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Parameter identification with a controlled free flying model of a spaceplane ☆

Parameteridentifizierung an einem geregelten, frei fliegenden Modell eines Raumflugzeugs

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Abstract

A flight test method for the investigation of flying qualities of a spaceplane with a radio controlled model is presented in this paper. Therefore a relatively simple model is equipped with several sensors and a telemetry transmitter. The model is dropped from a radio controlled carrier vehicle at an altitude of about 700 m. Because of the instability and the high wing loading a dynamically scaled model of the investigated spaceplane configuration PHOENIX cannot be controlled by vision from ground. A computer on ground is used to operate the model automatically by computing feedforward and feedback control algorithms. To avoid the high risk of a landing the model is recovered by a parachute.

The measured data are used to estimate the parameters of a quasi-steady aerodynamic model with an equation error method. A comparison of these parameters with available wind tunnel data indicates, that the quality of the estimated parameters is comparatively high.

Zusammenfassung

Es wird eine Flugversuchstechnik vorgestellt, die es erlaubt mit einem vergleichsweise einfachen, ferngesteuerten Versuchsträger die Flugeigenschaften eines Raumflugzeuges zu untersuchen. Dafür ist der Versuchsträger, welcher von einem anderen Modellflugzeug in ca. 700 m Höhe abgeworfen wird, mit umfangreicher Messtechnik und einer Telemetrieanlage ausgerüstet. Da die untersuchte Raumflugzeugkonfiguration PHOENIX aufgrund statischer Instabilität und einer hoher Flächenbelastung von einem Fernsteuerpiloten am Boden nicht beherrschbar ist, wird der Versuchsträger mit Hilfe von Steuerungs- und Regelungssystemen vollautomatisch betrieben. Der Rechner zur Steuerung und Regelung des Versuchsträgers befindet sich dabei dezentral am Boden. Um eine risikoreiche Landung des Modells zu vermeiden, wird der Versuchsträger am Fallschirm geborgen.

Aus den Messdaten der einzelnen Flüge werden mit einem Gleichungsfehlerverfahren die Parameter von quasistationären aerodynamischen Modellen identifiziert. Durch Vergleich der Ergebnisse mit Windkanaldaten kann gezeigt werden, dass die Qualität der so gewonnenen Daten vergleichsweise hoch ist.

Keywords: Parameter identification; Flight tests; Dynamic derivatives; Spaceplane configuration PHOENIX

Schlüsselwörter: Parameteridentifizierung; Flugversuche; Dynamische Derivative; Raumflugzeug PHOENIX

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Nomenclature

b	span	m
b_x b_y, b_z	accelerations	m/s^2
$\underline{C}$	covariance matrix	
C_X, C_Y, C_Z	force coefficients in the body fixed system	
C_A, C_W, C_Q	lift, drag and sideforce coefficient	
C_l, C_m, C_n	roll, pitch and yaw moment coefficient	
H	altitude	m
h	number of measured values	
I_x, I_y, I_z, I_{xz}	moments of inertia	kg m^2
J	cost function	
k	number of independent variables	
L	length of the body	m
$\underline{M}_{\mathrm{af}}$	transformation matrix	
m	mass	kg
N	scale factor	
n	air density ratio	
p, q, r	roll, pitch and yaw rate	1/s
$\bar{q}$	dynamic pressure	N/m^2
S	reference area	m^2
s^2	parameter variance	
$\underline{T}_f$	inertial tensor	kg m^2
V	velocity	m/s
$\underline{x}$	independent variable	div.
$\underline{X}$	matrix of regressors	div.
X_{MRP}, Y_{MRP}, Z_{MRP}	moment reference point	m
$\underline{y}$	dependent variable	
$\underline{Y}$	matrix of dependent variables	
α	angle of attack	°
β	angle of sideslip	°
Δt	cycle time of excitation	s
η	deflection of elevator	°
μ	ratio of kinematic viscosities at model/original flight	
$\bar{\theta}$	vector of unknown parameters	
σ	standard deviation	
ω_0	eigenfrequency	1/s
ξ	deflection of aileron	°
ζ	deflection of rudder	°

Subscripts

f	in the body fixed system
a	in the aerodynamic system
i	index variable

Abbreviations

CFD	computational fluid dynamics
RC	radio control
RLV	reusable launch vehicle

1. Introduction

The low speed characteristic of spaceplanes are always critical because the shapes of these configurations are usually optimized for the aerothermodynamic demands of hypersonic speed. For the analysis of movement patterns and the design of control systems for this kind of aircraft a very precise modelling of the aerodynamics is very important. Aerodynamic data sets for this modelling can be obtained from wind tunnel experiments, CFD-calculations and flight tests. The identification of aerodynamic parameters from drop model flight test data also has a long tradition because of the higher degree of similarity of the motion to the original aircraft compared to wind tunnel experiments. But until the beginning of the nineties the high performance sensor equipment that is needed for parameter identification purposes could only be installed in large drop models and prototype aircraft, that were very expensive to operate.

Now distinct simplifications for drop model flight tests are possible, because the high performance sensor equipment has become smaller in the last years. This makes it possible to apply parameter identification procedures to very simple, radio controlled models that are built of commercial components normally used in model airplanes. Sim and Murray [12] conducted flight tests with such a small model of NASA's X-33 spaceplane configuration with the objective to identify aerodynamic parameters from the data, but they have not published any results yet. Arning [1] investigated the spaceplane configuration ELAC with simple, radio controlled models and compared the results with standard wind tunnel test results. He found out that the variation of the identified parameters from wind tunnel data are comparable to results of much more ambitious drop model flight test programmes. In both flight test campaigns the model had to be operated with locations of the center of gravity (CG) that allowed a stable free flight without any controller. Unfortunately these CG-locations were not in accordance with the original spaceplanes, so the similarity conditions could not be met exactly. Furthermore both models had to be in a range of model-size and weight that enabled the operator a safe handling of the model by vision from ground.

In this paper an enhancement of this flight test technique is described. With the help of a ground based real time controller board in combination with a telemetry- and a telecommand system, it is possible to perform flight tests with a very simple model of the spaceplane configuration PHOENIX. In contrast to the other described examples the original and unstable CG-location could be used in the flight tests and basic controller functions allowed to fly the model without any pilot. After describing the methodology of this kind of flight testing, the free flying model and the other required hardware is presented. A main part of this report is the description of the parameter identification procedure and the comparison of the results with wind tunnel data. It will be shown, that the good consistency between wind tunnel and flight test results