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Experimental and numerical research on the aerodynamics of unsteady moving aircraft

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Abstract

For the experimental determination of the dynamic wind tunnel data, a new combined motion test capability was developed at the German–Dutch Wind Tunnels DNW for their 3 m Low Speed Wind Tunnel NWB in Braunschweig, Germany, using a unique six degree-of-freedom test rig called 'Model Positioning Mechanism' (MPM) as an improved successor to the older systems. With that cutting-edge device, several transport aircraft configurations including a blended wing body configuration were tested in different modes of oscillatory motions roll, pitch and yaw as well as delta-wing geometries like X-31 equipped with remote controlled rudders and flaps to be able to simulate realistic flight maneuvers, e.g., a Dutch Roll. This paper describes the motivation behind these tests and the test setup and in addition gives a short introduction into time accurate maneuver-testing capabilities incorporating models with remote controlled control surfaces. Furthermore, the adaptation of numerical methods for the prediction of dynamic derivatives is described and some examples with the DLR-F12 configuration will be given. The calculations are based on RANS-solution using the finite volume parallel solution algorithm with an unstructured discretization concept (DLR TAU-code).
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Contents

1. Overview, current situation and motivation

During the expensive process of aircraft development, it is highly desirable to obtain information about the future flight mechanics behavior of an aircraft already at a very early stage. The reliability of the predicted data is of eminent importance with regard to cost effectiveness within

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the design process. For the upcoming new airplane configurations (e.g., wide body, green aircraft, blended wing body) the approach up to now using semi-empirical methods as standard prediction tools is not as accurate as required. Hence, the DLR Institute of Aerodynamics and Flow Technology in Braunschweig, Germany, started to develop a new method for the reliable determination of the dynamic derivatives to be able to describe the handling qualities sufficiently and to be able to predict the dynamic loads of a new aircraft reliably. Of particular importance for the success of that project was a distinct improvement of the state-of-the-art measuring techniques to experimentally determine the derivatives as it was felt to be mandatory to validate the numerical method with a reliable experimental database. But during the development phase, it turned out that just with close interaction between CFD and the wind tunnel test environment, considerable progress could be achieved.

Dynamic wind tunnel testing has been performed for 30 years in the Low Speed Wind Tunnel DNW-NWB in Braunschweig. The two relevant model supports and the corresponding data acquisition equipment suitable for dynamic wind tunnel measurements will be described in some detail.

One model support is a classical Rolling and Spinning Derivative Support (RTD) which enables the model to perform a continuous rolling and spinning motion about the wind axis.

The other dynamic model support is the 'Model Positioning Mechanism' (MPM) that complements the above-mentioned RTD. The development and the performance of the MPM will be described as well as the instrumentation necessary for dynamic tests that includes the stereo pattern recognition technique with CMOS cameras. This system is used for determining the time-dependent model position and for measuring the appearing wing shape during a 3 Hz forced sinusoidal oscillation as well as during combined motions to simulate realistic flight maneuvers. The quality and performance of the dynamic instrumentation is of special importance as the quality of the results of dynamic measurements depends strongly upon the quality of the measurement of the model's instantaneous position with respect to the simultaneousness of the position signal and balance and pressure signals. This especially holds true when separate measurement systems are used for force/pressure and position measurement as is the case at DNW-NWB.

A first general survey about the determination of dynamic stability derivatives, necessary for the identification of the dynamic characteristic of aircrafts and for the calculation of the structural loads on individual components, is given in Ref. [1] in which an article by K.J. Orlik-Rueckemann, giving an overview of different techniques for the experimental determination of dynamic derivatives, can be found; see also Ref. [2]. Furthermore, in Ref. [3], the changing interest in the determination of dynamic derivatives regarding the requirements of increasing angles of attack during the 1970s is described. At extreme flight attitudes and on slender configurations with non-linear aerodynamic characteristics, e.g., by means of high angles of attack, strakes, transonic effects, it is up to nowadays very difficult to predict the airflow and therewith the aircraft's behavior correctly. This of course especially held true in the 70s. Of particular importance is, at that time as today, the determination of confidence levels and standard deviations which have to be taken into account in the correlation between theory, wind tunnel test and flight test.

Aerodynamic tests on maneuvers with high amplitudes and high velocities of highly agile combat aircraft were of interest at that time and furthermore in the 60s and 70s, the slender configurations like, e.g., Space Shuttle, Saenger and Concorde were the motivation for very comprehensive activities to investigate the relevant flow regime. From this, the demand for extensive dynamic wind tunnel tests in the western world can be derived, cp. thereto the aerodynamic flight mechanical Conference Proceedings, besides Ref. [1] also Refs. [4,5]. The latter is in close association with Ref. [6] in which the rolling and spinning experiments are discussed in some detail. The essential conclusion here was that all achievements show good correlation as long as the airflow is clear and without ambiguity. But if the flow is able to reach different states under same constraints, however, the results rather depend on the wind tunnel in which the tests were performed. From this, it was always tried to define boundaries inside of which safe flow states exist and within which an airplane control system can work reliably. But with the requirements for predictions of rapid high angle-of-attack maneuvers, it was found out that more studies about rather complex and unorthodox configurations were necessary with the extension of the speed range and with including data of time history effects, scale effects and aerodynamic interference effects. As the experimental data gained so far seemed to be insufficient to draw conclusions regarding these points, a new AGARD activity was started in the 90s, see Ref. [7], which for the first time provides a comprehensive database for rotary and oscillatory characteristics of a generic WG16 fighter type model configuration over a large range of angles of attack, with the objective to examine the reliability of test techniques. A further objective was to obtain comprehensive results on surface pressures, forces and moments for validation of reliable numerical codes which have so far not existed in this field. More validation experiments on simple generic shapes designed to provide detailed measured data for the verification of results from CFD codes are given in Ref. [8]. Here, the results for oscillating and transient movement patterns of complete configurations and for oscillating flaps can be found, including calculations of dynamic force and pressure measurements on an oscillating 65° Delta Wing by DaimlerChrysler Aerospace as well as measurements by DLR at DNW-NWB. That can be seen as one of the first examples of a fruitful interaction between experimental and numerical work as the data evaluation

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