A CONCEPT OF UNAMNNED FLYING LABORATORY FOR UNIVERSITY APPLICATIONS

Cezary Galiński	Mirosław Rodzewicz	Bogdan Hernik	Jarosław Hajduk
IAAM	IAAM	IAAM	AFIT
Nowowiejska 24	Nowowiejska 24	Nowowiejska 24	ul. Księcia Bolesława 6
00-665 Warszawa	00-665 Warszawa	00-665 Warszawa	01-494 Warszawa
Poland	Poland	Poland	Poland
cegal@meil.pw.edu.pl	miro@meil.pw.edu.pl	bhernik@meil.pw.edu.pl	jaroslaw.hajduk@itwl.pl

Abstract. This paper describes the concept of small unmanned airplane designed for research and educational purposes in the university. It should be inexpensive and easy to operate both on the ground and in flight. On the other hand it should provide training possibilities in areas of flight testing and autopilot operations. Moreover in-flight research opportunities should be provided by this airplane. In particular smart structures experiments would be desirable. The paper contains detailed requirements specification and analysis. Most interesting experiments are also listed and described. The concept of the airplane is proposed on this basis together with modifications necessary to perform certain experiments.

Keywords. UAV, smart structures, flight testing.

1 Introduction

Literature from recent years reveals growing interest in application of smart technologies in aeronautics. Smartness is understood as ability to automatically sense the environment conditions, analyze measured values, react and store the information in closed loop. New technologies like MEMS (Micro-Electro-Mechanical Systems) and solid state actuators technologies are to be used to achieve these abilities. Applicability of these new solutions extends from aerodynamics, through structural health monitoring to anti-icing systems.

1.1 Concepts description

Aerodynamic improvement is one of the most efficient methods of increasing aircraft effectiveness. It allowed increasing payload, range, speed and maneuverability of early designs. Later on it was used to decrease costs of commercial airplanes fleet thanks to vast fuel consumption savings due to the streamlining and drag reduction. Currently it can make airplanes more environment friendly since every decrease of the aerodynamic drag results with smaller fuel consumption and greenhouse gases emission.

Several smart technologies were proposed for aerodynamic enhancement, among them application of MEMS devices for drag reduction and lift enlargement. Submilimeter dimensions of MEMS systems as well as their easy integration with electronic control systems provide a unique opportunity to influence the boundary layer directly and “just on time” [1-6]. Lift can be increased due to the separation delay. It can be achieved by introduction of vortical flow generated by movable micro vortex generators or temporary artificial roughness increase due to synthetic jets or silicon micro bubbles raised from the otherwise flat aerodynamic surface. These methods can be particularly effective if applied in combination with standard high lift devices since they can be further deflected without separation. Increase of lift in high lift configurations allows for the wing area reduction and resulting drag reduction in high speed configurations. Artificial roughness increase can be also useful to enforce laminar/turbulent flow transition when disadvantageous phenomena like laminar bubbles or separation in laminar layer are probable. Micro-devices listed above can co-operate with micro-sensors’ matrices, so they can by applied only when needed thus enabling active flow control. MEMS-pulsed jet actuators or micro-pumps are also considered as devices reducing the drag in the turbulent boundary layer, since they can suck in or blow up low speed streaks existing between randomly occurring near-wall contra-rotating stream-wise vortices. This task however requires perfect co-operation of micro-actuator matrices and micro-sensors matrices combined with vast computational capability. Some sources suggest that the drag reduction can be also achieved by application of compliant coatings [7]. Furthermore adaptive structures driven by solid state (e.g. SMA, piezoelectric, etc.) actuators [8, 9] can be applied to optimize the aerodynamic surface shape to the current flight conditions [10-13]. This allows for reduction of conventional high lift or control devices thus providing an opportunity for the flow laminarization. Finally there are a few unconventional approaches to the high lift devices including vibrating and rotating elements. All of them are worth consideration.

Many issues can influence the safety of aerial vehicles. Among them icing and fatigue belong to the most critical ones. They are considered as frequent reasons of catastrophic events in aviation. In both cases smart solutions were proposed.

In the case of icing, there are two areas of possible smart devices applications: icing detection and measurement and deicing. There are well known conventional solutions in both cases. Current research in the area of ice detection and measurement is directed to the devices miniaturization which allows increasing the number of measurement points and improving the flow laminarisation in the same time. Several MEMS ice detectors are currently developed and tested [14, 15]. Miniaturization of ice detectors should allow increasing amount of information about icing and simultaneously decrease disturbances of the flow caused by the sensors installation.

There are also smart solutions proposed for deicing devices [16]. As an example SMA materials are considered for leading edge skin. Rapid shape changes due to martenzite transformation induced by temperature modulation can effectively break the ice thus enabling the ice removal by aerodynamic sources. Method is similar to the conventional ice breaking by rubber tubes installed on the leading edges of aerodynamic surfaces. Major advantage of the smart solution lies in the device durability. Nitinols are known as materials with high live time under fatigue loads as opposed to the rubber which is sensitive to both environmental conditions and time.

Piezoelelectric actuators can also introduce vibrations to the leading edge skins, thus breaking the ice. However this may decrease fatigue live time of the leading edge skins. Composites are known to have long fatigue live times so epoxy composite reinforced by conventional and piezoelectric or SMA fibers seems to be an interesting candidate for deicing device.

There are also proposed smart solutions in the area of structural health monitoring based on MFC (Micro Fiber Composite) application [17-19].

1.2 Experimental methods

Unfortunately most of these concepts are currently tested only in the laboratory environment which does not allow to asses fully their utility value in real conditions. Therefore some experiments in flight would be very useful.

IAAM has extensive experience in building experimental flying vehicles. The whole family of manned gliders and motorized gliders were designed and build at the Faculty [20]. Two of them (PW-5 and PW-6) are currently in serial production. More than 300 PW-5's are flying all over the world. Prototypes of these vehicles are still in use by IAAM and co-operating entities for research and educational purposes. PW-6 prototype is the best example of this activity (Fig.1) since flying wind tunnel was installed on it to explore new airfoils' characteristics in real environment, real air turbulence in particular [21]. The concept appeared to be useful, however it is quite difficult to use. Every modification to the relatively large manned vehicle has to be negotiated with aeronautical authorities since human live is exposed to the risk. Therefore it is useful for final tests rather than for research purposes. Smaller, unmanned aircraft would not require as many official efforts so it could be used almost on daily basis.

Figure 1: PW-6 EB flying laboratory

IAAM and AFIT have also an experience with research conducted on unmanned vehicles (Fig.2). A few of them were built as dynamically scaled models to explore flight qualities of full scale vehicles [22]. Among these projects, our participation in NACRE programme is the most impressive since large (140kg) twin-jet model of the commercial aircraft was built. Several prototypes of reconnaissance UAVs were also designed and built.

Each of these airplanes could be used as flying laboratories; however each of them was build for certain requirements, so they may not allow running the research in all interesting areas. Some of them are too small to test e.g. airfoils in interesting Reynolds numbers envelope and have too small payload for research equipment. Others are quite large and require full size airfield with a range for testing. Therefore a new airplane would be useful, designed particularly for smart technologies testing. The airplane itself should be conventional and poses conventional flying qualities (easy to control in radio control mode). It should be large enough to carry research payload and to test it in right conditions (Re numbers in particular). On the other hand it should be small enough for easy transport and operation from small, grass airfield (RC model club airfield). This would decrease the effort necessary to solve legal and other official issues. As a result operational costs would be minimized. The airplane should be also easily reconfigurable so that several different experiments could be run quickly one after another.

Figure 2: Some of the experimental UAVs designed, built and utilized by WUT [23] and AFIT

Airplane designed to fulfill these assumptions would be also very useful in the education process. It would be possible to teach safely how to conduct flight test programmes of real aircraft. Currently flight test methods can be presented to the students only during lectures in the classroom. As a contrary, an airplane described in this paper would provide an opportunity to conduct field laboratory exercises, where students could draw their own flight test programmes, participate in the flight experiment and process obtained data. Such an asset would be therefore very useful for young aeronautical engineers.

2 Aircraft design

2.1 Requirements

Flying laboratory should fulfill the following requirements:

1. Payload - 5kg
2. Various external and internal components should be easy to install to execute experiments. Their mass should be included in the payload
3. Estimated total takeoff weight should be in range between 15-20kg
4. Endurance – more than 1 hour
5. Minimum airspeed – less than 50km/h
6. Takeoff distance from grass runway – 50m
7. Three-cycle landing gear with front gear
8. Gasoline engine with power sufficient for climb rate more than 3 m/s
9. Easy to control in radio control mode
10. Easy to deploy by passenger kombi or minivan type car
11. Redundant control system
12. Propulsion system vibrations damping
13. Effective mufflers

2.2 General configuration and design

The requirements listed above suggest application of the conventional, high wing configuration with one engine and puling propeller (Fig.3.), since no long range reconnaissance tasks are predicted. Moreover it is possible to avoid highly populated areas when performing experiments. Assuming maximum lift coefficient of 1.3, wing area could be in order of 1,26m², which allows building a wing with span of 3,5m and chord of 0,36m. The wing can be sectioned into two parts. Suitable fuselage would have the length of 2m and horizontal stabilizer with span of 0,8m. Therefore after disassembly the whole aircraft could be contained in the luggage compartment of the kombi car, which is acceptable.

Propulsion system could consist of the motor like 3W-55i, 3W-56iB2 [24], Zenoach G62 [25] or similar.

Micropilot MP2028LRC [26] or similar autopilot could be used in the experiments where own autopilot design would not be available. It should be also possible to control the airplane remotely with conventional RC system.

The whole airplane could be build out of the composite materials (including both carbon-epoxy and glass-epoxy composites where suitable). The wing and empennage would be semi-monocoque with one composite spar and sandwich skins. The fuselage would have rectangular section with composite longerons in the corners, sandwich skins and frames in suitable places. Payload bay with suitable dimensions should be provided under the wing, near to the airplane's center of gravity. It should be also possible to install external payload bay below the fuselage for certain experiments. Fuselage would contain major components of the equipment except of servomechanisms. Servomechanisms should be installed near the certain control surfaces. Each control surface should be sectioned and driven by two servomechanisms for redundancy.

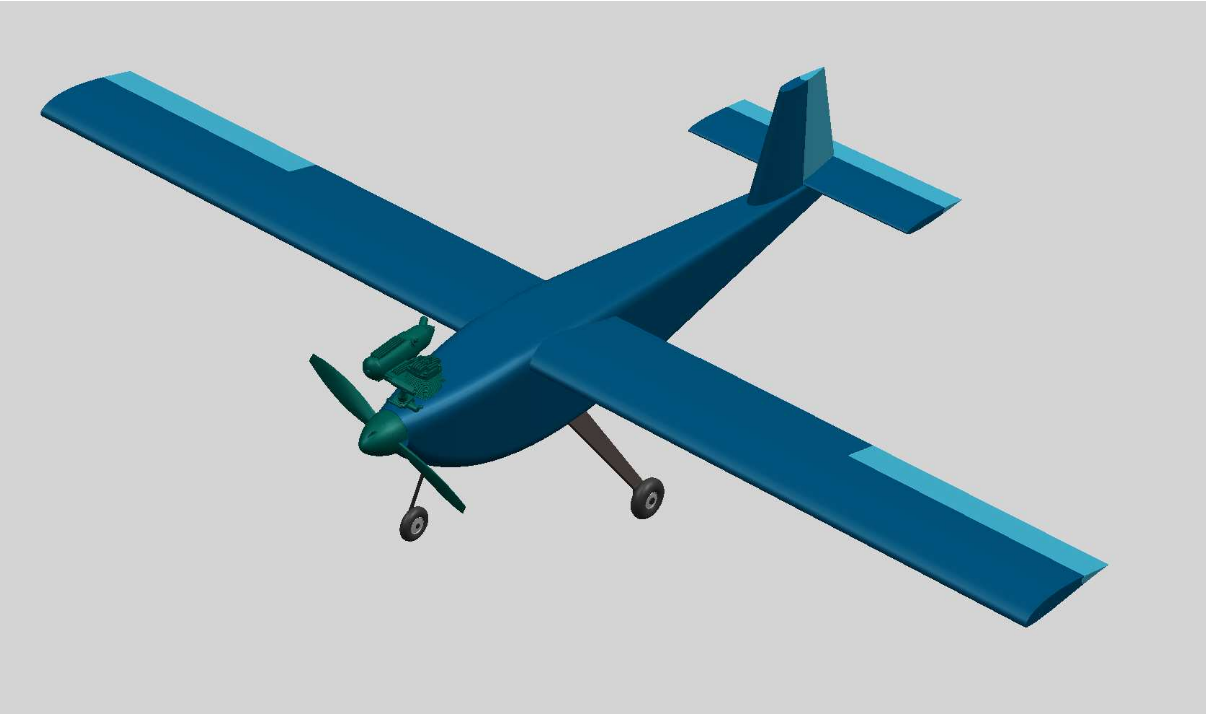

Figure 3: The concept of the UAV for smart technologies testing.

Connections between all components should be easy to disconnect so that they are easily disassembled for transport purposes as well as for exchange in the case of damage or certain experiment requirements. In particular there should be several different empennages build to maintain proper stability with different external components installed on the airplane.

3 Experimental functionalities

There would be several attachment ports provided for installation of certain experiments.

3.1 Control systems testing

The airplane would provide an opportunity to conduct research on flight control systems. Payload bay could be used for these experiments. Necessary connections to the power sources should be therefore available in the payload bay as well as connections to various sensors installed onboard of the airplane. There would be also possibility to install additional sensors as required.

3.2 Propulsion system tests

In this experiment airplane's standard propulsion system would be disassembled and replaced by experimental one. It would be also possible to install smaller engines on wings or on the pylon above the wing (Fig.4.). Installation on the pylon would require greater vertical stabilizer to provide sufficient directional stability.

Both electric and internal combustion engines are expected to be tested. Internal cargo bay would be used for measurement system. Also fuel cell can be installed in the internal or external payload bay. Wings can be covered by solar cells.

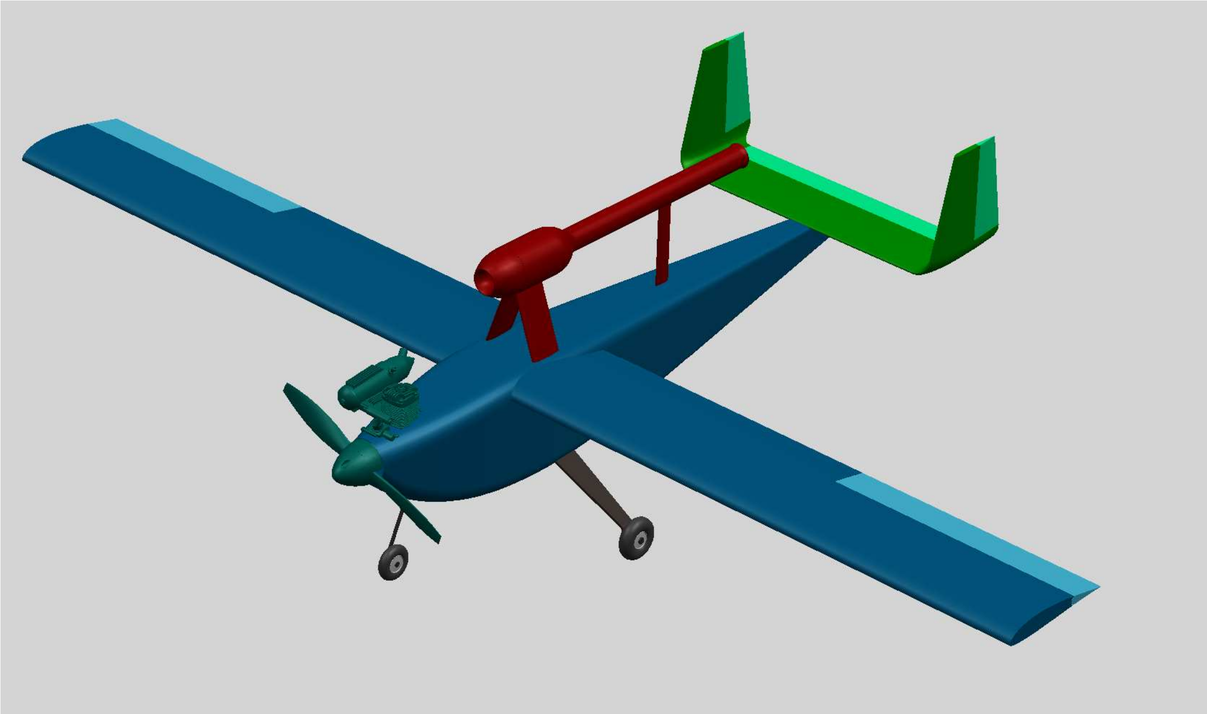

Figure 4: Experimental engine attached on the pylon.

3.3 Aerodynamic experiments

There would be three different attachment points for the installation of aerodynamic experiments: pylon above the fuselage, wingtips and the midwing sleeves.

3.3.1 On the pylon

Experimental aerodynamic surface with tip plates would be installed over the fuselage (Fig.5). This installation would allow for testing the airfoils equipped with various smart devices for quite small Re numbers. Installation would be quite easy since the pylon could be installed to the collars on the main wing, so it would be located directly above the payload bay. As a result all electrical connections would be short, easy and with the smallest possible electromagnetic interference.

The pylon would consist of the experimental aerodynamic surface, tip plates and a truss. Truss would connect remaining parts of the pylon with the airplane. Aerodynamic surface would contain the experiment. Tip plates would be installed on the experimental surface’s tips to simulate the infinite aspect ratio.

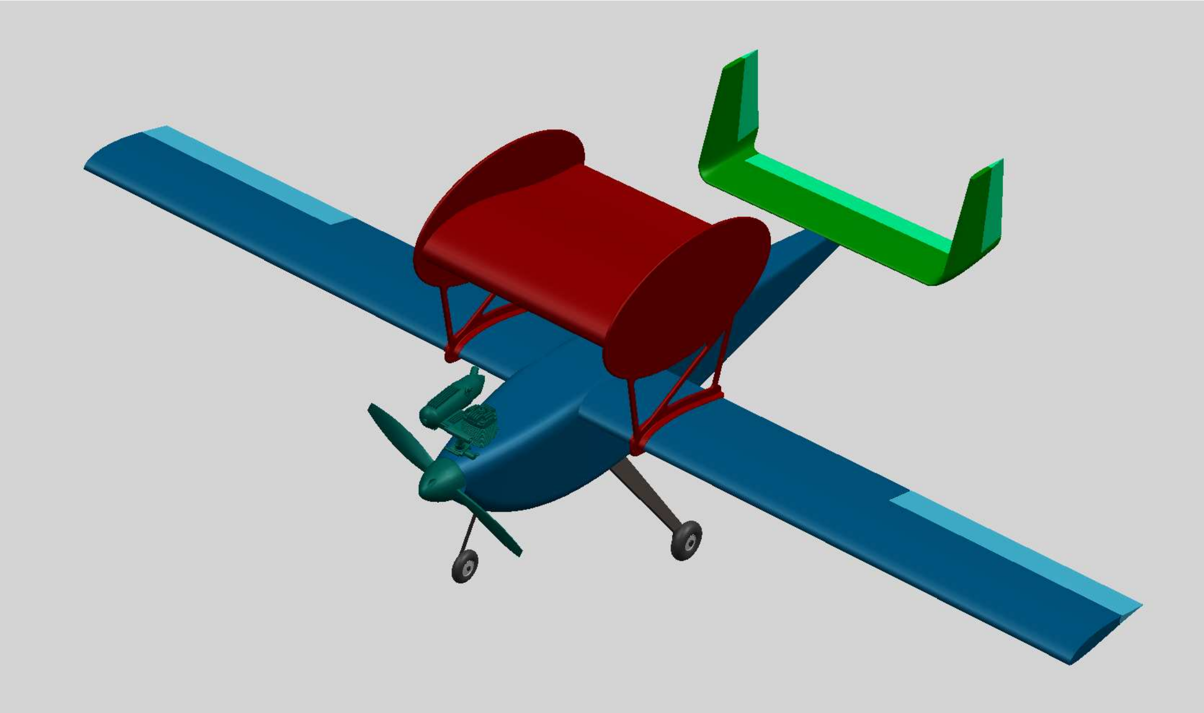

Figure 5: Experimental aerodynamic surface attached on the pylon.

Unfortunately this installation has the greatest impact on both airplane’s balance and stability. Therefore it is not possible to test large aerodynamic surfaces this way and even with small experimental surface, increased area of the empennage would be required with two vertical stabilizers on the horizontal stabilizer tips. As a result research for low Reynolds numbers would be possible in this case.

3.3.2 On the wingtips

Experimental aerodynamic surfaces would be attached to both wingtips (Fig.6.). This installation would allow for testing the smart systems designed for wingtips and winglets, since the flow similarity would be provided thanks to the same location on the wing. Reynolds number difference would not be too large since many full scale airplanes have tapered wings with quite short chords near the wingtips.

Other experiments possible in this case are connected with morphing wing concept. The constant variability of an airfoil shape is envisaged here to control the airplane and/or to modulate the lift generated by its wings.

This installation requires long electrical connections with a data acquisition system in the payload bay, so electromagnetic interference is possible thus requiring efficient filtration of measurement signals. It also has a great impact on the airplane’s stability so increased empennage will be also required; however single vertical stabilizer will be good enough.

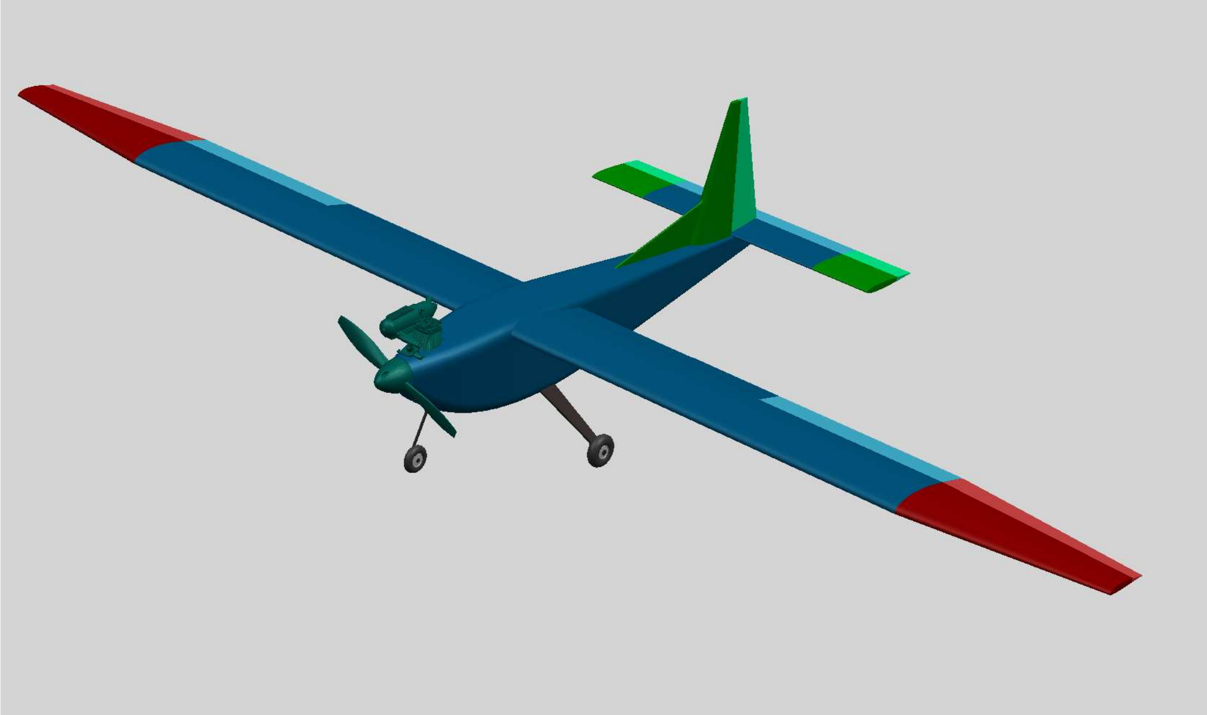

Figure 6: Experimental aerodynamic surfaces attached on the wingtips.

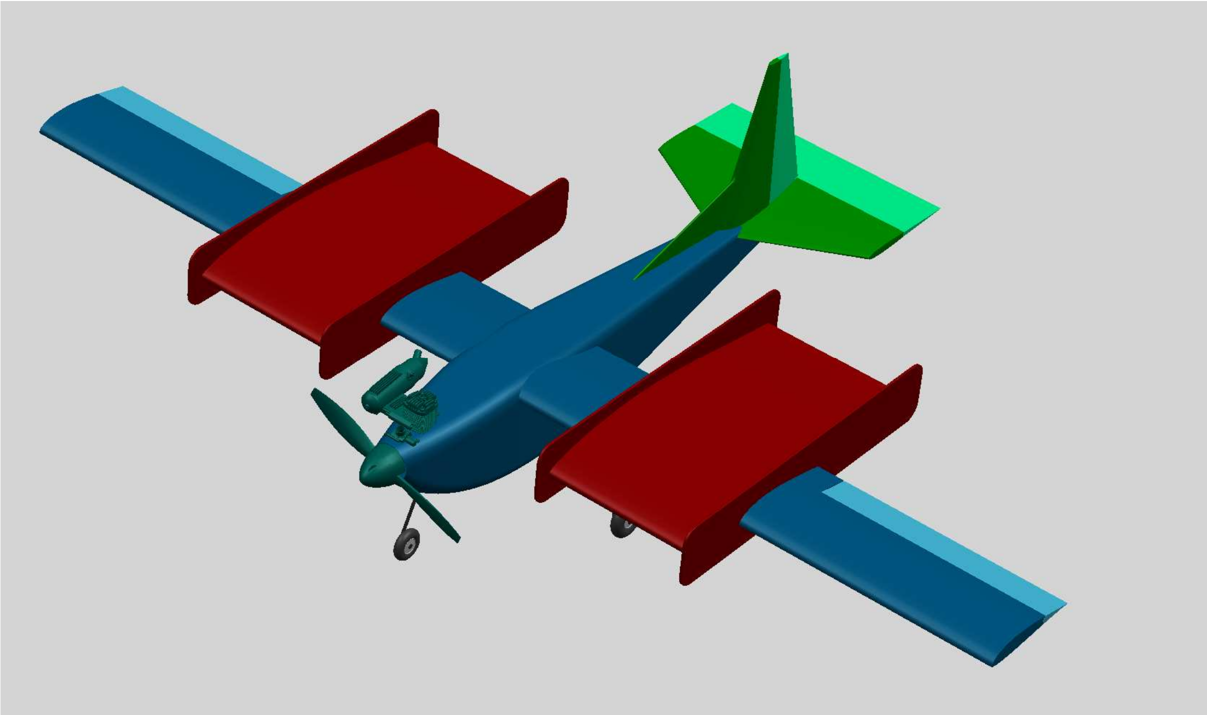

Figure 7: Midwing sleeves as an experimental aerodynamic surfaces.

3.3.3 Midwing sleeves

Experimental surfaces with tip plates would be designed as a sleeves attached to each wing approximately in the middle of its span (Fig.7.). This installation has the smallest impact on the aircraft balance and stability, so assuming application of increased empennage, aerodynamic surfaces with the longest chords can be tested. As a result highest Reynolds numbers would be enabled in this case.

Quite long electrical connections with the data acquisition system in the payload bay would be also required in this case. Therefore, as previously, electromagnetic interference is possible thus requiring efficient filtration of measurement signals.

3.4 Anti-icing testing

Icing would be induced by cooling the sample with liquid nitrogen and subsequent spraying the water. The anti-icing system should then detect the presence of the ice and activate the deicing devices. Effectiveness of the anti-icing system could be monitored with application of the TV system.

Experimental winglet would be installed on a top of the fuselage, vertically, behind the wing, so that liquid nitrogen installation, power sources and control system accommodated in the payload bay would be easily available (Fig.8.). Sprinklers will be installed on a top of the fuselage, vertically in front of the wing, so that the water spray could cover the experimental winglet easily. TV cameras would be installed on both sides of the sprinklers to observe the experimental winglet from both sides. Empennage with two vertical stabilizers installed on the horizontal stabilizer's tips would be suitable for this experiment so that the ice could not cover the vertical stabilizer.

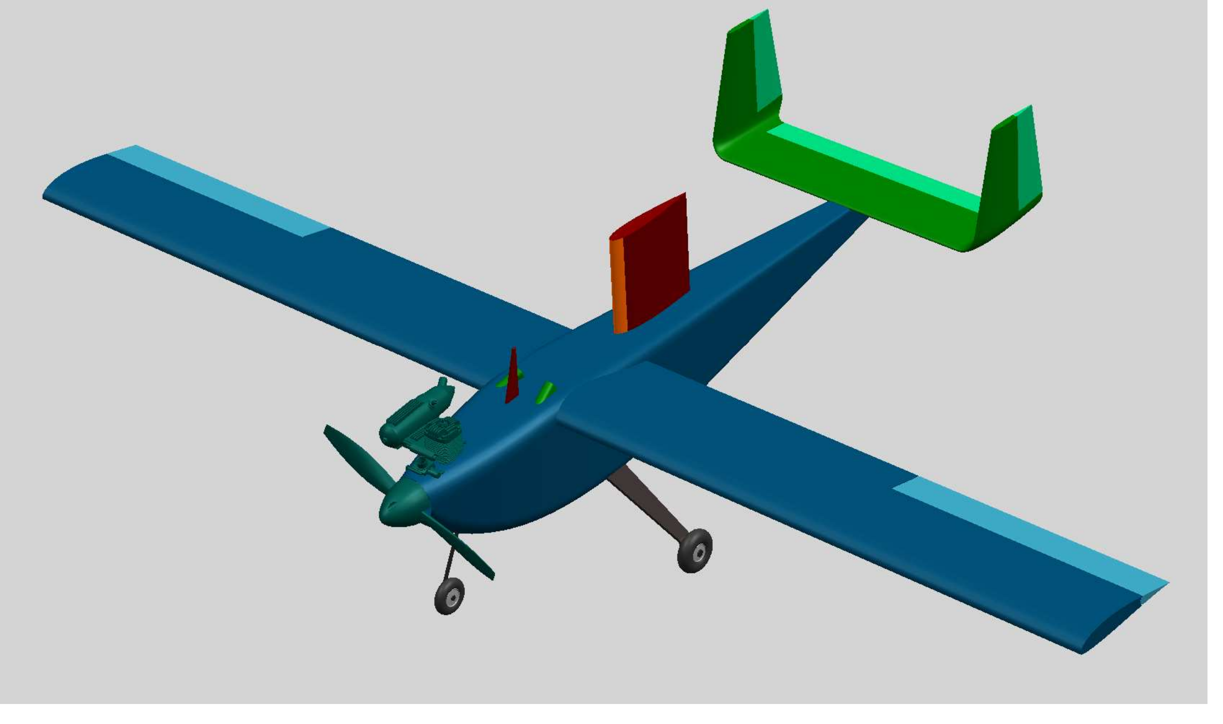

Figure 8: Anti-icing experiment installation.

3.5 SHM testing

As a demonstrator of this technology separate composite test wing would be built. In the course of the experiment, step change of the wing stiffness would be introduced in controlled way. This change should generate a small structural damage under flight loads. Damage size and location would be measured by MFC fibers rosettes. The information would be then

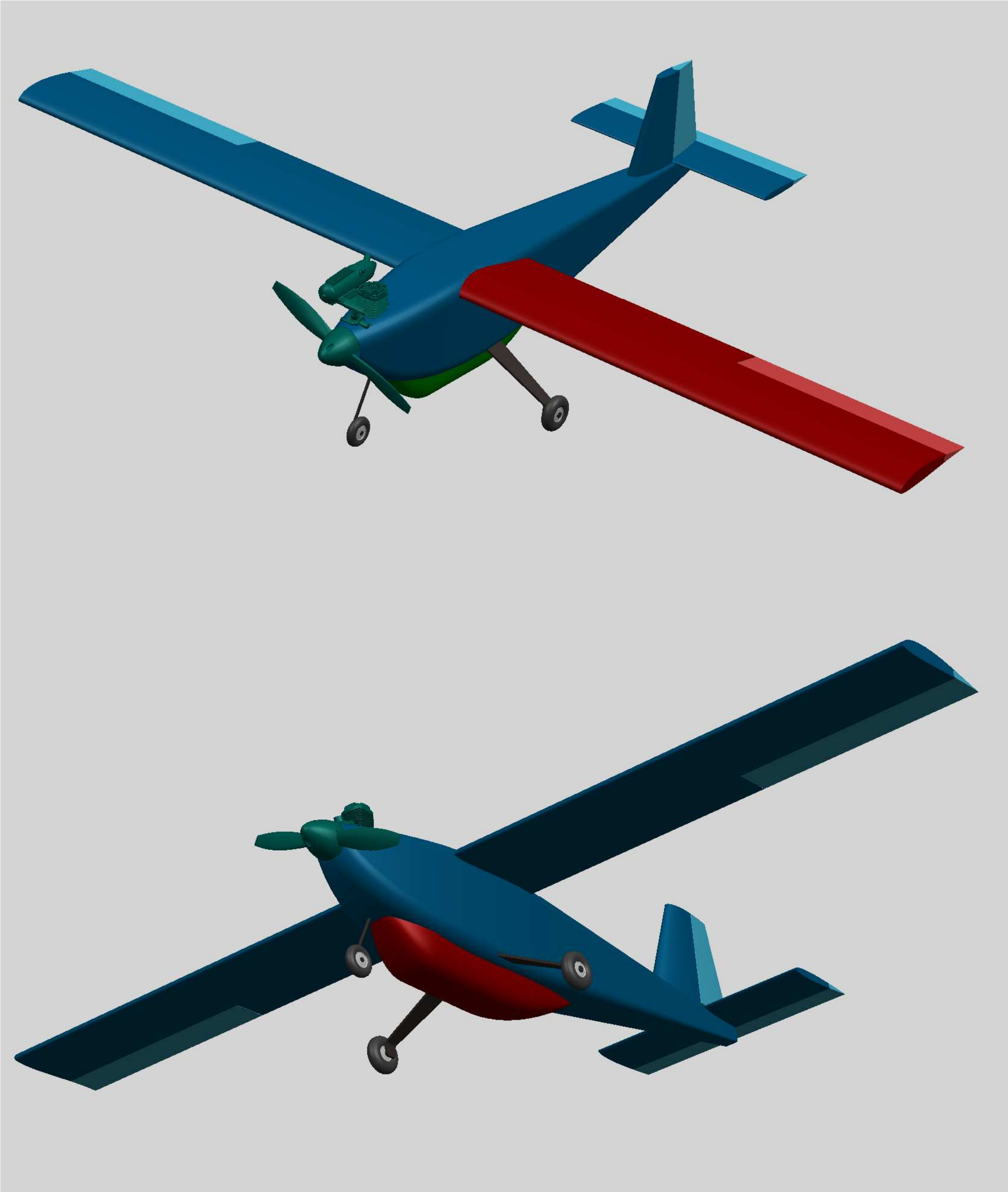

Figure 9: Experimental modifications necessary for SHM experiments.

transmitted to the Earth surface and analyzed. Post-flight verification would be conducted by conventional NDT method with application of ultrasonic defectoscope.

Experimental wing would contain the mechanism allowing for its stiffness modification in flight and experimental structural health monitoring system. Data acquisition system would be contained in the payload bay. The wing should be designed so that stiffness modification performed in the flight would cause minor damage of the wing structure. SHM system would be expected to detect this damage and asses the strength left. Results of the SHM system activity would be checked after flight in the laboratory.

Parachute system should be installed onboard of the airplane to protect it in the case of major damage of the wing during the experiment. It could be stored in the external payload bay below the fuselage (Fig.9.), so that parachute deployment can be facilitated by gravity forces.

3.6 "Robotic parachutes"

Other types of experiments would be also possible. For example possibility to deploy robotic rescue systems by the UAV could be tested. Such a system could be particularly useful during massive natural disasters when vast populated areas are cut from supplies and information. Robotic systems could perform many different missions in such cases, from deployable sources of information to search for survivors.

Both external and internal payload bay could be used to test the possibility of such systems deployment. Robots would be stored in the external bay. They would be released in flight at the command from the ground station. Internal bay would contain communication equipment necessary to exchange data between remotely deployed robots and the ground station. Therefore the airplane would act as a source of transportation for robots and a data relay.

4 Conclusion

The concept of experimental UAV has been envisaged. It would be useful for various experiments with smart technologies in aeronautics, providing an opportunity to test them safely in flight. The aircraft would be also useful for students in flight testing exercises. Students could conduct their own flight testing programmes including preparation, execution and data analysis.

Acknowledgment

This work has been partially supported from the statutory funds of the Institute of Aeronautics and Applied Mechanics (grant "New research methods in Aeronautics").

References

[1] Gad-el-Hak, M.: MEMS, Boca Raton ; London ; New York : CRC Press,cop., 2006, 0-8493-9137-7

[2] Löfdahl, L., Gad-el-Hak, M.: MEMS applications in turbulence and flow control, Progress in Aerospace Sciences, vol. 35 (1999), pp. 101-203

[3] Warsop, C.: Results and Lessons Learned from the European AEROMEMS II Project, AIAA 2006-3503, 3rd AIAA Flow Control Conference, 5-8 June 2006, San Francisco, California

[4] Petz, R.: Active Separation Control on a High-lift Configuration by a Periodically Pulsating Jet, Paper 118 of the 24th International Congress of the Aeronautical Sciences, Yokohama 2004

[5] Greenblatt, D., Wygnanski, I. J.: The control of flow separation by periodic excitation, progress in Aerospace Sciences, vol. 36 (2000), pp. 487-545

[6] Segawa, T., Mizunuma, H., Murakami, K. Li, F. C.: Turbulent drag reduction by means of alternating suction and blowing jets, Fluid Dynamics Research, vol. 39 (2007), pp. 552-568

[7] Gad-el-Hak, M.: Compliant coatings for drag reduction, Progress in Aerospace Sciences, vol. 38 (2002), pp. 77-99

[8] Srinivasan, A. V., McFarland, D.M.: Smart Structures, Cambridge 2001, Cambridge University Press, ISBN 0-521-65977-9

[9] Bojarski, Z., Morawiec H. Z. Metale z pamięcią kształtu, Warszawa 1989, PWN, ISBN 83-01-09346-3

[10] Stanewsky, E.: Adaptive wing and flow control technology, Progress in Aerospace Sciences, vol. 37 (2001), pp. 583-667

[11] Kudva, J. N.: Overview of the DARPA Smart Wing Project, Journal of Inteligent Material Systems and Structures, vol. 15-April 2004, pp. 261-267

[12] Wagg, D.: Adaptive structures: engineering applications, Chichester 2007, John Wiley & Sons, ISBN 978-0-470-05697-4 (HB)

[13] Scherer, L. B., Martin, C. A., West, M., Florance, J.P., Wieseman, C. D., Burner, A. W., Fleming, G. A.: DARPA/AFRL/NASA Smart Wing Second Wind Tunnel Tests Results, NASA- 20040086766

[14] Gardner, J. W., Vardan, V. K., Awadelkarim O. O.: Microsensors, MEMS, and smart devices, Chichester 2001, John Wiley and Sons, ISBN 0-471-86109-X

[15] DeAnna, R.G., Mehregany, M., Shuvo, Roy.: Microfabricated Ice-Detection Sensor, NASA TM 107432

[16] Goraj, Z. An Overview of the Deicing and Antiicing technologies with Prospects for the Future, Paper 547 of the 24th international Congress of the Aeronautical Sciences, Yokohama'2004

[17] Murayama, H., Kageyama, K., Naruse, K., Shimada, A., Uzawa, K.: Application of Fiber-Optic Distributed Sensors to Health Monitoring for Full-scale Composite Structures, Journal of Inteligent Material Systems and Structures, vol. 14, January 2003, pp. 3-13

[18] Tsuda, H.: Ultrasound and Damage Detection in CFRP Using Fiber Bragg Grating Sensors, Composites Science and Technology, vol. 66 (2006), pp 676-683

[19] Volanthen, M., Foote, P., Diamanti, K.: Development of a Practical Optical Fibre System for Health Monitoring Composite Structures, Proceedings of 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, May 2006, pp. 6224-6233

[20] http://www.strona.net.pl/szybowce/

[21] Rodzewicz, M. The EB-2 Fly-Lab of the Warsaw University of Technology, Technical Soaring 2009, Vol. 33, No. 3, pp. 66-71

[22] Galiński, C., Bartkiewicz, P., Hajduk, J., Lamers, P.: Results of the J-5 Marco Dynamic Similar Model Flight Tests Program, SAE Paper No. 975551, 1997 World Aviation Congress, October 13-16, 1997, Anaheim, CA.

[23] Galiński, C., Hajduk, J.: Design Criteria for Military or Paramilitary UAV System for Dual Applications. Assumptions and Experiences, Paper 1 in RTO-MP-052 proceedings of NATO Symposium "Unmanned Vehicles (UV) for Aerial, Ground and Naval Military Operations", Ankara 9-13 October 2000

[24] http://www.3w-modellmotoren.com/

[25] http://www.modelflight.com.au/rc_model_accessories/zenoah_g62.htm

[26] http://www.micropilot.com/