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**27th - 28th April 2017**

**AeroGust Project Workshop**

**University of Liverpool, UK**

*This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement number 636053.*
Location

The workshop will take place in Harrison Hughes Building at the University of Liverpool’s School of Engineering (circled in red).

Address: The Quadrangle, Brownlow Hill, Liverpool L69 3GH

Impact

AEROGUST brings together academic, research and industry experts to promote intellectual leadership in aerospace. The project will contribute to the goals of improving European industrial competitiveness by reducing reliance on wind tunnel testing through developing an innovative numerical gust loads process. By reducing reliance on wind tunnel testing in this way, a faster exploration of the design space using Reduced Order Models can be achieved – enabling the European aerospace industry to produce superior products at reduced cost.

AeroGust expects to have a positive impact in terms of delivering international collaboration for innovation and fostering new partnerships which will help integrate new knowledge into industry after the project end. The participants will work towards building the next generation of talent to populate the sector, which is still one of the most significant within the European Community, thereby serving to secure employment within the European industry.

The project will impact positively on the environment thanks to developing methods that will ultimately lead to lighter aircraft structures with lower fuel burn levels. Lowering aircraft fuel burn will result in reductions in CO2 emissions that will go a significant way to meeting the Flightpath2050 targets. The technology developed in AeroGust will have direct application in improving wind turbine design, for which gusts are a dominant issue. The transfer of knowledge in AeroGust will therefore improve the efficiency of this green technology.
High fidelity gust simulations around a transonic airfoil

B. Tartinville, V. Barbieux, L. Temmerman and C. Hirsch

Abstract: In order to investigate the non-linear flow behaviours around a transonic airfoil in the presence of three different gust scenarios a series of long-term high fidelity IDDES simulations has been performed. It appears that the detached flow caused by shock/boundary layer interaction is significantly influenced by the passage of the gust. The details of the flow structure downstream of the airfoil and the non-linear effects are investigated by a detailed analysis of the unsteady flow behaviour and a comparison to classical simulation results obtained within the scope of the AeroGust project.

The AeroGust project

AeroGust is a state of the art engineering computer simulation project investigating gust interactions with aircraft. The aim of the project is to develop innovative methods that allow radical aircraft design changes by responding to three main areas of work:

1) Investigations using Computational Fluid Dynamics (CFD) to gain a deeper understanding of the complexities in gust interactions with an aircraft;
2) Creation of a numerical gust loads process that does not require wind tunnel data for early design stages;
3) Development of efficient reduced order models for gust prediction that account for aerodynamic and structural complexity at an acceptable cost.

Whilst AeroGust mainly focusses on the problems associated with aeroelastic aircraft, the fundamental physics is common to large wind turbines. Therefore the methodology of AeroGust will find direct application in wind turbine design. This is a real advantage for the project and means that in the future wind turbines could be placed in areas such as the Arctic Circle and below the tropics, where the wind shear and gusts loads are currently prohibitive due to structural overdesign.

Consortium

The project is led by the University of Bristol and its partners combine academic (Universities of Bristol, Liverpool and Cape Town); industrial (Airbus Defence and Space, Dassault Aviation and Piaggio Aerospace); research institution (DLR, INRIA and NLR) and SME (NUMECA, Optimad and VALEOL) expertise.

AeroGust’s consortium members are experts in numerical modelling and aeroelasticity. Their knowledge will allow a better representation of real-world physics using Computational Fluid Dynamics (CFD) that will result in the development of more sophisticated models than the current standard.
### Program - Day 1

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<tr>
<td>13:00 - 13:30</td>
<td>Introduction &amp; industrial perspective</td>
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<td>13:30 - 14:00</td>
<td><strong>University of Liverpool</strong>: Frequency-Domain Non-linear Gust Response Computation</td>
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<tr>
<td>14:00 - 14:30</td>
<td><strong>German Aerospace Centre (DLR)</strong>: Towards reduced order modeling for gust simulations</td>
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<td>14:30 - 14:45</td>
<td>Tea and coffee break</td>
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<td>14:45 - 15:15</td>
<td><strong>University of Bristol</strong>: Extending Aeroelastic Analyses for Gust Loads to Include Nonlinearities</td>
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<td>15:15 - 15:45</td>
<td><strong>NLR</strong>: The Gust Error-correction Method for accurate gust propagation in CFD simulations</td>
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<td>15:45 - 16:00</td>
<td>Feedback and discussion</td>
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<td>Drinks reception</td>
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### Program - Day 2

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<td>09:00 - 09:30</td>
<td><strong>University of Cape Town</strong>: Toward Rapid Non-linear Aeroelastic Modeling For Design</td>
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<tr>
<td>09:30 - 10:00</td>
<td><strong>INRIA</strong>: Numerical zoom for the aeroelastic simulation of a wind turbine using ROMs</td>
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<td><strong>VALEOL</strong>: Numerical methods and experimental work for a better understanding of gusts on wind turbines</td>
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<td><strong>Optimad Engineering</strong>: High-Fidelity Gust Simulations based on mesh adaptation and high order methods in an immersed boundaries context</td>
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<td>10:30 - 11:00</td>
<td><strong>NUMECA</strong>: High fidelity gust simulations around a transonic airfoil</td>
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<td>11:00 - 11:15</td>
<td>Tea and coffee break</td>
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<tr>
<td>11:15 - 12:00</td>
<td>Feedback and concluding remarks</td>
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<td>12:00 onwards</td>
<td>Lunch</td>
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**High-Fidelity Gust Simulations based on mesh adaptation and high order methods in an immersed boundaries context**

H. Telib

**Abstract:** A cost efficient high-fidelity context is presented for simulating accurately fluid-structure interaction due to a gust impact:

1. In order to propagate the gust signal to and away from the airplane a kinematic energy conserving scheme is employed to avoid spurious effects of the discretisation;
2. The grid follows the gust signal in an adaptive way, i.e. it will refine across the gust signal and coarsen elsewhere in the far-field; and
3. In order to allow for arbitrary fluid-structure interaction, a compressible immersed boundary method is employed.
Numerical methods and experimental work for a better understanding of gusts on wind turbines

C. Taymans

Abstract: The aim of the present work is to better understand the effects of gusts on wind turbine blades. Valeol is developing a parallel CFD code resolving Navier-Stokes incompressible equations with Octree meshes taking into account of the structural model. Experimental results will be necessary to allow the calibration of numerical models. This presentation will explain how Valeol installed sensors on a wind turbine to get experimental data of pressure and strain of a blade when submitted to gusts. Some preliminary results with the numerical tool will be shown.

Industrial perspective

The aerospace industry continues to push forward the use of CFD for loads and aeroelastic predictions with the ultimate goal of having a fast, robust and accurate unsteady aerodynamic capability coupled with structural response. This will provide both a reduction of timescales and an improved aircraft design able to properly take into account nonlinear loading actions. Further benefit will come from the extension of this technology to wind turbine design, since wind shear and gusts create the largest loads on the turbines.

State of the art

Within the industrial sphere CFD is routinely used for wing shape design and flutter prediction. More and more it is being used for prediction of aerodynamic loadings across the Mach number and incidences ranges although there are still some limitations at the extremes of these ranges. The coupling of structures and CFD is being actively developed for both aeroelastic flutter analysis and manoeuvre loads. The use of CFD for the calculation of gust loads has not been addressed to any real extent. However, interest in this field is increasing with the aim of reducing the current levels of gust loading by taking account of non-linear behaviour.

Steps towards Industrial Goal

Clearly the first step towards the "ultimate" goal is development of the unsteady prediction capability of the CFD methods themselves so that the correct behaviour throughout the flight regime can be assessed. A second vital step is validation of the predictions against test data. This leads to a problem already discussed within the AeroGust project, namely the lack of suitable test data for validation purposes. An additional challenge the methods developed in aviation research projects like AeroGust have to face, is not only the necessity to describe physics correctly, but also to convince the aviation certification authorities about its validity.

As gusts and other unsteady phenomena require a substantial amount of modelling and computation to be properly predicted, the demand on efficient computational methods rises. Once the CFD methods are able to predict the required unsteady phenomena it will still be many years before computing power is sufficient to enable the full flight regime to be studied as a matter of routine in the design cycle. This is where ROM methods such as those being investigated in the AeroGust project come into their own by providing substantial savings in terms of computational effort and hence lead time.

Similar challenges are faced in wind turbine design. Due to the simplicity of the current gust prediction methods large safety factors have to be used, which leads to structural over design. Methods being investigated in AeroGust will also be applied to understand the effects of gusts on wind turbine blade loads. In addition sensors are to be installed on a wind turbine blade to provide data for validation of the models developed.
Frequency-Domain Non-linear Gust Response Computation

R. Thormann and S. Timme

Abstract: Gust analysis involves computationally expensive parameter studies with different gust shapes. In particular, the gust amplitude varies with gust length as defined by regulatory bodies. Linearised frequency-domain methods have demonstrated significant speed-up while providing a fair accuracy for shorter, lower-amplitude gusts. Longer, higher-amplitude gusts however, often dominant for aircraft sizing, result in over-predicted loads using these linearised methods, without accounting for non-linear effects. The linearised frequency-domain prediction quality is enhanced by substituting non-linear results at low frequencies. The novel method is demonstrated for an aerofoil at transonic flow conditions.

Numerical zoom for the aeroelastic simulation of a wind turbine using ROMs

A. Ferrero, A. Iollo and M. Bergmann

Abstract: The aim of the work carried out at INRIA is to explore different Reduced Order Modelling strategies which can be potentially exploited to reduce the simulation cost in several engineering fields. The simulation of the aeroelastic behaviour of a wind turbine is quite time consuming because it requires to take into account a large range of physical scales. When several working conditions have to be investigated, it is possible to reduce the computational cost of the simulation by using a domain decomposition approach in which the governing equations are solved only in a reduced portion of the domain while the remaining region is described by a low cost Reduced Order Model. The different tools required to study the aeroelastic effects of a gust on a wind turbine are under development and some preliminary results are shown on simplified problems.
Toward Rapid Non-linear Aeroelastic Modelling For Design


Abstract: Designing of lighter and more flexible aircraft require advanced new modelling tools to assist with gust related loads calculations. The work to be presented takes a comprehensive approach in developing tailored modelling technologies which range from full order to reduced order non-linear aeroelastic models. Non-linear effects accounted for include transonic flows and geometrically non-linear structural deflections. It is demonstrated that rapid yet accurate loads calculations may be achieved if using the aforementioned techniques in a co-ordinated manner.

Towards reduced order modeling for gust simulations

D. Friedewald¹, S. Görtz², R. Heinrich², J. Nitzsche², M. Ripepi² and M. Widhalm²

¹German Aerospace Center (DLR), Institute of Aeroelasticity, Göttingen, DE
²German Aerospace Center (DLR), Institute of Aerodynamics and Flow Technology, Braunschweig, DE

Abstract: The presentation gives an overview of the work done by DLR in the EU project, AeroGust. A highly accurate method, resolving gusts in the flow field, and the simplified field velocity approach are computed with TAU and compared on 2D and 3D test cases for different gust wave lengths. These computations will provide insight about the non-linearities in CFD-based gust simulations and will serve as a reference for the developed nonlinear unsteady reduced-order modeling (ROM) approach for gusts. Here, results concerning the application of the physics-based ROM are presented for a gust-like pitching oscillation forced motion of a full aircraft configuration and a series of gusts prediction for a 2D test case. Furthermore, recent developments in the updating of industry-type DLM gust load models with linearized CFD data will be presented.
Extending Aeroelastic Analyses for Gust Loads to Include Nonlinearities

R. Cook, C. Wales, A. Gaitonde, D. Jones and J. E. Cooper

Abstract: Work carried out in this presentation investigates aeroelastic simulations of aircraft-gust interactions in situations that push the limits of the linear assumptions typically made in industrial gust loads analyses, with particular application to structural loads predictions. On the aerodynamics side, this has been focused on modelling gust interaction using high-fidelity CFD methods, and using these to correct lower-fidelity methods such as DLM and UVLM, increasing accuracy of the aerodynamic loads predictions while minimising computational cost. These CFD-based aerodynamics techniques will then be coupled with structural solvers to investigate the free-free aeroelastic response to a gust. For the structural modelling, a geometrically-exact, nonlinear beam code has been developed to capture large deformations, and coupled with a low-order strip theory aerodynamics model to represent high aspect-ratio, flexible aircraft structures. This approach will then be used for uncertainty quantification of a nonlinear aeroelastic system, in order to understand how uncertainties in aircraft properties and flight conditions propagate through to the predicted loads.

The Gust Error-correction Method for accurate gust propagation in CFD simulations

H. van der Ven, J. C. Kok, M. R. Verhagen and M. P.C. van Rooij

Abstract: The simulation of gust encounters using CFD poses a challenge to the modelling of the gust, especially if a two-way coupling of the gust and the aircraft aerodynamics is required. A new method is proposed, which is similar in formulation to the split-velocity method. Its design, however, is quite different as the new method correctly captures the propagation of the gust, even on the coarse meshes in the far field of the flow domain. Results will be shown for a selected set of AeroGust test cases.