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PRELIMINARY SYSTEM SAFETY HAZARD ANALYSIS OF A TRANSPORT HELICOPTER SHM SYSTEM

Wstępna analiza zagrożeń bezpieczeństwa systemu SHM śmigłowca transportowego

Abstract: *The purpose of this paper is to provide the Mi-8/17 helicopter Structural Health Monitoring (SHM) System Preliminary System Safety Hazard Analysis (PSSHA). The PSSHA identifies and classifies potential hazards, and the actions necessary to reduce or eliminate the risks resulting from the installation and operation of SHM System on board of the helicopter. The overall objective of the PSSHA is to establish that the potential Mi 8/17 helicopter modification does not introduce unacceptable hazard conditions to both the helicopter and personnel. The MIL-STD-882 risk assessment methodology is applied to assess hazards and risk acceptance levels for both hardware and software elements of the SHM system.*

Keywords: PSSHA, Structural Health Monitoring System, hazard, risk

Streszczenie: *Celem niniejszego artykułu jest przedstawienie wstępnej analizy zagrożeń bezpieczeństwa systemu (PSSHA) monitorowania stanu technicznego struktury (SHM) dla śmigłowca Mi-8/17. PSSHA identyfikuje i klasyfikuje potencjalne zagrożenia oraz działania niezbędne do zmniejszenia lub wyeliminowania zagrożeń wynikających z instalacji i eksploatacji systemu SHM na pokładzie śmigłowca. Ogólnym celem PSSHA jest ustalenie, że potencjalna modyfikacja śmigłowca Mi-8/17 nie wprowadza niedopuszczalnych warunków zagrożenia zarówno dla śmigłowca, jak i personelu. Metodologia oceny ryzyka zgodna z MIL-STD-882 jest stosowana do oceny zagrożeń i poziomów akceptacji ryzyka zarówno dla elementów sprzętowych, jak i oprogramowania systemu SHM.*

Słowa kluczowe: wstępna analiza zagrożeń bezpieczeństwa systemu, system monitorowania stanu technicznego struktury, zagrożenie, ryzyko

1. Introduction

The fundamental objective of system safety is accident prevention. Accident prevention can be achieved by means of identification, assessment, and elimination or control safety-related hazards, to acceptable levels. A hazard is a real or potential condition that could lead to an unplanned event or series of events (i.e. mishap) resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment [1]. Risk expresses the impact of an unplanned or undesired event in terms of its severity and event probability.

Structural Health Monitoring (SHM) of fixed and rotary wing aircraft is one of the major current research and development direction which enhance safety of aircraft operation and may reduce maintenance costs [2-7].

The purpose of this paper is to provide an analysis of the Mi-8/17 helicopter systems and personnel safety hazards when potentially modified by installation of an SHM system. This Mi-8/17 Helicopter SHM System Preliminary System Safety Hazard Analysis (PSSHA) identifies and classifies potential hazards, and the actions necessary to reduce or eliminate the risks resulting from the installation and operation of SHM System on board of Mi-8/17 helicopter.

2. Configuration of Mi-8/17 Helicopter SHM System

For the purpose of this PSSHA it was assumed that Mi-8/17 Helicopter SHM System consists of 6 SHM subsystems [5-7] which could be optionally chosen by the military customer according to its needs and possibilities. A list of the hardware elements of the SHM system is presented in tab. 1.

Figure 1 presents a graphical representation of Mi-8/17 SHM System hardware variants. Particular block symbols used in fig. 1 are explained in the tab. 2.

Table 1

List of hardware elements of the SHM system

Equipment	Producer name	Sensor type	Installation purpose
Multichannel acquisition system KAM-500 with user-modules	CWC A&E (former ACRA Contol)	Wired foil strain gages (Tenmex or Vishay)	Strain/stress measurements
		Resistive crack propagation gage (Tenmex or Vishay)	Crack length determination
Multirole recorder SSR-500 with user-modules	CWC A&E (former ACRA Contol)	Wired foil strain gages (Tenmex or Vishay)	Strain/stress measurements
		Resistive crack propagation gage (Tenmex or Vishay)	Crack length determination
SMP unit	AFIT	N/A	Signal conditioning and sensor calibration unit for KAM-500/SSR-500
BZB unit	AFIT	N/A	Overcurrent protection for KAM-500/SSR-500 as well as for aircraft electrical power distribution system. Allows to switch on/off acquisition unit to operate.
Data acquisition unit DMI SR2	Direct Measurement Inc.	Wireless polymer strain gages	Strain/stress measurements
Wireless data acquisition unit WSDA - Base 104 USB Base Station	LORD Microstrain	Wireless strain gages SG-Link	Strain/stress measurements
FBG data acquisition unit	TEMAI/INTA	Fiber optic sensors, Draw tower gratings (DTG), (FBGS Technologies)	Strain/stress measurements
Data acquisition unit PAQ-16000D	EC Electronics	PZT Sensors (Noliac and Steminc ceramic sensors)	Distributed crack detection

Fig. 1. SHM System's configuration

Table 2

SHM System's configuration block symbols

Visual representation	Description
	This block represents the entire SHM system which consists of 6 subsystems.
	This block represents optional choice and has the same meaning as traditional OR gate.
	This block represents the particular SHM subsystem and has the same meaning as traditional AND gate.
	This block represents combined optional choice: one-out-of-two OR both of equipment.
	This block represents particular equipment/unit.

3. Application of MIL-STD-882 risk assessment methodology

3.1. Hazards and risk acceptance levels for hardware

All of the new or modified (sub)systems comprising of the SHM system were evaluated against a selected list of potential hazards shown in tab. 3. The risk identifier codes were used to identify the most likely risks incurred for each (sub)system.

Table 3

Mi-8/17 SHM systems hardware potential hazards

Hazard Identifier	Mi-8/17 SHM System Hardware Hazards
HAZ001	Equipment Fails to Function
HAZ002	Integration Problems with Existing Systems
HAZ003	EMI/EMC
HAZ004	High Voltage/Shock
HAZ005	Interference with Aircrew Duties
HAZ006	Sharp Corners
HAZ007	Short Circuits
HAZ008	Hazardous/Toxic Materials

HAZ009	Static Electricity
HAZ010	Improper Mating of Connectors
HAZ011	Electrical Grounding and Bonding
HAZ011	Mechanical Fracture/Failure
HAZ013	Extreme Temperatures (High or Low)
HAZ014	Ground Clearance
HAZ015	Trauma/Struck by Equipment
HAZ016	Icing
HAZ017	Workmanship
HAZ018	Equipment Access for Servicing
HAZ019	Lightning
HAZ020	Weight
HAZ021	System Radiation
HAZ022	Shadowing/Blockage/Obstruction
HAZ023	Pilot Distraction

Based on MIL-STD-882 [1] approach the Risk Assessment Code (RAC) for Mi-8/17 SHM system modification is shown in tab. 4.

Table 4

Risk Assessment Codes (RACs) for Mi-8/17 SHM system modification

PROBABILITY	SEVERITY			
	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Finally the mishap risk acceptance levels for the Mi-8/17 SHM System modification are shown in tab. 5 below. The mishap risk acceptance level for the low risk category was assigned a level of “Acceptable” based on an initial assessment of the potential modifications. All of the acceptance levels are subject to change by the Program Manager after consulting with the military customer and assessing the impacts of potential hazards on Mi-8/17 helicopter.

Table 5

Risk Assessment Codes, Mishap Risk Categories and Mishap Risk Acceptance Levels

Risk Assessment Code	Mishap Risk Category	Mishap Risk Acceptance Level
1A, 1B, 1C, 2A, 2B	High	Unacceptable Design action is required to eliminate or control hazard.
1D, 2C, 3A, 3B	Serious	Undesirable The hazard must be controlled or hazard probability reduced.
1E, 2D, 2E, 3C, 3D, 3E, 4A, 4B	Medium	Allowable Hazard control is desirable if cost effective.
4C, 4D, 4E	Low	Acceptable Not cost effective to control.
F		Eliminated

3.2. Example of hazard analysis of SMP unit

SMP unit is a signal conditioning and sensor calibration unit for KAM-500/SSR-500. The unit operates with up to 32 channels for strain gages. In each channel, a measuring bridge completion resistors are provided for half – and quarter – bridge configuration. Additionally, calibrating resistor is also installed for each channel, to calculate transfer function from volts to engineering units.

3.2.1. Anticipated Risks

SMP unit has not been tested to confirm compliance with the environmental specification requirements. It was developed as research equipment. However, SMP unit was designed for airborne experiments applications with consideration of all specific requirements for such, and as so all necessary tests can be conducted with no considerable hardware changes.

No new risks are expected as a consequence of the installation of the SMP unit as long as the installation is in accordance with commercial and military standards for avionics. However, integration safety hazards may include incomplete or incorrect integration with the KAM-500 or SSR-500. This can cause malfunctions in operation of both SMP unit and KAM-500 or SSR-500.

3.2.2. Risk Reduction/Mitigation

SMP unit should be installed in accordance with commercial and military standards for avionics. They were taken into account by ITWL during Operational Loads Programs (OLM) conducted on: PZL-130 Orlik TC II turboprop aircraft, Su-22 fighter-bomber aircraft, MiG-29 and MiG-29UB fighter aircraft, Mi-14 and Mi-24 helicopters. Therefore there are minimal risks involved with the potential installation and integration of this system on board of Mi-8/17 helicopter.

3.2.3. Ground and Flight Testing

Ground checkout procedures will be accomplished following the Ground Test Plans. Operational checks should be accomplished in flight to verify functioning of the complete system in accordance with appropriate airworthiness documents.

3.2.4. Hazard Assessments

Risks identified for the on-board installation of SMP unit include System Hazard Identifiers HAZ001, HAZ002, HAZ003, HAZ010 and HAZ022 from tab. 3. Risk mitigation efforts that include: accomplishment of aircraft electrical load analysis and power source capacity analysis, provision of all materials and equipment as specified in the appropriate airworthiness documents, performance of weight and balance check – since SMP unit is a new system added to baseline helicopter configuration – should be sufficient to ensure a successful installation. The probability and the severity of failure are outlined in tab. 6.

Table 6

SMP unit Hazard Assessment

System Hazard Identifiers		HAZ001, HAZ002, HAZ003, HAZ010 and HAZ022
Pre-mitigation	Probability Level	D (Remote)
	Severity Category	3 (Marginal)
	Risk Assessment Code	4D (Medium)
	Suggested Criteria	Allowable
	Recommended Mitigation Actions	Perform aircraft electrical load analysis and power source capacity. Provide all materials and equipment specified in the appropriate service bulletin. Install in accordance with commercial and military standards for avionics.

cd. tab. 6

System Hazard Identifiers		HAZ001, HAZ002, HAZ003, HAZ010 and HAZ022
		Weight and balance check. Monitor.
Post-mitigation	Probability Level	E (Improbable)
	Severity Category	4 (Negligible)
	Risk Assessment Code	4E (Low)
	Suggested Criteria	Acceptable
	Recommended Additional Mitigation Actions	Monitor

3.3. Application of MIL-STD-882 software risk assessment methodology

3.3.1. Hazards and risk acceptance levels for software

A selected list of potential software hazards is shown in tab. 7. The risk identifier codes were used to identify the most likely risks incurred for the software.

Table 7

Mi-8/17 SHM system software potential hazards

Hazard Identifier	Mi-8/17 SHM System Software Hazards
HAZ100	Software Fails to Function
HAZ101	Integration Problems with Existing Software
HAZ102	Interference with Maintenance Crew Duties

Software control categories (SCC), software safety criticality (SSC) and software criticality indices (SwCIs) were applied in accordance with MIL-STD-882 [1].

3.3.2. SHM system software hazard analysis

The Mi-8/17 SHM system software generates information of a structural integrity-related nature used to make decisions by the operator or maintainer, but requires neither maintainer nor operator action to avoid a mishap. It is ground-based software and neither exercises control authority over potentially safety-significant hardware systems, subsystems, or components nor issues commands over safety-significant hardware systems, subsystems, or components.

Risks identified include System Hazard Identifiers HAZ100, HAZ101 and HAZ102 from tab. 7. Risk mitigation efforts that include using an officially recognized standard, method, technique or practice for software risk elimination or reduction should be sufficient to ensure a successful software operation. The probability and the severity of software failure are outlined in tab. 8.

Table 8

SHM system software hazard assessment

System Hazard Identifiers		HAZ100, HAZ101 and HAZ102
Pre-mitigation	Software Control Category	Influential
	Software Severity Category	Critical (2)
	Software Criticality Index (SwCI)	SwCI 4
	Risk Criteria	Acceptable
	Recommended Mitigation Action	Use a officially recognized standard, method, technique or practice for software risk elimination or reduction. Monitor.
Post-mitigation	Software Control Category	Influential
	Software Severity Category	Marginal (3)
	Software Criticality Index (SwCI)	SwCI 4
	Risk Criteria	Acceptable
	Recommended Post-Mitigation Action	Monitor.

3.4. Hazard analysis summary

Finally hazard analysis summary for both hardware and software elements of the SHM system is presented in tab. 9.

Table 9

Hazard analysis summary for hardware and software elements of the SHM system

Item	Pre-mitigation			Post-mitigation		
	Probability Level	Severity Category	Risk Assessment Code	Probability Level	Severity Category	Risk Assessment Code
Multichannel acquisition system KAM-500	D (Remote)	4 (Negligible)	4D (Low)	E (Improbable)	4 (Negligible)	4E (Low)
Multirole recorder SSR-500	D (Remote)	4 (Negligible)	4D (Low)	E (Improbable)	4 (Negligible)	4E (Low)
SMP unit	D (Remote)	3 (Marginal)	4D (Medium)	E (Improbable)	4 (Negligible)	4E (Low)
BZB unit	D (Remote)	3 (Marginal)	4D (Medium)	E (Improbable)	4 (Negligible)	4E (Low)
DMI SR2 DAU	F (Eliminated)	N/A	N/A	N/A	N/A	N/A
Wireless DAU WSDA	B (Probable)	3 (Marginal)	3B (Serious)	C (Occasional)	3 (Marginal)	3C (Medium)
FBG DAU	B (Probable)	3 (Marginal)	3B (Serious)	E (Improbable)	4 (Negligible)	4E (Low)
PAQ-16000D DAU	F (Eliminated)	N/A	N/A	N/A	N/A	N/A
Wired strain gages network	D (Remote)	4 (Negligible)	4D (Low)	E (Improbable)	4 (Negligible)	4E (Low)
Resistive crack propagation gage network	D (Remote)	4 (Negligible)	4D (Low)	E (Improbable)	4 (Negligible)	4E (Low)
Wireless polymer strain gages network	F (Eliminated)	N/A	N/A	N/A	N/A	N/A
Wireless strain gages SG-Link network	B (Probable)	3 (Marginal)	3B (Serious)	C (Occasional)	3 (Marginal)	3C (Medium)
FBG's sensor network	B (Probable)	3 (Marginal)	3B (Serious)	E (Improbable)	4 (Negligible)	4E (Low)
PZT sensor network	F (Eliminated)	N/A	N/A	N/A	N/A	N/A
	Software Control Category	Software Severity Category	Software Criticality			
Index	Software Control Category	Software Severity Category	Software Criticality			
Software	Influential	Critical (2)	SwC1 4	Influential	Marginal (3)	SwC1 4

4. Conclusions

MIL-STD-882 risk assessment methodology was successfully applied to assess hazards and risk acceptance levels for both hardware and software elements of the Mi 8/17 helicopter SHM system.

The SHM System Preliminary System Safety Hazard Analysis (PSSHA) shows that the installation of an SHM system on Mi-8/17 helicopter does not introduce unacceptable hazard conditions to both the helicopter and personnel, provided that some mitigation actions are taken.

After imposing risk reduction/mitigation activities Risk Acceptance Levels for all identified hazards are not higher than Allowable.

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