

left: A DHL Airbus A-300 lands without hydraulic controls at Baghdad International Airport after being hit in the backboard wing by an infrared seeking surface-to-air missile, launched by Iraqi terrorists.

University of Technology and the faculty of Aerospace Engineering are involved. The Group for Aeronautical Research and Technology in Europe (GARTEUR) has installed action group AG16 with the specific goal to investigate the possibilities of fault tolerant control in aeronautics and to compare the results of different reconfiguring control theories applied on a reference benchmark scenario. Moreover, a similar research project was started at Delft University of Technology, performed at the division of Control and Simulation at the faculty of Aerospace Engineering and Delft Center for Systems and Control (DCSC), where the same scenario is used. That benchmark scenario is inspired by the so-called Bijlmermeer disaster of EL AL flight 1862, where a Boeing 747-200 cargo aircraft of Israel's national airline El Al lost two engines immediately after take-off from Amsterdam Airport Schiphol in the Netherlands and crashed into an apartment building in the area, while trying to return to the airport. A detailed simulation model of this damaged aircraft has been developed by Ir. Hafid Smaili in 1997 as his graduation work at the division of Control and Simulation. Now an extended simulation model is available from the NLR, where Hafid is employed currently.

One possible option for a satisfactorily performing FTFC strategy is using a model based control routine. In this setup, not only

a reconfiguring controller is needed, but also a suitable FDI/identification strategy. Both components will be elaborated upon in detail. The considered identification method in this study is the so-called two step method, which has been continuously under development at Delft University of Technology over the last twenty years. Key concept of the two step method is that the identification procedure has been split into two consecutive steps. The aim is to update on a priori aerodynamic model (obtained from windtunnel tests and CFD calculations) by means of online flight data. The first step is called the Aircraft State Estimation phase, where the second one is the Aerodynamic Model Identification step. In the Aircraft State Estimation procedure, a Kalman Filter is used to determine the aircraft states, sensor biases and the wind components by making use of the nonlinear kinematic and observation models, based upon redundant but contaminated information from all sensors. This contamination involves biases as well as noise. By means of this information, it is possible to construct the combined aerodynamic and thrust forces and moments acting on the aircraft, and by means of a recursive least squares operation, finally the aerodynamic derivatives can be deduced. An overview diagram can be found in figure 2. Validation tests have shown that this method is very accurate. Finally this recursive method has been implemented in Simulink (Matlab®)

and combined with the conventional sensor output of the earlier mentioned Boeing 747 simulator, together with connecting a joystick as input. This allows performing real-time computer based identification calculations while performing flight manoeuvres by hand in a Simulink aircraft simulator. The progress of the identification process is continuously visualized on the computer display, as can be seen in figure 3. Current work is focusing on modifications on the current status of the two step method, such that its performance improves for situations with aircraft sustaining heavy structural damage, which requires not only parameter estimation, but also real-time aerodynamic model structure development and mass property estimation. This resulting real time damaged aircraft model is par excellence suited for implementation in an adaptive control strategy, since this model approximates the real aircraft as well as possible.

The concept of Nonlinear Dynamic Inversion (NDI) is that the actual physical dynamics of the system of interest, in our case the aircraft, can be inverted by means of a smart chosen feedback structure such that the equivalent closed loop system behaves like a pure integrator, which means that all dynamics of the system have been cancelled or inverted. This pure first order system is then easy to control by a classic linear (PID) controller. However, the problem in this setup is that an accurate model of the system is needed, in order to invert the dynamics correctly. The interesting thing for this model based control technique is that an accu- ➤

figure 1: A McDonnell Douglas MD-11 lands at Dryden Flight Research Center equipped with a computer-assisted engine control landing system developed by a NASA-Industry team.



figure 2: Overview of the structure of the two step method and its connection to Adaptive Nonlinear Dynamic Inversion (ANDI).

