITY/CONTINUITY OF EGNOS/GALILEO, (A. LAGNOUX, IMT)

We consider the performances of the navigation system EGNOS. Nowadays, the practitioner only knows the individual probabilities of impact leading to the non-integrity by unit time. Hence the non-integrity is calculated only taking into account the individual Feared Event (FE). The goal here is to estimate the probabilities of concomitance in order to re-evaluate the system integrity. In that view, we perform a reinforced Monte-Carlo algorithm: the branching splitting algorithm. The principle of the algorithm is at first to run simultaneously several particles starting from the current level; after a while, some of them have evolved "badly", the other have evolved "well" i.e. have succeeded in reaching the next threshold. Then "bad" particles are moved to the position of the "good" ones and so on until the level of interest is reached. In such a way, the more promising particles are favored. Thus one can estimate the probabilities of concomitance and re-evaluate the system integrity.

5) IONOSPHERE MAGNETIC STORMS OCCURRENCE PROBABILITY, (M. CHASSAN, CNES)

Because they strongly disturb the ionosphere properties, the extreme magnetic storms are feared events for integrity and continuity of navigation applications such as WAAS (Wide Area Augmentation System) or EGNOS (European Geostationary Navigation Overlay Service), the European SBAS (Satellite-Based Augmentation System) complementing GPS. An accurate modeling of the intensity of occurrence of severe ionospheric storms is necessary. The aim of the presentation is to give an estimation of the frequency of such extreme magnetic storms per time unit (year) throughout a solar cycle.
An innovative approach based on a proportional hazard model is developed. Inspired by the Cox model, this method allows including non-stationarity and covariate influence. As in Extreme Value Theory (EVT) and especially in Peaks over Threshold modeling, all the high level events are used to make estimation and the results are extrapolated to the extreme level events. The model presented in this paper assumes that the number of storms during a cycle is a non-homogeneous Poisson process. The intensity of this process can then be expressed as the product of a baseline risk and a

risk factor. Contrary to what is done in the Cox model, the baseline risk is one parameter of interest (and not a nuisance one), this is the intensity to estimate.
The main data set used for this presentation is the ap index, the aa index is also utilized for comparison. After a precise description of data pretreatments, the innovative model is presented. The estimation results are given as well as several extensions. A prediction for the current solar cycle (24th) is also proposed taking into account the fact that the solar peak activity occurred in 2014.

6) MAXIMUM RESIDUAL ERROR OF THE IONOSPHERIC CORRECTIONS EGNOS COMPARED TO IGS DELAYS,
(M. CHASSAN, CNES)

The GIVDe (Grid Ionospheric Vertical Delay error) is available on the IGP grid, which is rather large. We want to estimate the difference between the GIVDe maximum over the grid and the unknown real GIVDe maximum over the area covered by the grid. We first apply a classical Kriging model. This model enables the spatial estimation of the GIVDe field on the area. Then, the maximum on the IGP is compared to the maximum estimated by Kriging.
Secondly, we develop a local approximation model, inspired by Slepian model. We give theoretical results enabling the construction of this local approximation and explain the implementation of the corresponding bound estimation. The bound obtained with our new method is then compared to the one obtained with Kriging.

7) COMPUTATION OF IXV SAFETY FOOTPRINT BOUNDARIES,
(R. HAYA, DEIMOS)

The Intermediate eXperimental Vehicle (IXV) is a re-entry demonstrator successfully flown past 11/Feb/2015 whose objective is to tackle the basic European needs for re-entry from LEO, consolidating the knowledge necessary for the development of any future European re-entry system while allowing risk limitation
The IXV vehicle will be injected by the Vega launcher in an equatorial suborbital trajectory to reach an entry velocity at the Entry Interface Point (EIP, 120 km altitude) above 7.4 km/s. After injection, the IXV flight will be comprised of three main phases; orbital, re-entry and descent. The re-entry phase for the IXV vehicle corresponds to a guided lifting entry during 8000 km ground track up to the deployment of a 3 stages parachute system, with the IXV flight terminating with splashdown on the Pacific Ocean.
Since the beginning of Phase C2 in 2009, one of the most restrictive requirements has been safety. In the frame of the mission analysis, a design target has been to ensure that there were no islands within the safety footprint, i.e. the footprint associated to a system/subsystem failure. Worst case methods were used to estimate that footprint during the design phase needed to derive the specification of the Entry Interface Point.

For moderate probability levels, like the 99% success with 90% confidence level, Monte Carlo technique can be used to populate the distribution and hence to apply standard confidential statistics. However, the verification of the safety requirement cannot be directly conducted with Monte Carlo Analyses, as the level of probability associated to the failure footprints (10^{-5} and 10^{-7}) is beyond the number of shots required to estimate the probability using confidential statistics. For instance, to estimate the 10^{-5} probability with 90% confidence level, a sample population of at least 230000 shots is needed.
Thus, it requires the use of non-common techniques, based for instance in the Generalised Pareto Distribution, for the estimation of the footprint boundaries to demonstrate compliance with safety regulations. The objective is to perform a fitting of the tails of the distribution using dedicated functions. The estimation of the parameters for the fitting is performed ensuring the stability of the predicted low probability boundary. A convergence indicator was created to analyze the stability of the prediction.
The computation of the low probability boundary was carried out by performing a variable change in order to ensure that the resulting distribution tail was compatible with the selected fitting technique.
The talk will be outlined as follows:

- Overview of the IXV Mission
- Safety challenges and requirements
- Techniques for tail estimation
- Selection of population variables
- Validation
- Application to IXV mission

8) SPACE COLLISION,
(J.C. DOLADO PEREZ, CNES)

Depuis le lancement de Spoutnik 1 le 4 octobre de 1947 la population de débris autour de la Terre n'a cessé d'augmenter. Un des mécanismes principaux à l'origine de cette augmentation est l'auto-génération de débris spatiaux suite à des collisions en orbite.
La France ainsi que d'autres états et acteurs internationaux disposent des moyens pour détecter et cataloguer un sous-ensemble de cette population. Compte tenu des limitations des différents systèmes de surveillance de l'espace, les catalogues existants contiennent autour de 20000 objets avec des tailles supérieures à 10 cm. Des efforts considérables sont faits afin d'améliorer les performances de détection des systèmes de surveillance de l'espace et ainsi pouvoir détecter et cataloguer d'ici à quelques années plusieurs dizaines de milliers d'objets de tailles supérieures à quelques centimètres.
Afin de limiter la prolifération de la population de débris, il est nécessaire de prédire les collisions entre les satellites opérationnels et les débris et ainsi mener à bien les manœuvres qui vont bien pour les éviter. En conséquence, dans un schéma de gestion opérationnelle des risques de collision, un

très grand nombre d'analyses doit être fait afin d'estimer si un ou plusieurs objets catalogués présentent un risque de collision pour un satellite opérationnel. Sous les hypothèses de mouvement relatif rectiligne et erreurs orbitales constantes autour de l'instant de rapprochement au plus près, nous sommes capables de simplifier le problème et ainsi d'augmenter l'efficacité de notre algorithme de recherche de risques de collisions. Malheureusement les hypothèses de mouvement relatif rectiligne et erreurs orbitales constantes autour de l'instant de rapprochement au plus près ne sont valables que lorsque la vitesse relative entre le satellite et les débris est suffisamment élevée pour linéariser le problème.
Cette présentation se focalisera sur la présentation et l'utilisation d'algorithmes efficaces pour estimer des évènements rares, ce qui est le cas du risque de collision débris – satellite, ne nécessitant pas des hypothèses simplificatrices. Via des cas d'exemples nous montrerons aussi l'utilisation de ces algorithmes pour étudier la sensibilité de l'évènement rare aux paramètres en entrée.

9) ESTIMATION OF A LAUNCH VEHICLE STAGE FALLOUT ZONE, (J. MORIO, ONERA)

The estimation of launch vehicle fall back safety zone is a very important problem in space application since the consequence of a mistake may be dramatic for the populations. This use case may be modeled as an input-output function with as inputs the launch vehicle stage fall-back phase initial conditions and several launch vehicle characteristics. The input-output function is the integration of the stage fall-back trajectory. The output is the distance between the estimated launcher stage fall-back position and the predicted one. The quantity of interest is the probability that the distance between the estimated launcher stage fall-back position and the predicted one is lower than a given threshold. This probability is of course rare and may hardly be estimated with crude Monte Carlo techniques. We analyze on this use case the performances of different rare event probability estimation methods notably described in [1].

[1] J. Morio et M. Balesdent (2016) Estimation of Rare Event Probabilities in Complex Aerospace and Other Systems, A Practical Approach, Woodhead Publishing, ELSEVIER, à paraître, ISBN : 978-0-08-100091-5

10) ASTERISK - RISKS FROM SPACE ASSOCIATED TO NEAR-EARTH OBJECTS, (D. HESTROFFER, IMCCE)

Albeit asteroids and comets, to their vast majority, orbit the Sun at astronomical distances from the Earth, some of them–called NEOs for Near-Earth Objects–orbit in the vicinity of our planet and Moon. Some trajectory paths may even threat the Earth by showing a probability to collide it, such objects are then classified as Potentially hazardous asteroids PHAs. The size of the body is an important parameter too to characterize the vulnerability and therefore a comprehensive view of the risk associated to an NEO collision. Fortunately, the size distribution (number of objects for a given size) is such that the fewer the larger the objects—and hence the most devastatingones. Conversely the small bodies are many, but it should be noted that cataloguing them is far from being complete and they are thus discovered at the last minute (passing close to the Earth or entering the atmosphere). Currently observation surveys are undertaken to detect the largest fraction of the population (present goal is to detect 90% of objects larger than 240m in size), combined with physical characterisation, computation of their orbits, uncertainty and impact probabilities monitoring, as well as studies to mitigate a possible threatening body. I will review some of the developments in research, R&D studies for space mission and programmatic response at international level.

PART III: ROUND TABLE

Conducted by Jean-Marc Azaïs.

Getting to ISAE-SUPAERO:

Please note that, unlike previous CCT ORB seminars:

This seminar will take place at ISAE-SUPAERO Amphitheater No. 4

10, avenue Édouard-Belin

31055 Toulouse

Tel: +33 5 61 33 80 80

To park your car: at campus of ISAE-SUPAERO

Contact and access map: http://www.isae.fr/

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Public transportation:

<table>
<tr><td><u>Arrival by plane</u>
From the airport, take the shuttle to Toulouse city center, up to « Compans Caffarelli » or the « Jean Jaurès » station</td><td><u>Arrival by train</u>
From the Toulouse Matabiau train station, take the metro line A, towards « Basso Cambo » and stop at « Jean Jaurès » station</td></tr>
<tr><td colspan="2">Then:
Take the metro line B towards « Ramonville » and stop at « Ramonville » station
Take the n°68 bus towards « La Terrasse » and stop at « ISAE CAMPUS SUPAERO » station
Or:
Take the metro line B towards « RAMONVILLE » and stop at « Faculté de Pharmacie » station
Take the n°78 bus towards « Lycée de St Orens » and stop at « ENAC » station, walk and reach back Édouard-Belin avenue to ISAE-SUPAERO (5 min)</td></tr>
<tr><td></td><td><u>Arrival by train</u>
From the Toulouse Matabiau train station</td></tr>
<tr><td colspan="2">Take the metro line A towards « BALMA-GRAMONT » and stop at « JOLIMONT » station
Take the n°37 bus towards « RAMONVILLE » and stop at « ENAC » station, walk and reach back Édouard-Belin avenue to ISAE-SUPAERO (5 min)</td></tr>
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Nota : your itinerary can be prepared at : http://www.tisseo.fr/

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