emerald
PUBLISHING

ISSN 1748-8842
Volume **91** Number **5 2019**

Aircraft Engineering and Aerospace Technology

Current trends in aircraft design (7th EASN)

Guest Editor: Zdobyslaw Jan Goraj

Publisher note from Stephanie Hull

I am delighted to present this special issue focusing on innovation in European aeronautics research and the ideas presented at the 7th EASN International Conference, an event that I was very fortunate to attend in Warsaw.

As publisher of *Aircraft Engineering and Aerospace Technology*, it is a pleasure to be able to work with a global network of academics and contribute to the progression of ideas based on reason, quality and scholarly excellence.

This special issue brings together almost 18 months of hard work from Professor Zdobyslaw Goraj and his colleagues. We are extremely thankful for his contribution to the journal.

As well as the eight papers published in this special issue, Professor Goraj kindly worked on five additional papers on this topic that were published earlier in this volume. These were:

1. AEAT-02-2018-0092, “Research and selection of MALE wing profile”.
2. AEAT-01-2018-0024, “Conflict-resolution algorithms for RPAS in non-segregated airspace”.
3. AEAT-01-2018-0056, “UAV APPLICATION FOR PRECISION AGRICULTURE”.
4. AEAT-01-2018-0036, “HYBRIDIZATION OF TRAINING AIRCRAFT WITH REAL WORLD FLIGHT PROFILES”.
5. AEAT-01-2018-0070, “MULTIROTOR UAV SENSOR FUSION FOR PRECISION”.

To further showcase this work, these papers will be promoted together and compiled to form a virtual special issue.

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/1748-8842.htm**

Aircraft Engineering and Aerospace Technology
91/5 (2019) 717
Emerald Publishing Limited [ISSN 1748-8842]
[DOI 10.1108/AEAT-05-2019-317]

Guest editorial

Special issue devoted to the 7th European Aeronautics Science Network (EASN) International Conference on "Innovation in European Aeronautics Research"

Dear Reader,
It is my pleasure to present this special issue of the *Aircraft Engineering and Aerospace Technology Journal*, dedicated to the topics of unmanned aerial vehicle (UAV) configurations, unmanned aircraft systems (UAS) architectures, performance of remotely control vehicles and systems for pilot support, discussed at the 7th European Aeronautics Science Network (EASN) International Conference on "Innovation in European Aeronautics Research"[1]. The Conference was organized by EASN together with the Institute of Aviation and Warsaw University of Technology (Faculty of Power and Aeronautical Engineering – Institute of Aeronautics and Applied Mechanics), 26-29 September 2017, Warsaw, Poland.

The EASN Association was officially established on 6 May 2008 by 20 founding members (individuals), following two European Commission (EC)-funded Specific Support Actions. EASN is:

- an international association based in Brussels;
- self-funded and self-sustainable; and
- coordinated and run by a board of directors, which is elected by the General Assembly for a three-year term.

Presently, the EASN Association has almost 400 members, including individuals and laboratories, from nearly all European universities dealing with aeronautical research.

The long-term goal of establishing EASN was to build an open, unique European platform to structure, support and upgrade the research activities of the European aeronautics universities, as well as to facilitate them to respond to their key role within the European aeronautical research community in incubating new knowledge and breakthrough technologies. The primary aim of the EASN association is the advancement of the aeronautics sciences and technologies. Any individual with interest in aeronautics and astronautics-related research may become a member of EASN. In addition, entities such as research establishments, small and medium-sized enterprises, industries and universities are welcome to join the EASN. More details about the EASN services, membership types and activities of EASN can be found at its website www.easn.net

Based on the EASN statute and coming from the assumption that dissemination of research results is one of the most important roles of EASN activity we decided to organize workshops, soon after gradually transformed into conferences. The first workshop was organized in Paris (2010) and the second in Praha (2012), and in the following years, successive workshops were held in Milano, Aachen and Manchester, and finally the real conferences were held in Porto (2016) and Warsaw (2017) (Figure 1).

During the Warsaw Conference, more than 350 participants attended and about 250 presentations were distributed amongst 45 technical sessions. Numerous papers were developed in current projects funded within the scope of the 7th and 8th Framework Programs (FP7/FP8), and a few of them are included in this *AEAT* Special Issue. Based on the session chairs' assessment, the authors of 83 conference presentations were invited to submit their full length papers for consideration into *AEAT* journal. The scope of this issue (13 papers, Vol. 91, Iss. 5) spans performance improvement of unmanned helicopter rotors, through less-skilled pilot decision support, control and monitoring assistance for pilots, preliminary design of 3D-printed fittings for UAVs, conflict-resolution algorithms for remotely piloted aircraft systems (RPAS) in non-segregated airspace, UAV applications for precision agriculture, 4D-trajectory time windows for uncertainty management, hybridization of training UAV aircraft, multi-rotor UAV sensor fusion for precision landing, research and selection of medium-altitude long-endurance aircraft wing sections, UAV speed polar graphs assessed by conducting flight tests, hybrid energy systems for UAVs, to innovative time-based separation procedures for civil RPAS integration.

In total, 14 papers devoted to stability, control, aero-elasticity and operations were included in Vol. 91, Iss. 3, and the rest of the accepted papers (25 of 52) devoted to aerodynamics, aero-acoustics, thermodynamics, flight dynamics and control, vibrations, operations, materials, structures, health monitoring, surface technology, measurements, UAV/UAS, engines, power plants to space technology and astronautics will be included in regular issues and published in years 2019 and 2020.

Furthermore, distinguished invited speakers updated the delegates about the newest opportunities for carrying out aeronautics related research, on available research infrastructure and novel research results. Amongst the keynote speakers were:

- Clara de la Torre, Director for Transport, DG Research and Innovation, European Commission with keynote lecture "Chances and Challenges for Research in Aeronautics within H2020" (FET, CleanSky 2, SC4 "Smart, Green and Integrated Transport", Marie Skłodowska-Curie actions);
- Dr Marian Lubieniecki, Managing Director and Site Leader at GE Engineering Design Center (Institute of Aviation) with keynote lecture "Design and Research Philosophy in the Environment of Global Competition";
- Christophe Hermans, President of the Council of European Aerospace Societies (CEAS) with keynote lecture "Aerospace Europe: Strengthening Collaboration and Knowledge Dissemination;
- Bruno Sainjon, Chairman of Association of European Research Establishments in Aeronautics (EREA) with keynote lecture "EREA, A Major Contributor to the Implementation of ACARE's SRIA;
- Alan Haigh, Head of Department – Horizon 2020 Energy and Transport, INEA Executive Agency – European

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/1748-8842.htm**

Aircraft Engineering and Aerospace Technology
91/5 (2019) 718–719
© Emerald Publishing Limited [ISSN 1748-8842]
[DOI 10.1108/AEAT-05-2019-295]

Figure 1 The route of EASN workshops (conferences) – from Paris in 2010, through Praha in 2012, Milano 2013, Aachen 2014, Manchester 2015, Porto 2016, Warszawa 2017 and Glasgow 2018

Note: In September 2019, the 9th EASN Conference will be held in Athens

Figure 2 Keynote speakers invited to the 7th EASN Conference in Warsaw

Note: All of them delivered very interesting presentations, well received and widely discussed by participants

Commission with keynote lecture "INEA's Role in Implementing Aviation Research in H2020: Feedback from 3 Years of Operations";
- Dr Bruno Stoufflet, Vice-President Scientific Strategic Research and Development and Advanced Projects, Dassault Aviation with keynote lecture "Challenges of Business Jets Technological Developments";
- Dr Fay Collier, Associate Director for Flight Strategy, Integrated Aviation Systems Program, NASA Langley Research Center with keynote lecture "Accelerating Market Introduction of Emerging Innovations through Integrated Technology Demonstrations";
- Hannes Ross, Design Advisor and Consultant for the Swiss Project Solar Impulse with keynote lecture "Flying Around The World With Solar Power – A Success Story";
- Prof Dr-Ing Mirko Hornung, Bauhaus Luftfahrt e.V. with keynote lecture "Aviation 5.0 – Challenges and Solutions for 2050";
- Dr Bruce Holmes, Vice President and Executive Director of the Skytelligence Group, SmartSky Networks with keynote lecture "Connected, Networked Aircraft and The Future of On-Demand Air Mobility; and
- Dr Frank Anton, Siemens Next47 Projects, eAircraft with keynote lecture "Electric Propulsion for Aircraft".

Finally, I would like to express my deep appreciation to Dr Askin T. Isikveren, Editor-in-Chief of the *Aircraft Engineering and Aerospace Technology Journal*, and Stephanie Hull, Senior Publisher in Emerald Group Publishing Limited, for offering to EASN the possibility to publish a number of selected papers and for their continuous support in preparing this special issue. Publishing this volume would not have been possible without the hard work of Beata Wierzbinska-Prus, the Administrative Officer at Warsaw University of Technology. Therefore, at the end of this acknowledgement, I would like to express my sincere gratitude to her for her assistance during the 7th EASN Conference and, thereafter, for the help and organizational effort given for the preparation of this special issue.

I hope you will find this special issue an interesting read.

Professor Zdobyslaw Goraj

Guest Editor and Vice-President of EASN

Zdobyslaw Jan Goraj

Note

1 When referencing this editorial please use the citation for the editorial published in *AEAT* volume 91 issue 3 as they form a single editorial for the "Current Trends in Aircraft Design", which is split into two parts. Part 1 in issue 3 and part 2 in issue 5. Goraj (2019)

Reference

Goraj, Z.J. (2019), "Guest editorial", *Aircraft Engineering and Aerospace Technology*, Vol. 91 No. 3, pp. 405-406, available at: https://doi.org/10.1108/AEAT-03-2019-291

Assessment of a small UAV speed polar graph by conducting flight tests

Adam Tomaszewski and Zdobyslaw Jan Goraj
Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, Warsaw, Poland

Abstract

Purpose – The purpose of this paper is to present an approach to a polar graph measurement by a flight testing technique and to propose a baseline research method for future tests of UAV polar graphs. The method presented can be used to demonstrate a conceptual and preliminary design process using a scaled, unmanned configuration. This shows how results of experimental flight tests using a scaled flying airframe may be described and analysed before manufacturing the full scale aircraft.

Design/methodology/approach – During the research, the flight tests were conducted for two aerodynamic configurations of a small UAV. This allowed the investigation of the influence of winglets and classic vertical stabilizers on the platform stability, performance and therefore polar graphs of a small unmanned aircraft.

Findings – A methodology of flight tests for the assessment of a small UAV's polar graph has been proposed, performed and assessed. Two aerodynamic configurations were tested, and it was found that directional stability had a large influence on the UAV's performance. A correlation between the speed and inclination of the altitude graph was found – i.e. the higher the flight speed, the steeper the altitude graph (higher descent speed, steeper flight path angle). This could be considered as a basic verification that the recorded data have a physical sense.

Practical implications – The polar graph and therefore glide ratio of the aircraft is a major factor for determining its performance and power required for flight. Using the right flight test procedure can speed-up the process of measuring glide ratio, making it easier, faster, robust, more effective and accurate in future research of novel, especially unorthodox configurations. This paper also can be useful for the proper selection of requirements and preliminary design parameters for making the design process more economically effective.

Originality/value – This paper presents a very efficient method of assessing the design parameters of UAVs, especially the polar graph, in an early stage of the design process. Aircraft designers and producers have been widely performing flight testing for years. However, these procedures and practical customs are usually not wide spread and very often are treated as the company's "know how". Results presented in this paper are original, relatively easily be repeated and checked. They may be used either by professionals, highly motivated individuals and representatives of small companies or also by ambitious amateurs.

Keywords Performance, Flight tests, UAV, Glide ratio, Polar graph

Paper type Case study

Introduction

Flight tests must be precisely planned and meticulously executed scientific investigations, where the hazards are minimized as much as possible (Corda, 2017). Moreover, flight tests play the key role in confirming the assumptions adopted at the design stage of the project (Etkin, 1982; Galinski and Goraj, 2004; Goraj, 2007). The value of an aircraft design is evaluated on the basis of flying qualities, flight performance and avionics functionality (National Test Pilot School, 1995). A series of tests allows the determination of the actual performance and flying qualities of the aircraft and enables corrections and improvements to the aircraft design to be made (Ward and Strganac, 1996). The majority of flight tests books are strictly related to General Aviation (Goraj *et al.*, 2012; Goraj, 2014), Passenger Transport Aviation (Goraj *et al.*, 2010a, 2010b) or military manned aircraft (Goraj and Baron, 2000; Goraj *et al.*, 2002; Goraj, 2014), whereas it is quite hard to find direct information about flight test techniques for unmanned aerial vehicles. Selected information based on personal experience related to UAV flight testing can be found in Goraj *et al.* (2010a, 2010b) and Galiński and Goraj (2004). UAV's flying quality evaluation can be significantly different than for manned aircraft due to the lack of stick force feedback, higher lateral, longitudinal and directional control sensitivities that are coupled with the relatively small size of the airframe and therefore small moment of inertia (Williams and Harris, 2002). The control method of UAV's (Atkins *et al.*, 2016) is also different than for manned aircraft. On board the GA (General Aviation) aircraft, the pilot is coupled with the airframe which allows him to feel and react on the slightest flight disturbances, whereas while piloting UAVs, the operator has to rely on FPV (First-person view, also known as remote-person view) cameras, onboard sensors or even eyesight contact during manual flight from the ground (Goraj, 2007).

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/1748-8842.htm**

Aircraft Engineering and Aerospace Technology
91/5 (2019) 720–727

[DOI 10.1108/AEAT-03-2018-0099]

Received 12 March 2018
Revised 12 March 2018
Accepted 3 April 2018

A popular method of determining the speed of descent for manned aircraft is the "Prop-feathered sinks" method (Kimberlin, 2003). It consists of carrying out a series of glide flights for different values of airspeed. During the flight, a series of climbs and descents is conducted with different speeds and within ± Δh from the selected flight level (Figure 1).

Speed of descent w (V) as a function of flight speed enables a speed polar graph to be constructed and is useful in finding important parameters including the best endurance and the best range speed. Moreover, the speed polar graph can help to find the dependence of the lift, drag and glide ratio on speed of flight (Roskam and Chuan-Tau, 1997). The polar graph is also the basis for determining the power required for flight (Figure 2).

Static and dynamic stability test techniques for manned aircraft are also well-known and widely described in technical literature (Kimberlin, 2003; Marques and Da Ronch, 2017). Although the physics of testing the stability is the same for manned and unmanned aircraft, the flight test techniques cannot be directly adopted.

The aim of this paper is to present the method for measuring glide performance on a small UAV. To achieve this goal, a set of flight tests has been conducted and therefore a real speed polar graph designated. The directional stability tests have been conducted to achieve the best configuration in terms of aerodynamic efficiency and performance. Flight test techniques have been developed based on modified manned aircraft flight test techniques.

Main section

As a part of the research and development work, flight tests of a "flying wing" aircraft were carried out (Galiński and Goraj, 2004). The tests were aimed at determining the speed polar graph of the aircraft in two aerodynamic configurations – with winglets and with classic directional stabilizers. The tests lead to the comparison of directional unstable and stable configuration in terms of a glide performance (Table I and Figure 3).

Figure 1 Flight path during test flight and speed polar graph

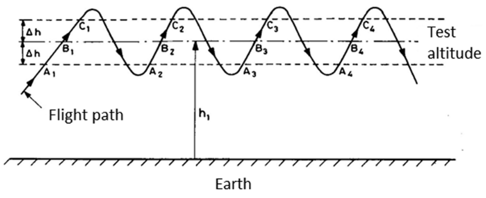
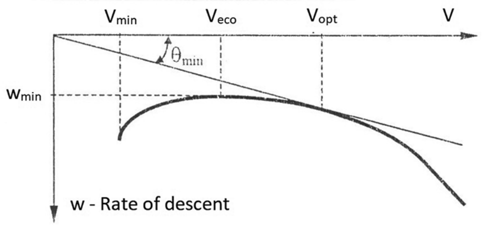


Figure 2 Typical speed polar graph with a number of characteristic points: V_{min}, V_{eco}, V_{opt}, w_{min}



First, a set of static and dynamic stability flight tests of each aerodynamic configuration was conducted, (Wolowicz and Yancey, 1972a, 1972b). Directional stability was the main factor measured during the flights, (Nelson, 1998; Napolitano, 2012). Comparison of the measurements registered in the flight tests (Tomaszewski, 2018) are described in Figures 4-6, for the configuration with winglets on the left side in Figures 4-6 and for the stabilizers on the right, respectively.

As it can be seen in Figures 4-6, the yaw displacement, speed and acceleration are much smoother in the configuration with stabilizers. The amplitude of oscillation of yaw is almost four times smaller for the configuration with stabilizers than that for the configuration with winglets. In the case of acceleration, the amplitude of oscillation for the configuration with stabilizers is up to six times smaller than that of for the configuration with winglets. Poor directional stability of the configuration with winglets creates difficulties when the aircraft is controlled manually. It must be emphasised that high frequency oscillations dissipate the kinetic energy of the aircraft and in this way decreases the speed of the aircraft and in consequence decreases the glide ratio. Moreover, this phenomenon can be understood as a coupling between lateral and longitudinal dynamics.

In the next step, the glide ratio for all UAV configurations being considered was performed. A set of sensors and autopilot were installed onboard the aircraft. The role of the autopilot is essential in performing long descent flights where it is necessary to maintain a stable flight path. Telemetry sensors installed onboard sent the flight parameters to the RC transmitter online and at the same time were recorded for redundancy. That allowed the duplication of the sources of the data and therefore reduced the possibility of gathering faulty measurements (Ward and Strganac, 1996). The most important sensors installed onboard the aircraft can be seen in Table II.

The speed polar graph allows the optimal speed (best range), the economic speed of the aircraft (best endurance, being associated with the lowest descent speed, w_{min}) and assessment of the power required for the flight (Kimberlin, 2003) to be found. This is the basis for choosing the optimal power unit and determining the flight endurance.

Table I Basic data of the aircraft (Flying wing configuration made of glass/carbon fibre composite)

Parameter description	Value, unit
Wing span	3.2 m
Length	1 m
Height	0.6 m
Wing area	1.1 m^2
MTOW	12 kg
Aspect ratio	9
Wing loading	10.90 kg/m^2
Design manoeuvring speed V_A	35 m/s
Stall speed V_S	16 m/s
Cruise speed V_C	22 m/s
Never exceed speed V_{NE}	55 m/s

Figure 3 Aircraft aerodynamic configurations – winglets and stabilizers

Figure 4 Comparison of the Yaw angles corresponding to configurations with winglets and with vertical stabilizers, both measured during the flight

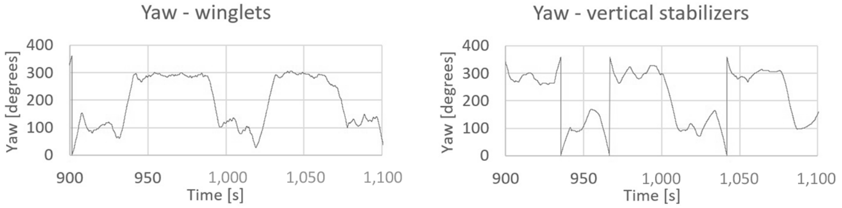


Figure 5 Comparison of the Yaw speed corresponding to configurations with winglets and with vertical stabilizers, both measured during the flight

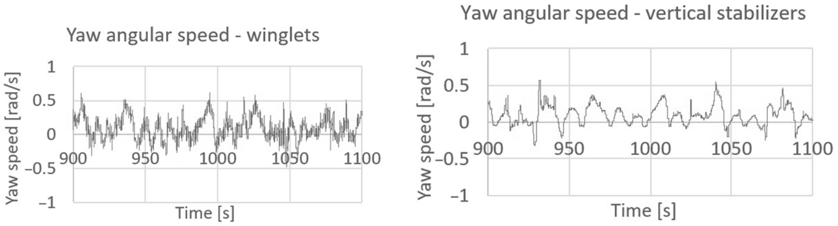


Figure 6 Comparison of the Y acceleration corresponding to configurations with winglets and with vertical stabilizers, both measured during the flight

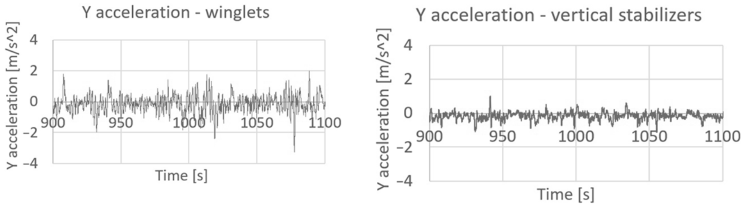


Table II Sensors installed on-board of the aircraft

Sensors	Autopilot	Telemetry
Accelerometers	X	
Gyroscopes	X	
GPS	X	
Barometer	X	X
Total pressure	X	X
Surface movements	X	X
Engine RPM		X
Current		X
Voltage		X
Outside temperature		X
Energy drained from batteries		X

Therefore, it is important to make a set of flight tests to assess the actual speed polar graph.

The authors decided to investigate the aircraft's speed polar graph in both configurations (one with stabilizers and the second one with winglets). In all of the tests, the propulsion (power and thrust) and total weight remained unchanged. A series of descent glides (with thrust equal to zero) were performed, each time changing the position of the height trimmer (the so-called height trimmer involves a deflection of the elevator in order to keep the hinge moment equal to zero), which allows data logging of several measurement points for each airspeed and corresponding elevator deflection. The measuring points cover the range from the speed close to the stall speed equal to V_s to the design manoeuvring speed equal to V_a. Finally, the comparison between the performance of both configurations was made. The parameters of the glide line are defined as follows: start altitude: 300 m; end altitude: 100 m and finally the glide line length: 600-1300 m.

One flight, covering the entire speed range takes about 40 min, see an example in Figure 7. During these flights, the aircraft was automatically stabilized by autopilot; otherwise, it would not be possible to maintain a stable flight in such a long glide distance.

A warm summer day with cloudy weather was selected for the measurements. The measurements were carried out two times a day. The first flight series took place around noon, between 11.00 and 13.00 and the second in the evening, between 17.00 and 19.00. This minimized the impact of atmospheric conditions on the measurements. During flights in the summer season, thermal gusts are a common problem (Done, 2010; Hoblit, 1988), which can significantly affect the value of the measured descent speed (Mohamed *et al.*, 2014a, 2014b; McCormick, 1979). Gathered flight parameters passed a preliminary "quality" control. In the curves of flight speed versus altitude in relation to time, a correlation can be observed between the speed and the gradient of the altitude curve. The higher the flight speed, the steeper the altitude curve is (higher descent speed, steeper flight path angle) (Figure 8). This is a basic verification that indicates if the recorded data have a physical sense. The polar speed chart is not linear, so that the tendency is reversed between minimum and optimal speed. It is worth investigating first what the minimum speed of the aircraft is. That will show in what region of a polar curve the glide flight was conducted.

In the next step, the so-called "measurement points" that are placed on the polar graph are determined. Determining the time interval, in which the measured parameters are to be stabilized, is done next, (Corda, 2017). For General Aviation airplanes, it is recommended that the aircraft should fly for at least one minute before making any measurements (Ward and Strganac, 1996). In the case of unmanned aircraft, the determination of the time interval (time interval might be defined as the period of time corresponding to both the constant airspeed gradient and the constant altitude gradient, see Figures 8-9) should be found for each individual glide flight. Usually, it relates to the end of the glide line, during the last 10 s of the glide flight (Figure 9).

On the graph in Figure 9, the arrows mark the segments for which the determination of the measurement point is subject to a large error. In the first case, the value of the speed of the flight is not stabilized yet, and which may be caused by an insufficient length of the glide line. In the second case, there is a disruption of the descent rate (the aircraft even began to climb for a moment). It might be caused by a sudden thermal gust. Such erroneous points should be removed from the list at the very beginning, but even their omission should be visible later in the form of points that significantly differ from the others, "falling out" from the range of the smooth polar graph line.

Knowing the limits of the flight sections with stabilized flight parameters and the absence of external interference, the measuring point can be determined. The flight speed is determined as the average of the speedometer's indications in a given time interval, while the descent rate is assessed as a derivative of the height with respect to time according to the following formulas:

$$V = \frac{\sum_{1}^{n} V_n}{n}; \quad w = \frac{H_1 - H_n}{\Delta t}$$

Measurement points collected for both aircraft configurations (winglets and stabilizers-fins) have been placed on the graph (Figure 10).

Two points are marked in Figure 10 that stand out from the others. These points are probably influenced either by

Figure 7 Record of speed and altitude during a polar graph measurement flight

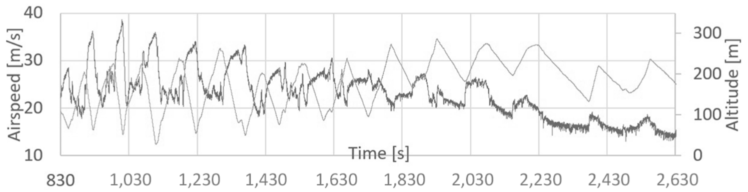
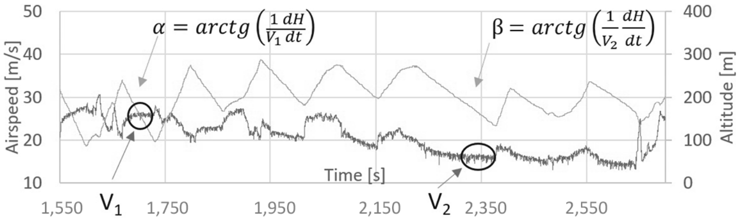
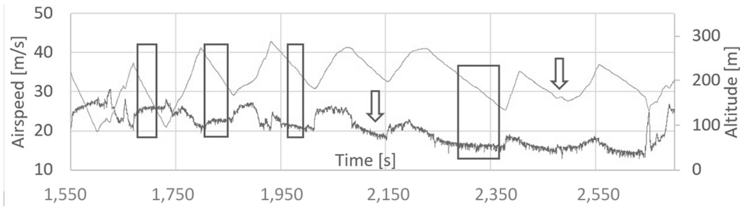


Figure 8 Dependence flight path angle on airspeed



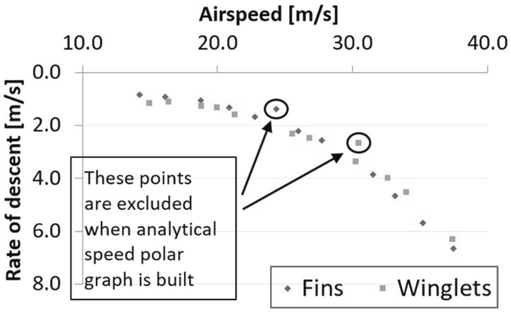
Notes: Airspeed curve is drawn in blue, altitude curve in red. Airspeed $V_1 > V_2$, flight path angle $\alpha > \beta$

Figure 9 Selected areas from which measurement points can be determined



Notes: In each time period inside the rectangles the airspeed and rate of descent have constant gradients versus time. Two arrows indicate the areas where neither airspeed gradient (first arrow) nor altitude gradient (second arrow) can be considered as constant

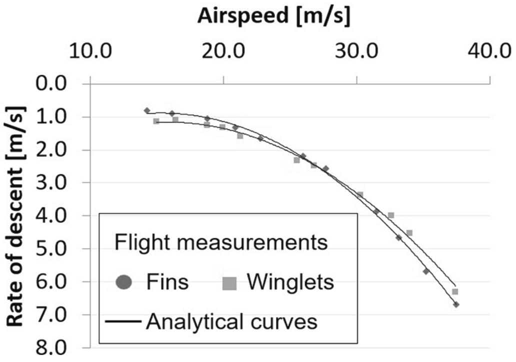
Figure 10 Speed polar graph designed basing on a number of points obtained from flight measurement



measurement errors or thermal gusts (Done *et al.*, 2011). Such erroneous points must be identified early at this stage and removed from the set of correct points. However, if left then their presence might have a big negative impact on the shape of the final graph. In the next step, a line of trends in the form of a second degree curve is constructed. As a result one can compare the speed polar graphs for configurations with fins and winglets (Figure 11).

The line of trends in the form of a second degree curve is a quite good approximation of the current polar graph of the aircraft. The resulting quadratic equations form the basis for further analysis of the aircraft's performance.

Figure 11 Speed polar graph as a second-degree polynomial curve approximated basing on a set of directly measured in flight



From the curves in Figure 12, it can be noted that the configuration with winglets is generally worse than that of the configuration with fins. It can be noticed that for speeds above approximately 27 m/s the angle of attack is small enough and the flow is stable enough (one can assume that at the higher Reynolds number the flow is less turbulent). In consequence, the lateral and directional stability will improve slightly and winglets will perform their stabilizing function a little bit better. At relatively small angles of attack, the induced drag is also small, and therefore the use of winglets as vortex destroyers is unjustified. The winglets at the speeds above 27 m/s are useless and vortex drag is negligible. So, at small angles of attack (i.e. at high speeds), the parasitic drag is the main component of drag while induced drag is the main component of the drag in the range of low flight speeds, i.e. at high angles of attack (Raymer, 1999) (Figure 13).

It is widely assumed that winglets improve aircraft performance by reducing induced drag. However, this is not so obvious, as it is very hard to design winglets that would be effective over the whole range of angles of attack (Gudmundsson, 2014; Keane *et al.*, 2017). Use of winglets as directional stabilizing surfaces sometimes is not effective, especially in the case of small backswept wing. All of that makes winglets a very difficult element to design and often greater benefits can be obtained by designing a traditional vertical tail, which will provide greater directional stability and thus better performance (Sadraey, 2017).

Figure 12 Polar graph for winglet and fins configuration, corresponding to aircraft weight equal to 9.8 kg