Journal of KONBiN 2021
Volume 51, Issue 2
DOI 10.2478/jok-2021-0020

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SMALL UAV SHM SYSTEM FUNCTIONAL HAZARD ANALYSIS

Funkcjonalna analiza zagrożeń systemu SHM małego bezzałogowego statku powietrznego

Abstract: *The safety assessment process tailored to Remotely Piloted Aircraft Systems (RPAS) applications has been discussed briefly. The modified Hazard Reference System for STANAG 4703 Category UAV including Non Safety Effect (NSE) severity category has been proposed. The Functional Hazard Analysis (FHA) for small Unmanned Aerial Vehicle (UAV) Structural Health Monitoring (SHM) system has been conducted.*
Keywords: UAV, Structural Health Monitoring system, functional hazard analysis

Streszczenie: *Proces oceny bezpieczeństwa dostosowany do zastosowań dla Zdalnie Sterowanych Statków Powietrznych (RPAS) został pokrótce omówiony. Zaproponowano zmodyfikowany system klasyfikacji zagrożeń dla UAV kategorii STANAG 4703, w tym kategorię bez skutków dla bezpieczeństwa (NSE). Przeprowadzono funkcjonalną analizę zagrożeń (FHA) dla systemu monitorowania stanu struktury (SHM) małego bezzałogowego statku powietrznego (UAV).*
Słowa kluczowe: bezzałogowy statek powietrzny, system monitorowania stanu technicznego struktury, funkcjonalna analiza zagrożeń

1. Introduction

Remotely piloted aircraft systems (RPAS) are currently used for various civilian and military operations in segregated airspace. Integration of RPAS into non-segregated airspace essentially requires addressing two challenges:

a) technical - ensuring the same level of flight as manned aircraft,
b) regulatory – harmonisation of regulations and requirements.

In case of RPAS events which engager its structural integrity such as: battle damage, bird strikes, hail impacts, lighting strike or hard landing must be identified by automated detection system called Structural Health Monitoring (SHM).

There are several definitions of Structural Health Monitoring (SHM) [1, 4, 9] and for the purpose of this paper US Department of Defense for Aircraft Structural Integrity Program (ASIP) [4] definition is used:

Structural health monitoring (SHM) - structural health monitoring is a nondestructive inspection process or technique that uses insitu sensing devices to detect damage.

The paper discusses the Functional Hazard Analysis (FHA), a first step in Safety Assessment process, of small UAV SHM system. For the FHA methodology numerical illustration purposes an example of UAV Hornet of Maximum Take Off Mass = 38 kg is used.

2. Safety assessment process in a nutshell

System Safety Assessment (SSA) is the complete process applied during the design of the system to establish safety objectives and to demonstrate compliance with appropriate safety related regulations and requirements [2, 5-8].

The intent of ARP 4761 [8] is to support the safety assessment of civil manned aircraft systems, however it may equally support safety assessment and safety compliance determination of military RPAS with the following additional considerations:

- different criteria definition for safety objectives,
- complexity of the system,
- complexity of the interfaces,
- different emergency conditions,
- integration with ATM (Air Traffic Management),
- the need to consider the Failure Conditions (FC) effects on: mission, third parties on the ground or on other systems in the air or on the ground.

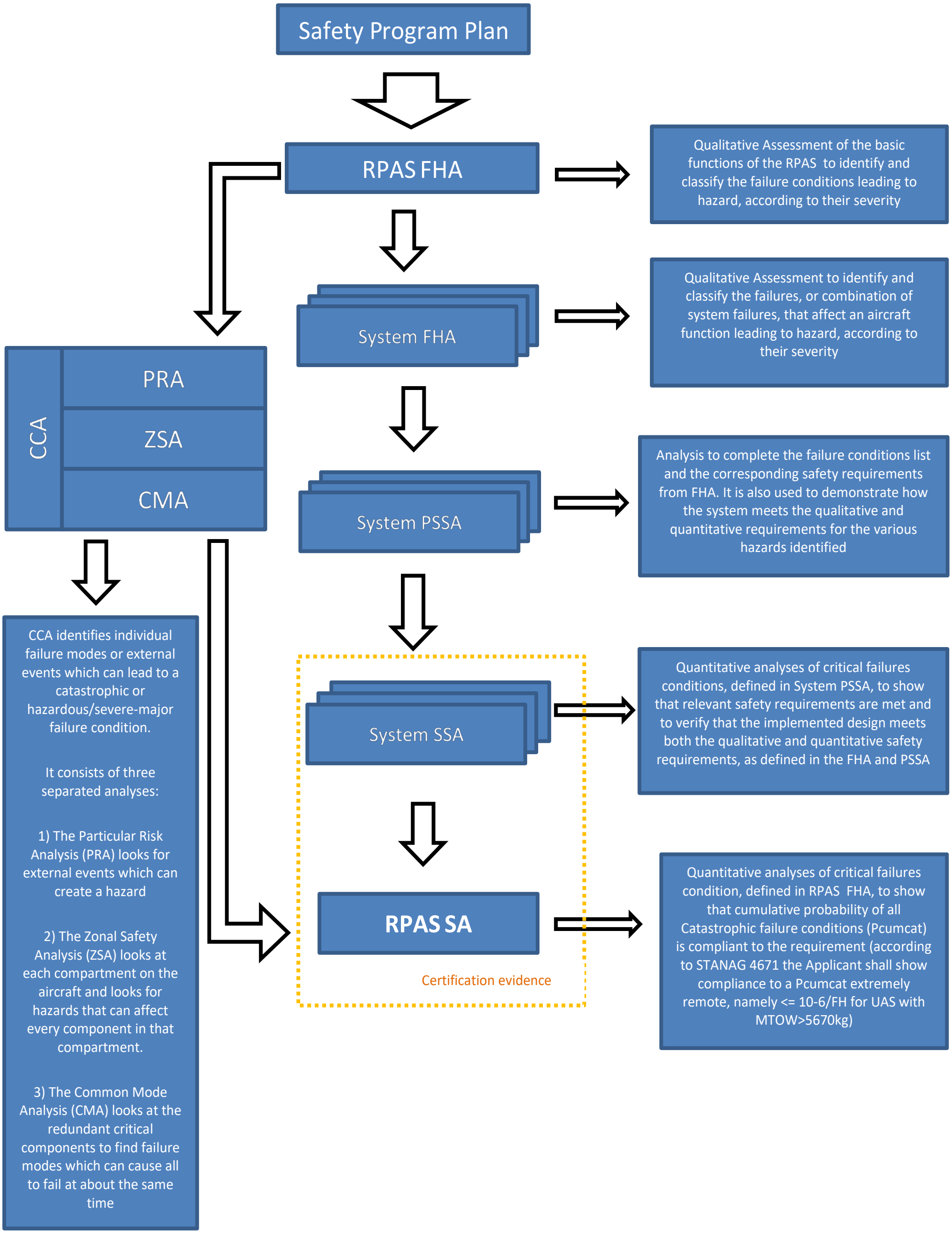

Fig. 1. Safety assessment process as per ARP4754A and ARP4761 tailored to RPAS applications [10]

Figure 1 represents the main steps of the process as per ARP 4754A [7] and ARP 4761 [8] tailored to RPAS applications. This iterative process is composed of RPAS FHA (Functional Hazard Assessment), System FHA, PSSA (Preliminary System Safety Assessment), SSA (System Safety Assessment) and CCA (Common Cause Analyses) first at RPAS level, then at RPAS' systems (subsystems) level. Here in this context an UAV is one of the RPAS system. Alternatively, the MIL-STD-882 [3] approach can be used for SSA. In this paper MIL-STD-882 [3] approach is not discussed.

One of the essential elements in a RPAS airworthiness certification process is the Safety Assessment as per STANAG 4671 [6] or STANAG 4703 [5].

3. Hazard Reference System for STANAG 4703 Category UAV

The UAV Hornet is dedicated for training of anti-aircraft defense forces and is used as carrier for towing target. The system contains of an aircraft (UAV) and a ground station (GS). The aircraft can be operated (controlled) via radio link and it can also perform mission with use of the autopilot in automated flight mode.

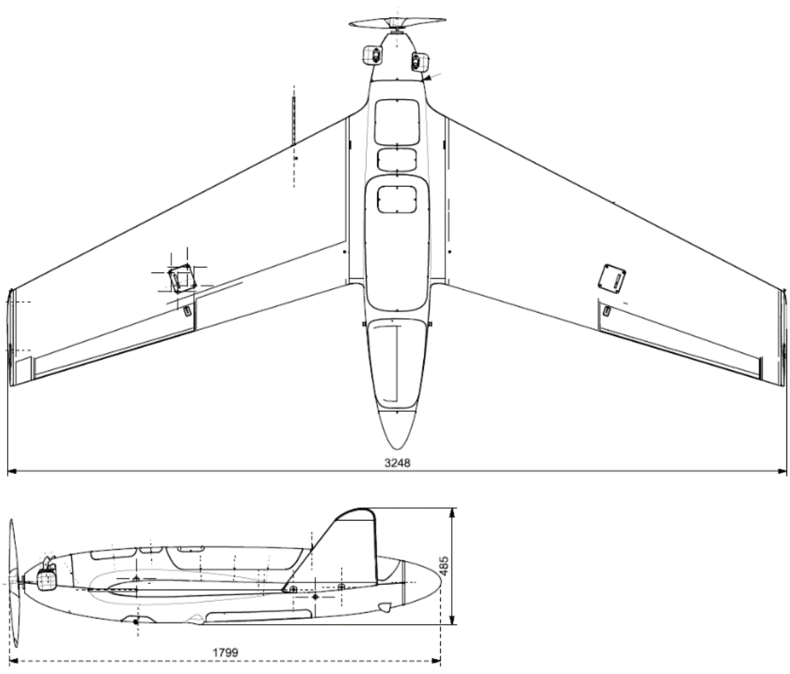

Fig. 2. Hornet UAV [10]

Based on [5] the following Severity Reference System has been assumed and it is presented in tab. 2.

Table 2

UAV Hornet Severity Reference System based on STANAG 4703 [5]

Severity	Definition
(1) Catastrophic	Failure conditions that are expected to result in at least uncontrolled flight (including flight outside of pre-planned or contingency flight profiles/areas) and/or uncontrolled crash. **OR** Failure conditions which may result in a fatality to UAV crew or ground staff.
(2) Hazardous	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in a controlled trajectory termination or forced landing potentially leading to the loss of the UA where it can be reasonably expected that a fatality will not occur. **OR** Failure conditions for which it can be reasonably expected that a fatality to UAV crew or ground staff will not occur.
(3) Major	Failure conditions that either by themselves or in conjunction with increased crew workload, are expected to result in an emergency landing of the UAV on a predefined site where it can be reasonably expected that a serious injury will not occur. **OR** Failure conditions which could potentially result in injury to UAV crew or ground staff.
(4) Minor	Failure conditions that do not significantly reduce UAV safety and involve UAV crew actions that are well within their capabilities. These conditions may include a slight reduction in safety margins or functional capabilities, and a slight increase in UAV crew workload.

The cumulative probability for catastrophic event (PCUM-CAT) is established in accordance with [5] provisions:

$$P_{CUM}\text{-CAT}=0{,}0015/MTOM=0{,}0015/38 = 3{,}95E\text{-}05 \qquad (1)$$

For the number of expected catastrophic failure conditions assumed to be equal 10 the following quantitative probability values for RPAS Hornet are obtained – tab. 3.

Table 3

UAV Hornet Probability Reference System

Level	Probability value
(E) Extremely Improbable	$P_{(E)} \leq 3{,}95E-06$
(D) Extremely Remote	$3{,}95E-06 < P_{(D)} \leq 3{,}95E-05$
(C) Remote	$3{,}95E-05 < P_{(C)} \leq 3{,}95E-04$
(B) Probable	$3{,}95E-04 < P_{(B)} \leq 3{,}95E-03$
(A) Frequent	$P_{(A)} > 3{,}95E-03$

Since STANAG 4703 [5] does not include Non Safety Effect (NSE) severity category in its Failure Condition Severity Reference System therefore it was decided to add this particular severity category. Finally design safety goals or safety objectives expressed as probability per 1 flight hour for each FC severity can be formulated as it is shown in tab. 4.

Table 4

Design safety goals for UAV Hornet

	Failure Condition Severity				
	(1) CATASTROPHIC	**(2) HAZARDOUS**	**(3) MAJOR**	**(4) MINOR**	**(5) NSE**
Design safety goals (FC probability <)	**3,95E-06**	**3,95E-05**	**3,95E-04**	**3,95E-03**	**None**

4. Functional Hazard Analysis

The Functional Hazard Analysis of the SHM system is based on the guidelines and methods of performing the safety assessment for certification of civil aircraft provided in the ARP4761 [8] in conjunction with the ARP4754A [7] and with the advisory material of AC 23.1309-1E [2].

The FHA objective is to consider functions at the most appropriate level and to generate, considering loss of functions or malfunctions, Failure Conditions (FC) and the associated classifications and safety/reliability requirements (qualitative and quantitative). Failure Condition definition is given in AC 23.1309-1E [2].

This FHA has been conducted in several steps, as follows:

- to identify system functions at aircraft level, exchanged functions and environmental configurations to be analyzed,
- to determine all possible losses of function or malfunctions and associated failure scenarios,
- to analyze repercussions of these failure scenarios,
- to group failure scenarios in significant failure conditions (FC).

Two types of functions of the SHM system have been analyzed:

- General functions when SHM system is considered as a "black box" with high level system functions; and
- Dependent SHM system functions (functions interfaced with aircraft).

Table 5

Functional Hazard Analysis for SHM system

ID	Function	Failure Condition	Phase of Operation	Scenarios	Classification of the Failure Condition	Probability requirement	Mitigation/ Remarks
General SHM system functions							
1	Provide loads monitoring						
1.A		Loss of the loads monitoring data	All	Loss of loads monitoring data => Loss of SHM system	NSE	No probability requirement	No effect on aircraft, people, mission and other systems.
1.B		Erroneous loads monitoring data	All	Erroneous of loads monitoring data => Loss of SHM system	NSE	No probability requirement	No effect on aircraft, people, mission and other systems.
2.	Provide impact monitoring						
2.A		Loss of the impact monitoring data	All	Loss of impact monitoring data => Loss of SHM system	NSE	No probability requirement	No effect on aircraft, people, mission and other systems.
2.B		Erroneous impact monitoring data	All	Erroneous of impact monitoring data => Loss of SHM system	NSE	No probability requirement	No effect on aircraft, people, mission and other systems.
Dependent SHM system functions							
3.	Provide power supplies						
3.A		Loss of power supplies	All	SHM System is not powered => Loss of SHM system.	NSE	No probability requirement	No effect on aircraft, people, mission and other systems.

General SHM system functions list identified at the aircraft level:

1. Provide loads monitoring,
2. Provide impact monitoring.

Dependent SHM system functions:

3. Provide power supplies.

Table 5 presents the SHM system functional failure and their effects on the aircraft, people, mission and other systems. All expected Failure Conditions for the SHM system were classified as Non Safety Effect (NSE). As described in [2] the Minor and Non Safety Effect (NSE) failure conditions not need a qualitative and a quantitative analysis but only verification by design and installation appraisal therefore neither qualitative nor quantitative safety analysis for the UAV SHM system is required.

5. Conclusions

In comparison with STANAG 4703 [5] the modified categorisation of Failure Condition Severity has been proposed to include Non Safety Effect (NSE) severity category.

SHM system is an airborne equipment and therefore it shall comply with the applicable airworthiness regulations and requirements. System Safety Assessment of the SHM system allows to establish safety objectives and to demonstrate compliance with appropriate safety related regulations and requirements.

For the small UAV SHM system considered Functional Hazard Analysis results shows that all expected Failure Conditions were classified as Non Safety Effect (NSE) therefore neither qualitative nor quantitative safety analysis is required.

Acknowledgments
The work presented in this paper has been partially supported by the European Defence Agency through Contract No B-1404-ESM2-GP entitled 'SHM Application to Remotely Piloted Aircraft Systems - SAMAS'. The two-national SAMAS project involves the following partners: Politecnico di Milano (consortium leader), and Leonardo S.p.A. represent Italy, Air Force Institute of Technology and Military Aviation Works No. 1 represent Poland.

6. References

1. ATA MSG-3. Operator/Manufacturer Scheduled Maintenance Development", Volume 1 - Fixed Wing Aircraft. ATA. Revision 2018.1.

2. AC 23.1309-1E - System Safety Analysis and Assessment for Part 23 Airplanes, Federal Aviation Administration. November 2011.
3. MIL-STD-882E. Department of Defense Standard Practice. System Safety. US Department of Defense. May 2012.
4. MIL-STD-1530D (w/CHANGE-1), Department of Defense Standard Practice: Aircraft Structural Integrity Program (ASIP). Department of Defense. October 2016.
5. NATO STANDARD AEP-83. Light Unmanned Aircraft Systems Airworthiness Requirements, Edition B Version 1. NATO. November 2016.
6. NATO STANDARD AEP-4671. Unmanned Aircraft Systems Airworthiness Requirements. Edition A Version 1. NATO. February 2017.
7. SAE ARP 4754 Rev. A. Guidelines for Development of Civil Aircraft and Systems. SAE Aerospace. December 2010.
8. SAE ARP 4761, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment. SAE Aerospace. December 1996.
9. SAE ARP6461. Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft. SAE Aerospace. September 2013.
10. SAMAS Deliverable D8.2. SAMAS compliance with regulations and feedback guidelines. EDA. October 2020.