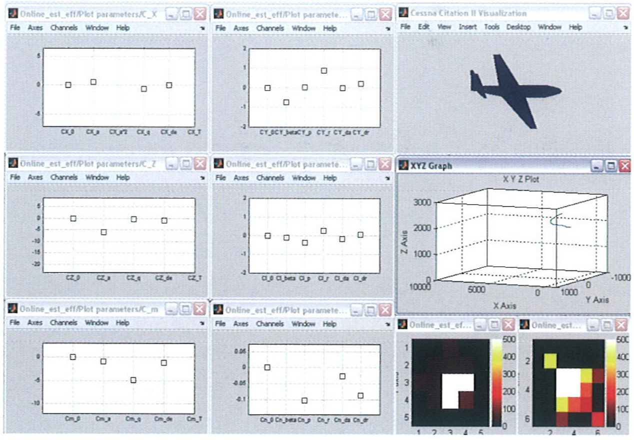
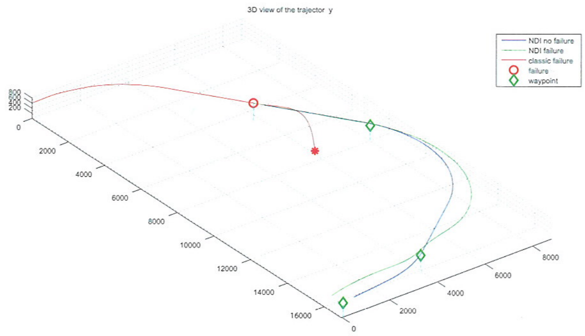
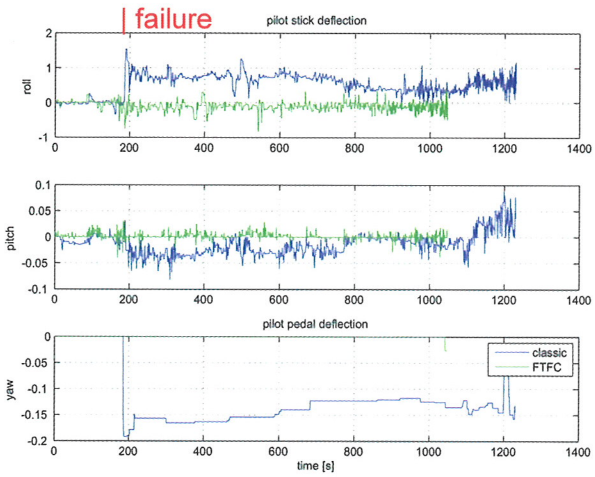

H. Husman

figure 3: Overview of the operator information screen for real time identification. The left and middle columns in the operator interface screen give the aerodynamic derivative values, the right column gives (from top to bottom) aircraft attitude, trajectory and covariances for symmetrical (left) and asymmetrical (right) estimates.



T. Lombaerts

figure 4: Comparison of the Boeing 747 El Al trajectory along three waypoints for classic failed (red), NDI unfailed (blue), NDI failed (green). Due to the damage, the NDI failed aircraft has a restricted bank angle and thus a larger turn radius.



T. Lombaerts

figure 5: Comparison of pilot control deflections between classic (blue) and fault tolerant flight controller (green). Considerably less control deflections are needed for the fault tolerant flight controller compared to the classical one, showing the reduced pilot workload.

rate real time damaged aircraft model is available thanks to the above mentioned two step method. As a consequence, also the damage characteristics of the aircraft can be inverted, and one can thus compensate for this failure damage. This concept is called Adaptive Nonlinear Dynamic Inversion (ANDI). This concept is one of the many alternative approaches to elaborate fault tolerant flight control for damaged aircraft, but research has revealed that NDI is a very powerful and promising approach. Not only stuck or hardover control surfaces (component failures) can be compensated, such as a stabilizer or rudder runaway, but also structural failures, like the loss of the vertical tail or the separation of right wing engines and the addition of right wing damage, as in the El Al disaster scenario. The trajectory of this failed aircraft with NDI control can be found in figure 4.

The research methods described above are just one way to achieve FTFC. In the above-mentioned Garteur Flight Mechanics Action Group 16 on FTFC, alternative methods have been investigated. Robust control, sliding mode control, subspace identification, model predictive control and many others have been under consideration for the same application in FTFC.

On November 20-21, the final workshop of this Action Group has taken place. During this workshop two fault tolerant controllers, comprising manual as well as autopilot control, have been demonstrated on the Simona Research Simulator, where the El Al failure mode has been simulated, as described earlier. Two weeks before this workshop, an extensive evaluation campaign has been organized, where several of these fault tolerant controllers have been evaluated and compared by professional wide body pilots, who have conscientiously analysed the performance as well as the workload. These pilots were Hessel Benedictus (retired Boeing 747 captain at KLM), Bob Mulder (Boeing 767 captain at ArkeFly) and Arun Karwal (NLR testpilot and Airbus A330 pilot). Olaf Stroosma and the simulator staff took care of the implementation of all model and controller soft- and hardware into and the operation of the Simona Research Simulator. As an example, the workload assessment figures for the failure of the rudder runaway, flown by Hessel Benedictus, can be found in figure 5. Here it is clear that considerably less control deflections are needed for the fault tolerant flight controller compared to the classical one. This research group has achieved some very interesting results, which might find application in practice in the longer term (10-15 years), and currently initiatives are being taken to elongate the very promising research activities of this dynamic group.

Finally, the author would like to thank Olaf Stroosma, Jan Breeman, Hafid Smaili, Diederick Joosten and all other action group colleagues for the fruitful cooperation in this innovative European project.

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Students who are interested in this disciplinary field and would like to have a graduation subject related to this research are encouraged to contact Thomas Lombaerts, dr. Ping Chu or prof. Bob Mulder.