



Hypothesis of Explosion in the Left Wing Outer Fuel Tank of Tu-154M due to Electrical Ignition of Fuel-Air Mixture

Hipoteza eksplozji w zewnętrznym zbiorniku paliwa lewego skrzydła samolotu Tu-154M na skutek zaplonu mieszanki paliwo-powietrze

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Roadmap of the Presentation



1. Problem statement
2. Similar air crashes
3. Examples of explosion of fuel tanks
4. Tu-154M fuel system
5. Tu-154M wing anti-ice system and electric wiring
6. Electric ignition of aircraft fuel – hazards and causes of fuel ignition in tanks
7. What could happen to the left wing?
8. Conclusions

Problem Statement



Lost of the left portion of wing



According to the Report of Polish Committee for Investigation of National Aviation Accidents KBWL, Annexure 4, Section 4.10.3, ***the lost of the left portion of the wing has caused the burst of the left fuel tank Nr 3, which is placed between rib nr 14 and 45.*** The severance of the 6.1-m long tip of the left wing was between the ribs nr 27 and 28.

Since the severance of the wing tip as a result of collision with 0.3 to 0.4-m diameter birch tree is rather impossible, the problem should be stated in opposite way: ***The burst of the left fuel tank Nr 3 caused the lost of the left portion of the wing***

According to **G. Szuladzinski**, the Tu-154M No 1 crash was due to **two explosions in the air**: one on the left wing and the second inside the fuselage.

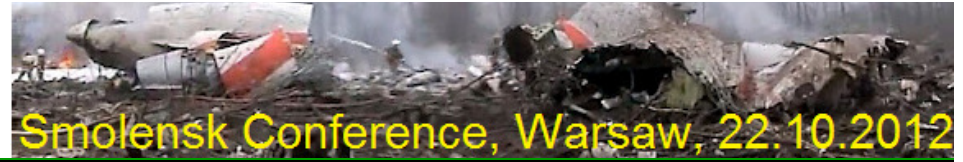
Crash Site



Only a **hypothesis of explosions** in the air can justify such fragmentation



Fuselage at Crash Site versus Burst Gas Cylinder



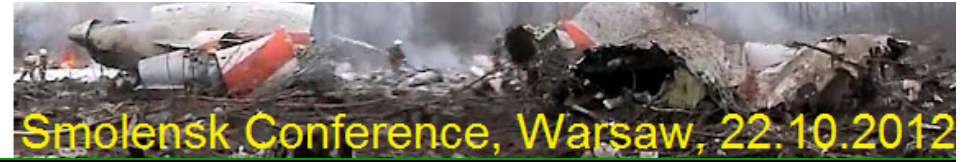
Comparison of the fuselage at the crash site on April 10, 2012 with burst gas cylinder



Burst gas cylinder

Other Examples of Inner Explosion

Walls open to the outside



<http://news.xinhuanet.com/englisch/china/2012-02/20/c-131420643.htm>

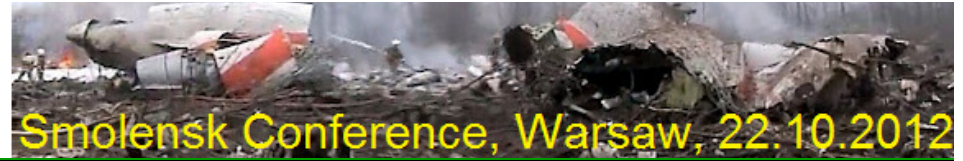


↑ Explosion of liquefied petroleum gas in truck tank, Xigu District of Lanzhou, China

← KS-135 fuselage pressure test explosion

<http://discity.com/kc135/>

Tu-154 versus Boeing 727



Tu-154 looks very similar to Boeing 727



JT8D PW low bypass turbofan engine



Bypass ratio 1.0:1.74
Thrust 117.5 kN



D30-KU Soloviev low bypass turbofan engine



Bypass ratio 1.0:2.3
Thrust 93.4 kN

Air Crashes Similar to Smolensk Crash

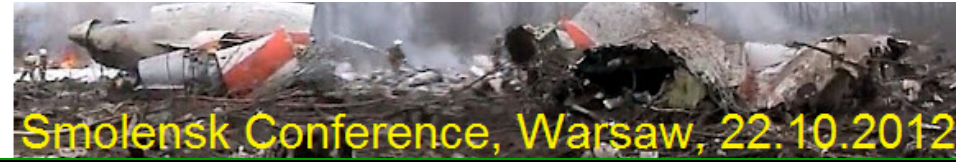
Tallahassee, FL, 26 July
2002 Boeing 727-232F



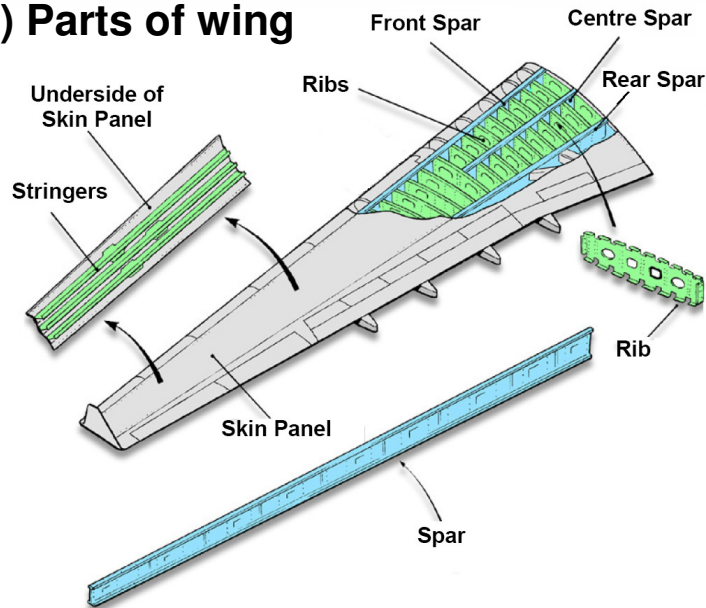
Sonoran Desert, April 2012,
Boeing 727, crash test



Construction of Wings of Passenger Aircraft



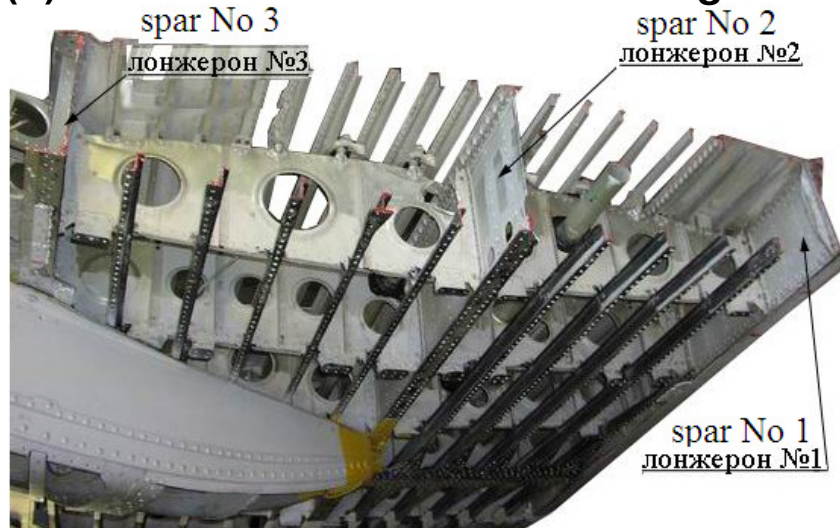
(a) Parts of wing



(c) Interior of the wing of a transport aircraft



(b) Construction of the Tu-154 wing



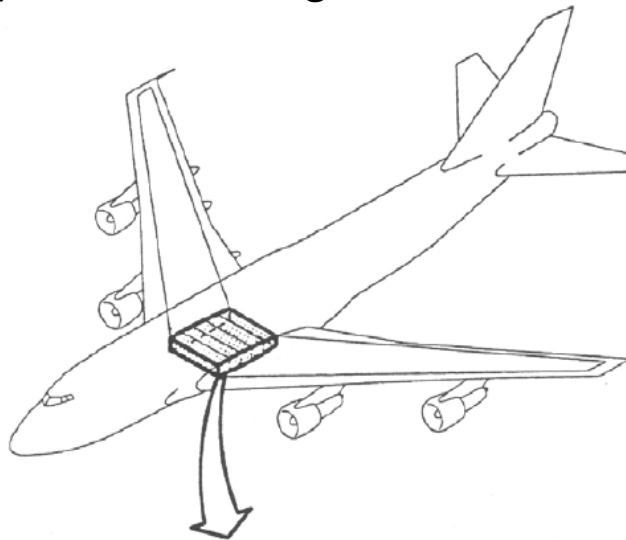
<http://www.littlerock.af.mil./shared/media/photodb/photos/100716-F-7087B-031.jpg>

Boeing 747-131 TWA, June 17 1996 Explosion in CWT

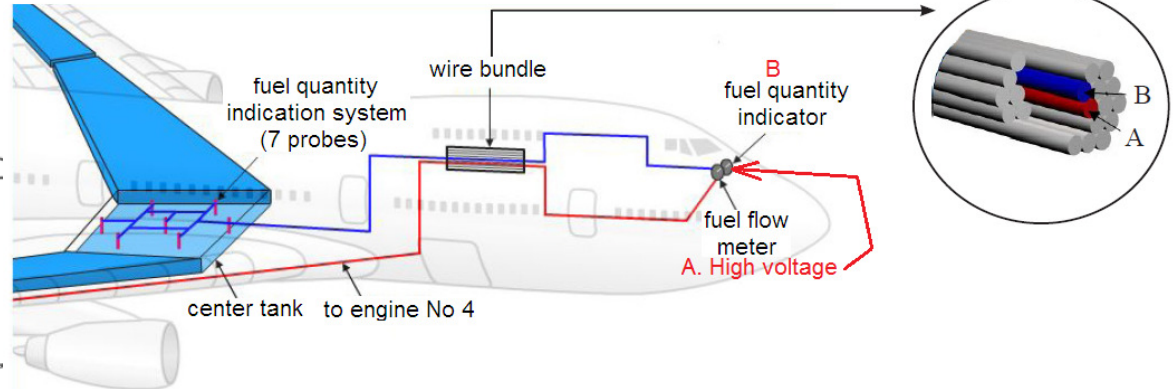


Short circuit in a bundle of electric wires caused fuel-air mixture ignition

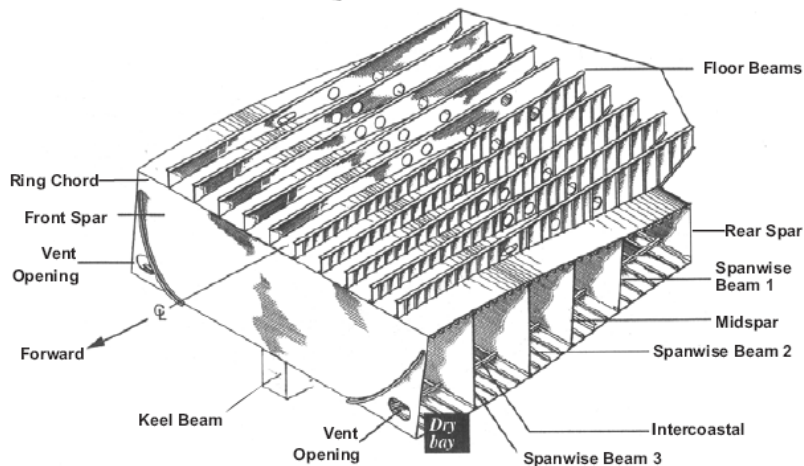
(a) CWT of Boeing 747



(b) High voltage from the fuel flow meter A passed to the fuel quantity indication system (FQIS) because of a short circuit in the wire bundle.



(c) Reconstruction of Boeing 747-131 TWA



Boeing 727-200, Transmile Airlines, Bangalore, May 4, 2006

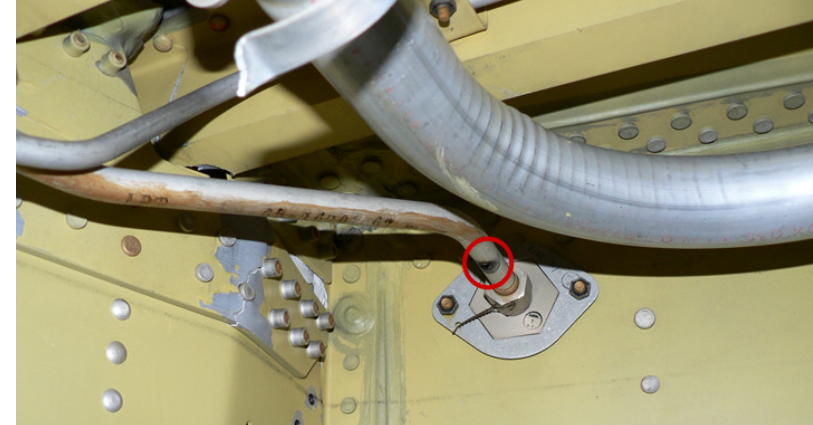


Electrical arcing in Al tube with fuel pump cable caused fuel-air mixture ignition

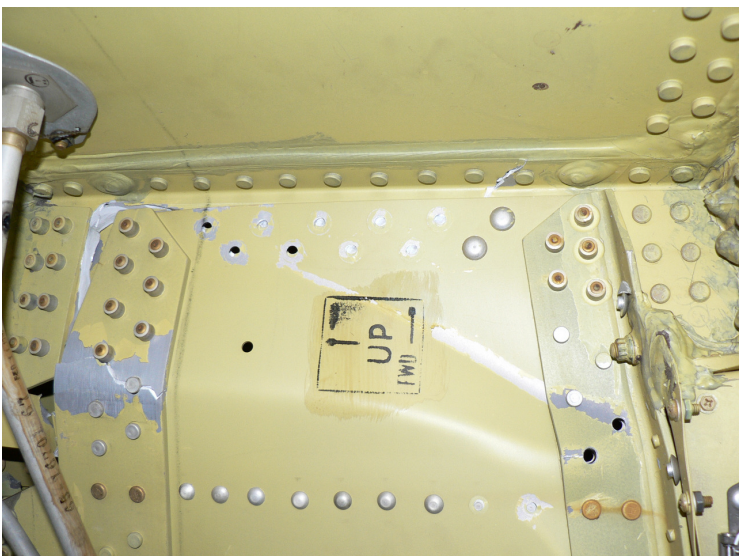
(a) Explosion destroyed the structural integrity of the left wing.



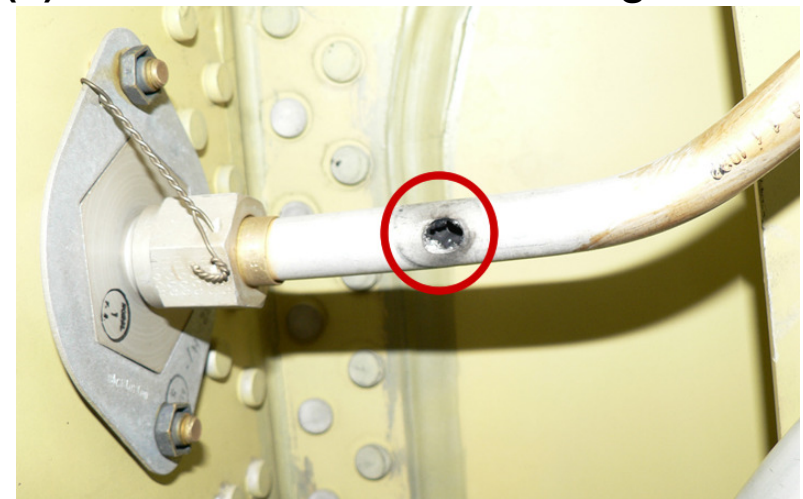
(c) Damaged electrical installation and electrical arcing in aluminum tube with 115-V AC cable feeding fuel pump motor in the left wing tank



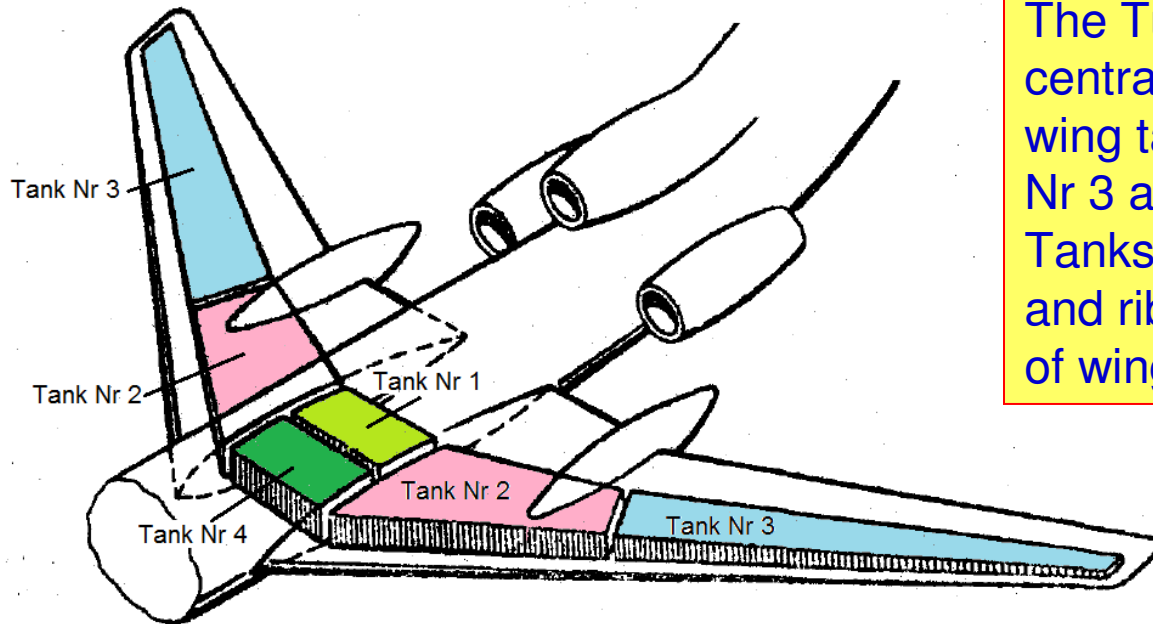
(b) Interior of left wing fuel tank



(d) Evidence of electrical arcing



Tu-154M Fuel Tank Configuration



The Tu-154M has six fuel tanks: one central fuel tank (CWT) Nr 1, two inner wing tanks Nr 2, two outer wing tanks Nr 3 and one additional tank Nr 4. Tanks Nr 3 are between spars 1 and 3 and ribs 14 and 45 of detachable parts of wings

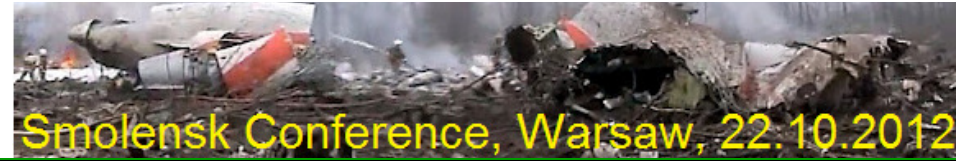
The Tu-154M was fueled on April 7 (22 568 l) and April 9 (9518 l).

Capacity of fuel tanks before and after crash

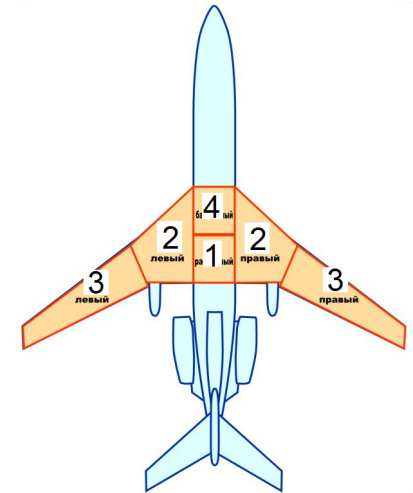
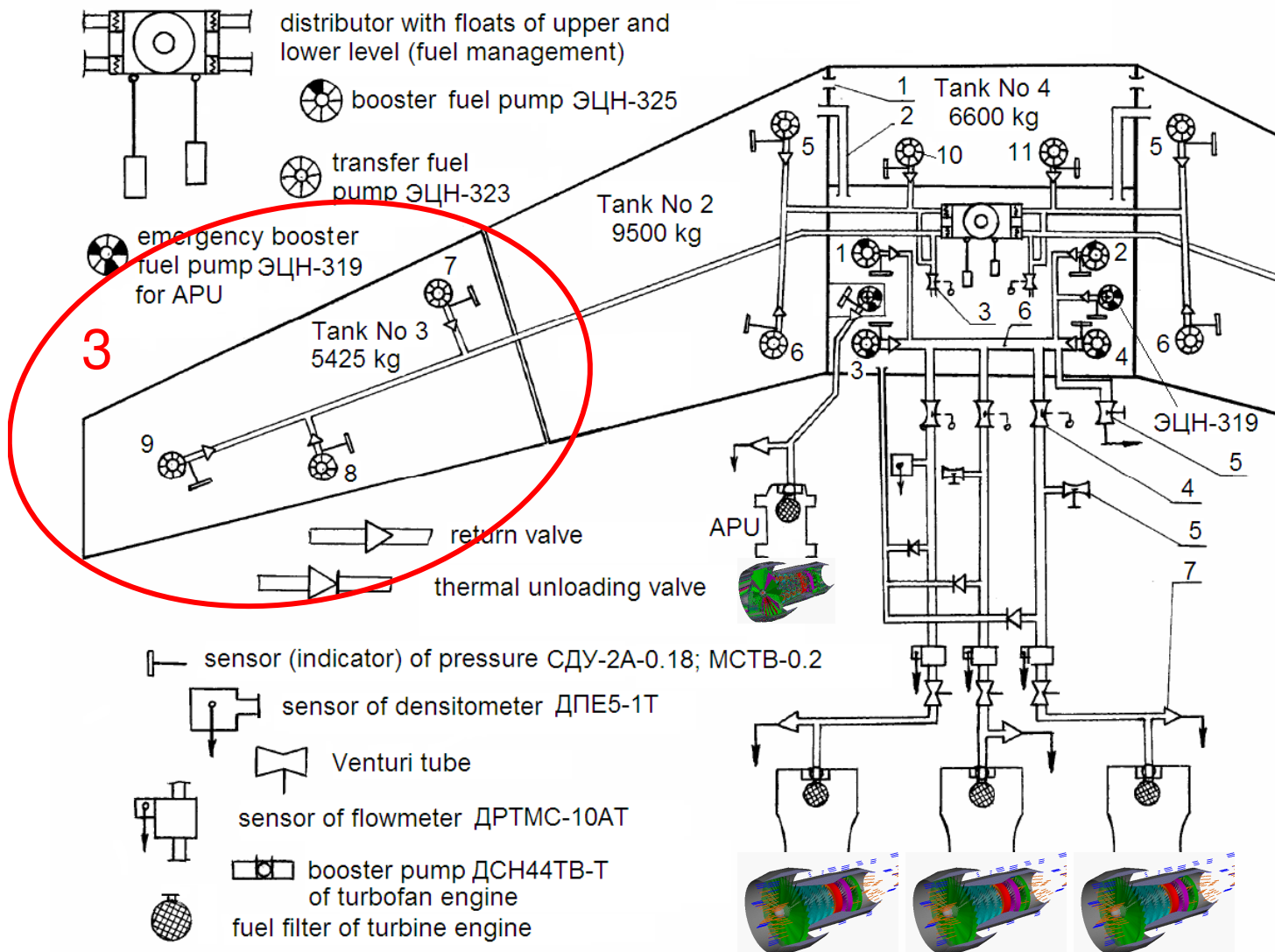
Nr of tank	Nominal capacity, kg	Last refueling, kg	After crash, kg
Nr 1 CWT (collector tank)	3300	3300	3150 to 3300
Nr 2 (two tanks)	2 x 9500 = 19 000	4000	0
Nr 3 (two tanks)	2 x 5425 = 10 850	5372	130 to 1450
Nr 4 (additional tank)	6600	6000	6000
Total	39 750	18 672	10 450 to 10 750

CINAA (KBWL). Aviation accident involving Tu-154M airplane, tail nr 101 on April 10, 2010, in Polish.

Tu-154M Fuel System



Tu154M fuel system layout. Fuel tanks, fuel pumps, fuel transfer lines, Д30КУ engine and APU have been shown



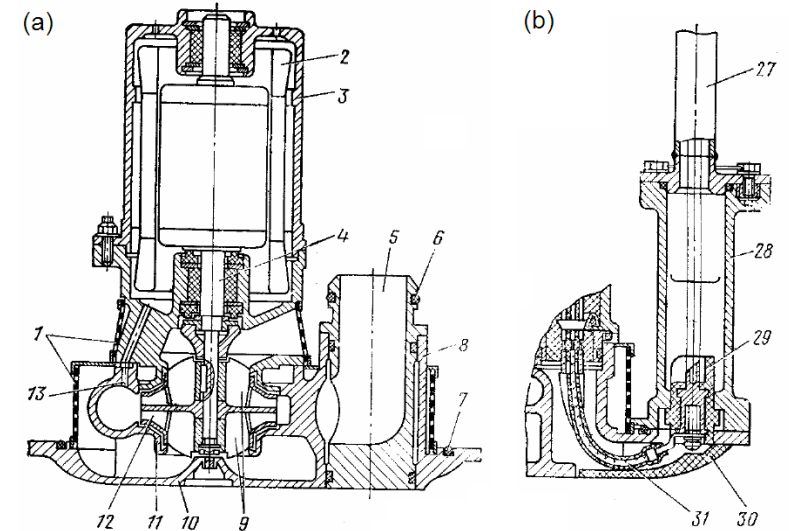
1,2 – feed lines of upper transfer from tanks No 4 and 1 to tank 2; 3 – faucet of reserve transfer; 4 – antfire faucet; 5 – discharge faucet, 6 – connector for maintenance of engines.

Fuel pumps of Tu154M



Specifications of fuel pumps of Tu154M

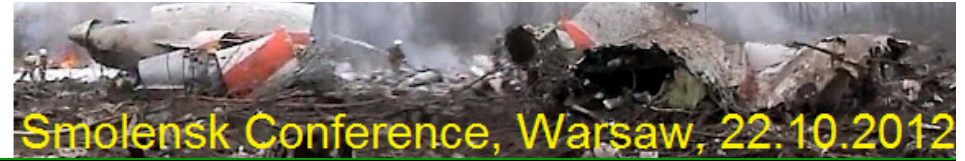
Specifications	ЭЦН-319	ЭЦН-323	ЭЦН-325
Type of pump	Emergency booster	Transfer	Booster
Electric motor	DC	Induction	Induction
Voltage, V	27	200	200
Rated current A	< 15	< 2.6	< 8.3
Starting current	unknown	< 15.6	49.8
Pressure drop, kG/cm ²	1.6	0.45	1.25
Flow, l/h	1500	2000...7000	3500...12,000
Mass of pump, kg	3.8	4.0	5.8
Number of pumps	2	12	4



Booster fuel pump ЭЦН-325: (a) cross section of fuel pump and induction motor; (b) electric wires. 1 – grid, 2 – induction motor, 3 – motor housing, 4 – shaft, 5 – tube, 6,7 – sealing rubber rings, 8 – pump housing, 9 – rotor, 10 – cover, 11 – snail, 12 – impeller, 13 – channel, 27 – conduit metal tube, 28 – tubing, 29 – terminal block, 30 – cover, 31 – electric cable. Construction of transfer fuel pump ЭЦН-323 is similar.

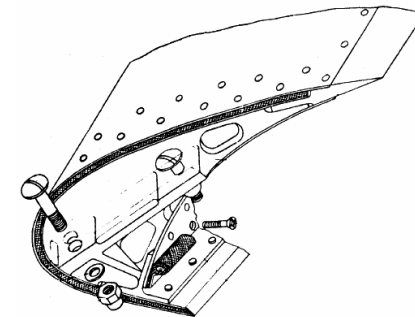
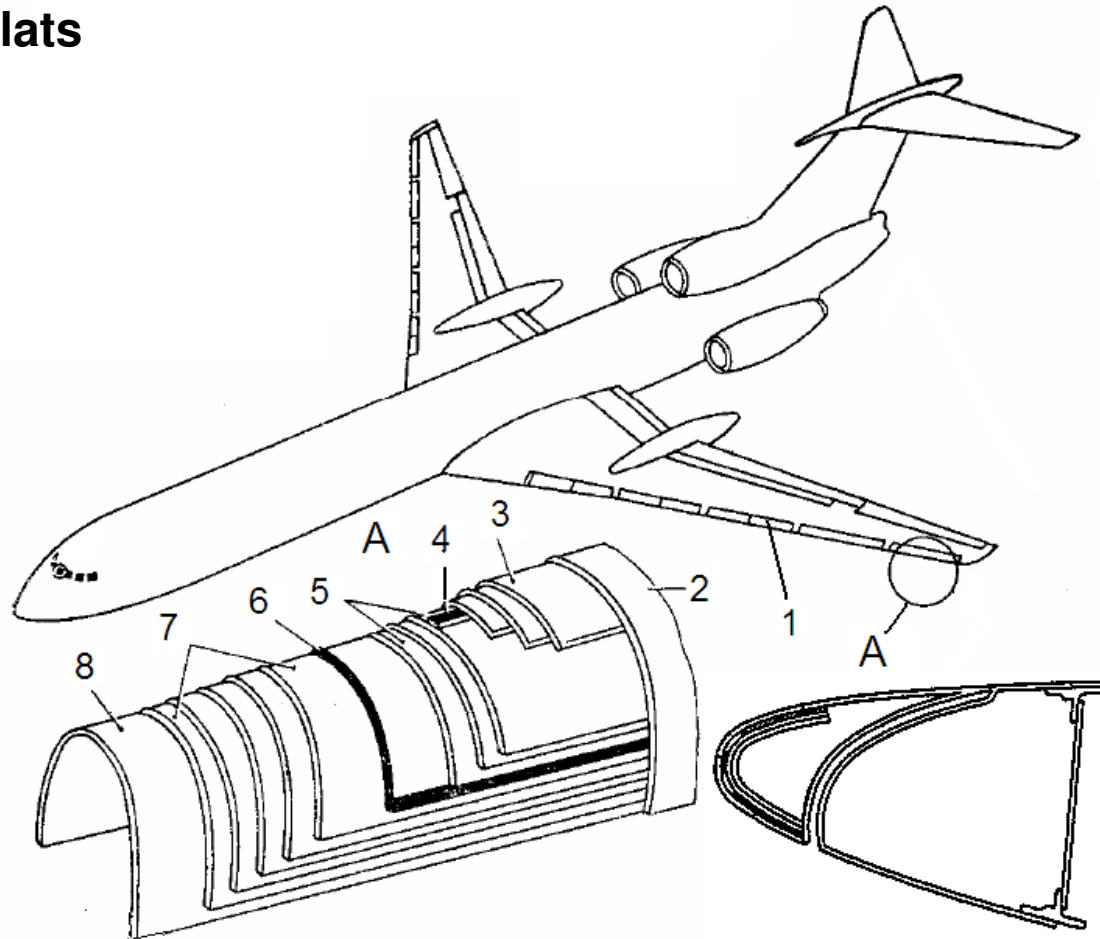
The Tu-154M has 18 fuel pumps driven by electric motors. The pumps are fuel-submerged and fuel-lubricated.

Tu-154M Wing Anti-Ice System



The Tu-154M uses electric resistive heating for anti-ice of the wing leading edge slats

The Tu154M cannot use hot bleed air for anti-ice control of outer wing leading edges as the turbofan engines are tail mounted and located far away from the wings



The generator ГТ40ПЧ6 Nr 2 driven by the mid turbofan engine feeds only electric grid No 2 dedicated to heating wing slats. The electric power is 43.6 kVA at 115 V and 130 A

Leading edge wing anti-ice system: 1 – slat, 2 – outer skin/sheathing, 3, 5, 7 – thermal glass insulation, 4 – thermal “knife” (NiCr foil), 6 – heating element (composites), 8 – inner skin/sheathing

Electric Ignition of Aircraft Fuel



The Tu-154 uses a kerosene-grade fuel Jet A-1

Characteristics of fuel Jet A-1

Density at 15°C, kg/m ³	775 to 840
Flash point, °C	38
Auto-ignition temperature, °C	210
Freezing point, °C	- 47
Open air burning temperature, °C	260 to 315
Maximum burning temperature, °C	980
Electric conductivity, x10 ⁻¹² S/m	1.0 to 20.0
Volumetric energy content, MJ/kg l	34.7

The *flash point* of the fuel is the minimum temperature at which sufficient vapor is released by the fuel to form a flammable vapor-air mixture near the surface of the liquid or within the vessel use.

Fuel samples have not been collected from the crash site for testing by Polish KBWL. The KBWL tested fuel taken from the cistern UJ00204 at Warsaw Airport. Laboratory tests have confirmed that the fuel meets quality requirements (Report Nr WK-2913-55-143-10). Fuel samples taken from the wreckage for tests by Russian MAK has confirmed good quality of fuel.

At the time of crash, it should be from 650 to 725 kg of fuel in the left wing tank No 3. The surface of the bottom of the tank No 3 has been estimated approximately as 57 m². Assuming the specific mass density of Jet A-1 fuel as 800 kg/m³, the fuel level in the tank No 3 was from 14 to 16 mm.

Electric Ignition of Fuel in Tanks



Hazard and causes of fuel ignition in tanks

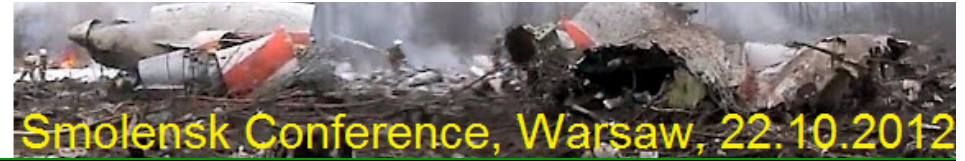
Hazard	Cause
In-tank electrical wiring	<ul style="list-style-type: none"> •hot wires •short circuit •induced currents •chemical damage •mechanical damage
Fuel pump motor wiring	<ul style="list-style-type: none"> •short circuit •electric arcing
Electric motor of fuel pump	<ul style="list-style-type: none"> •interturn short circuit •phase-to-phase short circuit •phase-to-housing short circuit •hot spots •arcing on terminals

Pump dry-running (there are fuel lubricated bearings)	Sparks generated due to mechanical friction
Adjacent systems, e.g., electric anti-ice system	<ul style="list-style-type: none"> •electric arcing external to the fuel tank •heating of tank walls •explosion within the adjacent area
Static electricity build-up due to fuel circulation or ECA	Electrical discharge (ESD) from fuel surface to tank walls
Lighting	<ul style="list-style-type: none"> •electrical discharges within the fuel tank •electrical arcing between components (inadequate distance between components)

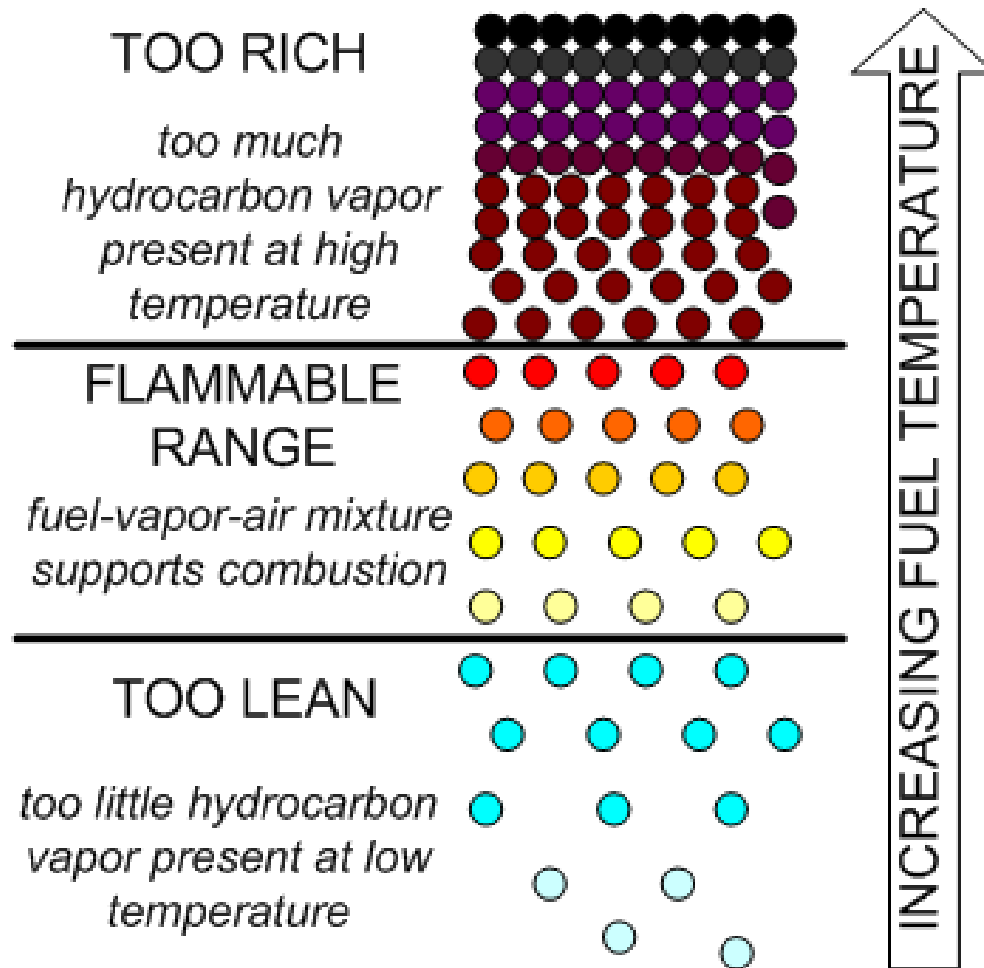
Electrostatic discharge (ESD) is a result of ECA

Electrostatic charge accumulation (ECA) is due to low conductivity liquid flow in pipes and ducts. It is well known problem in petroleum and transformer industry

Flamability Limits of Aircraft Fuel



Flammability concept for fuel vapor-air mixture



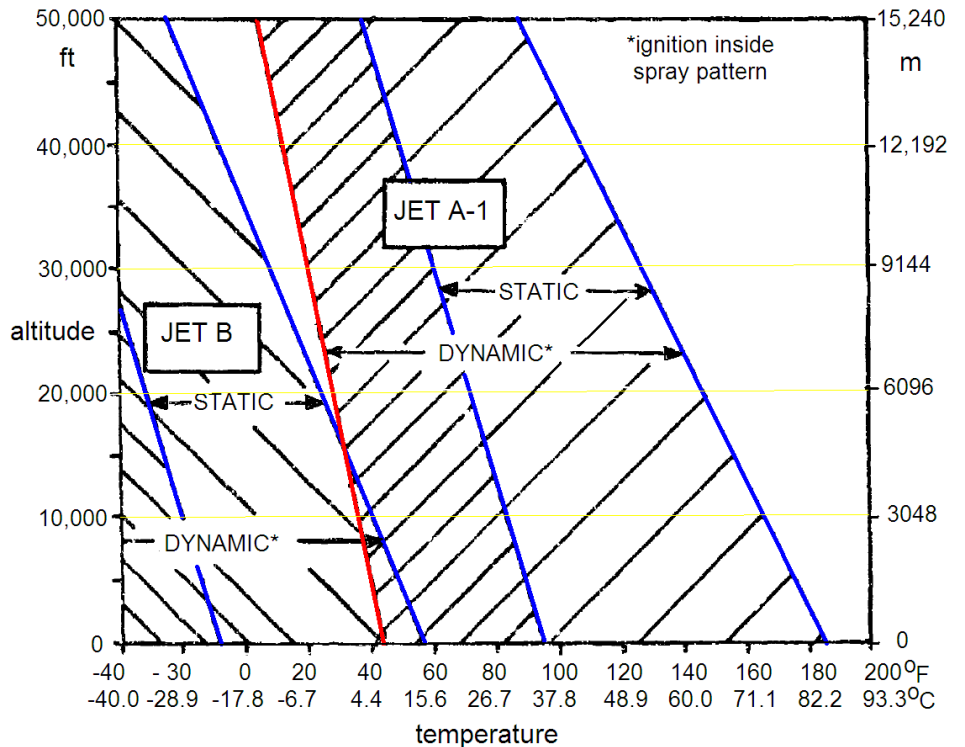
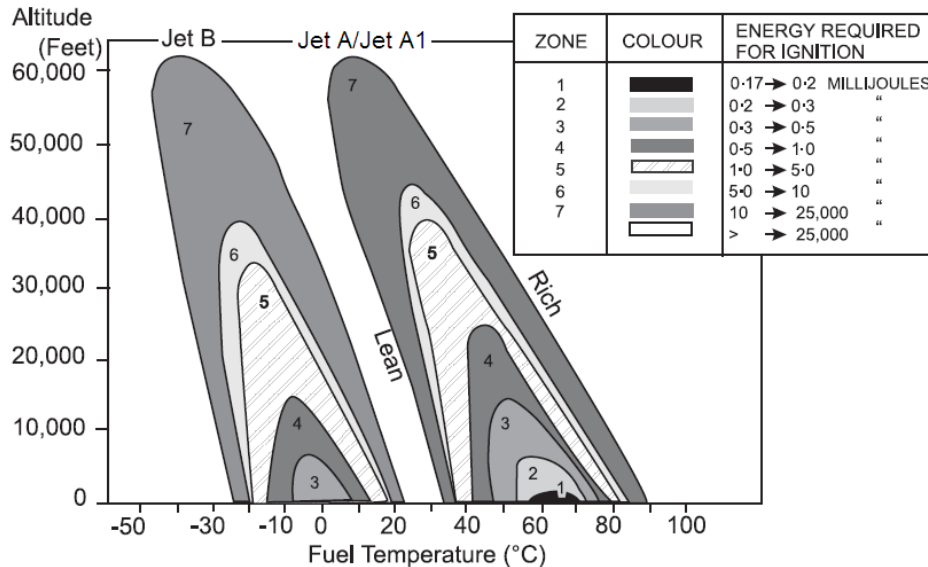
There is a definite concentration range over which mixtures of each hydrocarbon in air will burn. This is called the *flammable range*. Not all fuel-air mixture can be ignited. The composition of the fuel-air mixture in the vapor space is dependent on the fuel type, temperature and physical state, i.e., vapor or mist. Sloshing of the fuel in the tank is the mechanism that is typically associated with mist formation.

Source: J.T. Leonard, *Generation of electrostatic charge in fuel handling systems: a literature survey*, NRL Report Nr 8484, Naval Research Laboratory, Washington DC, 1981.

Flamability Limits of Aircraft Fuel



Under equilibrium conditions (temperature and altitude), the **ullage** can be made either flammable or nonflammable



Fuel-to-air ratio is determined by the temperature and pressure (altitude)

Hill, R. and Hughes, Report DOT/FAA/AR-98/26, 1998

Nestor, L.J. Raport No DS-67-7, 1967

Flammability limits are experimentally determined upper and lower flammability boundaries of fuel concentration between which the fuel-air mixture only burns. The upper (**UFL**) and lower (**LFL**) flammability limits in the air depend on initial temperature and pressure. Thus, there is a limiting minimum and maximum **fuel-to-air** ratio. Below the LFL, the fuel-air mixture is too lean to burn. When UFL is exceeded, the vapor space mixture is too rich in fuel to be flammable.

What could happen to the left wing?



Detailed investigation of the wreckage can answer the question what really happened to the left wing of the Tu-154M No 101

So far, the wreckage is not available to independent investigators and only photographs taken at the crash site can be examined.

The partially empty fuel tank is more dangerous than the full tank as the ullage for the formation of flammable vapors is larger.

The explosion in the left wing tank No 3 could be a result of fuel ignition due to:

- (a) **short circuit** and **arcing** inside the tank No 3;
- (b) **fuel ignition due to static electricity build-up (ECA)**;
- (c) **explosion** within the **adjacent area** of tank No 3.
- (d) **Malfunction of anti-ice electric heating system**. Malfunction of anti-ice electric heating system installed in slats could lead to **local temperature rise** in the tank wall and create friendly conditions for fuel ignition by sparks or arcing.

Conclusions



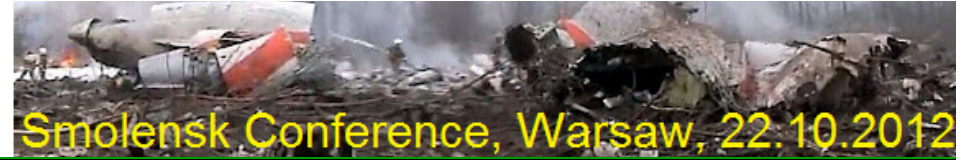
Although probability of **explosion of fuel** in the left wing tank No 3 due **static electricity (ECA)**, **electric short circuit** or **arcing** is low, this problem cannot be neglected in further investigation of the accident, especially examination of the wreckage and its remaining electrical equipment, wiring and left wing fuel tank No 3.

Careful attention should be given to:

- fuel pumps,
- induction motors for fuel pumps,
- slat electric anti-ice system,
- all power cables/wires in fuel tank No 3 and in its vicinity.

The hypothesis of the **second explosion** in fuselage (G. Szuladzinski) could theoretically also be caused by explosion of fuel in CWT.

Disclaimer



Smolensk Conference, Warsaw, 22.10.2012

Although all precautions have been taken and all findings are documented by appropriate references, the analyzed scenario and cause of the crash, unless confirmed by detailed investigation of the wreckage, is only a hypothesis.