UTOPIÆ

Uncertainty Treatment and Optimisation in Aerospace Engineering

Handling the unknown at the edge of tomorrow

UTOPIAE is a **€3.9M** research and training network supported by the European Commission to focus on uncertainty treatment and optimisation

UTOPIAE will last 4 years starting 01 January 2017

Coordinated by Strathclyde University

15 partners over Europe

11 full partners + 4 associate partners

- 7 universities
- 3 companies
- 5 national research centres
- 1 university research centre

15 researchers will be recruited within UTOPIAE

8 major training & outreach events organised within UTOPIAE

- Who's who in the network?
- Where are they?

- Who’s who in the network?
- Where are they?

UTOPIAE, the first of its kind, is going to train the next generation of engineers, scientists, decision makers to face uncertainty and use optimisation to build resilience in complex engineering systems

How?

- 3 training schools on the major topics of the research programme
- 4 workshops involving the international community
- One final global conference
- One final book

TRAINING EVENTS

Training School (TS)

Classic one or two week school with frontal lectures and training activities

Supervisory board (SB) will meet at every TS

Global Virtual Workshop (GVW)

International workshop in which people from outside UTOPIAE are invited to attend via videoconf

In particular joint workshops with the US and Japan are expected

Local Training Workshop (LTW)

Workshop within UTOPIAE though it can be made open to external people

UTOPIAE conference (wow)

Final event structured as a proper international conference with papers and invited talks

Internships/Secondments

- The activities within each internships/secondments are discussed by the Supervisory Board at the annual meeting preceding the internship/secondment

- The institution sending the ESR and the one receiving the ESR present a proposal in front of the SB
  - Proposal should contain all the details of the secondment/internship such as technical/research specifics, contractual, management, organisation/logistics, etc.

Complementary Skills

- Dedicated activities at each training event
- One full day of complementary skill training at the LTW-I
- LTW-II will be totally dedicated to entrepreneurship

- Project Working Groups as practical activity to experience:
  - Leadership and management
  - Planning and time management across disciplines and locations
  - Remote team work
  - Presentation skills
  - Proposal writing
  - Project development

Project Working Groups

- Working groups are a peculiarity of this ITN and are there to promote cross-disciplinary training and activities

- The aim of PWGs are to:
  - Provide cross-disciplinary training to the ESRs
  - Provide management/supervision training to the ESRs
  - Blend the activities within this ITN to effectively reach the common goals of this ITN: optimisation and uncertainty quantification

WORKING GROUPS

PWGs are formed by ESRs of different institutions who work on a joint project for up to 6 months

The initial coordination and supervision of the PWGs is provided by the supervisors of the ESR

PWGs will work remotely using online tools to communicate and organise their work

Results of a set of PWGs will be presented at a LTW or a TS, after which a new set of PWGs will be started

The SB will decide which projects the PWG will work on

The Research Questions

How to find the ideal compromise between performance and reliability/robustness?

Is the current way to model uncertainty sufficient?

How to tackle increasingly complex systems?

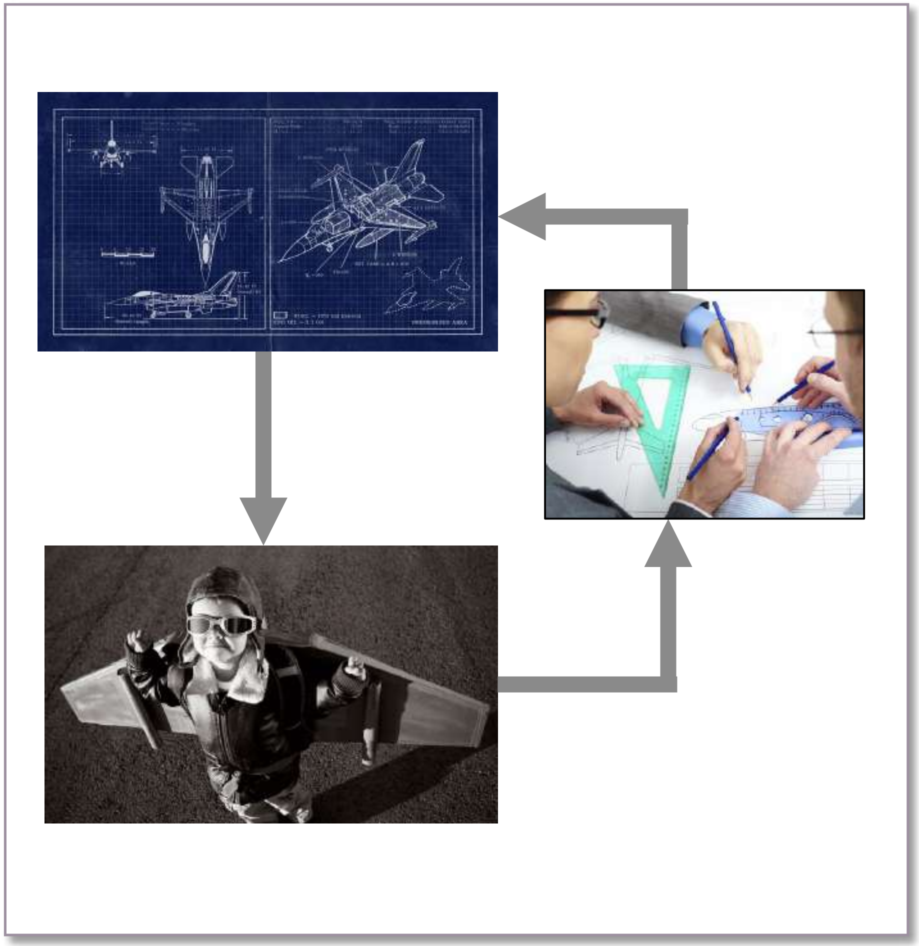
How to engineer resilience in complex systems?

How to make all this computationally tractable?

The Research Objectives

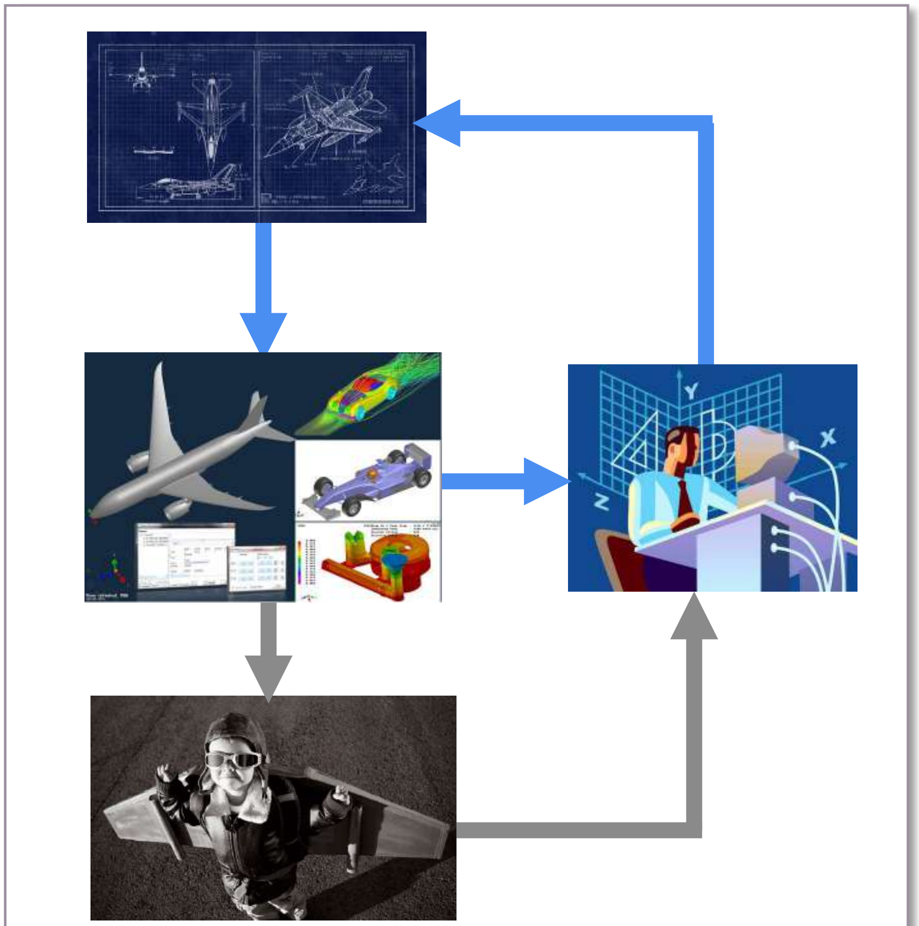
- ✓ To develop fundamental mathematical methods and algorithms to bridge the gap between Uncertainty Quantification and Optimisation
- ✓ To bridge the gap between Probability Theory and Imprecise Probability Theory for Uncertainty Quantification,
- ✓ To efficiently solve high-dimensional, expensive and complex engineering problems.

THE PASTS AND THE PRESENTS



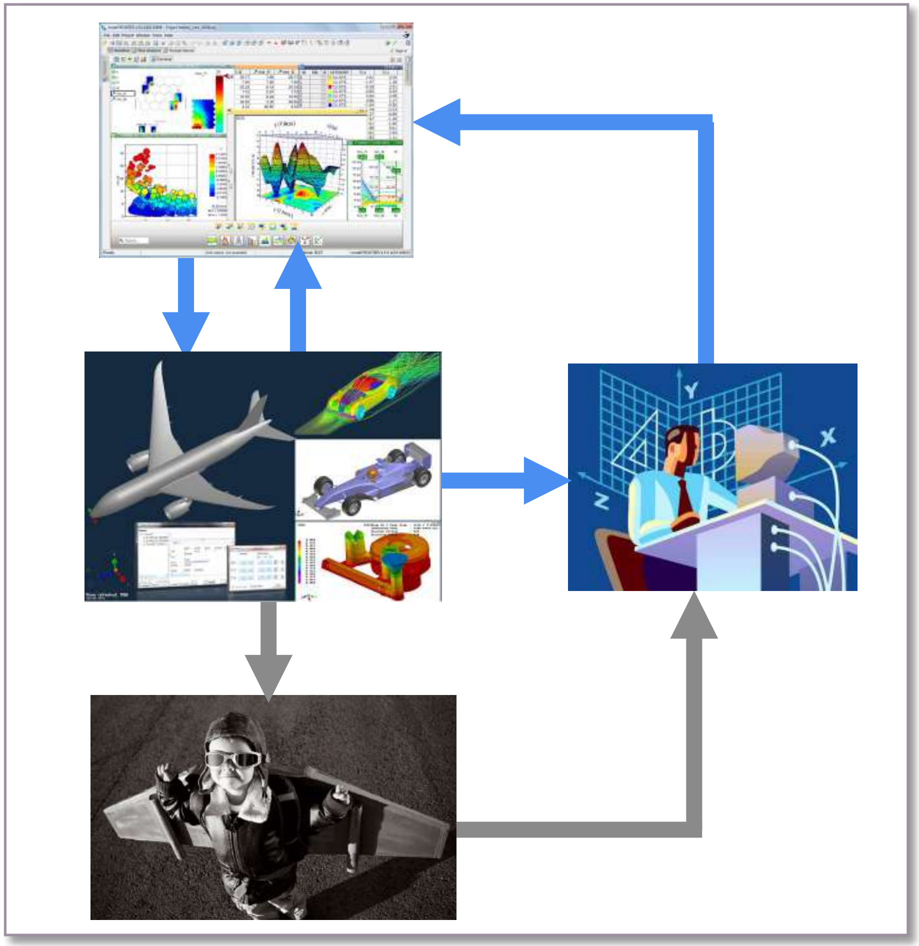
- Human in the loop
- Human design and decision making
- Blue prints
- Physical prototyping
- Testing
- Feedback to designer

DESIGN BY ANALYSIS



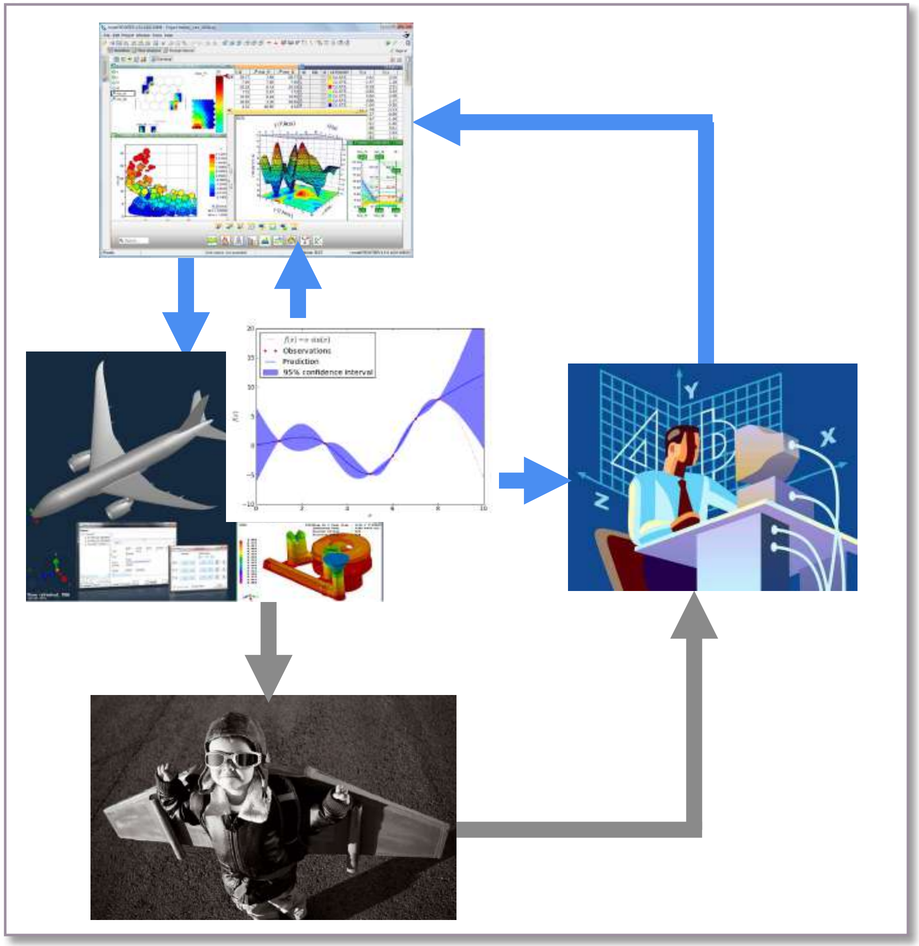
- Human in the loop
- Computer assisted design
- Analysis informed design solution
- Virtual prototyping
- Feedback to designer
- Physical prototyping
- Feedback to designer

From Design by Analysis to Design by Optimisation



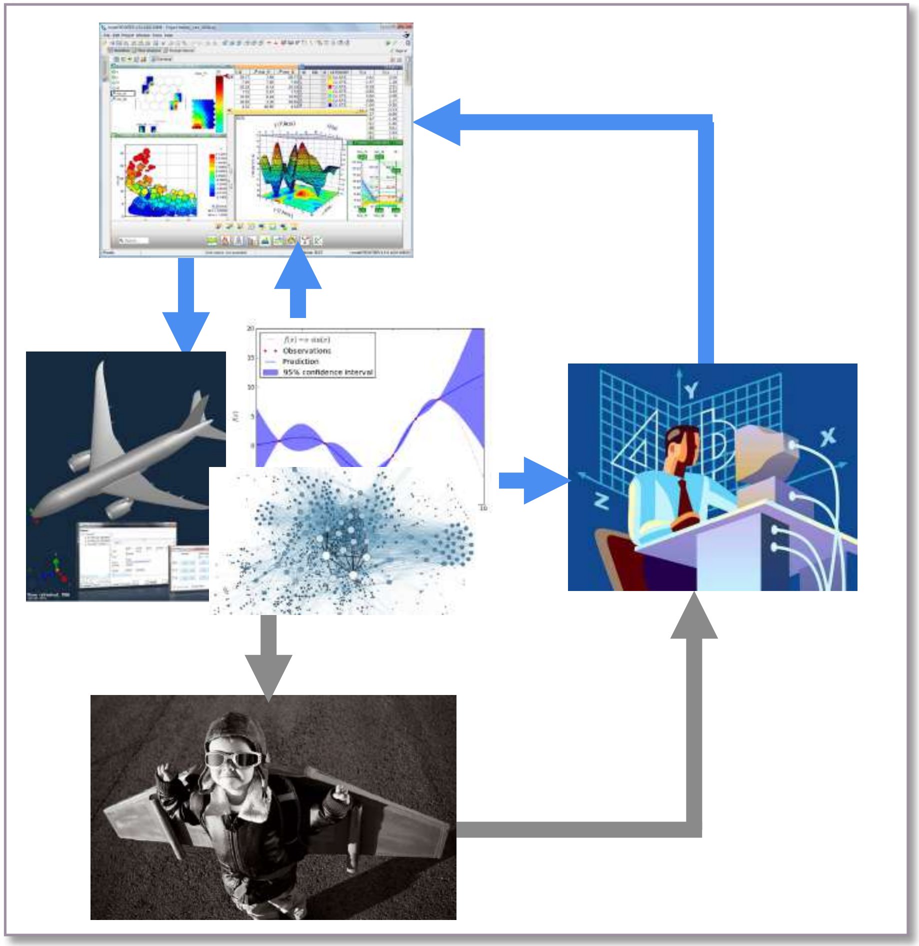
- Human in the loop
- Algorithm assisted design
- Optimised design solution
- Virtual prototyping
- Feedback to designer
- Physical prototyping
- Feedback to designer

From Design by Optimisation to Design by Robust Optimisation



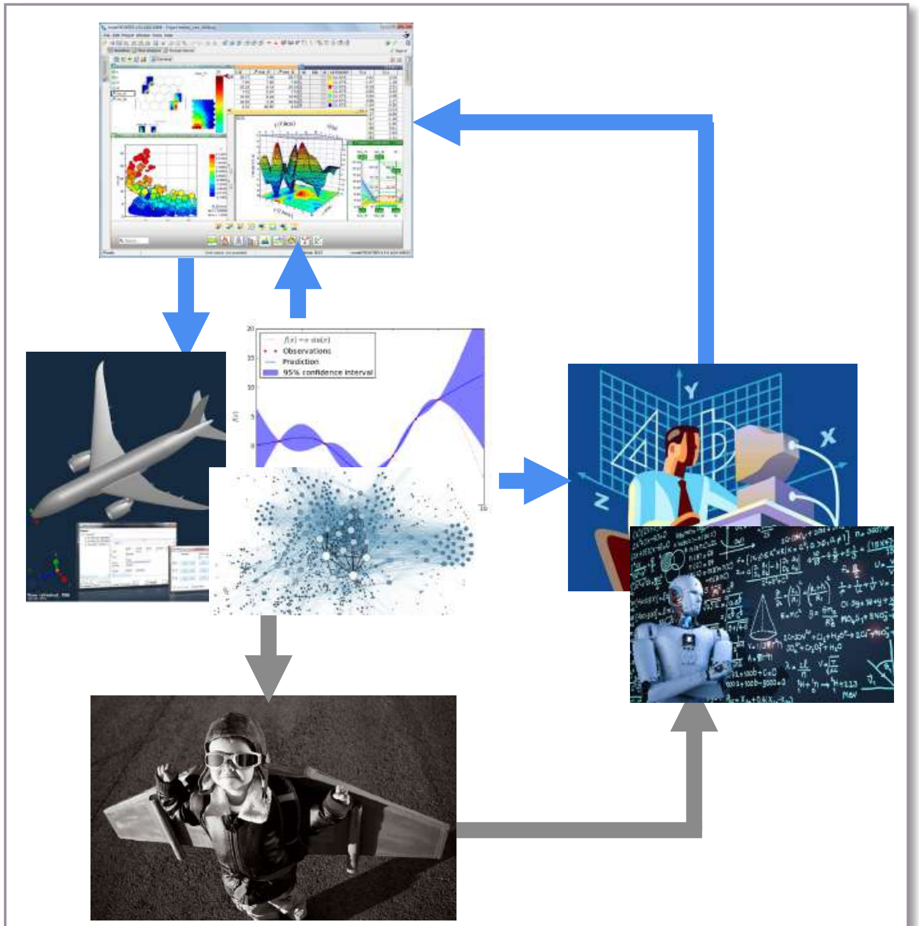
- Human in the loop
- Algorithm assisted design
- **Optimised design solution under uncertainty**
- Virtual prototyping
- Feedback to designer
- Physical prototyping
- Feedback to designer

GOAL - RESILIENCE ENGINEERING



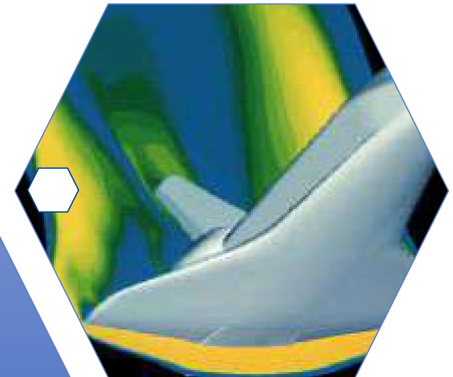
- Algorithm assisted design
- **Optimised design solution under time dependent uncertainty**
- Inclusion of transition to failure and recovery
- Virtual prototyping
- Feedback to designer
- Physical prototyping
- Feedback to designer

VISION - AI ASSISTED ROBUST DESIGN

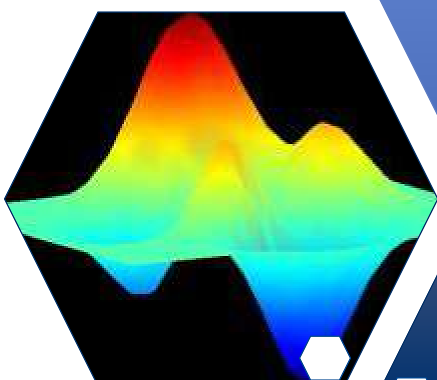


- AI assisted design
- **Optimised design solution under time dependent uncertainty**
- **Data in the loop**
- Inclusion of transition to failure and recovery
- Virtual prototyping
- Feedback to designer
- Physical prototyping
- Feedback to designer

AREAS OF RESEARCH

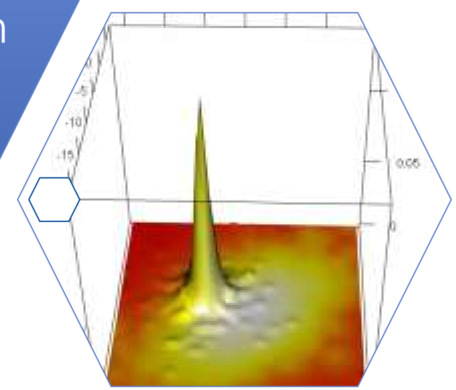


Modelling

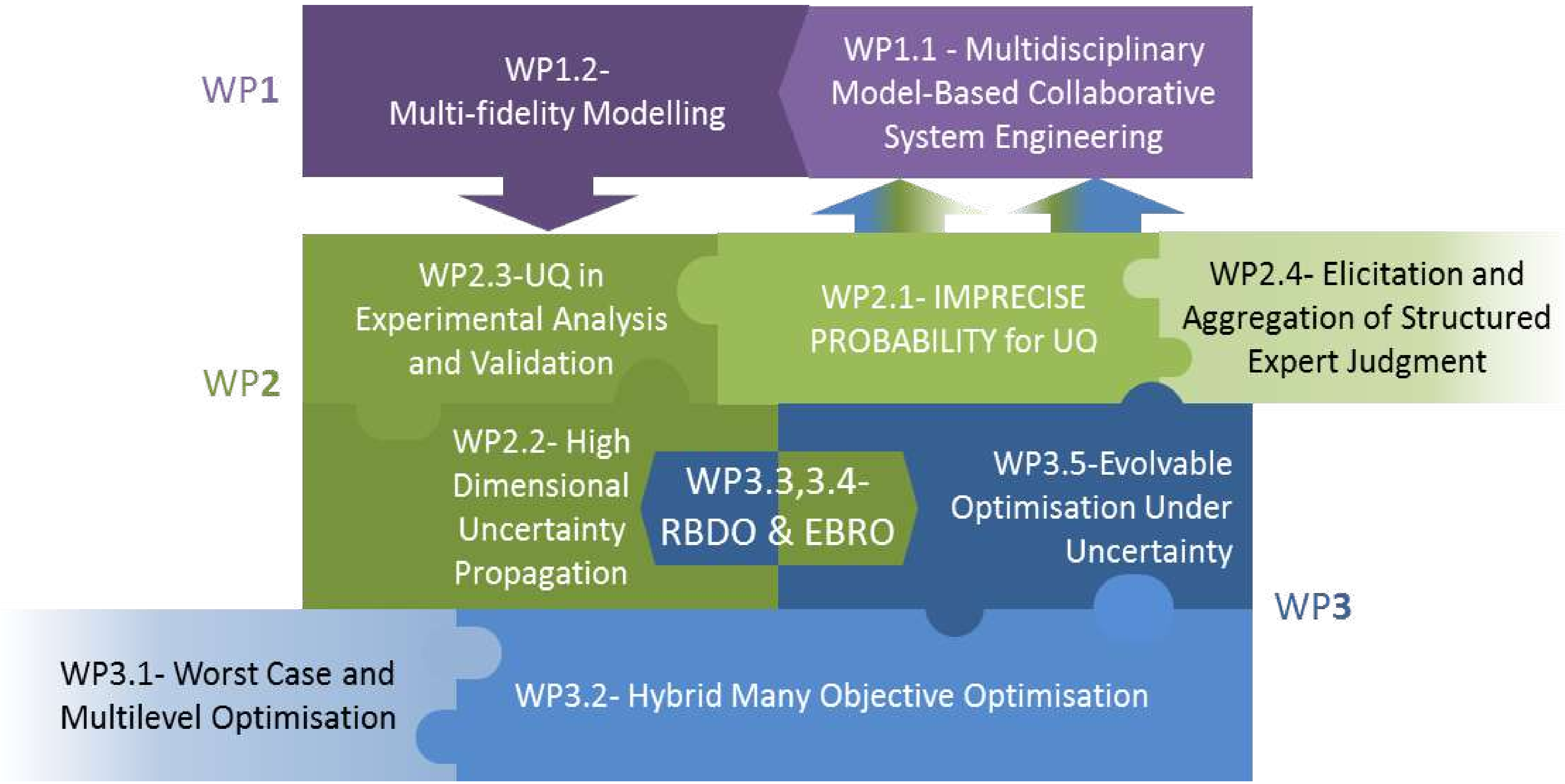


Uncertainty Quantification

Optimisation Under Uncertainty



WORK PROGRAMME

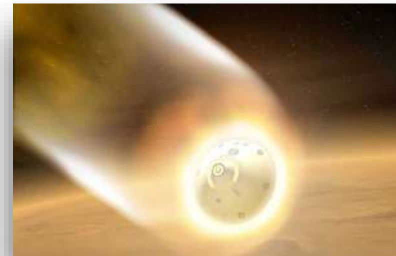


Major Scientific Results

ROBUST BAYESIAN INFERENCE METHODOLOGY FOR CATALYSIS DETERMINATION IN REAL PLASMA WIND TUNNEL TESTING

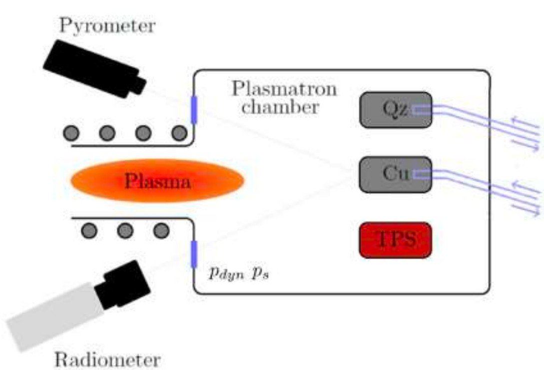
Access to LEO

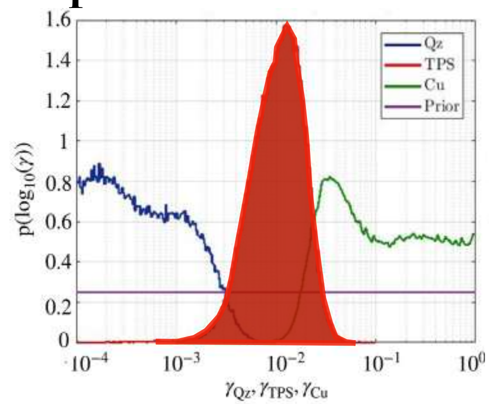
Space Exploration

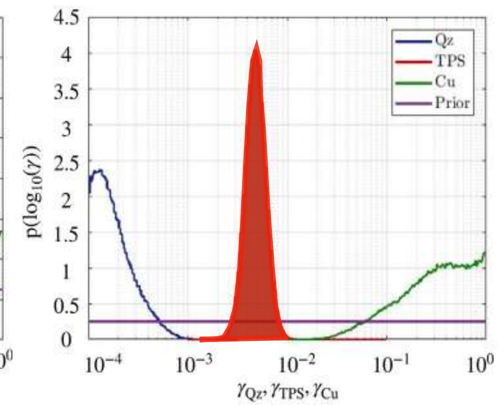


Meteor phenomena

- **Gas-Surface Interaction represents one of the main sources of uncertainties**
- **Design of experimental campaign through the inference method**
- **Result: high accuracy on catalytic parameter**





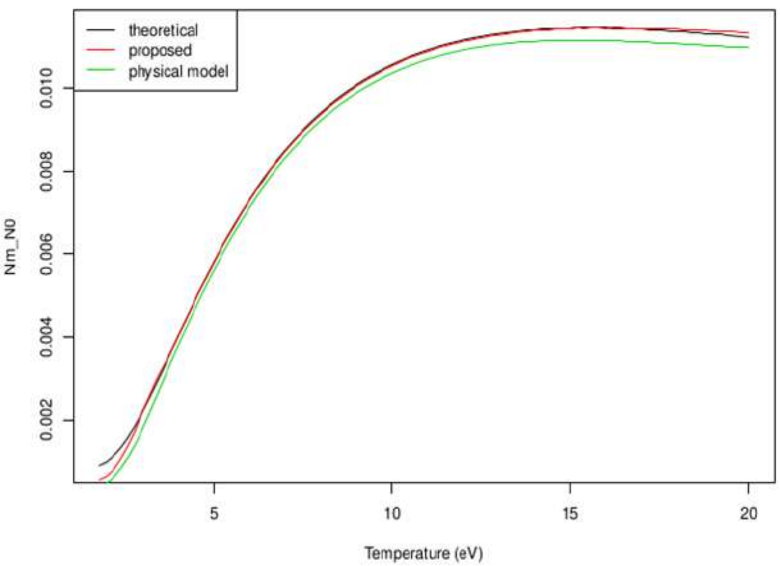


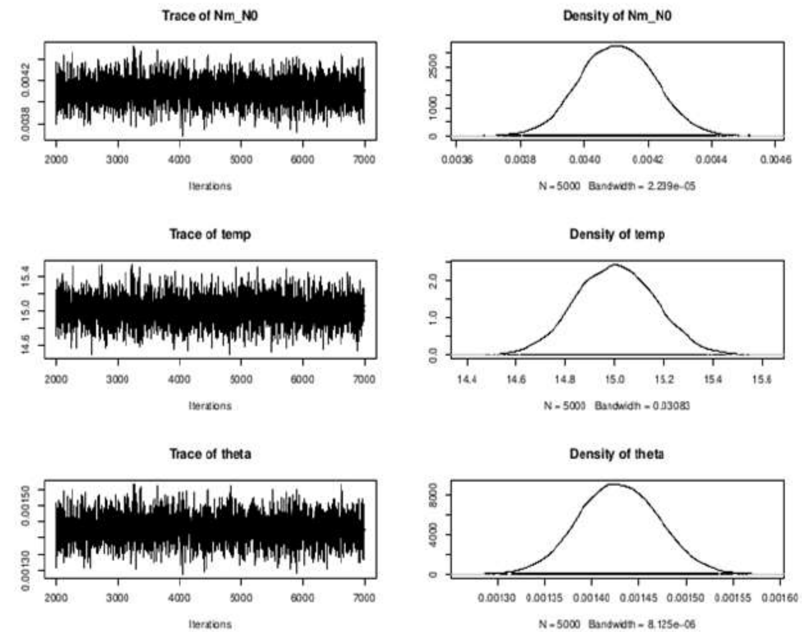
UTOPIAE Uncertainty Treatment and Optimisation in Aerospace Engineering

utopiae_network http://utopiae.eu

STATISTICAL INFERENCE TOOL FOR MEASUREMENT PROBLEMS WITH LIMITED INFORMATION

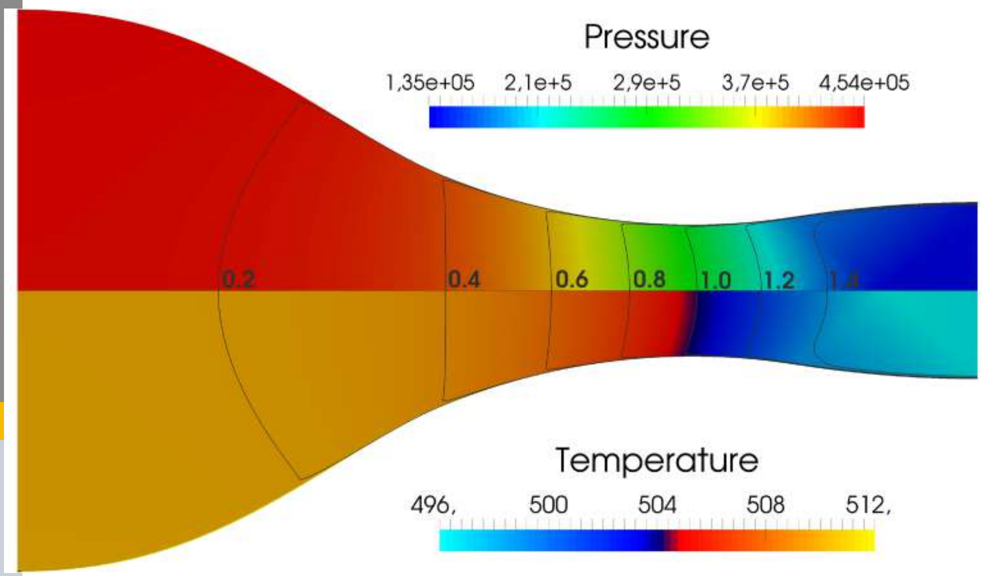
Use of imprecise probabilistic approach for measurement problems. The experiments are costly and therefore the measurements are few in number. This leads to severe uncertainty and we used the idea of imprecise probability to deal with this.

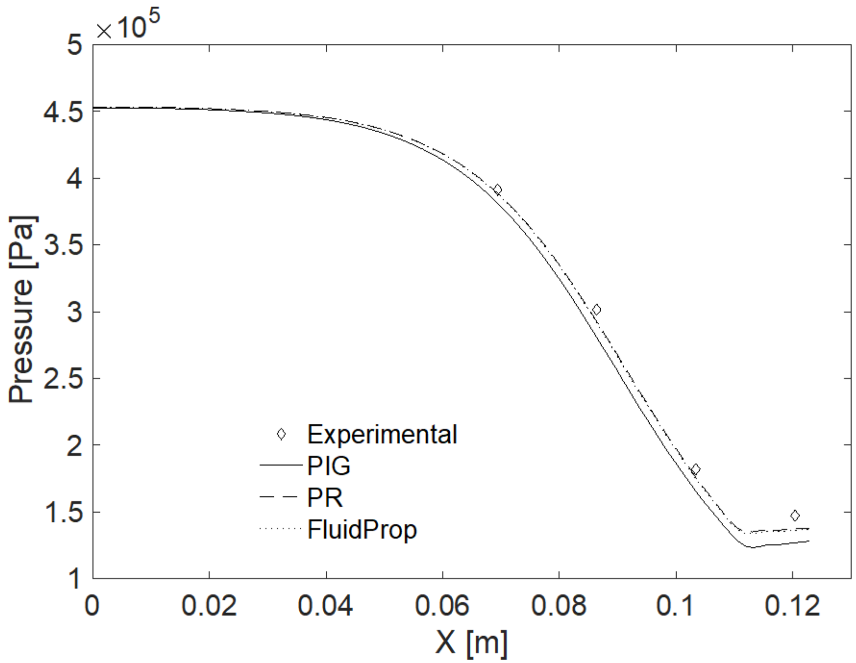




Fluid	Total T/T_c	Total P/P_c	Z
MDM	0.9	0.32	0.81

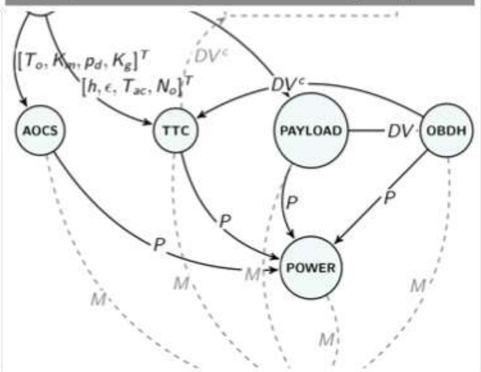
- Viscous simulations (Spalart-Allmaras and Menter SST-ω)
- Implicit second-order accurate MUSCL scheme of Roe type (Venkatakrishnan flux limiter)



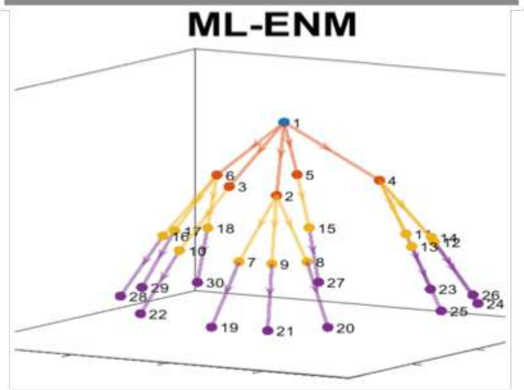


ENGINEERING RESILIENCE IN COMPLEX SPACE SYSTEMS

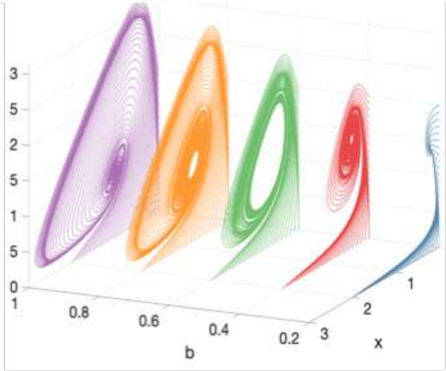
The complex System is represented as a graph



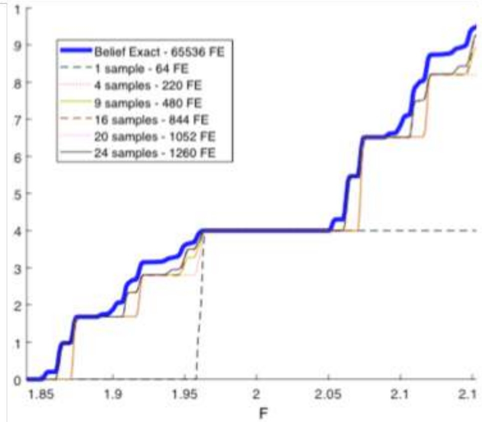
Multi-layer Evidence Network Model



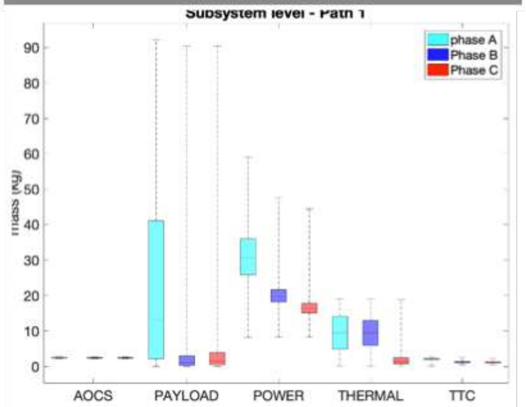
Bifurcation theory is used to model the evolution of the subsystems' state



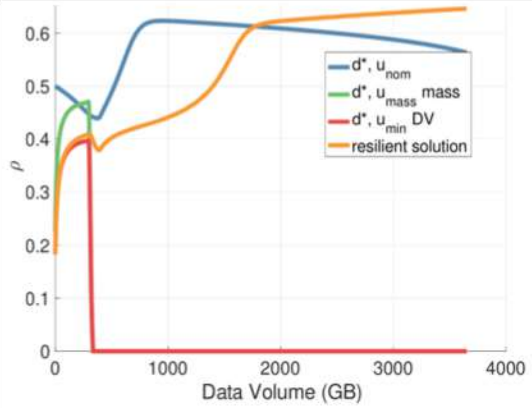
A decomposition approach evaluates Belief and Plausibility



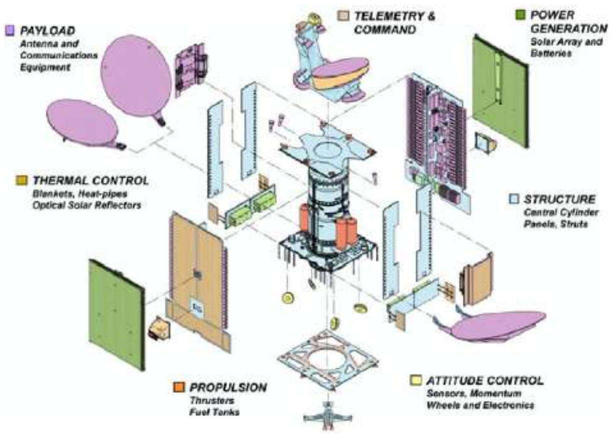
Epistemic uncertainty is propagated through the design phases



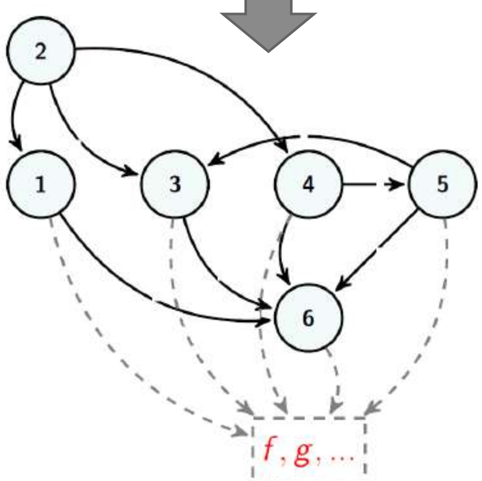
The design solution maximise resilience and performance

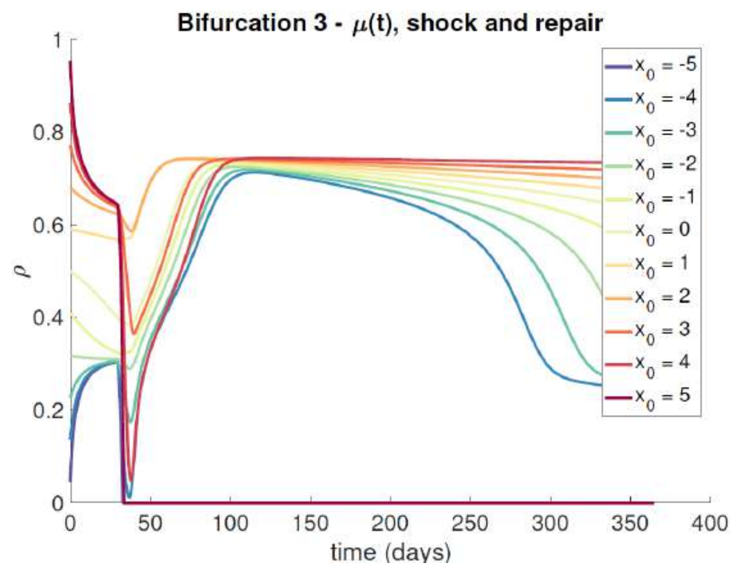


Resilience Engineering of Space Systems with Catastrophe Theory

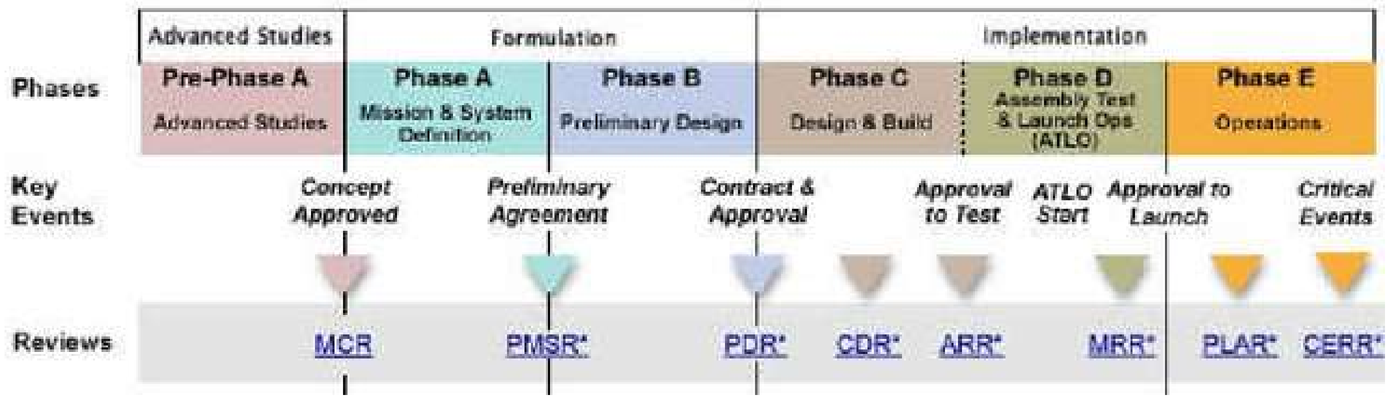


System modelled as a multi-connected network. Nodes are dynamical systems with possible degradations and failures. Dynamics is optimised together with system performance to achieve optimal resilience (maximum probability of recovery and maximum performance).

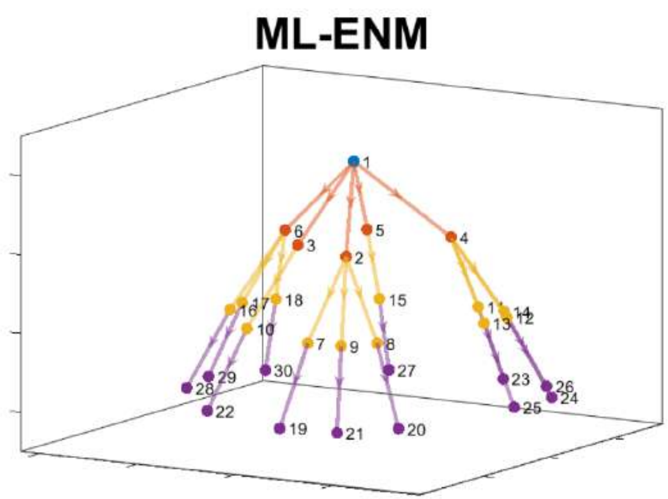


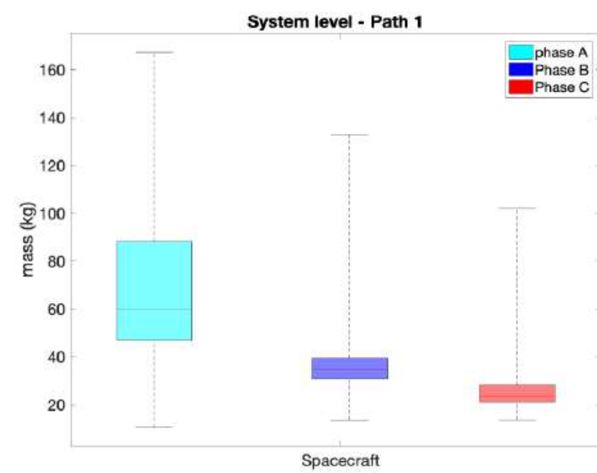


Multi-Phase Robust Optimisation

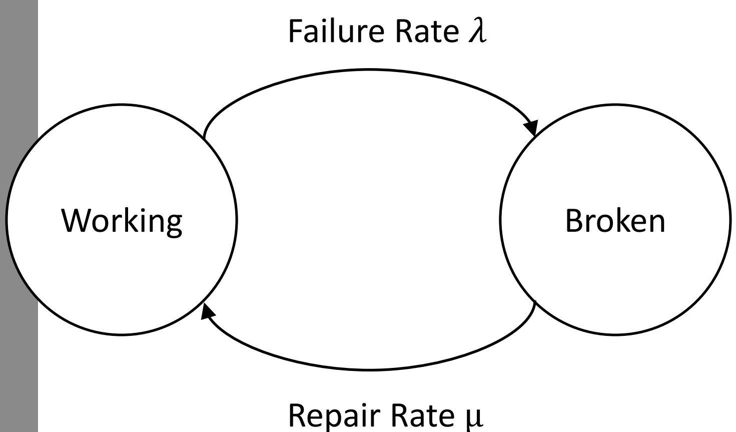


Design process modelled with a multi-layer network with uncertainty at subsystem level and interphase level. Allows for system level optimisation accounting for uncertainty in subsequent phases.





Imprecise Probabilistic Estimator for Parameters of Markov Chain



- How to learn λ and μ from observed (historical) data X?

- Use (conjugate) Bayesian prior distributions $\lambda \sim P(\lambda_0, s)$ and $\mu \sim P(\mu_0, s)$

where $s > 0$ is the strength of the prior, and λ_0, μ_0 are prior guesses

- Then compute posterior $P(\lambda, \mu | \lambda_0, \mu_0, s, X)$

But how to choose initial guesses λ_0 and μ_0?

Don't! Use an **imprecise probabilistic** prior instead!

Simply **consider all possible values** for λ_0 and μ_0

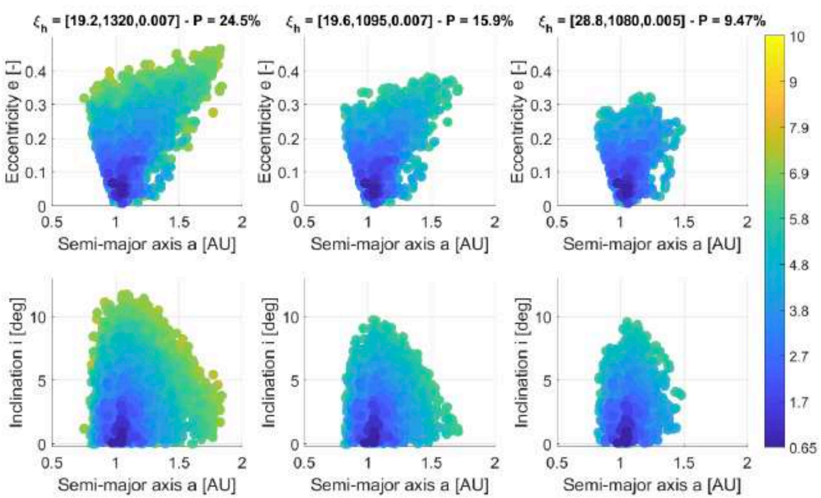
Posterior inference is **set-valued** $\{ P(\lambda, \mu | \lambda_0, \mu_0, s, X) : \lambda_0 \geq 0, \mu_0 \geq 0 \}$

Krak et al.: *An Imprecise Probabilistic Estimator for the Transition Rate Matrix of a Continuous-Time Markov Chain*, Proceedings of SMPS 2018, https://arxiv.org/abs/1804.013

Optimal Control Problems Under Uncertainty

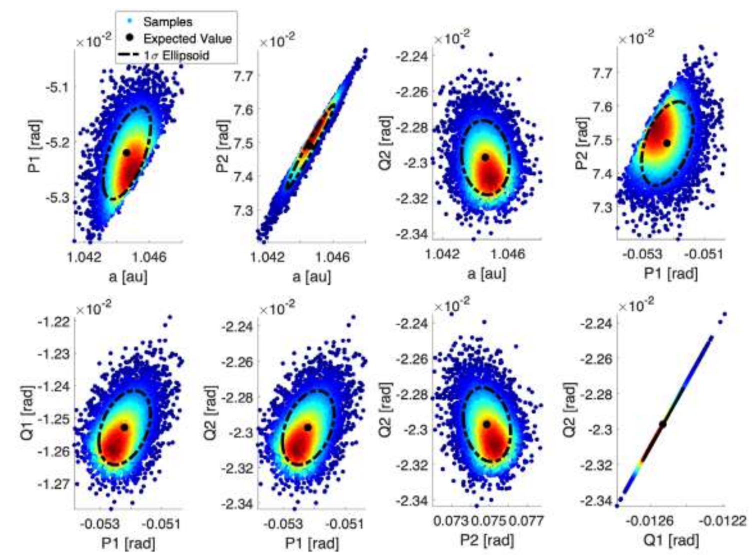
- Framework for OCPUU with general uncertainty models
- **Generalised stochastic Shooting transcription**
- Intrusive and Non-intrusive Polynomial Expansions for UP
- Efficient approach to decouple uncertainty in multi-phase dynamical systems

Analysis of low-thrust NEOs reachability
under Dynamical and System Uncertainty



Greco, et Al. (2018) *Analysis of NEOs reachability with nano-satallites and low-thrust propulsion*

Optimal-fuel low-thrust Interplanetary Rendezvous
with uncertain initial conditions



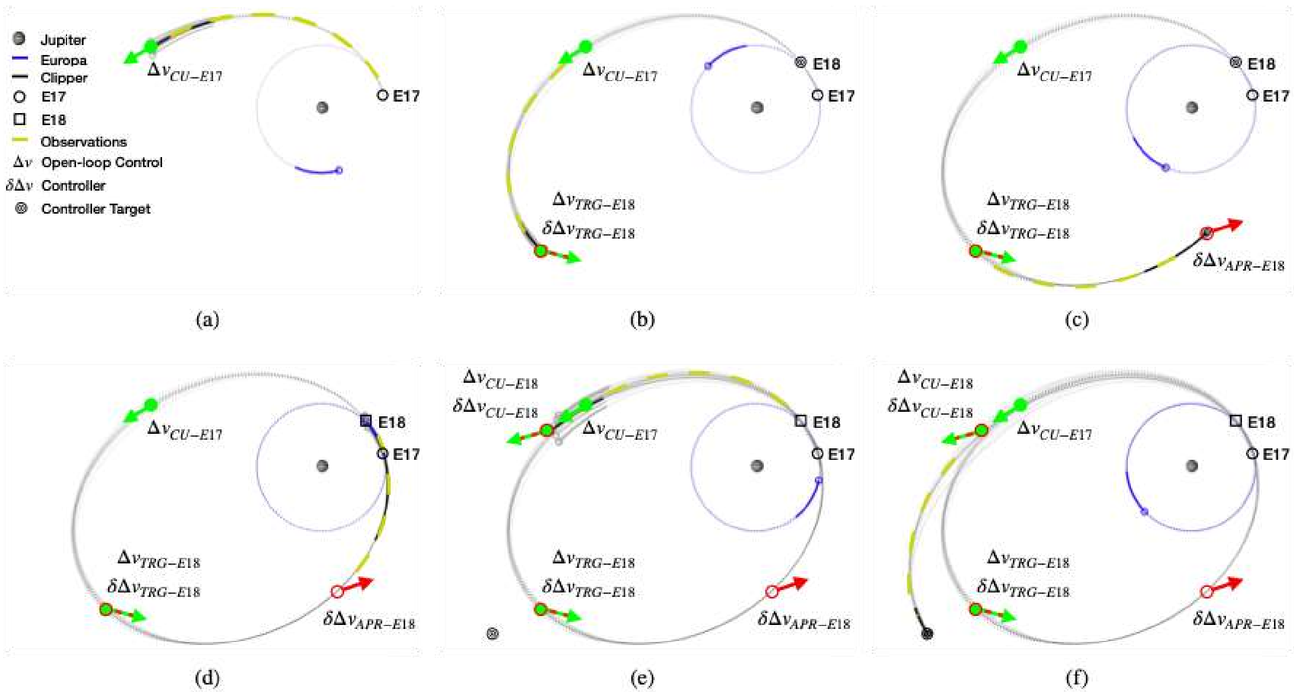
Greco, et Al. (2019) *Direct Multiple Shooting Transcription with Polynomial Algebra for OCPUU*

Greco, et Al. (2019) *Robust Space Trajectory Design using Belief Stochastic Optimal Control (to appear)*

Optimal Control Problems Under Uncertainty

- Applications to both low-thrust and high-thrust platforms
- Collaboration with JPL on the design of the Europa Clipper mission
- Closed loop between trajectory design and navigation analysis

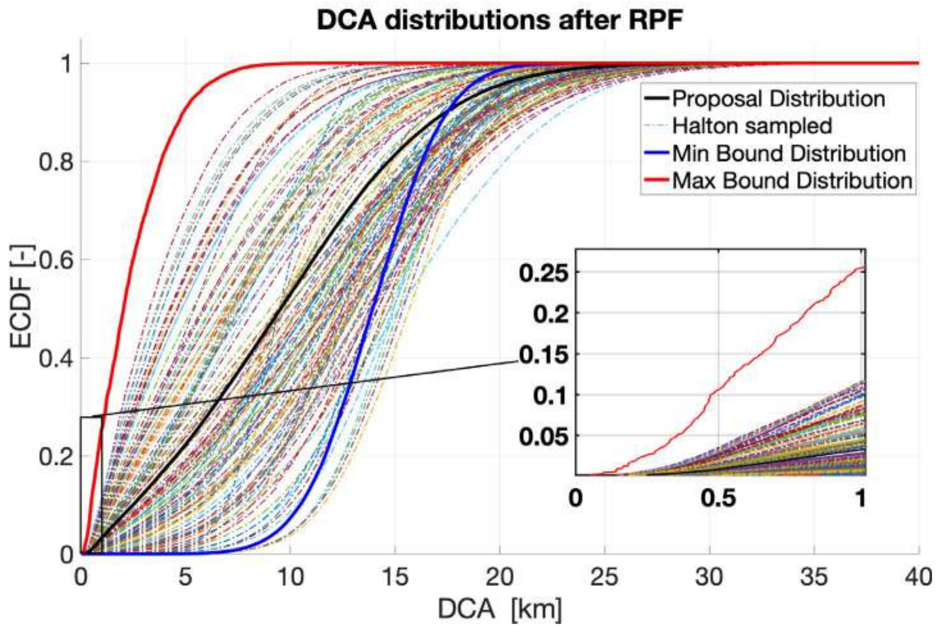
Robust Trajectory Design for Europa Clipper under initial dispersion, execution errors and navigation analysis



Greco, et Al. (2019) *Robust Space Trajectory Design using Belief Stochastic Optimal Control (to appear)*

NAVIGATION UNDER GENERALISED MODELS OF UNCERTAINTY

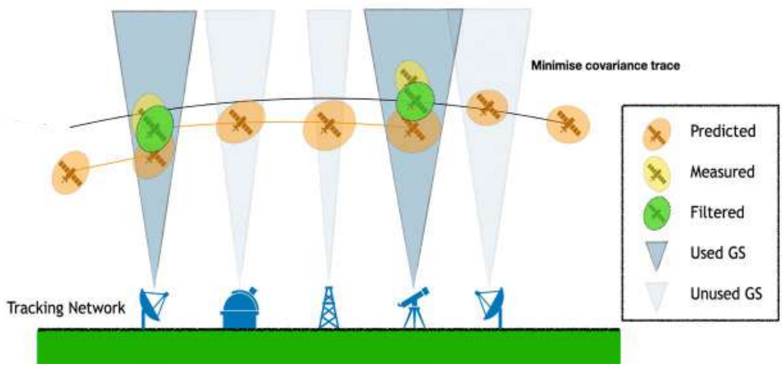
- Robust Particle Filter with Epistemic Observations
  - Algorithm for computing lower and upper expectations
  - Intrusive Polynomial Expansion for UP
  - Application to robust collision probability computation for space debris

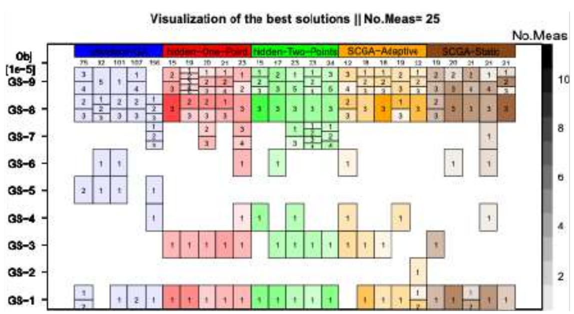


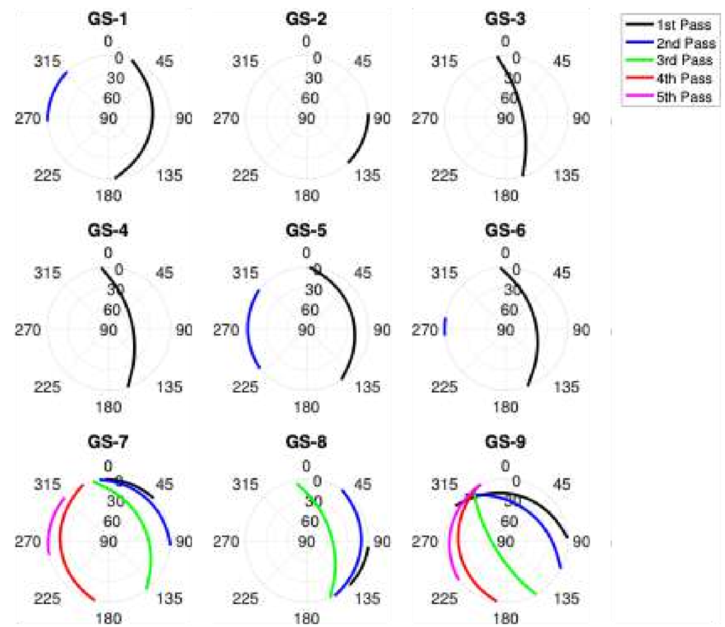
Greco, et Al. (2019) *Robust Particle Filter for Space Objects Tracking under Severe Uncertainty*

Optimal Scheduling Algorithms for Satellite Tracking and TCM

- Structured-Chromosome Genetic Algorithm with Sequential Filter
- Minimise uncertainty while respecting budget allocations
- Applications to near-Earth and deep-space satellite tracking and TCMs







Greco, et Al. (2019) *Autonomous Generation of Observation Schedules for Tracking Satellites with SCGA*

Gentile, et Al. (2019) Structured-Chromosome GA Optimisation for Satellite Tracking

Gentile, et Al. (2019) An Optimization Approach for Designing Optimal Tracking Campaigns for Low-Resources Deep-Space Missions

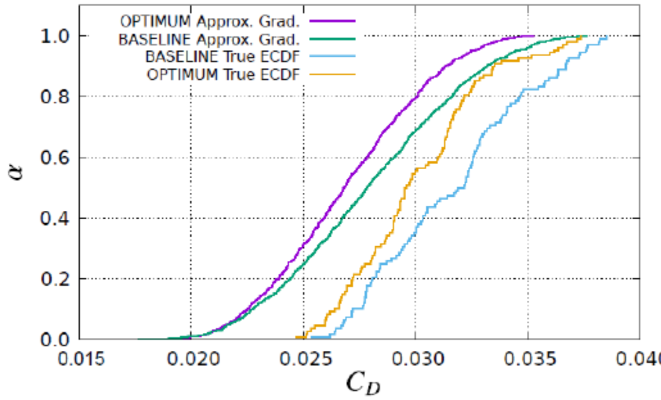
CUMULATIVE DISTRIBUTION FUNCTION APPROXIMATION FOR ROBUST AERODYNAMIC DESIGN

- Use a Gradient Based ECDF approximation for the Robust Aerodynamic Design of a Blended Wing Body (BWB) aircraft central section. The statistical measure used for the optimization is the Conditional Value at Risk (CVaR).
- How we obtained the Gradient Base ECDF
  - RANS adjoint solution returns the gradients of the QoI w.r.t the uncertainty variables almost at the cost of one RANS flow solution.
  - A linear approximation of the QoI is built by means of the extracted gradients.
  - Empirical Cumulative Distribution Function (ECDF) is calculated.
  - CVaR is estimated

$$q(\boldsymbol{x}) = q(\boldsymbol{x}_0) + \sum_{i=1}^{n} \frac{\partial q(\boldsymbol{x}_0)}{\partial x^{(i)}} \left(x^{(i)} - x_0^{(i)}\right)$$

- Robust optimization problem: Drag reduction with geometric and aerodynamic constraints.
- Uncertainties are taken in Mach number, angle of attack and in shape.

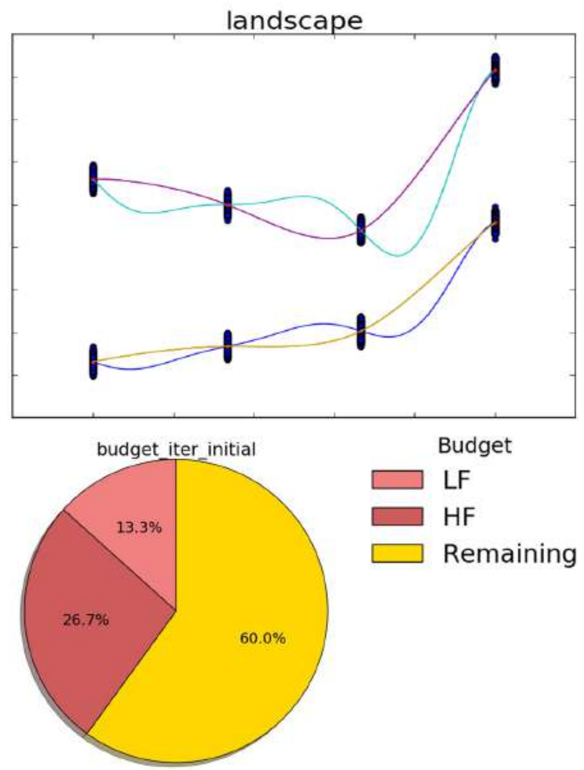
- A remarkable improvement of the upper tail is obtained, while a deterioration of the lower tail is avoided (advantage w.r.t classical approaches based on μ and σ).
- Despite a shift of the approximated solution, the trend of the true ECDF is captured, therefore the approximated $\text{CVaR}^{0.9}$ is perfectly usable for robust optimization.
- To improve the shift due to the linear approximation → second order approximation.
- We think that the presented method shows the best trade-off between cost efficiency and effectiveness of the optimization.



[2] Morales Tirado Elisa, Bornaccioni Andrea, Quagliarella Domenico, Iemma Umberto, and Tognaccini Renato. "Gradient Based Empirical Cumulative Distribution Function Approximation for Robust Aerodynamic Design".

UNCERTAINTY-BASED DESIGN OPTIMISATION OF A DUCTED FAN PROPULSION SYSTEM

Multi-fidelity surrogate based optimisation



Multi-fidelity solvers

Potential flow theory

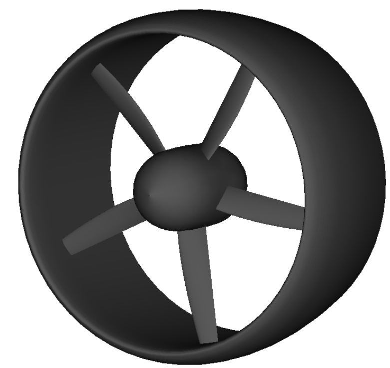
Accuracy ↓ ↑ Cost

Euler equation

Accuracy ↓ ↑ Cost

Reynolds-averaged Navier–Stokes

Final design



DEVELOPMENT OF EFFICIENT ROBUST DESIGN FRAMEWORKS

Bi-Level Surrogate for Global Robust Optimization [1]

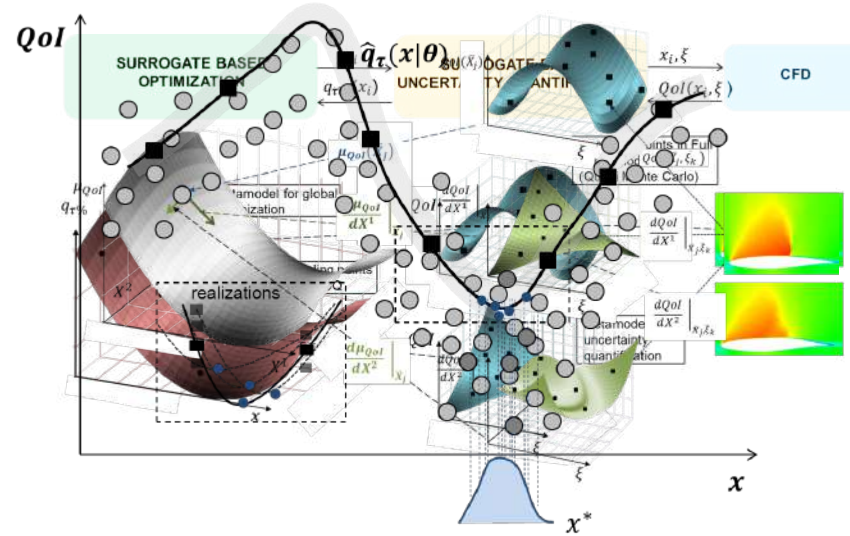
- Use of Gaussian Processes at different levels: for Optimization and for Uncertainty Quantification
- Good Accuracy of Statistics at each iteration
- Active infill accelerates convergence

Bayesian Quantile Regression [2]

- Insensitive to the number of uncertainties
- Availability of the error in predicting the quantile at any design

Gradient-Based Robust Design [3]

- Insensitive to the number of Design Parameter
- Use of the Adjoint and Gaussian Processes to obtain the gradients of the statistics
- Quick convergence in finding the optima



[1] Christian Sabater and Stefan Goertz. "An Efficient Bi-Level Surrogate Approach for Optimizing Shock Control Bumps under Uncertainty", AIAA Scitech 2019 Forum, (AIAA 2019-2214)
[2] Christian Sabater, Olivier le Maitre, Pietro Congedo. “Optimization under Uncertainty of Large dimensional Problems using Quantile Bayesian Regression”, CMAME Journal (Under submission)
[3] Christian Sabater and Stefan Goertz. “Gradient-Based Aerodynamic Optimization under Uncertainty using the Adjoint Method and Gaussian Processes”, EUROGEN 2019, Guimarães

Application to the Robust Design of Shock Control Bumps

Global Robust Design of a SCB for Laminar Airfoil

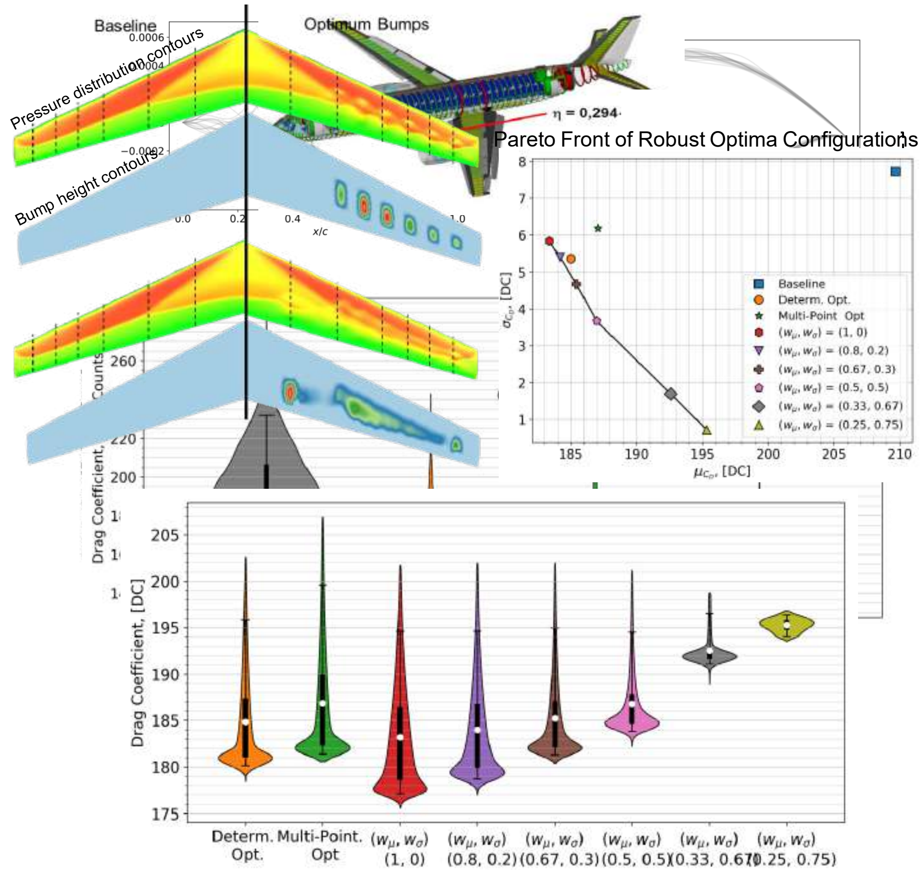
- Robust Optimum configuration reduces wave drag while mantaining laminarity

Robust Design of a SCB under hundreds of Uncertainties

- Geometrical uncertainties as a Gaussian Field
- Framework is able to obtain the robust 95% and 50% quantile of drag

Gradient-Based Robust Design of a SCB for a 3D Wing under Operational Uncertainties (AIRBUS Secondment)

- Multiple and Continuous Bumps reduce Drag
- Bump defined with 200 design parameters
- Pareto Front of mean vs standard deviation of drag obtained at a reduced number of iterations



SOME UTOPIAE OUTREACH ACTIVITIES

Jörg Bewersdorff delivers public lecture and interviews for science magazine as part of OTS

FOUR SEPARATE ACTIVITIES DEVELOPED BASED ON **UTOPIAE OTS** OUTREACH SESSION

DELIVERED TO PUBLIC AUDIENCES AS PART OF UTOPIAE LTW OUTREACH SESSION

UTOPIAE LTW

OUTREACH

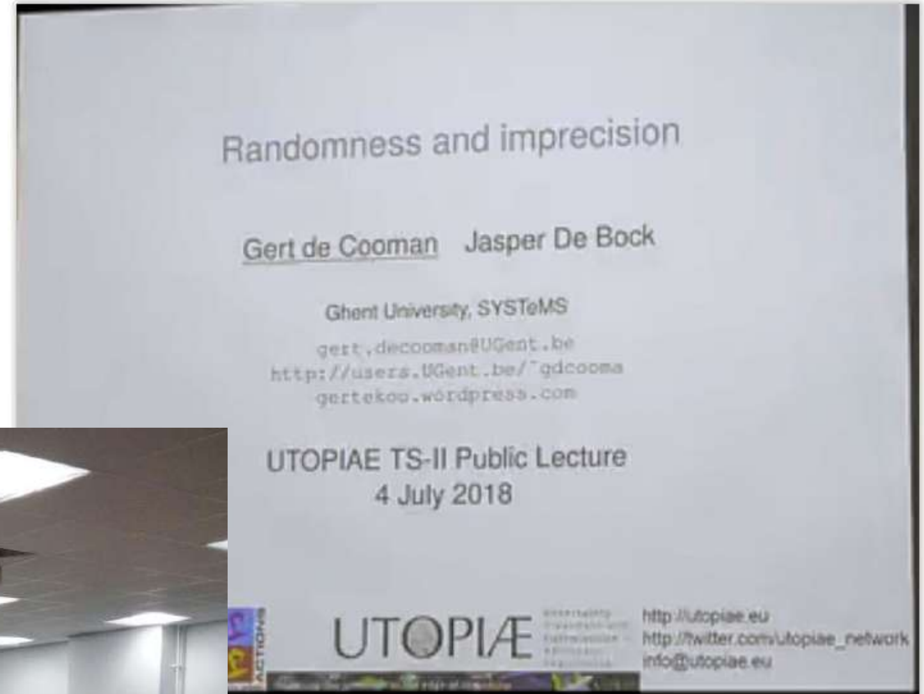
TSII Outreach Recording outreach videos for dissemination in 2019

Image Credit: ESR Anabel del Val: Twitter @Apolo_XIII

Image Credit: ESR Anabel del Val: Twitter @Apolo_XIII

UTOPIAE ESRs working on a tricky optimisation problem

TSII Public Lecture on Randomness and Imprecision



European Researchers' Night activities

UTOPIAE CPD ACTIVITY FOR ADVANCED HIGHER AND BACCALAUREATE TEACHERS

Optimisation and Uncertainty Quantification CPD training course

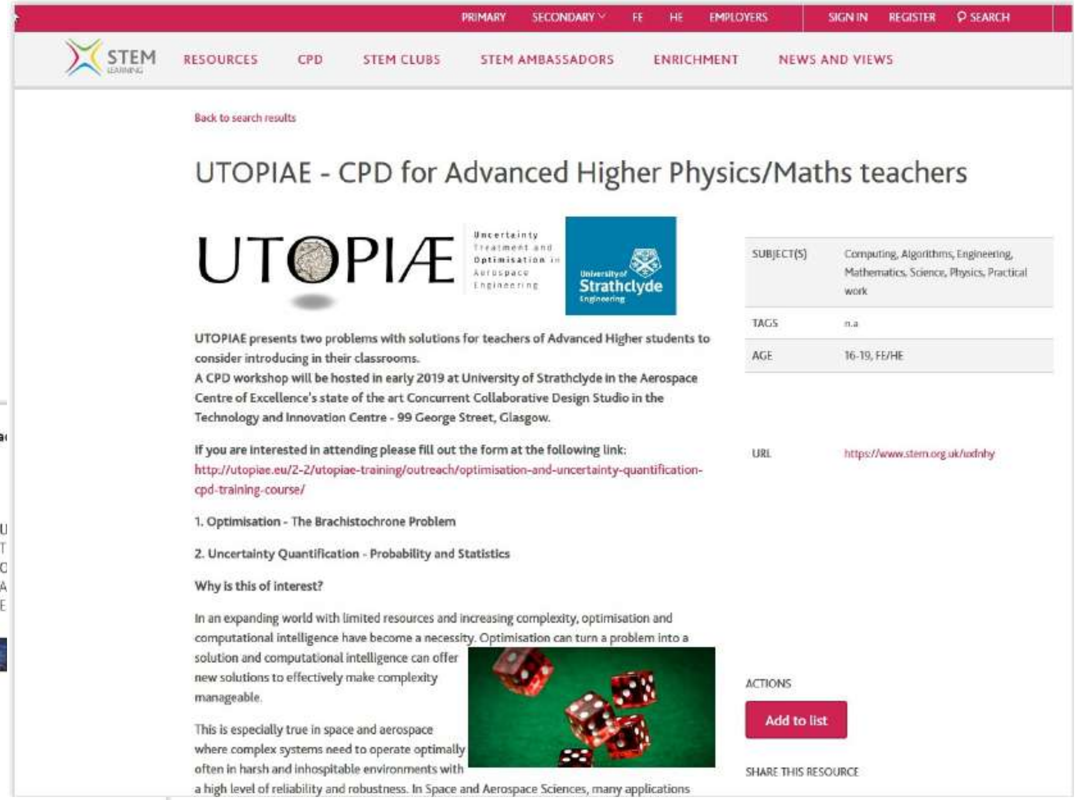
UTOPIAE presents two problems with solutions for teachers of Advanced Higher students to consider introducing in their classrooms.

This training session will focus on the following in line with the Curriculum for Excellence Advanced Higher syllabus:

1. Optimisation – The Brachistochrone Problem
2. Uncertainty Quantification – Probability & Statistics

Pre-registrations can be registered below.

Your Name (required)



Back to search results

UTOPIAE - CPD for Advanced Higher Physics/Maths teachers

SUBJECT(S)	Computing, Algorithms, Engineering, Mathematics, Science, Physics, Practical work
TAGS	n.a
AGE	16-19, FE/HE
URL	https://www.stem.org.uk/rxdnhy

UTOPIAE presents two problems with solutions for teachers of Advanced Higher students to consider introducing in their classrooms.
A CPD workshop will be hosted in early 2019 at University of Strathclyde in the Aerospace Centre of Excellence's state of the art Concurrent Collaborative Design Studio in the Technology and Innovation Centre - 99 George Street, Glasgow.

If you are interested in attending please fill out the form at the following link:
http://utopiae.eu/2-2/utopiae-training/outreach/optimisation-and-uncertainty-quantification-cpd-training-course/

1. Optimisation - The Brachistochrone Problem

2. Uncertainty Quantification - Probability and Statistics

Why is this of interest?

In an expanding world with limited resources and increasing complexity, optimisation and computational intelligence have become a necessity. Optimisation can turn a problem into a solution and computational intelligence can offer new solutions to effectively make complexity manageable.

This is especially true in space and aerospace where complex systems need to operate optimally often in harsh and inhospitable environments with a high level of reliability and robustness. In Space and Aerospace Sciences, many applications

ACTIONS

Add to list

SHARE THIS RESOURCE

PUBLIC LECTURES AT THE UNIVERSITY OF TRIESTE

PWG COMPETITION AT WINTER OF CODE

Next Steps

Two key events:

- Join UTOPIAE final conference UQOP 2020 in conjunction with BIOMA 2020

Major results expected

- Continue the collaboration with JPL on Europa Clipper
- Knowledge Transfer to Stardust-R on:
  - Space Safety and Space Environment Management
  - Re-entry analysis and Demise
- Maximise impact on industrial partners (e.g. Airbus and ESTECO)

Next Steps

BIOMA 2020 | Call for Papers | Submission | Registration | Speakers | Venue | Committees | Contact | UQOP 2020

BIOMA 2020

Important Dates

Submission of initial papers: Contact organisers
Notification of acceptance: 17 Aug 2020
Submission for revised papers: 4 Sept 2020

Download Call for Papers

The 9th International Conference on Bioinspired Optimisation Methods and Their Applications

JOINT CONFERENCE WITH THE INTERNATIONAL CONFERENCE ON UNCERTAINTY QUANTIFICATION & OPTIMISATION (UQOP)

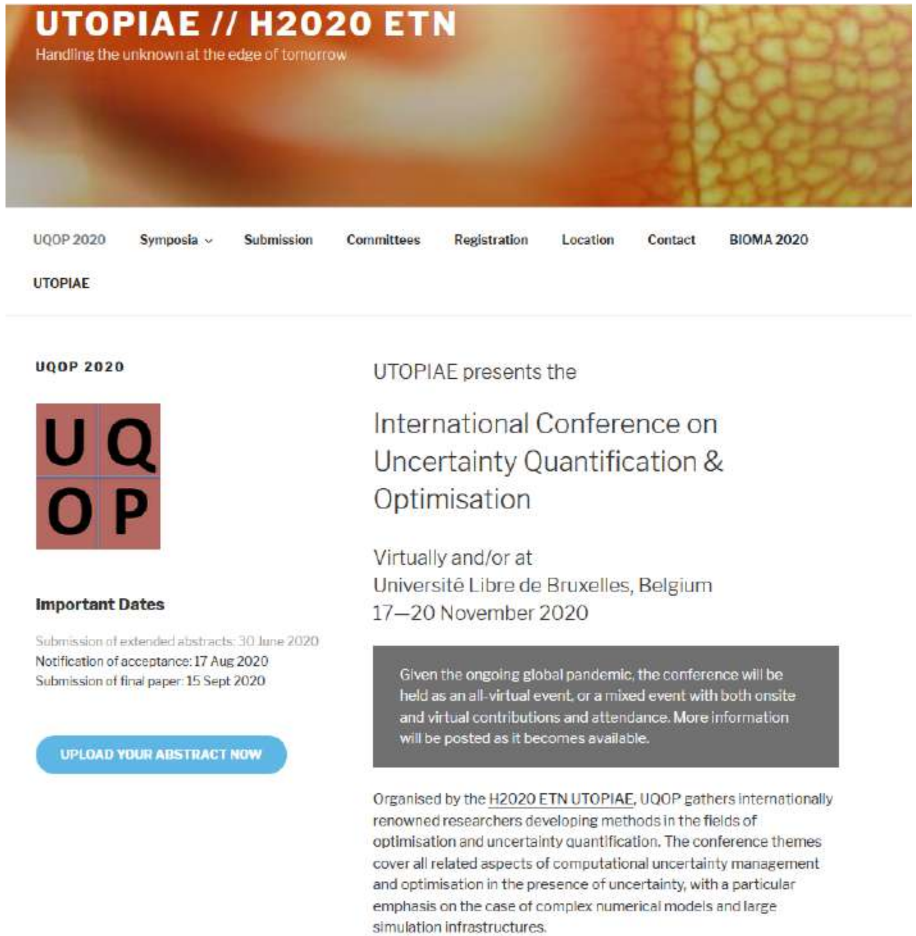
Virtual and/or at Université Libre de Bruxelles, Belgium, 17—20 November 2020

Regarding the current Covid-19 pandemic, we can gladly confirm that BIOMA 2020 and the joint conference UQOP will go ahead as planned.

The format will be either entirely virtual, or a mixed format of virtual and in-situ. We are monitoring the ongoing developments and will update the website accordingly, including any discount of the fees in the case of a purely virtual event. The proceedings will appear in Springer's LNCS series as planned, independently of the format of the conference.

While many things have changed this year, interesting and innovative research still continues and we look forward to the presentations and discussions that this conference always brings.

Next Steps


UTOPIAE // H2020 ETN
Handling the unknown at the edge of tomorrow
UQOP 2020
Symposia
Submission
Committees
Registration
Location
Contact
BIOMA 2020
UTOPIAE
UQOP 2020
UQ
OP
Important Dates
Submission of extended abstracts: 30 June 2020
Notification of acceptance: 17 Aug 2020
Submission of final paper: 15 Sept 2020
UPLOAD YOUR ABSTRACT NOW
UTOPIAE presents the
International Conference on Uncertainty Quantification & Optimisation
Virtually and/or at
Université Libre de Bruxelles, Belgium
17—20 November 2020
Given the ongoing global pandemic, the conference will be held as an all-virtual event, or a mixed event with both onsite and virtual contributions and attendance. More information will be posted as it becomes available.
Organised by the H2020 ETN UTOPIAE, UQOP gathers internationally renowned researchers developing methods in the fields of optimisation and uncertainty quantification. The conference themes cover all related aspects of computational uncertainty management and optimisation in the presence of uncertainty, with a particular emphasis on the case of complex numerical models and large simulation infrastructures.

Here are the UTOPIAE ESRs

Handling the unknown at the edge of tomorrow

UTOPIÆ

Uncertainty Treatment and Optimisation in Aerospace Engineering

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