ZRÍNYI MIKLÓS NATIONAL DEFENCE UNIVERSITY
Doctoral Committee

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COMPUTER-AIDED ANALYSIS AND SYNTHESIS OF CONTROLLERS OF FLIGHT CONTROL SYSTEMS

Author's synopsis and official report on the Ph.D. thesis

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FORMULATION OF THE SCIENTIFIC PROBLEM

Designing unmanned aerial vehicles is a complex process, full of challenges. It is carried out through the application of new initiatives, ideas and technologies based on the customer's demands, conditions and requirements and/or remarks and feedback from the manufacturer. One phase of this complex activity is the preliminary design of the autopilot system, during which one of the objectives is to solve the regulation technical problem of the aircraft.

The stabilisation and control problems of the unmanned aerial vehicle may stem from external disturbance and internal noise affecting the aircraft, or malfunction of the controls.

Through controlling the effects of manoeuvre orders resulting from intentional or environmental influence, either internal or external, it is possible to ensure for the safe aerial operation of the unmanned aerial vehicle, and the safety of the onboard equipment. A possible way to preserve the operating capabilities of the aircraft is the use of the autopilot (flight controller). In its design, a basic requirement is exploring, by using the equations of state of the dynamic models available, the operating characteristics of the regulated equipment, which requires that tests related to time and frequency domains be carried out and analysed.

Based on the results of the analyses, it is possible to design the flight controller, which provides spatial stabilisation, as well as the suitable noise suppression characteristics.

At present, there is no unmanned aerial vehicle in service in the Hungarian Defence Forces. As a result of the Hungarian-Czech development process, started in 1988, the Sojka-III unmanned aerial vehicle was constructed. It is a typical robot plane of the 90s, with low-cost (HUF 150 million) development. As for its possible uses and operating, it's a relatively simple and cheap piece of equipment.

In my opinion, the Sojka-III unmanned aerial vehicle can be one of the alternatives of the cost-effective solution to several problems of the defence forces, which are in the process of reorganisation and modernisation.

RESEARCH OBJECTIVES

During writing my doctoral dissertation, I embarked on providing a solution to a sub-process of aircraft design. In my thesis, I had the following research objectives:

1. to systematise and summarise the body of regulation technical knowledge related to the theory of flight control systems, and applied during the preliminary design of the controller of the flight control system to the extent necessary for solving the problem, in a manner that makes it useful for flight engineer training as well, and to conduct tests of controllability and observability in order to prove that the flight-mechanical mathematical model of the Sojka-III unmanned aerial vehicle is a suitable starting point in the preliminary designing process of the controllers of modern robot planes;

2. to complete the preliminary design of the flight controller, to prepare in MATLAB® context the new source program required for the tests related to time and frequency domains for it, and to demonstrate on the flight-mechanical mathematical model used the practical applicability of the created MATLAB® m-files during the tuning of the controllers of aircraft and the preliminary design of aircraft;

3. to do the deterministic and stochastic analysis of the flight control system designed with computer aid, which enables us to draw conclusions about the operation and applicability of the flight control system yielded by the simulations.

RESEARCH METHODS

In order to achieve my research objectives and complete the dissertation, I applied the following methods:

- I studied the literature related the subject of the dissertation, and did appropriate research in libraries and on the internet;
- I systematised the body of knowledge accumulated;
- I consulted experts dealing with and/or experienced in aeronautics;
- I created MATLAB® m-files for the tests to be carried out;
- I conducted tests of controllability and observability;
- I carried out analyses in time and frequency domains;
- I had partial results of the activity related to my objectives and my research published regularly, and I also presented them at conferences;
- I requested and received feedback, remarks and help about my work from my colleagues, and I incorporated those in my dissertation;
- I conducted computer aided controller design using the results of the analyses

SUMMARY OF THE TESTS CONDUCTED

The dissertation is divided into 6 principal components: an introduction, 4 chapters and a summary. At the end, there is a list of references and a list of publications. The dissertation also contains two electronic appendices, with the multiple-variable mathematical models of the Sojka-III unmanned aerial vehicle and the new source program written in MATLAB® computer package context necessary for meeting research objectives, respectively.

In the introduction, I described the motivating factors that inspired me to write the dissertation. It is here that I pointed out the timeliness of the research, explained the method of research, and formulated my research hypothesis, my research objectives, and the expected results. The introduction concludes with a description of the Sojka-III unmanned aerial vehicle complex.

In Chapter 1, using references to the literature, I summarised the system of co-ordinates used for defining the spatial movement of aircraft, and the equations describing the straight and rotary movements of fixed-wing aircraft. I presented the transfer functions of movement along the longitudinal and lateral axes. I introduced the concepts of controllability, observability, and stability. I concluded that the mathematical model of the Sojka-III unmanned aerial vehicle satisfies the necessary and sufficient criteria of controller design.

In Chapter 2, I detailed the classic and modern design procedures, in time and frequency domains, followed during the preliminary design of flight control systems, as well as the MATLAB® functions and auxiliary programs related to the subject of the dissertation. As a result of examining the procedures of controller design, I concluded that:

- ✈ the classic controller design procedures can only be applied for single variable systems;
- ✈ there are several integral criteria available for the design in time domain of single variable, deterministic control systems;
- ✈ selecting the integral criteria in a suitable manner in practice is a very complex task;

- ✈ a closed loop system designed on the basis of a particular integral criterion may be considered optimal with respect to that criterion, while not necessarily so with respect to the others;
- ✈ the flight-mechanical mathematical models of unmanned aerial vehicles have multiple variants even in noise-free cases, so the robot pilots of aerial vehicles can only be designed in the state space;
- ✈ in modern control theory, there are several methods known for the design of multiple variable control systems, which make the design of optimal and not optimal control systems possible in the case of both deterministic and stochastic systems.

In Chapter 3, I described the general structure and method of operation of robot pilots used on aircraft. Using the specialized literature and standards, I identified the quality requirements of control theory necessary for the design of flight control systems. I carried out the system analysis of the uncontrolled aerial vehicle in time and frequency domains. I prepared a preliminary controller design. I carried out tests of basic signal tracking. Based on the results of the test, I concluded that:

- the uncontrolled longitudinal and lateral motion of the Sojka-III is unstable;
- it is reasonable to design a flight control system in order to ensure for the safe aerial operation of the aircraft, and to meet control theory quality requirements.

Using the Linear Quadratic Regulator (LQR) design method based on optimising the squared integral criterion and the method of pole relocation, I conducted computer aided controller design. I carried out analyses in time and frequency domains. I found that the altitude and bank angle stabilising systems designed meet the basic signal tracking requirements of closed loop systems.

In Chapter 4, I modelled external disturbance by using filters for creating stochastic signals from the signals of the white noise generator. I determined the stochastic time progression of the vertical component of atmospheric turbulence for medium-speed wind. I created a new MATLAB® source code for the computer aided modelling of atmospheric turbulence. I examined the noise suppression capability of the altitude and bank angle stabilising system described in Chapter 3. Due to lack of space in the dissertation, in the remainder I only concentrated on the flying altitude stabilising system. On the basis of the tests, I concluded that it is necessary to improve the noise suppression capabilities of the flying altitude stabilising system with a P-regulator on the Sojka-III unmanned aerial vehicle. For the purpose of improving the noise suppression capabilities of the flying altitude stabilising system, I designed a newly structured closed loop system operating with a PDT1 (proportional-differentiation-single-store band filter) regulator. Using computer aided tests, I proved that the basic signal tracking and noise suppressing characteristics of closed loop systems operating with PDT1 filter meet the standard control theory quality requirements.

In the Summary, I summed up the research I had done, and organized my new scientific results into theses. I made recommendations regarding the usefulness of the dissertation, as well as the possible directions of further research.

SUMMARY OF CONCLUSIONS

The multiple variable flight-mechanical mathematical model of the Sojka-III unmanned aerial vehicle satisfied the necessary and sufficient criteria of controller design.

The type P regulators designed for the flying altitude and bank angle stabilising systems of the Sojka-III unmanned aerial vehicle ensured for the stability of the control systems and acceptable basic signal tracking, and satisfied control theory quality criteria, but it was necessary to improve the noise suppressing capability of the altitude stabilising system.

The basic signal tracking and noise suppressing characteristics of closed loop systems operating with PDT1 filters meet the standard control theory quality requirements.

I achieved the research objectives set; using the computer aided preliminary design method outlined in the dissertation, I designed and analysed the altitude stabilising robot pilot of the Sojka-III unmanned aerial vehicle.

The design method can be used not only for the design of the flight control system of the Sojka-III unmanned aerial vehicle, but can be generally used during the design of the flight control system of any other flying technique.

NEW SCIENTIFIC RESULTS

I summed up the scientific results of my research presented in the dissertation in the following theses:

Thesis 1 I developed a computer aided preliminary design procedure demonstrating the joint application of aviation mechanics and modern control theories [S.3, S.2, S.5, S.6, S.7, S.10, S.11, S.13, S.14.].

1.1. In order to solve the control technical problem, I outlined, appropriately organised, and summarised the theory related to the mathematical modelling of the spatial movement of aircraft, and the body of modern regulation technical knowledge related to the theory of flight control systems and applied during the design of controllers.

1.2. As a result of computer aided tests, I concluded that the multiple variable aviation mechanical mathematical model of the Sojka-III unmanned aerial vehicle satisfied the necessary and sufficient criteria of controller design.

1.3 I proved with computer aided analyses in time and frequency domains that the uncontrolled aerial vehicle determined with multiple variant aviation mechanical mathematical model will have an unstable flight. I follows that safe aerial operation of the aircraft requires the design of a closed flight control system, meeting the standard control theory quality requirements, which provides the aircraft with stability.

Thesis 2 Based on the system analysis carried out with the multiple variant flight-mechanical mathematical model, and applying the design method (LQR) built on the squared integral criterion and the design method with pole relocation, I carried out a computer aided controller design, which can me applied according to sample in the future [S.3., S.4., S.6., S.8.].

2.1. Applying the LQR controller design method, I designed the optimal complete state-feedback closed loop system which provides for the stability of the state variables of the longitudinal motion of the Sojka-III unmanned aerial vehicle. Based on the results of the computer aided analyses in time and frequency domains, I found that the closed loop system meets the standard set of control theory quality requirements.

2.2. Evaluating the results of the analyses in time and frequency domains of the closed loop system stabilising the state variables of the lateral motion of the Sojka-III unmanned aerial vehicle, I concluded that applying the LQR design method makes it possible to design a system with appropriate quality characteristics. However, setting the weighting matrices of the LQR method proved difficult, so a new controller needs to be designed in the interest of the widely accepted practice of utilising the influence of the dominant pair of poles.

2.3. Applying the method of pole relocation, I designed the controller of the closed loop system stabilising the state variables of the lateral motion. With analyses in time and frequency domains, I proved that the closed loop system meets the standard set of control theory quality requirements.

2.4. Examining the basic signal tracking characteristics of the flying altitude stabilising and the bank angle stabilising closed loop systems, I found that the basic signal tracking of the control systems meet the general control theory quality requirements of closed loop systems.

Thesis 3 I designed a newly structured controller in the interest of enhancing the noise suppressing capability of the flying altitude stabilising system [S.1., S.2., S.9., S.12., S.15.].

3.1. To model the effect of external disturbance, I used step signals and stochastic signals created with filters from the output signals of the white noise generator. I determined the stochastic time progression of the vertical component of atmospheric turbulence for medium speed wind. I created a new MATLAB® source code for the computer aided modelling of atmospheric turbulence.

3.2. On evaluating the results of the deterministic and stochastic noise suppression analyses carried out, I found that it is necessary to enhance the noise suppression capability of the flying altitude stabilising system operating with a type P regulator of the Sojka-III unmanned aerial vehicle.

3.3 Based on the results of the computer aided system analysis, I recommended the application of a newly structured closed loop control system operating with a PDT1 (proportional-differentiation-single-store band filter) controller to enhance the noise suppression capability of the flying altitude stabilising system.

3.4 With computer based analyses, I proved that the basic signal tracking and noise suppressing characteristics of closed loop systems operating with PDT1 filters that I designed meet the standard control theory quality requirements.

PRACTICAL APPLICABILITY OF THE RESEARCH FINDINGS, RECOMMENDATIONS

The dissertation can be used in aviation technical engineer training. The controlling and their analyses in the dissertations were conducted with computer simulation. Using the results, it is possible to construct an experimental device the testing of which can be conducted under real life circumstances. The design methods and findings can serve as the basis of comparison with other methods of control design in the course of designing new controllers.

The tests can be extended to carrying out a non-linear dynamic analysis. The MATLAB® files created can be used for the design of controllers of aircraft. The tests conducted can serve as the starting point of the preliminary design of the robot pilot systems of other aircraft.

LIST OF PUBLICATIONS AND OTHER SCIENTIFIC PUBLIC ACTIVITIES RELATED TO THE DISSERTATION

S.1. Szegedi, P. An Investigation of the Noise Suppression of the Flight Control System of the Sojka-III Unmanned Aerial Vehicle II., National Defence University Publications, Budapest, 2005 (in print)

S.2. Szegedi, P. An Investigation of the Noise Suppression of the Flight Control System of the Sojka-III Unmanned Aerial Vehicle I., National Defence University Publications, Budapest, 2005 (in print)

S.3. Szegedi, P. Designing the Flight Controller of the Sojka-III Unmanned Aerial Vehicle with the LQR Method, Aviation Science Publications, Szolnok, 2005 (in print)

S.4. Szegedi, P. The Preliminary Design Process of the Lateral Motion Controllers of the Sojka-III Unmanned Aerial Vehicle with the Pole Relocation Method, Aviation Science Publications, Szolnok, 2005 (in print)

S.5. Szegedi, P. An Analysis of the Sojka-III Unmanned Aerial Vehicle, Aviation Science Publications, Szolnok, 2005 (in print)

S.6. Szabolcsi, R – Szegedi, P. The Preliminary Gauging of the Flight Regulating Systems of Unmanned Aerial Vehicles, Half a Century on Rotary Wings in Hungarian Military Aviation, Scientific Conference, Special Electronic Edition of Aviation Science Publications, Szolnok, 15 05 2004 (on CD supplement)

S.7. Szegedi, P. An Investigation of the Controllability and Observability of Unmanned Aerial Vehicles, Aviation Science Publications, Vol. XIV., Issue 34., Szolnok, 2003, (129-150).

S.8. Szabolcsi, R. – Szegedi, P. Computer Aided Control Law Synthesis For The Unmanned Aerial Vehicle, Pannonian Applied Mathematical Meetings PC–141, Balatonalmádi, Hungary, 22–25 May 2003. (in print).

S.9. Szabolcsi, R. – Szegedi, P. Modelling Atmospheric Disturbances Affecting Motion of the UAV, Pannonian Applied Mathematical Meetings PC–141, Balatonalmádi, Hungary, 22–25 May 2003. (in print).

S.10. S.10. Szabolcsi, R – Szegedi, P. Computer Aided Analysis of Unmanned Aerial Vehicles, Szolnok Scientific Publications, Szolnok, 2002 (on CD-ROM)

S.11. Szabolcsi, R. – Szegedi, P. Robustness Analysis of Control Systems, Pannonian Applied Mathematical Meetings PC–136, 24–26 January, Göd, Hungary, 2002. (in print).

S.12. Szabolcsi, R. – Szegedi, P. Robustness Analysis of the Flight Control Systems, 8th Mini Conference on Vehicles System Dynamics, Identification and Anomalies, November 11–13, Budapest, 2002. (in print).

S.13. Szabolcsi, R. – Szegedi, P. Robustness Analysis of the Flight Stability Augmentation Systems, Pannonian Applied Mathematical Meetings PC–136, 24–26 January, Göd, Hungary, 2002. (in print).

S.14. Szabolcsi, R. – Szegedi, P. Robustness stability and robust performance of the automatic flight control systems, AARMS, MZNDU, vol. 1., issue 2., Budapest, 2002. (253–269).

S.15. Szabolcsi, R.—Szegedi, P. Design of the Chebyshev BR filter for the Elastic Aircraft Longitudinal Stability Augmentation System, Procedings of The 1ST

International Symposium on „Future Aviation Technologies", Budapest-Szolnok, Hungary, 12-14 April, 2002. (43-52).

Scientific public activities

1. Member of organising committee of conference „Which Way Helicopter", 1998;
2. Member of organising committee of conference „Renewing Hungarian Aviation Expert Training", 2000;
3. Member of organising committee of conference „The Influence of the 20th Century Military Technical Revolution on Military Aviation in the 21st Century", 2001;
4. Co-Chairman of section of „Engineering Systems and Their Investigation" at the conference „The Influence of the 20th Century Military Technical Revolution on Military Aviation in the 21st Century", 2001;
5. Member of organising committee of the „1st International Symposium on Future Aviation Technologies", held in Szolnok, 2002;
6. Co-Chairman of section of „Multidisciplinary Sciences I." at the „1st International Symposium on Future Aviation Technologies", held in Szolnok, 2002;
7. Member of organising committee of conference „100 Years of Flying Machines. The Aircraft of Military Systems, The Systems of Military Aircraft", 2003;
8. Co-Chairman of the section of „Unmanned Aerial Vehicles" at conference „100 Years of Flying Machines. The Aircraft of Military Systems, The Systems of Military Aircraft", 2003;
9. Co-Chairman of the section of „Computer Networks" at conference „100 Years of Flying Machines. The Aircraft of Military Systems, The Systems of Military Aircraft", 2003;
10. Member of the committee launching the BSc in electrical engineering major at ZMNE BJKMF, 2004;
11. Member of the organising committee of scientific conference „Half a Century on Rotary Wings in Hungarian Military Aviation", 2005;
12. Co-Chairman of the section of „Unmanned Aerial Vehicles" at scientific conference „Half a Century on Rotary Wings in Hungarian Military Aviation", 2005;
13. Member of the Air Force Section of the Hungarian Military Science Society, 2005;
14. Member of the Aviation Technical Work Committee of the MTA DAB Technical Committee, 2005.

PROFESSIONAL ACADEMIC BACKGROUND

My name is Péter Szegedi, and I was born in Miskolc in 1969. I went to secondary school there, and took the school-leaving examinations at the 2nd Industrial Secondary Technical School. In 1987 I started my studies at Zalka Máté Military Engineering College. In 1990 I graduated with „Good" results from the Military Telecommunications Operator Branch, specialising in Transmission Technical Devices.

On the 1st September 1990 I got my first officer's assignment with the 5th Jász-Nagykun-Szolnok Air Defence Artillery Brigade. I served as sub-unit commander until 1992. In September that year, I was sent, upon my request, to the certified special engineering course in telecommunications, organised for military officers at the Faculty of Electrical Engineering and Information Technology of Budapest Technical University. I passed the state exam with „Excellent" marks and graduated with „Good" results in 1995.

On 1st January I became an instructor at Szolnok Aviation Officer Training College. I did four months of field service with the 59th Szentgyörgyi Dezső Tactical Fighter Wing in Kecskemét. At the end, I passed an exam in carrying out the engineering duties related to the MiG-29 aircraft.

On 1st September 1996 I became a college assistant lecturer, and later a university assistant lecturer at the On-Board Systems Department of the Faculty of Management and Organisation of Zrínyi Miklós National Defence University. At present I am an associate professor at the On-Board Systems Department at the Aviation Technical Institute of the Bolyai János Faculty of Military Engineering of Zrínyi Miklós National Defence University.

On 1st April 2004 I was tasked with the duties of deputy head of the Aviation Technical Institute of the Bolyai János College Faculty of Military Engineering of Zrínyi Miklós National Defence University.

During my ten-year career as an instructor, I have taken part in the training of cadets studying electrical and mechanical engineering.

In 1999 I did an intermediate level English language course.

In 2000 I attended an ECDL basic computer operator course. At the end of the course I passed my exams and received the European Computer Driving Licence.

In 2000 I successfully participated in the distance learning programme organised by the Institute of Informatics Systems of Gábor Dénes College. My diploma work consisted of developing students' guide to the subject 'Analogue Electronics' in compliance with the special requirements of distance learning. I defended my diploma work in front of a Qualifications Board.

In 2001 I took a CADKEY design program operator course organised by the Weapons Technical Department of the Bolyai János College Faculty of Military Engineering of Zrínyi Miklós National Defence University.

In 2003 I attended an elementary Russian language course.

Since 1st September 2004, I have been carrying out the duties of deputy head of the Aviation Technical Institute of the Bolyai János Faculty of Military Engineering of Zrínyi Miklós National Defence University.

Since September 2004 I have taken part in the work of the committee launching the BSc in electrical engineering major at Bolyai János Faculty of Military Engineering of Zrínyi Miklós National Defence University.

On 14th September 2004 I was sent by the MoD Department of Education and Science Management to a distance learning tutor training course organised by the Centre for Distance Learning and Adult Education of BME, which I completed successfully.

In 2005 I attended a Lapoda 2.1 multimedia editor course.

In March 2005 I became a member of the „MHHT” Air Force Section.

Since October 2005 I have been a member of the Aviation Technical Workgroup of the „MTA DAB” Special Technical Committee.

I have type „A” and „B” intermediate state exams in English, and a type „C” state exam in Russian, all with military specialisation.

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I hereby would like to thank all the people who have provided invaluable assistance, in the form of constructive criticism, advice and informed opinion, in achieving my scientific objectives.
Special thanks to Dr. Habil. Róbert Szabolcsi, my scientific consultant, for his efforts and counselling through all these years.

Szolnok, 21st Octber 2005

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