ANALYSIS OF COMPONENTS OF ELECTRIC SYSTEM OF THE TU-154M PLF 101 AFTER CRASH

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Abstract

An attempt to localize and analyse the distribution of components of electric system on the crash site of the Tu-154M PLF101 aircraft on April 10, 2010 has been presented. All available sources of information as photographs, movies, articles, reports and blogs have been used. Only a few components of the electric system have been recorded in available documents. Location of components and parts of the electric systems can help to trace the sequence of disintegration of the aircraft.

Keywords *- Components, crash site, electric system, location, parts, Tu-154M PLF101.*

Streszczenie

Przedstawiono próbę lokalizacji i analizy rozkładu części składowych układu elektroenergetycznego samolotu Tu-154M PLF101 na polu katastrofy w dniu 10 kwietnia 2010. Zostały wykorzystane wszystkie dostępne źródła informacji takie jak zdjęcia, filmy, artykuły, raporty oraz blogi. Bardzo ograniczona liczba części składowych układu elektroenergetycznego została utrwalona w dostępnych dokumentach. Lokalizacja części składowych systemu elektroenergetycznego może pomoc w odtworzeniu sekwencji rozpadu samolotu.

Słowa kluczowe *– Części składowe, lokalizacja, pole katastrofy, Tu-154M PLF101, układ elektroenergetyczny.*

1. INTRODUCTION

Many publications devoted to the Tu-154M PLF 101 crash in Smolensk on April 10, 2010 have been elaborated so far by independent researchers, engineers, lawyers, journalists and sociologists. Although the wreckage and original "black boxes" are not available for independent investigations, the common conclusion from these publications is that the *Tu-154M PLF 101 aircraft did not crashed as a result of collision with ground, but the aircraft disintegrated in the air*. This conclusion is supported by:

- distribution of debris (Fig. 1);
- large number (tens of thousand) of small parts on the crash site;
- fragments of the aircraft skin on trees;
- lack of crater;
- lack of fuel (at least no records) and fuel fire on the ground.

Only photographs taken and movies made on the crash site have been analyzed. Photographs taken after transportation of the wreckage to the place of its storage are of limited credibility. There is no guarantee that the remains at the place of storage were intentionally or accidentally damaged, replaced with the parts of another wreckage of the Tu-154M, jet-washed or cleaned off with the use of chemicals.

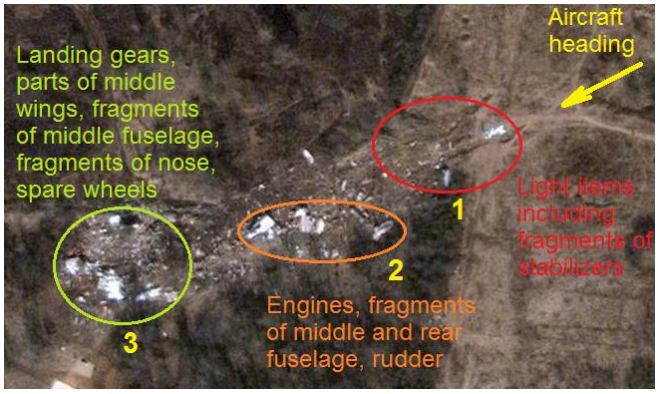

Fig. 1. The Tu-154M PLF 101 wreckage trail plot grouped by location of parts of the aircraft: (1) light items including fragments of stabilizers; (2) engines, fragments of middle and rear fuselage, rudder; (3) landing gears, parts of middle wings, fragments of middle fuselage, fragments of nose, spare wheels.

2. COMPONENTS OF ELECTRIC SYSTEM

Components of electric systems (Fig. 2) include:

- generators, i.e., main generators mounted at turbofan engines and generator of the auxiliary power unit (APU);
- electrical energy conversion devices as solid state converters and electromechanical energy conversion devices;
- electric motors, as for example, fuel pump motors;
- electromagnetic devices, as for example, valves, actuators, relays, transformers, etc.;
- batteries;
- connecting power cables.

3. GENERATORS

The main generators are three 40-kVA, 115/200 V, 400 Hz, 6000 rpm, constant speed drive (CSD) ГТ40ПЧ6 wound–field synchronous generators (Fig. 3) driven by three Д-30КУ turbofan engines (Fig. 2). Each generator feeds one channel. There is also a reserve 40-kVA, 115/200 V, 400 Hz auxiliary power unit (APU), which consists of ГТ40ПЧ6 synchronous generator driven by independent ТА-6А turbine engine [1, 2, 3, 4 5].

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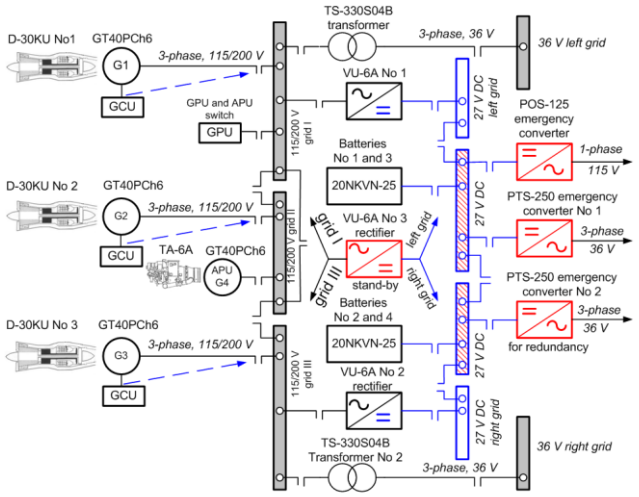


Fig. 2. Block diagram of electric power system of Tu-154M [2].

Main synchronous generators are hidden under engine cowl (cover) and if the engines are not shattered, the generators are invisible. The only available photographs are in Annexure No 4.20.22 „Note on the inspection at crash site of the Tu-154M No 101 on April 11-13, 2010" to the CINAA (KBWLLP) Report [6], which show the main generator on the left engine No 1 (Fig. 4). The generator and associated gaers look undamaged and are firmly fixed to the engine body. Other photographs of ГТ40ПЧ6 generators taken after crash of the Tu154M PLF101 are not available.

Fig. 3. Wound-field synchronous generator ГТ40ПЧ6.

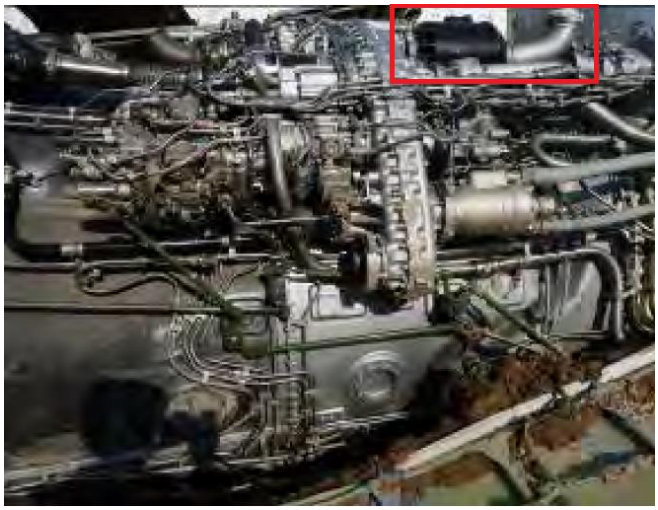


Fig. 4. Generator ГТ40ПЧ6 on the engine No 1 (left). The engine cover (cowl) has been removed. Photo taken between 11 and 13 April 2010 on the crash site. Source: Annexure No 4.10.22 to KBWLLP Report [6].

4. ELECTRICAL ENERGY CONVERSION DEVICES

No electromechanical energy conversion devices have been found on the available photographs and movies. Fig. 4 shows the electromechanical rectifier ВУ-6В which feeds the 27 V DC bus. The DC 27 V, 200 A system (Fig. 2), receives power from the main system via two transformers ТС-330С04Б and three ВУ-6А or ВУ-6Б rectifiers (two operation and one backup) and four 20НКВН-25 batteries. The rectifiers ВУ-6 are located in the front part of the fuselage under the cockpit floor. These devices consist of a transformer with two secondary windings (wye and delta), two Larionov's diode rectifiers and a fan.

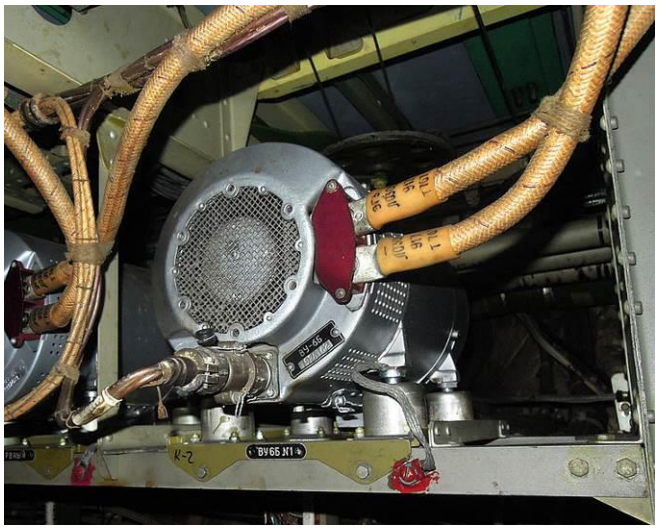


Fig. 5. Rectifier ВУ-6Б 208 V 400 Hz/27 V DC on the Tu-154 aicraft. Source: http://commons.wikimedia.org/wiki/File:VU-6B-rectifying-device-on-Tu-154.jpg

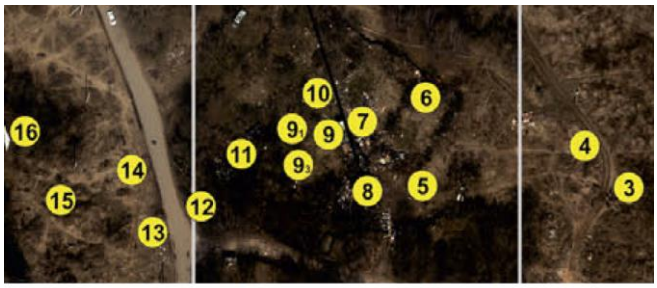
The ВУ-6 electromechanical rectifiers of the Tu-154M PLF101 have not been identified on available photographs taken after the crash.

5. ELECTRIC MOTORS AND ACTUATORS

The Д-10 АРУ (D-10 ARU) d.c. electric motor is an integral part of the ТЭМ-4 electromagnetic brake for flap control mechanism (Fig. 6). The ТЭМ-4 electromagnetic brake, according to IAC (MAK) report [5], was found near the famous birch tree, before Gubenko Street (Fig. 7 and Fig. 8). This is the fragment No 9.2 in Fig. 7 the photograph of which is shown in Fig. 9. Nearby the ТЭМ-4, the screw actuator of flaps (No 14 in Fig. 7) and flap gear reducer (No 13 in Fig. 7) were also found. These parts are shown in Fig. 9, Fig. 10 and Fig. 11.

Fig. 6. Brand new Д-10 АРУ d.c. electric motor.

Both photographs in Fig. 9 and Fig. 10 have been downloaded on April 10, 2010 at 18:44 by a Russian blogger MAKS at http://www.forum.smolensk.ws . The photograph of the same parts shown in Fig. 11 has been taken later. The authors' request for the date and time of this photograph being e-mailed to the Team for Explanation of Causes of Smolensk Crash [7], personally to M. Lasek, the chairman, has remained unanswered.



9	Fragment of the left aileron, left flap fairing. Fragment of left slat.	845	-42
9.1	Left outer flap tip.	838	-36
9.2	Left outer flap tip fairing, TM-4, D-10ARU №00900002.	838	-37
9.3	Left flap track, slat fragment, flap housing.	837	-42
10	Fragment of left wing skin panel.	839	-30

Fig. 7. Fragments of Tu-154M PLF 101 on the wreckage field before Gubenko Street according to Interstate Aviation Committee (MAK) [8]. 3 - site of impact №2 on a tree, h=4.1m, 4 - site of impact №3 on a group of trees, 5 - site of impact №4 on a group of trees, 6 - site of impact №5 on a group of trees, 7 - site of impact №6 on a tree, h=4.8m, 8 - fragments of the left wing in the tree trunk, h=5m, 9 - fragment of the left aileron, left flap fairing, fragment of left slat, 9.1 - left outer flap tip, 9.2 - left outer flap tip fairing, ТЭМ-4, Д-10 АРУ №00900002, 9.3 - left flap track, slat fragment, flap housing, 10 - fragment of left wing skin panel, 11 - spoiler track drive fragment №15483514131 of the left outer wing, 12 - fragment of the outer slat tip of the left outer wing, 13 - fragments of left wing skin panels, flap drive gear box fragment, 14 - flap drive fragment, 15 - collision with power lines and wire tear off, 16 - fragment of left outer wing with a fragment of slat, left aileron.

Fig. 8. Location of screw actuator of flaps and electromagnetic brake ТЭМ-4 on N. Bodin'lot before Gubenko Street. Source: elaboration by blogger *Wielki55*.

The photo of the screw actuator of flaps (Fig. 10) shows that this part dropped from the aircraft before the birch tree at N. Bodin's lot. The Interstate Aviation Committee (MAK) report [8] indicates the location of the actuator behind the birch tree (Fig. 7). Without doubt, the illustrative material in figures Fig. 8 to Fig. 11 is a proof that the screw actuator of flap control and electromagnetic brake ТЭМ-4 have been intentionally moved at the crash site to make the official version of the crash [8, 9, 6] more authentic. In the official version of the crash [8, 9, 6], the "armored" birch tree is the main cause of the crash.

The principle of the flap control of the Tu-154M aircraft is shown in Fig. 12 Flap actuators are used to move the flaps transforming screw rotation into forward movement of flaps. The angle of deflection of flaps is from 0^o to 45^o. A hydro-electro-mechanical system has been designed for pulling-out and retraction of flaps. The mechanism SPZ-1A for moving the flaps consists of a transmission and screw actuators. The transmission of flaps transfers the torque from the steering gear to the screw actuators and provides synchronous sweep-up and pull-out of flaps on right and left wings. Transmission is located on the rear wall of the third spar including the detachable part of the wing. Transmission consists of shafts, supports, airtight tips (terminals) and reducers. Shafts are made of mutually connected duralumin transmission tubes, reducers, slotted tips of screw actuators and cardan shafts. Cardan shafts are used to connect the transmission shafts if their axles intersect at an angle of up to 8^o. Cardans eliminate bending and jamming of transmissions upon deformation of the wing and serve to compensate for this mutual displacement of its mechanisms.

Fig. 9. Electromagnetic brake TEM-4. Photograph taken probably on April 10 2010 before 18:44. Source: http://www.forum.smolensk.ws/viewtopic.php?p=6889622#p6889622 **Author: MAKS.**

Fig. 10. Screw actuator of flaps found near N. Bodin'shed. Source: S. Amielin [10].

The actuators of external flaps differ from the actuators of internal flaps because their heads are inclined at a certain angle with regards to the screw axis. There is reducer in the head of actuator consisting of a pair of bevel gears mounted on bearings in the body of the actuator.

Fig. 11. Screw actuator for left wing flaps (1), electromagnetic brake ТЭМ-4 (2) and reducer (3). Photo taken by IAC (MAK) [8] Source: www.faktysmolensk.gov.pl

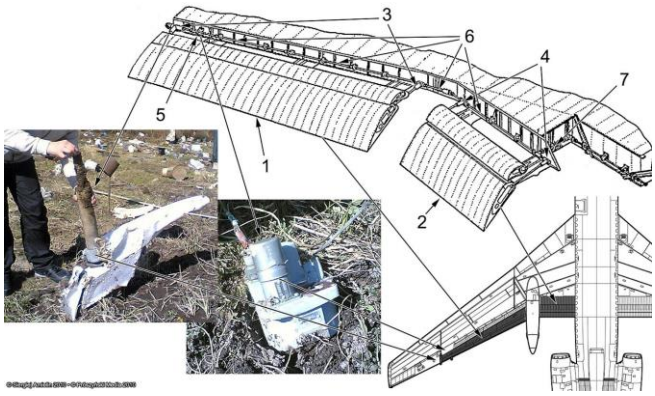


Fig. 12. Parts of flap control system found on crash site and principle of flap control of the Tu-154M aircraft. 1 – outer flap, 2 - inner flap, 3 - screw actuator of outer flap control, 4 - - screw actuator of inner flap control, 5 - electromagnetic brake TEM-4 of mechanism of flaps, 6 - transmission shaft, 7 - hydraulic motor. Source: S. Amielin [110].

6. BATTERIES

The nickel-cadmium batteries 20НКБН-25-У3 (Fig. 13) of the aicraft electric system provide:

- autonomous start of the main engines and APU;
- power to the ground conditions of individual loads when the engines and APU do not operate;
- start in flight;
- feeding in flight 1st category loads under emergency conditions.

Fig. 13. Nickel-cadmium battery 20НКБН-25-У3.

The Tu-154M aircraft is equipped with four 20НКБН-25-У3 batteries and two spare batteries. Three out of six of the 20НКБН-25-У3 batteries of the Tu-154M PFL 101 have been found undamaged at the crash site (Fig. 14).

Fig. 14. Undamaged batteries at the crash site. Source: SuperVizjer_Smolensk_4.wmv (http://www.youtube.com/watch?v=dB08tmbl2TQ**).**

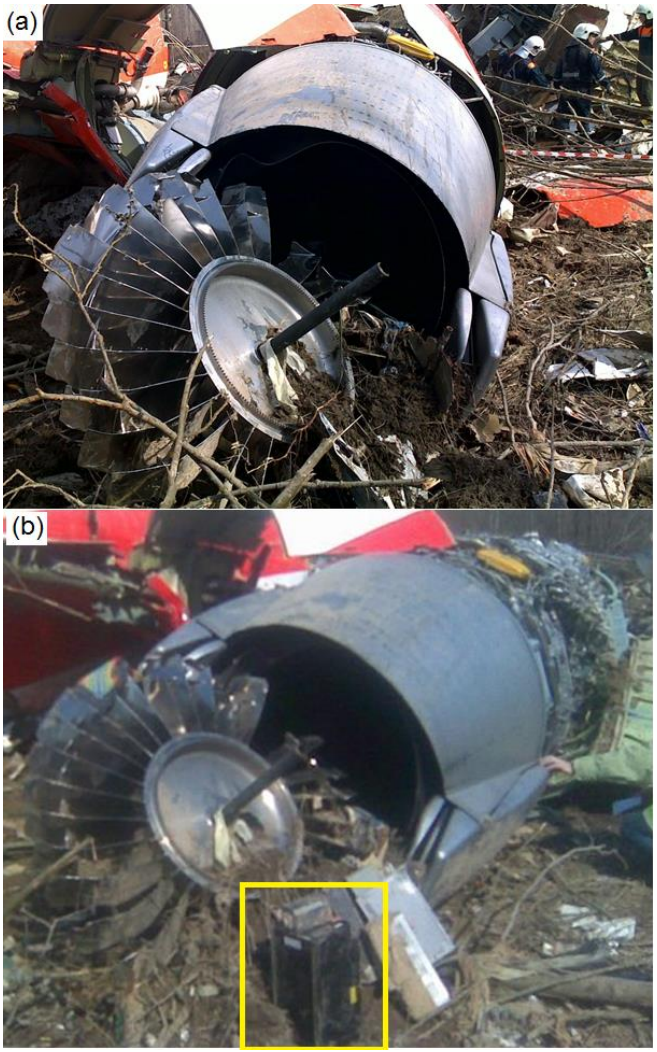


Fig. 15. Low pressure compressor (LPC) of the left engine No 1 at the crash site. (a) the blades were spinning before touching the ground because their tip portion is covered with soil (b) the object in rectangular frame beside the LPC is probably the battery 20НКБН-25-У3. Source: Fig. 15a www.faktsmolensk.gov.pl **, Fig. 15b unknown source.**

It is impossible to locate on the basis of available illustrative material where the batteries have been dropped after the crash. Fig. 15 shows that the batteries have been moved at the crash site from place to place.

7. LANDING LIGHTS

The Tu-154M is equipped with four landing/taxi lights PRF-4 27 V 35.5 A: two mounted on the wings and two mounted on the fuselage before the front landing gear. The fuselage landing lights are shown in Fig. 16.

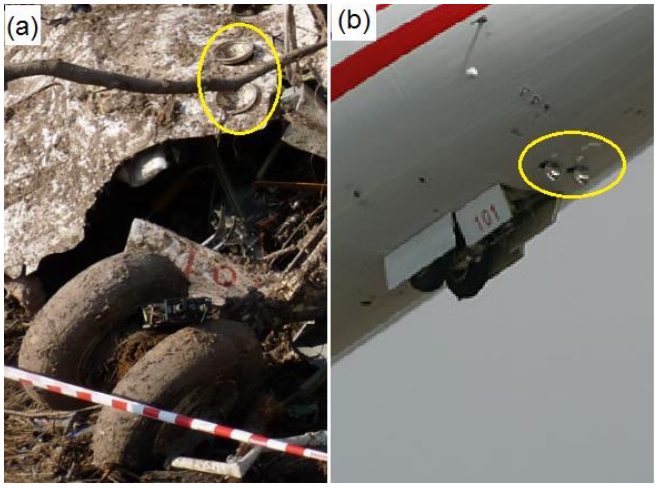


Fig. 16. Landing/taxi lights PRF-4 mounted on the fuselage of the Tu-154M PLF 101: (a) found on the crash site with broken glasses [8], (b) ejected lights at landing approach. Source: Fig. 16a Raport IAC (MAK) [8], Fig. 16b M. Franczyk, www.galeria.aviateam.pl .

Each time, when the TU-154M approaches landing, the PRF-4 lights are always ejected, both at daytime and nighttime (Fig. 16b). It is enigmatic that after the crash the landing lights looked like in stowed position (Fig. 16a and Fig. 17).

Fig. 17. Condition of landing/taxi lights PRF-4 mounted on the fuselage of the Tu-154M PLF101 after the crash. Photograph taken at the place of storage of the wreckage. Source: Annexure No 4 KBWL [6].

8. FUEL PUMPS

Fuel pumps of the Tu-154M are driven by 115/220-V induction motors and 27 V DC brush motors [2]. A flange mounted motor and pump constitute one integral unit. The feeding cables in fuel tanks are in aluminum tubes. There are two types of fuel pumps on the Tu-154M [2, 3]:

- Fuel transfer pumps ЭЦН-323, which perform the task of transferring fuel between the aircraft fuel tanks to ensure that the engine fuel feed requirement is satisfied;
- Fuel booster pumps ЭЦН-325, ЭЦН-319, also called engine feed pumps, which are used to boost the fuel flow from the aircraft fuel system to the engine.

Fig. 18 and Fig. 19 show the fuel booster pump ЭЦН-325 of the wing fuel tank in the left centerwing at the place of storage of the wreckage.

Fig. 18. Fuel booster pump ЭЦН-325 of the wing fuel tank in the left centerwing. Photograph taken at the place of storage of the wreckage. Source: www.faktysmolensk.gov.pl [7].

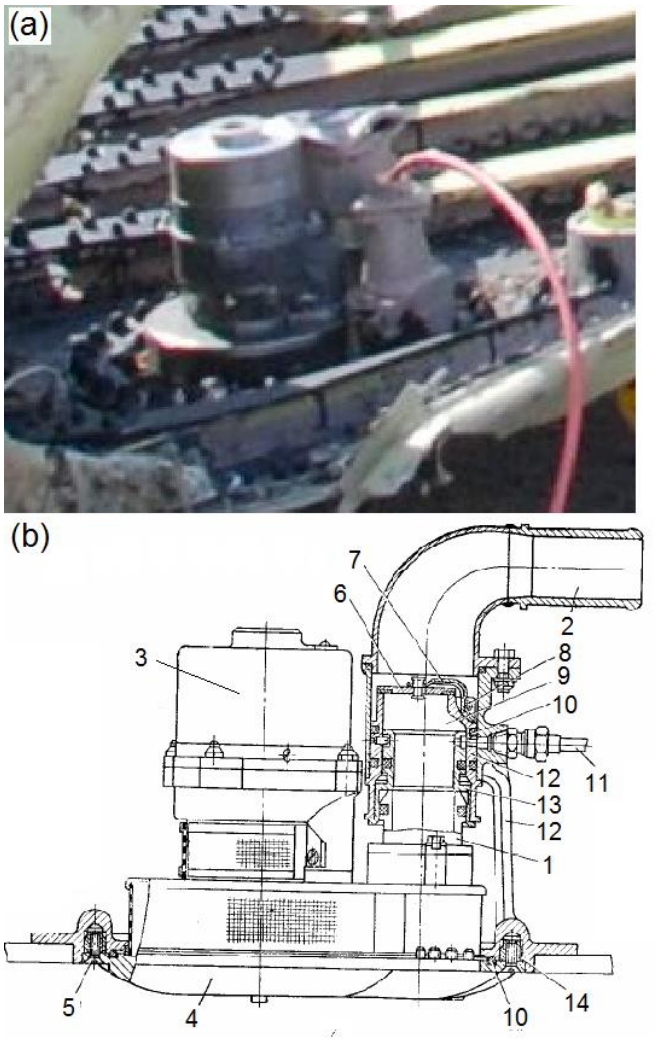


Fig. 19. Identification of the fuel booster pump ЭЦН-325: (a) magnified circled area of Fig. 18; (b) outline of the fuel booster pump ЭЦН-325 [3]: 1, 2 – tubes, 3 – induction motor driven pump, 4 – cover, 5 – screw, 6 – disk cover, 7 – lever, 8 – spring, 9 - non-return valve, 10 - rubber ring, 11 – pipeline, 12 – body, 13 – base, 14 - fittings.

9. POWER WIRING

Typical aircraft have from 16 to 160 km of wire installed such that wire from one system is often collocated with wire from many other systems. Electrical wiring can be classified into power wiring (heavy current) and light current wiring.

In modern aircraft, power wires, feeding e.g., electric motors, are not routed through the cockpit. Switches in the cockpit are connected to light current wires (control wires), which active relays of heavy current circuit.

After crash, wiring is normally scattered throughout the wreckage, but major wire bundles remain more or less intact.

Fig. 20. A boundle of electric wires located before front spar of the detached portion of left wing. The front skin has been probably damaged when the severed part of wing hit the bushes at the crash site, while dropping. Note that slat covering the front skin has not been damaged Source: www.faktysmolensk.gov.pl **[14 7].**

Fig. 21. Destruction of electric wiring and pneumatic hoses and tubing fixed the wing spar during rescue action at the crash site. Photo: A. Gargas, „Special Mission", Polish TVP1 program.

Wiring is inspected visually. The condition of wires and their insulation is a good indicator of the source of overheating. External overheating discolor or burn the insulation, while the wire strands should be intact and shiny. Internal or severe external overheating discolor the wire strands.

A boundle of electric wires located before front spar of the detached portion of left wing is shown in Fig. 20. These wire can either be for energy delivery to the heating elements (de-icing of slats), to the fuel pumps, or electric lighting. The front skin of the wing has been ripped of, while the slat covering the front skin has not been damaged.

Fig. 21 shows how the pneumatic hoses and tubing and electric wires have been destructed by Russians at the crash site.

Fig. 22 and Fig. 23 show bundles of electric wires pulled of the fuselage as a result of axial forces acting inside the fuselage. The origin of these forces can only be explained by internal explosion in the fuselage.

Fig. 22. Distinctive bundles of electric wires pulled out from the rear portion of the fuselage torn around the frame No. 65 at the crash site [5 8].

Fig. 23. Transportation of the rear portion of the fuselage shown in Fig. 22 from the crash site to the storage place. Pulled out electric wires are clearly visible.

10. OTHER DEVICES

Fig. 24a shows low-frequency amplifiers УНЧ in the technical compartment No 1 (avionics compartment) after the crash, while Fig. 24b shows undamaged amplifiers of the Tu-154M PLF2. The compartment No 1 is located under the cockpit. The photograph in Fig. 24a, which shows a heap of debris is turned upside down with respect to the original photograph [7]. In the bottom left corner of Fig. 24 there is the airborne collision avoidance system ACAS, also called the traffic-alert and collision avoidance system (TCAS)[1] [7].

[1] The airborne collision avoidance system (ACAS), in practice the US designed traffic alert and collision avoidance system (TCAS), is a transponder-based aircraft system designed to alert pilots to collision risk. It provides a cockpit display of all ACAS or transponder equipped traffic in the vicinity. If a conflict develops, the ACAS tells the pilot to climb or descend to avoid the collision.

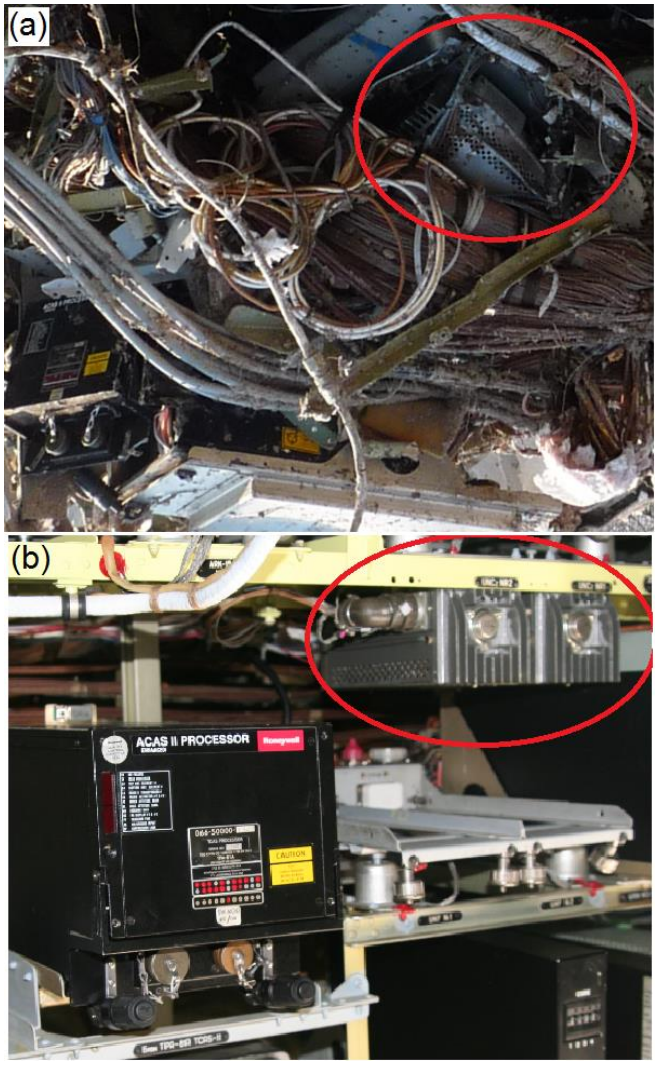


Fig. 24. Low frequency amplifiers УНЧ: (a) after the crash; (b) in the technical compartment No 2 of the Tu-154 PLF2. Source: www.faktysmolensk.gov.pl **[7].**

11. CONCLUSIONS

From the presented illustrative material and its analysis, the following conclusions can be drawn:

1. Very few components of electric system of the Tu-1654M PLF 101 are visible on available photographs taken at the crash site.
2. Components of electric system such as main generators ГТ40ПЧ6, batteries 20НКБН-25-У3 and d.c. motors Д-10 АРУ have not been damaged as a result of crash.
3. Some photographs show that the components were moved at the crash site and it is difficult to identify the initial position of the rest of fallen objects from the Tu-154M, e.g., figure Fig. 8 - Fig. 11, Fig. 14 and Fig. 15.
4. It is unknown if original places of fall have been accurately recorded and described by investigators. Both official Russian report [8] and Polish report [9, 6] show coordinates of fragments at the crash site, e.g., Fig. 7, but credibility of these reports is questionable.
5. It is unknown if the components of the electric system have been put apart for further detailed investigation and if any other investigations except visual inspection have been done. References [11, 2, 12] discuss, how the components of electric system are to be investigated and analyzed after crash.
6. Photographs shown in figures Fig. 10, Fig. 11, Fig. 15, Fig. 18, Fig. 21, Fig. 23 and Fig. 24a are clear examples of a shame and disgrace to the CINAA (KBWLLP) [9, 6, 7], Prosecution General, Polish Ministry of Foreign Affairs and, first of all infamy, to the Polish Government lead by D. Tusk, the Prime Minister. Disorder, muddle, chaos, debris clutter, horrifying pictures of the destruction of the wreckage at the crash site and improper storage of the wreckage of the Tu-154M PLF 101 is a real international scandal and proof of incompetence, lack of basic diplomatic skills of negotiation with Russian authorities, lack of knowledge how to investigate air crashes and lack of goodwill to explain the death of the President of own country and other notable Polish persons.

12. ANNEXURE: POSTCONFERENCE COMMENTS

Since the Office of the Military Prosecutor of Poland has released recently some reports on the visual inspection of the wreckage of the Tu-154M PLF 101 and its avionics equipment to the Organizing Committee of the 3rd Smolensk Conference, some observations and comments have been presented below:

1. **Secondary artificial horizon AGR-72**. The IAC (MAK) has determined the angle of impact with the ground on the basis of "frozen" indication of this instrument. During investigations by the Office of the Military Prosecutor this instrument has shown different pitch angle than that on the photograph published in the IAC (MAK) report [8]. It is advisable in future investigations to verify the extent to which the artificial horizon can be adjusted and what is the learned value of the readings shown by IAC (MAK) [8]. It cannot be neglected that the final conclusion on the angle of impact with the ground drawn on the basis of indication of the AGR-72 is premature.
2. **Indication of the flap position in the middle panel of instruments in the cockpit**. The authors believe, that the reason why this instrument shows different inclinations of flaps of the left wing (about 18^{o}) and right wing (36^{o}) requires uncompromising explanation. If such position of flaps is true, the one of possible reasons of imbalance in lifting forces could be desynchronization of flaps. This in turn would put into questions the completeness and credibility of the existing CVR[2] transcription, which contains neither the sound of malfunction/retraction of flaps nor the command and announcement of pilots associated with this activity.
3. **Console PU**-46. The knob "TURN" has been turned to the right. A question arises what is the credibility of such setting, which can origin from the impact with the ground. An attempt to compensate for the increasing tilt to the left hand side still under the control of the ABSU[3]

[2] Cockpit voice recorder (CVR)

[3] Автоматизированная бортовая система управления (АБСУ). Automated on-board control system (ABSU) of the Tu-154M gets information about the spatial position of the aircraft from a variety of gyroscopic sensors, acceleration sensors, radio and navigation systems. ABSU manages aircraft at the rate, roll and pitch in manual control, stabilization or automatic mode. ABSU is structurally divided into the longitudinal channel (pitch) and side-channel (roll and heading). Each channel can operate completely independently of the other. It can anual control in one channel, and automatic - in another. ABSU can operate in

side channel (roll and heading) seems to be unlikely, because if it is not disconnected by the "AP DISCONNECT" button, it would be necessary to switch into manual control by turning the volant and thus compensate for the imbalance of lifting forces.

4. **Indicator USz-3[4] of the TKS[5] system in the navigator's console**. It is necessary to clarify the 204° inclination of the indicator and the 15° inclination of the indicator K (gyromagnetic course) of the USz-3. The last one is different than the reading of the preserved PNP[6].
5. **Potentiometers of radio altimeters**. These potentiometers show respectively: 28.2 and 27.3 (first instrument) and 19.3 and 32.6 (second instrument). The question related to the lack of correlation of these values with the graph "WYSRADIO" in the CINAA (KBWLLP) report [9] (last value about 300 m) seems to be justified.
6. **Primary artificial horizon No 9460491202 (PKP[7])**. The record "the indicator is set to the position of maximum left-side roll, the angle of the pitch is close to zero" shows that PNP has stopped around 90° roll and zero degree pitch. It is necessary to verify the roll angle indicated by the instrument in order to detect its accurate value. The statement that the roll angle equals about 67° (similar to the last records "PRZECHYL/PKPRZECH") would be a prerequisite of the possibility of electric power failure during the flight.
7. **Ni-CD batteries 20НКБН-25-УЗ**. The available photo of 6 batteries shows that the three of them are visually in good condition, while the remaining 3 batteries are with damaged covers (broken and bent).

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[9] Final Report on the examination of the aviation accident no 192/2010/11 involving the Tu154M airplane, tail number 101, which occurred on April 10th, 2010 in the area of the Smolensk North airfield, Committee for Investigation of National Aviation Accidents (CINAA), Komisja Badan Wypadkow Lotniczych Lotnictwa Panstwowego (KBWLLP), in Polish, Warsaw, 2011.

[10] S. Amielin, ,"The last flight 101'', Photo Album, https://plus.google.com/photos/107906898396623830387/albums/5552448258916359489?banner=pwa

[11] G. Ellis, "Air crash investigation of general aviation aircraft", Capstan Publications, Greybull, WY, USA, 1984.

[12] R.H. Wood, R.W. Sweginnis, "Aircraft accident investigation", 2nd ed., Endeavor Books, Casper, WY, USA, 2006.

many modes including automatic control of the course (ZK mode) and automatic go-around (Uhod - Уход).

[4] Указатель штурмана УШ-3с. The pointer USz-3 of the navigator. The USz-3 has an index pointer and two indicators: "K" and "PU". The indicator "K" shows the gyromagnetic course (aircraft heading). The indicator "PU" (путевой угол) indicates the track angle.

[5] Точная курсовая система (ТКС). The accurate course system (TKS) is a device that combines magnetic and gyroscopic means for measuring the course.

[6] Плановый навигационный прибор (ПНП). Horizontal navigation indicator (PNP).

[7] Пилотажный командный прибор (ПКП). Flight and command device (artificial horizon).