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THE VULNERABILITY OF COMMERCIAL AIRCRAFT
AVIONICS TO CARBON FIBERS

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N80-20317 #

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1.0 INTRODUCTION

This effort is part of the NASA Graphite Fiber Risk Analysis Program. This Risk Analysis required an estimation of the effect of a carbon fiber release on commercial aircraft. The objective of this investigation was to secure data relating the exposure to carbon fibers and the occurrence of fiber induced malfunctions in representative avionics. The results are to be used in forecasting the vulnerability of similar avionics equipment and commercial aircraft.

Use of corporate products or names of manufacturers in this report does not constitute official endorsement of such product or manufacturer, either expressed or implied by the National Aeronautics and Space Administration.

The assistance of the Research Aircraft Support Section of the Flight Mechanics Division is gratefully acknowledged. Without the ability, experience and support of this group this experiment would not have been possible. In particular, I wish to thank Messrs. Robert M. Peterson, Thomas L. Whittico and Robert C. Kendall for their help and the cheerful and timely support with a wealth of avionics expertise.

2.0 SELECTION OF EQUIPMENT FOR TESTING

2.1 Test Location

It was decided that representative avionics must be tested to provide a base for vulnerability predictions. All avionics testing was done in the existing chamber at the NASA Langley Research Center. The Ballistics Research Laboratory at Aberdeen, Maryland conducted the relays and terminal block tests and supplied that data for this report. A test mock-up was constructed prior to the test of each item and power cables were installed to enable full operation in the graphite fiber chamber.

2.2 Selection of Test Items

It was desirable to test as few black boxes as possible and obtain data that could be applied to all the different categories of aircraft electronics. Criteria for selection of equipment were:

- The item had to be available for test within 180 days.
- Test bench requirements had to be available or be able to be built in a reasonable time.
- The item should not be obviously invulnerable, i.e., a totally sealed box or one that is fully coated for circuit protection. A single box with coated boards was tested for completeness and did have a single high exposure failure.
- The device should be used in commercial aircraft and should be representative of other equipment. It should not be specific to one aircraft.

Representatives of the major aircraft producers supplied lists of their recommendations. Approximately 200 avionics items were studied and evaluated against the criteria. A visit was made to the United Airlines Avionics Repair Facility in San Francisco, CA and equipment was more closely evaluated. It was possible to compare the circuitry of various devices with the covers off and get a first hand look at the requirements for test and repairs.

2.3 Final Selection of Test Items

Technical data was researched on about 35 boxes and this was narrowed to a list of 15. Eliminating duplication and similarity gave the following avionics devices for procurement and testing.

- ATC Transponder;
- VHF Transceiver;
- Distance Measuring Equipment;
- Instrument Landing Receiver;
- Flight Director System consisting of an
  - Amplifier
  - Computer
  - Two Indicators; and,
- Relays and Terminal Strips.

In going through the repair manuals no item was selected that was specified as having conformal coating. However, research and phone conversations with knowledgeable sources has led to the conclusion that conformal coating is only applied when a customer specifically requests it or the design engineer specifies its necessity to enable compliance with moisture or humidity requirements. However these conditions are changing as manufacturers are instituting further use of coatings to take care of environmental effects; greater use of coatings will be seen on future avionics. A description of the coating on each box is provided in the paragraph describing results in Section 4.0.

3.0 METHOD OF TESTING

3.1 The Chamber

The NASA Langley Research Center Graphite Fiber Chamber is an enclosure 2.4 meters x 2.4 meters x 3.0 meters. Figure 1 shows a drawing depicting location of the automatic chopper, the ball sensor and fiber feed tube. The chopper can be set to cut fiber lengths from 1 mm to 20 mm. For this test lengths varying by a factor of approximately the $\sqrt{10}$ were selected to provide data across the spectrum of lengths; tests were run at lengths of 1 mm, 3 mm and 10 mm. For further data on the chamber see Reference 1.

All fibers used in this test were unsized Thornel 300 fibers of 8 microns diameter and approximate density of 1.8 grams/cc. The chopper automatically cuts the fibers to any preset length from one to 20 mm. The fibers are cut from a spool of graphite yarn or tow having about 3000 fibers in the tow. As the tow is chopped a brief puff of air moves the chopped tow to the center of a chimney. Air flow in the chimney is carefully set to disperse the fibers and transport single fibers up the chimney and into the free fall chamber; clumps of fibers tend not to be lifted into the chamber and fall into a refuse container. The chamber is continually vented through a closed loop system to prevent an over pressure and maintain atmospheric pressure.

A ball sensor and multichannel analyzer system was used

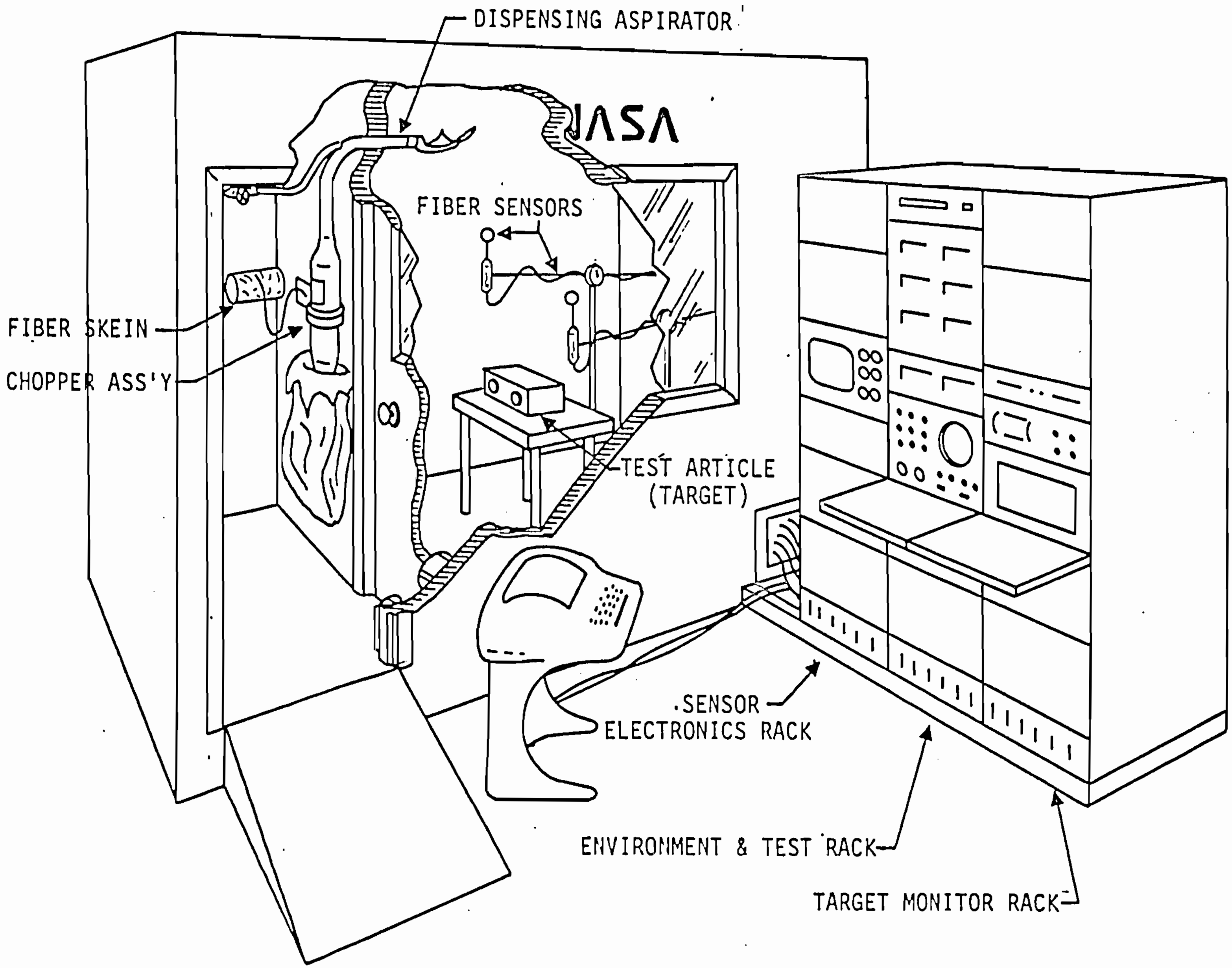

FIGURE 1 CARBON FIBER TEST CHAMBER INSTALLATION AT THE NASA LANGLEY RESEARCH CENTER

to calculate exposure. Figure 2 shows the VHF radio in the chamber with the ball positioned over it. The second ball shown with an insulator covering it was used as a differential device to enable subtraction of noise between the two balls and increase counting accuracy. Figure 3 shows the ball sensor electronics and the chamber. At the left the ante-chamber door is open and the chopper and dispersion chimney can be seen. The chamber is a still air free fall room.

Avionics are subjected to cooling air in an aircraft which could move fibers. To achieve realism, the amount of airflow and method of cooling each test item was determined. If draw through cooling was the normal mode the airflow was generated by a fan and measured with an anemometer to provide the proper volume of air. In other devices cooled by airflow present in the aircraft electronics compartment the airflow required by the Technical Manual was provided by a fan blowing across the equipment at a velocity similar to that in an aircraft.

3.2 Development of the Test System or Mock-up

Prior to each test, construction of cabling was required to apply power and operate the box in the chamber. A mock-up was built as recommended and detailed in the Technical Manual. Test points, outputs or indicators were monitored outside the chamber to enable immediate indication of a failure.

Failure criteria were defined for each specific device with the general criterion that to be a failure the problem had to last for at least thirty seconds. Problems that lasted for a shorter time and cleared itself was not judged critical and not

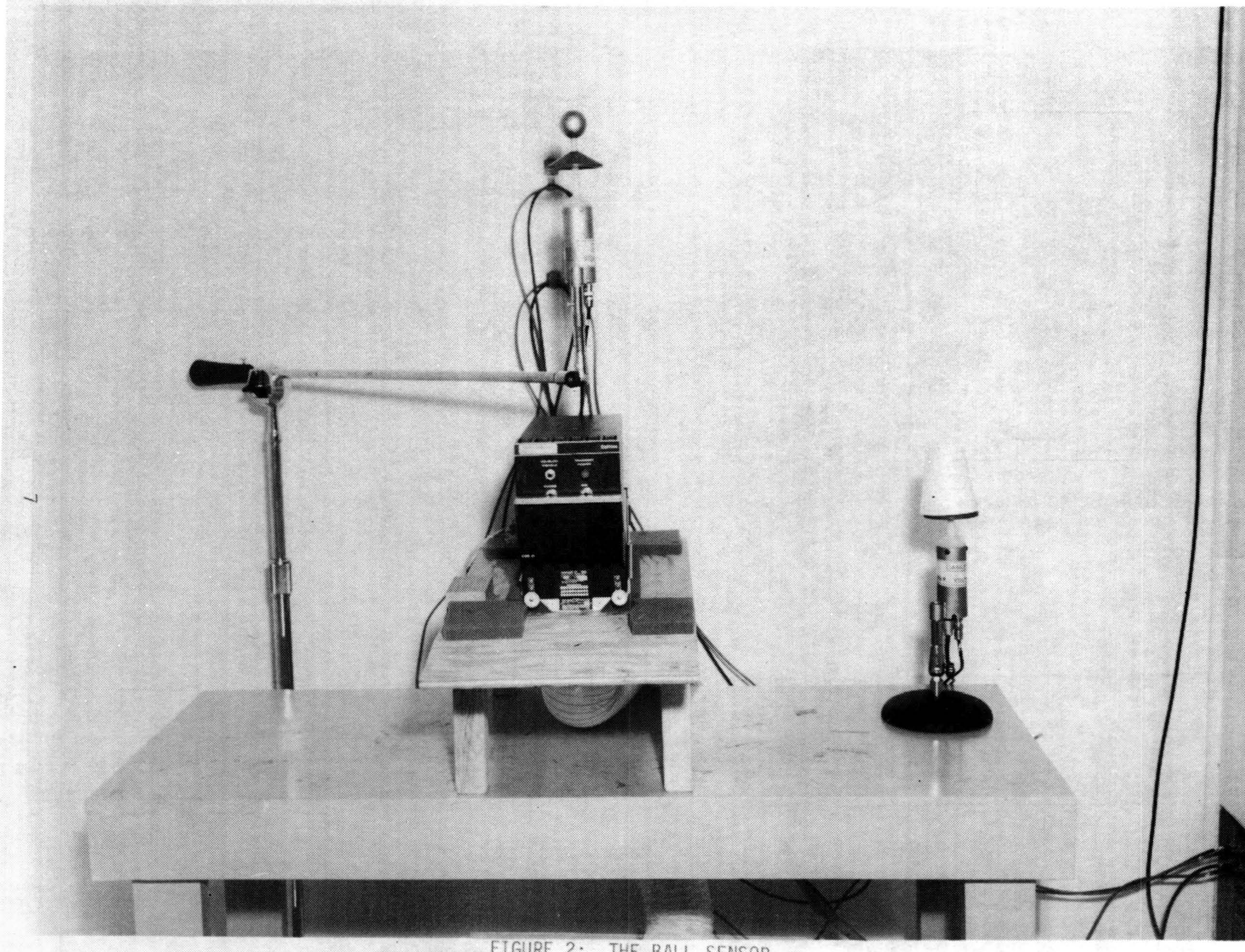

FIGURE 2: THE BALL SENSOR

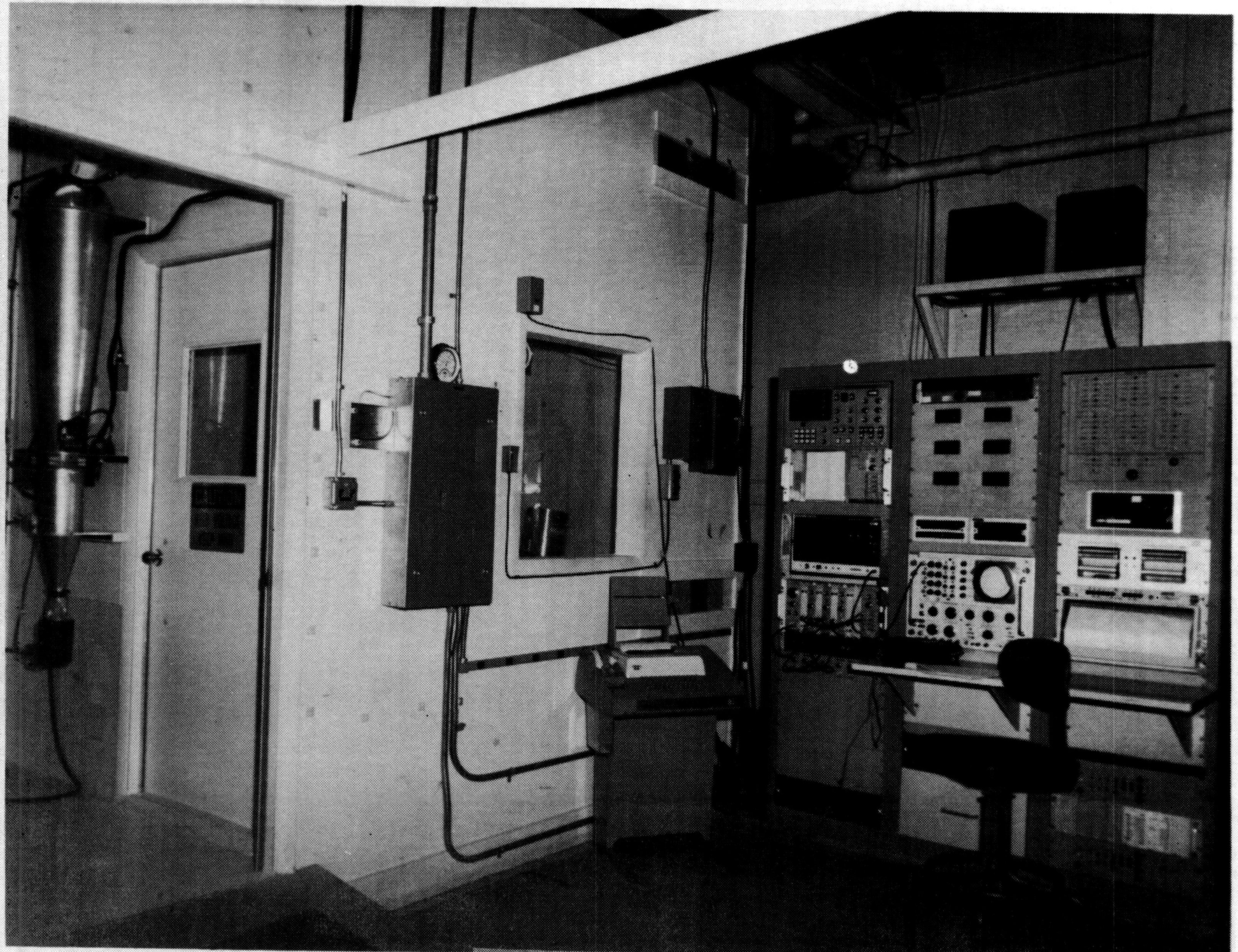
FIGURE 3: THE CHAMBER

reported in the results. If normal operation was sufficient to burn the fiber after a time or if normal airflow or vibration was similarly able to clear the fault and no bench time was required, no significant failure was considered to exist.

3.3 Simulated Flight Environment

To test the avionics equipment as realistically as possible application of actual flight environment was desirable. A system to simulate conditions was developed. An operating commercial aircraft has a sound level of between 90 and 105 decibels in the avionics bays. The electronic equipment is subjected to G-Forces on landing, takeoff and in turbulence in flight.

To provide a simulation of flight environment, the test items were subjected to manual movement six inches front to rear four times, then repeating the movement four times in a side to side direction and finally up and down. This movement produced accelerations of .5 to .8 G's. After this movement the electronic box was subjected to 100 decibels of pink noise for five minutes. A shaper, amplifier and mixer were set for a flat response from 40 Hz to 1000 Hz. The sound energy was measured at the case of the avionics box with a sound pressure level meter.

This motion and noise energy application was repeated at specific intervals in the test program as described in the next section. In referring to Flight Environment (FE) in the remainder of this report the entire motion and noise sequence is meant.

3.4 The Test Routine of Exposure

A test routine was developed to cut down the time required for exposure and specifically determine the exposure level at failure. Application of the simulated FE was necessary at various intervals and required a cessation of carbon fiber dispensing since the operator had to enter the chamber to move the test item.

The test routine consisted of two phases. Phase I was called gross vulnerability testing and involved three steps. After turning the test device "on" it was exposed to 3×10^7 fiber-seconds/meter^3 (fs/m^3) of selected length fibers and then an application of FE. Occurrence of a failure directed proceeding to the Avionics Vulnerability Testing Phase shown in Figure 4. If no failure occurred the device was not cleaned but subjected to an additional exposure of 3×10^7 fs/m^3 and another FE. A failure at any time dictated entry into the detailed plan of Figure 4. No failure brought another application of 3×10^7 fs/m^3 and FE. No failure after this total exposure of 9×10^7 fs/m^3 (3 times at 3×10^7) and three applications of FE led to a determination that the test item was not vulnerable.

If an item failed, the system shown in Figure 4 enabled an accurate determination of the failure level. Exposure was increased in steps multiplying by the $\sqrt{10}$, starting with 1×10^5 fs/m^3. FE was applied after each step. This plan enabled narrowing down the exposure to CF that caused a failure to a specific value and taking four different runs to provide data for an average exposure to failure.

TEST METHOD FOR AVIONICS

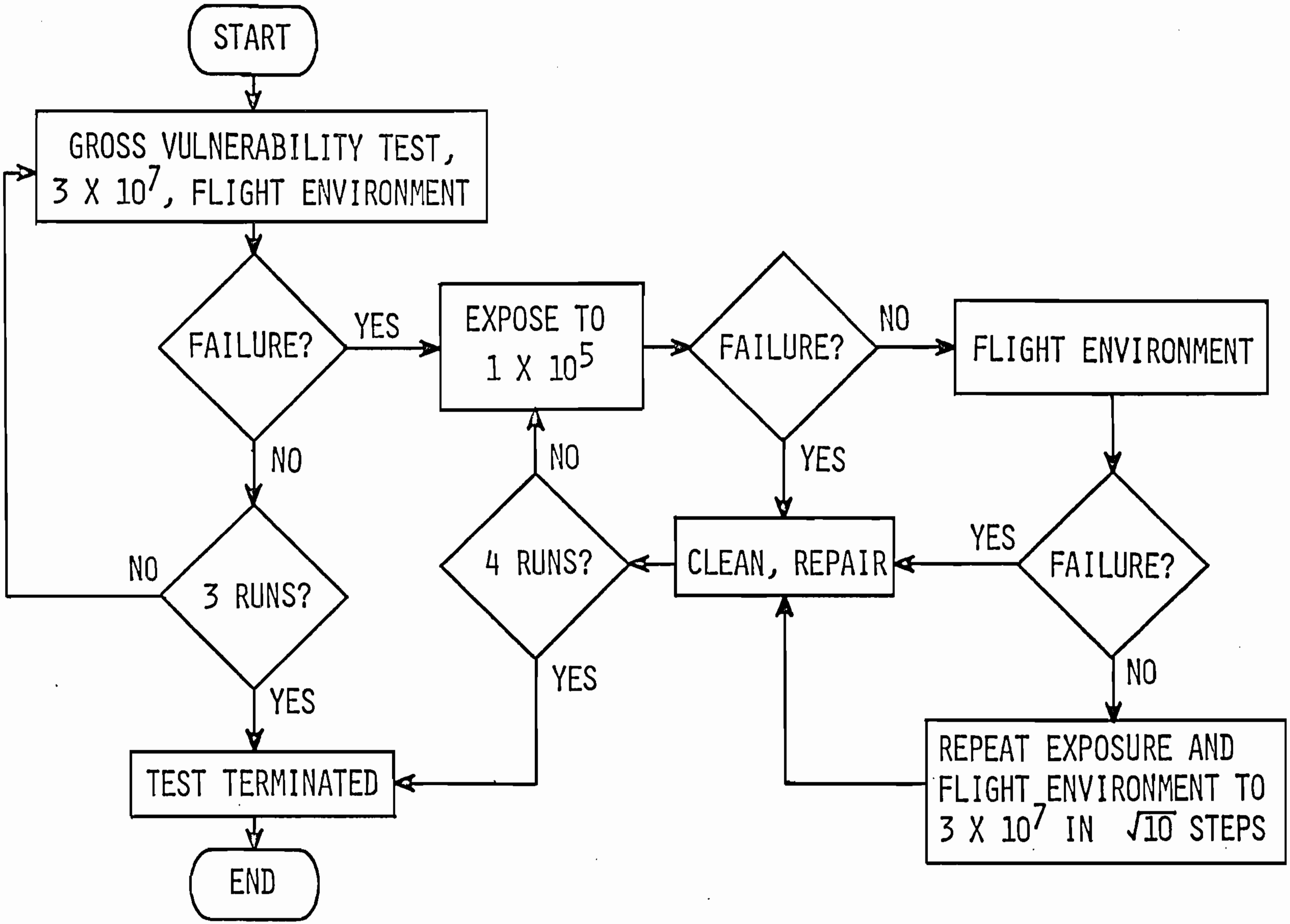

FIGURE 4 AVIONICS VULNERABILITY TESTING

4.0 RESULTS

4.1 The ATC Transponder

The transponder is shown in Figure 5. Its physical size is approximately 15 x 19 x 50 cm and weight is 12 kilograms. The figure shows the box with the dust cover off. The dust cover is perforated on both sides with 3.2 mm (1/8 inch) holes. The device is convectively cooled by airflow in the electronics bay and drawthrough cooling is not used. The electronics bays of most aircraft have an airflow of about 30 meters/minute (100 feet/minute). This airflow is equivalent to the sensation of speaking in a normal voice at your hand, three inches from your mouth. This airflow was used in testing and produced the recommended level of cooling air.

The transponder has a portable test set that enabled a thorough and continuous checkout of the device during test. Construction of a mock-up or test set for this item was unnecessary and only cabling and 400 Hz power was required to begin testing. The following parameters were monitored during testing:

Pilot Code	Ident Pulse
Altitude Code	Invalid Altitude
Peak Transmitter Power	Receiver Decoder
Transmitter Frequency	SLS Tests
Receiver Sensitivity	Pulse Spacing

Any parameter out of specied tolerance for 30 seconds was noted as a failure. Testing was started using 1 mm fibers then 3 mm and finally 10 mm fibers of Thornel 300. Concentration in the chamber was held between 10^3 and 10^4 fibers/meter^3. Airflow of

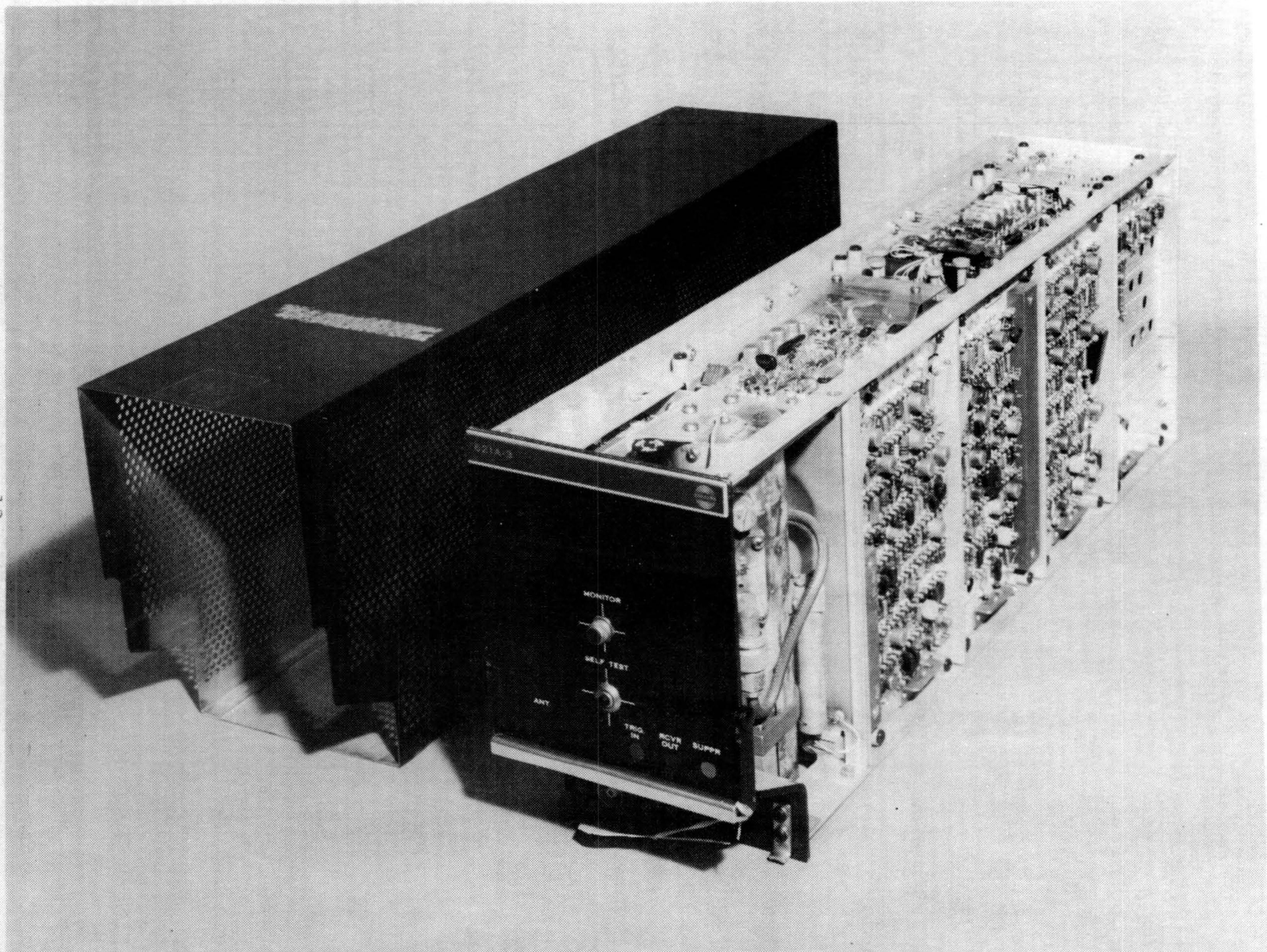

FIGURE 5: ATC TRANSPONDER

30 meters/minute was directed across the transponder.

The transponder selected for testing was visually and electronically checked for conformal coatings. It had no coatings. The technical repair manuals do not specify coating on this device however other transponders of the same type and model were inspected that had some boards coated. The length of the air gaps were measured and the average length from post to post was 2.3 mm and the average gap from post to board was 3.0 mm. The device was mounted in the chamber similar to the unit shown in Figure 2 but had no duct at the bottom since draw through cooling was not used. A fan on the test bench provided the required airflow of 30 meters/minute.

Table 1 shows the failure levels in each test run and the Average Exposure to Failure ($\bar{E}$). The $\bar{E}$ levels were estimated according to the method described in Reference 2. The Appendix shows how the data is analyzed. Figure 6 shows a plot of $\bar{E}$ versus fiber length. The lowest failure level was expected with 10 mm length fibers because they could most easily bridge the gap to cause a short. Actually 3 mm fibers yielded the lowest $\bar{E}$ since the dust cover was a filter for the longer fibers; the dust cover was perforated with 3.2 mm diameter holes and the average gap length in the transponder was 2.3 mm. It can be seen that this device is most vulnerable to 3 mm fibers and only affected by one mm fibers at high exposures where multifiber chains are possible.

A large number of tests were performed on the transponder. The set failed many times in experimenting and test set up. Each failure was corrected by dismantling the transponder, vacuuming and then blowing with compressed air. No permanent failure requiring

AVERAGE EXPOSURE TO FAILURE OF THE ATC TRANSPONDER

FIBER LENGTH	TEST RUN NUMBER	EXPOSURE AT FAILURE	FAILURE OCCURRED DURING FLIGHT ENVIRONMENT (FE) OR EXPOSURE	$\overline{E}$ AVERAGE EXPOSURE TO FAILURE
1 MM	1	6.0×10^7	FE	$>5.5 \times 10^7$ NOTE: TWO RUNS WITH NO FAILURE
	2	4.5×10^7	EXPOSURE	
	3	6.0×10^7	NO FAIL (TEST STOPPED)	
	4	6.0×10^7	NO FAIL (TEST STOPPED)	
	5	4.9×10^7	EXPOSURE	
3 MM	1	3.0×10^6	FE	4.4×10^6
	2	3.7×10^6	FE	
	3	2.2×10^6	EXPOSURE	
	4	1.0×10^7	EXPOSURE	
	5	3.0×10^6	EXPOSURE	
10 MM	1	3.4×10^7	EXPOSURE	1.6×10^7
	2	9.9×10^6	EXPOSURE	
	3	8.7×10^6	EXPOSURE	
	4	1.8×10^7	EXPOSURE	
	5	9.1×10^6	EXPOSURE	

TABLE 1: AVERAGE EXPOSURE TO FAILURE OF THE ATC TRANSPONDER

ATC TRANSPONDER
$\bar{E}$ VERSUS FIBER LENGTH

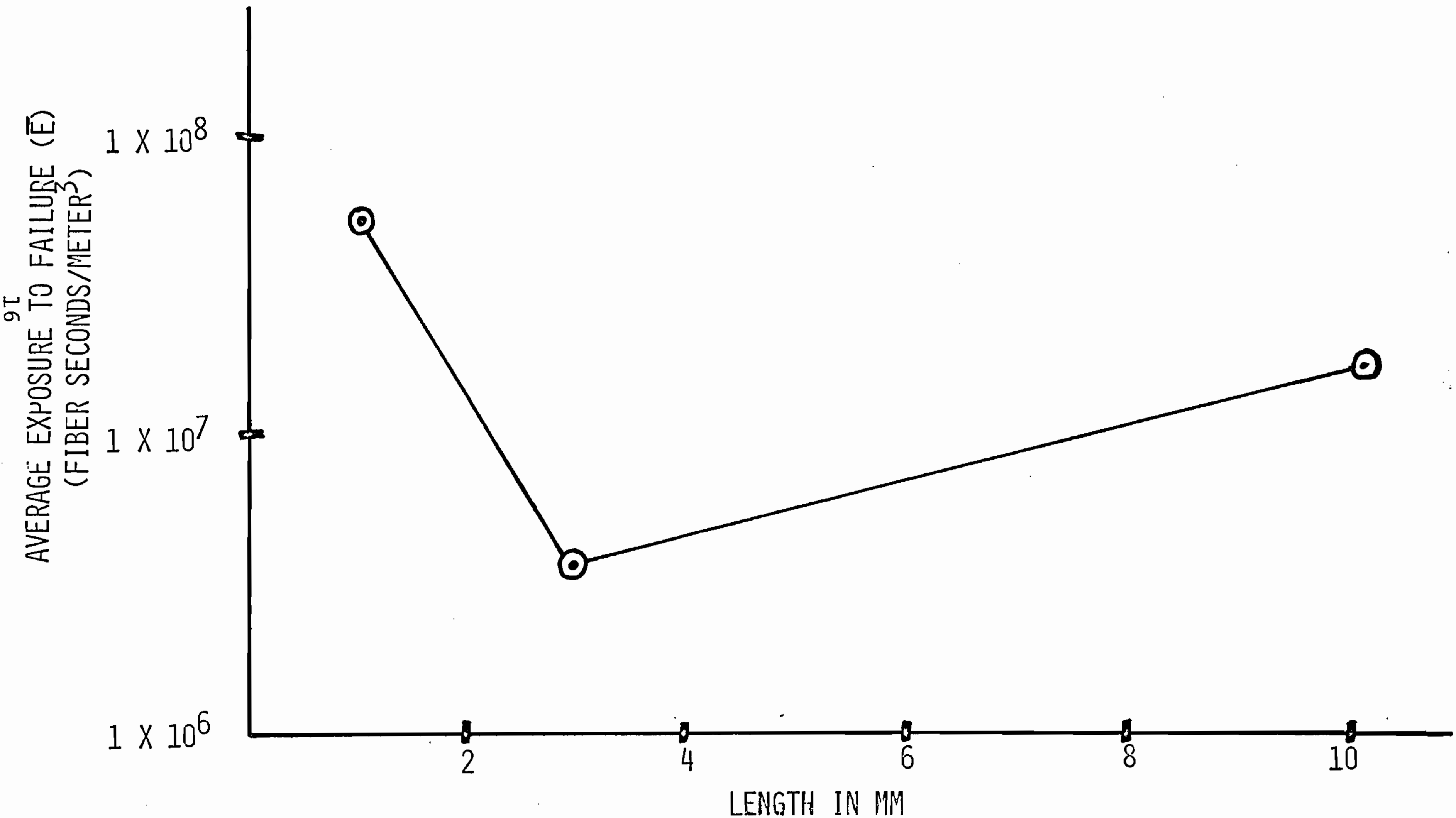

FIGURE 6: $\bar{E}$ VERSUS FIBER LENGTH OF THE ATC TRANSPONDER

replacement of parts or electrical work was witnessed. The failures observed were about 50% coding discrepancies caused by shorting the circuits of the coding boards and 50% total power failures apparently caused by a fiber in the high voltage power supply. The single fibers were invisible to the naked eye and by the time the chamber was cleared, the dust cover removed and the box disassembled the fiber causing the short could not be found.

4.2 The VHF Transceiver

The transceiver is shown in Figure 7 with the dust cover off. The dust cover has 3.2 mm (1/8 inch) holes on only one side and some at the bottom. The figure has the dust cover upside down showing the bottom holes. This device is normally cooled by blowing cooling air through from top to bottom at a rate of 0.3 meter^3/minute. During all testing air was drawn through the device at this rate. The size of the box is 13 cm x 25 cm x 46 cm.

A setup for testing was constructed as specified in the repair manual. Figure 8 shows a copy of the test parameters that were verified during the test runs. A complete checkout was made every 30 minutes of test time with output power, side tone and receiver sensitivity monitored continuously. Testing was accomplished with Thornel 300 fibers of 1, 3 and 10 mm lengths. The concentration in the chamber was held between 10^3 and 10^4 fibers/meter^3 as in the previous tests on the ATC transponder.

The technical manual did not specify any conformal coating on the VHF transceiver. It was visually and electronically checked for coatings and found to be uncoated.

Air was drawn by a fan through a four inch duct mounted at the bottom. Airflow was calculated as follows:

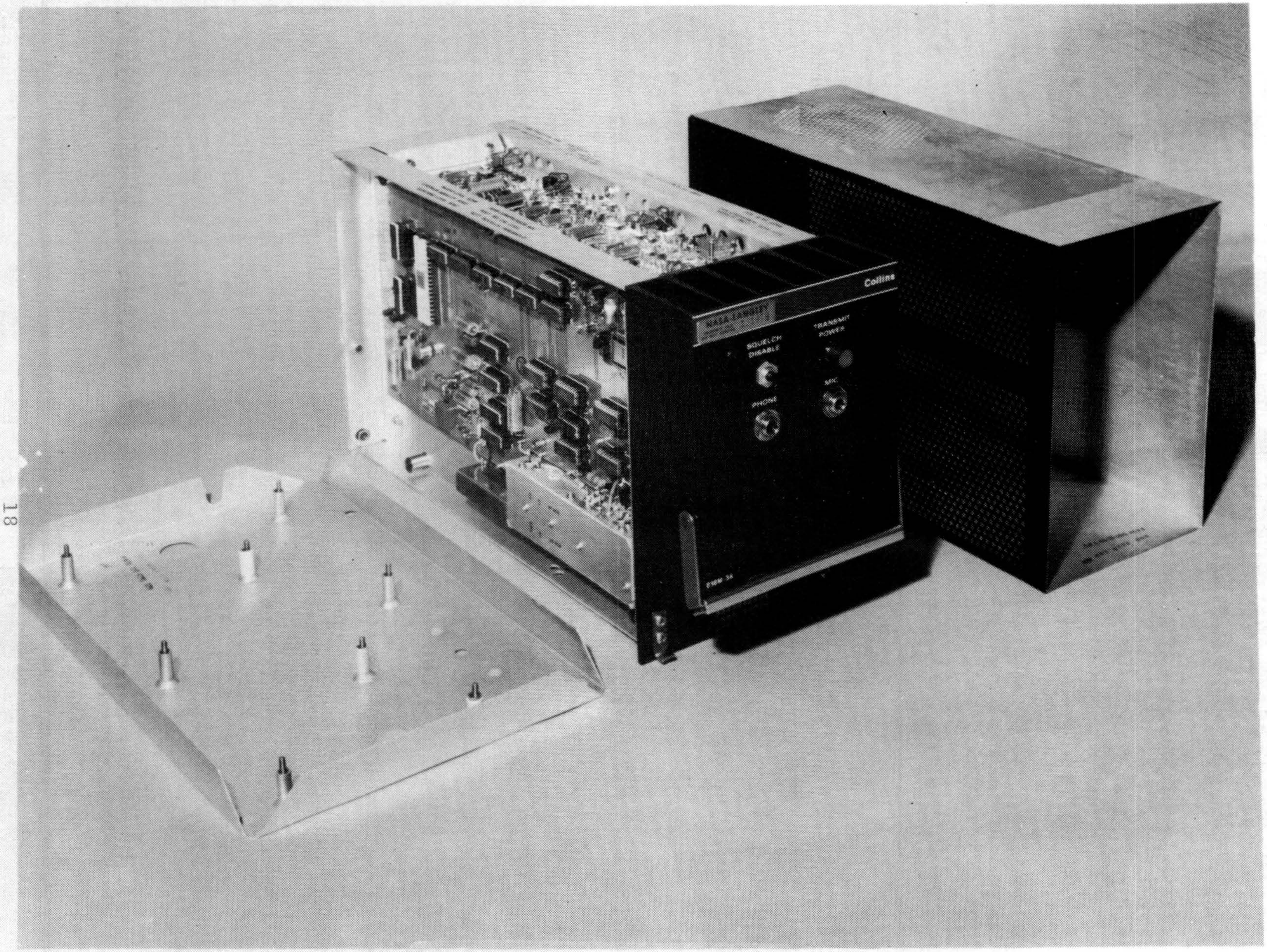

FIGURE 7: THE VHF TRANSCEIVER

VHF 618M-3 TESTS

DATE:____________________ TIME:____________________

RUN #:____________________ LENGTH FIBER:____________________

FAIL COUNT:____________________ TYPE COOLING:____________________

1. RECEIVER MODE CURRENT DRAIN TEST
2. RECEIVER AUDIO OUTPUT TEST
3. RECEIVER SELCAL OUTPUT TEST
4. RECEIVER SENSITIVITY TEST
5. SQUELCH TEST
6. SQUELCH DISABLE TEST
7. CARRIER-TO-NOISE SQUELCH HYSTERESIS TEST
8. CARRIER OVERRIDE SQUELCH TEST
9. XMIT MODE CURRENT DRAIN TEST
10. XMTR POWER OUTPUT TEST
11. XMTR FREQUENCY ACCURACY TEST
12. MODULATOR TESTS
13. SIDETONE LEVEL TEST

FIGURE 8: VHF TRANSCEIVER TEST SHEET

VHF TRANSCEIVER

FIBER LENGTH	$\overline{E}$	REMARKS
1 MM	9.0×10^7	NO FAILURES
3 MM	$> 3.0 \times 10^7$	ONE FAILURE DURING FLIGHT ENVIRONMENT GROSS VULNERABILITY TEST. NO FAILURES IN FOUR RUNS TO 3×10^7.
10 MM	9.0×10^7	NO FAILURES

TABLE 2: $\overline{E}$'s OF VHF TRANSCEIVER

$$\text{Flow rate} = \text{Volume rate/Area} = (0.3 \text{ meters}^3/\text{min})/\pi (0.5 \text{ meters})^2 = 12 \text{ meters/min.}$$

The airflow rate was extracted from Reference 2.

The average airgap size in the VHF transceiver was approximately 2.3 mm. Table 2 shows the VHF to be invulnerable to exposure levels expected in a Carbon Fiber (CF) release. One failure was witnessed during the 3 mm tests showing this length to again be the most significant in causing CF problems. This malfunction caused deterioration of the output level of the receiver and the sidetone. Vacuuming and blowing with compressed air rectified the problem.

4.3 The Instrument Landing System Receiver

The ILS Receiver, (Figure 9), is shown with the dust cover off in Figure 9A. Physical size is approximately 9 x 20 x 38 cm and weight is 4.1 kg. The dust cover is perforated with 3.2 mm (1/8 inch) holes located in two strips at the top of both sides; the rectangular strips are 4 x 36 cm's. The cover also has a rectangular set of holes in its bottom that is 5 x 8 cm's. No specific cooling requirements were set forth in the repair manual and the operating temperature limits were high. Since 30 meters/minute (100 FPM) is an estimate of the airflow to be seen in an aircraft electronic bay this flow was used in testing.

The test setup and checkout procedure for this device is lengthy. The system is described in Reference 3. The test mock-up was used to detect malfunctions during testing and the same test procedures were used as in paragraph 4.1.

The ILS-70 had no conformal coating. The length of air

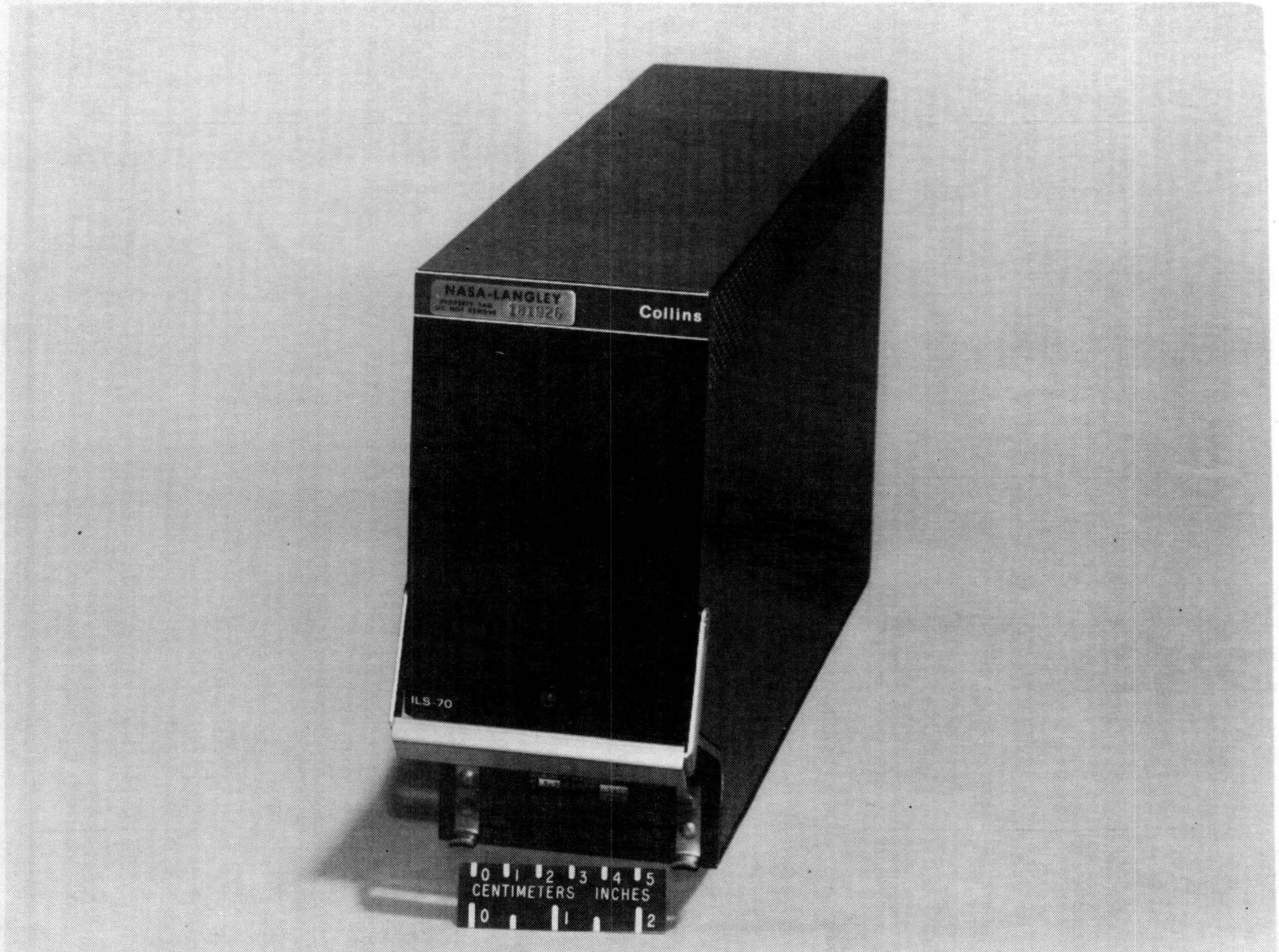

FIGURE 9: THE ILS RECEIVER

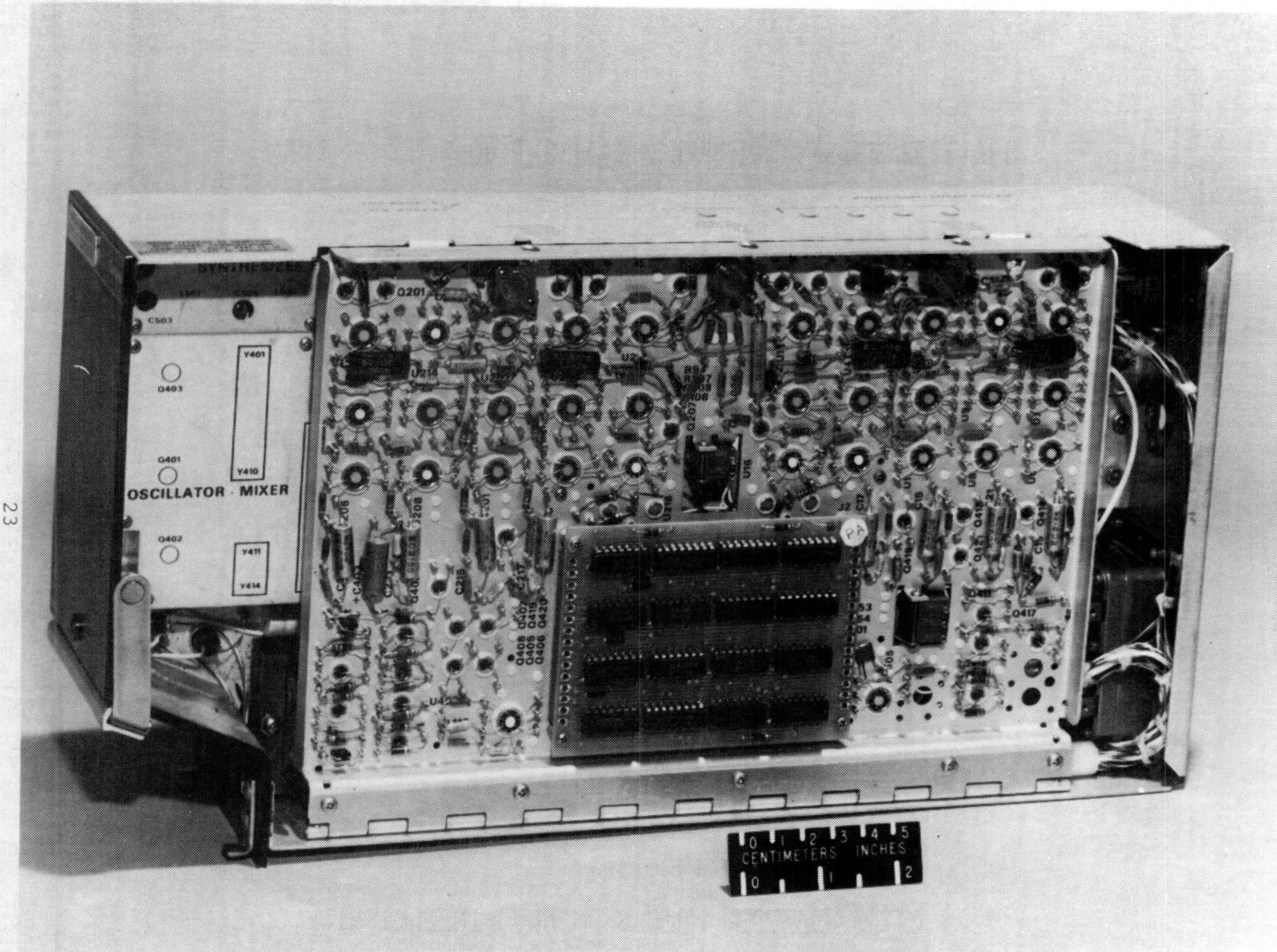

FIGURE 9A: THE ILS RECEIVER INTERNAL VIEW

INSTRUMENT LANDING SYSTEM RECEIVER (ILS)

FIBER LENGTH	$\overline{E}$	REMARKS
1 MM	9.0×10^{7}	NO FAILURES
3 MM	9.0×10^{7}	NO FAILURES
10 MM	9.0×10^{7}	NO FAILURES

TABLE 3: $\overline{E}$'s OF INSTRUMENT LANDING SYSTEM RECEIVER

gaps was similar to the other boxes tested and was slightly less than 3 mm. Table 3 shows that no failures were encountered during testing.

4.4 Distance Measuring Equipment

The DME is shown in Figure 10. Physical size is approximately 12 x 19 x 38 cm's and weight is 7.8 kg's. Figure 10 shows the 3.2 mm (1/8 inch) holes in strips 2.5 cm's wide and 36 cm's long at the top of both sides. A test setup was constructed as specified in the maintenance manual. Figure 11 is a copy of the test sheet and shows the parameters that were monitored to detect a malfunction and insure proper operations.

Cooling in the DME is handled by a thermostatically controlled internal fan. Since more fibers should be drawn into the device when the fan is operating and the exposure to failure should be lower the DME was tested with the fan jumper wired in the on position. Testing was conducted in the same manner as in paragraph 4.1.

This device was conformally coated and is the only device tested that was completely coated. The airgap distances were of the same order as the other devices which were slightly less than 3 mm. Table 4 shows the results of testing.

One failure was observed with this device. A fuse blew in the indicator which was external to the chamber. The indicator is powered by 26 VAC derived from 115 VAC, 400 Hz input power to the DME. It is believed a short inside the DME caused excess current to flow and blew fuse F-501 in the indicator. This fuse rendered the DME nautical readout inoperative; however, audio

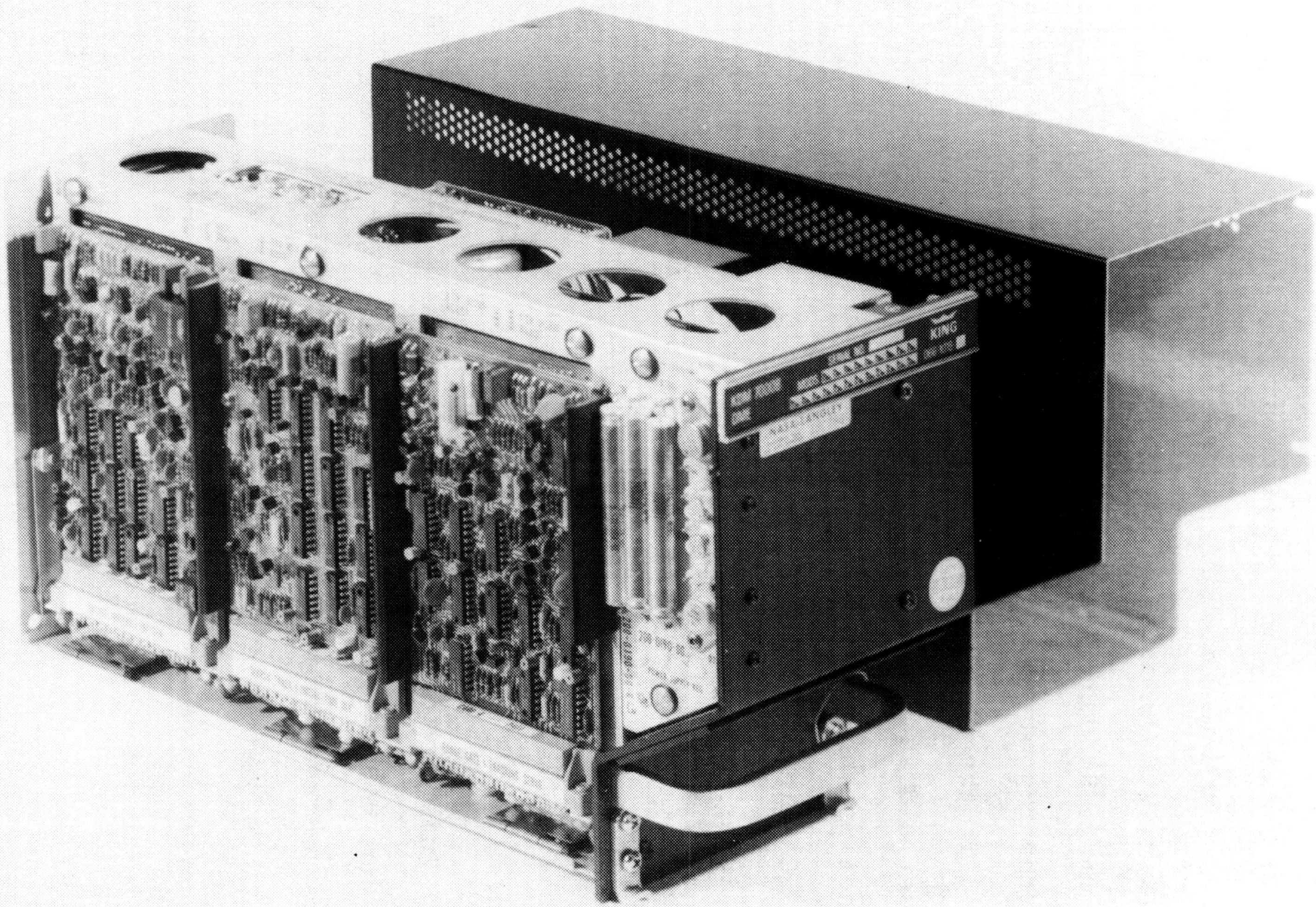

FIGURE 10: THE DISTANCE MEASURING EQUIPMENT (DME)

KDM 7000B FIBRE TEST SHEET

RUN NO.: ______________ TIME: ______________________

DASS: _________________ FAIL: ______________________

TEST:	INDICATIONS PRERUN	INDICATIONS POSTRUN
1. LOCK-ON		
2. VELOCITY		
3. TRANSMITTER PRF		
4. MEMORY		
5. VELOCITY MEMORY		
6. TRANSMITTER PEAK POWER/FREQUENCY		
7. IDENT TONE		
8. POOR SIGNAL TRACK (PERCENT REPLY)		
9. SQUITTER LOCK OUT		
10. AUTO STANDBY		
11. RANGE ACCURACY		
12. FUNCTIONAL		
13. ECHO PROTECTION		
14. DME HOLD		
15. SUPPRESSOR PULSE		

SUPPLEMENTAL TESTS USING ATC-1200Y3 TEST SET

1. RECEIVER SENSITIVITY
2. AUDIO OUTPUT

FIGURE 11: DME TEST SHEET

DISTANCE MEASURING EQUIPMENT

FIBER LENGTH	$\overline{E}$	REMARKS
1 MM	9.0×10^{7}	NO FAILURES
3 MM	$> 2.7 \times 10^{7}$	1 FAILURE - DURING FLIGHT ENVIRONMENT, GROSS VULNERABILITY TEST
10 MM	9.0×10^{7}	NO FAILURES

TABLE 4: $\overline{E}$'s OF DISTANCE MEASURING EQUIPMENT

functions remained within specifications. Vacuuming, blowing with air and changing the fuse restored complete operation.

4.5 The Flight Director System

The whole system (including the test set) is shown in Figure 12. Figure 13 shows the internal construction. The dust covers are perforated as shown in Figure 12 with a pattern of 3.2 mm (1/8 inch) diameter holes. The display instruments, the flight director and horizontal situation indicator, are sealed units which are panel mounted. The computer box and the amplifier box are remotely mounted in the avionics bay where they are cooled by ambient conditioned air at a rate of about 30 meters per minute. Examination showed that none of the "book" type circuit boards were coated. Wire to ground gaps of less than 2 mm were observed; 3 mm electrical spacings were typical.

The computer and amplifier were mounted in the test chamber. The instrument displays and test set were mounted externally. The following parameters were monitored during testing:

Glide Slope	VOR
Localizer	Radio Altimeter
Turn Commands	Flags
Runway	Gyro Compass
Pitch	
Bank	
Slow/Fast	

A controlled fan directed the air in the chamber through the boxes at a rate of about 30 meters per minute.

The fiber, Thornel 300 was used in the testing. One mm

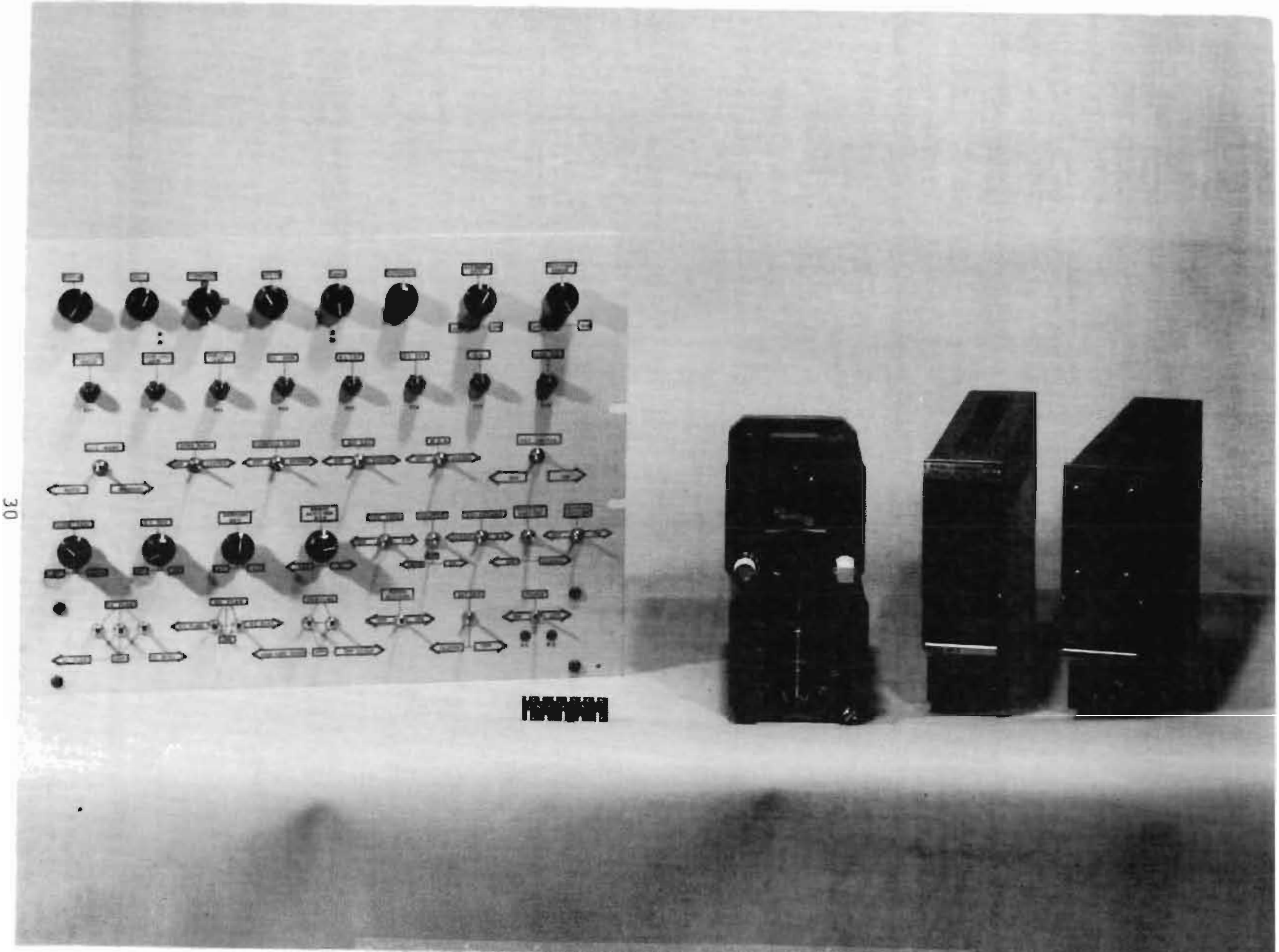

FIGURE 12: THE FLIGHT DIRECTOR SYSTEM

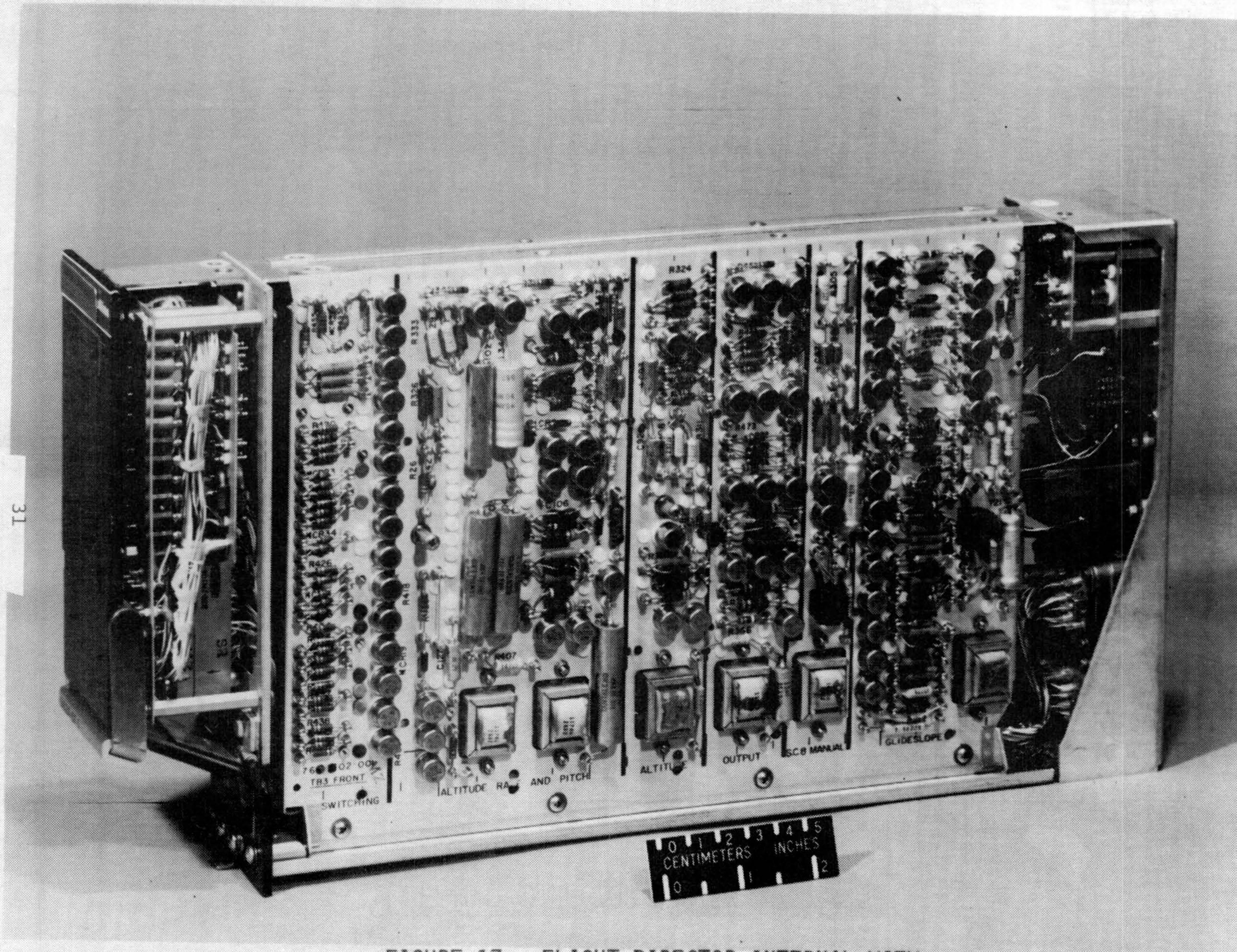

FIGURE 13: FLIGHT DIRECTOR INTERNAL VIEW

FLIGHT DIRECTOR SYSTEM

FIBER LENGTH	$\overline{E}$	REMARKS
1 MM	9.0×10^7	NO FAILURES
3 MM	$> 3.0 \times 10^7$	ONE FAILURE DURING EXPOSURE AT 9×10^6
		ONE FAILURE DURING FLIGHT ENVIRONMENT AT 1×10^7
		ONE FAILURE DURING FLIGHT ENVIRONMENT AT 3×10^7
10 MM	$> 6.0 \times 10^7$	ONE FAILURE DURING FLIGHT ENVIRONMENT AT 1.5×10^8
		ONE FAILURE DURING FLIGHT ENVIRONMENT AT 6×10^7

TABLE 5: E's OF FLIGHT DIRECTOR SYSTEM

fibers were first introduced into the chamber to an exposure of 9×10^7. No failures were observed during any part of the test sequence as indicated in Table 5. The chamber was cleaned and fibers of 3 mm length were then used for the tests. Data in Table 5 indicates that there were three (3) failures but that the remaining runs without failure brought the Average Exposure to Failure ($\bar{E}$) to $> 3 \times 10^7$. Similarly 10 mm fiber lengths caused two failures but again the $\bar{E}$ was $> 6 \times 10^7$.

It should be noted that none of the failures were permanent and all were readily cleared by the simple expedient of vacuuming the boxes. The only unusual pattern of the failures is that they all occurred in the computer and none were indicated by flags on the instruments. More modern digital equipment now includes sufficient built in tests so as to reasonably assure a failure notice with failures similar to those experienced here.

4.6 Aircraft Relays and Terminal Blocks

The relays and terminal blocks were tested by Ballistics Research Laboratory in Aberdeen, Maryland. Figure 14 shows the mounting of two relay blocks for exposure testing with carbon fibers. There are roughly 80 to 150 relay blocks in a small commercial aircraft. The relays can be mounted horizontally (with connectors facing up) or vertically (connectors facing sideways). They can carry 115 VAC or 28 VDC. Table 6 shows the $\bar{E}$'s of relays tested horizontally and vertically. The values of exposure for a short to an adjacent terminal or a terminal on the opposite side of the plastic separating strip are given. The exposure to produce a short to an opposite connector is higher as might be expected.

AIRCRAFT RELAYS

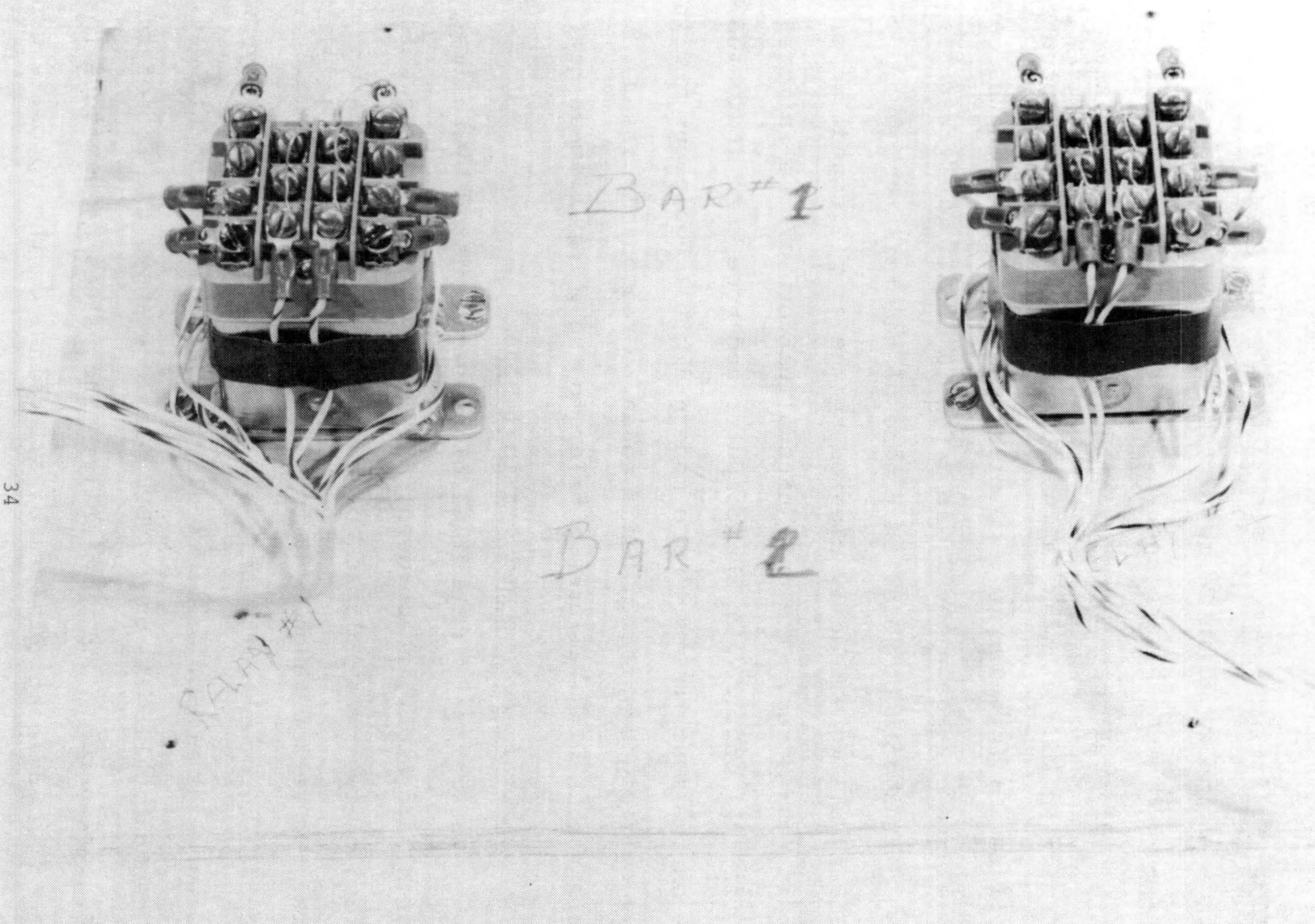

FIGURE 14: AIRCRAFT RELAYS

RELAY TESTING

LENGTH	ORIENTATION	TYPE	CURRENT	E (115V)	E (28V)
3.5 MM	HORIZ	1	1	3.9 X 7	1.3 X 8
		1	2	2.4 X 7	1.8 X 8
		2	1	1.2 X 8	3.9 X 8
		2	2	>2.5 X 8	3.6 X 8
	VERT	1	1	6.9 X 7	>7.8 X 8
		1	2	1.6 X 8	>3.9 X 8
		2	1	5.9 X 8	>7.8 X 8
		2	2	2.8 X 8	>3.9 X 8
7 MM	HORIZ	1	1	8×10^6	3.0 X 7
		1	2	8×10^6	1.3 X 8
		2	1	2.4 X 7	8.1 X 7
		2	2	2.1 X 8	>2.8 X 8
	VERT	1	1	1.8 X 7	1.8 X 8
		1	2	4.5 X 7	1.6 X 8
		2	1	3.0 X 7	>7.2 X 8
		2	2	3.0 X 6	>3.6 X 8
15 MM	HORIZ	1	1	3 X 6	9 X 6
		1	2	2 X 6	6 X 6
		2	1	6 X 6	6 X 7
		2	2	8 X 6	1 X 8
	VERT	1	1	3 X 6	1.8 X 7
		1	2	1.8 X 6	1.8 X 7
		2	1	1.2 X 7	1.6 X 8
		2	2	1.2 X 7	>8.4 X 7

TYPE 1 = SHORT TO ADJACENT TERMINAL
TYPE 2 = SHORT TO OPPOSITE TERMINAL (ACROSS PLASTIC SEPARATOR)
CURRENT 1 = $I \leq 10$ MA
CURRENT 2 = $I > 10$ MA

TABLE 6: $\overline{E}$'s OF AIRCRAFT RELAYS

The $\bar{E}$ value to produce a shorting current of less than 10 ma and greater than 10 ma is also given. Current could not go much above 10 ma as the fiber would burn out at values above 12 ma.

Figure 15 is a plot of the lowest $\bar{E}$ value given in Table 6 for each fiber length regardless of condition. A separate curve is shown for 28 VDC and 115 VAC.

Table 7 gives the $\bar{E}$'s for the terminal blocks with the same variations as above except only one orientation is used in aircraft. The horizontal orientation is eliminated. The type of short varied from terminal to terminal or to the mounting bar. There are about 100 to 200 terminal blocks on a small commercial aircraft depending on configuration and equipment. Figure 16 is a photograph of the terminal blocks and Figure 17 shows a plot of the lowest $\bar{E}$ for each fiber length regardless of the type of short or current value.

$\bar{E}$'s are of the same order or higher than those of the avionics tested. Since the protection of a dust cover filtering out long fibers was not available, lower $\bar{E}$'s are found with increasing fiber length. A higher $\bar{E}$ is indicated at 28 VDC than 115 VAC. This can be attributed to lower effect of contact resistance at the higher voltage.

AIRCRAFT RELAYS
AVERAGE EXPOSURE TO FAILURE VERSUS FIBER LENGTH
THE LOWEST $\overline{E}$, REGARDLESS OF CONDITION IN TABLE 6 IS PLOTTED

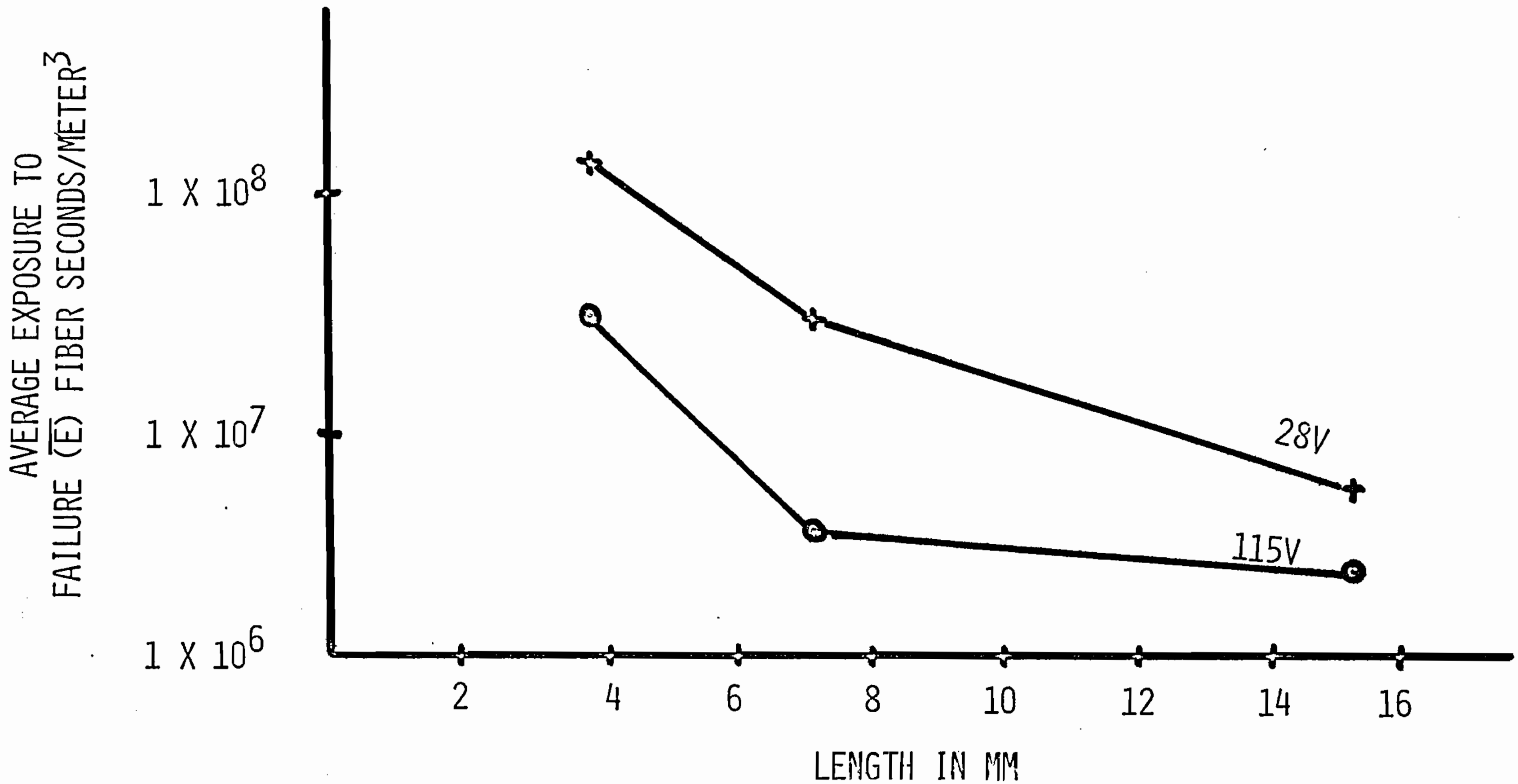

FIGURE 15: $\overline{E}$ OF AIRCRAFT RELAYS

TERMINAL STRIP TESTING

LENGTH	TYPE	CURRENT	E (115V)	E (28V)
3.5	1	1	1 X 8	2.9 X 8
	1	2	3 X 8	No Fail
	2	1	> 3 X 8	No Fail
	2	2	> 3 X 8	No Fail
7.5	1	1	2.3 X 8	2.8 X 8
	1	2	1.3 X 8	2.9 X 8
	2	1	2.6 X 8	2.9 X 8
	2	2	> 3.1 X 8	No Fail
15	1	1	3.2 X 7	7 X 7
	1	2	1.6 X 7	No Fail
	2	1	6.4 X 7	3.1 X 8
	2	2	3.6 X 7	No Fail

TYPE 1 = SHORT TO ADJACENT TERMINAL

TYPE 2 = SHORT TO MOUNTING BAR

CURRENT 1 = $I \leq 10$ MA

CURRENT 2 = $I > 10$ MA

TABLE 7: $\overline{E}$'s OF AIRCRAFT TERMINAL STRIPS

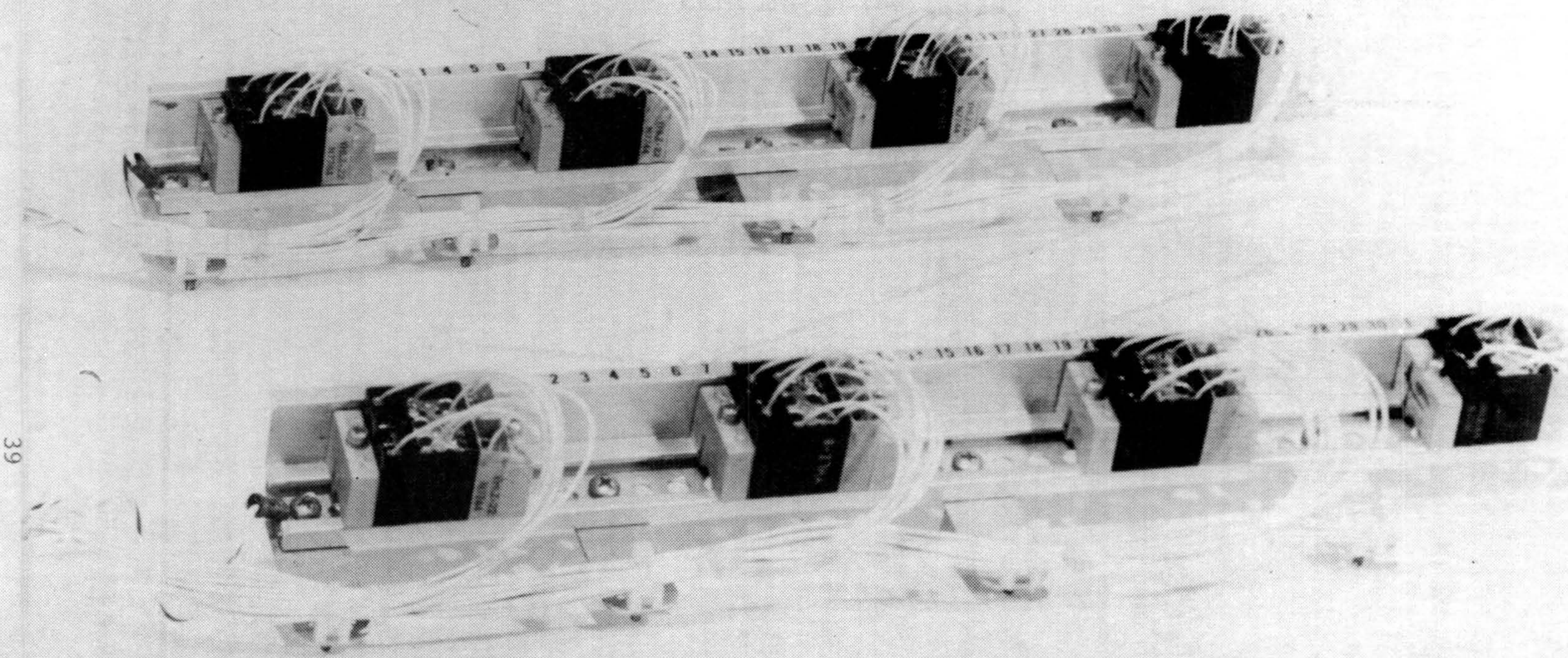

FIGURE 16: AIRCRAFT TERMINAL STRIPS

AIRCRAFT TERMINAL STRIPS
AVERAGE EXPOSURE TO FAILURE VERSUS FIBER LENGTH
THE LOWEST $\overline{E}$ REGARDLESS OF CONDITION IN TABLE 7 IS PLOTTED

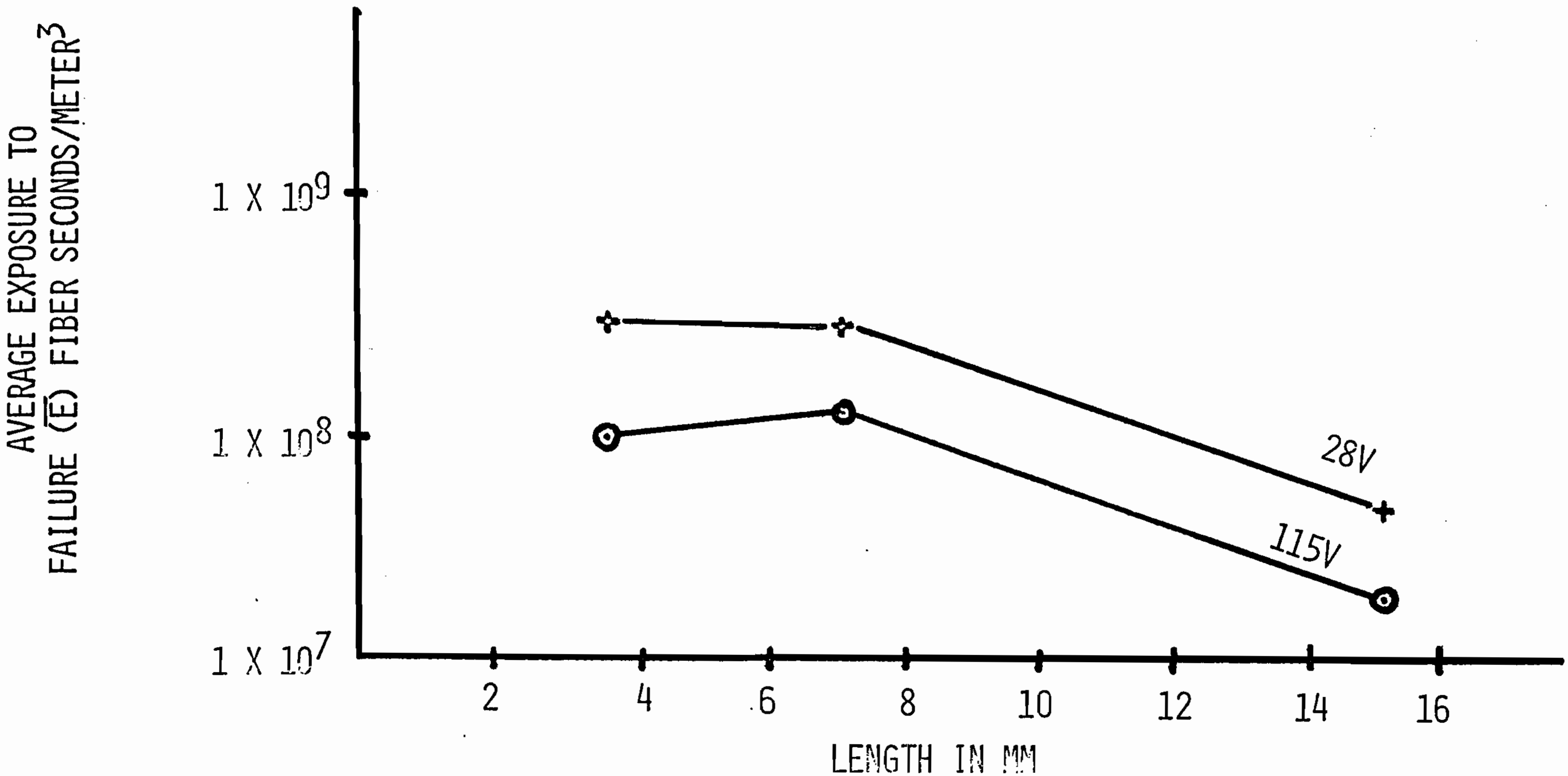

FIGURE 17: $\overline{E}$ OF AIRCRAFT TERMINAL STRIPS

5.0 SUMMARY AND CONCLUSIONS

A summary of the $\bar{E}$'s of the test items is shown in Table 8. All the items tested were uncoated except the Distance Measuring Equipment (DME). All $\bar{E}$'s are above 4×10^6 fiber-seconds/meter^3 with the ATC transponder having the lowest values. This was the oldest piece of equipment tested and was introduced early in the 1960's. The transponder also had the greatest open area for ingesting fibers. The dust cover is shown in Figure 5 and both sides are entirely perforated with 1/8 inch holes.

Because of gap sizes and filtering action of the dust covers 3 mm fibers are the most significant in terms of electrical contamination of avionics equipment. The relays and terminal strips should be considered separately as they have no dust covers but have plastic separating strips between contacts. Inspection of Figures 14 and 16 show that to create a short more than one fiber is required since a bend must be made to get from one contact to another. Since a short is a multifiber event a higher level of exposure is required before two fibers can form the short. The requirement for more than one fiber caused the $\bar{E}$'s in Table 8 to be of the same order as the equipment with dust covers. It is interesting to note that the longest fibers are most effective in causing a short on the relays and terminal strips. This is most always the case; however, the dust covers filtered out many of the 10 mm fibers from the avionics.

SUMMARY OF AVIONICS AVERAGE EXPOSURES TO FAILURES (E)

FIBER LENGTH	ATC TRANSPONDER	VHF	ILS	DME	FLIGHT DIRECTOR	RELAYS	TERMINAL STRIPS
1 MM	5.5×10^7	9.0×10^7	9.0×10^7	9.0×10^7	9.0×10^7	1.0×10^8	1.0×10^8
3 MM	3.7×10^6	$>3.0 \times 10^7$	9.0×10^7	$>2.7 \times 10^7$	$>3.0 \times 10^7$	2.4×10^7	1.0×10^8
10 MM	1.6×10^7	9.0×10^7	9.0×10^7	9.0×10^7	$>6.0 \times 10^7$	8.0×10^6	6.0×10^7

TABLE 8: SUMMARY OF AVIONICS AVERAGE EXPOSURES TO FAILURES (E)

REFERENCES

1. NASA Contractor Report 159076, "Carbon Fiber Behavior in an Enclosed Volume", by Mark C. Harvey, June 1979, Contract NAS1-15238.

2. NASA Contractor Report 158999, "Vulnerability of Quick Disconnect Connectors to Carbon Fibers", by Jerome A. Meyers, January 1979, Contract NAS1-15238.

3. "Collins Maintenance Manual for Instrument Landing Receiver - ILS-70", dated January 15, 1979, pages 774S to 745.

APPENDIX

TEST DATA ANALYSIS

Estimate of the Exposure to Failure

To determine the best estimate of the average exposure to failure, $<E_o>$, assuming the single fiber model (exponential), the maximum likelihood estimate is used, that is

$$f = 1/<E_o> = m/ \sum_{i=1}^{n} E_i$$

where n is the total number of experiments, E_i is the exposure to which the i^{th} test is run, and m is the number of failures. The special case where there are no failures is treated later.

Examples

Applying the above methodology to example data, we compute the point estimates of the exposures to failure and then use the point estimate to construct the confidence limits for the exposure to failure.

The same values of E_i are used in each example to illustrate the effect of "no malfunction", (runs that did not fail) on $<E>$.

Example 1.

Item A is tested five (5) times and malfunctions (fails) every time at the E_i shown.

Test Number	E_i (fs/m^3)
1	1×10^6
2	1×10^7
3	5×10^6
4	5×10^6
5	8×10^6
n = 5	m = 5

$$\langle E_o \rangle = \frac{\sum_{i=1}^{n} E_i}{m} = \frac{2.9 \times 10^7}{5}$$

$$\langle E_o \rangle = 5.8 \times 10^6 \ \text{fs/m}^3$$

Example 2.

Item B is tested five (5) times and malfunctions on three (3) tests. On the two tests where there were no malfunctions, the tests were terminated at E_i, shown as ($<E_i$).

Test Number	E_i (fs/m^3)
1	1×10^6
2	($>1 \times 10^7$) no malfunction
3	5×10^6
4	5×10^6
5	($>8 \times 10^6$) no malfunction
$n = 5$	$m = 3$

$$\langle E_o \rangle = \frac{\sum_{i=1}^{n} E_i}{m} = \frac{2.9 \times 10^7}{3}$$

$$\langle E_o \rangle = 9.7 \times 10^6 \ \text{fs/m}^3$$

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7. Author(s) Jerome Meyers, Seymour Salmirs		8. Performing Organization Report No.
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15. Supplementary Notes

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16. Abstract

A variety of avionics components, commonly used in commercial aircraft, was tested for vulnerability to failure when operated in an environment with a high density of graphite fibers. The components were subjected to a series of exposures of graphite fibers. Each exposure was at different fiber lengths. Lengths used for the tests were (in order) 1 mm, 3 mm and 10 mm. The test procedure included subjecting the equipment to characteristic noise and shock environments.

Most of the equipment was invulnerable (did not fail at the maximum exposure tested) or did not fail until extremely high average exposures were reached. The single exception was an air traffic control transponder produced in the early 1960's. It had the largest case open area through which fibers could enter and it had no coated boards.

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