THE IMPACT OF THE INSTALLATION OF DIGITAL AVIONICS EQUIPMENT ON THE POWER CONSUMPTION OF THE HELICOPTER

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Abstract

The subject of the following paper is to analyze and present the impact of the type of avionics built on a helicopter on its energy requirements. The test object was SOKOL helicopter with different versions of equipment:
- Classic avionics (analogue);
- A partially modernized version (enhanced with digital elements);
- Theoretical upgrade with a fully implemented 'glass cockpit'.

This is an important topic, as it emphatically demonstrates the extent to which the development of technology in the avionics market influences the overall design of a new helicopter and how cost-effective it is to upgrade in-service machines. There is no doubt that the glass cockpit has a positive impact on pilot ergonomics.
All necessary information is on fully customizable displays and the human-machine interface itself is significantly simplified in operation (compared to analogue avionics), clear and pilot-friendly.

1. NOTATION

Symbols

A	Ampere
AC	Alternating current
Ah	Ampere-hour
DC	Direct current
Hz	Hertz
kVA	Kilovolt-ampere
kW	Kilowatt
V	Volt

2. INTRODUCTION

All versions of the PZL-W3A and W-3() SOKOL helicopters comply with the regulations of the FAR-29 in terms of electrical and avionics equipment requirements.

PZL Świdnik takes care of the continuous development of the project, modernizing it according to customer expectations and applying new technologies.

An important element of the implementation of the new, future-oriented version of the W-3 SOKÓŁ is the development of a glass cockpit, which will significantly reduce the number of individual flight parameter displays, placing them on fully customizable pilot screens. Each pilot will have two displays reflecting the position of the helicopter in space, indicating system operating parameters such as hydraulic system pressure, turbine speed, rotor lift torque (and other parameters), and, clearly signaling failures.

Due to the planned significant change in the helicopter's design, an electrical analysis is required to ensure safe and stable operation of the electrical systems in all phases of flight. In addition, an analysis of the manufacturer's technical documentation for the systems to be installed will verify whether the helicopter's power sources have a reserve of generated current, and if so, what size.

An important decision affecting the future configuration of the W-3 Sokół helicopter was to improve the legibility of the cockpit and to gather all indicators in one place (on the instrument panel), with the best possible access to information by both pilots.

Three important stages in the implementation of the new cockpit were defined:

- Stage of selecting the individual components of the glass cockpit system and parts that work with it.

- Design stage, in which all the mechanical and electrical connections of the components of the new system will be prepared.

- System testing on the helicopter, including the first commissioning tests of the new system.

This article presents the systematic methodology used to test the impact of the development of digital avionics on the energy requirements and the overall power system of the helicopter.

3. DESCRIPTION OF ELECTRICAL LOAD ANALYSIS

The analysis is a document containing the sum of the electrical loads connected to a given system under specific operating conditions of the helicopter, taking into account the capacity limitations of the power supply equipment.

The document contains operation in the normal state (operational power sources) and in the emergency state.

An emergency condition is a situation where the primary electrical power source ceases to function and a backup source is required.

4. DESCRIPTION OF ELECTRICAL DESIGN

Installation of a DC power system is a two-channel type with automatic connection of the both channels.

Each channel is a separate circuit that supplies half (in terms of load) of the consumer equipment.

An AC generator GT40PCz8B via a transformer-rectifier WU-6B connected to the central bus powers the left channel and a battery connected to the central bus of the left battery.

The right channel is powered by a WG-7500Ja-2s DC generator connected to the central power bus and a set of batteries connected to the central bus of the right battery pack.

Batteries are charged and stabilize the voltage under normal operating conditions. Under emergency conditions, they take over the power supply of the entire DC system.

Connection of the two channels takes place automatically when the on-board grid is supplied with DC power from a ground source at the airport, during start-up and during flight, either automatically or manually.

Output power of the WG-7500Ja-2s generator and WU-6B rectifier is sufficient to power both channels together. The operating condition, when both or one of these sources is operating, is the normal condition.

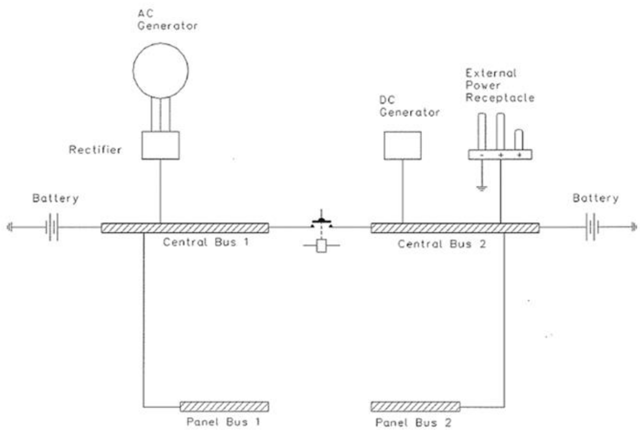

Figure 1: DC power system diagram

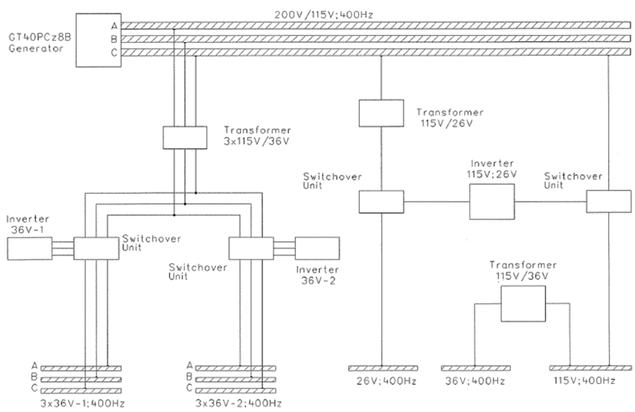

Figure 2: AC power supply system diagram

5. PZL W-3 SOKOL POWER ANALYSIS

This chapter presents the basic power parameters of the SOKÓŁ helicopter.

First version of the helicopter was developed in the 1970's. The helicopter was equipped with Russianmade avionics, the installation of which on the instrument panel is shown below.

Figure 3: Cockpit of PZL W-3 SOKÓŁ helicopter (for reference only)

Basic classification is predicated on the fact that the powered components need both AC and DC voltage.

Table 1 W-3 SOKÓŁ power supply output data

NAME	**DIRECT CURRENT GENERATOR**	**ALTERNATING CURRENT GENERATOR**	**TRANSFORMER RECTIFIER**
Number of devices	1	1	1
Rated power	9.0 kW	40 kVA	6 kW
Voltage	28.5 V	3 x 200V/115 V	28 V
Frequency	---	400 Hz ± 5%	---
Power factor	---	0.8 ÷ 1.0	---
Configuration	---	star with neutral conductor	---
Manufacturer	Russia	Russia	Russia
Type	WG-7500 Ja-2s	GT40PCz8B	WU-6B
Overload capacity	350A (1 minute)	60 kVA (5 minutes) 80 kVA (5 seconds)	300 A (2 minutes)
Control block	R-27	BRN 120T 5A-2s	---
Rated current	300 A	111 A	200 A

Emergency power is provided by two batteries used to power the on-board systems in case the main power sources fail during flight. An additional function is to start the engine on the ground if ground power systems are not available.

Table 2: Battery data

NAME	**MAIN BATTERY**
Unit	Rechargeable battery
Number of devices	2
Power rating	-
Voltage	24 V
Manufacturer	Russia
Model no.	20 NKBN-25-U3
Overload capacity	-
Voltage holding	-
Capacity	25 Ah
Maximum current	650 A

Based on the manufacturer's data on power sources and individual electrical equipment, a chart was drawn up showing the DC power requirements of the on-board systems during the various phases of flight, including emergency situations.

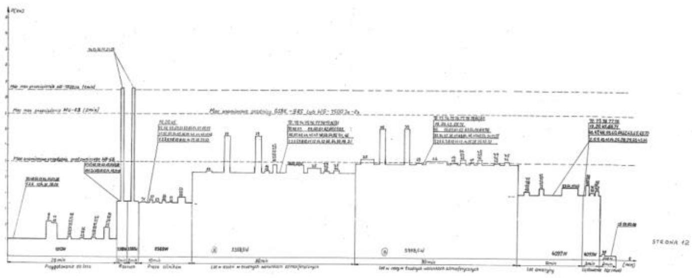

Figure 1: DC requirement diagram

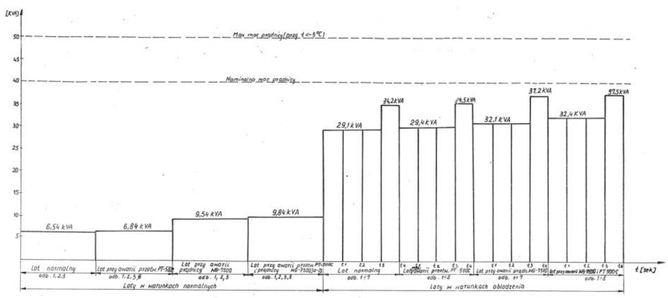

Figure 2: AC requirement diagram

Based on the data from the power sources and the individual electrical devices, a chart was drawn up showing the AC energy requirements of the onboard systems during the different phases of the flight, including emergency situations.

It shows that throughout the flight, the power demand does not exceed the load of the sources.

Maximum power consumed by the helicopter's onboard systems is 5958.5 W and occurs during flight in severe atmospheric conditions at night. During flight in severe atmospheric conditions during the day, the required power decreases and is 5358.5 W.

Under possible worst-case conditions, which are not emergency conditions, the maximum current delivered by both DC generators will be 198.2 A. The AC generator will deliver 84.3 A at the same time.

In special cases where auxiliary equipment is used, the rated current of the WU-6B may be exceeded. The value and time of the overload is within the permissible limits specified by the manufacturer without causing permanent damage.

If the WG-7500Ja-2s alternator malfunctions, there is a power deficit during daytime operation in severe weather conditions with the winch running. In severe weather conditions at night there is a power deficit when the winch and floodlight are operating.

Given the possibility of a short-term overload of the rectifier, the power requirement will be provided.

When both main power sources are out of operation, all DC mains consumers are supplied from the battery bank.

In this case, the operating mode switch must be switched from normal mode "NORM" to emergency mode "AWAR".

Channels are then connected, the central buses of the faulty rectifier and generator are disconnected and the dual power bus consumers are disconnected.

The batteries then power only the receivers necessary for a safe 30-minute flight and landing.

6. PZL W-3A SOKOL POWER SUPPLY OUTPUT DATA

This chapter presents the basic power parameters of the W-3A SOKÓŁ helicopter.

It is a modernized version of a helicopter developed in the 1990s, which has been equipped with partially upgraded avionics, including a moving map system.

Figure 3: Cockpit of PZL W-3A SOKÓŁ helicopter (for reference only)

DC power system on the W-3A helicopter is a two-channel system. Each channel is a separate system that supplies half (in terms of load) of the power consumers. The power source for the left channel is a GT40PCz8B AC generator working with a WU-6B transformer-rectifier unit.

Right channel is powered by a WG-7500 Ja-2s DC generator connected to the central bus 2. In addition, an F20/25H1CT2 battery is connected to each channel to recharge and stabilize the voltage under normal operating conditions. Under emergency conditions (no main power source), the batteries take over the power supply of the entire DC system. The connection of the two channels occurs automatically when one of the main power sources or only the batteries are energized.

Central bus bar 1 and 2 supply power to console bus bar 1 and 2 respectively, distributing power to the individual helicopter receivers.

Power supply to the console bus bars is provided in a double-track manner via backup fuses built into the left and right channel DC switchboards.

Table 3: W-3A SOKOL power supply output data

NAME	DIRECT CURRENT GENERATOR	ALTERNATING CURRENT GENERATOR	TRANSFORMER RECTIFIER
Number of devices	1	1	1
Rated power	9.0 kW	40 kVA	6 kW
Voltage	28.5 V	3 x 200V/115 V	28 V
Frequency	---	400 Hz ± 5%	---
Power factor	---	0.8 ÷ 1.0	---
Configuration	---	star with neutral conductor	---
Manufacturer	Russia	Russia	Russia
Type	WG-7500 Ja-2s	GT40PCz8B	WU-6B
Overload capacity	350A (1 minute)	60 kVA (5 minutes) 80 kVA (5 seconds)	300 A (2 minutes)
Control block	R-27	BRN 120T 5A-2s	---
Rated current	300 A	111 A	200 A

The power generation equipment was not changed during the upgrade. Instead, the battery system was changed. A BFGoodrich emergency battery was added and the Russian battery pack was replaced with a VARTA product.

The emergency power is provided by the battery to supply power to the onboard systems in case the main power sources fail during flight. The function of starting the engine on the ground, when ground power systems cannot be used, is taken over by separate battery packs.

Table 4 Battery data

NAME	MAIN BATTERY	EMERGENCY BATTERY
Unit	Rechargeable battery	Rechargeable battery
Number of devices	2	1
Power rating	13 kW	-
Voltage	24 V	24 V
Manufacturer	VARTA (Germany)	BFGoodrich Avionics Systems
Model no.	F20/25H1CT2	PS-885A
Overload capacity	-	-
Voltage holding	-	-
Capacity	25 Ah	2.5 Ah
Maximum current	650 A	25A

6.1. ANALYSIS OF THE DC POWER SYSTEM

The following flight phases were taken into account when developing the energy balance for the W-3A helicopter:

Table 5: Flight phases

Symbol	Phase of flight
G-1	Ground work
G-2	Calibrations
G-3	Preparation and loading
G-4	Start-up and warm-up
G-5	Taxiing
G-6	Take-off and climb
G-7	Flight
G-8	Operational flight
G-9	Landing
G-10	Emergency condition

The load tables for the different phases of flight are shown below. Each phase is divided according to the maximum current duration. This division makes it possible to determine whether a possible overload of the power supply components over time will be destructive.

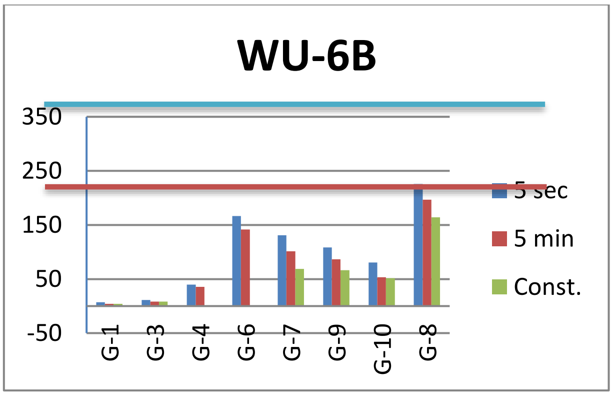

Chart 1: Loads on the rectifier during the various flight phases (left channel)

Table 6: Loads during each phase of flight

	G-1			G-3			G-4			G-6		
	5 sec	5 min	Const.	5 sec	5 min	Const.	5 sec	5 min	Const.	5 sec	5 min	Const.
Load on central bus 1												
Sum	7,2	4,2	4,3	11,4	8,4	8,5	39,4	35,8		166,4	141,6	
Load on central bus 2												
Sum	14,2	11,2	11,3	14,2	11,2	11,3	319,8	134,7		218,2	198,4	
Load on central bus 1 & 2												
Sum	21,4	15,4	15,6	25,6	19,6	19,8	359,2	170,5		384,6	340	

	G-7			G-9			G-10			G-8		
	5 sec	5 min	Const.	5 sec	5 min	Const.	5 sec	5 min	Const.	5 sec	5 min	Const.
Load on central bus 1												
Sum	130,8	101,4	69,0	108,5	86,6	66,5	80,3	53,3	51,5	226	196,6	164,2
Load on central bus 2												
Sum	373,7	345,6	160,6	234,5	207,2	161,3	272,8	247,2	122,1	419,3	382,2	197,2
Load on central bus 1 & 2												
Sum	504,5	447	229,6	343	293,8	227,8	353,1	300,5	173,6	645,3	578,8	361,4

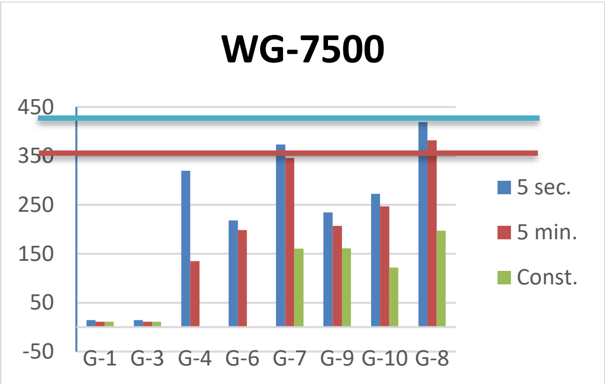

Chart 2: DC generator loads during individual flight phases (right channel)

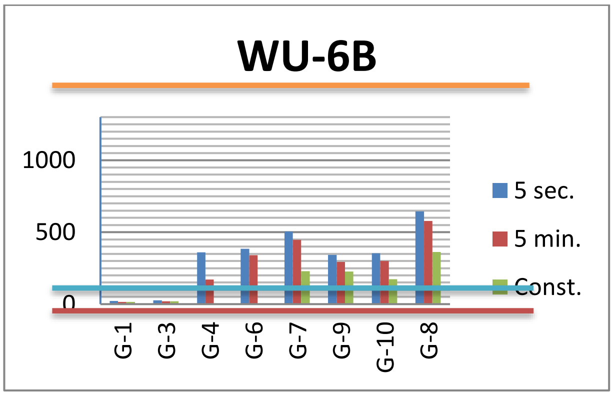

Chart 3: DC system loads during individual flight phases (left and right channels connected)

On the basis of the load analysis table (Table 6) and the load diagram (Chart 1), it can be concluded that for normal system operation, in the G-8 condition (combat flight), the 5 sec. load of the channel supplied by the WU-6B rectifier device is exceeded.

Due to the possibility of overloading the rectification device up to 300A in 2min, adequate power must be provided to supply the DC loads.

On the basis of the load analysis table (Table 6) and the load diagram (Chart 2), it can be concluded that for normal operation of the system in state G-4, the load of 5 sec. is exceeded, and in states G7; G-8 (combat flight) the load of 5 s and 5 min of the channel supplied from the DC generator WG-7500 is exceeded. Due to the possibility of overloading the DC generator up to 350A in time of 1 min, sufficient power is ensured to supply the DC receivers taking into account the inclusion of the following interchangeably into operation: winch, SX-16 reflector or medical apparatus.

On the basis of the load analysis table (Table 6) and the load diagram (Chart 3), it can be concluded that in the event of failure of the transformer-rectifier WU-6B or the generator GT40PCz8B, there is a 5-second power deficit in operating states G4; G6; G7; G9 G10 and G-8, a 5-minute power deficit in states G6, G7 and G8, and a continuous power deficit in states G-9.

This results in the need to shut down the 76378-360 winch. When the WG-7500 Ja -2s alternator fails, there is a 5-second power deficit for the operating states: G4 G6; G7; G9, G10 and G8 and 5min for states G-6, G-7, G8 and G-9, and there is a continuous deficit for states G7 AND G8. Short-term increased power consumption will be provided by the WU-6B transformer-rectifier unit (potential for overloading). A power deficit in the G-8 operating state requires that only the basic equipment necessary to continue the flight is left on.

Operating the system with both primary power sources inoperative is an emergency operation. In this case, all of the helicopter's essential receivers are powered from the battery bank and the helicopter's flight time is limited to 30 minutes.

In the case of the W-3A SOKÓŁ helicopter, there is an increase in power consumption. The DC buses require 229.6 A of power during normal flight. When converted, this gives an increase in power requirements of 6428.8 W.

6.2. AC SYSTEM

Primary sources of AC power in the W-3A helicopter are the GT40PCz8B AC generator and the EP-10 and PC-350 inverters (Figure 2).

During normal helicopter flight, the 3x36V-1, 3x36V-2, 26V, 36V, 115V buses are supplied from the respective inverters (the 36V bus additionally via a transformer), while the 3x200V/115V bus is supplied directly from the GT40PCz8B generator. The power supply to the loads is provided directly from the generator (115V bus) or via suitable transformers (26V, 36V, 3x36V buses).

On the basis of the AC load diagram (Figure 5) and the load diagram of the individual buses it is concluded that the AC consumers installed on the medium have full power protection during normal operation of the primary power sources as well as during the failure of all inverters.

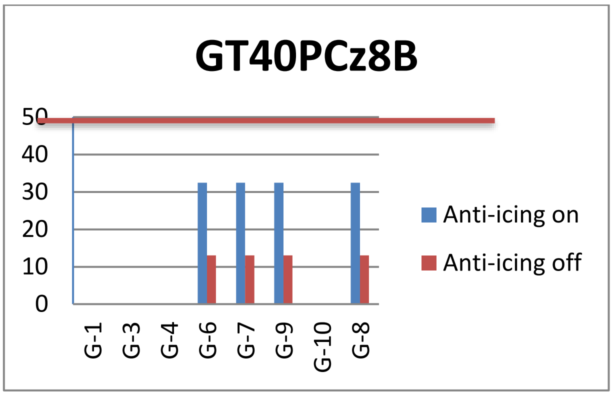

Chart 4: AC power system loads 200V/115V; 400Hz.

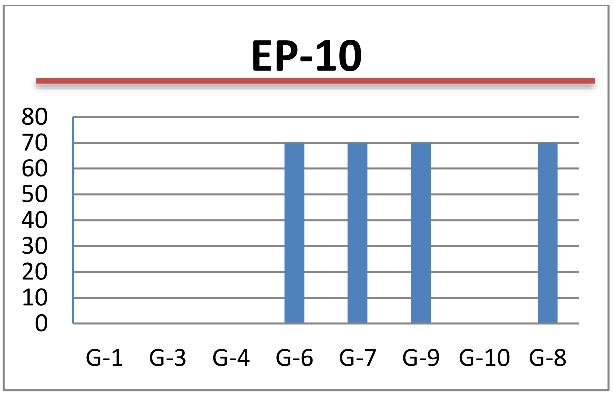

Chart 5: AC power system loads 3X36V-1; 400Hz

The power taken from the AC bus bars is 37 kVA, which, after conversion, results in a current value of 106.8 A.

7. W-3 VERSION WITH MODERNIZED AVIONICS

Changing and growing requirements for combat, technical, operational and flight safety capabilities resulted in the need to check the impact on energy demand of the upgrade consisting of the installation of glass cockpit-based avionics.

It was assumed that the modernised version of the PZL W-3 helicopter would be equipped with power systems and connections identical to those of the PZL W-3A helicopter (point 6).

Tests conducted on a version of the helicopter equipped with a full glass cockpit were performed in order to obtain an answer as to whether the power system, with which the helicopter is currently equipped, will not be overloaded in any way or whether the installation of modern equipment will significantly reduce production or operating costs.

Because the work was based on assumptions, it is not possible to clearly define the equipment complement that would be used/upgraded in the finished product.

The focus was mainly on electrical equipment without considering other elements that could be changed. Therefore, consideration was given to replacing the analogue displays with a display system with dedicated sets of sensors and transducers.

Based on the available documentation, the electrical system load results were obtained.

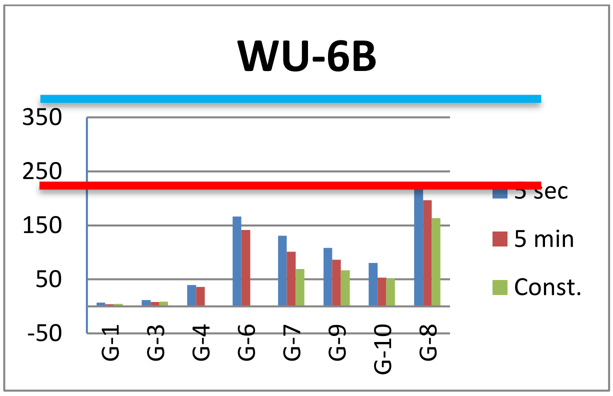

Chart 6: DC generator loads during individual flight phases (right channel)

The graph above clearly shows that the limits of the continuous current draw will not be exceeded, while the other values will be within the limits specified by the generator manufacturers.

8. CONCLUSION

After an analysis comparing the electrical load requirements of the equipment, it was concluded that:

- The installation of modern avionics has a practically negligible effect on the helicopter's power requirements.

After the analysis, it was found that the result obtained is mostly due to the mechanical operation of the analogue avionics, where the element requiring power was the SM-37-type bulb used to illuminate the indicator dials. It should be added that such a bulb has a current consumption of only 0.05A. By placing the displays in place of the analogue indicators, it can be concluded that the energy requirements of the components will be at a similar level.

In spite of the result obtained from the tests carried out, it should be remembered that a full aircraft electrical load analysis and power source capacity is required for each aircraft electrical equipment upgrade/replacement operation. This is due to the fact that each unit is constructed differently, which makes it impossible to clearly state the impact that the changes will have.

Undoubtedly, however, the installation of modern avionics in each case will have a significant impact on increasing comfort, safety, operational capabilities.

The percentage change in power consumption in the above study will be less than 1 percent. Therefore, it can be assumed that this value will be negligible.

The work it has been performed on real data and on a specific helicopter model, but analysis of results are able to provide a wider series of consideration applicable to other products. Suggesting also implications of the overall integration of digital equipment's on the overall platform Performances.