



UTOPIÆ

Uncertainty
Treatment and
Optimisation in
Aerospace
Engineering

OSE5

5th Optimisation in Space Engineering Workshop

Book of Abstracts

Ljubljana, 21-22 November 2019

Welcome @ OSE5

Dear Delegate,

welcome to the 5th edition of the Optimisation in Space Engineering Workshop. This edition of the workshop is organised by the European Space Agency, the University of Strathclyde, the Jožef Stefan Institute of Ljubljana and ESTECO.

The goal of the OSE initiative is to provide a forum for space companies, universities, research institutes and organisations to discuss recent advances in space technology and further research in the area of optimisation in space engineering.

The workshop this year is held in conjunction with the second UTOPIAE Global Virtual Workshop. UTOPIAE is a European research and training network looking at cutting edge methods bridging optimisation and uncertainty quantification applied to aerospace systems.

We hope you will enjoy the talks and have the chance to network with old and new peers. And last but not least that you will enjoy your time in Ljubljana!

Best regards,
OSE5 organisation committee.

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Abstracts

Distributed optimisation tools

Optimisation platform for remote collaboration of different teams

21 Nov
9:50am

Gregor Papa and Gašper Petelin
Jožef Stefan Institute (Slovenia)

The multi-objective optimisation is a natural approach to solve difficult real-world problems. We developed and implemented a web-service-based platform for an efficient optimisation with different methods and approaches. Its main role is to allow testing of the effective optimisation methods for the numerical optimisation (i.e., geometry). The platform allows comparison of single objective as well as multi-objective algorithms. The platform is based on web services and allows remote work of different experts, while keeping important, secret features and characteristics hidden. Remote access enables experts to use the evaluation of the proposed solution regardless of their location. The platform allows remote access towards any evaluation and simulation tools (e.g., FEM analysis). Since actual parameter values of the problem that needs to be solved are masked for optimisation process and to ensure that no secrets about the problem are being shared among different groups of users, the platform hides the important properties of the solutions. In this sense, all parameter values and evaluation results are being normalised within the pre-specified interval. This way, the problem can be tackled by any optimisation expert without acquiring any relevant knowledge (e.g., actual dimensions, problem specifications) about the problem. Initially the platform was developed for numerical optimisation, while this work presents its usage also in discrete problem (i.e., satellite scheduling) optimisation. The platform is one of the steps towards the wider working platform, which would make possible the collaboration of users and tools from different geographical location, from different disciplines, as well as with different level of fidelities. This might finally lead to reduced development time within any design process, where various development teams are involved into multidisciplinary design cycle.

Tools and strategies for multidisciplinary design optimization

21 Nov
10:10am

Carlos Kavka, Mariapia Marchi and Carlo Poloni
ESTECO spa (Italy)

ESTECO is an independent software provider, highly specialized in design optimization, simulation data management and process integration and automation. ESTECO engineering suite offers enterprise-wide solutions. VOLTA, the web platform for multidisciplinary business process optimization and simulation data management, leverages knowledge, resources and computing power within a single framework. VOLTA keeps teams on track by allowing to concurrently compare, validate and decide on design solutions with advanced data intelligence tools. VOLTA allows concurrent and distributed execution of simulations on multicore workstations, HPC clusters and public clouds, while ensuring respect of security standards. VOLTA track change system facilitates

capturing engineering knowledge and IP protection. modeFRONTIER is a comprehensive solution for process automation and optimization in the engineering design process. modeFRONTIER platform guarantees the management of all logical steps of an engineering design process. The workflow formalization and the integration with third party tools enable the automation of the simulation process. A suite of design of experiments and optimization algorithms drives the search for optimal solutions. Picking the right design gets easier with a set of advanced tools for data analysis and visualization and decision making. modeFRONTIER modular environment aims at reducing complexity, improving efficiency and cutting development time. Over 300 international organizations have chosen ESTECO to consolidate specialized expertise, streamline teamwork and boost product development across a wide spectrum of industrial sectors. If you want to find out more about our software suite, visit us at ESTECO showcasing boot during the coffee breaks.

Space exploration and decision making

Proposal of an Optimization Benchmark Problem Based on Lunar Lander Landing Site Selection

21 Nov
11:00am

Akira Oyama

Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (Japan)

An optimization benchmark problem based on Lunar lander landing site selection studied in Japan Aerospace Exploration Agency is proposed. For evaluation of single-objective optimization algorithms, this benchmark problem has one objective, i.e., minimization of continuous shade days. For evaluation of multi-objective optimization algorithms, this problem has three objectives, i.e., minimization of continuous shade days, maximization of total communication time to the Earth, and minimization of inclination angle of the landing site to evaluate multi-objective optimization algorithms. Although this problem has only two design variables (latitude and longitude of the landing site), it is very difficult to solve because of very severe constraints on the continuous shade days and inclination angle of the landing site.

Finding an Optimal Lunar South Pole Landing Site at a Reduced Computational Cost

21 Nov
11:20am

Bogdan Filipič*, Aljoša Vodopija* and Akira Oyama†

*Jožef Stefan Institute and Jožef Stefan International Postgraduate School, (Slovenia), † Japan Aerospace Exploration Agency (Japan)

The Evolutionary Computation Symposium held in Fukuoka in 2018 hosted a competition in solving an optimization problem provided by the Japan Aerospace Exploration Agency. The problem originated from selecting a landing site for a lunar lander in the south pole area of the Moon and was presented in two variants, single- and multi-objective. The single-objective task was to find the latitude and the longitude of the landing site maximizing the total communication time with Earth and respecting constraints for consecutive shaded days and the landing site inclination angle. In the multi-objective case, it was to maximize the total communication time, and minimize the consecutive shaded days and the landing site inclination angle, while satisfying the constraints for the latter two objectives. The values of decision variables and objectives were scaled, and the evaluation of candidate solutions was made possible by querying a database prepared from the data recorded by the Kaguya lunar orbiter. The participants were instructed to use population-based algorithms handling the problem in the black-box manner. The algorithms were assessed with respect to the achieved objective/hypervolume value, while an additional criterion was the number of solution evaluations. Several teams were able to find the same best objective value and similar best hypervolume values but at very different computational costs. The best performing were

customized algorithms trying to account for the problem multimodality and disconnected feasible regions. In a study carried out after the competition, we have in contrast focused on finding suitable algorithms among the existing ones by matching the problem characteristics with algorithm properties and tuning the selected algorithms. This way we were able to better characterize the problem and reproduce the best results at a lower number of solution evaluations. We see these findings as relevant for solving similar problems in the future.

An optimisation approach for designing optimal observation campaigns: application to low-resources deep space missions

21 Nov
11:40am

Lorenzo Gentile*, Cristian Greco[†], Edmondo Minisci[†], Thomas Bartz-Beielstein*, Massimiliano Vasile[†]

*TH Koeln (Germany), [†]University of Strathclyde (UK)

In the last years, the technology readiness level reached by low-budget small platforms has allowed small organizations, to launch low-budget satellites in the near-Earth orbits. However, space missions beyond the near-Earth environment are still out of the reach of these stakeholders. One of the key limiting factor is the maturity of the associated ground segment and its tracking capabilities. In the aim of moving deep-space missions for small organizations one step closer to feasibility, this paper presents an approach for the optimal scheduling of observation campaigns for tracking deep-space small spacecraft under limited resources. Given a network of available ground stations, the developed method autonomously generates optimized tracking observation campaigns, in terms of stations to use and time of measurements, that minimize the uncertainty associated to the state of the satellite. The outcome is a spectrum of optimal solutions characterized by different allocated budgets. The developed approach relies on a Structured-Chromosome Genetic Algorithm that copes with mixed-discrete global optimization problems with variable-size design space. This operates on a hierarchical reformulation of the problem by means revised genetic operators. The step of estimation of the spacecraft state, and its uncertainty, given a set of measurements is performed using a novel particle filter approach able to handle imprecise observations likelihood. To show its potentials, this approach has been applied to the design of observation campaigns for tracking a nanoSat in its interplanetary cruise to an asteroid.

Polytopal Approximation of Dynamically Constrained Convex Sets

21 Nov
12:00pm

Kai Wah Chan*, Matthias Knauer*, Christof Büskens*, David Seelbinder[†], Stephan Theil[†]

*University of Bremen (Germany), [†]DLR Bremen (Germany)

During critical mission phases in deep space the reachability analysis is an undertaking often avoided due to its computational complexity and replaced by rough estimations. However, the knowledge of all reachable states constitutes an essential layer of information that supports the decision-making on board of autonomous spacecrafts in selecting alternative trajectories and avoiding hazards. The reachable set consists of all states of a dynamical system which are attainable from a given starting point, using admissible control inputs. Though several means exist to compute such a dynamically constrained set, we choose to approximate it by an iteratively refined convex polytope. In this approach vertices are found on the boundary of the reachable set by (concurrently) solving optimal control problems posed by every face, and connected according to the barycentric subdivision. The resulting polytope is an under-approximation of the reachable set.

The combination of optimization techniques and geometric ideas leads to an algorithm which is applicable in arbitrary dimensions without the necessity of a convex hull method. One benefit of the polytopal structure is the inherent half-space representation which allows a quick check if a state is inside the approximated region via matrix-vector multiplication. Moreover, a post-optimal analysis leads to low-cost parametric sensitivities for every solved optimization. They represent a delimitation of the potentially reachable and definitely not reachable area, and thus bear an iteratively updated over-approximation of the reachable set.

The benefits of the algorithm are illustrated on landing dynamics on the Moon and on Mars. A hazard map of the surface, overlaid with a reachable set, may provide an eligible reference to choose an alternative landing spot from if the nominal destination has to be reconsidered during the mission.

Optimisation techniques under uncertainty

21 Nov
2:00pm

Bounding limit expectations of Markov chains using evolutionary algorithms

Margarita Antoniou*, Thomas Krak†, Alexander Erreygers†, Jasper De Bock†, Gert De Cooman†
*Jožef Stefan Institute (Slovenia), †Ghent University (Belgium)

Markov chains are popular stochastic models to describe the evolution of dynamical systems under uncertainty. Of particular interest in many applications is the limit distribution over the states of this system, as time tends to infinity. It is well known that under some regularity conditions this limit distribution can be obtained by solving a linear system involving the transition (rate) matrix that describes the model's uncertain evolution.

Unfortunately, when the number of possible states of the system becomes very large, solving the corresponding linear system becomes infeasible. However, based on recent advances in the theory of imprecise probabilities, expectations with respect to this limit distribution can then still be conservatively bounded, using an imprecise Markov chain that is obtained by lumping (Erreygers and De Bock, 2019). In particular, bounds on limit expectations can then be obtained as the solution of a linear program, of dimensionality equal to that of the lumped (reduced) state space.

The tightness of these bounds (or lack thereof) however depends on the linear inequality constraints of this linear program, and there are various ways in which these can be chosen. In this work, we propose to find good constraints (thus leading to relatively tight bounds on the expectation of interest) by means of evolutionary algorithms.

In particular, our formulation leads to a bilevel optimisation problem in which the lower level problem is a linear program, and the upper level design vector represents the lower level problem's inequality constraints. We aim to investigate the performance of state-of-the-art evolutionary algorithms for solving this bilevel optimisation problem, and to compare our new approach to other methods for bounding limit expectations, both in terms of runtime efficiency and in terms of tightness of bounds.

A Review of Convex Optimisation Techniques for Piecewise Differentiable Functions

21 Nov
2:20pm

Tathagata Basu, Matthias C. M. Troffaes, Jochen Einbeck
Durham University (UK)

Optimisation is one of the most important tools in engineering and statistical modelling. For smooth objective functions, optimisation methods are well developed and understood. However, with the increasing complexity of models in modern applications, non-differentiable or piecewise differentiable objective functions are occurring more often than before. The classical approach like gradient descent method cannot be applied to piecewise differentiable functions as we do not obtain the first order derivatives. In this paper, we examine three different optimisation methods for piecewise differentiable functions: the subgradient method, the proximal gradient method, and the co-ordinate descent method, as well as Nesterov's accelerated versions of the subgradient and proximal gradient methods. We review the mathematical properties of these methods, as well as publish a novel **R** implementation for optimisation with piecewise differentiable objective functions. To demonstrate our implementation, we apply these methods on the LASSO (sparse regression) which essentially demands optimisation of a piecewise differentiable function.

Cooperative-Coevolution with Two-Stage-Grouping Based on Variable Effects and Interactions for Large Scale Global Optimization

21 Nov
2:40pm

Dani Irawan
TH Koeln (Germany)

Large Scale Global Optimization (LSGO) problems can be solved efficiently by using the divide-and-conquer method. The challenge in solving LSGO using this method is how to group the variables and how to allocate the computing resources. Cooperative Coevolution (CC) is a widely used framework to solve large scale global optimization. While there are varieties of implementations, most algorithms based on the CC framework are directed to detect the interactions between variables and spend a lot of computing resource to do it. On the other hand, Multilevel Optimization Framework Based on Variable Effects (MOFBVE) uses sensitivity analysis to detect the most significant design variables but lacks the ability to identify interactions. The two different approaches complement each other and can be combined to exploit their strength to some extent. In this work, a two-stage grouping scheme for CC is proposed. The first stage uses sensitivity analysis to detect and group the variables that contribute the most to the objective function; the second stage further groups the variables based on their interaction. While some variable interactions may be lost, the separable (non-interacting) variables will stay separable and a specialized solver for separable optimization problem can be used on this subgroup. To recover the missed interaction, optimization is carried in several cycles as per standard for the CC framework. Interconnection steps (optimization over the whole decision space) are also used for the same purpose.

An efficient surrogate model-based bi-level optimisation algorithm

21 Nov
3:00pm

Lorenzo Gentile*, Gianluca Filippi†, Edmondo Minisci†, Thomas Bartz-Beielstein*, Massimiliano Vasile†

*TH Koeln (Germany), †University of Strathclyde (UK)

A new algorithm is proposed to deal with the bi-level optimisation problems plagued with computationally expensive fitness functions. In this context, we applied the proposed strategy to a particular bi-level class of optimisation problems, the "worst-case optimisation". Two different types of variables influence this particular kind of problems: the control and the environmental variables. On the one hand, the former is assumed to be a quantity under control that has to be tuned. On the other hand, the latter is assumed to be quantities out of control, that typically have an undesirable effect, over which the chosen design has to result robust. In the worst-case optimisation, the performance indicator of a design is the worst performance with respect to the environmental variables. Therefore, the algorithm proposed searches for a mini-max solution, i.e., values of the control variables that minimise the maximum of the objective function with respect to the environmental variables. The proposed algorithm makes use of surrogate models for enhancing the search in both deterministic and environmental search spaces. The backbone of the proposed approach is using efficiently the information gained in every maximisation step to allocate resources optimally. By means this strategy, it is possible to conduct a relatively thorough search despite a limited budget of function evaluations.

Optimal Control

21 Nov
5:00pm

Intelligent Control by Genetic Programming

Francesco Marchetti, Edmondo Minisci
University of Strathclyde (UK)

In this work, an Intelligent Control approach was developed using Genetic Programming (GP), a Machine Learning technique which pertains to the class of Evolutionary Algorithms (EAs). Through GP it is possible to obtain a control law of the considered plant starting from a poor knowledge of its control system structure; hence the interest in using this technique to model complex control systems such as the ones used in aerospace applications. In order to define the obtained controller as Intelligent, the control law was derived twice: the first time it was derived for the nominal operating conditions of the plant; the second time it was derived while the system was operating and with a variation of one or more plant parameters, in order to simulate a sudden variation in the environmental conditions. The aim of this work is to show the possibilities and limits of Genetic Programming when applied to Intelligent Control applications and discuss future approaches involving this technique, through a well known benchmark problem for aerospace applications: a modified version of the Goddard Rocket problem.

21 Nov
5:20pm

Learning to Control a Spacecraft

Callum Wilson, Annalisa Riccardi, Edmondo Minisci
University of Strathclyde (UK)

Reinforcement Learning entails many inherent and intuitive approaches to solving a wide variety of problems. Its main premise is to learn how to complete tasks by interacting with their environment and observing the returns received in the future. This approach lends itself well to games which have finite action spaces and well defined rewards, for example points-based scores or winning/losing. As such, the majority of RL research is focussed on algorithms which play games. These approaches have many real world applications, such as optimal control problems where the metric to be optimised can be expressed as a reward function. A current limitation of RL is the ability of agents to safely explore new environments. Since most agents are trained offline before deployment, this does not allow safe operation in highly uncertain environments, such as in space. This research aims to formulate the problems of spacecraft GNC and AOCS as games where an onboard agent interacts with its unfamiliar environment to achieve a high-level goal. This requires lightweight and robust learning architectures which can adapt online.

21 Nov
5:40pm

Non-linear uncertainty propagation in a Guidance, Navigation Control system for approach operations using Differential Algebra

Kostas Konstantinidis
Advanced Concepts Team (ACT), ESA (Netherlands)

"Future space missions will require increasingly more complex Guidance, Navigation Control (GNC) systems. It is important that the design and analysis of these non-linear and complex systems can be performed accurately and efficiently. Uncertainty propagation in models of GNC systems has been traditionally either performed by linearizing them at the cost of accuracy or by performing accurate but computationally expensive Monte Carlo simulations.

A compromise between the two is offered by Differential Algebra (DA), a numerical technique to automatically compute high order Taylor expansions of a given function. In the DA framework, the Taylor expansion of a system model function is calculated once at relatively high computational expense. This expansion however can then be used to evaluate any input value around the nominal with negligible computational costs.

In this talk I will describe the application of the DA framework for non-linear uncertainty propagation in a GNC model for approach operations (e.g. asteroid landing, debris capture), including a) navigation and mapping, b) hazard detection and avoidance, and c) guidance and control functions. I will also discuss the use of this formulation of uncertainty for the robust optimization of GNC systems. A concept for a software tool will be presented and some preliminary results will be given. "

Improving the Evolutionary Optimization of interplanetary low-thrust trajectories using Machine Learning surrogates

21 Nov
6:00pm

Leon Stubbig, Gómez Pérez, Pablo; Liu, Yuxin; Cowan, Kevin
Delft University of Technology (TU Delft, Netherlands)

The design of interplanetary missions relying on low-thrust propulsion has been a research topic for many years and poses interesting challenges especially when viewed as an optimization problem. Here, we examine the problem of preliminary trajectory optimization based-on a two-body problem, considering orbit injection, flybys, and multiple rendezvous. Previous research has shown that Evolutionary Algorithms (EAs) are well suited to find global solutions to these problems as they do not require gradient information and are able to balance exploration and exploitation. In this work, two approaches to using Machine Learning (ML) surrogate models trained on previous fitness function evaluations are investigated. Surrogates can assist EAs by reducing the computational effort. The first approach is based on the hodographic shaping method and Neural Networks (NN) to construct the surrogate. A Genetic Algorithm (GA) from the PyGMO toolbox is run for a set number of generations. Then the NN is trained and utilized to find new candidate solutions that are reinserted into the original population following an elitist metric. It was found that a purely online approach often results in an insufficient surrogate quality, not justifying the overhead. Much better results are obtained by pretraining the NN on a general data set of shaped transfers and using incremental training during the GA run. The second approach aims to optimize transfers generated with the direct Sims-Flanagan method and trains an OS-ELM model integrated into a Differential Evolution loop (PyGMO's DE1220). Here, an error estimation is used to evaluate the surrogate's accuracy in real time. The fitness function is replaced by the surrogate if the estimated error is smaller than a set threshold. This way the ML model is integrated more deeply into the algorithm with less computational overhead and only the minimum necessary training data is generated. First results are promising and are being further evaluated.

Belief Stochastic Optimal Control for Robust Space Trajectory Design

22 Nov
9:50am

Cristian Greco*, Stefano Campagnola[†], Massimiliano Vasile*

*University of Strathclyde (UK), [†]NASA Jet Propulsion Laboratory (USA)

Space trajectories are typically optimised to meet the science and flight system constraints in a nominal scenario. However, in real-life applications, perfect compliance to the reference trajectory is impossible to achieve as uncertainty always affects the system; uncertainty can be due to imperfect state knowledge, imperfectly known dynamical parameters, missed thrust events or execution errors.

In the design phase, the reference trajectory robustness and reliability to these uncertainties is usually evaluated a posteriori through a navigation analysis and the nominal design adjusted through several iterations. To improve the robustness, small tweaks to the trajectory are ensured either by adding propellant margin and enforced coasting arcs for TCM, or by reducing the thrust level. Hence, this iterative procedure mainly treats the nominal trajectory optimisation as decoupled from the uncertainty treatment phase. This process is generally time-consuming and may lead to sub-optimal trajectories with over-conservative margins.

Recent works have been carried out to generate robust trajectories by solving the stochastic optimal control problem, that is considering the uncertainty directly within the trajectory design phase. This presentation shows novel developments in the field of stochastic optimal control, which

extend previous research on optimal control under uncertainty employing a generalised multiple shooting stochastic transcription. This extended work includes orbit determination campaigns during the trajectory to update the knowledge of the state uncertainty, in order to enable the direct coupling of trajectory optimisation with navigation analysis.

The developed method is applied to the robust optimisation of a flyby with Jupiter's moon Europa, a scenario where proper uncertainty treatment is crucial to ensure appropriate close-approach conditions and low probability of impact.

Multi-Objective Optimization of Low-Thrust Trajectories under Epistemic Uncertainty

22 Nov
10:10am

Simão Marto, Massimiliano Vasile
University of Strathclyde (UK)

We propose a novel method to obtain robust solutions for trajectory optimization problems under the effect of epistemic uncertainty in the system's and launcher's parameters. This type of uncertainty is typical in the early stage of the design process, when there is incomplete knowledge of each option available. The uncertainty is modelled using p-boxes with a family of distributions defined using Bernstein polynomials. The lower expectations of certain quantities of interest being below some threshold are then optimized to guarantee robustness in the solution. Lower expectation represents the lowest possible expectation which can be obtained with the distributions in the family that defines the p-box. The expectations are calculated using FABLE (Fast Analytical Boundary value Low-thrust Estimator), an analytical tool for the fast design and optimisation of low-thrust trajectories. An optimization method is proposed to calculate the lower expectation. We are using a multi-objective formulation, so the lower expectations on all metrics, as well as the respective thresholds, are jointly optimized. To speed up the optimization, we employ a dimensionality reduction technique, along with a surrogate model on this reduced dimensionality space. This model is iteratively refined with solutions from the multi-objective optimization. Optimizing this multi-objective problem consists in finding a set of Pareto optimal control laws, that maximize lower expectations and minimize thresholds. This is done using MACS (Multi Agent Collaborative Search), a memetic multi-objective optimization algorithm. This method provides designers with various solutions that represent the trade-offs between the multiple objectives. The approach proposed in this paper is applied to the design of a multi-flyby mission to a set of Near Earth Asteroids with a small spacecraft with limited resources.

Improved Model Predictive Control for Hypersonic Vehicle Under Incomplete Data Transmission

22 Nov
11:00am

Erfu Yang*, Jia Song[†], Yanxue Zhang[†]

*Space Mechatronic Systems Technology Laboratory - Strathclyde Space Institute - University of Strathclyde (UK), [†]Beihang University (China)

The incomplete data transmission will cause control performance descent of the hypersonic vehicle (HV) networked control system (NCS). An improved model predictive control (MPC) method is designed to solve the "data packet dropouts" problem and track large-scale control commands for the flight control of the HV. The same packet loss randomness is considered in both sensor-controller and controller-actuator channels in NCS. A Lyapunov-based theory for HV asynchronous dynamical system is presented. By solving the Lyapunov function with linear matrix inequality (LMI), the state feedback control is designed to improve the anti-fault robustness of the original MPC system. Then a multi-model predictive control is designed to achieve large-scale command tracking. The flight speed model switching strategy optimization is proposed to shorten the tracking time. Simulation results are given to demonstrate the effectiveness of the proposed approach in HV control systems under incomplete data transmission. Meanwhile, the control command can satisfy the constraints of the actuators.

Application of active disturbance rejection control for hypersonic vehicles with reaction control system faults

22 Nov
11:20am

Erfu Yang*, Ke Gao[†], Jia Song[†]

Space Mechatronic Systems Technology Laboratory - Strathclyde Space Institute - University of Strathclyde (UK), [†]School of Astronautics, Beihang University (China)

The Reaction Control System (RCS) is plentifully designed and plays an important role in the control system of hypersonic vehicles during the cruise phase. This study investigates the active disturbance rejection control (ADRC) scheme for the flight control of hypersonic vehicles to ensure safety and reliability in the event of RCS faults. The performance of the ADRC method is studied. Firstly, the great inhibiting ability to external disturbances of the ADRC method is proved. Then sensitivity analysis is carried out to demonstrate the strong robustness of the ADRC method under parameter perturbations. The performance analysis results show that the ADRC method has the advantages of strong fault-tolerant robustness. The RCS thrust reduction fault and the thrust complete failure are mainly studied and considered. Finally, the simulation results indicate that the ADRC approach has satisfactory performance in terms of rapidity, accuracy, and robustness under the RCS fault condition.

Quantifying the effects of gyroless flying of the Mars Express Spacecraft with machine learning

22 Nov
11:40am

Matej Petković*, Luke Lucas[†], Dragi Kocev*, Sašo Džeroski*, Redouane Boumghar*, Nikola Simidjievski[‡]

*Jožef Stefan Institute (Slovenia), [†]Mars Express - Mission Planning Spacecraft Operations (Germany), [‡]University of Cambridge (UK)

The gyroscopes on-board the Mars Express (MEX) spacecraft, responsible for orientation and pointing actions, are slowly decaying. On 16th April 2018, a new software was deployed to MEX which optimizes the energy consumption and reduces gyroscope usage by 90%. In this paper, we investigate the effect of gyroless flight on the power consumption of MEX's thermal subsystems. In particular, we train predictive models from telemetry data obtained before the event on 16th April 2018 and estimate their performance on time periods before and after the event. This offers the chance to evaluate machine learning models on new situations (e.g., gyroless scenarios) while these models have been trained on scenarios that were yet unencountered. The results show that the predictive performance of the models estimated in the gyroless period is lower when compared to the estimated performance before the event. Notwithstanding, the estimated performance in both scenarios is very good and the differences are not practically significant. Hence, the models can be utilized for accurate prediction of the thermal power consumption in practical sense.

Given MEX's new gyroless situation, which is likely to occur also on any other long-lasting mission, we investigate the impact of the gyroscopes on the thermal power consumption and quantify the effects. Such modeling and analysis provides important insight into the spacecraft's new behavior, and still allows for planning optimization of MEX's operations, despite the radical change in the operational methodology. "

22 Nov
12:00pm

Optimization of 5G Satellite Swarms

Matthias Knauer, Christof Büskens
University of Bremen (Germany)

Aerospace is currently changing politically, economically and technologically. In the „New Space“ private companies are pushing into the market and swarms of lightweight, cheap and readily available satellites will replace conventional „old space“ satellites in some applications, as communication, e.g. Likewise the development of 5G (fifth generation cellular network technology) will change the way communication takes place: between machines and things. However, for many of these applications a reliable and nationwide supply is necessary, which cannot be achieved by purely terrestrial communication systems.

In the recently started project 5GSatOpt partners from telecommunications, space engineering and mathematics work together to develop a simulation tool for analysis and optimization of cluster flights of small satellites to provide 5G services.

The model of an individual satellite will consist of its flight dynamics and communication capabilities. For a swarm of satellites the exact costs for correction maneuvers, size of a covered area and the latency can be computed and swarm parameters can be optimized in this regards. Additionally general orbit maneuvers will be investigated. Orbit injection strategies are studied to find good initial constellations or to increase the swarm size. Controlling multiple interrelated trajectories in order to ensure a stable swarm behavior is another task covered in this project.

In this talk, we will present the goal of the project 5GSatOpt and preliminary optimization results

Optimisation of Space System

A Multi Layer Evidence Network Model for the Design Process of Space Systems under Epistemic Uncertainty

22 Nov
2:00pm

Gianluca Filippi, Massimiliano Vasile
University of Strathclyde (UK)

The design of space systems is a complex, expensive and long process that is, usually, decomposed in smaller and more manageable pieces separated by check and decision points (phase A, ...,F). For the process to succeed, multiple factors have to be considered. Different types of uncertainty, indeed, affect the space system design. There is uncertainty in the mathematical models, in the manufacturing and in the operational life. There is also uncertainty in the design process itself: the final goal is usually not clear, different people are involved in the project and then objectives and requirements often change during the process. As the design proceeds through the different phases, the knowledge about the whole mission increases and the uncertainty gradually reduces from epistemic to aleatory.

This presentation introduces a new method for the optimisation of the design process of complex systems (with an application on space systems). The epistemic uncertainty is modelled with the use of the Dempster-Shafer Theory of Evidence (DST). A multi-layer network is finally proposed to model the entire design process describing both the transitions between adjacent design phases and the coupling between components of the complex system. In this multi-layer network, called Multi-Layer Evidence Network Model (ML-ENM), each layer represents a design phase with a particular detail definition, each node a subsystem and each link a sharing of information.

Evidence-Based Resilience Engineering of Dynamic Space Systems

22 Nov
2:20pm

Gianluca Filippi, Massimiliano Vasile
University of Strathclyde (UK)

In this presentation I will describe a new method for the design of complex space systems under epistemic uncertainty when the characteristics of the subsystems are time-varying. The complex system is represented as a network of interconnected nodes, each of which is characterised by one or more quantities of interest. The quantities of interest of each subsystem are dependent on a number of decision and uncertain variables that are strictly related only to that subsystem. A set of scalar quantities, called coupling functions, exchange information between pairs of subsystems. Each pairing function is dependent on a set of coupling uncertain parameters.

The uncertainty associated to all uncertain variables is modelled using Dempster-Shafer theory of evidence. Thus the network is called Evidence Network Model (ENM). This presentation in particular will consider the case in which the quantity of interest of each subsystem has a state that depends on the uncertainty and can change with time. In this way we can simulate continuous transitions between fully functioning and degraded states and the effect of disruptions and shocks that can perturb the system. One of the quantities of interest is the mass of the subsystem that we will use as generic performance indicator of the overall system. Hence, the value of the ENM is the sum of the individual masses of each subsystem. The problem is, therefore, to minimise the system mass under uncertainty while all the other quantities of interest are concurrently optimised.

Employing Agile Principles for Making Decisions during System Design Phases

22 Nov
2:40pm

Daniel Krpelik, Frank Coolen, Louis Aslett
Durham University (UK)

Ensuring reliability of complex systems becomes increasingly important in today's society. Modern systems engineering methods enable us to describe systems holistically - their functions, associated operational and maintenance procedures, physical and logical components, interfaces among distinct parts, mathematical models of system performance and reliability, and other factors we want to take into account and communicate among the stakeholders. Such models enable us to seamlessly track the dependences among our analyses and seamlessly compare multiple variations of proposed systems. We aim to utilize these principles for risk management. Both the design and operation of systems are subjected to many uncertainties. During the design process, we are uncertain about the actual technologies which will be present in the final system, how they will behave in the presence of other components and in the environment in which the system will be operated, and whether the project as a whole will be economically sustainable. These considerations drive our decisions on how to allocate our resources. Since there is no "free lunch" in uncertainty analysis and decision making theory, we want to consult analyses based on multiple frameworks to ensure robustness. We will show how to add another modelling layer to the existing systems engineering framework in order to support decisions during the system life-cycle. This layer involves several statistical and decision making methods, which differ in assumptions and computational complexity. Our method utilizes the advantages of meta-programming. We include the data, and other information sources, to the specification of our system. Then, we can automatically compile efficient source codes for analyses based on various frameworks. In the case of their disagreement, the used assumptions may be analysed separately - via expert assessment or sensitivity analysis - in order to ensure consistency in our knowledge.

22 Nov
3:00pm

On the Inference of Chemical Models Parameters for Tomorrow's Space Journeys: an Overview on Reusable and Ablative Space Systems

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Venturing into Space requires large amounts of energy to reach orbital and interplanetary velocities. The bulk of this energy is exchanged during the entry phase by converting the kinetic energy of the vehicle into thermal energy in the surrounding atmosphere through the formation of a strong bow shock ahead of the vehicle. The way engineers protect spacecraft from the intense heat of atmospheric entry is by designing two kinds of protection systems: reusable and ablative. Reusable systems are characterized by re-radiating a significant amount of energy from the hot surface back into the atmosphere. Ablative materials, on the other hand, transform the thermal energy into decomposition and removal of the material.

The resulting aerothermal environment surrounding a vehicle during atmospheric entry is consequently extremely complex, as such, we often need efficient uncertainty quantification techniques to extract knowledge from experimental data that can appropriately inform the proposed models. A physical model that accounts for uncertain measurements leads to an improvement in the design of potential engineering systems in terms of reliability. We develop robust Bayesian frameworks that aim at characterizing chemical models parameters for re-entry plasma flows in the presence of both types of protection systems. Special care is devoted to the treatment of nuisance parameters which are unavoidable when performing flow simulations in need of proper boundary conditions beyond the interest of the specific inference. Traditional Bayesian approaches deal with this problem by prescribing prior distributions on such parameters at the expense of some of the observations consumed to evaluate these nuisance parameter posteriors. Our formulation involves a particular treatment of these nuisance parameters by solving an auxiliary maximum likelihood problem. Results will be shown for models that account for reusable and ablative systems.

Optimisation for Aerospace Systems and Manufacturing

22 Nov
5:00pm

Robust Airfoil Design using Gradient Based Risk Function Approximations

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A robust optimisation approach based on the use of a risk function, namely Conditional Value at Risk (CVaR), is presented. An application is given for the robust aerodynamic design of a Blended-Wing-Body (BWB) aircraft wing section in a transonic field. The Risk function is estimated using an approach based on the empirical cumulative probability distribution (ECDF). The quantities of interest (QoI) of the risk functions are the aerodynamic characteristics of the airfoil, namely lift, drag and pitching moment coefficients, which are obtained by solving the Reynolds-averaged Navier-Stokes equations with the open source fluid-dynamic solver SU2. Consequently, the calculation of the CVaR is very expensive from the computational point of view and the characterizing aspect of the work is the use of techniques and methods for the reduction of the cost mentioned above. In particular, the estimate of the approximate CDF is obtained by exploiting the QoI gradients with respect to the uncertain variables computed through the discrete adjoint module of SU2. The CDF can be approximated both with a first order series expansion using efficiently calculated gradients from SU2 and with a second order expansion in which the Hessian matrix is approximated with a technique similar to the one used in the method of quasi-Newton BFGS optimization. These methods are also compared, in terms of precision and efficiency, to CDF approximation techniques based on Gaussian processes.

Multi-fidelity efficient global optimization for propeller optimisation under uncertainty

22 Nov
5:20pm

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In this work, an optimisation workflow is presented for uncertainty-based design optimisation using a multi-fidelity Gaussian process regression. The motivation of the proposed techniques is to solve a propeller design optimisation problem under uncertainty. This problem involves expensive CFD simulations to evaluate the aerodynamic performance which prohibits the application of standard optimisation techniques and the direct calculation of statistical measures. Therefore, a surrogate-based optimisation workflow is proposed. The computational budget limits the number of high-fidelity simulations which makes impossible to accurately approximate the design landscape. This motivates the use of cheap low-fidelity simulations to obtain more information about the unexplored locations of the design landscape. The information stemming from the low- and high-fidelity numerical experiments can be fused together with multi-fidelity Gaussian process regression to build an accurate surrogate model despite the low number of high-fidelity simulations. In efficient global optimisation the surrogate model is refined by new samples at the location of the maximum expected improvement. When employing a multi-fidelity Gaussian process in the optimisation workflow, an additional strategy has to be added to decide whether to evaluate the expected improvement location with a high-fidelity or low-fidelity solver. The proposed optimisation workflow is discussed through applying it on benchmark functions and on a simple propeller design optimisation problem under uncertainty.

Introducing Efficient Surrogate Based Methods for the Robust Design of Shock Control Bumps

22 Nov
5:40pm

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Shock control bumps are passive flow control devices that increase the performance of transonic wings by decreasing wave drag. As these are highly sensitive to the location of the shock wave, the random fluctuations in flight and the wing manufacturing tolerances must be taking into account during its design. However, exploring the stochastic design space to find the global robust optimum increases the computational cost making the optimization unfeasible when dealing with expensive numerical simulations. The objective of this presentation is the introduction of different surrogate assisted frameworks for the efficient aerodynamic robust optimization of shock control bumps. The choice for a given framework is dependent on the number of design parameters and uncertainties. On the one hand, a gradient based approach with an adjoint formulation is preferred when dealing with a large number of design parameters. On the other hand, if the number of uncertainties is very high, these should be considered from a Bayesian perspective. Finally, the combination of an Efficient Global Optimization algorithm with the use of Gaussian Processes with adaptive sampling for uncertainty quantification is effective when the dimensionality is not too high in both design and uncertain parameters. The formulations are able to efficiently come up with shock control bumps that are more robust against uncertainties compared to the configuration obtained with classical deterministic optimization.

22 Nov
6:00pm

Global Direct Search and an application to Additive Manufacturing (3D Printing)

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We propose a new method for unconstrained or bound constrained nonlinear optimization where derivatives of the objective function are unavailable or are difficult to obtain. The goal is to derive a fully parallelizable method for the efficient and accurate solution of large-scale problems. It is not our aim to design an approach capable of determining all local minimizers for small pathological problems of small dimension (say with less than 20 variables) with an high number of local minima. Instead target at an approach that does reasonably well for such problems, but that is then capable of determining the main (or leading) local minimizers of higher dimensional problems (say with hundred or even thousands of variables). The methodology is based on multistarting (probabilistic) direct search which has been shown to be an efficient and robust method for optimizing without derivatives in the context of local optimization. The initial multistarted set of runs can be split according to criteria of clusterization and variability in function values or according to the solution of appropriate nonconvex model subproblems, in both cases by looking at the data generated at a given run. Given that multiple runs may concur to the same point, a merging procedure has also been developed. We provide numerical results on a large set of nonconvex unconstrained and bound-constrained problems. We will describe the application of our global solver to the optimization of object orientation in additive manufacturing (3D printing), in the context of an applied industrial project.

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