A SUMMARY OF

EXPLOSIVE SUPPRESSANT FOR AIRCRAFT

UK MoD PROJECT

"eXess"

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Date: 02 OCTOBER 2009

Section 1 – Introduction

1. DO Systems Ltd (DOSL)

DO Systems Ltd (DOSL) is part of the Defence Optical Systems Holdings Ltd DOS(H) group of companies, and is based at Old Sarum Airfield near Salisbury in Wiltshire, United Kingdom.

The company is a contractor to the United Kingdom Ministry of Defence (UK MOD) for special aviation projects in high threat or geographically demanding environments.

Other Clients include the British Government Foreign and Commonwealth Office (FCO), the British Government Home Office and other NATO countries in the theatre of operations. The company owns and operates a number of Military and Civilian registered Aircraft and provides technical solutions for a variety of product requirements.

2. Background

The UK Government have instructed DOS to design, certify and supply a fuel tank inerting system (FTI) to prevent re-occurrence of the C130 in-flight explosion experienced by the RAF. The requirement is for a system able to be retro-fitted to all Number 2 Group aircraft in service and would be required for other Military aircraft outside of the UK.

3. Capabilities

DO System's design and certification is carried out by a wholly owned sub company, Banbury Aviation. Their activities include EASA part 21 maintenance, sub part G for manufacture and Part 21 design certification. The aviation manufacturing and certification is carried out at Old Sarum airfield in the 8000 sq ft of factory and clean area. Testing is conducted at RAF Boscombe Down in Wiltshire.

The company holds ISO9000 certification and is EASA 145 compliant.

4. FTI Program

The initial trials are near completion with the final explosive testing due in October 2009. The UK Civil Aviation submission to date is at Annex A.

On completion of B200 certification a number of other aircraft types will be added to the STC approvals; this includes a number of common helicopter types, B767 wide body and Tristar aircraft. There is a requirement of >70 platforms within No.2 Group for FTI to be installed and certified. Outside of the RAF, the US military have a requirement for all C12 aircraft (military B200) followed by all other types to be fitted with the FTI as soon as possible.

There are over 200 medium twin aircraft in the US inventory requiring this product in the Middle East theatre alone.

5. Timescale for delivery of Programme 1

The UK Government has issued an in-service date (ISD) requirement for Jan 2010 (B200 King Air). eXess Group and DO Systems are working to ensure this is achieved through collaboration with the eXess Group Headquarters in Michigan, USA and the certification team in the UK.

Banbury Mod-18 fire suppressant / fuel tank inerting investigation

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Introduction

It has been requested by the MOD that aircraft operated within a conflict zone be fitted with an explosion prevention system to prevent an explosion in the case of a ballistic strike to the fuel tanks Ref. 1.
Banbury Aviation are investigating the possibility of fitting "eXess" cylinders to the DO Systems Beechcraft King Air B200.
This document reports investigation into the explosion prevention in aircraft fuel tanks by filling the tank with aluminium mesh.
"eXess" is an aluminium metal network (mesh) that can be used within fuel tanks to prevent explosion.
The network can be produced in flat pliable sheets, cylinders and rolls, examples are shown in Figure 1.
The advantage of the cylinders, due to their small size, is that they can be retrofitted.


eXess network (NW)


eXess network cylinder (NWC)


eXess network rolls (NWR)

Figure 1 View of eXess types

The eXess network, when filling the entire volume of a fuel tank, transfers the heat by high speed away from the ignited heated region so that burning is slowed to a minimum which reduces the temperature and pressure and hence minimizes the chance of an explosion. This is enabled by the aluminium mesh having a large surface area and a high heat conductivity factor.

The profit of the use of eXess in fuel tanks due to the material- and structure characteristics resulting abilities is enormous.

Explosion Protection
Investigations of accepted institutes (TUEV Vienna, Industrial Technology Research Institute Taiwan) with 20 and 400 liters explosion containers showed that the upper explosion limit can be reduced with the installation of eXess so far that an explosion is prevented by heat absorption (depending on the installed eXess volume).

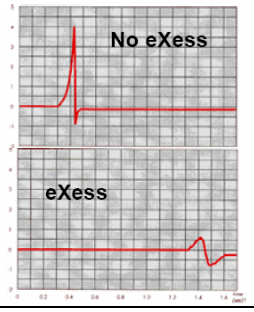


Figure 2 Excerpt from Ref. 1

The eXess network will occupy between 1.4 to 1.7% of the tank volume.

The dimensions of the cylinders can be specified between:
Diameter 16 to 24mm
Height 20 to 24 mm
Foil thickness: 65micron

The weight is approximately 0.045kg/litre.

Summary

From the information available the "eXess" mesh is an excellent retrofit to prevent explosion and possibly fire in fuel tanks. Depending on the aircraft fuel tank type the retrofit may need minimal or no modifications to the tanks.
The qualification of the mesh will involve tests to a fuel tank mock-up, ground tests and possibly flight tests to show that there is very little or possibly no change to the fuel flow rates and operation up to the minimum unusable fuel state.
The mesh cylinders will add 111 kg to the empty mass of the King Air B200 (111/3804) which is approx 3% on the empty weight with a reduction in fuel capacity of approximately 8.2 UK gallons and an increase in the total unusable fuel of 8.2 UK gallons.

Certification

The certification of the "eXess" cylinders could be through the CAA to obtain an FAA TSO (Technical Standard Order). This would qualify its use as an aircraft product, but does not qualify its use on an aircraft.
Due to the following changes:

1. Change in empty cg and mass.
2. Reduction in fuel capacity.
3. Increase in unusable fuel.
4. Airplane Flight Manual (AFM) changes i.e. fuel state.
5. Assuming no change to fuel pick-up points in tank then the modification would be termed Major (STC – Supplemental type certificate)

Further points for study

Corrosion to the aluminium foil with water contaminated fuel may be an issue if the corrosion is sufficiently severe to block the fuel filters between services. A point worth noting is that since the foil can quickly dissipate heat away from the fire zone then it can also dissipate heat from the fuel to the tank skins and possible freeze the moisture in the tanks during prolonged operation in subzero temperatures.

Further information needed

1. Documents from the AEROSAFE program (These have been requested)
2. How far down the line is the TSO of the eXess mesh in the AEROSAFE program. (Question has been asked)
3. Info from Beechcraft Ref. section 0. I think this would be better coming from DO Systems.

4. We can obtain a TSO design approval through the CAA with the FAA for the mesh but you need a TSO to show that you are compliant with. Catch 22 – in the FAA list of TSO's there is not a standard for us to meet. Further research is needed or contact with Aerodac. I will wait and see the reply I get on 1 and 2 above.
5. The eXess material has been fitted to the following kit aircraft (info from eXess):

   Wild Thing
   Japiru
   FK12 Komet
   Kit Fox in US bekannt (über Vertrieb in D)
   CorVus Phantom MK1

   Some of the above aircraft are also sold as certificated aircraft, whether the eXess material has been fitted to those versions is not known at present.

Document updating

This document will be updated as more information becomes available.

Project AEROSAFE VSI

The Vehicle Safety Institute (VSI) of Graz University has been engaged on a project called "AEROSAFE". This project is to develop and test new materials and structures that are to be placed into an aircraft fuel tank to improve safety performance. eXess cylinders are one of the material/structures chosen to be studied. One of the aims is to develop fire/explosion protection for aircraft tanks. The project has been split into six work packages which are described in Ref. 3 and shown as an excerpt in Figure 3 to Figure 5.

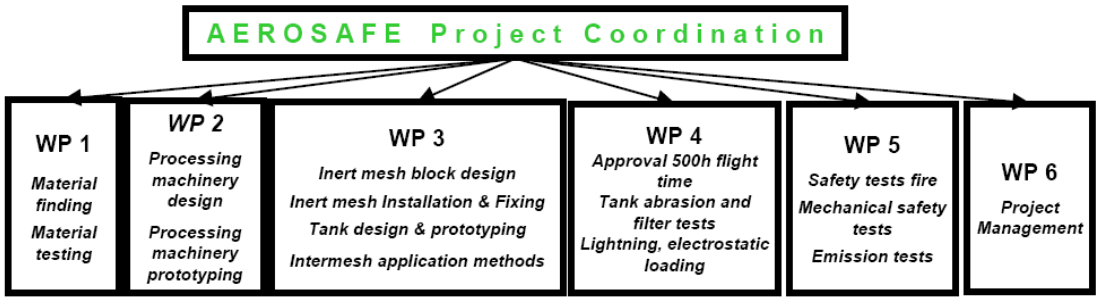


Figure 3 Work packages excerpt from Ref. 3

Within work package 4 & 5 the following will be (have been?) carried out (excerpt from Ref. 3:

Work-Package 4
Objectives

As for aircraft applications many regulations must be fulfilled (FAA) also for tank applications, this Work package together with Work package 5 deals with the proof of the newly developed system.

The system will be proven within the following applications: (The tests will be correlated with LBA)

- 500 hours of flight time
- Tank abrasion and filter tests
- Lightning, electrostatic loading

As result of this test series a TSO certificate should be reached

Work-Package 5
Objectives

In addition to the required safety tests these set of tests will demonstrate the capabilities, advantages and limits of the new product Intermesh.

Especially the improved sloshing capabilities the improved explosion performance and the reduced tendency to burn will be demonstrated.

Figure 4 WP 4 & 5 description excerpt from Ref. 3



Figure 5 Test photographs excerpt from Ref. 3

Comparison of eXess with foam

The following information has been obtained from Ref. 4.
Note: Ref. 4 author is "eXess Engineering.

Volume loss

Foam 3%
eXess 1.5%

Wetting

The draining behaviour in both cases is approximately the same but the remaining fuel in the foam is 60% greater.
Remaining fuel:
Foam: 2.4%
eXess: 1.5%

Absorption

Foam: up to 1.5%
eXess: 0%

Volume Summary

Approximately 3.9% more tank volume is available from eXess when compared with foam.

Safety increasing effects summary

The details of the testing can be found in Ref. 4 section 3.1. the summary as an excerpt is shown as Figure 6.

The general safety by thermal or mechanical stress of the tank will be raised by filling the tank with foam or metallic net-shaped filler.
PU-foam tends under certain conditions to reactions with the tank content; they are not resistant against aging, can brittle with low temperatures, melt over 275°C and are bad heat conductors, additionally the possibility of electrostatic charge (sparking!) exists.
Metallic meshes – as e.g. eXess® - achieve much more safety and can prevent a backfire with subsequent explosion of the tank. The explosion of the gas/air-mixture as a result of ignition inside the tank will be damped or totally prevented.

Figure 6 Safety summary excerpt from Ref. 4

Fuel stabilization summary

The details of the testing can be found in Ref. 4 section 3.2. the summary as an excerpt is shown as Figure 7 below.

> The analysis of the executed investigations shows unique the outstanding fuel-slosh-damping-effect of both materials, whereby in the case of eXess® a better damping behavior is to be detected. This can be explained easily by the structure of the grid network, thus the baffle plate effect of the filler becomes more effective than the "round" pore connections of the foamed plastic material.

Figure 7 Stabilization excerpt from Ref. 4

Weight & cg effects of eXess on the King Air B200

The following sections calculate the increase in mass of an empty and full fuel tank.
Note: The following calculations use 0.72 kg/l for avgas.

Increase mass of empty fuel tanks

Beech Craft King Air B200 Max fuel 2460 litres Ref. 5

Mass of eXess cylinders = 2460 x 0.045 kg/litre
= 110.7 kg

Reduction in fuel capacity

Fuel capacity reduction Ref. section 0:
Volume = 0.015 x 2460
= 36.9 litres (58 lbs)

Increase in unusable fuel

Wetting (Unusable fuel) Ref. section 0:
= 0.015 x 2460
= 36.9 litres (58 lbs)

Example calculation on mass increase on a single tank

Example for 500litre tank
Delta increase on empty mass of tank = 500 x 0.045
= 22.5 kg

Decrease capacity = 500 x 0.015
= 7.5 litres

Therefore total increase in full tank mass = 22.5 - (7.5 x 0.72)
= 17.1 kg

The increase in mass as a percentage of the total capacity negating the weight of the tank structure = 17.1 / (500 x 0.72) x 100
= 4.75 %

Summary

The inclusion of eXess in the fuel tanks will:

1. King Air B200 increase in the empty weight of the aircraft by approx 111 kg.
2. Reduction in fuel capacity by approximately 36.9 litres (8.2 UK gallons).
3. Increase in unusable fuel by approximately 36.9 litres (8.2 UK gallons).

Stress

The tanks were probably designed for slosh pressures rather than a static mass, therefore this increase in mass will possibly make no difference to the maximum stress on the tanks. There are two reasons for this:

1. Slosh pressure will be reduced due to the reduction in fuel capacity by 1.5% Ref. section 0.
2. The slosh pressures are reduced due to the eXess cylinders acting as baffles Ref. section 0.

Possible design changes

Fuel pickup

Fuel pickup point within the tank may need protection. If the pickup is of a clunk type then a box may have to be inserted in the tank to allow continual free movement of the klunk. The box would be free from eXess cylinders.

Retention mesh

A tank insert to stop the eXess cylinders being blown/forced/falling out when refuelling.

Airplane Flight Manual

Change to empty weight and reduced fuel capacity.

Continued airworthiness

Change to maintenance manual for tank inspections and corrosion check

Hydraulics and oil tanks

Should the other tanks holding volatile liquids be protected also.

Testing

The testing on the eXess cylinders will be:

1. Using existing test data from the AEROSAFE projects Ref. section 0.
2. Ground tests on a fuel tank mock-up (worse tank)
3. Ground and flight tests on the King Air B200

Testing covered by AEROSAFE project

1. Wear and tear on tank sealant
2. Fuel capacity gauge (capacitance type)
3. Show by test that the eXess cylinders are electrically bonded
4. Lightning protection CS 23.954
5. Condensation of fuel vapour CS 23.961 (possible flight test)

Further tests on aircraft type

1. Check that capacity gauge is working correctly.
2. Ground test for minimum unusable fuel in each tank (CS 23.959)
3. Check max fuel flow rate is above minimum for engine (ground test).
4. Measure max fuel flow rate pre & post modification and show that there is no difference. CS 23.951(c), 23.955(a)
5. Flight test Cs 23.951(a), 23.959(a), 23.961 (possible)

Tests on mock-up

1. Fuel flow rate CS 23.951, 23.955
2. Unusable Fuel CS 23.959
3. Fuel tank sump volume with eXess cylinders CS 23.971

Information from Beechcraft

1. Strength of tanks and attachments with increased mass CS 23.963, 23.965, 23.967
2. Individual capacities of fuel tanks and sumps. Tank cg positions. CS23.971
3. Fuel pump delivery pressure and flow from previous certification test that showed compliance with CS 23.955.

Compliance with CS-23

The following paragraphs will be shown compliance through flight, ground & mock-up testing and are excerpts from Ref. 6.

CS 23.951General (a) & (c)

Means of compliance

(a) Flight test.
(c) Ground test using mock up.

(a) Each fuel system must be constructed and arranged to ensure fuel flow at a rate and pressure established for proper engine and auxiliary power unit functioning under each likely operating condition, including any manoeuvre for which certification is requested and during which the engine or auxiliary power unit is permitted to be in operation.

(c) Each fuel system for a turbine engine must be capable of sustained operation throughout its flow and pressure range with fuel initially saturated with water at 27°C (80°F) and having 0·75cc of free water per 3.8 l (US-gallon) added and cooled to the most critical condition for icing likely to be encountered in operation.

CS 23.954 Fuel system lightning protection

Means of compliance:
Test results from Ref. 3

The fuel system must be designed and arranged to prevent the ignition of fuel vapour within the system by –

(a) Direct lightning strikes to areas having a high probability of stroke attachment;

(b) Swept lightning strokes on areas where swept strokes are highly probable; and

(c) Corona or streamering at fuel vent outlets.

CS 23.955 Fuel flow

Means of compliance:
(a) Ground test on Mock-up pre & post modification to show there is no change in the flow. If this is the case then this negates tests to show compliance with some other paragraphs.

(a) *General*. The ability of the fuel system to provide fuel at the rates specified in this paragraph and at a pressure sufficient for proper engine operation must be shown in the attitude that is most critical with respect to fuel feed and quantity of unusable fuel. These conditions may be simulated in a suitable mock-up. In addition –

(1) The quantity of fuel in the tank may not exceed the amount established as the unusable fuel supply for that tank under CS 23.959 (a) plus that necessary to show compliance with this paragraph;

(2) If there is a fuel flowmeter, it must be blocked during the flow test and the fuel must flow through the meter or its by-pass.

(3) If there is a flowmeter without a by-pass, it must not have any failure mode that would restrict fuel flow below the level required in this fuel flow demonstration;

(4) The fuel flow must include that flow needed for vapour return flow, jet pump drive flow and for all other purposes for which fuel is used.

(d) *Auxiliary fuel systems and fuel transfer systems*. Sub-paragraphs (b), (c) and (f) apply to each auxiliary and transfer system, except that –

(1) The required fuel flow rate must be established upon the basis of maximum continuous power and engine rotational speed, instead of take-off power and fuel consumption; and

(2) If there is a placard providing operating instructions, a lesser flow rate may be used for transferring fuel from any auxiliary tank into a larger main tank. This lesser flow rate must be adequate to maintain maximum continuous power but the flow rate must not overfill the main tank at lower engine power.

(e) *Multiple fuel tanks*. For reciprocating engines that are supplied with fuel from more than one tank, if engine power loss becomes apparent due to fuel depletion from the tank selected, it must be possible after switching to any full tank, in level flight, to obtain 75% maximum continuous power on that engine in not more than –

(1) 10 seconds for naturally aspirated single-engine aeroplanes;

(2) 20 seconds for turbocharged single-engine aeroplanes, provided that 75% maximum continuous naturally aspirated power is regained within 10 seconds; or

(3) 20 seconds for twin-engine aeroplanes.

(f) *Turbine engine fuel systems*. Each turbine engine fuel system must provide at least 100% of the fuel flow required by the engine under each intended operation condition and manoeuvre. The conditions may be simulated in a suitable mock-up. This flow must –

(1) Be shown with the aeroplane in the most adverse fuel feed condition (with respect to altitudes, attitudes and other conditions) that is expected in operation; and

(2) For twin-engine aeroplanes, notwithstanding the lower flow rate allowed by sub-paragraph (d), be automatically uninterrupted with respect to any engine until all the fuel scheduled for use by that engine has been consumed. In addition –

(i) For the purposes of this paragraph, "fuel scheduled for the use by that engine" means all fuel in any tank intended for use by a specific engine.

(ii) The fuel system design must clearly indicate the engine for which fuel in any tank is scheduled.

(iii) Compliance with this paragraph must require no pilot action after completion of the engine starting phase of operations.

CS 23.959 Unusable fuel supply

Means of compliance:
Ground test on mock-up

(a) The unusable fuel supply for each tank must be established as not less than that quantity at which the first evidence of malfunctioning occurs under the most adverse fuel feed condition occurring under each intended operation and flight manoeuvre involving that tank. Fuel system component failures need not be considered.

(b) In addition, the effect on the unusable fuel quantity as a result of a failure of any pump must be determined.

CS 23.961 Fuel system hot weather operation

Means of compliance:
Reduced vapour in the tank due to condensing on the mesh Ref. 3. If a sufficient argument cannot be made from the "AEROSAFE" test results then a flight test will be needed.

Each fuel system must be free from vapour lock when using fuel at its critical temperature, with respect to vapour formation, when operating the airplane in all critical operating and environmental conditions for which approval is requested. For turbine fuel, the initial temperature must be 43°C – 0°, + 2.7° (110°F, -0°, +5°) or the maximum outside air temperature for which approval is requested, whichever is more critical.

CS 23.963 Fuel Tanks General

Means of compliance:
Contact with Beechcraft Structures group to find out if there would be a problem by increasing the tank mass by 4.75% Ref. section 0. It is not anticipated that there would be a problem unless the Margins of Safety (MS) for the tanks are at present <0.05.

(a) Each fuel tank must be able to withstand, without failure, the vibration, inertia, fluid and structural loads that it may be subjected to in operation.

(b) Each flexible fuel tank liner must be shown to be suitable for the particular application.

(c) Each integral fuel tank must have adequate facilities for interior inspection and repair.

(d) The total usable capacity of the fuel tanks must be enough for at least ½ hour of operation at maximum continuous power.

(e) Each fuel quantity indicator must be adjusted, as specified in CS 23.1337 (b), to account for the unusable fuel supply determined under CS 23.959 (a).

CS 23.965 Fuel tank tests

Means of compliance:
See section 0 CS 23.963 Fuel Tanks General

(a) Each fuel tank must be able to withstand the following pressures without failure or leakage:

(1) For each conventional metal tank and non-metallic tank with walls not supported by the aeroplane structure, a pressure of 24 kPa (3·5 psi), or that pressure developed during maximum ultimate acceleration with a full tank, whichever is greater.

(2) For each integral tank, the pressure developed during the maximum limit acceleration of the aeroplane with a full tank, with simultaneous application of the critical limit structural loads.

(3) For each non-metallic tank with walls supported by the aeroplane structure and constructed in an acceptable manner using acceptable basic tank material and with actual or simulated support conditions, a pressure of 14 kPa (2 psi) for the first tank of a specific design. The supporting structure must be designed for the critical loads occurring in the flight or landing strength conditions combined with the fuel pressure loads resulting from the corresponding accelerations.

(b) Each fuel tank with large, unsupported, or unstiffened flat surfaces, whose failure or deformation could cause fuel leakage, must be able to withstand the following test without leakage, failure or excessive deformation of the tank walls:

(1) Each complete tank assembly and its support must be vibration tested while mounted to simulate the actual installation.

(2) Except as specified in sub-paragraph (b) (4) , the tank assembly must be vibrated for 25 hours at a total displacement of not less than 0·8 of a mm (1/32 in) (unless another displacement is substantiated) while 1/3 filled with water or other suitable test fluid.

(3) The test frequency of vibration must be as follows:

(i) If no frequency of vibration resulting from any rpm within the normal operating range of engine or propeller speeds is critical, the test frequency of vibration is the number of cycles per minute obtained by multiplying the maximum continuous propeller speed in rpm by 0·9 for propeller-driven aeroplanes, except that for non-propeller driven aeroplanes, the test frequency of vibration is 2 000 cycles per minute.

(ii) If only one frequency of vibration resulting from any rpm within the normal operating range of engine or propeller speeds is critical, that frequency must be the test frequency.

(iii) If more than one frequency of vibration resulting from any rpm within the normal operating range of engine or propeller speeds is critical, the most critical of these frequencies must be the test frequency.

(4) Under sub-paragraph (3) (ii) and (iii) , the time of test must be adjusted to accomplish the same number of vibration cycles that would be accomplished in 25 hours at the frequency specified in sub-paragraph (3) (i) .

(5) During the test, the tank assembly must be rocked at a rate of 16 to 20 complete cycles per minute, through an angle of 15° on either side of the horizontal (30° total), about an axis parallel to the axis of the fuselage, for 25 hours.

(c) Each integral tank using methods of construction and sealing not previously proven to be adequate by test data or service experience must be able to withstand the vibration test specified in sub-paragraphs (1) to (4) of paragraph (b).

(d) Each tank with a non-metallic liner must be subjected to the sloshing test outlined in sub-paragraph (5) of paragraph (b) , with the fuel at room temperature. In addition, a specimen liner of the same basic construction as that to be used in the aeroplane must, when installed in a suitable test tank, withstand the sloshing test with fuel at a temperature of 43°C (110°F).

CS 23.967 Fuel tank installation

Means of compliance:
See section 0 CS 23.963 Fuel Tanks General

(e) Fuel tanks must be designed, located and installed –

(1) So as to retain fuel when subjected to the inertia loads resulting from the ultimate static load factors prescribed in CS 23.561 (b) (2); and

(2) So as to retain fuel under conditions likely to occur when an aeroplane lands on a paved runway at a normal landing speed under each of the following conditions:

(i) The aeroplane in a normal landing attitude and its landing gear retracted.

(ii) The most critical landing gear leg collapsed and the other landing gear legs extended.

In showing compliance with sub-paragraph (e) (2) , the tearing away of an engine mount must be considered unless all the engines are installed above the wing or on the tail or fuselage of the aeroplane.

(3) For commuter category aeroplanes, fuel tanks within the fuselage contour must be able to resist rupture and be in a protected position so that exposure of the tanks to scraping action with the ground is unlikely.

CS 23.971 Fuel tank sump

Means of compliance:
Ground test on mock-up. With the eXess cylinders in the tank the sump capacity will be reduced by 1.5%.
Information needed from Beechcraft on fuel tanks and sumps capacities.

(a) Each fuel tank must have a drainable sump with an effective capacity, in the normal ground and flight attitudes, of 0·25% of the tank capacity, or 0·24 litres (0·05 Imperial gallon/1/16 US-gallon), whichever is greater.

(b) Each fuel tank must allow drainage of any hazardous quantity of water from any part of the tank to its sump with the aeroplane in the normal ground attitude.

(c) Each reciprocating engine fuel system must have a sediment bowl or chamber that is accessible for drainage; has a capacity of 30 cm^3 (1 oz) for every 75·7 litres (16·7 Imperial gallon/20 US-gallon) of fuel tank capacity; and each fuel tank outlet is located so that, in the normal flight attitude, water will drain from all parts of the tank except the sump to the sediment bowl or chamber.

(d) Each sump, sediment bowl and sediment chamber drain required by sub-paragraphs (a), (b) and (c) must comply with the drain provisions of CS 23.999 (b) (1) and (2).

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