Determination of UAV pre-flight Checklist for flight test purpose using qualitative failure analysis

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Abstract. Safety aspects are of paramount importance in flight, especially in flight test phase. Before performing any flight tests of either manned or unmanned aircraft, one should include pre-flight checklists as a required safety document in the flight test plan. This paper reports on the development of a new approach for determination of pre-flight checklists for UAV flight test based on aircraft’s failure analysis. The Lapan’s LSA (Light Surveillance Aircraft) is used as a study case, assuming this aircraft has been transformed into the unmanned version. Failure analysis is performed on LSA using fault tree analysis (FTA) method. Analysis is focused on propulsion system and flight control system, which fail of these systems will lead to catastrophic events. Pre-flight checklist of the UAV is then constructed based on the basic causes obtained from failure analysis.

1. Introduction
The use of Unmanned Aerial Vehicle (UAV), either for military or civil applications, has been increasing rapidly in the last decades. Acceleration of technology developments, especially in electronics, has driven massive developments and productions of UAVs with a wide range of capabilities and relatively low cost. As a consequence of the increasing market, many enterprises which are designing, developing and manufacturing UAVs with wide variation of size, configuration, and mission have been significantly increasing as well.

In the process of designing, developing, and manufacturing UAV, flight testing will become an important phase which has to be performed. In practice, incidents and/or accidents occasionally occur in flight tests. The application and use of checklists during flight tests helps eliminate the errors that can be made in an intense high workload flight test environment. These checklists should be developed and presented in the flight test plan [1].

Meanwhile, failure analysis is a process of collecting and analysing data to determine the cause of a failure, often with the goal of determining corrective actions or liability. Failure analysis has been used in the development of new UAVs and for the improvement of existing ones, either for a specific subsystem such as flight control system [2] or for the whole UAV system [3][4].

In order to minimize the probability of incidents/accidents occur in flight test, a more detail pre-flight checklists should be determined. In this research, a new approach for determination of pre-flight checklist is developed by using qualitative failure analysis of the UAV.
2. Method of Analysis
The UAV evaluated in this study is the Lapan’s LSA (Light Surveillance Aircraft) manufactured by Stemme AG, a German aircraft manufacturer. In this analysis, the aircraft is assumed to have been transformed into the unmanned version. Failure analysis performed on the UAV in this study uses a deductive approach, namely Fault Tree Analysis (FTA) method.

2.1. Lapan’s LSA (Light Surveillance Aircraft)
The National Institute of Aeronautics and Space (Lapan) has an aircraft named LSA (Light Surveillance Aircraft). LSA is actually the Stemme ASP S15-1 aircraft. It is a two-seat single-engined, all composite construction, powered sailplane with the engine mounted in the center fuselage. The cockpit has room for two in side-by-side configuration. It has a shoulder wing, a conventional T-tail and a retractable nose wheel landing gear.

The aircraft received type certificate from European Aviation Safety Agency (EASA) in October 2013 [5]. The general specifications and 3-view drawing of the aircraft are shown in table 1 and figure 1, respectively [6].

| Parameters                      | SI Unit | British Unit     |
|--------------------------------|---------|------------------|
| Length                         | 8.52 m  | 27 ft 11 in      |
| Wingspan                       | 18 m    | 59 ft 1 in       |
| Height                         | 2.45 m  | 8 ft 0 in        |
| Wing area                       | 17.4 m² | 187 sq ft        |
| MTOW                           | 1,100 kg| 2,425 lb         |
| Powerplant: 1x Rotax914F2       | 84.5 kW | 113.3 hp         |
| Propellers diameter: 3-bladed Muhlbauer Type MTV-7-A/170/051 | 1.7 m | 5 ft 7 in |
| Stall speed                     | 107 km/h| 58 kts           |
| Take-off distance               | 833 m   | 2832 ft          |
| Maximum rate of climb           | 3.0 m   | 591 ft/min       |
| Maximum cruise speed            | 234 km/h| 126 kts          |
| Maximum endurance               | 6.22 h  | 6.22 h           |
| Maximum range                   | 1119.6 km | 604.5 nm       |
2.2. **Fault Tree Analysis of LSA**

Fault Tree Analysis method is selected to be used in conducting failure analysis on the LSA. Fault Tree Analysis (FTA) is a deductive, failure-based approach. As a deductive approach, FTA starts with an undesired event, such as failure of the main engine, and then determines (deduces) its causes using a systematic, backward-stepping process. In determining the causes, a fault tree (FT) is constructed as a logical illustration of the events and their relationships that are necessary and sufficient to result in the undesired event, or top event. The FT is a qualitative model that provides extremely useful information on the causes of the undesired event. The FT can also be quantified to provide useful information on the probability of the top event occurring and the importance of all the causes and events modeled in the FT [7].

3. **Failure Analysis and Pre-flight Checklists Determination of LSA**

Failure analysis conducted on the LSA is focused on propulsion system and flight control system, which fail of these systems will lead to catastrophic events. In the case of LSA, the propulsion system is equipped with an engine and a propeller, which both are connected with drive section, to provide thrust to the UAV platform, as shown in figure 2.

![Figure 1. 3-view drawing of LSA [6].](image1)

![Figure 2. The propulsion system of LSA [6].](image2)
Figure 3. FT of the propulsion system.

It is considered Loss of Propulsion as a top event, which may be caused by either Engine Failure, Propeller Failure, or Drive Section Failure. The engine comprises four important subsystems, i.e. engine control system, ignition system, fuel system, and lubrication system. Failure of the engine is considered because of failure of either one of them. Meanwhile, the Propeller Failure may be caused by either structural damage of the propeller or failure of propeller pitch control. The drive section, which transfers power from the engine to propeller, can fail because of either the gear failure or the shaft failure. The Fault Tree of the propulsion system is shown in figure 3 and the Fault Tree of the ignition system, fuel system, and lubrication system are shown in figure 4 to figure 6, respectively.

Figure 4. FT of the ignition system.

Ignition System failure results from three derivative failures, i.e. spark plug failure that results in an ignition process does not occur, cable/wire failure that results in generator not working properly, and the battery as a power supply does not work well.

Fuel system failure may occur due to five derivative failures, i.e. failures/defects of the filter, fuel tank, pipes/hoses, pumps, and sensors. The defective filter may prevent the filter to screen out dirt and rust particles from the fuel, which in turn can defect other components or degrade the system performance. Defective fuel tanks such as leakage may cause running out fuel and hence engine stop. Blocked pipes/hoses usually affect the failure to start the engine. Failure of the fuel pump, commonly using an electric pump, gives rise to unconveyability of fuel to the engine. Failure of fuel sensors (pressure and temperature) can cause the fuel system not working properly.
The failure of the lubrication system has three derivative failures. Failure of this system is almost same as the failure of the fuel system, consisting of sensors failure, pumps failure, and defective or blocked pipes/hoses. These three failures can make the engine not get enough oil and cause the engine to be damaged.

Flight control system of LSA is mainly comprised the control surfaces (elevator, ailerons, rudder, trim tab, flaps, and airbrakes), the actuators which deflect the control surfaces through the linkages, and Flight Control Computer. Failure of either one of them will cause a failure of flight control system. Meanwhile, control surface failure results from structural damage or jammed linkages. Beside hardware or software failure, failure of sensors (air data sensors or deflection angle sensors) can lead to a failure of flight control computer. Figure 7 illustrates the Fault Tree of Flight Control System of LSA.

**Figure 5.** FT of the fuel system.

**Figure 6.** FT of the lubrication system.

**Figure 7.** FT of flight control system.
Based on the basic causes obtained from fault tree analysis of the LSA, one can determine pre-flight checklists to mitigate the likelihood of incident/accident occurrence. The developed checklist resulted from qualitative failure analysis of the LSA is shown in Appendix.

4. Concluding Remarks
In this report, qualitative failure analysis of a UAV has been performed using the Lapan’s LSA as a study case. Pre-flight checklist of the aircraft is then determined from the failure analysis. This concludes development of a new approach for determination of pre-flight checklist of UAV, i.e. based on qualitative failure analysis. In the future research, the developed checklist can be tested and implemented to the LSA aircraft.

References
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Appendix. Pre-flight checklist of the LSA resulted from qualitative failure analysis

| Systems                  | Yes | No |
|--------------------------|-----|----|
| **engine (general)**     |     |    |
| breather inlet clear     |     |    |
| engine exhaust clear     |     |    |
| all connections (bolts, nuts, etc) properly tightened | | |
| **fuel system**          |     |    |
| amounts of fuel, oil, and coolant in proper level | | |
| fuel lines connected and no leakage or blockage | | |
| fuel filters clean and no defect | | |
| fuel tanks have no cracks and leaks | | |
| fuel sensors are well-functioned | | |
| fuel pumps are well-functioned | | |
| **lubrication system**   |     |    |
| amounts of oil in proper level | | |
| oil sensors are well-functioned | | |
| oil pumps are well-functioned | | |
| oil tank has no cracks and leaks | | |
| oil lines connected and no leakage or blockage | | |
| **ignition and electrical system** | | |
| spark plugs cleaned, undamaged, and properly torqued | | |
| all wiring connected, undefect, and secured | | |
| battery capacity is sufficient (min. 16Ah) | | |
| **propeller**            |     |    |
| propeller blades free for cracks and damage | | |
| propeller hub free for cracks, rusts and damage | | |
| propeller pitch control well-functioned | | |
| spinner has no cracks and mounted correctly | | |
| **drive connection**     |     |    |
| shaft has no cracks and damage | | |
| gear has no cracks and damage | | |
| cowling has no cracks and mounted correctly | | |
| **flight control system**| | |
| control surfaces free from cracks and damage | | |
| control rods and cables free from cracks, rusts and damage | | |
| actuators well-functioned | | |
| control surfaces movement has no jam and resistance | | |
| no foreign object/contamination in pitot-static tube | | |
| air data sensor well-functioned | | |
| FCC well-functioned | | |
| datalink well-functioned | | |
| GPS signal available | | |
| weight and c.g position within the limits | | |