AUTOROTATION: PHYSIOLOGICAL MEASURES OF WORKLOAD

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Abstract

The workload assessment to perform a full autorotation on the AS-350 aircraft (Airbus Helicopters) was performed during a Flight Test Campaign with 80 flight hours and 227 data collection procedures, considering 10 pilots with different piloting skill levels, among such military pilots, flight instructors, and test pilots. During the tests, these pilots were subjected to unexpected engine failures, to evaluate the actual reaction time of each pilot, and to test the ability to make a safe landing under the conditions prescribed by the aircraft manufacturer. The testing method used began with unexpected engine failures when only the lead test pilot knew that the engine failure would be simulated. In the sequence, several points of autorotation were performed, from the simplest profile to the most complex. All the procedures have registered the performance parameters and handling qualities of the aircraft, along with the physiological parameters of the pilots. The aircraft was equipped with dedicated instrumentation for in-flight testing and the pilots have been instrumented with an Electroencephalogram (EEG), Electrocardiogram (EKG), Respiration Belt and Galvanic Skin Response (GSR), Eye Tracking and Face Recognition Camera equipment. This instrumentation was employed to determine physiological markers that could determine the pilot workload, quantitatively, reducing the subjectivity of measures that use only qualitative scales of evaluation, such as Handling Qualities Rate (HQR) and Bedford Workload Scale (WL). In this work, only the preliminary results of the analysis obtained by the Galvanic Skin Response markers will be presented. Major potential applications of the results from the present research range from cockpit design guidelines and human-machine interface systems for supporting pilotage such as more effective alarm systems, interactive cockpits, enhancement of active autopilots with semi-automatic flight commands. Besides that, the results and conclusions from this research can also improve processes and methods for the training-based formation of pilots, along with the development of flight simulators with physiological measurements parameters quantification, feeding back data for a piloting performance assessment.

1. SYMBOLS AND ABBREVIATIONS

Dδc	Collective pitch control position	%
Dδl	*Lateral pitch control position*	*%*
Dδm	*Longitudinal pitch control position*	*%*
Dδn	*Pedal pitch control position*	*%*
DδT	*Fuel level control position*	*%*
EEG	*Electroencephalogram*	*-*
EKG	*Electrocardiogram*	*-*
GSR	*Galvanic Skin Response*	*μS*
HQR	*Handling Qualities Rating*	*-*
I	*Moment of inertia*	*-*
KIAS	*Knots indicated airspeed*	*kt*
Ng	*Engine gas generator speed*	*%*
NR	*Main rotor speed*	*RPM*
p	*Angular velocity about x-axis*	*°/s*
q	*Angular velocity about y-axis*	*°/s*
r	*Angular velocity about z-axis*	*°/s*
Tq	*Engine torque*	*%*
θ (theta)	*Pitch angle, shaft angle*	°
φ (phi)	*Roll angle*	°
ψ (psi)	*Yaw angle*	°

2. INTRODUCTION

The autorotative flight of single-engine helicopters requires a high degree of training yielding the pilot to perform all the maneuvers to land safely, especially on low-inertia helicopter rotors [1].

In 2014, SCARPARI and DE ANDRADE [2] have called the attention to the reaction time associated

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September 2019

with the pilot performing an autorotation after a sudden failure of the engine along with all the actions to allow the recovery of the main rotor RPM. Depending on the model of the aircraft and on the flight profile at the time of the engine failure, the pilot has less than one second to complete all the tasks.

The Standard FAR-Part 27 [3], which applies to light helicopters with a maximum takeoff weight of up to 2,741kg (6,000lb), establishes performance criteria and flight qualities, including the autorotation. Yet, the latter is subjective in some aspects. Paragraph §27.87 (a) indicates that if there is any combination of height and speed, including hovering, where a safe landing cannot be made after an engine failure, a flight envelope containing an unsafe combination of the two aforementioned parameters must be determined – the height-speed diagram or the "dead man's curve".

Some authors propose mathematical models to characterise this curve. Figure 1 shows a boundary that divides the combinations of height and speed that allow the transformation of the translational kinetic and gravitational potential energy in rotation of the main rotor [4].

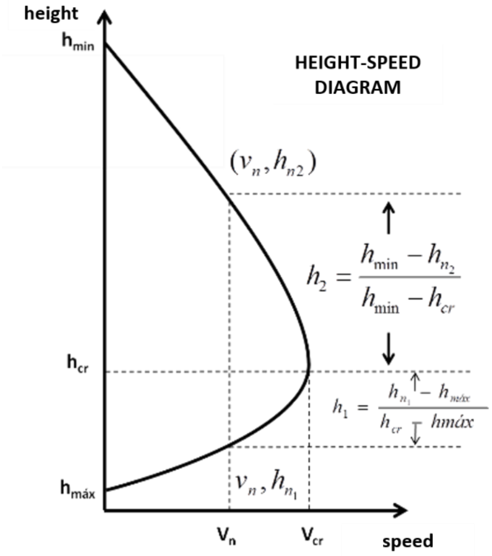

Figure 1: Mathematical model of Height-Speed Diagram

This traditional mathematical model is a strict flight physics-based model, it does not consider important interaction factors, such as training, pilot skills level, field of vision, among others, which might turn the dimensions and limits of this curve dependent the human facts already described.

FERRELL, K. R. et al. [5] show that this curve expresses a workload ratio, where the combination of height and speed in the internal area represents an excessive workload to perform all maneuvers needed for a safe landing in autorotation, making landing unlikely safe.

The United States Naval Test Pilot School (USNTPS) [6] establishes criteria for carrying out the test flights necessary to determine this curve, taking qualitative opinions of its test pilots by means of workload scales such as the Handling Qualities Rating (HQR) [7] and the Bedford Workload Scale (WL) [8], confirming the influence of the workload in defining the limits of this curve.

There is an indication from the previously identified work that there are two possible ways to tackle the autorotation challenge: (1) flight physics energy transfer-based and (2) interview-based workload assessment.

Nevertheless, there is a potential problem, given that, despite the shape and dimensions of the curve, it is very hard for a pilot to perceive the engine's failure and react in time to satisfy all the requirements for a safe landing, especially for helicopters with low inertia rotor systems. In addition, in general, no successfully lands are observed on aircraft with real engine failure.

SCARPARI, J. R. S. et al. [9] demonstrate that several factors influence the accomplishment of an autorotation, e.g., pilot's ability to perceive engine's failure, pilot's reaction time, the attitude of the helicopter at the time of the engine's failure and the environmental conditions, especially the wind's intensity and direction.

Thus, in addition to workload and flight physics behavior, there are also three major contributing factors to the emergency autorotation recovery analysis: (1) the aircraft (machine); (2) the environment; and (3) the pilot. Regardless of the machine technologies and with the impossibility of controlling the environment, a crucial factor for the success of an autorotation points out to the human being aboard the operating aircraft.

Therefore, to better understand the role of the pilot working at autorotation maneuver, this research propose to reveal that, from pilot's physiological factors submitted to an engine failure, the is the need of the pilot react properly and quickly, regardless of height and speed at the moment of emergency, which point out that the Height-Speed diagram might be considered as a minimum requirement to be superimposed the psychophysiological information for turning the autorotation flight maneuver safe.

During the Flight Test Campaign, all pilots have worn physiological sensors to measure their main reactions in the condition of stress and nervousness of a real emergency.

3. THE FLIGHT TEST CAMPAIGN

To understand the physiological behavior of the pilots during the autorotative flight, a Flight Test Campaign was conducted with 10 pilots of different levels of experience, all of the flight instructors, 6 test pilots and 4 operational pilots from the Brazilian Air Force (BAF).

The following physiological sensors were employed, Figure 2: Electroencephalogram (EEG), Electrocardiogram (EKG), Respiration Belt Sensor, Heart Rate, Respiration Sensor, Galvanic Skin Response (GSR) Sensor, Eye Tracking and Face Recognition Camera.

Figure 2: Physiological sensors

Each of the pilots performed three flights in autorotation aboard the AS-350 helicopter of the Brazilian Air Force. The aircraft was instrumented with an Inertial Measurement Unit (IMU), providing measurement of *p, q, r, θ, φ, and ψ*; a time-resolved; quantification of the input measured quantities such as *Dδc, Dδl, Dδm, DδT; and measurement of output quantities namely: Ng, Tq, NR,* and Fuel Quantity.

During the tests, the pilots held simulated engine failures in various combinations of height and horizontal speed, considering the points outside and inside the dead's man curve, as well as some of the borderline between the areas to avoid defined by the aircraft manufacturer.

In the first autorotation event for each pilot, the engine failure was simulated by moving the fuel flow lever to flight idle position (*Ng* = 67%) without the pilot knowing and being prepared for that situation. It was a simulation for an unexpected engine failure.

To maintain the desired surprise effect, the pilot was instructed to perform a task that required high concentration and workload, that is: keeping the flight level at 200ft and speed of 80kt and these parameters set within ± 10ft and 1kt for 1 minute. It was also requested that silence was kept in the cockpit, with the “pseudo-objective” of facilitating the synchronization of the physiological data with the aircraft's counterparts.

Thus, each pilot performed over 20 full autorotational flights, three of which under unexpected conditions. At all points, the pilots performed a task with the purpose of testing the workload, considering the Handling Qualities Rating (HQR) and Bedford Workload Scale (WL) scales.

3.1. AUTOROTATION TASK:

In the following, the autorotation tasks will be quantitively described:

1) KIAS > 55 kt

- Carry out the complete landing in autorotation;
- Get the recommended speed of autorotation;
- Achieve the recommended RPM for autorotation;
- Perform the complete maneuver with HQR ≤ 4,5.

2) KIAS < 55 kt

- Carry out the complete landing in autorotation;
- Maintain RPM above 320RPM;
- Perform the complete maneuver with HQR ≤ 4,5

Desirable: landing at speeds less than 30 kt;
Adequate: landing at speeds less than 40 kt;

The following objectives have been achieved during these flights:

1) Test the workload to achieve the complete autorotation procedures on approach and landing profiles.

2) Evaluate the reaction time of the pilots.

3) Evaluate the physiological reactions of the pilots during the autorotation.

4) Validate the method of construction of the Diagram Height x Speed (ISO-HQR).

4. DEAD MAN'S CURVE: ENERGY BALANCE VERSUS WORKLOAD

Although there is a curve that delineates the conversion of translational kinetic and gravitational potential energy into the main rotor rotational speed (to keep rotational kinetic energy in the blades of the main rotor system), this research focuses on the human factor contributions which can extend or alter the boundaries of the curve. It considers the physiological response of the pilots, under conditions that are required to react adequately due to engine failure, especially when it comes unexpectedly.

To demonstrate that the workload has an influence on the dead man's curve, three hypotheses were established:

1st HYPOTHESIS - The physiological reactions are different among pilots: (a) in each combination of height and speed of the dead man's curve; (b) in combinations of specific points specifically if it is "outside", on the boundary or "inside" of the height and speed curve; (c) depending if the engine's failure occurs expectedly or unexpectedly;

2nd HYPOTHESIS – Experience and training influence the physiological response of pilots during an autorotation;

3rd HYPOTHESIS – There are physiological markers that might show high workload situations during engine failure.

In order to evaluate the human being response, driven by the aforementioned hypotheses, measured parameter based physiological results along the Flight Test Campaign are presented, including GSR, EKG, EEG, eye-tracking, heat maps, flight command positions and interview-based qualitative evaluation of pilots based on two workload scales, HQR and WL.

Here only the preliminary results of the analysis obtained by the Galvanic Skin Response markers will be presented.

4.1. GALVANIC SKIN RESPONSE (GSR)

The measurement of involuntary physiological responses of the human body is under the scope of Biometry. It can be performed in many ways, such as heartbeat, breathing, and pupil dilatation of the eye [10]. In particular, this research uses the Galvanic Skin Response (GRS) measurement sensor, which detects changes in the electrical conductivity of the skin.

The selection of this sensor for this research is supported by the fact that it is related precisely to emotional changes, especially stress. The human body responds physiologically to cardio alterations and to certain hormones such as adrenaline and cortisol [11] when subjected to threat events. The use of GRS-type sensors can easily characterize the emotional variations associated with autorotation operations [12].

Going towards understanding the physiology and related autonomic reaction. The autonomic nervous system can be divided into two subsystems: the sympathetic and the parasympathetic. The former is oriented towards the motor reactions of the organism, like the alterations of the heartbeat, an increase of blood pressure, sweating and motor preparation. Variations within the sympathetic subsystem inducing emotional changes in the pilot can be measured [13].

The GSR takes advantage of a human physiological feature, which is the variation of sweat glands activity, occurring under the condition of emotional changes and stressful stimuli, which is interrelated with the variations in the sympathetic activity system [14].

Herein one presents and analyses the GSR responses, in amplitude, according to parameters showed in Figure 3 [15]: rising time, peak amplitude and recovery time. The baseline for quantifying the results coming from the pilot's marks is stablished in one minute prior to the helicopter's unexpected engine failure.

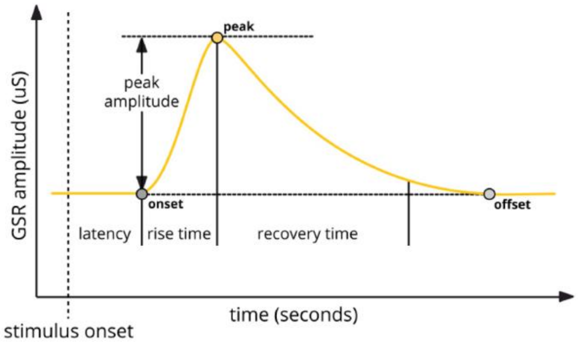

Figure 3: GSR analysis parameters

The graphs show the physiologic data of each pilot, taking into consideration three groups of analyses: (1) individual for each pilot; (2) averages of each pilot in 26 different combinations of height and speed and (3) per level of experience. In all of them, it is possible to analyse the differences in rising time, peak amplitude, latency and recovery time.

The unit of measurement of the GSR sensor used is Siemens (S), which measures the electrical conductance and admittance. Siemens equals the inverse of the Ohm.

A GSR sensor was attached to the fingers of the pilots during all flight time, Figure 4. All data were transmitted in real-time and synchronised by means of the NINA™ application, a software developed for synchronisation between physiological and aircraft data.

Figure 4: GSR sensor

NINA™ also provide tools for all data analyses, making the combinations of aircraft and pilot's physiology data be possible, even those with different frequencies, that varies from 2 to 100hz. Beyond that, this software plots all graphs, considering special filters and all statistics tools.

4.2. GROUPS OF PILOTS

The pilots were divided into groups of different levels of experience, namely: (1) test pilots with great experience in autorotation (those whom have performed more than 1,000 autorotation flights); (2) test pilots with little experience in autorotation (those whom have performed less than 1,000 autorotation flights); and (3) experienced pilots, but with no experience in complete autorotation flights.

4.3. CRITICAL WORKLOAD

"A bad ending of an autorotation is usually survivable, but a bad beginning of an autorotation is usually not." [16]

Based on this statement, Prouty summarizes the problem faced by pilots after an engine failure. The entry into autorotation depends on the perception of the engine failure and in the psychomotor actions of the pilot (the relationship between cognitive functions and physical movement) fundamentally in the immediate lowering of the collective pitch control and in all subsequent controlling maneuvers.

In addition, it is important to note that an improper entry may make it impracticable to carry out autorotation, especially because of the delay in recovering the nominal main rotor RPM recommended by the aircraft manufacturer, and may incur the following problems [17]:

(1) divergence RPM;
(2) the increase of the bending moments at the rotor blade roots;
(3) decrease the rotor-fuselage vertical physical separation (structural interference);
(4) decrease the power of control; and
(5) loss of lift.

5. RESULTS

The plots summarizing the results, presented herein have the contribution of the aircraft flight mechanics and instrumentation, physiological data (obtained from the sensors installed in the pilots), and qualitative evaluation based on HQR and WL scales. They serve to confirm the research's established hypotheses.

As previously stated, the results presented herein represent only the GSR response. The data were normalized based on an initial amplitude reference for all pilots. For all test points, the engine was reduced to flight idle regime (*Ng* = 67%) and each pilot performed at least three autorotations with unexpected engine failures. The comparisons among groups were made taking into account the average of the results of all test points, considering the period of 10 seconds prior to the simulated engine failure until the end of the flare.

They shall be based on the three previously described hypotheses' analyses as follow.

1st HYPOTHESIS: The physiological reactions between pilots are different.

Before going into specifics, one can observe in Figure 5 differences in the GSR amplitude among ten pilots, in a calm condition, instants prior to the simulated engine failure.

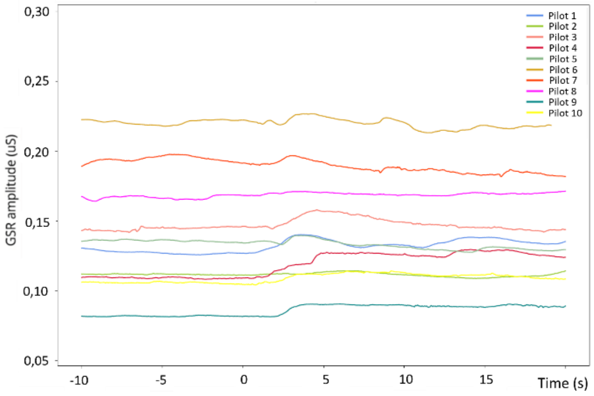

Figure 5: GSR individual pilot's response

This feature reveals that training should be personalised because different people react physiologically differently to emotional stimuli.

a) The physiological reactions are different among pilots: in each combination of height and speed of the dead man’s curve

Under this aspect, one considers that there are different levels of difficulty to perform an autorotation, depending on the combination of height and speed. Points at low height and speed (knee of the dead’s man curve) are more critical, Figure 6. Points C2 e D2, and high-altitude hover (E2), Figure 7, confirm the data published in 2014 by Scarpari and de Andrade [2].

In Figure 6 it is possible to verify the behavior of a pilot in different regions of the Height x Speed diagram. It is observed that the greatest physiological reactions exactly happened at the most critical height and speed conditions.

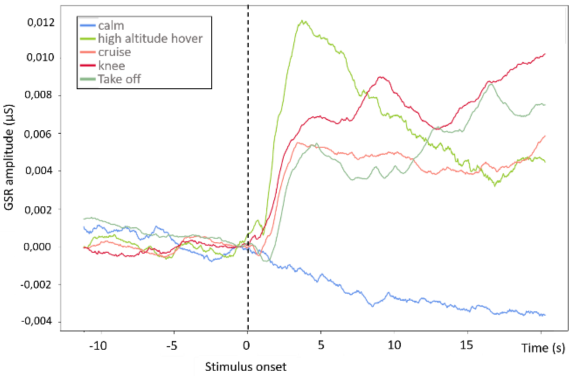

Figure 6: GSR average of pilots in different combinations of height and speed

Higher GSR values represent greater emotional changes for the pilot.

This information can be confirmed by the pilots' subjective assessment, which indicated higher workload values (HQR and WL) in the same height and speed combinations where the greatest variations and amplitudes of the GSR occurred, as can be seen in Table 1. For the purpose of qualitative evaluation, only the data provided by the test pilots who had specific training for this evaluation were considered.

Table 1: Pilot’s HQR and WL results

PILOT	E2		EFG		DH	
	HQR	WL	HQR	WL	HQR	WL
SCA	4	5	4	5	7	8
CRE	4	4	4	6	6	7
CTL	4	4	4	6	6	7
ROQ	4,5	6	4	6	7	8
MTS	4,5	6	5	6	6	7
Average	4,2	5,0	4,2	5,8	6,4	7,4

Observation: E2, EFG, DH, and ABC are and point and quasi-linear segments within the height-speed diagram in Figure 7.

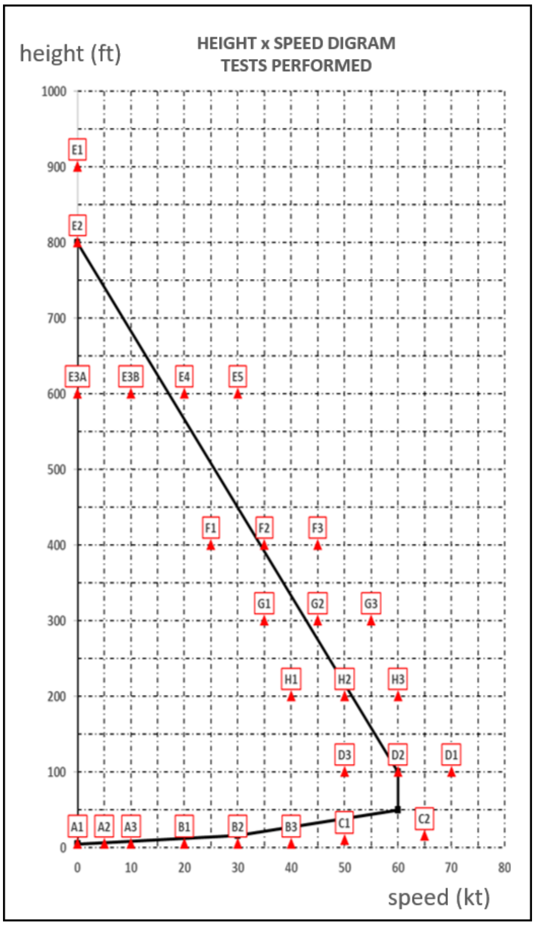

Figure 7: Height x Speed Diagram: tests performed

It is important to emphasise the great difference in the GSR amplitude between the average of the results of the pilots in the calm condition when compared with the results obtained during the autorotations.

The only exception occurred in the high-altitude hover flight test point (E2) when a very high response peak can be observed, even greater than the test points in the knee of the curve. This response occurred due to two main reasons, namely:

i) the dynamics of the autorotation entry in this test implies the pilot to perform great variations in the attitude of the aircraft involving the sudden decrease of the collective pitch angle and about 25 degrees of pitch down and to maintain this condition until the recovery of the main rotor rotation speed.

ii) The large excursion of the pilot's arm during this maneuver also influences the GSR's peak response. In the tests performed, it was inferred that this factor contributed up to 20% of the peak value.

Indeed, the initial workload is much higher than that of the other combinations of height and speed but decreases rapidly as speed and RPM increase.

This characteristic is also confirmed in the graph of Figure 6, when after GSR peak (green line), a large decrease occurs in a short time, bringing the results to the levels predicted initially and consistent with the subjective evaluation of the pilots.

b) The physiological reactions are different among pilots: in combinations of specific points, if it is "outside", on the boundary or "inside" of the Height-Speed curve

About this hypothesis, as shown in Figure 8 associated with Table 2, it is possible to observe that the dead man's curve imposes a boundary between the ability to perform autorotation within a workload supported by a trained pilot and the area where safe landing would be unlikely.

The plot in Figure 8 validates the hypothesis that the workload increases when the engine failure occurs in regions closer to the dead man's curve established by the aircraft manufacturer, turning an excessive workload for scenarios within this area.

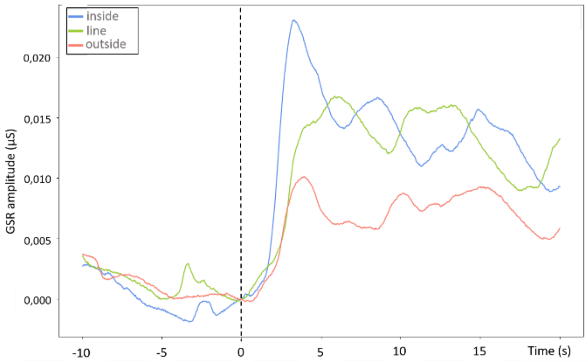

Figure 8: GSR average of the pilots in the outside, inside and on the limits of the height-speed curve

As mentioned before, this characteristic has adherence to the qualitative opinions of pilots, expressed by means of the workload assessment scales, as shown in Table 2.

Table 2: Workload assessment on the outside, inside and on the limits of the height-speed curve

PILOT	F			H		
	inside	line	outside	inside	line	outside
SCA	5	4,5	4	9	7	5
CRE	6	4,5	4	8	6	4
CTL	5	4,5	4	9	7	4
ROQ	6	5	4	9	6	5
MTS	6	4,5	5	9	7	6
Average	5,6	4,7	4,2	8,8	6,6	4,8

The workload results in Table 2, corresponding to the linear segment "F" of the dead man's curve in Figure 7, confirm the physiological characteristics of the operation therein, showing much larger workload values inside the dead man's curve. The limit of acceptable workload on the curve is HQR = 4.5 and one observes the low level of workload outside of the curve.

c) The physiological reactions are different among pilots: depending on if the engine's failure occurs expectedly or unexpectedly

The first autorotation event of all the pilots of the campaign was unexpected, i.e., they were involved in performing high-workload tasks when they got surprised by the engine failure. In Figure 9 one verifies the high peak of the galvanic response of the pilots when this happens (green curve).

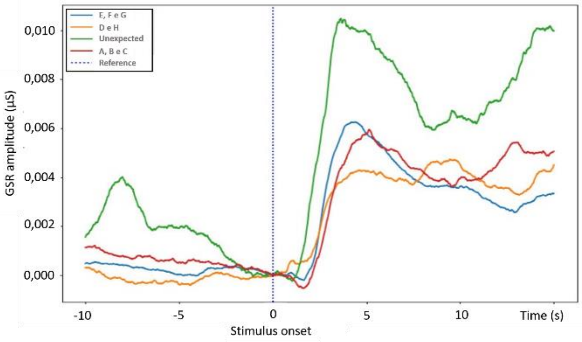

Figure 9: GSR average after an unexpected engine failure

The green curve represents the average values of the GSR amplitudes for the pilots during the unexpected events of simulated engine failure. On average, they were twice as high at the points where the pilots were warned with an imminent engine failure.

This shows that traditional training, with just the lowering of the collective command without the reduction to the engine flight idle regime, even with pilots aware of the timing of the simulated engine failure, does not fully represent effectively the reality of the event as a whole.

Even before the unexpected engine failure, the physiological behavior of the pilots was already different from those when the pilot knew beforehand about the engine failure. It works as if the pilot has already prepared himself psychologically for that training.

Other important information is that during unexpected events, even after the GSR peak, galvanic response levels remain higher than those GSR for pilots who have already been prepared for the simulated engine failure. Even after a few seconds, GSR levels stay much higher.

2nd HYPOTHESIS – Experience and training influence the physiology of pilots during an autorotation

As one observes in Figure 10, the experience of the pilots, specifically in the necessary execution of autorotation maneuvers, is an influential factor in the success of the procedure.

In Figure 10, Team 1 is composed by test pilots with a large experience in autorotation; Team 2 is composed by test pilots without experience in autorotation and Team 3 by operational pilots.

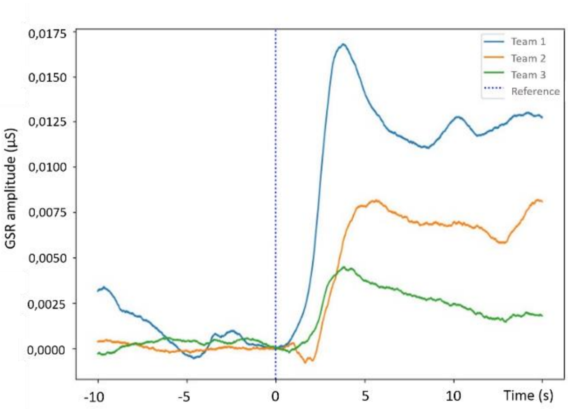

Figure 10: GSR average of pilots of different levels of experience

The first important analysis of the graph shows a clear difference in the response of the three groups, where the most experienced pilots present GSR 3.5 times higher than the other two groups.

Another important information was the reaction time, where, despite the GSR sensor latency, the most experienced pilots began to react physiologically, on average, in less than one second, while the others, on average, reacted after 2 seconds, which would make it impossible to perform the main rotor rotational speed recovery in most events.

The analysis of this graph shows that the most experienced pilots in the autorotation maneuvers (Team 1) had the GSR increasing faster and with more amplitude than the others. This information is relevant because these pilots were successful in all tests, and the others had to be aided by the instructors in most tests.

This characteristic shows that the experience factor in the autorotation maneuver makes the pilot more familiar with the engine failure information and react more quickly, reaching a level of maximum attention, much earlier than the pilots of the other groups.

Since all the pilots who took part in the Flight Test Campaign had a lot of experience, all experienced instructors with 1,000+ flight hours, the differential factor for them lies precisely in the experience of performing the complete autorotation maneuver.

3rd HYPOTHESIS – There are physiological markers that show high moments of workload during the engine failure

Despite the basal metabolism and the galvanic responses of the pilots before an unexpected engine failure, the campaign's tests prove that there are physiological markers involved autorotation events. In Figure 11, one observes the physiological variations of the pilots (GSR) almost immediately after the engine failure.

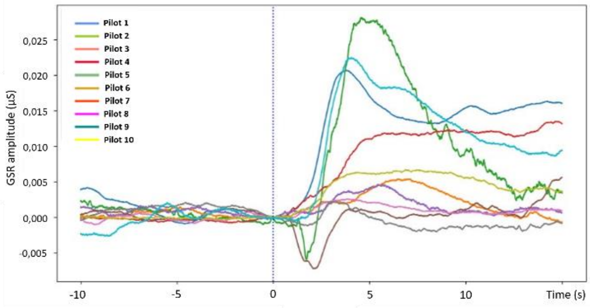

Figure 11: Physiological Workload Markers on individual pilots

In the curves present in Figure 11, all levels of the galvanic response of pilots were truncated, and the oscillations after the engine failure presented. It considers value "zero" for all the pilots in the moments before the engine failure.

The results in Figure 11 clarifies that there is an important physiological marker at the moment when there is the greatest workload reported by pilots: engine failure followed by entry into autorotation. In the graph one observes variations in the levels of pilot's GSR responses for rise time, peak and reaction time from pilot to pilot; nonetheless, it is clear the correlation with the workload levels along the associated time.

In summary, regardless of the amplitude, transient direction just after the engine failure, and the peak of the GSR variation, all pilots had a very large variation in the galvanic response levels.

5.1. OTHER PHYSIOLOGICAL RESULTS

In addition to the GSR responses presented in this paper, physiological data have been collected from other sensors. Their analyses are in process and corresponding results will be published timely; among them are electroencephalogram, electrocardiogram, facial recognition analysis, heat map analysis results and the sequence-of-events obtained by eye-tracking (Figure 12).

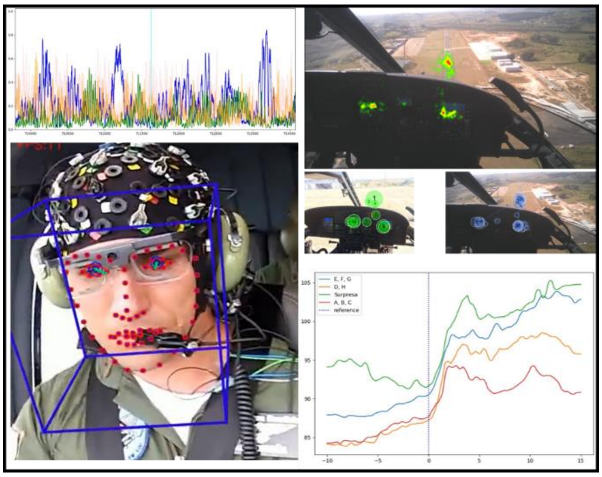

Figure 12: Other physiological data collected in the autorotation Flight Test Campaign

6. CONCLUSION

Preliminary results of this research, especially the galvanic responses of the pilots (GSR) submitted to autorotation tasks after a sudden and unexpected simulated engine failure, unveiled important information on pilots' physiology and associated workload.

Three hypotheses were proposed within the boundary conditions imposed by the method adopted for this flight-testing based investigation.

The main preliminary conclusions are that the individual physiological behavior of pilots is significant and has to be considered during the training planning, which should be personalised in quantity and content.

The limits of the dead man's curve express a boundary of the workload to make the safe landing. This characteristic shows that, despite the energy transfer predicted by the mathematical models of the dead man's curve, human factors severely affect its shape dimensions.

In this Flight Test Campaign, all the flight operations were led by experienced helicopter pilots. The most successful maneuvers and associated best physiological results happened with pilots who had specific autorotation training though.

The workload varies greatly depending on the region of the dead man's curve when the engine failure occurs. Thus, it is important that the training of pilots is performed in various combinations of height and speed, especially in those that require greater workload, such as hovering at high height and at high horizontal speed and low altitude, in the "knee" of the curve.

The results of the tests revealed especially a great difference in performance and physiological behavior with pilots who were not expecting a sudden engine failure. This indicates that autorotation's training should consider the possibility of unexpected engine's failure, under the penalty of not performing complete maneuver training.

Finally, one of the clearest answers in this research shows that GSR amplitudes can be employed with a physiological workload marker and that it can be used as a tool for quantitative workload measurements, a sign of training efficiency and pilot performance evaluation.

The preliminary results of the research along with the complete flight responses coming from other sensors, still to be published, are expected to contribute with future helicopters design and operation, such as: more efficient alarm systems; interactive cockpits, enhancement of active autopilots with semi-automatic flight commands; improvement of the process and in the methods of training; and in the development of flight simulators with physiological measures to evaluate pilots.

ACKNOWLEDGMENTS

The AUTHORS wish to thank the Brazilian Air Command's Flight Test and Research Institute (IPEV) for supporting the complete Flight Test

Campaign. In addition, the AUTHORS wish to thank the Bio-Engineering Laboratory of the Technological Institute of Aeronautics (Laboratório de Bio-Engenharia do ITA), especially the Doctor Maj. Brig. José Elias Matieli, for all academic support and integration with the Neuroscience Centers of Brazil.

Likewise, the AUTHORS acknowledge all researchers with the Albert Einstein Israeli Hospital, especially Dr. Elisa Kozasa, for all technical coordination in obtaining and validating the physiological data of pilots.

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