

ACTUATION SYSTEM MODELING FOR ERICA TILTROTOR

Przemysław Bibik, Associate Professor, pbibik@meil.pw.edu.pl
Antoni Kopyt, Ph.D. student, akopyt@meil.pw.edu.pl
Janusz Narkiewicz, Professor, jnark@meil.pw.edu.pl
Department of Automation and Aeronautical Systems,
Warsaw University of Technology,
ul. Nowowiejska 24; 00-665 Warsaw, Poland

Abstract

The paper presents results achieved by a research team from Warsaw University of Technology (WUT) during its participation in the NICETRIP („Novel Innovative Competitive Effective Tilt Rotor Integrated Project") EC funded project. In the NICETRIP project the WUT team was responsible for modeling and simulation of the actuation system of the tiltrotor.

Based on the data of the actuators proposed by the project partners, the simulation models of flight control system actuators were developed. To maintain the whole tilt-rotor simulation model operation in a real-time, the actuators were modeled as the first-order systems. The numerical models of the actuators were developed and tested using SIMULINK[®] software. According to the safety requirements for a tiltrotor, all control system actuators have two or three levels of operational modes specified in terms of working speed and load. During the validation process of control system model, the time responses and frequency domain characteristics were checked to fulfill all the requirements stated by the System Segment Specification document for all levels of operating conditions.

The validated models of the actuators were applied to the Flight Control System of ERICA tiltrotor. The model of ERICA tiltrotor was developed by other partners of the NICETRIP project using FLIGHTLAB[®] software. The WUT team developed a methodology of collaborating the FCS models in SIMULINK[®] with tiltrotor simulation model in FLIGHTLAB[®][1].

The tests of the ERICA tiltrotor time responses (with FCS including developed actuators models) to various control inputs were done. The results obtained by the WUT team were compared with the results obtained using the generic models elaborated previously. The tiltrotor responses in various flight conditions proved the proper behavior of the aircraft with improved actuators. Also some improvement of the flight qualities may be observed.

1. INTRODUCTION

The work reported in this paper is a part of a EC funded project NICETRIP - Novel Innovative Competitive Effective Tilt Rotor Integrated Project. The project is devoted to integration of technologies leading to development of the European tiltrotor called ERICA [1]. In the project the scaled prototype of ERICA tiltrotor was built and was tested in the wind tunnel. The Warsaw University of Technology research team was responsible for modelling and simulation of the flight control actuation system.

The tiltrotor concept was well known for several decades, however up to date there is only one fully operational and certified design – the Bell Boeing V-22 Osprey. Its first fly was on March 19th 1989 and it was introduced to operational service with the US Marine Corps on Jun 13th, 2007. There is also another tiltrotor under development today – the AgustaWestland AW609. This tiltrotor prepared for civil market is currently in the process of FAA certification, which is forecasted at 2017. The configuration of both tiltrotors, the V-22 and AW609 is the same. The rotorcraft looks like typical fixed-wing twin engine aircraft with high wing and tail fin with horizontal stabilizer. The difference from fixed-wing aircraft is due to the engines nacelles with quite big propellers

mounted on the tip of each wing which can rotate with respect to the wing fixed to the fuselage [2]. Such configuration allows to take-off and land vertically (in so-called Helicopter Configuration H/C) and cruise with speed of an fixed-wing aircraft (in so-called Aircraft Configuration A/C). Unfortunately such configuration have two significant drawbacks: one is caused by the large size of propellers not allowing the aircraft to take-off and land in A/C mode, the other one is a problem of a blockage effect of the outer parts of the fixed wings to the rotors slipstream in H/C mode. Both these aspects were analysed and solved in the AgustaWestland led projects leading to development of ERICA tiltrotor. ERICA, in the contrary to the V-22 and AW609, has propellers small enough to allow the ground operations in A/C mode, which was possible due to a design of new shape of blades for propellers. The problem of the wings blockage effect was solved by adapting elements from tiltwing rotorcraft allowing the outer parts of the wings to rotate independently from inner part of wing and the engine nacelles (Fig. 1). Such a design allows to optimize the size of the outer parts of the wings to minimize the thrust and power losses and to make the aircraft much more efficient in the H/C mode.



Fig. 1 ERICA tiltrotor in three flight model – from A/C to H/C

2. ERICA TILTROTOR ACTUATION SYSTEM

The design of ERICA tiltrotor described in the previous chapter has many advantages but inevitably leads to mechanical complexity of the system. One of the results is high number of hydraulic actuators required to rotate all independent elements of the wings and engine

nacelles, to deflect all aerodynamic surfaces ailerons, flaperons, rudder and elevator, to control the swashplates of the propellers and rotations of outer part of wings.

Actuators used for various functionalities differ from each other in terms of physical parameters such as maximum stroke, speed of operation, possible maximum load, deflection

accuracy and bandwidth. For the actuators applied to the swashplate the important parameters are the speed and a high bandwidth while for the actuators used in the nacelles actuation system the most important parameter is the maximum load level. Unfortunately due to the data sensitivity it is not possible to present the detailed data of the actuators in the paper.

3. A HYDRAULIC ACTUATOR MODELING

As it was already mentioned all the actuators selected for ERICA tiltrotor are hydraulic. Due to this fact the same model of actuator was used for all actuators, with varying magnitude of physical parameters. It was decided to use simple model of an actuator in a form of first order inertia system, as not all actuators had already been selected. The transfer function of such element has a form:

$$(1) G(s) = \frac{k}{Ts + 1}$$

Based on the physical parameters of the already selected actuators the gain and time constant for each of the actuator were determined. In Fig. 2 Step response of a model actuator is presented together with corresponding plot of the actuator speed. The step response is expressed in degrees corresponding to the angle of deflection of the actuated aerodynamic surface. This kind of an output signal was chosen for convenient integration of the actuators models with already existing Flight Control System model developed by other partners in Flightlab® software.

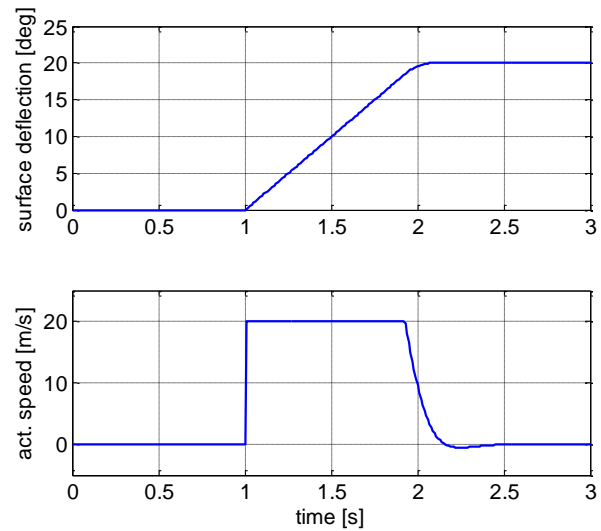


Fig. 2 Step response of a model actuator

Presented in Fig.2 time characteristics are typical for a hydraulic actuators which have very short time of reaction to the input signal and maintain constant speed of piston which results in a linear deflection of an actuated element.

Additionally to the time characteristics the phase characteristics were also calculated. The resulting Bode plots are presented in Fig. . From the plots the phase and magnitude margins may be read. Characteristics of the actuators were checked for both assumed levels of operation in normal conditions and in situations of hydraulic system performance degradation. In all conditions the actuator were acting properly and the required performance of actuators was assured.

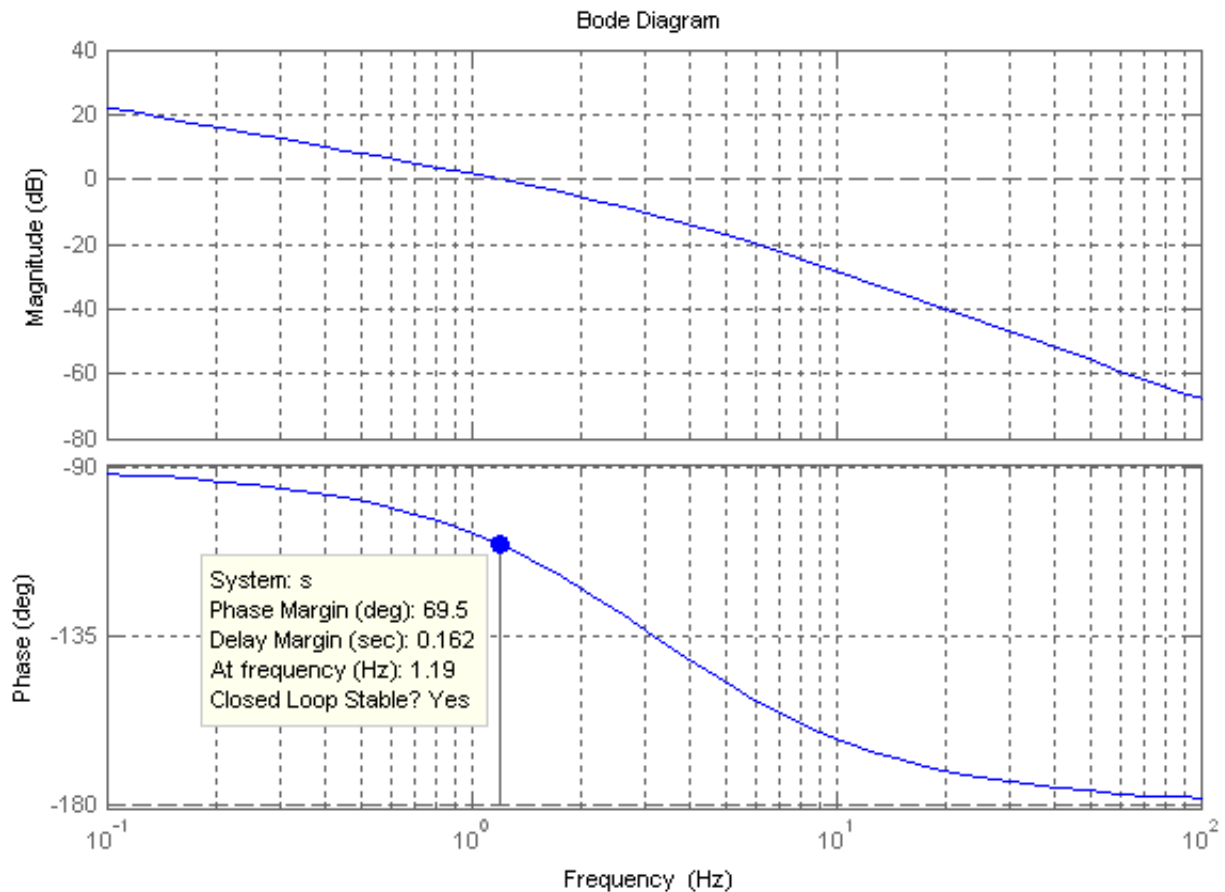


Fig. 3 Bode characteristics of a modeled actuator

4. ERICA TILTROTOR SIMULATION WITH NEW ACTUATORS MODELS

Developed models of actuators after proving their proper behavior were implemented into the Flightlab[®] based Flight Control System of the ERICA tiltrotor. The time responses of the whole aircraft to given single channel inputs were investigated and the behavior of the aircraft was analyzed. The resulting time responses were compared to the model of aircraft with a generic actuators models which parameters were not selected in detail.

Several types and shapes of input signals were generated and the corresponding reaction

of the aircraft was observed. In Fig. 4 an example of the impulse signal in the channel of rotors collective pitch control is presented for a helicopter mode of tiltrotor operation. The input was applied in the trimmed horizontal flight with the velocity of 20 m/s. The response to this signal is presented in Fig. and Fig. 6 (red line is the response of the aircraft with generic actuators models, blue line is the response of the aircraft with WUT modeled actuators)

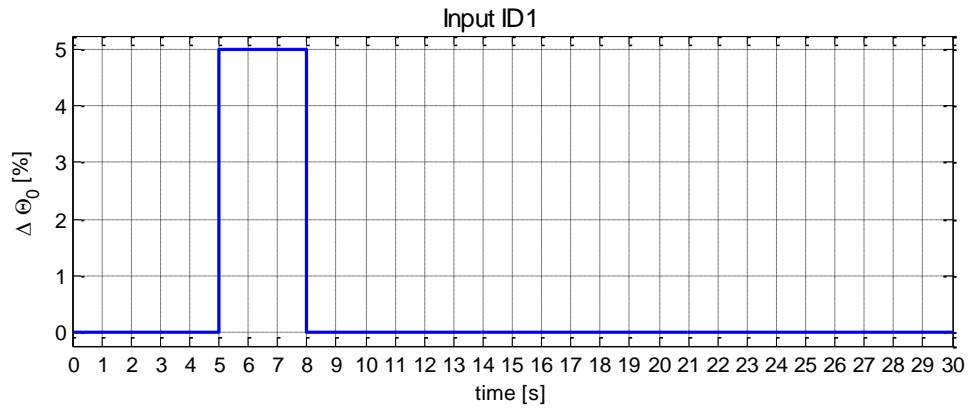


Fig. 4 Control input in the collective control channel

Acceleration, velocity, position (speed = 20 [m/s], case ID = 1)

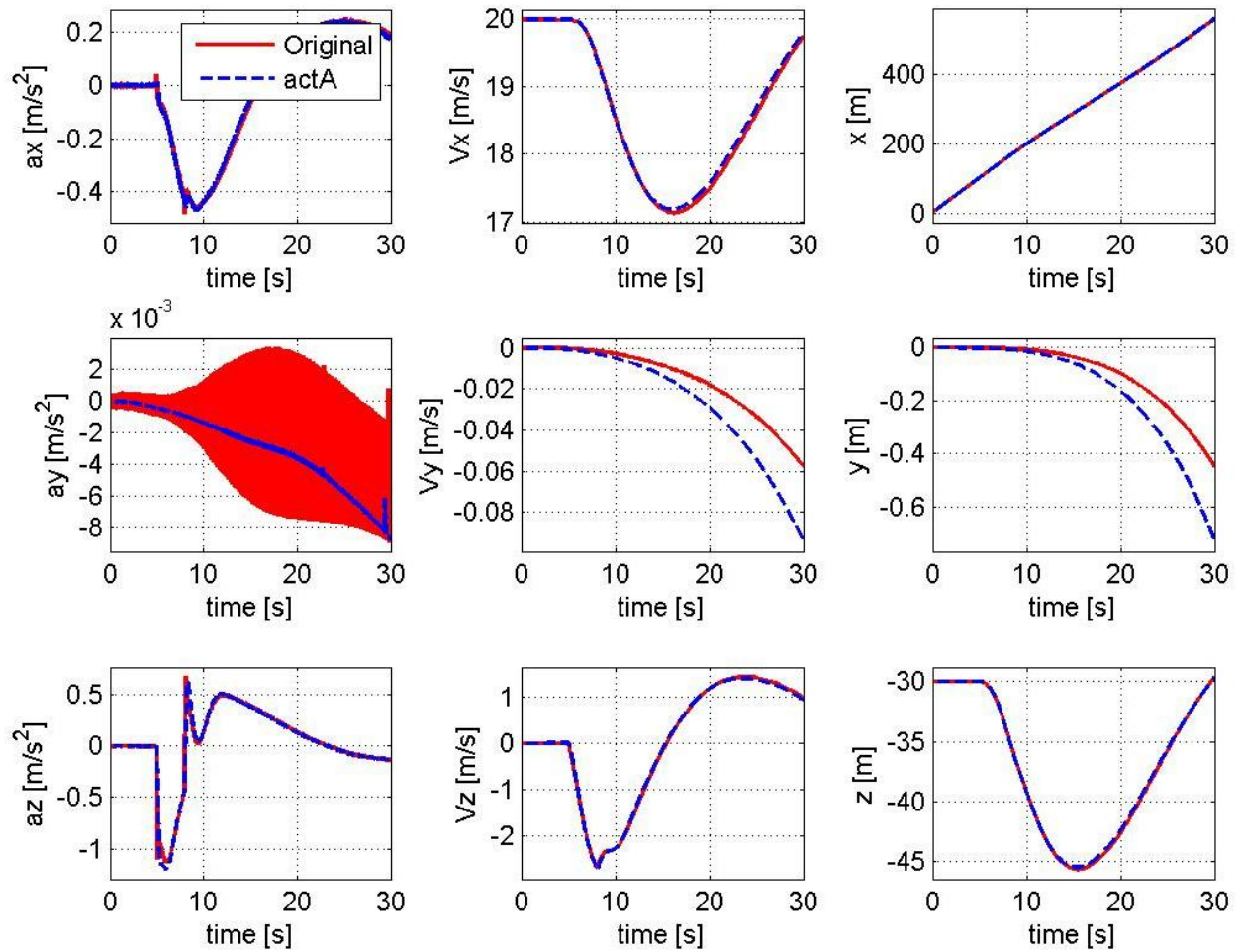


Fig. 5 Linear acceleration, velocities and translation of the tiltrotor in response to the input signal in collective pitch control, H/C mode

Angular acceleration, rate, attitude (speed = 20 [m/s], case ID = 1)

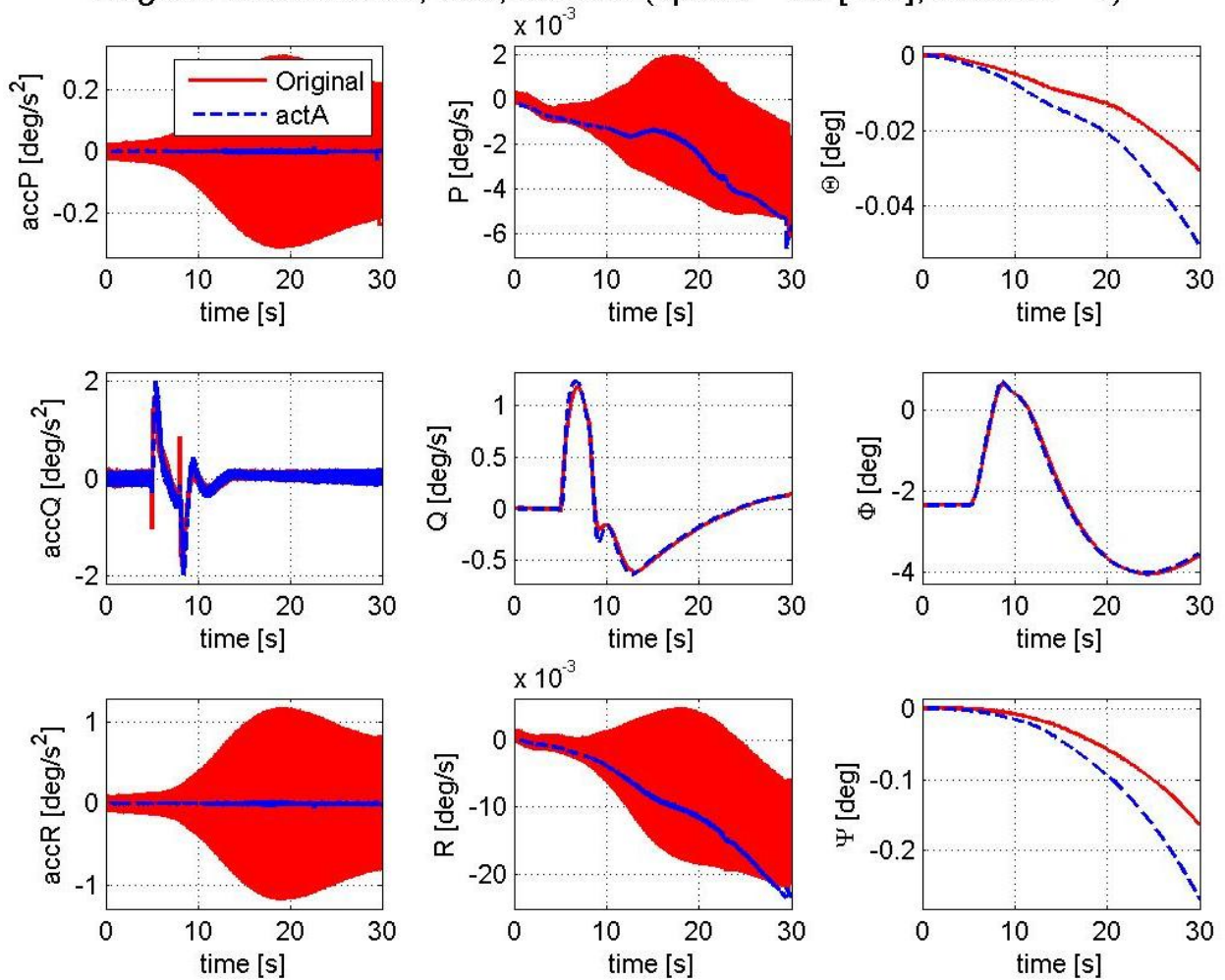


Fig. 6 Angular acceleration, angular rates and rotation angles of the tiltrotor in response to the input signal in collective pitch control, H/C mode

From the presented figures the change in rotorcraft behavior may be noticed. In some channels (e.g. lateral acceleration, roll acceleration, roll rate, yaw acceleration and yaw rate) after a rapid change of the control signal oscillations may be noticed (the red line). These oscillations do not appear in the model with new model of control system actuators which illustrates an improvement in ERICA behavior after inserting the new model of the flight control system.

5. SOFTWARE USED

The WUT team was provided by AgustaWestland with already developed Flightlab model of the ERICA tiltrotor. The model contained also a model of Flight Control

System with generic models of actuators. To make the simulations more efficient WUT research team adopted the methodology to couple the Flightlab® model of vehicle dynamics with SIMULINK® model of control system presented in [3]

The Flightlab® software allows the user to model both the vehicle dynamics and the flight control system (Fig. 7).

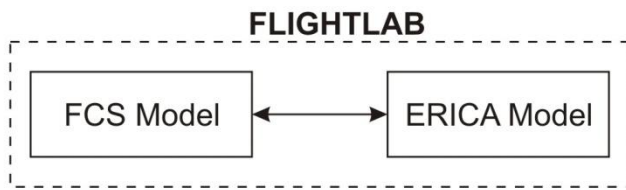


Fig. 7 Structure of FLIGHTLAB simulation model

However, sometimes it is more convenient to model the control system in other software package, like SIMULINK[®]. Such method of working allows for parallel work of different engineering groups in the process of model development. SIMULINK[®] is nowadays some kind of a standard software used in modeling of control systems and is specially dedicated to

such tasks having several toolboxes making the development and tests of control systems much more efficient than the software included for this task in Flightlab. On the other hand Flightlab is specialized in modeling and simulation of the rotorcraft. Combining these two software tools leads to increased efficiency and flexibility in development of an aircraft model and its control system (8). These kind of a solution was also important in the NICETRIP project due to the fact that not all partners involved in the FCS development had access to the Flightlab software and all partners possessed MATLAB[®]/SIMULINK[®] software.

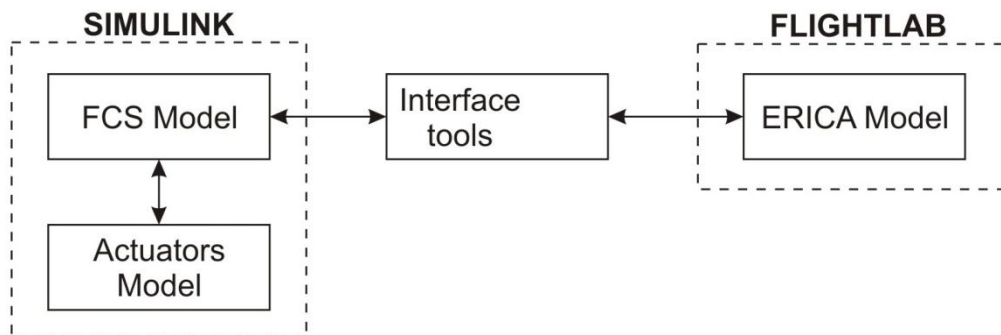


Fig. 8 Structure of simulation model using SIMULINK[®] FCS model and FLIGHTLAB[®] vehicle model

Acknowledgment

The research presented was part of the project „Novel Innovative Competitive Effective Tilt Rotor Integrated Project (NICETRIP)“, under the EU supported FP6/Aeronautics project AIP5-CT-2006-030944.



6. CONCLUSIONS

Presented work was part of a EC funded project NICETRIP devoted to development of a new tiltrotor called ERICA. The Warsaw University of Technology was involved in the project and was responsible for actuation system modeling. Simple models of hydraulic actuators were developed at WUT based on the parameters of actuators selected by other

project partners. The isolated models of actuators were developed and tested using SIMULINK[®] software. After validation the models of actuators included in the already developed FCS Flightlab[®] model were replaced with the models developed at WUT. Improvement of flight qualities of the ERICA tiltrotor model was noticed with the new actuators models.

Additional work done at WUT was dedicated to combining Flightlab based tiltrotor dynamics model with SIMULINK® Flight Control System model. These work was required due to the fact that not all project partners had access to Flightlab® software.

7. BIBLIOGRAPHY

- [1] Fabio NANNONI, Giorgio GIANCAMILI, Marco CICALI: ERICA: THE EUROPEAN ADVANCED TILTROTOR, 31st European Rotorcraft Forum, September 11-14 2001, Moscow, Russia
- [2] A.Scandroglio, S. Melone, A. D'Andrea: Numerical Analysis of Advanced-Innovative Tiltrotor Configurations (ERICA) 19th European Rotorcraft Forum, September 16-19, 2008, Liverpool, UK
- [3] Geoffrey J. Jeram, Kristopher Strobe, and Christopher Borden: Combining Simulink® and Flightlab® for Handling Qualities and Crew Station Prototyping, Proceedings of the American Helicopter Society 64th Annual Forum, Montreal, Canada, April 19 - May 1, 2008.