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GUST ALLEVIATION OF NASA COMMON RESEARCH MODEL USING CFD

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Abstract: *This paper presents a CFD study of a typical commercial aircraft entering the gust. The NASA Common Research model of an airliner is used as the baseline configuration. The gust model is based on adding artificial gust velocities into the governing equations, this method is usually referred to as Disturbance Velocity Approach. A series of gusts is used to measure response of the aircraft and to establish dynamic gust model. The movable control surfaces are defined and their efficiency is assessed by the CFD using the mesh deformation technique in the unsteady simulation. Finally, the dynamic model based on both the gust data on one hand and on the control surfaces action on the other hand is used to prescribe movement of the control surfaces with the aim to alleviate the gust interaction. The required time response of the control surfaces is studied to clarify limits of this alleviation technique.*

Keywords: CFD, Gust response, Active control surfaces, NASA Common Research Model.

1. Introduction

The gust, as a sudden and unpredictable disturbance of the airflow relative to the flight path, is source of potential troubles. Besides compromising passenger comfort, the gusts also cause severe problems for aircraft stability, control, and introduce additional force exerted on the airframe. Therefore, gust alleviation methods come to play. The idea behind this paper is to use aircraft's control surfaces to counteract the gust input and to develop rules for the controls action based on the gust evaluation and identification.

The requirement for the aircraft to handle gusts is part of the certification process and is covered in detail in relevant regulations, as EASA (2007). Both vertical (positive and negative) and lateral gusts have to be considered. The gust profile is given by the '1-cosine' shape with gradient distance between 9 to 107 meters and amplitude (maximum perpendicular velocity deviation) depending on the aircraft weight parameters and flight altitude.

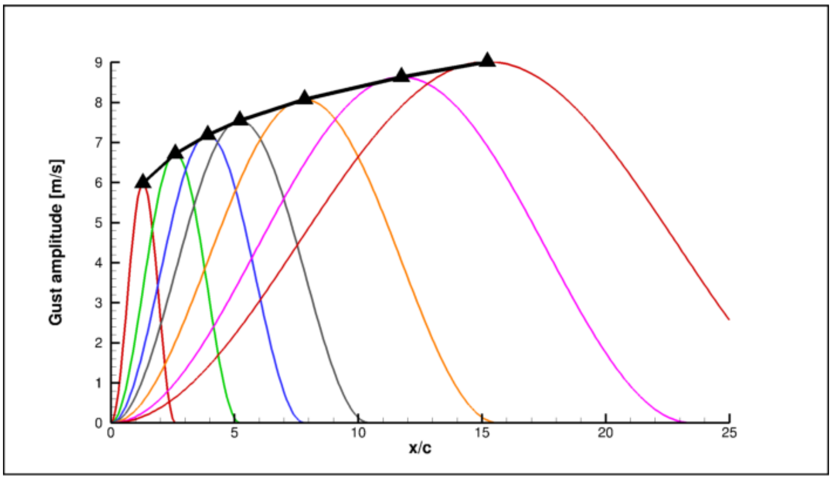

Fig. 1: Gust shapes in the required range.

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Fig. 1 shows example of gust shapes and amplitude envelope required by the regulations, relative to the scale of the aircraft wing chord. We are focusing on upward vertical gusts, because they introduce additional stresses to the already loaded structure of the aircraft's main wing. On the other hand, the wing is equipped with number of control surfaces that can be used to act against the gust input.

The computational geometry used throughout this paper is the NASA Common Research Model (CRM) described by Vassberg et al. (2008), which consists of a contemporary supercritical transonic wing and a fuselage that is representative of a widebody commercial transport aircraft. The CRM is designed for a cruise Mach number M = 0.85 and a corresponding design lift coefficient C_L= 0.5. These conditions were used in our calculations. The CRM is widely used for various Computational Fluid Dynamics (CFD) studies, and it is also used for code evaluation during the Drag Prediction Workshops (Eliasson et al., 2013).

The Edge (Eliasson, 2002) is the CFD code used for the presented simulations. All the simulations are carried out as unsteady RANS with EARSM turbulence model. The gust model implemented in the solver is based on the Disturbance Velocity Approach validated among others by Heinrich (2014). For example, the continuity equation includes the contribution from the gust velocity,

$$\frac{d}{dt}\int_V \rho\, dV - \oint_S \rho\left(\boldsymbol{v} - \boldsymbol{v}_b - \boldsymbol{v}_g\right)\cdot \boldsymbol{n}\, ds = 0, \qquad (1)$$

where $\boldsymbol{v}_b$ is the velocity of boundary of the control volume and $\boldsymbol{v}_g$ is the gust velocity. The advantage of this approach is that it can be used on standard CFD grids with no special requirements on the resolution in the far field. The mesh deformation technique was used to simulate movement of the control surfaces which are used to alleviate the gust. The obtained data from gust response and control surfaces effect are processed in MATLAB. The dynamic systems are identified and feed-forward law is designed to prescribe control surfaces movement to counteract the gust effect.

2. Gust response identification

To create dynamic model of the gust a series of CFD calculations was carried out for the selected gusts within the required range (Fig. 1). The response of the aircraft was evaluated and decomposed to individual parts; main wing, horizontal tail plane (HTP) and fuselage. It was observed that this decomposition plays important role in gust identification. The transport delay between gust acting on the main wing and on the HTP is clearly visible for shortest gust, as Fig. 2 shows. While HTP contribution to CL is minor, the pitching moment C_M augmentation is more significant due to long moment arm. As we can see, while gust amplitude varies by at most 30 %, the C_L increments by a factor of 4 in the prescribed gust length range. There is an interesting C_M dependence with maximum deviation at medium-length gusts which is due to the gust interaction with the fuselage.

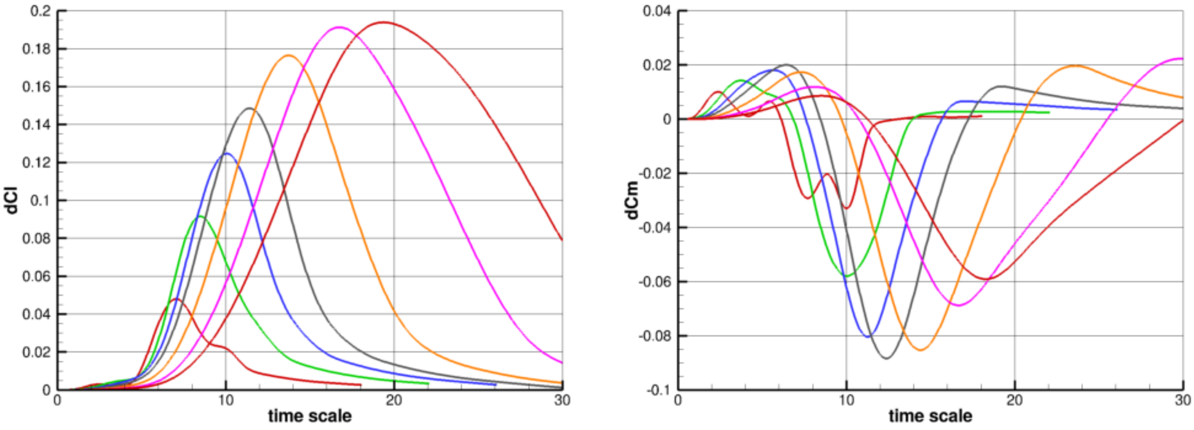

Fig. 2: Dynamic response of the gust. Deviation of C_L and C_M.

3. Control surfaces and gust alleviation

A set of control surfaces was defined on the airplane model, see Fig. 3. In the real-world application we anticipate that flaperon, aileron and spoilers should be used. However, in CFD calculation the spoiler deployment is very demanding and, hence, this contribution is modeled by additional trailing edge devices similar to ailerons. The '1-cosine' input to the control surfaces was prescribed and the response was evaluated.

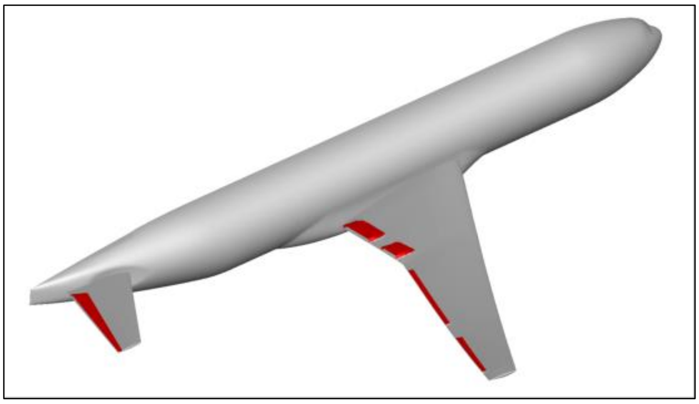

Fig. 3: NASA Common Research model with defined control surfaces (red). Control surfaces on the inboard and middle section simulate the effect of spoilers.

The obtained data served as a basis to set up control laws to prescribe control surfaces movement based on measured gust, identified as the change in the angle of attack. Both systems, gust response and controls deflection, are identified using System Identification Toolbox in Matlab. Time delay in gust dynamics plays significant role in feed-forward control. It provides time slot to compute controls deflection. Dynamics of controls deflection (aileron, flaperon, spoilers) are identified together.

It was decided that that control surfaces of the main wing will be responsible for the alleviation of the CL increment measured on the main wing and the role of HTP will be to reduce pitching moment CM deviation. Several calculations were carried out to understand how the control surfaces on the wing influence flowfield near the HTP. It was observed that the movement of the control surfaces on the main wing in order to reduce C_L causes increased contribution to the C_L and C_M by the HTP. On the other hand, the elevator movement contributes to the total values only through the alteration of the flowfield on the HTP and on the rear section of the fuselage.

As mentioned above, control law is designed as feed-forward (Stevens, 1992). Gust alleviation has two targets in this case. The first one is to reduce gust effect on the wing (C_L), second one to reduce total pitching moment (C_M). Scheme of the control law is depicted in Fig. 4. Five dynamic systems are identified using Laplace transform. Wing controls and elevator deflections are described based on the control law scheme.

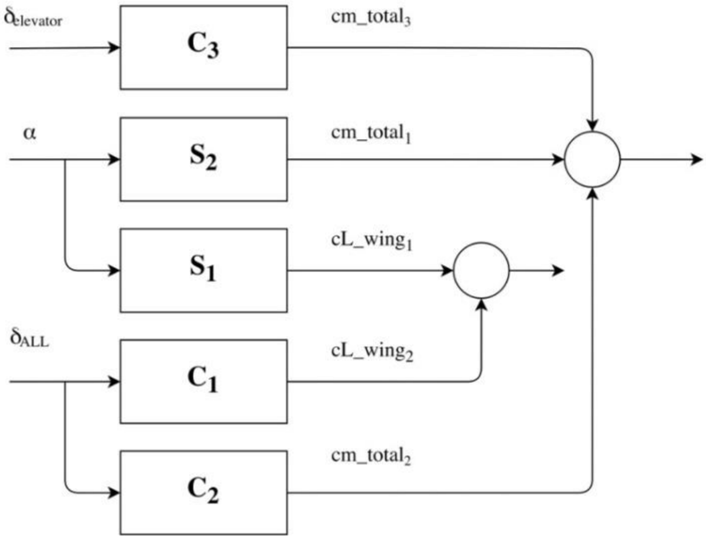

Fig. 4: Control laws diagram.

The described method was applied to the gust with medium length. Fig. 5 shows encouraging results as the maximum increment of C_L was reduced by approximately 85 % and the pitching moment by almost

90 %. It is worth to note that the control system used only a-priori information and no feedback from the course of the CFD computation with gust and active control surfaces was used. Such a feedback loop could further improve the results.

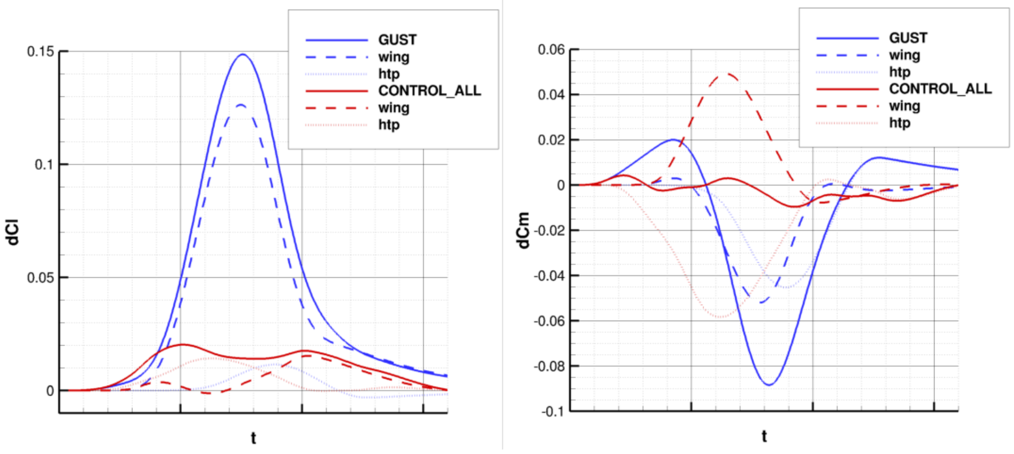

Fig. 5: Comparison of plain (blue) and controlled gust (red). Contributions from the main wing (dashed) and HTP (dotted) is displayed.

4. Conclusions

Computation study of the gust alleviation using active control surfaces was presented. Although only forward control system was used, the maximum increment of the lift and pitching moment was reduced by the order of magnitude.

In the next step we plan to focus on the gust interaction with the flexible aircraft using decomposition to the normal modes, which was studied in our previous work (Vrchota et al., 2017). This aeroelastic coupling would provide additional information about, e.g., wing bend and twist caused by the gust. The combination of feed-forward and feedback control law could be used to minimize loading of the wing locally through the use of various control surfaces independently.

These results could be further generalized to produce Recued-Order Model for the gust response, which was investigated by, e.g., Zaide et al. (2006).

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References

EASA (2007) Certification Specifications for Large Aeroplanes (CS-25). Amendment 3, European Aviation Safety Agency, September 2007.

Eliasson, P. (2002) Edge, a Navier-Stokes solver for unstructured grids, in Proceedings to Finite Volumes for Complex Applications III., pp. 527-534. ISTE Ltd., London.

Eliasson, P., Peng, S.-H. and Tysell, L. (2013) Computations from the fourth drag prediction workshop using the Edge solver. Journal of Aircraft, 50, 5, pp. 1646-1655.

Heinrich, R. and Reimer, L. (2014) Simulation of Interaction of Aircraft and Gust Using the TAU-Code, in: New Results in Numerical and Experimental Fluid Mechanics IX, Springer.

Stevens, B.I. and Lewis, F.L. (1992) Aircraft Control and Simulation. John Wiley and Sons, ISBN 0471613975.

Vassberg, J.C., DeHaan, M.A., Rivers, M.B. and Wahls, M.S. (2008) Development of a Common Research Model for Applied CFD Validation Studies, AIAA Paper 2008-6919.

Vrchota, P., Prachar, A. and Šmíd, M. (2017) Improvement of Computational Results of NASA Common Research Model by Modal Analysis, Journal of Aircraft (accepted).

Zaide, A. and Raveh, D.E. (2006) Numerical Simulation and Reduced-Order Modeling of Airfoil Gust Response, AIAA Journal, 44, 8, pp. 1826-1834.