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Reference number 5/1493/2021:
Review of the doctoral thesis by Ing. Jan VLK titled
“Modern Flight Control System Design and Evaluation”

Dear Ladies and Gentlemen,

With pleasure I accept your appointment conveyed to me as of January 29th, 2021 under your reference number 5/1493/2021 to act as objector for the doctoral thesis

“Modern Flight Control System Design and Evaluation”

submitted by Ing. Jan VLK.

For the structure of my review document, I follow the headlines as specified by your request letter.

1. Appropriateness and up-to-datedness

While commercial air transportation provided by airlines utilizing large passenger transport airplanes has reached a very high level of maturity and an extremely high level of safety, the world looks very different in General Aviation, where the probability of fatal accidents is orders of magnitude higher than in commercial air transport. Large airliners are routinely equipped with fly-by-wire flight control systems, providing excellent handling qualities to the pilot at very low workload with automatic protection of the aircraft envelope and with autoflight and autothrust systems completely relieving highly qualified multi-person cockpit crews from routine task. In contrast to that, unexperienced pilots of general aviation aircraft are left mechanical cables, push rods and pulleys, just like at the dawn of aviation. It seems to be the most straightforward solution to apply what has been developed for large planes to small ones – however, that would be inappropriate and completely unprofessional as those solutions in no way account for the cost, weight, size and application constraints of the general aviation domain.

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On the other hand, many call the current time the third revolution in aerospace – driven by electrification and automation, suddenly new modes of aerial mobility become possible that promise to make sustainable regional and short haul aerial transportation an attractive alternative for a large audience. In the United States, a law has been passed to revitalize General Aviation and global rulemaking activities are on their way to simplify and reduce cost for certification of general aviation aircraft and at the same time move towards Simplified Vehicle Operation (SVO) to reduce the qualifications required to operate a manned airplane, with the final objective of making classical pilot licenses obsolete.

In front of this background, the research group of Prof. Peter Chudy has been a visible global player for many years. While many universities perform theoretical research on isolated details, the number of groups demonstrating real capabilities in actual flight tests of manned aircraft can be counted by two hands. To the best of my knowledge, I am not aware of any group that is successfully demonstrating those comprehensive capabilities with so few personnel like the Chudy team.

In this context, Ing. Jan Vlk is providing the whole functional scope to be detailed in the next section.

His topics are therefore highly appropriate for doctoral research, addressing highly-relevant, up to date research questions that contribute to contemporary scientific and engineering challenges of great practical relevance and application potential.

2. Contributions, Quality of Results, Relevance and Application Potential

As already mentioned, the work of Ing. Jan Vlk spans the whole functional scope comprising

- Modeling and simulation, including disturbances and subsystems like actuators and sensors.
- System analysis and parameter estimation from actual flight test data
- Autoflight control law structural development for pitch, lateral and energy
- Estimator development (Kalman Filter)
- Gain design (LQR / LQG)
- Adaptive controller augmentation using MRAC and PCH
- Closed loop assessment, validation and verification
- Implementation for on-board real-time use in embedded aircraft avionics
- Flight test preparation, execution and evaluation

This is an extreme scope to be handled by just one person – Jan Vlk successfully accomplished it! – At most places I know, it is a whole team working on such a scope, at my institute it is more than 20 people for the same part – so I do sincerely admire Ing. Vlk.

While the main contribution of his work is definitely providing one consistent framework for everything in an integrated model-based development process, where the different aspects fit together in a harmonic manner, different interesting contributions can also be found in many of the detail chapters.

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For the simulation model, he accounts for the correct noise characteristics retrieved from measurements from the Allan variance. State estimation is performed using Kalman filters and smooth noise-robust differentiation provides time derivatives for aerodynamic offline and online parameter estimation based on the (recursive) equation error method.

LQR control is turned into a tracking controller based on the robust servo-compensator approach. As only output feedback is available, a Kalman filter is used for state estimation, stability reserves are recovered following the Lavretsky-Wise approach to Loop Transfer recovery (LTR). Direct MRAC is used to provide resilience against model uncertainties and damages. Parameter drift is inhibited by projection and hedging is used to hide hard nonlinearities in control effector dynamics from adaptation. In total, the chosen control methodology approach is oriented along the lines of Lavretsky and Wise and forms a consistent strategy.

For onboard use, real-time capable C-Code is automatically generated from a time-discrete Simulink implementation. One big (positive) surprise for me was, that Ing. Vlk did not rely on the classical cascaded auto flight approach but provided a full order, single shot integrated system. Here, some peculiarities and details not mentioned in the thesis would be of great interest.

The whole control system is extensively verified in simulation-based analyses utilizing the identified simulation model. There a really broad set of evaluation metrics is applied which cover all relevant categories – many of them are retrieved form applicable aerospace guidance material for certification, particularly the SAE AS94900. The considered criteria span from formal observability and controllability assessment via time domain response metrics (general transient and steady state and variable specific from AS94900), control effector utilization, riding quality limits for states, loop sensitivity for disturbance rejection to linear stability margins. Especially the influence of the LTR tuning parameter ν plays a prominent role in the assessment. The power of the adaptive augmentation is demonstrated by the sudden injection of uncertainties (unknown to the controller) for which the non-adaptive system loses control whereas the augmented system almost recovers baseline performance.

Of course, the greatest difference to most academic research theses are the highly successful flight tests of the whole system on a real manned LSA airplane. Already the scope, complexity, fidelity and depth of the simulation model used by Ing. Vlk goes far beyond what you normally find in academic research, where very often simple, decoupled, linear models are used. However, demonstrating the robust performance and compliance with a broad range of certification relevant criteria and metrics in real flight is an outstanding aspect to be emphasized – and a highly visible success, which the candidate, his supervisor and the university can be proud of.

It is very important to realize that contributions in a doctoral thesis measure original achievements by the candidate in all relevant fields of science that change things for the better – unfortunately, research is by many often mistaken as the number of theorems and mathematical findings. The methodology, the process and the strategy detailed by Ing. Vlk as contributions are at least of equal value – and with a great potential for real-life applicability – with the bold perspective to change things for the better.

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3. Publications, Research Erudition and Visibility

Ing. Jan Vlk as a doctoral candidate has contributed to seven Scopus listed publications – for three of them he was the first author. Given the fact that the applied flight control community is not so publication intensive (I could show some renowned full professors in that domain that do have less publications over the same period of time!) this is really a lot – and far beyond for example what the statutes of the graduate center of my university require for retrieving a PhD.

In his summary of the state of the art in the different fields, he proves to be very knowledgeable with a deep and intuitive insight into the topics. There are many research efforts where doctoral candidates try to impress with the intensive use of mathematical formulations where a closer look reveals that they are victims of their own work as they loose control and traceability of what happens. – Ing. Vlk describes his concepts and strategy in a very tangible manner with great clarity, never leaving a doubt that he exactly knows what he is doing, always clearly sitting in the driver seat. Thanks to this, the interested reader can draw valuable insights and knowledge from his publications as well as from the submitted thesis and learn in almost a tutorial way on how to implement a modern flight control system.

4. Special Appraisal: Wide Scope of the Thesis

One aspect that definitely deserves special appraisal is – as already mentioned several times – the extremely broad scope of the thesis. A chain is always only as strong as its weakest link. Ing. Vlk spans the whole spectrum from modeling, simulation, parameter estimation, control design, control implementation, validation and verification to real-life flight test in a manned aircraft with considerable depth, clarity and quality.

This puts him in a quite small group of people who are capable of mastering the whole process in an efficient way. While there are many who are very deep in singular aspects, only few understand the interdependences along the whole process chain. That puts him in a very attractive position for his future.

5. Conclusion

Opening the skies of tomorrow for a broader audience in a sustainable manner is one of the perspectives the current exciting time of disruptive progress shaped by electrification and automation offers. The community designates these times as nothing else than the third revolution of aerospace. However, the single most important aspect to make this vision come true is safety – only if a high level of safety can be provided at a level of cost that is more oriented at the consumer domain than at classical aerospace.

Prof. Peter Chudy's group is an internationally visible team with the great reputation of making visions really fly with a very small team. This is also reflected in the thesis of Ing. Jan Vlk. The scope he addresses, develops, implements and demonstrates in real flight in a manned aircraft (!) is at my institute handled by more than 20 people. Thus, I have a great admiration how the candidate and the group can accomplish such a broad scope and still add innovations beyond the state-of-the art on the detail level. Ing. Jan Vlk directly implements path and trajectory control in one integrated control loop and files an adaptive system.

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His original work is innovative and bears great potential for real-life application – it is a bold contribution to the vision highlighted above and may serve as a strong support especially for small and medium sized enterprises in general and sports aviation and their suppliers.

Therefore, in my opinion, the thesis more than just meets the requirements and I support and recommend the conferment of the title of PhD to Ing. Jan VLK with emphasis!

If you have any questions or need further information, feel free to ask anytime.

Garching, March 7th, 2021