Mechanical strength of the aircraft control chains in certain unusual cases

Cristian TECUCEANU*,[1], Dumitru POPOVICI[1], Mariana POPOVICI[2], Peter KALMUTCHI[3]

*Corresponding author
*,[1]AIAS - Civil Aviation Safety Investigation and Analysis Authority (SIAA), Piata Walter Mărăcineanu nr. 1-3, etaj 6, sector 1, 010155 Bucharest, Romania, cristian.tecuceanu@aias.gov.ro
[2]CIP Mariana Popovici,
[3]Private consultant

DOI: 10.13111/2066-8201.2023.15.4.21

Received: 22 October 2023/ Accepted: 08 November 2023/ Published: December 2023

Abstract: *The paper focuses on certain specific occurrences involving sports aircraft and their mechanical flight control chains. Usually the flight controls and their control chains are subject of thorough checking procedures, but frequently such details are not observed or are easily ignored during the maintenance and airframe checking processes. The authors aim to provide information enabling proper training of flight crews, technical, and design staff/ personnel, allowing the avoidance of severe occurrences/ events caused by failures of the mechanical control chains. The analysis focuses on lighter aircraft, such as sports aircraft, which have full mechanical control chains.*

Key Words: *Mechanical, Strength, Aircraft, Control, Chains*

1. INTRODUCTION

The paper aims to outlining certain aspects of the mechanical strength failures in the aircraft control chains which might develop into serious and dangerous flight occurrences / events [6], [7], [8], [9]. For a classic airplane, a stabilized and properly controlled flight includes the following controls:

- The rudder, which is the mobile part of the vertical empennage/tail unit, determines the aircraft rotation relative to its vertical axis (yaw rotation). The rudder is controlled by the pilot using the two pedals;
- The elevator, the mobile/ movable surface of the horizontal empennage/tail unit, determines the aircraft' pitch, i.e. the rotation relative to its transversal axis (pitch). The elevator is controlled by forward and backward movements of the control column/stick. Sometimes it is also called depth rudder;
- The ailerons, are mobile surfaces located on the extremes of the wing, on the trailing edge of the wing determining the aircraft rolling motion, i.e. the rotation relative to the longitudinal axis of the aircraft. Ailerons are controlled by lateral movements of the control column/stick.

All flight controls are nearly simultaneously moved to provide proper control of the flight by enabling the movement of the control surfaces. Additional controls such as engine controls;

fuel supply controls, slats, flaps, spoilers, aerodynamic brakes, landing gear controls as well as trimming surfaces complete the aircraft controls.

All these controls enable the pilot to properly follow the flight path and to enable the proper attitude of the aircraft. The flight characteristics of the aircraft determine the stability and maneuverability of the aircraft.

The aircraft stability is determined by its design and construction characteristics and the ability of the flight crew to control it. Static stability of the aircraft is the aircraft reaction if it is moved out from a balanced position, while the dynamic stability is provided by the aircraft capacity to recover if a perturbation occurs and to regain its balanced flight position. Basically, this is a damping oscillation phenomenon:

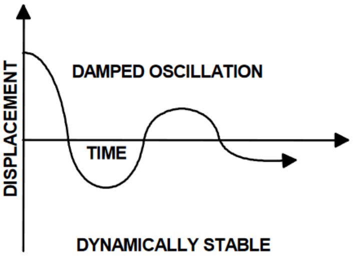

Fig. 1 Dynamic Stability

Stability and maneuverability of an aircraft are complementary, since a stable airplane is less maneuverable, while a less stable airplane is more maneuverable.

These characteristics are very much exploited during pilot training, since a highly stable aircraft is rather useful during initial training, since the student pilot is learning from a slower reaction to controls, while an acrobatic flight is convenient for a less stable aircraft.

In our paper, we will focus on longitudinal stability, which is largely influenced by the mass and balance of the aircraft, mainly the aircraft mass distribution. A less visible reason is that our paper is based on severe occurrences where the involved failures affected the longitudinal stability.

Aircraft manufacturers are providing an aircraft manual explaining the operation of the specific aircraft. This is usually given as a range of positions for the center of mass, either related to the mean aerodynamic chord or to a specific area of an airframe component, such as a firewall or a bulkhead. Trimmers / trimming surfaces/ trimming facilities enable the application of regular control forces on the pilot controls.

If the center of gravity moves forward, the aircraft becomes more stable, restricting maneuverability and, if the mass center moves beyond its forward limit, it is disabling the possibility to recover from a high descending pitch movement.

This is a frequent situation occurring during light aircraft operation, where the maximum admissible pilot and payload mass is exceeded. If the center of gravity is shifting towards its backward limits, could prevent the return to a regular incidence flight after a high incidence (ascending pitch) flight.

If the center of gravity moves progressively backward, the force applied on the column enabling the elevator control has to be increased and it is difficult to return to the intended flight attitude. At a certain weight, it is reached a position of the gravity center on the aerodynamic chord where the airplane has no more the tendency to return to its pre-disturbance attitude and continues to maintain the perturbed position. This is the neutral point of the aircraft and it is defined as the mass center position providing neutral static stability.

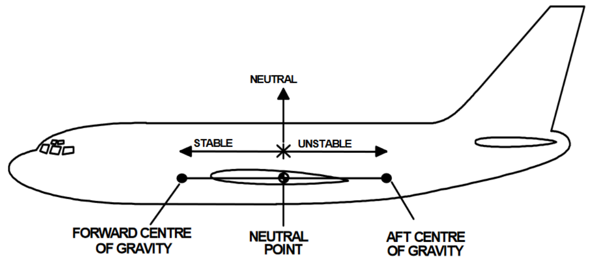

Fig. 2 The Neutral point and the center of gravity positioning

Any motion behind this position will determine a longitudinally unstable aircraft. Most aircraft we refer to are designed to be longitudinally static stable so that the center of gravity is usually located in front of the neutral point.

Currently, such thing is shown by representing the pitch moment as a function of the angle of attack (or the lift coefficient) with the column compensated / trimmed to its neutral position for the aircraft flight attitude selected in flight by the pilot, as below:

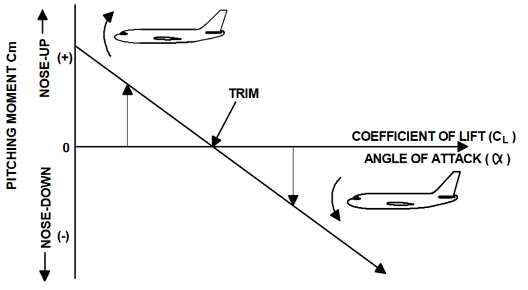

Fig. 3 Pitch moment when occurring a perturbation

According to the selected flight attitude, respectively according to the flight speed, determined by trimming the aircraft, and taking into account different loadings (weights) will generate a graphic representation as the one in figure 4.

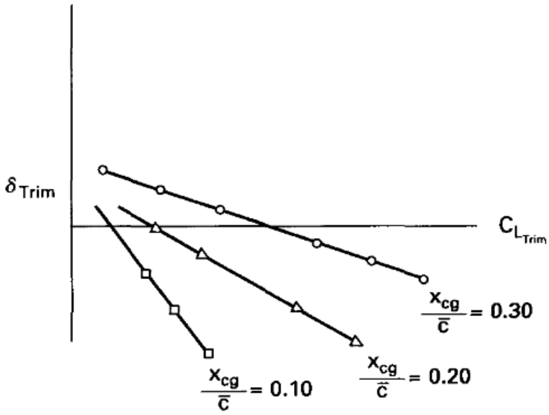

Fig. 4 Graphic determination of the column' neutral point

Understanding the neutral point significance requires the following remarks:

The control surface enabling the longitudinal stability provides a moment that can be used to balance or trim the airplane (compensating the force on the column) for different angles of

attack or different lift coefficients. If the airplane is not trimmed, this moment will determine the change of the flight position of the aircraft, respectively i.e. the changing of the airplane's flight attitude, until the rotation will be balanced by the horizontal tail unit lift moment.
Usually, the most important trimming moments occur when the airplane is configured for landing (flaps and landing gear extended), while the center of gravity is located at its front limit (airplane loading is the highest admitted).

Thus the neutral point means the point where the airplane will have an attitude for which the column is in a neutral position, respectively there is no force acting upon to determine position changes which would be followed by an aircraft attitude modification.

2. A KNIFE-EDGE SPIN ENDING IN A CRASH

This is a case study [1], [2] of an occurrence involving a sports aircraft during flight training for an acrobatics competition. After performing a series of aerobatic figures on the runway vertical, the pilot put the aircraft into a "knife edge spin". The knife edge spin is an evolution with the wings oriented vertically while the cockpit canopy is oriented towards the exterior of the rotation movement.

From this evolution, the aircraft entered a flat tailspin which was not initiated by the pilot. During this spin evolution, the wings were horizontal, nose down about 30°, while the aircraft was rotating leftward. The staff on the aerodrome noticed the abnormal occurrence and broadcasted to the pilot to start recovering and pressing the right pedal. The aircraft continued rotating and losing height, approaching the critical height.

The evolution was initiated at more than 900 m over the ground. After 1-2 rotations the pilot intended to stop this evolution and recover by entering an evolution enabling recovering the flight height. During the investigation, witnesses stated that after a complete rotation, the airplane continued with a flat spin. A witness was astonished since he was aware that usually, the pilot wouldn't connect the two evolutions.

The pilot tried to re-establish the aircraft control, but he lost height very quickly and hit the ground plate. It shall be remarked that the pilot was still able to cut the engine fuel supply, stopping it. Due to the hard ground impact the aircraft burst into flames and the pilot was killed.

According to witnesses' statements, the pilot complained some month before the accident that the pedals are offset, and certain evolutions, requiring the rudder to be turned right were harder to initiate. The pilot complained that the right pedal cable in the rudder control chain was "elongated". The technical crew checked the complaint and noticed that the rudder right turning angle was 5° less than the left turning angle. Witnesses stated that the pilot explained himself why certain evolutions, requiring full right rudder turnings, were hard to perform. After the check, the right pedal cable in the rudder control chain was replaced. The left pedal cable was not replaced.

The scattering area of the aircraft components was small. The fuselage twisted, showing several points of rupture of the metal beams in its structure. The aircraft engine detached from the body, and moved/fell sideways to the right of the carriage. Two propeller blades remained on the hub and were partially burned – proof that the engine was shut down before the impact. The landing gear broke and remained under the fuselage.

The cinematic chain of the rudder controlled was separated from the wrack and a metallographic analysis of it was conducted to determine the conditions of its destruction.

Fig. 5 The rudder and direction control chain

During the knife edge spin evolution, the pilot has configured the controls as follows: left pedal pressed, column pulled, and whole engine power. After 1 -1½, rotations followed the evolution recovery controls, pressing the right pedal, the column fully pushed forward, and the engine whole power. During recovering from the knife edge spin occurred something that determined the rudder right turning to be blocked, and, thus, the whole recovery was blocked. Since the rudder was blocked and turned to the left the airplane entered uncontrolled in a tailspin losing height and rotating left. An analysis of the cinematic control chain of similar aircraft revealed that a strong pressing of the pedals, specific to an acrobatic evolution, generates deformation of the pedals assembly sliding bracket, which, combined with the free drilling shaft play in this assembly, determine changes of the pedals assembly vertical axle, enabling pedals assembly components to touch the adjacent oblique beam in the fuselage structure.

Experiments revealed an extended axial play in the horizontal pedal articulation screw based on the elastic deformation of the guiding tubes of the sliding bracket of the pedal assembly. Pressing the pedals, a vertical unbalancing is induced determining that the pedals edge and the head of one of its mounting screws shall rub or even hang on an oblique fuselage beam. Elastic deformation of the guiding brackets of the pedals tray is the highest when the pedal sled is in the middle area of the tubes, a position used by the pilot according to the length of its own legs. It is to be noted that only the normal pressing of the pedals involves the natural occurrence of a lateral component (oriented towards the exterior). Combining these forces and the position of the foot over the articulation axis on the assembly tray generates a pedal swinging touching frequently the adjacent airframe components. Assisted by the aircraft operator technicians the investigators demonstrated the frequent hanging of the left pedal on the lateral beam, even on the ground using only regular hand power.

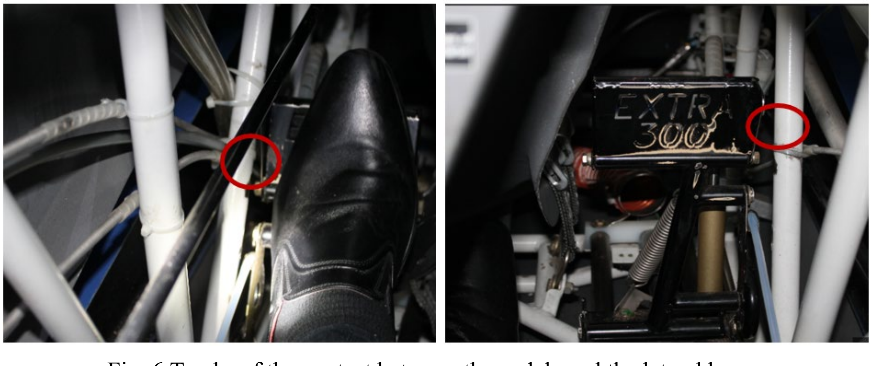

Fig. 6 Tracks of the contact between the pedals and the lateral beams

The analysis of the cinematic rudder control chain revealed operation abnormalities and braking of certain components. Just for reference the left pedal chain, which wasn't replaced, revealed significant friction traces and even some broken strands. These reveal very high strength in the cables or friction with the airframe parts.

During the investigation it was noticed that the S bracket of the right pedal cable was broken from the structure (broken weld), most probable due to the pilot effort to overrun the blockage of the left pedal. Even more, the left S-bracket showed a broken upper part denoting a high traction / stretching force applied to the cable, most probable due to blocking of the left pedal in the fuselage.

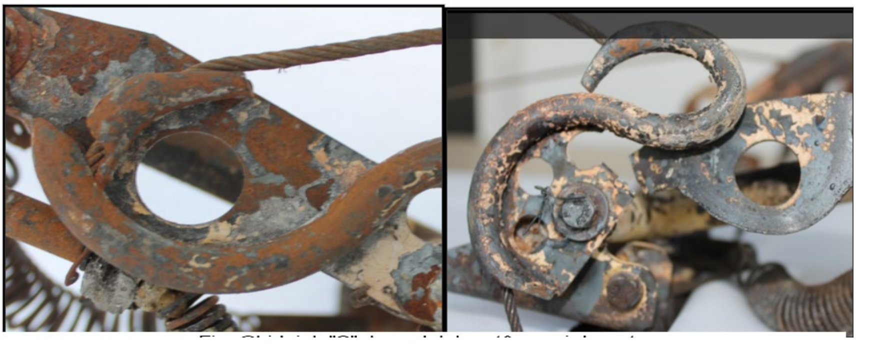

Fig. 7 The S-breakage of the left and right pedals

According to the cinematic scheme, the control chain consists of two working branches connecting the left and right pedal through the control cables and the rudder horizontal hinge lever. Applying a force on one of the working branches will generate an opposed force on the opposite branch. The value of the forces on the two branches is the result of the tensions that occurred in the system springs combined with the aerodynamic forces on the rudder surface.

Consequently, if there wouldn't have occurred the blockage of the rudder control in the position extreme left (as found in the wrack), the rudder would have returned to the neutral position, under the combined action of aerodynamic forces and the system springs, as soon as the pressure on the left pedal was dropped to enable pressing the right pedal, to recover from the spinning.

It could be imagined following chain of events: after several acrobatic figures between 500 and 50 m, the pilot initiates climbing to about 900 m, commands a left overturning of the aircraft, keeping the left pedal pressed as required also for the next evolution, the knife edge spin, and after 1 - 1½ spins the pilot tried to recover (right pedal pressed, column pushed fully forward, whole power) but entered in a tail spinning, continuing to rotate leftwards. The pilot realized the inefficiency of the pedal control and tried to determine a pitching evolution using engine revs.

The aircraft continued to turn leftward, with a slight nose balance under the horizontal. At about 200- 150 m height the pilot called the breaking of the pedals probably to high pressure applied by himself on the right pedal, while trying to recover from the spinning. 20 m over the ground the engine was cut by the pilot desperately trying to limit damage.

Since similar aircraft were in operation and since friction traces were identified on the cables of similar aircraft the manufacturer was required to identify and implement proper solutions to avoid oscillations of the pedals assembly for the specific aircraft type, avoiding contact between the pedals and the structure beams of the airframe, unlimited y the flight evolutions.

3. PSYCHOLOGICAL EXPLANATION AND HUMAN LIMITS, EXPLAINING THE PILOT'S REACTION AFTER THE EMERGENCY OCCURRENCE, REPRESENTED BY THE LEFT SIDE RUDDER PEDALS ASSEMBLY BLOCKAGE

The study of Griffith University Aerospace Strategic Study Center, in Brisbane, Australia, entitled "The Effects of Startle on Pilots During Critical Events" [3], conducted by Wayne L. Martin, Patrick S. Murray and Paul R. Bates, show that in such cases occurred the pilot's startle/surprise, due to the unexpected blockage: "*The startle or surprise reaction is commonly called the 'fight or flight' response and involves a number of bodily systems.*" The study also states: "*Research shows that activation of this startle/surprise/fight or flight reaction may have deleterious effects on information processing for up to 30 seconds. This has major implications in the aviation paradigm for situational awareness, problem solving and decision making*."-

In the EASA study commissioned to the Dutch authorities, NLR-CR-2018-242 is stating "*Startle and surprise effects can influence pilot performance in many detrimental ways. At the very least, these effects serve as a distraction which can disrupt normal operation and erode safety margins. On a more critical level, they can lead to inappropriate intuitive actions or hasty decision making. Well learned procedures and skills can be discarded and are substituted by the first thing that comes to mind. This study is concerned with the impact of startle and surprise effects in aviation and how to mitigate these effects by pilot training*". Further it is stated: "*The startle reflex is the first response to a sudden, intense stimulus. It triggers an involuntary physiological reflex, such as blinking of the eyes, an increased heart rate and an increased tension of the muscles. The latter are necessary to prepare the body for the fight-flight response (Koch, 1999). The startle response is accompanied by an emotional component which for a large part influences how a person responds to the unexpected event (Lang, Bradley, & Cuthbert, 1990).*" There is also mentioned *that "From an evolutionary, survival perspective it makes sense to have an over-cautious, 'better safe than sorry' system in place when dealing with unexpectedness; an automatic and fast threat attribution to a Startle or Surprise. Afterwards, a slower and deliberate analysis of the situation takes place, possibly leading to a 'false threat' assessment. By then, all the physiological (increased heart rate, muscle tension and breathing, adrenaline secretion, etc.) and psychological (fear, possibly leading to anxiety and uncertainty) responses are taking place. If enough information is available to make this assessment rapidly, these responses fade away*".

The startling effect involves as well physical reaction, as well mental reaction to a sudden unexpected stimulus. While physical reaction is automatic and, practically, instant, mental reaction – i.e. conscious processing and evaluation of sensory information – can be much slower.

In fact, the ability to process sensory information assessing the situation and taking adequate measures – might be seriously affected or even overwhelmed by intense physiological answers/reactions. These changes in the physiological activity involve the muscle system and the fact that the muscles are tense to enable immediate action.

In her article "*Adrenaline and its role in the organism*" [4], published in 2018, Mălina Mancaș, stated that "*Adrenaline or epinephrine is hormone produced by adrenal gland, as a reaction to stress or danger*", while the effect is a temporary increase of the physical power, adding that "*Under adrenaline excess conditions a person might have an extremely high power, which would be impossible under normal conditions. It is called also <<hysterical force>> or <<temporary superhuman powers>>*". The consequence of increased physical force in the leg muscles was the breaking of the brackets supporting the rudder cable, transmitting the movement of the pedal to the rudder, and the deformation of the right side pedal which would have been impossible in normal conditions.

The EASA "Certification Specifications and Acceptable means of Compliance for Large Airplanes" (CS-25), section CS 25.397 "Control Systems Loads" is limiting the effort of the pilot on the pedals to be at least 578 N or 130 lbf. (58.939 kgf) and highest 1335 N or 300 lbf. (136.132 kgf).

Analyzing the pilot's behavior after the emergency occurred, referring to his action, it can be found out that he reacted trying to release the rudder pedals system blockage, pressing strongly the right pedal and determining the rupture of the rudder cable brackets, in order to recover from the spinning. After the surprise moment, he cut the engine, according to the emergency recommendations, to minimize damages at ground impact.

According to his behavior, we appreciate that the pilot should have reacted to leave the aircraft, parachuting, as soon as he found out that it is impossible for him to recover the aircraft from the spin.

4. GLIDER CRASH-LANDING DUE TO IMPROPER OPERATION OF THE FLAPS LOCKING SYSTEM

The glider which is the subject of this case study [1] took off in airplane towing for a long-distance en-route training flight. When returning from the en-route flight, the pilot performed three spirals of 360° in the aerodrome area in order to lose height, continuing the flight in runway lap in order to land on the western heading.

Due to malfunctions of the flap positioning mechanism (slot), the pilot had to repeat a few times the flap pulling maneuver in position 3 and as a consequence, when exiting the turn for centering on the heading chosen for landing, he noticed that he was higher and to the right of the landing heading.

As a result, during the final landing approach, in configuration flap position 3, pulled aerodynamic brakes and variable speed below 80 km/h, the pilot performed a series of left-right turns in order to fit the aircraft on the optimal slope for landing.

While applying the control to exit the last turn, at a height of almost 30-40 m, the pilot lost the aircraft control, and he entered an uncontrolled rotation evolution. The glider impacted the ground on the grassy surface in the aerodrome area. The impact angle of the glider was nearly 90°.

After the ground impact, the aircraft was destroyed. Due to its attitude when impacting the ground, in an almost vertical position, the fuselage (nose and cockpit) was compressed, the left plan broke from the flap area – the aileron and rear fuselage broke at almost 80 cm from the joint area of the vertical empennage.

Upon the impact, the cockpit canopy detached from the structure, and the aircraft bounced off and overturned.

The glider is of classic, metallic construction, with the wing positioned "up", with a positive dihedral angle of 2°, and a double trapezoidal contour. A schematic representation of the glider is shown in Figures 8 and 9. The wing is provided with ailerons (1), with curvature flap (2), and with Hutter-type aerodynamic brakes (3), which open on the upper side wing. The horizontal stabilizer (10) is fixed, placed in T-shape on the vertical empennage (13), with a classic statically balanced depth rudder with spring (11).

By means of a lever in the cockpit on the left side panel, the flap is directly operated, through a mechanical system, by the pilot by placing the lever in the proper cut. The lever is shown in Figure 10.

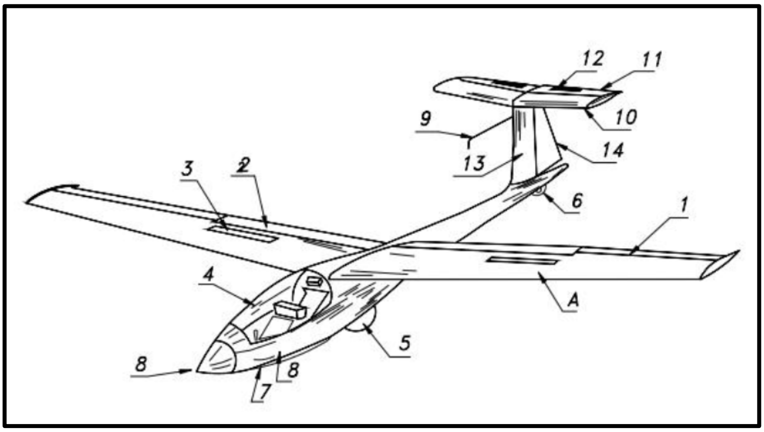

Fig. 8 schematic representation of the glider

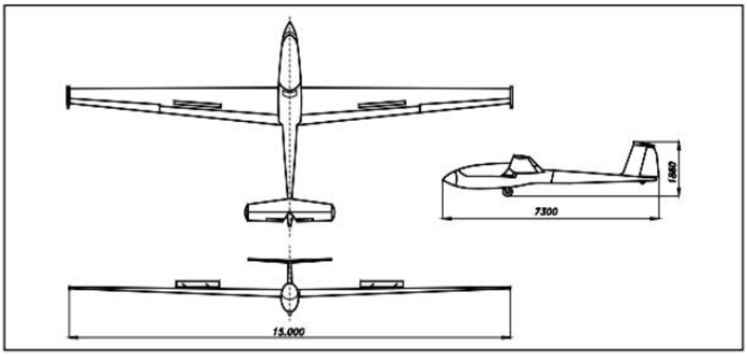

Fig. 9 Three view scheme of the glider

Fig 10 Panoramic view of the cockpit

In order to record the flight parameters of this flight, the pilot used an application installed on his cell phone.

The file containing the last flight data was downloaded and analyzed providing objective data en-route and the aircraft flight profile from take-off until the impact.

The information on the aircraft involved in the occurrence, collected during the investigation, revealed that at higher speeds, in many cases, the flaps lever could not be locked on position 3, since it always moved, randomly, to the previous positions 1 and 2. Therefore checking and testing of the flaps control system was conducted. When checking the flap control system in the cockpit there was revealed:

- the flap control lever was in position “1”;
- advanced wear of the flap lever positioning cuts;
- fake and unstable position of the control lever for the “Flap 3” and “Flap -1”, created by wear, in the process of in-flight operation, behind the normal cut for position “3” and in front of “-1”.
- accentuated wear of the “Flaps 2” position cut, compared to the normal position “3”. It can be identified the inappropriate fixing position behind the normal position 3, where the flap control lever is unstable.

  The cut for position 3 has much less wear than that of position 2 (considered as a reference), because most of the time the flap lever was positioned in the fake position „3”. The lever instability in this position was also accentuated by the accumulation of wear on the spring and the fixing pin.
- very advanced wear on the flap control lever fixing pin. The pin was not centered on the flap lever and had no stable position on the lever (it moved slightly left-right) in its lever positioning channel,

Under the influence of aerodynamic forces and due to malfunction of the positioning and safety system of the flap control lever, it frequently “jumps” from position “3” (sometimes also from position “2”) to the positions in front (1 and 0), uncontrollably modifying the glider aerodynamic characteristics, resulting in an unexpected increase in the stalling speed value.

Fig. 11 Bottom views of the flaps lever positioning system

The investigation found out that for gliders in newer manufacturing series than the glider in the accident, the manufacturer modified the constructive solution of the flaps control.

In a turn with an inclination of 40°, with the slot turned on position "3", the minimum limit flight speed determined by calculation is 80 km/h. This is achieved by starting from the limit speed in horizontal flight,that was declared by the manufacturer as 65 km/h, by using the formula:

$$\nu_{LV} = \nu_{LO}\sqrt{\frac{1}{\cos\beta}} \tag{1}$$

where:
ν_{LV} = limit speed in turn; ν_{LO} = limit speed in horizontal flight; β = inclination angle in turn

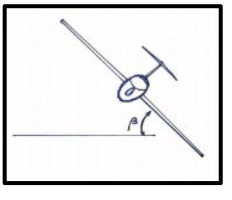

Fig. 12 Glider in turn

If the flap lever (under the pressure of aerodynamic forces and due to the imprecision of the positioning system) jumps from position 3 to front positions (2 or 1), the stalling speed suddenly increases from 65 Km/h (for the horizontal flight) to 75 Km/h.

For this glider type, the evolution near the limit speed is characterized by the excessive increase of the lever movement for its control around the longitudinal axis (pitch angle) and vibrations along the transverse axis, which can be felt in the lever, determined by the turbulent flow of air on the wing tips, in the area of the aileron.

After performing the turn to initiate the final procedure, the pilot performed the maneuvers to prepare the configuration for landing: he pulled the landing gear wheel and the flap in position 3 (15°), a maneuver that he had to repeat 3-4 times, because the safety flap in position 3 randomly jumped under the force of aerodynamic forces, in positions "2" or "1".

The instability of the flap control lever position distracted the pilot, and repeating the flap positioning maneuvers led to oscillating evolutions of the glider vertically.

As it can be noticed in fig.12, between points 9 and 12 (almost 360 m), the aircraft descended quite a bit (50m).

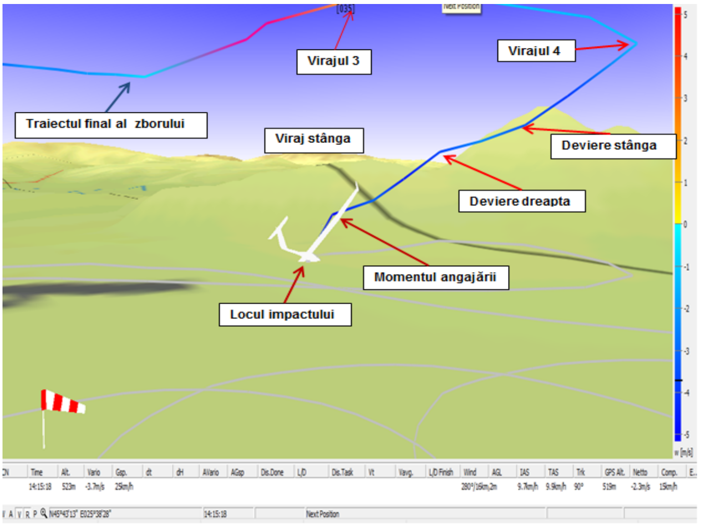

Fig. 13 Glider vertical evolution diagram

Then the pilot performed a left turn to center on the landing heading, in the usual area of the hilltop, coming out a little to the right from the direction in which he intended to land and at a height of approximately 70 m from the ground.

According to the analysis of the recorded data, the glider evolution on the landing slope after the centering turn on the heading began with a speed of 80 Km/h (G_{sp}), the glider being in landing configuration with flap 3**.** Considering the front wind component (approx.15 Km/h), it can be assessed that the indicated flight speed sometimes exceeded 95 Km/h, in gusts: G_{sp} = IAS+ (+/-V_v) from which: IAS = G_{sp}+ V_v.

Appreciating that he is still too high from the place chosen for landing, the pilot pulled the aerodynamic brake and let it pulled out to avoid the speed increase and at the same time for the loss of height. In order to accentuate the height loss, he performed consecutive turns, left, right.

Before the last heading correction, the glider was on a left turn, with an inclination of almost 40° and the speed decreased towards 58 Km/h/G_{sp} (taking into account the wind, IAS = 73 - 75 Km/h) (point 16), thus below 80 Km/h (IAS) which is the stalling speed for a flight with an inclination of 40°.

When the pilot pushed the lever to the right, to exit the last turn and to center on the landing heading (point 16), given the fact that the aircraft was in landing configuration (flap 3 and aerodynamic brake pulled-out) and the indicated speed was decreasing towards 70 Km/h, the aircraft being inclined to the left, on the left semi-plane, at least in the area of the left aileron, the critical angle of incidence has been exceeded. Consequently, the lift on the left semi-plane decreased drastically and the glider entered in deep spin, with rotation to the left.

Fig.14 shows a qualitative analysis of the evolution of incidence angles on the wind, when operating the ailerons, for a glider in turn.

For the particular case when the glider is in the next vicinity of the limit speed (so the wing incidence angle is already next to the maximum value) when operating the lever to exit the inclination in the aileron area from the lowered wing (left in this case) the critical incidence angle is increased and exceeded, which determines the loss of lift in that area of the wing with the consequence of rotating to the left and putting the glider into a spin.

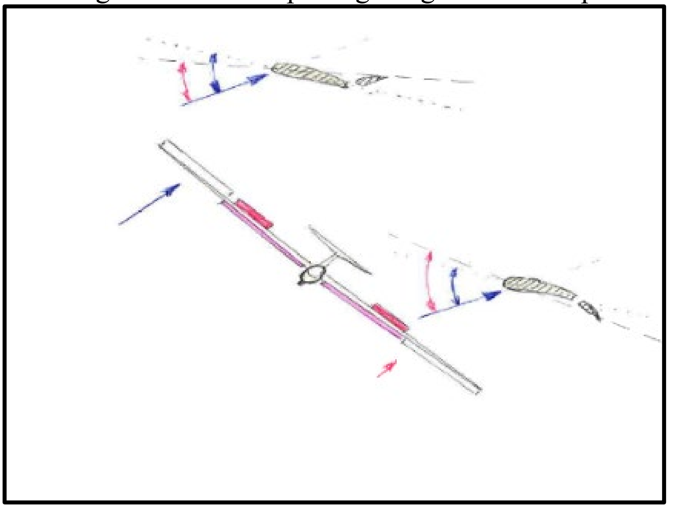

Fig. 14 Incidence angles in the aileron areas of the two semi-planes

The pilot lost the aircraft control, while the glider continued to spin to the left. From the height of entering into the spin almost 40 m, till the ground contact, the glider performed about 2/3 of the spin turn.

Upon the ground impact, the glider fuselage was almost in vertical plan, the ground contact being made on the left plan tip and the nose, continuing the rotation movement around the longitudinal axis, so that on ground impact, the glider felt on the back.

Because upon the ground contact, the glider was rotating and slightly inclined to the left wing, when the impact occurred, the end of the left wing broke. Because of rotation on contact, the nose and cockpit deformations are determined by torsion.

The rotation, at the moment of the ground impact, at a slight angle below the vertical and with the fuselage slightly inclined to the left, caused the aircraft to be flipped sideways to the left and back with almost 3,5 m from the initial contact point.

Analyzing the profile of the glider evolution from the take-off till the ground impact, it can be concluded that it went normally until starting the landing procedure.

After the turn for starting the landing procedure and performing the maneuvers to prepare the aircraft for landing, the inaccuracy of the flap positioning system distracted the pilot's attention from following the flight parameters and correcting them: speed, height, and descending speed.

The investigation shows that the accident could have been avoided if the pilot would have permanently monitored the flight speed so that he could have noticed the entering in the stalling area and consequently he could have started the maneuvers to exit the evolution before the aircraft become uncontrollable.

The investigators also consider that, in the particular analyzed situation, the pilot could have used slides instead of turns for height loss.

During the flight preparation on that day, the pilots were theoretically instructed to perform the long-distance flight, including landing correcting through slides, but during the practical preparation in flight, following interrupted flight activity, there were not also performed slide exercises.

5. PSYCHOLOGICAL EXPLANATION AND HUMAN LIMITS, EXPLAINING THE PILOT REACTION AFTER THE EMERGENCY OCCURRENCE, REPRESENTED BY THE IMPOSSIBILITY TO LOCK THE FLAP CONTROL

Analyzing the pilot behavior after the occurrence of the emergency it can be noticed that, even if he shall have been focused on the final approach for landing on the runway axis, with or without slats, he was rather focusing on putting the flaps (trailing edge slat) on the position for final approach and, than, using turning left and right to reduce the height and getting a better position towards the runway,

The previously quoted Griffith University study [3] shows: "*The effects of startle, an autonomic reaction with deleterious effects on information processing, may be a strong contributor to poor pilot performance during critical events. These effects may seriously impair situational awareness, decision making and problem solving, all critical skills in the handling of a complex emergency.*" Completing the statement "*Coupled with much work on the human element over the last thirty years, through initiatives such as Crew Resource Management (CRM) and Non-Technical Skills (NTS) training, Threat and Error Management (TEM) strategies, Fatigue Risk Management Systems (FRMS) and Flight Data Monitoring (FDM) systems, the whole aviation system has become very safe.*" Concluding the authors are stating: "*If pilots are not expecting things to go wrong, because they never do, then the level of surprise or startle which they experience when they do go wrong, can be significant and underperformance, due to the effects of this startle on the body's systems, can be detrimental to their handling of such events. Simons (1996) suggests that when people are subjected to some sort of startling stimulus where a real threat exists, then the intensity of that startle is enhanced. This fear potentiated startle is a distinct possibility where pilots are suddenly confronted with a potentially life threatening situation, which may engender a distinct mortality salience within certain individuals*". Further the study' authors are mentioning: "*The problem remains an issue when the threat persists and the startle transitions from a simple aversive reflex movement to a full-blown startle or surprise reaction. This involves the activation of the sympathetic nervous system and the endocrinal system in a reaction commonly known as the 'fight or flight' reaction. This reaction affects heart rate, blood pressure and respiratory rate and directs blood away from the extremities to the major muscle groups. This process contributes to the 'confusion' or delays in processing, commonly experienced following a strong startle*".

The NLR-CR-2018-242 document [5] shows that: "*Startle and surprise effects can influence pilot performance in many detrimental ways. At the very least, these effects serve as a distraction which can disrupt normal operation and erode safety margins. On a more critical level, they can lead to inappropriate intuitive actions or hasty decision making. Well learned procedures and skills can be discarded and are substituted by the first thing that comes to mind. This study is concerned with the impact of startle and surprise effects in aviation and how to mitigate these effects by pilot training. Commercial airline training has always included training for emergencies and abnormal situations, whether at ab-initio training, or during a pilot's career in type conversion and recurrent training. To some extent a level of "unexpected events" may be included in training programs, which may lead to some of the effects associated with startle and surprise.*"

Regarding the surprise, the NLR study [5] authors remark: "*The effects of surprise are in part comparable to those of startle. Physiological responses to surprise include increased heart rate and blood pressure, cognitive responses include confusion and loss of situational* *awareness, and may involve the inability to remember the current operating procedures (...). Even though startle and surprise often occur together, the startle reflex can be triggered without the notion of surprise.*"

Taking into account these studies and adding the investigation finding, we will remark that the pilot was not prepared to act in case of inability to put the flaps on specific landing position. A proper reaction would have been landing with flaps on position 0 or any other position in which the flaps control could be properly locked. It is considered that in such unusual situation, the pilot should have proceeded to a slide flight which enables flight height reduction.

6. CONCLUSIONS

The cases studies referred to provide the following conclusions regarding the aircraft operation, design, and maintenance, and pilots training:

There are serious safety occurrences [1], [2], [7], [8], [9] determined by failures in the aircraft' mechanical control chains. Such failures can be avoided by proper design and maintenance of the airplanes, disabling all identified causes of failure of the control chains. A significant part of the safety occurrences is determined by initial minor failures in the control chains. In time, due to normal wearing, such failures develop to be more and more dangerous and need to be properly addressed (repair / replacement).

The severe consequences of failures can be reduced by the proper startle/surprise reaction of the pilots. A proper reaction can enable saving lives and, even aircraft.

The pilots' training shall include the development of proper reactions during startle or surprise occurrences during aircraft operation, taking into account information provided by operational analysis and psychological research supporting the investigation of serious occurrences.

A fine-tuning of these capabilities shall be provided by recurrent training of licensed flight personnel, especially if these crew personnel has interrupted flying, even if it is only for a specific aircraft. Training curricula needs to be constantly updated due to improved techniques or procedures and observation of psychological studies, safety investigations, and flight safety research.

Safety recommendations of the air accident investigations shall be carefully implemented by the concerned parties.

Technical measures shall be based on detailed analysis of failure' causes and shall refer to all life stages of aircraft' life design, construction, and manufacturing, operation, and maintenance.

REFERENCES

[1] * * * *Safety investigation reports issued by the Romanian Safety Investigation and Analysis Authority SIAA/AIAS*, available on the website www.aias.gov.ro.

[2] * * * *Safety investigation reports available from other safety investigation bodies operating under ICAO Annex 13, Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC Text with EEA relevance and any other similar regulatory / legal documents*.

[3] W. *L.* Martin, P. *S.* Murray, P. *R.* Bates, *The Effects of Startle on Pilots During Critical Events: A Case Study Analysis*, Griffith University, Brisbane, Queensland, Australia, 2012.

[4] M. Mancaș, *Adrenalina și rolul său în organism (Adrenaline and its role within the organism)*, February 8, 2019, https://sfaturimedicale.ro/author/malina-mancas/page/18/, website by ruxandramicu.ro.

[5] * * * *Final Report EASA_Rep_RESEA_2015_3 Research Project "Startle Effect Management" NL*R – Netherlands Aerospace Centre, NLR-CR-2018-242, 2018.
[6] * * * *Annex 6 to the Convention on International Civil Aviation, - Operation of Aircraft*.
[7] * * * *Annex 13 to the Convention on International Civil Aviation, Aircraft Accident and Incident Investigation*.
[8] * * * *ICAO Doc 9756 - Manual of Aircraft Accident and Incident Investigation*.
[9] * * * *Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC.*