2014 International Conference on Unmanned Aircraft Systems (ICUAS)
May 27-30, 2014. Orlando, FL, USA

A Low Cost Prototyping Approach for Design Analysis and Flight Testing of the TURAC VTOL UAV

Yucel Orkut Aktas[1], Ugur Ozdemir[2], Yasin Dereli[1], Ahmed Farabi Tarhan[1], Aykut Cetin[3], Aslihan Vuruskan[1], Burak Yuksek[4], Hande Cengiz[5], Serkan Basdemir[5], Mesut Ucar[5], Murat Genctav[5], Adil Yukselen[6], Ibrahim Ozkol[6], Metin Orhan Kaya[6], Gokhan Inalhan[7]

Abstract**—**

Over the last decade, the market share of civilian UAVs within the general UAV market has consistently increased. As such, these systems are increasingly being used for applications ranging from the monitoring of crops to the tracking of air emissions around high-pollution areas. Most of the civilian applications of UAVs require these vehicles to be of low-cost and for the portability and packaging to be easy while also having vertical take-off and landing capability. TURAC - a VTOL Tilt Rotor UAV with these capabilities - is designed. Although mathematical and CFD analyses were performed iteratively in order to optimize the design, testing in real life conditions were needed to see the real performance of the TURAC UAV. However, as with such an iterative design process, the manufacturing process costs, including different molds for each design, can be exorbitant. In addition, once an imperfection in the design is encountered, making radical design modifications on the UAV in real life is difficult and expensive. Therefore, a cheap, rapid, and easily reproducible prototyping methodology is essential. In this study, the end result of an iterative design process of TURAC is presented. In addition, a low-cost prototyping methodology is developed and its application is demonstrated in detail by explaining all of its phases. The ground and flight tests are applied on a fully functional prototype and the results are given.

I. INTRODUCTION

Nowadays, civil UAVs are actively utilized for civilian purposes such as the monitoring of traffic and wildlife and for conducting geological or mining research. UAVs with features such as vertical take-off, landing, and hovering capability, easy portability and the ability to work with different kinds of payloads have come into prominence. A civilian Tilt Rotor VTOL UAV with these features, namely TURAC, was designed [1]. As shown in Figure 1 during a hover test, TURAC UAV has one main co-axial rotor in the rear and 2 tilt rotors in the front. The design features of TURAC are shaped by the extensive background of the associated research group on various UAVs such as tilt-rotor VTOL UAV [1], tailless UAV [2], tailsitter UAV [3] and conventional fixed wing and rotary UAVs. We refer the reader to [1] for an extensive treatment of the civilian VTOL mini-UAV market and its needs, the potential advantages of the TURAC concept and how TURAC is positioned in terms of performances with regards to vehicles tailored towards similar operational concepts.

Figure 1 TURAC VTOL Tilt Rotor UAV

In the present paper, the design of TURAC VTOL UAV is explained briefly by referring to our first study [1]. The iterative design process with the contribution of CFD analyses is explained. Another study about mathematical modeling and CFD analyses [4] is referred for more details. The final sizing and configuration information and performance calculations are given in Section 2.

In section 3, a low-cost prototyping approach is introduced. The manufacturing process starts with the foam core body production in a CNC counter. Later, the vehicle frame is embedded in the foam core through aluminum profiles. After surface sanding and the cleaning process, the body foam with an aluminum vehicle frame is coated with epoxy resin and glass fiber composite materials.

Following our analysis, we converged on prototyping a ½ scale of the original vehicle as it was sufficient for

**This research is supported in part by the Republic of Turkey, Ministry of Science, Industry, and Technology SANTEZ Program Contract 1585.STZ.2012-2 and HAVELSAN A.S.

[1] Y.O.A., Y.D, A.F.T and A.V. are M.Sc. Students at the Istanbul Technical University, 34469, Istanbul, Turkey. (Corresponding Author e-mail: orktaktas@gmail.com)

[2] U. O. is a Ph.D. candidate at the Istanbul Technical University

[3] A. C. is a B.Sc. student at the Istanbul Technical University

[4] B. Y. is a Ph.D. student at the Istanbul Technical University

[5] K.D, A.E. and G.D.K are with the HAVELSAN A.S., M. Kemal Mah. 2120. Cad. No:39, 06510, Cankaya, Ankara

[6] I.O., M.O.K and A.Y are professors at the Istanbul Technical University,

[7] G. I. is an Assoc. Prof. at the Istanbul Technical University, Faculty of Aeronautics and Astronautics, 34469, Istanbul, Turkey (e-mail: inalhan@itu.edu.tr) and G. I. is the PI of the associated Research Project.

978-1-4799-2376-2/14/$31.00 ©2014 IEEE

representing the dynamic behavior of the original system and at the same time it gave us the flexibility to use COTS products in many subsystems. Section 3 also includes a detailed account of the integrations of such subsystems to obtain the ready-to-test TURAC prototype.

In section 4, the general architecture of the ground station and avionics system is reviewed. TURAC UAV includes different kinds of flight phases such as: hovering, transition from hovering to cruise and vice versa. Given the inherently unstable flight modes, TURAC UAV heavily relies on the autopilot hardware and algorithms [5-7] for flight. We refer the reader to [8] for more detailed information on the avionics and the ground station system used for TURAC [8].

In section 5, the test cases are established for both ground and flight tests. The tests on the ground include thrust, structural, mechanism and command-check tests, whereas the flight tests involve conventional takeoff and landing, vertical takeoff and landing, autonomous and transition flights. The initial results of the tests on both TURAC and its functional prototypes are illustrated.

II. DESIGN OF THE TURAC VTOL UAV

TURAC system has unique design features such as blended wing multi-copter hybrid design to have superior performance. System includes several major innovations in order to overcome VTOL challenges like thrust vectoring, transition flight and mechanical transformation from VTOL to CTOL flight. In consequence, a series of analyses and tests applied systems and subsystems to verify the design.

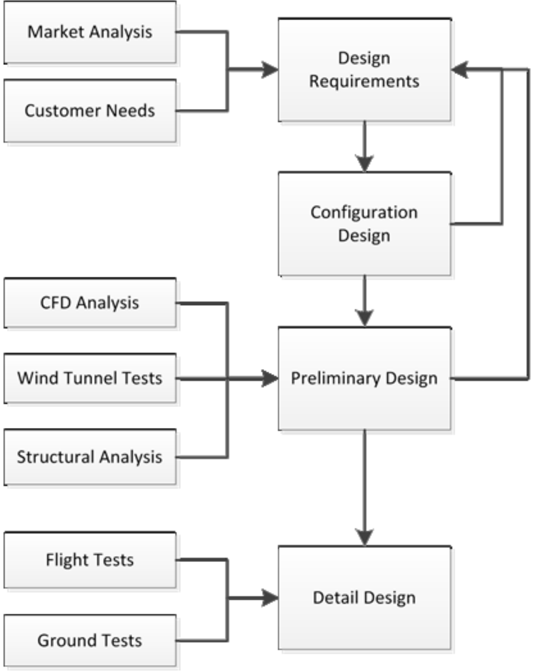

Figure 2 TURAC design process

Computer aided fluid, structure, and stability analyses were used to lower the development cost, but tests are indispensable for the aircraft development stage to confirm the analyses and design. System tests are one of the most critical stages of the TURAC design process, which can be seen in Fig. 2.

A. *Configuration and Sizing*

TURAC is a unique design that combines the hover flight capability of helicopters and the efficiency of conventional aircraft.

TURAC has a blended wing airframe with a coaxial main lift fan and a two tilt rotor electrical propulsion system. The aerodynamic efficiency of the system is enhanced up to 20% with a blended wing design in comparison with the conventional fixed wing aircraft design. [9] Therefore, the system does not require a runway or a complex launch system for take-off and landing. It has superior endurance to perform successful surveillance and mapping missions. Moreover, the TURAC UAV system uses an electrical propulsion system and this provides the aircraft with silent and efficient flight. The system configuration is:

- Blended wing multi-copter hybrid design,
- 2 Tilt rotor and one main coaxial lifting fan for VTOL operations,
- Winglet rudder hybrid design to reduce the structural weight and enhance aerodynamic efficiency,
- Electrical propulsion system for silent operations and superior propulsion efficiency,
- Tricycle retractable landing gear configuration for maximum ground control and reduced drag,
- Main lift fan doors for reduced drag,
- Redundant power and control system for safer civilian operations,
- High capacity rechargeable lithium polymer power pack for long endurance,
- Modular payload bay design for different missions,
- Attachable wings for easy transport and variable size wings for different operation requirements.

Some minor design modifications after aerodynamic and stability analysis were applied to the TURAC system to enhance the performance and stability of the aerial platform. The final design is tabulated as Table 1.

Table 1 TURAC final sizing results

TURAÇ SIZING RESULTS		
WEIGHT	MTOW	47 kg
	Structure	7 kg
	Avionics	5 kg
	Battery	22 kg
	Propulsion	5 kg
	Payload	8 kg
GENERAL SIZING	Length	1.8 m
	Wingspan	4.2 m
	Height	1.05 m
	Wing Area	3.36 m2
	Empty Weight	39 kg

	MTOW	47 kg
	Aspect Ratio	5.25
	Mean Chord	0.8 m
	Propeller Diameter	0.43 m
	Aerodynamic Center*	0.754275 m
	Center of Gravity *	0.709075 m
* Distance from the center chord's leading edge		
FUSELAGE	Center Airfoil	NACA 54115
	Tip Airfoil	NACA 54115
	Fuselage Length	1.8 m
	Fuselage Span	1.6 m
	Center Chord	1.8 m
	Tip Chord	0.58 m
	Taper Ratio	0.322
	Elevator Length	0.7 m
	Elevator Root Width	0.3 m
	Elevator Tip Width	0.16 m
WING**	Root Airfoil	NACA 54115
	Tip Airfoil	NACA 34112
	Chord	0.58 m
	Span	1.2 m
	Swept (LE)	10°
	Anhedral	5°
	Aileron Length	1 m
	Aileron Width	0.145 m
** Wing consists of 2 attachable parts, results for each part.		
WINGLET	Airfoil	NACA 04012
	Area	0.313 m2
	Length	0.634 m
	Swept (LE)	38°
	Root Chord	0.6 m
	Tip Chord	0.278 m
	Aspect Ratio	1.5
	Taper Ratio	0.397
	Rudder Length	0.5 m
	Rudder Tip Width	0.07 m
	Rudder Root Width	0.15 m
LANDING GEAR***	Height	0.421 m
	Front LG Distance	0.4 m
	Main LG Distance	0.897 m
*** Distance from the center chord's leading edge		

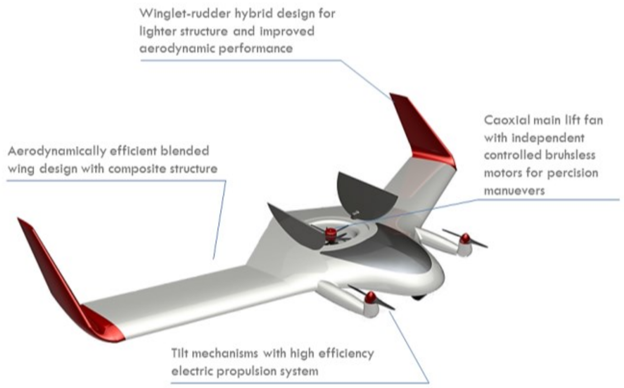

Figure 3 TURAC UAV design features

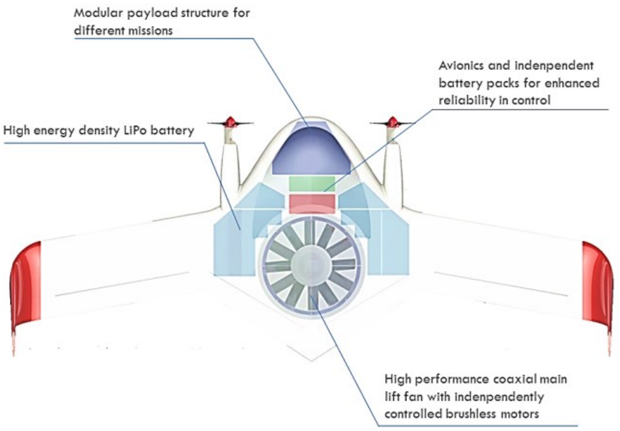

Figure 4. TURAC inboard design

B. *Modeling and Analysis*

One of the most important parts of the design is the main co-axial rotor which provides a bigger portion of the required lifting in the VTOL and hovering phases. Although the main rotor in the rear provides lifting, it is not active in the cruise flight. Therefore, the hole in which the fans are located causes some amount of aerodynamic ineffectiveness. Fan doors are thought of as a solution to recover this situation. The analyses related with this topic are performed in this section. Two cases are mentioned: 1) fan open and 2) fan closed. The Computational Fluid Dynamics (CFD) analyses are applied to both cases and the decision for which case is selected in forward flight is explained with reasons in the previous study [1].

Aerodynamic parameters of the TURAC for forward flight have been calculated by using CFD methods. Another goal of the project is defining the aerodynamic parameters for transition flight including the propeller effect [4]. There are four propellers: two of them are in the rear of the body and the rest of them are in front of TURAC as seen in Fig. 5.The rotors that are located in the front are tilted during the transition flight in Fig.5. The propellers are modeled as actuator disks to reduce the number of cells in the model. The angle of γ is determined as an angle between the vertical axis and the normal to the tilted actuator disk.

The angle of attack (α) and forward velocity are taken as 0˚and 20 m/s, respectively, in the analyses. When the speed of forward flight increases, the flow blown by propellers moves backward as clearly seen in Fig.6. In the transition flight regime, the flow field around UAV is in the effect of free stream velocity at higher forward velocities. In Figure 6, the streamlines go through the tilted propellers and then into the open part of the body. With respect to this, during the transition flight elevator will not have a high contribution to the stability of TURAC.

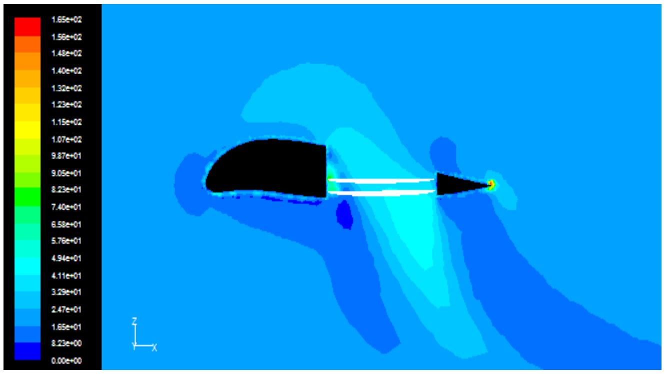

Figure 5. α=0˚, γ=45˚, V=20 m/s Velocity Contour on the Body Axis Plane

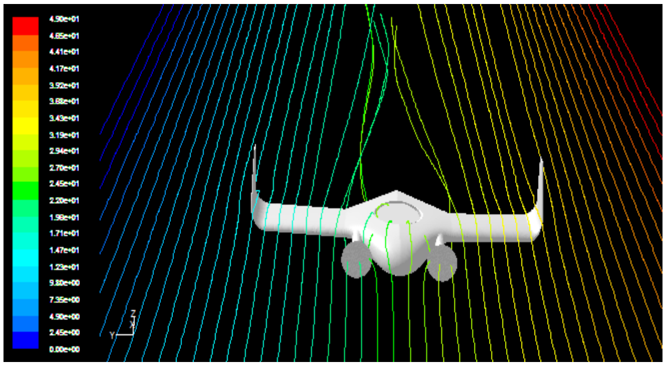

Figure 6. α=0˚, γ=45˚, V=20 m/s Pathlines

According to the mentioned CFD analysis, the lift coefficient (C_L) is 0.722, drag coefficient (C_D) including propellers thrust and TURAC's drag force is 0.002 and the pitching moment (C_M) is 0.105.

Mathematical representations of the flight modes of TURAC are obtained based on Newton's second law using the body axis system. In hover model, the equations of motion (EOM) are obtained for near hover conditions. Thrust and drag coefficients of the propellers are calculated using thrust test data. In the transition flight model, the tilt angle and angular velocity of the propellers are used as system inputs. CFD analysis is performed in order to obtain the aerodynamic coefficients of TURAC in various transition conditions. Each coefficient is modelled as a function of the airspeed and angle of attack. Aerodynamic forces and moments are calculated during simulation using the abovementioned surface function. Stability and control coefficients of the horizontal flight model are obtained using XFLR5 which runs based on the VLM method. After the linearization process of the nonlinear EOM of the horizontal flight, the dynamical characteristics of the longitudinal and lateral modes are studied [4].

C. *Performance*

The performance calculations of the finalized TURAC design are presented in this section. The propulsion system is the LiPo based electrical propulsion system that has more than 60% efficiency. [10] In addition, the hover optimized main lift fan with coaxial rotors and duct case dramatically increases the hover time related to conventional rotor systems. [11] The main performance parameters of the TURAC system are tabulated in Table 2.

Table 2 Main performance parameters for TURAC UAV

PERFORMANCE RESULTS			
Mission Profile		Thrust Distribution	
Starting Altitude	Sea Level	**1. Tilt Thruster**	15%
Mission Altitude	1000 m	**2. Tilt Thruster**	15%
Max. Altitude	4500 m	**Main Thruster**	70%
Endurance			
VTOL		CTOL	
Flight Mode	Time (min)	**Flight Mode**	Time (min)
VTOL	10	**VTOL**	none
Climb	7.5	**Climb**	7.5
Cruise	60	**Cruise**	180
Descent	7.5	**Descent**	7.5
TOTAL	85 min	**TOTAL**	195 dk
Speeds			
Range (V_{cruise})	25 m/s	**Max L/D**	12.47
Endurance (V_{loiter})	20 m/s	**Max. Climb Angle**	18.3°
Max (V_{max})	43 m/s	**Max. Rate of Climb**	6,27 m/s
Stall (V_{stall})	17 m/s	**Min. Sink Rate**	2.17 m/s

TURAC UAV is primarily planned to be used for civilian surveillance and mapping missions that require long endurance. For this reason, the minimum thrust and minimum power flight velocities of aircraft are calculated for long endurance and range flights. In addition, the maximum rate of the climb condition is an important parameter for mission planning and power management. Moreover, the maximum glide range must be calculated in case of emergency conditions such as propulsion system malfunction.

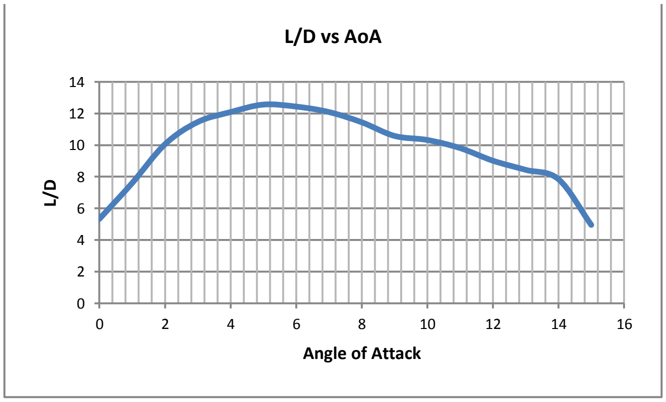

Figure 7 L/D related to the alpha (CFD results)

CFD results are used for performance calculations at the preliminary design stage in order to refine the design. The aerial platform is modeled on a computer and analyzed with CFD software with different speed and angle of attack conditions. The minimum required thrust condition is maximum L/D condition that allows the aircraft to fly at best endurance. Endurance calculations are generally used for UAVs to enhance mission success. Fig.7 shows that the maximum L/D ratio is an approx. 5^o angle of attack condition and that this is also the trimmed flight condition for TURAC UAV.

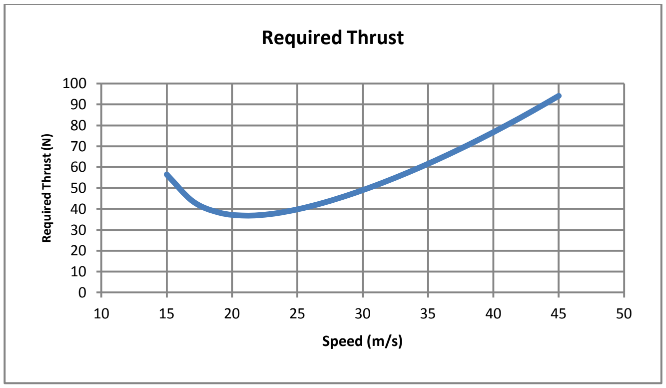

Figure 8 Required thrust related to flight speed

Required thrust is calculated and the results are shown in Figure 8. The stall speed of TURAC in conventional flight is 17 m/s. UAV missions are generally carried out for surveillance and it requires the maximum possible flight time. Minimum thrust speed allows the system to maximize endurance. Fig. 8 shows that TURAC's endurance speed is 20 m/s. Nevertheless, the minimum required power allows aircrafts to maximize their range. Therefore, the cruising speed of TURAC is 25 m/s. The maximum speed of TURAC, which is directly related to the maximum thrust available at a given speed, is 43 m/s.

The calculated performance parameters are used for enhancing the mission performance of TURAC with the fusing of these parameters with autopilot and a power management system.

III. PROTOTYPING OF TURAC VTOL UAV

Prototyping is one of the most important issues in the TURAC UAV development stage. All aerodynamic, structure, and system tests are applied on fully functional prototypes. Therefore, the prototyping process must be rapid and low cost in order to match the project schedule and budget. At the same time, the prototype must be fully functional to confirm the design and be durable enough to make several tests on one prototype. In addition, after an event such as a hard landing or crash, keeping the time to make new prototypes as short as possible, allows the project team to keep their focus and reduce the turnaround time for testing.

A. A low-cost Manufacturing Approach

A low-cost, rapid, and reproducible manufacturing approach is used for TURAC development. Some design changes and selections are made on the TURAC's ½ scaled version for rapid and low cost prototyping.

The ½ scale model provides enough dynamic similarity with the full scale system and it is easier to operate and manage. In addition, the scaled model allows the project team to use standard parts such as propellers, ESC, and brushless motors easily on local hobby stores. Prototype production utilizes COTS parts as much as possible to reduce the time, energy, and cost. This is in comparison to the original TURAC system that has numerous custom design parts such as landing gear and door mechanisms.

No molds are used in prototyping in order to reduce cost. Machine shop and CNC production in the university facilities is preferred for low cost production. Simple internal design is done to reduce the production time. Velcro and zip ties are used for fastening batteries, ESC, and electronic hardware.

A durable prototype design and manufacture are required to make several tests on one prototype. A foam core glass fiber composite design with an aluminum profile supported structure is used for making durable prototypes.

B. Manufacturing Process

Computer aided design is used in the design process. Moreover, all the technical drawings are done with CAD software. Therefore, the manufacturing process naturally starts with CAD outputs. The manufacturing process of TURAC scaled prototype is shown in Figure 9 and the prototyping sequence is photographed step by step and it is shown in Figure 10.

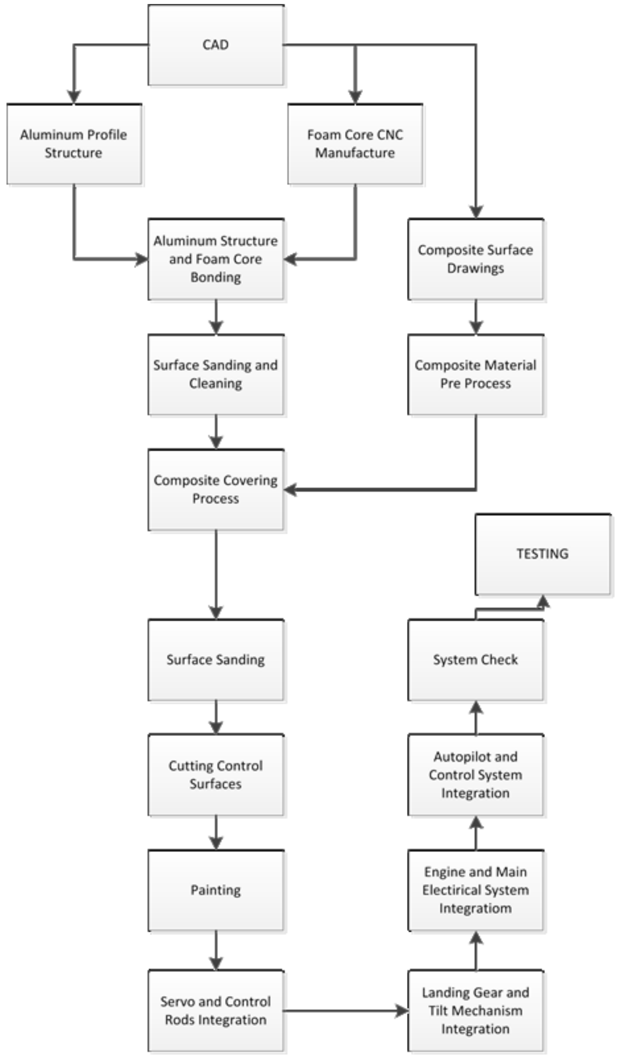

Figure 9 1/2 scale TURAC prototype manufacturing process

Aluminum profiles are formed and cut with hand tools according to the CAD drawings. While the aluminum structure is being manufactured, the foam core is formed with a CNC machine in parallel to reduce the production time. After the aluminum structure and foam core are produced, two components are bonded together with foam adhesive. The bonding method makes the structure stiffer than joining with bolts.

After the aluminum support structure and foam core are bonded together, surface sanding and the cleaning process are begun to prepare for the composite coating. Composite materials are cut with scissors with respect to the CAD drawings. Epoxy resin and glass fiber composite materials are used for coating the foam core with aluminum support. The sanding and cleaning process is carried out after composite curing, and then it becomes ready for painting and cutting control surfaces.

Control surfaces are cut with a high speed metal disk. Then, hinges and control horns are integrated with control surfaces. Later on, the surface is cleaned with pressurized air and a wet cloth painting process is begun to make the surface free from dust. Three layers of paint are applied on the surface to make the surface smoother.

Finally, the landing gear, mechanisms, propulsion units, and control system integration are done to make a system check for testing.

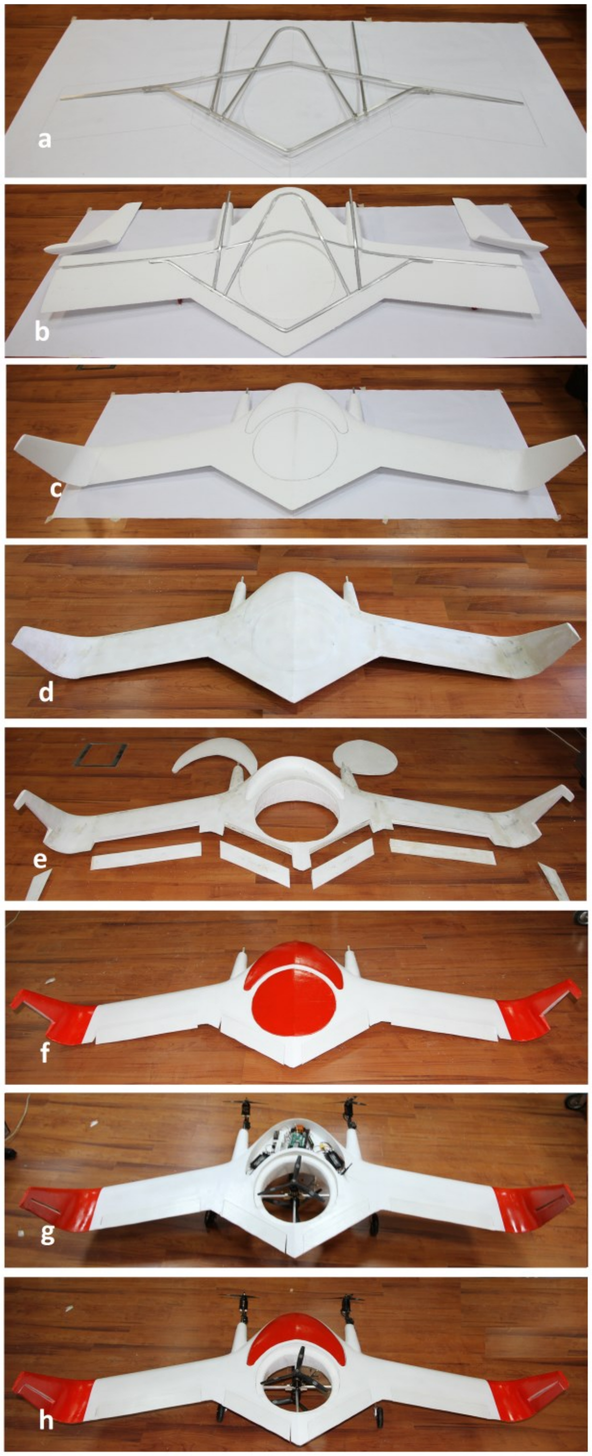

Figure 10. a) Aluminum structure production with technical drawings b) Foam core CNC manufacturing c) Aluminum structure and foam core bonding d) Composite material covering and surface sanding e) Cutting control surfaces f) Painting g) Systems integration h) System check

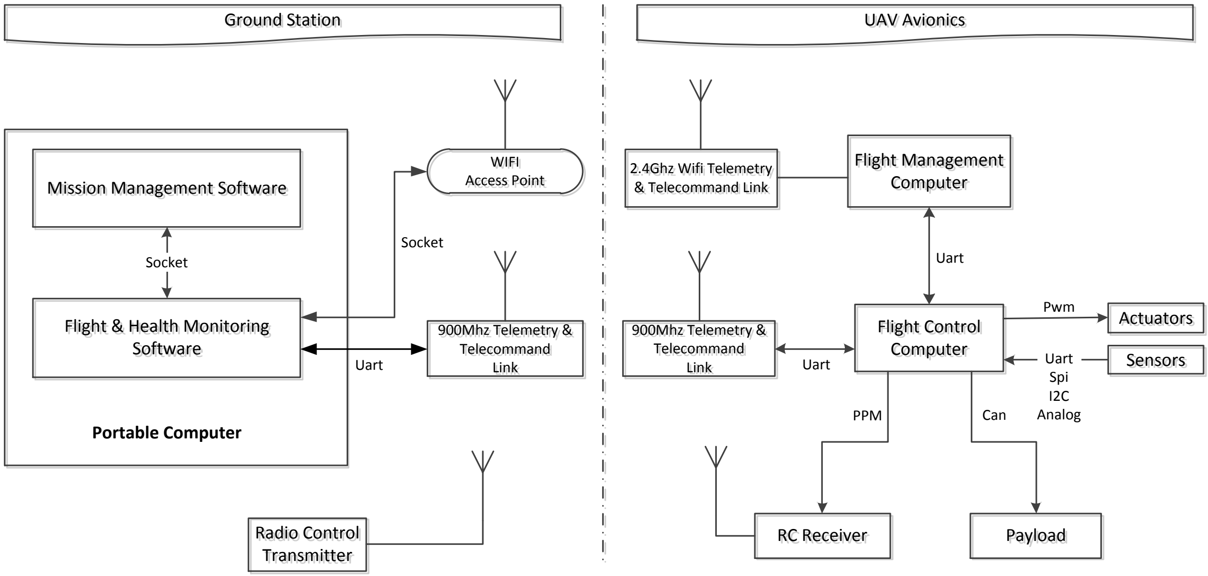

Figure 11 Architecture of the Ground Station and Avionics

IV. AVIONIC SYSTEM AND GROUND STATION

A. *Avionic System*

The general architecture of the system is shown in Fig. 11. The entire system can be divided into two sub systems as the ground station and avionics. The avionic system includes an autopilot, sensor packages, radio control receiver, telemetry modules, and actuators. The autopilot system includes a flight control computer and a flight management computer. The Flight control computer handles the low level control loops of the vehicle while the flight management computer executes the high level navigation loops of the mission.

The flight control computer is based on a 32 Bit STM32F4 processor that has a Cortex-M4 core, 168 MHz clock rate, 192 KB RAM and 1 MB Flash. The flight control computer is a custom board with an STM32 development board to get the other units connected as shown in Fig 12. It handles low level in-circuit communication as shown in Fig. 13. External peripheral units, such as the IMU/INS/GPS sensor kit, radio control receiver, actuators, data-logger, pitot tube, alpha and beta sensors, battery management sensors and, naturally flight management computer are connected to the flight control computer by the serial or analog interfaces. Detailed information can be found at **[8]**.

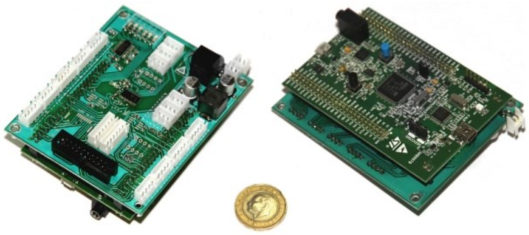

Figure 12 The Flight Management Computer and Expansion Board

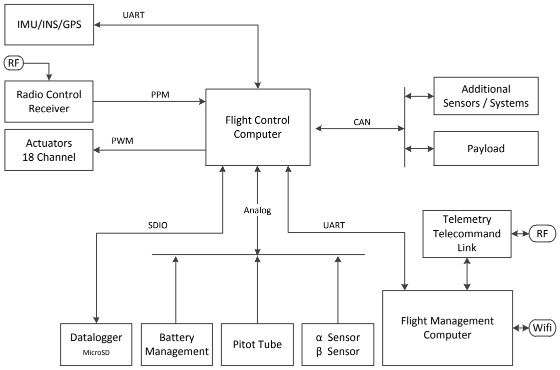

Figure 13 Flight Control Computer and Its Peripherals

The Flight Control Computer deals with flight control loops besides for managing low level communications as mentioned above. Flight control loops can be seen in Fig. 14 for the hover state. Our IMU/INS sensor suite, which is MTI-G-700 from Xsense, outputs feedback values, such as position, velocity, orientation, and angular rates for controllers. Position and attitude blocks consist of a cascaded PI and Washout-PI for each axis, which are north, east, up, roll, pitch, and yaw. The output of the position controller is an input for altitude controller and it is called desired orientation. Desired control signals (u_i) are calculated by the attitude controller. These control signals are then converted to the desired forces (F_i) for each axis. The transformation matrix transforms the desired force signals to the appropriate actuator according to the vehicle actuator geometry.

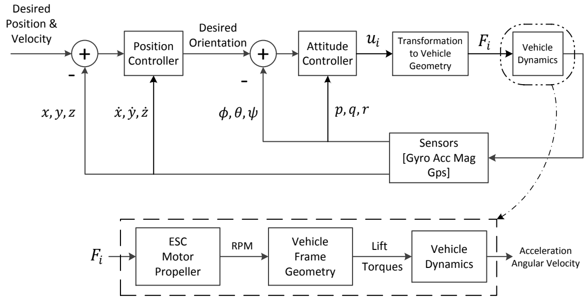

Figure 14 Control loops running on the flight control computer

The Flight Management Computer (FMC) executes high level navigation operations and also drives the flight control computer when autonomous navigation mode is enabled. The Flight Management Computer is based on a Linux operating system and a single board computer that runs at 720 MHz clock speed and is called "Raspberry Pi". The FMC is connected to the ground station with two options, which are 2.4GHz WiFior900Mhz RF modems. Both have some advantages to each other. A Wi-Fi modem has a short range but very high data rate which is 54 Mbps in theory. Furthermore, RF modems (900 MHz xTend by Digi) have a very long range but a low data rate (about 115 Kbps) in theory. Each one can be selected in flight depending on how far the aircraft is to fly.

B. *Ground Station*

The Ground Station (GS) includes a radio control unit for manual flights, a RF modem, a Wi-Fi router and a computer that runs a GUI of the ground station as shown in Fig. 15. The main communication link is established by a Wi-Fi connection but an RF modem is considered as a backup communication link and is connected via USB.

Figure 15 Ground station graphical user interface

Ground Station Software (GSS) is developed in C# programming language. It allows for health monitoring, configuring primary control parameters and uploading full autonomous mission steps. Main Graphical User Interface (GUI) consists of three sections as seen in Fig.15. The upper left side is a head-up-display with real time video from the vehicle camera on the background. On the head-up-display all of the flight data such as orientation, coordinates, altitude, battery status, communication status, operator control inputs, vehicle mode and navigation health status can be viewed. The right side of the GUI is a map overlay. This overlay allows for tracking the vehicle and managing autonomous missions by adding/editing mission steps such as takeoff, waypoint, and landing. The left downside of the GUI has control buttons. Operators can download the mission map from cache or the Internet, upload flight parameters and view flight parameters in detail by real time plotting. Additional software suites such as payload control, synthetic vision, or mission management software can be connected via socket if needed. Fig. 16 shows the synthetic vision suite of the ground station software. This add-on program enables the operator to manage the vehicle in poor weather conditions such as foggy weather or during night flights.

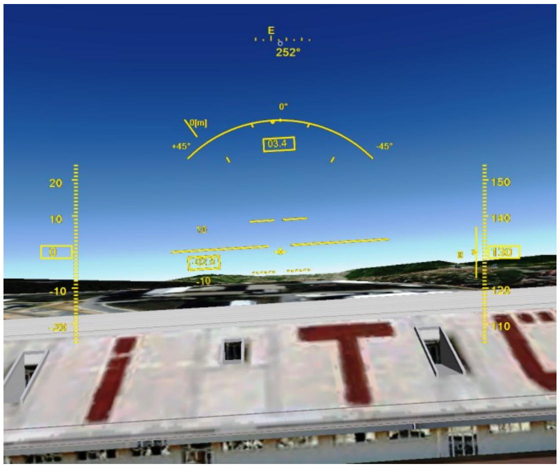

Figure 16 Synthetic Vision Suite

V. GROUND AND FLIGHT TESTS

Tests are planned and applied on main and subsystems in order to meet the requirements and performance goals. TURAC tests are composed of two major test group; ground tests and flight tests. (Figure 11)

(CTOL, VTOL, transition and autonomous flight tests are used to ensure the entire system's real life performance. All of these tests are named as flight tests. All ground tests are needed to be completed before the flight tests with intent to avoid undesirable damage and time delay at the project schedule.

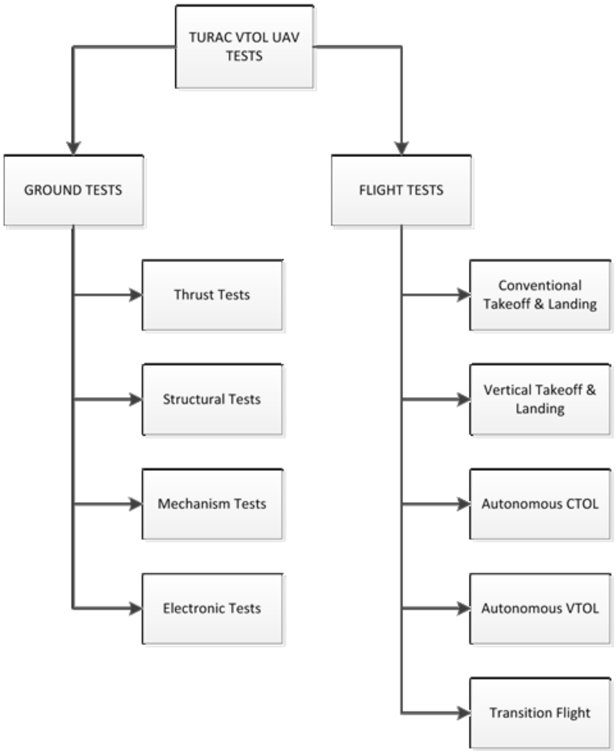

Figure 11 TURAC system test plan

A. Ground Tests

Ground tests are composed of TURAC's subsystems, such as mechanisms and avionics. (Figure12) Tests are conducted with a simulating working environment and using special test equipment such as a thrust test bench and a hydraulic structural tensile test system. The test results are used in the design and development stage in order to minimize the unwanted interaction of systems and enhance overall performance.

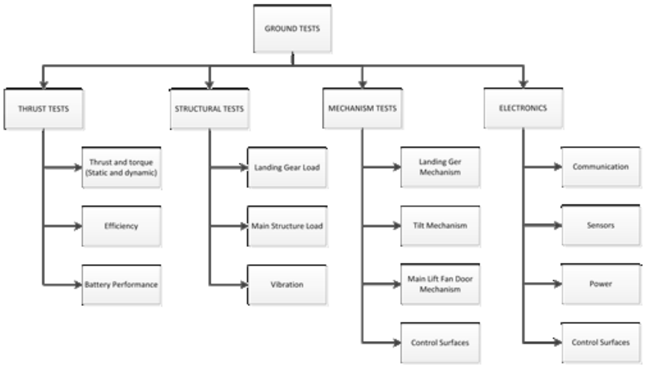

Figure 12 Ground tests plan

Thrust, torque, RPM, current, voltage, and system efficiency data are vital for aircraft performance calculations. A computer controlled automatic sequence thrust test bench is designed and built to get thrust performance parameters with high precision in a short time. (Figure 13)

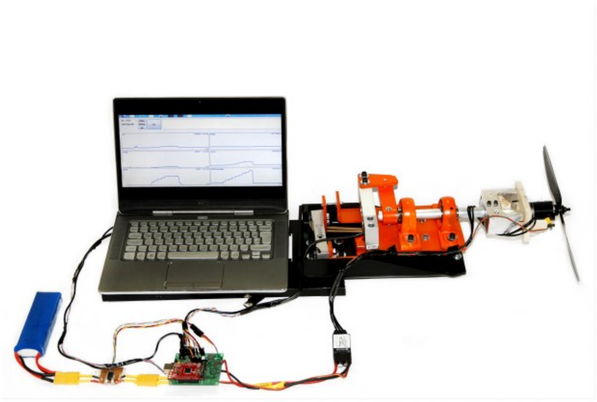

Figure 13 Thrust Test Bench

The Thrust Test Bench automatic sequence starts with PWM generation (1000-1800) which is used for throttle from 0% to 100%. When the sequence starts, the data of thrust, torque, RPM, PWM, current, and voltage are recorded. Thrust forces and torque are decomposed with mechanical linkages and connected with independent load cells. Then, resistance differences over load cells are transformed in digital output with the test bench's electronic mainboard. This mainboard also collects data from current, voltage, and RPM sensors and transform them into a digital output. Throttle increases step by step automatically after collecting 100 samples. Samples are filtered on MS Excel and the results are used in performance calculations at the next step. Test data collected on MS Excel spreadsheet and visualized on the test bench's software.

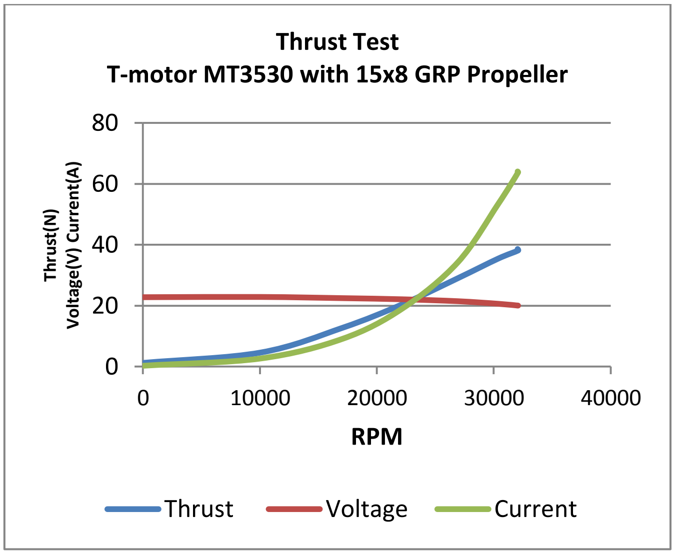

Figure 14 Thrust test bench tilt rotor propulsion system for 1/2 TURAC prototype

The test bench is used for testing the ½ scale TURAC prototype's tilt rotor propulsion system and test results are shown in Figure 14. T-Motor MT 2814-10 brushless out runner motor, 4S-14.8 V continuous 20C rate LiPo battery with 12x4.5 inch carbon propeller is used for testing. For the selected propulsion system, the thrust increases with the increase of the throttle until 75% throttle, which is the most efficient working condition at almost 50% efficiency and 16N thrust.

B. Flight Tests

Flight tests are used for analyzing the whole system's performance after modification of the systems and subsystems. For this reason, TURAC's performance can be verified in flight tests before the product design. CTOL, VTOL, transition and autonomous flights are the subtests of TURAC's flight test. All flight tests are performed on a multi-copter test-bed and a ½ scaled version of TURAC to reduce the test budget.

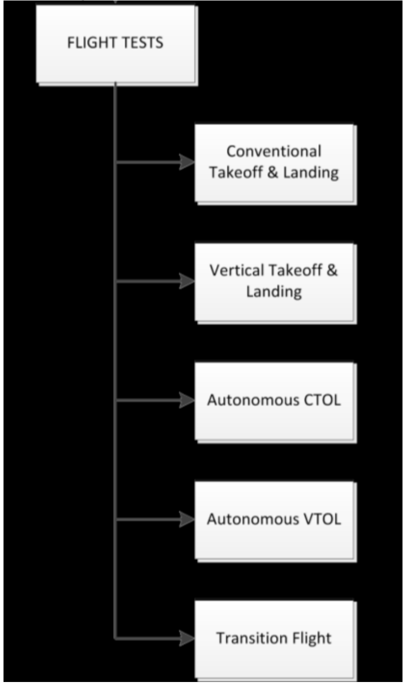

Figure 155 Flight Tests

Prototype of TURAC model that is equipped with our avionic system is modelled, fine-tuned and flown successfully. T-Motor 3530 motors with 15x7 3-Blade props by Master Air Screw and Monster 2000 speed controllers are used for the prototype of TURAC.

Figure 15 TURAC UAV is in the air

In addition to these tests, a scaled model is used to develop an autopilot system as seen in Fig. 16. This scaled model has the same engine placement and frame geometry compared to the VTOL mode of TURAC. Although this model also has four brushless motors, their sizes are different. However, all avionics are the same as TURAC. Especially take off, transition between waypoints, and landing missions are developed with this mini size UAV. Fig. 17 gives an example of a full autonomous flight. This example includes take off, transition between three waypoints, and landing, respectively. In addition, the vehicle position can be traced from the following screenshots.

Figure 16 One of the first multicopter prototypes of TURAC is used when developing autopilot

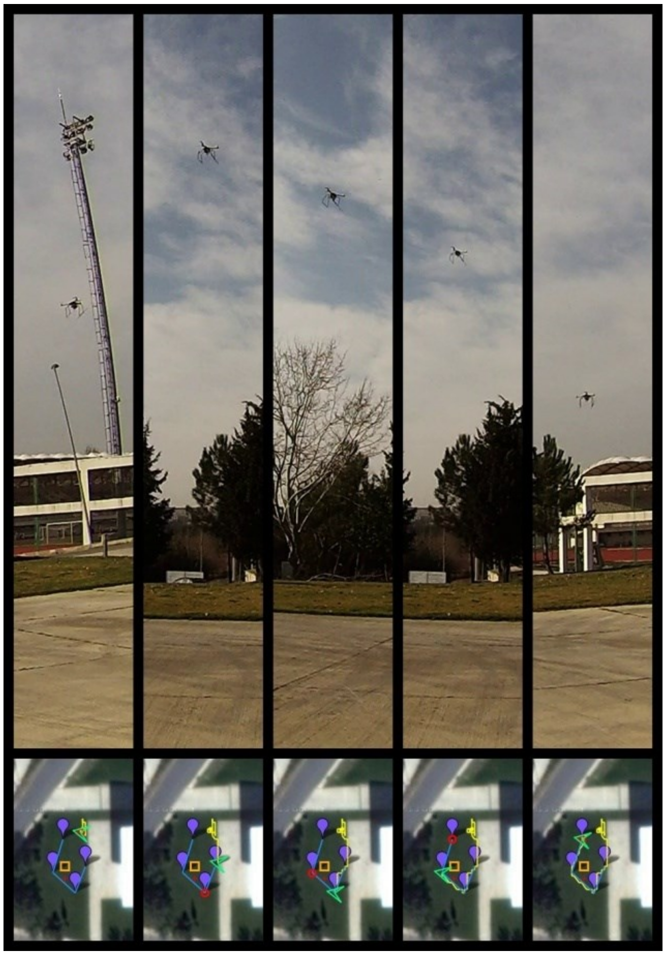

Figure 17 Full autonomous flight of the prototype: takeoff, transition between waypoints, and landing, respectively

VI. CONCLUSION

In this paper, we reviewed the design of the TURAC VTOL fixed wing UAV and further detailed a low-cost manufacturing process that allows for an efficient method for fast prototyping different variants and designs. The process as presented provides considerable savings both in time and man-power. Given the inherent unstable flight configurations, the operation of TURAC UAV heavily relies on the automatic flight control system implemented within the avionics system. The ground station with a HUD and synthetic vision provide a highly scalable and user-friendly operative monitoring and control of the UAV flight and mission. TURAC UAV is currently undergoing extensive ground and flight tests in which the control system designs for all the operation phases, including hover, transition, and forward flight, are being designed and refined.

REFERENCES

[1] Ugur Ozdemir, Gökhan İnalhan, et.al, ”Design of a Commercial Hybrid VTOL UAV System”, Journal of Intelligent & Robotic Systems, 10.1007/s10846-013-9900-0, (2013)

[2] H. Karakaş, E. Koyuncu and G. Inalhan, “ITU Tailless UAV Design”, Journal of Intelligent & Robotic Systems, 69, 131-146, (2013)

[3] M. Aksugur, G. Inalhan, “Design Methodology of a Hybrid Propulsion Driven Electric Powered Miniature Tailsitter Unmanned Aerial Vehicle”, Journal of Intelligent and Robotics Systems, 57(1-4): 505-529, January 2010 .

[4] A. Vuruskan, B. Yuksek, U. Ozdemir, A. Yukselen and G. Inalhan, “Dynamic Modeling of a VTOL Fix-Wing UAV”, in review for publication with the Proceedings of 2014 International Conference on Unmanned Aircraft Systems

[5] Mutlu, T., Karaman, S., Çomak, S., Bayezit, İ., İnalhan, G., and Guvenç, L., “Development of a Cross-Compatible Micro-Avionics System for Aerorobotics”, Proc. IEEE Intelligent Vehicles Symposium, Istanbul, 1258-1265, IEEE, 2007.

[6] Karaman, S., Aksugur, M., Baltaci, T., Kurtulus, C. and Inalhan, G., “Aricopter: Aerobotic Platform for Advances in Flight, Vision Controls, and Distributed Autonomy”, Proc. IEEE Intelligent Vehicles Symposium, Istanbul, 918-925, IEEE, 2007.

[7] Ateş, S., Bayezit, I. and Inalhan, G., “Design and Hardware–in–the–Loop Integration of a UAV Microavionics System in a Manned–Unmanned Joint Airspace Flight Network Simulator”, Journal of Intelligent and Robotic Systems, 54, 359-386 (2009).

[8] F.A. Tarhan, E. Koyuncu, M. Hasanzade and G. İnalhan, “Formal Intent Based Flight Management System Design for Unmanned Aerial Vehicles”, in review for publication with the Proceedings of 2014 International Conference on Unmanned Aircraft Systems

[9] Pitera, D.M., DeHaan, M., et al., Blended Wing Body Concept Development with Open Rotor Engine Integration, NASA GRC and The Boeing Company, Huntington Beach, California, November 2011

[10] Gur, O. ve Rosen, A., “Optimizing Electric Propulsion Systems for Unmanned Aerial Vehicles”, Journal of Aircraft, Vol. 46, No. 4 July-August 2009, pp. 1340-1353

[11] Zhao, H.W.: Development of a Dynamic Model of a Ducted Fan VTOL UAV. MSc. Thesis, RMIT University (2009)