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THE NEW SECTION 23 OF DO160C/ED14C LIGHTNING TESTING OF EXTERNALLY MOUNTED ELECTRICAL EQUIPMENT

B J C Burrows
Lightning Test and Technology, Culham Laboratory, Abingdon, Oxfordshire, OX14 3DB, England

1 INTRODUCTION

This paper introduces the new Section 23 which has only very recently been fully approved by the RTCA for incorporation into the first revision of DO160C/ED14C. Full threat lightning direct effects testing of equipment is entirely new to DO160, the only existing lightning testing is transient testing for LRU's by pin or cable bundle injection methods (see Section 22[(1)]), for equipment entirely contained within the airframe and assumed to be unaffected by direct effects. This testing required transients of very low amplitude compared with lightning itself, whereas the tests now to be described involve full threat lightning testing, that is using the previously established severe parameters of lightning appropriate to the Zone, such as 200kA for Zone 1A as in AC20-136[(2)]. Direct effects (ie damage) testing involves normally the lightning current arc attaching to the object under test (or very near to it) so submitting it to the full potential for the electric, mechanical, thermal and shock damage which is caused by high current arcing.

Since equipment for any part of the airframe require qualification, tests to demonstrate safety of equipment in fuel vapour regions of the airframe are also included.

2 SUMMARY OF EQUIPMENT INCLUDED AND EXCLUDED FROM THE TESTS OF SECTION 23

Examples of equipment covered in these tests are:- aerials (antennas), exterior lights, air data probes, anti-ice and de-ice equipment, and sensors. Likewise, electrical and electronic equipment such as lights and fuel quantity probes, and pumps mounted on fuel tanks and exposed to direct or swept strokes are covered by this section. Mechanical devices, for example fuel filler caps, are not covered.

Equipment such as aerials that are protected by a dielectric covering specific to that item and exposed directly to lightning attachment is included in the tests, but any aircraft specific dielectric covers over aerials such as radomes, etc, used for a specific aircraft to cover one or more aerial systems are not included. (Tests to radomes are given in other standards eg, CLM-R163[(3)], MIL STD 1757A[(4)], etc.)

3 CATEGORIES OF EQUIPMENT

Equipment is categorised as for the familiar lightning testing described in other specs ([(2)], [(3)], [(4)], [(5)]) using the Zone numbers as category numbers. Thus, equipment in Zone 1B is in category 1B etc. In addition to the five familiar lightning Zones (1A, 1B, 2A, 2B, 3) there is an additional category, X, which is used to designate equipment for which lightning effects are insignificant or inapplicable.

Equipment for use in fuel vapour regions requires special tests to determine freedom from sparking in the fuel vapour region when the equipment is subject to the appropriate Zone currents. Thus, equipment for any of the categories above may also be subjected to, and pass, the fuel vapour region tests, which allows the addition of the suffix 'F' after the category, and thus the use in 'fuel vapour' designated areas, or any other area, of the airplane.

4 NOVEL TEST METHODS FOR DIRECT EFFECTS TESTING

Section 23 includes four areas for which either new tests are described, or significantly improved and more closely specified tests are described. These are as follows:

4.1 HIGH VOLTAGE TESTS

These tests are to determine the surface flashover/breakdown properties of specimens with dielectric covers. The novel features are the specification of the preferred waveform (using the V_{90} voltage and the UDVTM), and the specification of the test geometry using large electrodes instead of ones with an unspecified size as previously. As well as the preferred one, two alternative voltage waveforms are also described, one a fast rising waveform of 1000kV/µs ± 50% and also a slow rise waveform, going to peak between 50-250µs, with breakdown to occur at or around peak voltage. The waveforms are shown in Figures 1a), b) and c).

These three test methods are not exactly equivalent, the first and the third are likely to give close results, but owing to the very high rate of rise of the second method significantly different test results might occur which are believed by some to be not so typical of lightning attachment to aircraft components. This test method was put in to provide consistency with the existing test specifications (eg Reference 4) but is not as satisfactory as the other two.

Significantly different test results occur depending on the specification of test electrode size. Hitherto a rod electrode has been widely used but this is not ideal since it encourages the pre breakdown streamer to occur from itself, followed by rapid breakdown, instead of streamering from the test object. A large profiled electrode as in Figure 2 coupled with waveforms a) or c) promote streamering from the test object and not from the electrode and prevent unrealistic puncture of that point of the test object nearest to the electrode, as occurs with a pointed electrode and a fast rise waveform of unlimited amplitude.

The other aspect of the test method is the specification of the electrode sizes and spacings as a function of the test specimen size. This prevents either unrealistically short gaps, or unnecessarily long gaps to be used, the former giving biased results, the latter requiring excessive voltages.

4.2 HIGH CURRENT TESTS OVER DIELECTRICS

No previous test specification has called for full threat high current tests along side of a dielectric cover, where high voltage tests have shown that a surface flashover occurred. Section 23 specifies such a test by requiring that high current tests are done to demonstrate freedom from damage on the test object when an arc is initiated (using the appropriate current waveforms according the Zone) along the line of any flashovers. This is done by supporting and initiating wire (with a diameter of 0.1mm) between 5 and 15mm from the surface along the line of the flashover and driving the lightning test current components through it, so fusing the wire and causing an arc at that position. This test will then show freedom (or otherwise) from blast, shock and thermal effects of the arc.

Considerable difficulties could occur with very long arcs for very large objects in maintaining components C current for the full duration owing to the large arc drop; and stability of the arc is a problem owing to the effect of return conductors which have a very strong influence on component B and C arcs and their movement.

4.3 FUEL SYSTEM TESTS

The section of fuel vapour tests describes, in considerable detail, how to perform these tests, and new material from recent work in the UK and elsewhere are included in these test requirements. Two main methods of detecting sparking or arcing are suggested, namely (i) photographic methods and (ii) gas mixture ignition tests.

Photographic and other optical methods have many advantages for engineering and certification tests on the equipment owing to the ease of identifying the location of sparks of sufficient energy which can be divided into voltage sparks or thermal sparks. By contrast, gas methods only reveal that there was at least one spark somewhere in the gas volume of sufficient energy to cause ignition. Previously, photographic methods have been too loosely defined for adequate spark detection, eg, by saying that .... "using a camera with an aperture of f/4.7 with 3000ASA film that sparks can be detected adequately". This is not the case unless the camera lens focal length and maximum distance to the spark are specified, or alternatively and more simply, by specifying the maximum field of view available at the spark distance. The latter method is the most useful, and 1m is recommended as the <u>maximum</u> field of view, see Figure 3. This then specifies the minimum size of image on the film and the minimum amount of light that will be incident on it. Very importantly Section 23 also requires that for any variants in photographic technique, it must be demonstrated that the technique employed can detect 200μJ sparks, including the effect on the sensitivity of mirrors, where used for obtaining views of possible sparking sources hidden from direct view of the camera. The limitation on field view, which for a given lens in a given camera implies a maximum lens to spark distance, must not of course be exceeded by the sum of the lens to mirror plus mirror to spark site distance. Accurate focusing in any case requires these distances to be the same for all sites observed by one camera.

For gas mixture ignition tests additional details compared with those hitherto used, are presented to assist in making the test more definitive. The two important details are that: a) the gas mixture ignitability should be checked with a 1.5 to 2.0mm long 200μJ spark, and shown to have a high ignition probability, and b) the most useful gas for making a mixture of high ignition probability with a 200μJ spark is ethylene/air in a 1.3 to 1.4 stoichemetric mixture. Other gas mixtures such as propane/air are not sensitive enough unless oxygen enrichment is used.

The typical test set up is shown in Figure 4. This shows the usual high current connections, etc, and also the method used to ensure that the gas mixture is correct by incorporating a test cell in the output pipe with a repetitive calibrated spark. Note also the use of purge gas in the blackout region containing the camera to ensure that the whole blacked out volume will not contain the ignitable gas mixture.

For flush mounted objects the typical set up illustrated will be modified somewhat by having a gas enclosure around the object on the inside within the camera volume.

In all cases where an explosion is possible the provision of a blow out panel is important, to limit the violence of any ensuing explosion.

Pass/fail criteria for the tests will be specified in the test plan agreed before the tests commence.

4.4 CONDUCTED ENTRY TESTS

For these tests a double transmission line set up is suggested as shown in Figure 5. This allows the maximum surface current density levels to be established which are flowing past the test object by scaling from the current, I, and the perimeter, p, of the electromagnetic field tight box. For fairly closely spaced return conductors (ie, $S \leq 0.5W$), the surface current density J_S is given approximately by:

$$J_s = \frac{\hat{I}}{p} \; A/m \qquad \text{where p is in metres.}$$

A value of J_S = 50kA/m is recommended in Section 23.

These tests are unlikely to be necessary for anything except fuel vapour region components, and will demonstrate if sparking occurs at the fixing interface to the skin.

5 DESCRIPTION OF LIGHTNING ZONES

A word of explanation is required to explain the meaning of the terms 'high possibility' and 'low possibility' where used for the lightning zone definitions. A mathematically correct description would be to use the term 'probability' instead of possibility since probability law and statistics in mathematics does not use the rather subjective term 'possibility'. The word probability is intended, but owing to an objection to its use from the FAA, the unfortunate substitute was possibility. In each case in these zone definitions where the word possibility is used it should be mentally converted to probability and will make proper statistical meaning.

6 SUMMARY AND CONCLUSIONS

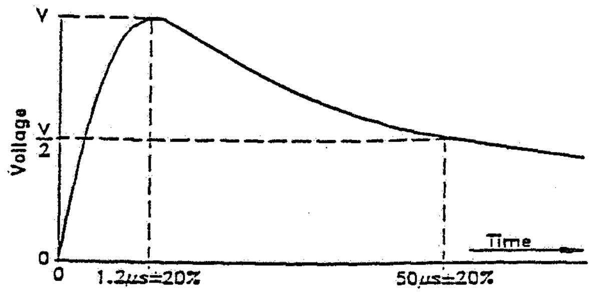
The new Section 23 fills a gap in the standards required for adequate lightning testing of aircraft components. Although progress on providing a complete set of technically sound lightning standards is good, there are still many required for satisfactory definition of the comprehensive range of tests. These additional areas are being looked at by the WG31 technical committee of EUROCAE in Europe and by SAE AE4L in the USA.

ACKNOWLEDGEMENTS

The author would like to acknowledge the effort by co members of the EUROCAE WG31 SG2 Committee which drafted the standard and the assistance of the SAE AE4L Committee in the USA in finalising its technical content for submission to RTCA.

REFERENCES

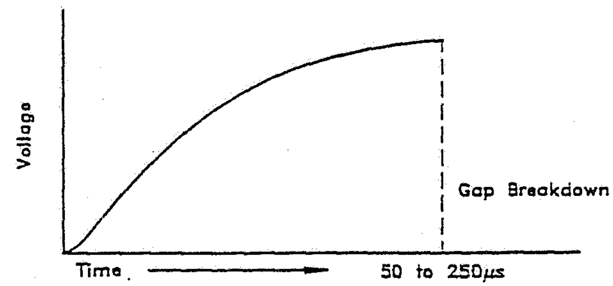
1. Section 22 DO160C/ED14C published by RTCA. December 1989.
2. AC20-136 FAA Advisory Circular. Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning 1990. (Previously known as the 'Orange Book'.)
3. Phillpot J — Recommended Practice for Lightning Simulation and Testing Techniques for Aircraft. Culham Laboratory CLM R163. 1977.
4. MIL STD 1757A Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware. July 1983.
5. FAA Advisory Circular AC20-53A: Protection of Airplane Fuel Systems Against Fuel Vapour Ignition due to Lightning. 1985



a)

Total Gap Length	Electrode Positive	Electrode Negative
0.5m	250kV	600kV
0.8m	400kV	900kV
1.0m	500kV	1100kV
1.5m	800kV	1500kV

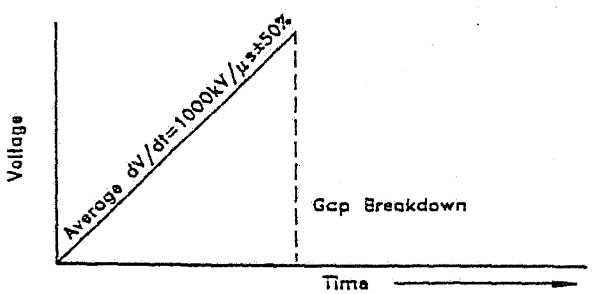
Approximate Voltage Requirements



c)

Total Gap Length	Electrode Positive	Electrode Negative
0.5m	350kV	400kV
1.0m	500kV	600kV
1.5m	600kV	700kV

Approximate Voltage Requirements



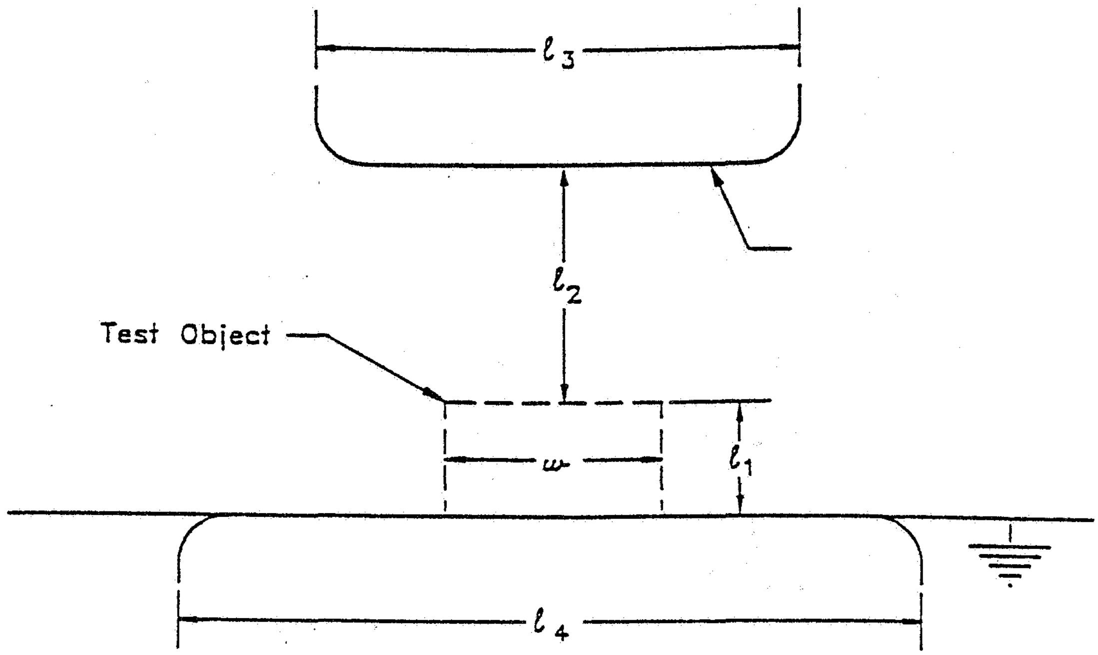
b)

Total Gap Length	Electrode Positive	Electrode Negative
0.5m	750kV	790kv
1.0m	1300kV	1400kV
1.5m	2250kV	2400kV

Approximate Voltage Requirements

FIGURE 1 High Voltage Test Waveforms

a) for V_{90} method.
b) 1st alternative method.
c) 2nd alternative method.



Note: The ground plane may be either a very broad flat one, or one with a profiled edge of width ℓ_4.

Test Set-up Dimensions	For w and ℓ_1 <100mm	For $\ell_1 > w$ and ℓ_1 >100mm	For $w > \ell_1$ and w >100mm
ℓ_2	150mm	$\geq 1.5\,\ell_1$	$\geq 1.5\,w$
ℓ_3	$>2\,\ell_2$	$>2\,\ell_2$	$>2\,\ell_2$
ℓ_4	$\geq \ell_3$	$\geq \ell_3$	$\geq \ell_3$

Gap and Electrode Dimensions for High Voltage Tests

Notes: The tolerance for ℓ_2 is $^{+20\%}_{-\ 0\%}$

The values for ℓ_3 and ℓ_4 are minimum values.

FIGURE 2 TEST ARRANGEMENT AND DIMENSIONS FOR HIGH VOLTAGE TESTS

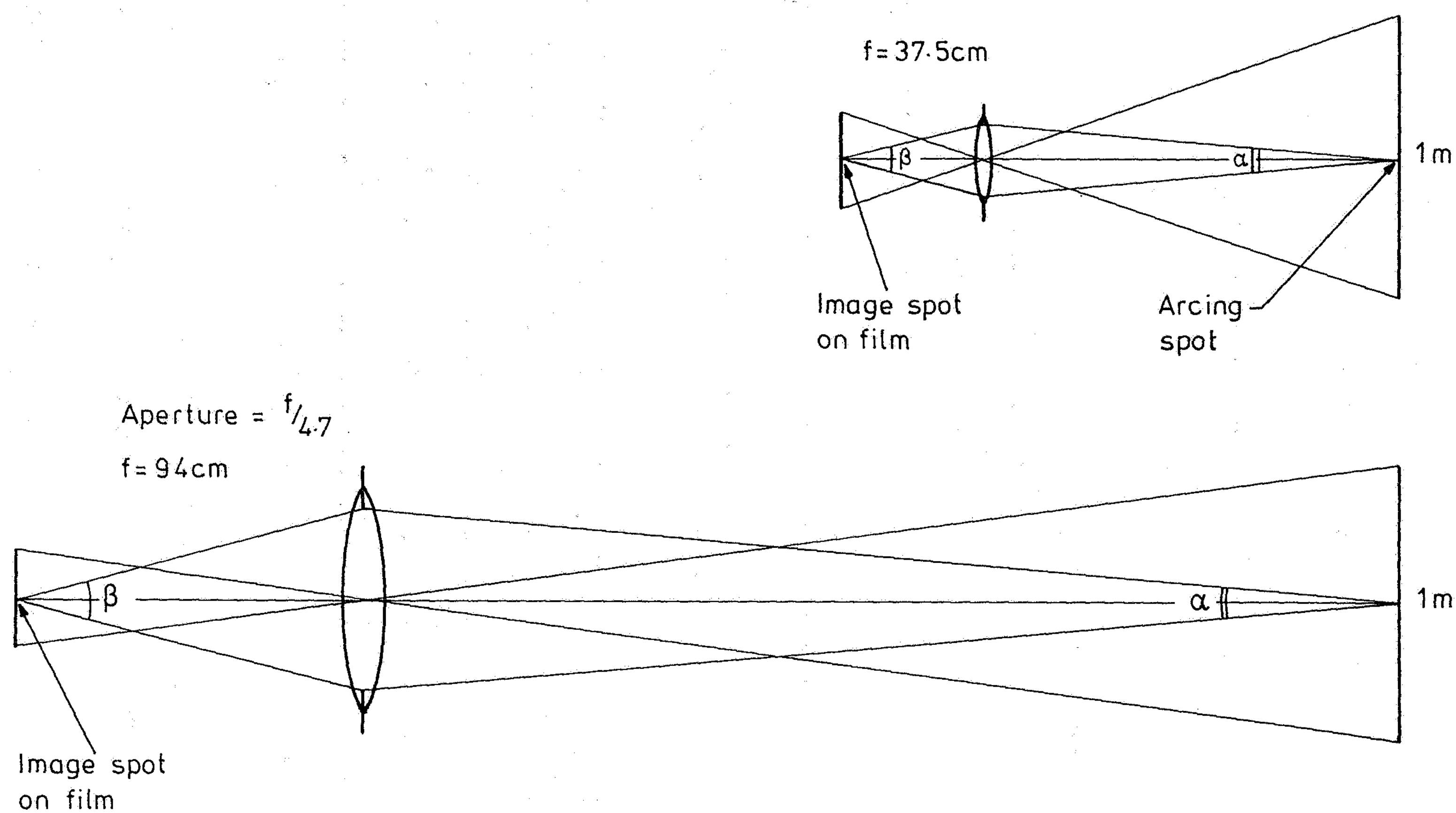


Fig 3 Comparism of different focal length camera lenses
(Aperture sizes magnified by 3·25 for emphasis)

Note: May also need Injected Current and Voltage Recorder as in Fig. 23.5

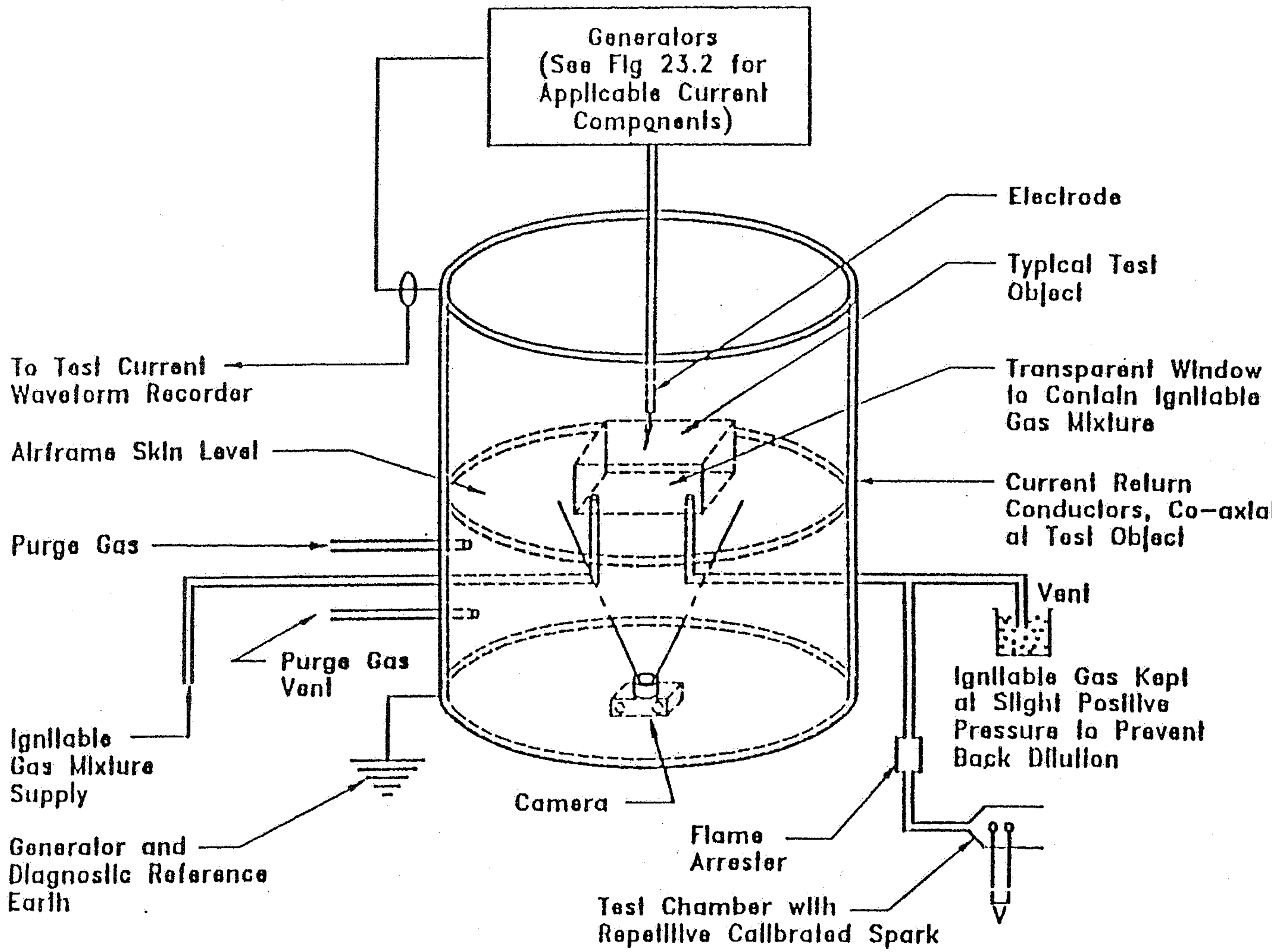


FIGURE 4 TYPICAL HIGH CURRENT SET-UP FOR FUEL VAPOR REGION REQUIREMENTS

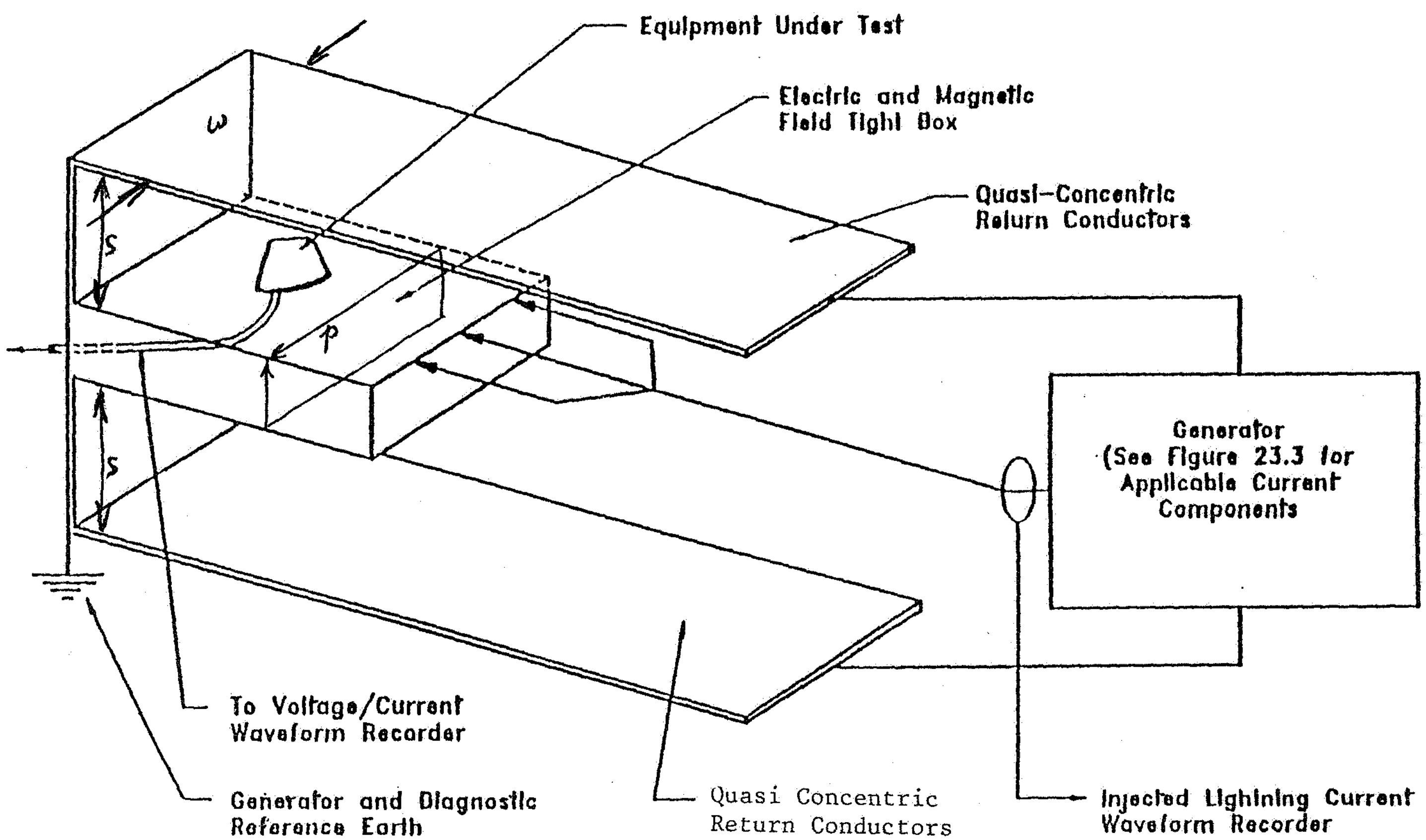


FIGURE 5 TYPICAL HIGH CURRENT SET-UP FOR NON-FUEL AREAS CONDUCTED ENTRY TESTS.