JOURNAL OF AIRCRAFT
Vol. 46, No. 5, September–October 2009

Unscented Kalman Filtering for Reentry Vehicle Identification in the Transonic Regime

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DOI: 10.2514/1.42256

Parameter identification methods for processing flight data are frequently used to validate and improve a preflight aerodynamic database and, specifically, to reduce the associated uncertainties. In this framework, the paper describes an identification methodology developed for the first flying test bed of the Italian Aerospace Research Center, a demonstrator of technologies relevant to future reusable launch vehicles. The analysis is focused on aerodynamic modeling of the reentry vehicle configuration in the transonic flow regime, in which flight control system performance is affected by a significant level of parameter uncertainty. The parameter estimation is formulated as a nonlinear filtering problem and solved through a multistep approach, in which the aerodynamic coefficients are identified first and, in a following phase, a set of model parameters is updated. In each step, an unscented Kalman filter is used as a recursive estimation algorithm. The methodology is applied to the flight data of the Dropped Transonic Flight Test mission of the vehicle, carried out during the winter of 2007. The reported results demonstrate the good characteristics of the technique in terms of convergence, reduction of uncertainty of the a priori aerodynamic model, and capability of extracting the information content from a rather limited set of flight data on vehicle response.

Nomenclature

C_D, C_S, C_L = aerodynamic force coefficients in wind axes
C_X, C_Y, C_Z = aerodynamic force coefficients in body axes
C_l, C_m, C_n = aerodynamic moment coefficients in body axes
$\mathbf{c}$ = vector of aerodynamic force and moment components
$\mathbf{F}_A$, $\mathbf{M}_A$ = aerodynamic force and moment
$\mathbf{F}_\mathbf{g}$, $\mathbf{g}$ = gravity force and acceleration
$\mathbf{I}$ = inertia matrix
M = Mach number
m = vehicle mass
n_x, n_y, n_z = load-factor components in body axes
P_S, P_{dyn} = static and dynamic pressure
p, q, r = angular velocity components in body axes
S = reference surface
T_S = air static temperature
u, v, w = velocity components in body axes
$\mathbf{x}$, $\mathbf{U}$, $\mathbf{y}$ = system state, input, and observation vectors
α, β = aerodynamic angles
δ_e, δ_a, δ_r = control angles for pitch, roll, and yaw
η, ν = process and measurement noises
$\boldsymbol{\Theta}$ = vector of unknown aerodynamic parameters
τ = correlation time
φ, θ, ψ = Euler angles
$\boldsymbol{\omega}$ = angular velocity
$\hat{\ }$ = nondimensional

Superscript

a = augmented

I. Introduction

THE Italian Aerospace Research Center (CIRA) is conducting an unmanned space vehicle (USV) program within the framework of the Italian Aerospace Research Program (PRORA). The main objective of this program is designing and manufacturing unmanned flying test beds (FTBs), conceived as multimission flying laboratories, to test and verify innovative materials; aerodynamic behavior; advanced guidance, navigation, and control functionalities; and critical operational aspects peculiar of the future reusable launch vehicle [1].

The first vehicle of the USV program, named FTB1, is unmanned and unpowered and has been developed to perform flight missions for investigation of subsonic, transonic, and low-supersonic regimes. The FTB1 is a winged slender configuration, with two sets of aerodynamic effectors: the elevons, which provide both pitch control when deflected symmetrically and roll control when deflected asymmetrically, and the rudders, which deflect only symmetrically to allow yaw control. Lateral-directional stability is enhanced by means of two ventral fins. A hydraulic actuator system controls the aerodynamic effectors. Three onboard computers host the software that implements the guidance, navigation, and control algorithms and manages all the subsystems and the experimental payloads. The FTB1 vehicle is shown in Fig. 1.

The first FTB1 mission, named the Dropped Transonic Flight Test (DTFT1), was aimed at evaluating the transonic flight of a reentry vehicle. This mission was carried out in February 2007 from Sardinia (Italy). Flight data recorded during DTFT1 were used to increase the accuracy of the FTB1 model by means of system identification methods.

Postflight data analysis and system identification are inherent activities in aerospace projects for the evaluation of vehicle performance, stability, and control. There is a specific interest in obtaining vehicle aerodynamic characteristics from flight data to better understand theoretical predictions and wind-tunnel test results and to obtain more accurate and comprehensive mathematical

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Received 18 November 2008; revision received 8 May 2009; accepted for publication 8 May 2009.

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