Reliability Assessment of UAV Systems

Enrico Petritoli, Fabio Leccese
Science Department, Università degli Studi "Roma Tre"
Via della Vasca Navale n°84, 00146, Roma, Italy
e_petritoli@libero.it, fabio.leccese@uniroma3.it

Lorenzo Ciani
Department of Information Engineering, University of Florence
Via S. Marta n°3, 50139, Florence, Italy
lorenzo.ciani@unifi.it

***Abstract* — This paper deals with the reliability assessment for an UAV (Unmanned Aerial Vehicle) system: once a specific architecture is selected (after a trade-off phase), the reliability assessment represents a key issue to optimize the design of any complex system. The final aim is to evaluate the *intrinsic reliability* at the design stage to avoid any critical failure that may leads to a catastrophic effect on the UAV.**

Keywords — UAV, RAMS Reliability, Availability, Maintainability, Safety.

I. Introduction

The reliability of UAV has dramatically improved over the past 25 years: it has taken improvements in many subsystems for this to happen (engines have gotten more reliable, MEMS avionics have improved, etc.) The general approach around drones' reliability has changed as well: a lot of people have had the mentality that drone crashes are to be expected and they shouldn't be surprised when they happen.

Nowadays, this is unacceptable: because UAVs do not carry pilot or people does not mean they can be designed with lower standards in mind. This inevitably leads to poor design decisions and poorly performing systems. Focusing on reliability will be hugely important as we start to transition these systems from military environment into the commercial market as well. Therefore, it is necessary to stay on this trend and keep reliability a priority [1].

II. Definitions

Reliability

Reliability corresponds to the "probability that the element is capable of performing its required function in the established time interval, under established conditions." Reliability can be determined through mathematical models (law of reliability) or measured and estimated through statistical parameters, for example the Mean Time To Failure (MTTF) or the Mean Time Between Failures (MTBF) [2].

Availability

The term Availability defines the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided [2].

Operative Environment

According to MIL-HDBK-217F2, in the reliability prediction the following environment was considered [3]:

A_{UF} Airborne, Uninhabited, Fighter	Environmentally uncontrolled areas which cannot be inhabited by an aircrew during flight. Environmental extremes, of pressure, temperature and shock may be severe.

III. RAMS Assessment

The *RAMS assessment* represents an essential study in a UAV project. It is looked upon as a requirement for increase the availability of the aerial equipment, but also to reduce repair costs and to optimize spare parts management.

To maximize system performance it is also important to know how often such failures may occur, which involves predicting the occurrence of failures.

Most notably, in the design phase the prediction is useful not only to prevent failures, but also for many other purposes that can be summarized in the following list:

- to compare alternative designs,
- to identify potential design weaknesses,
- to analyze life-cycle costs,
- to plan logistic support strategies,
- to establish objectives for further reliability test,
- to optimize the conditions of use,
- to optimize the thermal design on electronic parts.

Once a particular UAV architecture is selected after a trade-off phase, see Fig. 1 for example, the reliability assessment may be a useful guide by showing the highest contributors to failure. It may also reveal other fruitful areas for change (e.g., over stressed parts). The impact of proposed design changes on reliability can be determined only by comparing the predictions of the existing and proposed designs. The ability of the design to maintain an acceptable level of reliability under environmental extremes may be assessed through RAMS predictions. These predictions, for example, may be used to evaluate the need for environmental control systems or to duplicate a critical subsystem (redundancy): the effect of the increase in complexity on the probability of mission success can be evaluated apart [4].

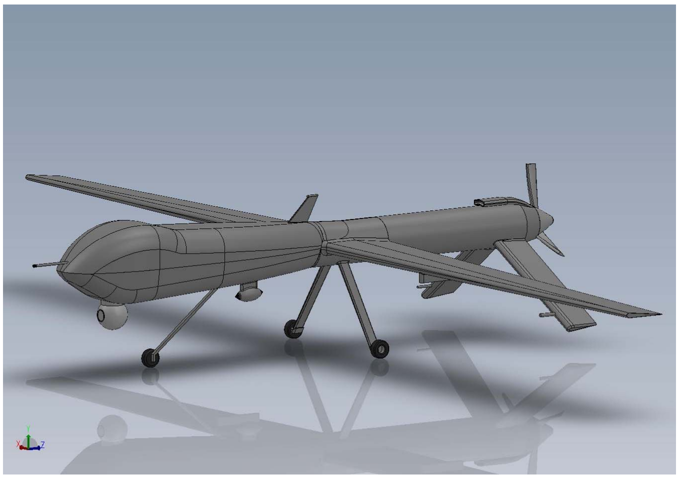

Fig. 1. Drone CAD Model.

The need for redundant or back-up systems may be determined with the aid of reliability predictions. A trade-off of redundancy against other reliability enhancing techniques must couple with other pertinent considerations such as cost, space limitations, etc. The prediction will also help evaluate the significance of reported failures[5,6].

For example, if several failures of one type or component occur in a system, the predicted failure rate can be used to determine whether the number of failures is commensurate with the number of components used in the system, or, that it indicates a problem area. Finally, reliability assessment is also used to evaluate the probabilities of failure events described in a Failure Modes, Effects and Criticality Analysis (FMECAs)[7,8].

IV. HOW RELIABLE DOES A DRONE HAVE TO BE?

During a typical flight profile [9] some failures are more problematic then others. Loss of control, uncontrolled landing, loss of the payload, of example, what else failures that is not catastrophic? To determine exactly what should be a reliable drone is first necessary to establish different levels of severity which can give yourself suffer. Then it is necessary to categorize them appropriately according to the type of mission and type of UAV that is considered. Therefore, it is necessary to establish, for each scenario, the minimum required level of reliability [10].

Firstly, it is necessary to define the criteria for the need for reliability in aircraft, and the level depending upon the sum of failures.

- Catastrophic failures: they cause the drone to crash and possibly cause injury or loss of life to people on the ground.
- Severe failures: they cause severe, probably irreparable, damage to the drone.
- Moderate failures: they cause debase the drone function, may cause a "mission abort" but not cause it to be severely damaged.

In order to obtain a reliable UAV system, we must seek its *intrinsic reliability*. For *intrinsic reliability,* we mean that reliability is studied *a priori*. Generally, the reliability study of the system takes place after the design phase: some of the classic output of an analysis of reliability or a FMECA are a series of recommendations and a list of criticality points that are sent back to the designers so that they must fix or repair changing their projects. In the seek for *intrinsic reliability*, the concept is completely overturned: in fact, knowing (briefly) the distribution of failure of a system (in our case the drone), it is possible directly during the design stage, to take certain measures to reduce the criticality and upgrade them in advance in order to increase the level of reliability [11].

This, on the one hand, move the new responsibilities on the design staff but, from another point of view, greatly reduces the risk of criticality (Single Point Failures) that might occur in a subsequent study. This is why the QA Responsible are beginning to be involved more and more in the design, right from the start.

V. UAV RELIABILITY

The reliability assessment must be performed on the UAV for the main purpose of finding the baseline for the requirement of making the UAV a magnitude more reliable. There was a secondary benefit from the analysis, though: the analysis helped show which components of the current subsystem are the most unreliable, those which are the most critical to the system [4,12].

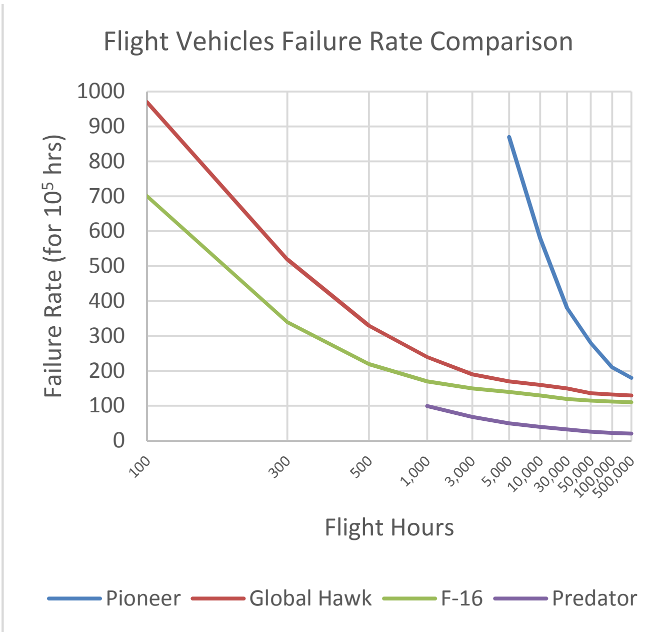

Fig. 2. Failure Rate vs. Flight hrs for the F-16 and some common drones.

In Fig. 2 is shown comparison of failure rate between several aircrafts: Northrop Grumman RQ-4 Global Hawk, General Atomics RQ-1 Predator, AAI RQ-2 Pioneer (for the drone category) and General Dynamics F-16 jet fighter.

VI. Reliability Assessment Hierarchy

In Fig. 3 is exposed the hierarchy of the reliability assessment for the UAV whole system: it shows the distribution of system, subsystems and single parts for every 10^3 failures (it is considered a base of 1000 failures that are then subdivided between subsystems and parts) [13].

In the following, we will see in detail the division of failure as a function of the considered subsystem:

Ground Control System

The GCS is a system with a portion of rather low reliability: this is due, as the matter of fact, that all systems are easily maintainable during the mission and is based, in general even on COTS type devices that allow a large warehouse low cost supply.

This does not mean that the system should inherently be less reliable: the fact that it is placed to the soil allows a good percentage of redundant systems (hot and cold). The high failure rate is however offset by an almost zero "off-line" time.

Mainframe

Properly considered and designed drone mainframes have had a good record of reliability, unlike those from model aircraft makers who generally have little knowledge of air-loads, etc. or understanding of the design of lightweight structures.

Where Fails have occurred it usually at rivets, welding and connection in the structure where the diffusion of stresses across metallic joints or from connections into a plastics composite part, has been not well evaluated. The extra cost and weight of applying a more generous reserve factor in these areas is well justified.

Power Plant

Defects may occur within the power-plant or in other sub-systems but caused by the power-plant. The former includes inadequate consideration in the initial design of the ambient conditions in which the aircraft will operate.

Hence, unless sufficient cooling is provided, a piston engine, in particular, may suffer overheating in hot conditions and seize, or fuel may become vaporized. This is particularly true on long-duration missions.

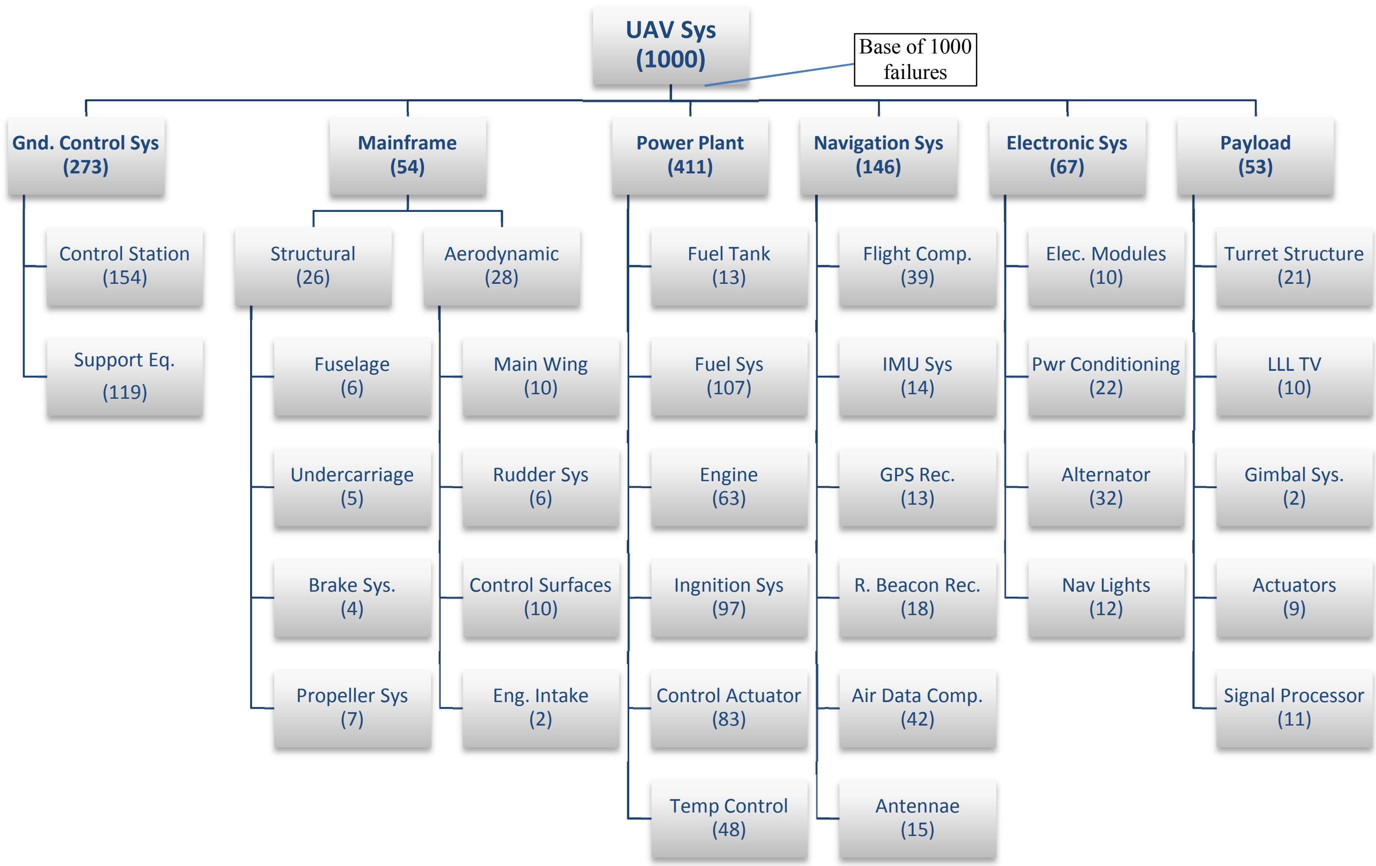

Fig. 3 UAV Hierarchy of the Reliability Assessment (every 10^3 system failures).

Navigation System

The navigation system is the brain of the whole drone: despite being prone to a failure rate quite high in comparison to other systems, for sure it has the highest range of hot redundancy. So it is possible to totally duplicate, for example, not only the navigation computer but also the GPS system receiver [14,15].

All this is due not only to the low cost that has reached the hardware in this field, but also the extreme calculation speed and computing power that allows to put multiple systems in parallel without problems.

In addition, the integrated IMU systems benefits from a strong development and miniaturization resulting from the automotive market that needed them more and more frequently on many vehicles.

The ancillary electronics, if properly placed in ideal conditions temperature, benefits from remarkable reliability and unthinkable until a few years ago.

Electronic System

For the electronic system applies as for the navigation system: if properly placed under ideal environmental conditions, it has a very high reliability. In the discussion, we wanted to separate it although sometimes an integral part of on-board electronic. The system supervises all other activities not purely dedicated to navigation, while being just as useful.

The only critical part is undoubtedly the power supply: provides suitably conditioned power to both the navigation system and to the payload. Its redundancy is instead expensive in terms of harness as doubling the cables means imposing a very considerable extra weight [16,17].

Payload

It is not possible to generalize the payload in a single configuration, shape or weight: the example that we brought is a payload of a normal surveillance drone. This will consist of a movable turret, suitably placed on a gimbal that contains an optical multisensor (in this case a LLLTV).

The turret structure is the most fragile part: in addition to static loads, it suffers all the dynamic loads of the camera and, more importantly, all the aerodynamic loads because is inserted directly into the aerodynamic flow of the aircraft. It should be noted that the reliability of the ancillary electronic section is extremely high [18].

VII. CONCLUSIONS

Each complex system such as UAVs, being inserted in a generally very extreme environment, it must have an intrinsic reliability. Therefore, reliability evaluation of a system is an important task. Mean Time Between Failure and Failure Rate can suggest useful information about diagnostic aspects, maintenance and investments.

The intrinsic reliability is in fact the one that comes from a careful study of its parts so that there is a set of design criteria that take into account the vulnerabilities of the drone considered. Obviously not all the parts or subsystems have the same failure rate so not all parts or subsystems will be oversized or redundant. By means of the reliability, prediction is possible to individuate the most critical components from the reliability point of view and thus suitably monitor it. Moreover the reliability model can be also used to assess key product parameters (voltage, temperature and so on) in order to perform devices stress and derating analyses.

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