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Carbon/Graphite Fiber Risk Analysis and Assessment Study

An Assessment of the Risk to Douglas Commercial Transport Aircraft

H. C. Schjelderup, et al

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Long Beach, California 90846

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NASA CONTRACTOR REPORT 159212

CARBON/GRAPHITE FIBER RISK ANALYSIS AND ASSESSMENT STUDY

AN ASSESSMENT OF THE RISK TO DOUGLAS COMMERCIAL TRANSPORT AIRCRAFT

January 1980

Prepared Under Contract NAS1-15508
for
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

by

Douglas Aircraft Company
McDonnell Douglas Corporation
Long Beach, California

X80-10045 #

PREFACE

This final report was prepared by cognizant personnel at the Douglas Aircraft Company, a division of the McDonnell Douglas Corporation, under NASA Contract No. NAS1-15508. The contract was administered by the NASA Langley Research Center. Mr. J. L. Humble of NASA was the Douglas Aircraft Technical Monitor and Mr. R. J. Huston was the overall Program Manager for NASA.

The work was performed under the general supervision of Dr. H. C. Schjelderup. The following Douglas personnel made significant contributions to the program:

Electrical/Electronic Component Characterization - C. Q. Cook, E. Snyder
Fiber Transfer Functions - B. Henning
Potential Equipment Exposure - J. Hosford
Equipment Vulnerability Assessment - D. L. Gilles, C. W. Swanstrom

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SECTION 1
INTRODUCTION

The use of carbon/graphite composite material in aircraft structure is increasing every year and the increase is expected to continue for the foreseeable future. Concern has been expressed recently over the potential hazard to electrical and electronic devices should there be a release of free fiber due to a crash and fire. NASA established a comprehensive study program to estimate the expected dollar loss due to accidental release of carbon/graphite fibers. Work programs were conducted by a variety of firms and Government agencies to acquire data as to exposure and equipment sensitivity in order to provide data for a risk analysis.

This report presents the results of the following studies assigned to Douglas:

- DC-9/DC-10 Electrical/Electronic Component Characterization
- DC-9 and DC-10 Fiber Transfer Functions
- Potential for Transport Aircraft Equipment Exposure to Carbon Fibers
- Equipment Vulnerability Assessment.

SECTION 2
SUMMARY AND CONCLUSIONS

This report was prepared under contract to NASA and contains information necessary to evaluate the risk — to Douglas-manufactured commercial jet aircraft — caused by the accidental release of free carbon/graphite fibers from composite material. Detailed data from this report and similar reports prepared by Boeing Commercial Airplane Company and Lockheed California Company have been used by Arthur D. Little Inc. and Operations Research Institute Inc. to determine their estimate of the national risk factor.

Since the major threat would be to the aircraft avionics, the first two tasks undertaken were to determine entry path and filtration to the avionics compartment, and to classify the avionics equipment as to its vulnerability. Further tasks included an assessment of the average number of aircraft on the ground at selected airports during the day and at night and the vulnerability configuration of these aircraft, i.e., the probability of avionic equipment failure, the cost of maintenance, and the hazard to the aircraft.

Considerable interface with NASA risk analysis contractors, Arthur D. Little Inc., and Operations Research Institute Inc., is evident, and the use of their input is gratefully acknowledged.

This study established that there is only a negligible increase in risk, either now or projected to 1993, for the DC-9 and DC-10 fleets due to accidental release of free carbon/graphite fibers.

SECTION 3
DC-9/DC-10 ELECTRICAL/ELECTRONIC COMPONENT CHARACTERIZATION

3.1 Introduction

The identification, tabulation, and categorization of the DC-9 and DC-10 electrical and electronic components for carbon fiber (CF) risk assessment was accomplished in compliance with NASA Contract NAS1-15508.

3.2 Selection of Equipment for Categorization

The preliminary DC-9 Master Component List and the DC-10 Master Component List identifies all Line Replaceable Units (LRU) that have reliability, maintenance, or cost significance. The components evaluated by this study were obtained from these lists and are identified on the Component Data Sheets. The Component Data Sheets were assembled by ATA Chapters which are identified in Table 3-1. Reflected in Tables 3-2 and 3-3 are the number of data sheets and the number of units open/closed for the DC-10/DC-9 aircraft. These data sheets were previously submitted to NASA via letters C1-091-ACEE-537, dated 9 November 1978 and C1-091-ACEE-153, dated 26 March 1979 and are not included herein.

3.3 Component Data Sheets

The information contained in the data sheets relates primarily to internal and external box construction, ventilation, voltage and power requirements, and location of the equipment in the aircraft. Sheets containing this data were completed for those components whose enclosure construction was open, particular care for completeness being given to those units regarded as candidates for CF testing. The data sheet form utilized was reviewed by NASA.

Data sheets for equipment whose enclosure construction was regarded as sealed were not completed in detail although exceptions are found. While sealed equipment is not regarded as being subject to CF influence, component

TABLE 3-1

ATA INDEX (3-DIGIT)

21-00	AIR CONDITIONING
20	DISTRIBUTION
30	PRESSURIZATION CONTROL
40	HEATING
50	COOLING
60	TEMPERATURE CONTROL
22-00	AUTO FLIGHT
10	AUTOPILOT
20	SPEED ATTITUDE CORRECTION
30	AUTO THROTTLE/SPEED CONTROL (AT/SC)
40	SYSTEM MONITOR
23-00	COMMUNICATIONS
10	HIGH FREQUENCY (HF)
20	VERY HIGH FREQUENCY (VHF)
30	PASSENGER ADDRESS AND ENTERTAINMENT
40	INTERPHONE
50	AUDIO INTEGRATING
60	STATIC DISCHARGING
70	VOICE RECORDERS
24-00	ELECTRICAL POWER
10	GENERATOR DRIVE
20	AC GENERATION
30	DC GENERATION
40	EXTERNAL POWER
50	ELECTRICAL LOAD DISTRIBUTION
25-00	EQUIPMENT/FURNISHINGS
10	FLIGHT COMPARTMENT
20	PASSENGER COMPARTMENT
30	BUFFET/GALLEY
40	LAVATORIES
50	CARGO AND ACCESSORY COMPARTMENTS
60	EMERGENCY
26-00	FIRE PROTECTION
10	FIRE DETECTION
20	FIRE EXTINGUISHING
27-00	FLIGHT CONTROLS
10	AILERON
20	RUDDER
30	ELEVATOR
40	HORIZONTAL STABILIZERS
50	FLAPS
60	SPOILER
70	DAMPERS
80	LIFT AUGMENTING
28-00	FUEL SYSTEM
10	STORAGE
20	DISTRIBUTION
30	DUMP
40	INDICATING
29-00	HYDRAULIC POWER
10	MAIN
20	AUXILIARY
30	INDICATING
30-00	ICE AND RAIN PROTECTION
10	AIRFOIL
20	AIR INTAKES
30	PITOT AND STATIC
40	WINDOWS AND WINDSHIELDS
70	WATER LINES
80	DETECTION
31-00	INSTRUMENTS
10	PANELS
20	INDEPENDENT INSTRUMENTS
30	RECORDERS
40	COMPUTERS
50	CENTRAL WARNING SYSTEMS
32-00	LANDING GEAR
10	MAIN GEAR AND DOORS
20	NOSE GEAR AND DOORS
30	EXTENSION AND RETRACTION
40	WHEELS AND BRAKES
50	STEERING
60	POSITION AND WARNING
33-00	LIGHTS
10	FLIGHT COMPARTMENT
20	PASSENGER COMPARTMENTS
30	CARGO AND SERVICE COMPARTMENTS
40	EXTERIOR
50	EMERGENCY LIGHTING
34-00	NAVIGATION
10	FLIGHT ENVIRONMENTAL DATA
20	ATTITUDE AND DIRECTION
30	LANDING AND TAXIING AIDS
40	INDEPENDENT POSITION DETERMINING
50	DEPENDENT POSITION DETERMINING
60	POSITION COMPUTING
35-00	OXYGEN
10	CREW
20	PASSENGER
30	PORTABLE
36-00	PNEUMATIC
10	DISTRIBUTION
20	INDICATING
38-00	WATER/WASTE
10	POTABLE
30	WASTE DISPOSAL
40	AIR SUPPLY
49-00	AIRBORNE AUXILIARY POWER
10	POWER PLANT
20	ENGINE
30	ENGINE FUEL AND CONTROL
40	IGNITION/STARTING
50	AIR
60	ENGINE CONTROLS
70	INDICATING
80	EXHAUST
90	OIL
52-00	DOORS
10	PASSENGER/CREW
30	CARGO
40	SERVICE
50	FIXED INTERIOR
70	DOOR WARNING
80	LANDING GEAR
53-00	FUSELAGE
50	AERODYNAMIC FAIRINGS
54-00	NACELLES/PYLONS STRUCTURE
50	FILLETS/FAIRINGS
55-00	STABILIZERS
20	ELEVATORS
40	RUDDER
50	ATTACH FITTINGS
56-00	WINDOWS
10	FLIGHT COMPARTMENT
20	CABIN
30	DOOR
57-00	WING
20	AUXILIARY STRUCTURE
50	FLIGHT SURFACES
71-00	POWER PLANT
10	COWLING
72-00	ENGINE
73-00	ENGINE FUEL AND CONTROL
10	DISTRIBUTION
20	CONTROLLING
30	INDICATING
74-00	IGNITION
10	ELECTRICAL POWER SUPPLY
20	DISTRIBUTION
30	SWITCHING
75-00	AIR
10	ENGINE ANTI-ICING (SERIES 20 ONLY)
20	ACCESSORY COOLING
30	COMPRESSOR CONTROL
40	INDICATING
76-00	ENGINE CONTROLS
10	POWER CONTROL
20	EMERGENCY SHUTDOWN
77-00	ENGINE INDICATING
10	POWER
20	TEMPERATURE
30	ANALYZERS
78-00	EXHAUST
30	THRUST REVERSER
79-00	OIL
10	STORAGE
20	DISTRIBUTION
30	INDICATING
80-00	STARTING
82-00	WATER INJECTION (P&W)
10	STORAGE
20	DISTRIBUTION
30	DUMPING
40	INDICATING

TABLE 3-2

DC-10 DATA SHEETS/CHAPTER BREAKDOWN

CHAPTER		DATA SHEETS	UNITS OPEN	UNITS CLOSED
21	AIR CONDITIONING	38	5	33
22	AUTO FLIGHT	28	3	25
23	COMMUNICATIONS	30	12	18
24	ELECTRICAL POWER	35	8	27
25	EQUIPMENT/FURNISHINGS	11	2	9
26	FIRE PROTECTION	6	2	4
27	FLIGHT CONTROLS	10	0	10
28	FUEL SYSTEM	13	0	13
29	HYDRAULIC POWER	17	1	16
30	ICE AND RAIN PROTECTION	12	2	10
31	INSTRUMENTS	16	5	11
32	LANDING GEAR	14	2	12
33	LIGHTS	8	2	6
34	NAVIGATION	56	23	33
35	OXYGEN	3	0	3
36	PNEUMATIC	10	3	7
38	WATER/WASTE	5	0	5
49	AIRBORNE AUXILIARY POWER	10	0	10
52	DOORS	0	0	0
53	FUSELAGE	0	0	0
54	NACELLES/PYLONS STRUCTURE	0	0	0
55	STABILIZERS	0	0	0
56	WINDOWS	0	0	0
57	WING	0	0	0
71	POWER PLANT	2	0	2
72	ENGINE	0	0	0
73	ENGINE FUEL AND CONTROL	10	1	9
74	IGNITION	2	1	1
75	AIR	2	0	2
76	ENGINE CONTROLS	1	0	1
77	ENGINE INDICATING	9	0	9
78	EXHAUST	1	0	1
79	OIL	6	0	6
80	STARTING	2	0	2
82	WATER INJECTION (P&W)	2	0	2
		359	72	287

TABLE 3-3

DC-9 DATA SHEETS/CHAPTER BREAKDOWN

CHAPTER		DATA SHEETS	UNITS OPEN	UNITS CLOSED
21	AIR CONDITIONING	21	0	21
22	AUTO FLIGHT	16	0	16
23	COMMUNICATIONS	26	12	14
24	ELECTRICAL POWER	20	9	11
25	EQUIPMENT FURNISHINGS	5	0	5
26	FIRE PROTECTION	2	1	1
27	FLIGHT CONTROLS	5	0	5
28	FUEL SYSTEM	5	0	5
29	HYDRAULIC POWER	3	0	3
30	ICE AND RAIN PROTECTION	3	1	2
31	INSTRUMENTS	4	0	4
32	LANDING GEAR	7	2	5
33	LIGHTS	11	1	10
34	NAVIGATION	64	28	36
35	OXYGEN	0	0	0
36	PNEUMATIC	3	0	3
38	WATER/WASTE	0	0	0
49	AIRBORNE AUXILIARY POWER	10	0	10
52	DOORS	0	0	0
53	FUSELAGE	0	0	0
54	NACELLES/PYLONS STRUCTURE	0	0	0
55	STABILIZERS	0	0	0
56	WINDOWS	0	0	0
57	WING	0	0	0
71	POWER PLANT	0	0	0
72	ENGINE	0	0	0
73	ENGINE FUEL AND CONTROL	7	0	7
74	IGNITION	0	0	0
75	AIR	0	0	0
76	ENGINE CONTROLS	0	0	0
77	ENGINE INDICATING	5	0	5
78	EXHAUST	2	0	2
79	OIL	7	0	7
80	STARTING	0	0	0
82	WATER INJECTION (P&W)	0	0	0
		226	54	172

data sheets for these equipments were included in the report, both for report completeness and to provide visibility into the number and range of the equipment examined.

3.4 Observations/Recommendation

The study shows 20 percent of the DC-10 components and 23 percent of the DC-9 components examined have open construction. Most of these are found in Chapter 23, Communication; Chapter 24, Electrical Power; and Chapter 34, Navigation.

The guidelines of NASA Technical Memorandum 78788 were used to categorize these open units. This memorandum, "A Summary of Data Related to the Carbon/Graphite Fiber Electrical Hazard Resulting from Accidental Release from Aircraft (U)," dated November 1978, states that in general the nature of the hazard is determined by the voltage and power level at which the equipment operates. Equipment operation is broken down into three broad regimes: low voltage, medium voltage, and high voltage. Table 3-4, received from NASA during Douglas/NASA discussions, summarizes the voltage regimes and the typical effect that carbon fibers are likely to cause. The open units from the Douglas study are identified and categorized in Tables 3-5 and 3-6 in accordance with this voltage/power criteria; hence, the equipment in the principal problem areas of low-voltage, low-power; medium-voltage, high-power; and high-voltage, high-power categories is readily identified.

Tables 3-7 and 3-8 identify by chapter each component determined by the study to have open construction, thereby warranting consideration for CF testing. In addition to the internal/external box construction, ventilation, and installation location, the recommendation of a unit as a test candidate also considered representation from various voltage and power regimes, type of equipment and its use, ease of testing, and any unique feature of a unit such as internal fan, conventional wiring, etc. Tables 3-7 and 3-8 identify those units thought to be representative of test candidates.

TABLE 3-4

TYPICAL FIBER EFFECTS

VOLTAGE RANGE	LOW POWER (UP TO 100W)	HIGH POWER (ABOVE 100W)
LOW (0 TO 30 VOLTS)	SUSTAINED SHORTS FIBER NOT BURNED MALFUNCTIONS NO LOCAL DAMAGE	SUSTAINED SHORTS FIBER NOT BURNED NO EQUIPMENT DAMAGE
MEDIUM (30 TO 1000 VOLTS)	SPARKING OR SHORTS POSSIBLE FIBER BURN TRANSIENTS BLOWN FUSES STRESSED COMPONENTS LOW DAMAGE POTENTIAL	SOME SUSTAINED ARCS FIBER BURNS TRANSIENTS BLOWN FUSES STRESSED COMPONENTS DAMAGE USUALLY REPAIRABLE
HIGH (>1000 VOLTS)	SPARKS, NO SUSTAINED ARCS LOW VOLTAGE CORONA TRANSIENTS INTERRUPTIONS	SUSTAINED ARCS CORONA FLASHOVER MAY BE SEVERE DAMAGE

TABLE 3-5

DC-10 OPEN UNITS OPERATING REGIME

* LOW VOLTAGE – LOW POWER	LOW VOLTAGE – HIGH POWER
CABIN ALT WARN – ANEROID PRESSURE SWITCH CARGO COMPARTMENT TEMP SENSOR ZONE TEMP INDICATOR SENSOR DUCT TEMP INDICATOR SENSOR VHF TRANSCEIVER (2) PASSENGER ADDRESS AMPLIFIER HANDSET AUDIO CONTROL PANEL SWITCH ASSEMBLY, ROLLER CONTROL BATTERY/LIGHT, EVAC EQUIPMENT SMOKE DETECTOR SMOKE DETECTOR INDICATOR THERMAL SWITCH, ANTI-ICE PROXIMITY ELECT UNIT WARN AND CAUTION CONTROLLER HORIZONTAL SITUATION INDICATOR MARKER BEACON RECEIVER (2) INERTIAL SENSOR DISPLAY UNIT VOR/ILS RECEIVER (2) ADF RECEIVER LIGHT SWITCH	
MEDIUM VOLTAGE – LOW POWER	*** MEDIUM VOLTAGE – HIGH POWER**
TAPE ANNOUNCEMENT REPRODUCER MAIN MULTIPLEXER SUB MULTIPLEXER OVERHEAD DECODER BATTERY VENT PUMP FLIGHT DATA ENTRY PANEL FLIGHT DATA ACQUISITION UNIT WEIGHT AND BALANCE COMPUTER INDICATOR/CONTROL PANEL (WT AND BAL) CENTRAL AURAL WARNING UNIT ANTI-SKID CONTROL UNIT VERTICAL GYRO STANDBY ATTITUDE INDICATOR ILS RECEIVER RADIO ALTIMETER R/T UNIT GROUND PROXIMITY WARNING COMPUTER VOR RECEIVER FLIGHT DATA STORAGE UNIT CONTROL SWITCH FUEL FLOW ELECTRONICS UNIT ENGINE IGNITION SWITCH	STANDBY CABIN PRESSURE CONTROLLER FLIGHT GUIDANCE PITCH COMPUTER FLIGHT GUIDANCE ROLL COMPUTER FLIGHT GUIDANCE YAW COMPUTER PA AMPLIFIER TIMER/DECODER, PASSENGER ENTERTAINMENT AC GENERATOR 1200 VA STATIC INVERTER TURBINE GENERATOR ASSEMBLY TRANSFORMER/RECTIFIER POWER SUPPLY BATTERY CHARGER GROUND POWER RECEPTACLE TRANSFORMER, INSTRUMENT BUS AUX PUMP, HYDRAULIC POWER WINDSHIELD ANTI-ICING CONTROLLER LAMP DIMMER CENTRAL AIR DATA COMPUTER INERTIAL NAVIGATION UNIT DME (2) ATC TRANSPONDER NAVIGATION COMPUTER UNIT PNEUMATIC SYSTEM CONTROLLER
HIGH VOLTAGE – LOW POWER	*** HIGH VOLTAGE – HIGH POWER**
WEATHER RADAR INDICATOR	HF TRANSCEIVER WEATHER RADAR R/T UNIT CONTROL DISPLAY UNIT (RNAV)

*PRINCIPAL AREAS OF CONCERN

TABLE 3-6

DC-9 OPEN UNITS OPERATING REGIME

*** LOW VOLTAGE – LOW POWER** VHF TRANSCEIVER (2) PA AMPLIFIER CABIN SPEAKER PILOT'S CALL BELL MECHANIC CALL HORN AUDIO PANEL JACK PANEL FLIGHT COMP SPEAKER FLIGHT INTERPHONE AMPLIFIER SMOKE DETECTOR ANTI-SKID CONTROL BOX PROXIMITY SW CONTROL MASTER CONTROLLER MARKER BEACON RECEIVER (2) VOR/ILS RECEIVER ADF RECEIVER (2)	**LOW VOLTAGE – HIGH POWER** NAV INSTRUMENT FAILURE MONITOR
MEDIUM VOLTAGE – LOW POWER TAPE REPRODUCER BATTERY VENT FAN INSTRUMENT AMPLIFIER VERTICAL GYRO FLIGHT DIR ROLL COMPUTER FLIGHT DIR PITCH COMPUTER NAV COMPARATOR UNIT RATE-OF-TURN RACK STANDBY HORIZON INDICATOR RADIO ALTIMETER R/T (2) GROUND PROXIMITY WARNING COMPUTER FLIGHT DIRECTOR COMPUTER	*** MEDIUM VOLTAGE – HIGH POWER** WINDSHIELD TEMPERATURE CONTROLLER AC GENERATOR GENERATOR CONTROL PANEL BUS CONTROL PANEL AC REGULATOR AC RELAY EMERGENCY INVERTER TRANSFORMER-RECTIFIER BATTERY CHARGER TOTAL AIR TEMPERATURE SENSOR INSTRUMENT AMPLIFIER RACK NAV SMART RACK NAV COMPARATOR UNIT SPEED COMMAND COMPARATOR
HIGH VOLTAGE – LOW POWER WEATHER RADAR INDICATOR (2)	*** HIGH VOLTAGE – HIGH POWER** HF TRANSCEIVER ATC TRANSPONDER (2) DME INTERROGATOR WEATHER RADAR R/T UNIT

*PRINCIPAL AREAS OF CONCERN

TABLE 3-7

DC-10 TEST CANDIDATE DETERMINATION

CHAPTER	COMPONENT	TEST CANDIDATE YES	TEST CANDIDATE NO	REMARKS
21-31-05	STANDBY CABIN PRESSURE CONTROLLER		X	OPENING IS SCREENED AND FILTERED, REDUNDANT UNIT
21-33-03	ANEROID PRESSURE SWITCH (CABIN ALT WARN)		X	SWITCH ENCLOSED, TYPICAL EXTERNAL SCREW TERMINALS
21-41-02	CARGO COMPARTMENT TEMP SENSOR		X	CARGO COMPARTMENT HEAT — SIMPLE COIL SENSOR
21-64-02	ZONE TEMP INDICATOR SENSOR		X	COMPARTMENT HEAT SENSOR — SIMPLE COIL SENSOR
21-64-03	DUCT TEMP INDICATOR SENSOR		X	DUCT TEMPERATURE SENSOR — SIMPLE COIL SENSOR
22-11-01	FLIGHT GUIDANCE PITCH COMPUTER		X	DIFFICULT TO SIMULATE/TEST
22-12-01	FLIGHT GUIDANCE ROLL COMPUTER		X	DIFFICULT TO SIMULATE/TEST
22-13-01	FLIGHT GUIDANCE YAW COMPUTER		X	DIFFICULT TO SIMULATE/TEST
23-11-01	HF TRANSCEIVER	X		FORCED COOLING, HIGH VOLTAGE, HIGH POWER
23-21-01	VHF TRANSCEIVER (2 LISTED)	X		LOW VOLTAGE, LOW POWER, TYPICAL CONSTRUCTION
23-31-02	PASSENGER ADDRESS AMPLIFIER		X	PASSENGER ADDRESS
23-31-02	PA AMPLIFIER		X	PASSENGER ADDRESS
23-31-05	HANDSET		X	PASSENGER ADDRESS
23-32-01	REPRODUCER, TAPE; ANNOUNCEMENT		X	PASSENGER ADDRESS
23-33-01	MAIN MULTIPLEXER		X	PASSENGER ENTERTAINMENT
23-33-02	SUB MULTIPLEXER		X	PASSENGER ENTERTAINMENT
23-33-03	TIMER/DECODER, SECTION		X	PASSENGER ENTERTAINMENT
23-33-06	OVERHEAD DECODER		X	PASSENGER ENTERTAINMENT
23-51-05	AUDIO PANEL CONTROL		X	FLIGHT INTERPHONE

TABLE 3-7 (CONT)

DC-10 TEST CANDIDATE DETERMINATION

CHAPTER	COMPONENT	TEST CANDIDATE		REMARKS
		YES	NO	
24-21-01	AC GENERATOR		X	ENGINE GENERATOR
24-24-01	1200 VA STATIC INVERTER	X		MEDIUM VOLTAGE, HIGH POWER – REPRESENTATIVE
24-25-01	TURBINE GENERATOR ASSEMBLY		X	IN FLIGHT USE ONLY – EMERGENCY HYDRAULIC POWER
24-31-01	TRANSFORMER/RECTIFIER POWER SUPPLY	X		MEDIUM VOLTAGE, HIGH POWER – CONVENTIONAL WIRING
24-34-03	BATTERY CHARGER		X	NOT USED CONTINUOUSLY
24-35-01	BATTERY VENT PUMP		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
24-41-03	GROUND POWER RECEPTACLE		X	GROUND OPERATION ONLY
24-51-01	TRANSFORMER, INSTRUMENT BUS		X	MEDIUM VOLTAGE, HIGH POWER – INSULATED WINDINGS
25-52-05	SWITCH ASSEMBLY, CONTROL, ROLLER		X	NOT CRITICAL, CARGO LOADING SYSTEM
25-61-06	BATTERY AND LIGHT		X	EVACUATION EQUIPMENT
26-14-01	SMOKE DETECTOR		X	CARGO COMPARTMENT, CASE OPEN, COMPONENTS SEALED
26-15-02	SMOKE DETECTOR INDICATOR		X	LIGHT
29-21-01	PUMP, ELECT MOTOR DRIVE		X	HYDRAULIC POWER BACKUP – CHECKED ON GROUND
30-22-05	THERMAL SWITCH		X	TYPICAL EXTERNAL SCREW TERMINAL CONNECTIONS
30-41-01	WINDSHIELD ANTI-ICING CONTROLLER	X		MEDIUM VOLTAGE, HIGH POWER

TABLE 3-7 (CONT)

DC-10 TEST CANDIDATE DETERMINATION

CHAPTER	COMPONENT	TEST CANDIDATE		REMARKS
		YES	NO	
31-31-04	FLIGHT DATA ENTRY PANEL		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
31-31-05	FLIGHT DATA ACQUISITION UNIT		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
31-41-01	WEIGHT AND BALANCE COMPUTER		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
31-41-02	INDICATOR/CONTROL PANEL (WT AND BAL)		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
31-51-01	CENTRAL AURAL WARNING UNIT		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
32-45-01	ANTISKID CONTROL UNIT		X	MEDIUM VOLTAGE, LOW POWER – NON-CRITICAL REGIME
32-61-05	PROXIMITY ELECT UNIT		X	LOW VOLTAGE, LOW POWER, REQUIRED/CHECKED AT DISPATCH
33-11-04	LAMP DIMMER		X	LOCATED FLT ENG PANEL – INSTRUMENT LIGHT CONTROL
33-15-01	WARN AND CAUTION CONTROLLER		X	BASICALLY A SWITCHING BOX
34-16-01	CENTRAL AIR DATA COMPUTER	X		UNPROTECTED WIRE WRAP MOTHERBOARD
34-22-01	HORIZONTAL SITUATION INDICATOR		X	ESSENTIALLY PROTECTED
34-23-01	VERTICAL GYRO		X	ESSENTIALLY PROTECTED
34-28-01	STANDBY ATTITUDE INDICATOR		X	HAS FILTERS, BACK-UP UNIT
34-31-01	MARKER BEACON RECEIVER (2)	X		DRAW-THROUGH COOLING, METAL CHASSIS
34-32-01	ILS RECEIVER	X		TYPICAL RADIO CONSTRUCTION
34-41-01	WEATHER RADAR R/T UNIT		X	HAS FILTER, DIFFICULT TO TEST
34-41-03	WEATHER RADAR INDICATOR		X	HIGH VOLTAGE, LOW POWER – NON-CRITICAL CATEGORY, HARD TO TEST
34-42-01	RADIO ALTIMETER R/T UNIT	X		TYPICAL CONSTRUCTION, FORCED COOLING

TABLE 3-7 (CONT)

DC-10 TEST CANDIDATE DETERMINATION

CHAPTER	COMPONENT	TEST CANDIDATE YES	TEST CANDIDATE NO	REMARKS
34-43-03	INERTIAL NAVIGATION UNIT		X	HIGH COST ITEM; DIFFICULT TO TEST
34-43-11	INERTIAL SENSOR DISPLAY UNIT		X	REQUIRES INTERFACING EQUIPMENT TO TEST
34-45-01	GROUND PROXIMITY WARN COMPUTER		X	TYPICAL CONSTRUCTION
34-51-01	VOR/ILS RECEIVER (2)	X		TYPICAL CONSTRUCTION, DUAL FUNCTION
34-51-01	VOR RECEIVER	X		TYPICAL CONSTRUCTION, FORCED COOLING
34-52-01	DME (2)	X		FORCED COOLING, INTERNAL FAN
34-53-01	ADF RECEIVER		X	TYPICAL RADIO CONSTRUCTION
34-54-01	ATC TRANSPONDER	X		REPRESENTATIVE TEST UNIT
34-61-01	NAVIGATION COMPUTER		X	HIGH COST ITEM, DIFFICULT TO TEST
34-61-02	TAPE CARTRIDGE UNIT		X	REQUIRES INTERFACING EQUIPMENT TO TEST
34-61-03	CONTROL DISPLAY UNIT		X	REQUIRES INTERFACING EQUIPMENT TO TEST, HIGH COST
36-10-01	CONTROL SWITCH, PNEUMATIC		X	TYPICAL ROTARY SWITCH, EXTERNAL TERMINALS
36-23-04	LIGHT SWITCH		X	TYPICAL SWITCH
36-27-06	CONTROLLER, PNEUMATIC SYSTEM		X	REDUNDANT UNIT
73-31-03	FUEL FLOW ELECTRONICS UNIT		X	MEDIUM VOLTAGE, LOW POWER — NON-CRITICAL REGIME
74-30-01	ENGINE IGNITION SWITCH		X	TYPICAL ROTARY SWITCH, EXTERNAL TERMINALS

TABLE 3-8

DC-9 TEST CANDIDATE DETERMINATION

CHAPTER	COMPONENT	TEST CANDIDATE YES	TEST CANDIDATE NO	REMARKS
23-11-01	HF TRANSCEIVER	X		ALSO A DC-10 CANDIDATE
23-21-01	VHF TRANSCEIVER (2 LISTED)	X		ALSO A DC-10 CANDIDATE
23-31-02	PASSENGER ADDRESS AMPLIFIER		X	LOW VOLTAGE-LOW POWER, TYPICAL CANDIDATE
23-31-05	CABIN SPEAKER		X	PASSENGER ADDRESS
23-32-01	TAPE REPRODUCER		X	PASSENGER ENTERTAINMENT
23-41-02	PILOT CALL BELL		X	INTERPHONE
23-41-03	MECHANIC CALL HORN		X	INTERPHONE
23-52-01	AUDIO PANEL		X	INTERPHONE
23-52-02	JACK PANEL		X	INTERPHONE
23-52-03	FLIGHT COMPARTMENT SPEAKER		X	INTERPHONE
23-52-05	FLIGHT INTERPHONE AMPLIFIER		X	INTERPHONE
24-21-01	AC GENERATOR		X	ENGINE GENERATOR
24-21-02	GENERATOR CONTROL PANEL		X	PART OF POWER GENERATION SYSTEM
24-21-03	BUS CONTROL PANEL		X	PART OF POWER DISTRIBUTION SYSTEM
24-21-05	AC REGULATOR		X	PART OF ELECTRICAL POWER SYSTEM
24-21-06	AC RELAY		X	PART OF ELECTRICAL POWER SYSTEM
24-23-01	EMERGENCY INVERTER	X		MEDIUM VOLTAGE-HIGH POWER-ALSO A DC-10 CANDIDATE
24-31-01	TRANSFORMER-RECTIFIER	X		MEDIUM VOLTAGE-HIGH POWER-ALSO A DC-10 CANDIDATE
24-31-03	BATTERY CHARGER		X	MEDIUM VOLTAGE-HIGH POWER REPRESENTATIVE
24-31-08	BATTERY VENT FAN		X	MEDIUM VOLTAGE-LOW POWER, NON-CRITICAL REGIME
26-11-07	SMOKE DETECTOR		X	CASE OPEN, COMPONENTS SEALED
30-41-01	WINDSHIELD TEMPERATURE CONTROLLER	X		MEDIUM VOLTAGE-HIGH POWER REPRESENTATIVE
32-45-01	ANTI-SKID CONTROL BOX		X	LOW VOLTAGE-LOW POWER REPRESENTATIVE
32-61-01	PROXIMITY SWITCH CONTROL		X	LOW VOLTAGE-LOW POWER, REQUIRED, CHECKED AT DISPATCH
33-12-01	MASTER CONTROLLER		X	LIGHTING CONTROL

TABLE 3-8 (CONT)

DC-9 TEST CANDIDATE DETERMINATION

CHAPTER	COMPONENT	TEST CANDIDATE		REMARKS
		YES	NO	
34-18-03	TOTAL AIR TEMPERATURE SENSOR		X	HIGH POWER HEATING ELEMENT TEMPERATURE PROBE
34-21-05	INSTRUMENT AMPLIFIER RACK		X	MULTIPLE CHANNELS – DIFFICULT TO SIMULATE
34-22-03	INSTRUMENT AMPLIFIER		X	MULTIPLE CHANNELS – DIFFICULT TO SIMULATE
34-22-04	VERTICAL GYRO		X	ESSENTIALLY PROTECTED
34-24-03	FLIGHT DIRECTOR COMPUTER	X		TYPICAL TRANSISTORIZED ANALOG COMPUTER
34-24-07	FLIGHT DIRECTOR ROLL COMPUTER		X	MEDIUM VOLTAGE, LOW POWER, NON-CRITICAL REGIME
34-24-08	FLIGHT DIRECTOR PITCH COMPUTER		X	MEDIUM VOLTAGE, LOW POWER, NON-CRITICAL REGIME
34-26-02	NAV INSTRUMENT FAILURE MONITOR		X	LOW VOLTAGE, HIGH POWER, NON-CRITICAL REGIME
34-26-02	NAV SMART RACK		X	DIFFICULT TO TEST
34-26-03	NAV COMPARATOR UNIT (2 LISTED)		X	MULTIPLE CHANNELS – DIFFICULT TO SIMULATE
34-26-04	SPEED COMMAND COMPARATOR		X	DIFFICULT TO TEST
34-28-02	RATE-OF-TURN RACK		X	MEDIUM VOLTAGE, LOW POWER, NON-CRITICAL REGIME
34-29-01	STANDBY HORIZON INDICATOR		X	MEDIUM VOLTAGE, LOW POWER, NON-CRITICAL REGIME
34-31-01	MARKER BEACON RECEIVER (2 LISTED)	X		ALSO DC-10 CANDIDATES
34-32-01	VOR/ILS RECEIVER	X		ALSO DC-10 CANDIDATE
34-33-05	ADF RECEIVER (2 LISTED)	X		ONE TYPE ALSO A DC-10 CANDIDATE
34-41-02	ATC TRANSPONDER (2 LISTED)	X		ONE TYPE ALSO A DC-10 CANDIDATE
34-42-02	DME INTERROGATOR	X		FORCED COOLING, CHASSIS TYPE CONSTRUCTION
34-43-02	WEATHER RADAR R/T UNIT		X	DIFFICULT TO TEST
34-43-04	WEATHER RADAR INDICATOR (2 LISTED)		X	HIGH VOLTAGE, LOW POWER, NON-CRITICAL REGIME
34-44-01	RADIO ALTIMETER R/T UNIT (2 LISTED)	X		TYPICAL CONSTRUCTION – FORCED COOLING
34-51-01	GROUND PROXIMITY WARN COMPUTER		X	MEDIUM VOLTAGE, LOW POWER, NON-CRITICAL REGIME

SECTION 4
FIBER TRANSFER FUNCTIONS

4.1 Introduction

The operating modes of the DC-10 and DC-9 were analyzed with respect to CF environment and the following modes defined as those during which the aircraft will be vulnerable to CF ingestion:

1. Main engines supplying bleed air to the air-conditioning packs and through the cockpit or cabin to the avionics compartments. Air can be extracted from either low- or high-stage bleed port depending on engine power setting.

2. Auxiliary Power Unit (APU) supplying bleed air to the air-conditioning packs.

3. Pneumatic ground cart(s) supplying air to the packs (cockpit windows and passenger doors may be open or closed).

4. Conditioned air cart(s) supplying air directly to the cockpit and cabin distribution ducting (windows and passenger doors open or closed).

5. Open cockpit windows and/or passenger doors open and avionics cooling fan drawing air into avionics compartments.

6. Avionics compartment door(s) open and the avionics cooling fan drawing air directly into the avionics compartment (conditioned air may or may not be supplied by packs or carts).

Operating modes 1 and 2 above can occur with the aircraft either static (parked) or moving during taxi, takeoff, or low-level flight and results given are applicable to any of these conditions. Operating modes 3, 4, 5 and 6 apply only to aircraft which are parked.

The transfer function for the passage of CF through the aircraft defines the ratio of the weight concentration of CF at a given point within the aircraft (C_I) to the weight concentration of CF in the ambient air outside the aircraft (C_0). This function is dependent both on the aircraft operating mode and the point within the aircraft under consideration. In order to simplify the analyses and provide maximum flexibility in the use of results, each operating mode was analyzed and an overall transfer factor (OTF) was established for that mode from the relationship:

$$OTF = (1 - \eta_1)(1 - \eta_2)(1 - \eta_3) - - - -$$

where η_1 is the CF extraction efficiency of the first element in the flow paths of the CF-laden air and η_2, η_3, etc. are successive elements in the flow path up to the point of interest within the aircraft.

The overall transfer factors may be considered single mode transfer functions and CF concentration during a given operating mode may be determined from:

$$C_I = C_0(OTF)$$

The following sections develop the extraction efficiencies and overall transfer factors for all modes of interest which in the the aggregate define transfer functions for the DC-9 and DC-10 aircraft. A more detailed analysis is presented in McDonnell Douglas Report MDC J8320.

4.2 DC-10 Transfer Function

The overall transfer factors for the DC-10 can be calculated from:

$$OTF = (1 - \eta_e)(1 - \eta_p)(1 - \eta_c)$$

where: η_e is extraction efficiency of the air supply source,

η_p is the extraction efficiency of the air-conditioning packs, and

η_c is the filtering effect of cockpit and cabin furnishings.

This expression applies to the avionics compartment and the center accessory compartment (CAC) of the DC-10 with extraction efficiences as shown in Table 4-1. The expression defines the transfer of fibers to the air in the compartments. The effects of the "black box" enclosures and individual cooling techniques are not included. They are discussed in detail in McDonnell Douglas Report MDC J8320. It will be noted that there are some differences in OTF between the two compartments when no air-conditioning is being supplied. These differences are caused by variations in the cooling system operation for these modes. Specifically, the avionics cooling system will draw outside air into the compartment while the CAC system will recirculate air within the aircraft with little or no outside air entering the compartment.

The values of η_e for main engines were derived from the results of dirt ingestion tests conducted with coarse Arizona road dust. The specific values given are for the P&WA JT9D engine and include the effects of switching bleed ports and varying power settings. A comparison of bleed port configuration and service experience with the GE CF6 engine indicates that these values will also apply to that engine. The value of η_e for the APU was likewise derived from test data which indicated that the particle removal characteristics of this engine are negligible.

The values of η_e for ground carts were determined by contacts with cart suppliers and airline users. Both these groups also stated that these units are used infrequently on the DC-10 because of the availability of the APU.

The values of η_p were calculated for packs with a water separator bypass configuration* for both a hot day and a cold day situation to define maximum and minimum values. Water separator bag filtering efficiency was assumed to be 0.9 after contact with bag suppliers, and comparison with known filter media.

The value of η_c was calculated from the known settling rate (0.2m/s) of composite fibers and the airflow velocities through the cockpit and cabin. Both re-entrainment and crack-capture effects have been ignored due to lack

*This is the configuration of the domestic, short-range DC-10-10.

TABLE 4-1

TRANSFER FUNCTION FOR CF TO THE AVIONICS AND CAC COMPARTMENTS OF THE DC-10

NO.	OPERATING MODE	AVIONICS COMPARTMENT				CENTER ACCESSORY COMPARTMENT			
		η_e	η_p	η_c	OTF	η_e	η_p	η_c	OTF
1	MAIN ENGINES 70 PERCENT TAKEOFF POWER (8TH STAGE BLEED)	(3) 0.957	HOT DAY 0.898	0.31	0.00136	0.957	HOT DAY 0.898	0.31	0.00136
			COLD DAY 0.684	0.31	0.00421		COLD DAY 0.684	0.31	0.00421
	90 PERCENT TAKEOFF POWER (8TH STAGE BLEED)	(3) 0.962	0.898	0.31	0.00120	0.962	0.898	0.31	0.00120
			0.684	0.31	0.00372		0.684	0.31	0.00372
	GROUND IDLE (HIGH STAGE BLEED)	(3) 0.9956	0.898	0.31	0.00014	0.9956	0.898	0.31	0.00014
			0.684	0.31	0.00043		0.684	0.31	0.00043
2 3	APU OR PNEUMATIC CART	(3) 0	0.898	0.31	0.03162	0	0.898	0.31	0.03162
			0.684	0.31	0.09796		0.684	0.31	0.09796
4	CONDITIONED AIR CART	(4) 0	0	0.31	0.69000	0	0	0.31	0.69000
5	OPEN COCKPIT WINDOWS AND PASSENGER DOORS	0	0	0.31	0.69000	0	0	0.31	0.69000 (1)
								1.00	0 (2)
6	OPEN AVIONICS COMPARTMENT AND CAC DOORS	0	0	0	1.00000	0	0	1.00	0

(1) FOR AIRCRAFT WHICH DRAW AIR FROM CABIN.

(2) FOR AIRCRAFT WHICH DRAW AIR FROM UNDER THE CABIN FLOOR.

(3) IF TRANSFER FUNCTION IS DESIRED FOR FIBERS GREATER THAN 1 MM, THIS VALUE BECOMES 1.0 AND OTF = 0. SEE BIONETICS DATA (REFERENCE NASA CONTRACTOR REPORT 159183).

(4) FOR THE SAME CONDITIONS AS NOTE 3, THIS VALUE SHOULD BE 0.50 AND OTF = 0.35.

of data which would apply to aircraft interiors. It should be noted that these two factors tend to cancel each other and the effect of ignoring them may not significantly affect the final answers.

The settling of fibers in both the avionics compartment and the CAC was considered to be negligible because of high air velocities and turbulence in these compartments which should cause substantial re-entrainment. The avionics compartment has a large recirculating fan which draws air from the forward left side of the compartment and discharges it into various areas of the compartment at velocities up to 1400 m/min (4600 fpm). Most aircraft also have three inertial navigation cooling fans dumping into the compartment at 370 m/min (1224 fpm). These fans are in addition to the fan which draws air through the compartment.

The CAC has a large fan which draws air from the upper cabin on early aircraft and from below the cabin floor on later versions. This fan discharges into the compartment at a velocity of approximately 1140 m/min (3745 fpm). In addition, when conditioned air is being supplied to the cabin with cabin doors closed, approximately 57 percent of the conditioned air passes through the CAC prior to exhausting overboard. It is expected that these air flow mechanisms will prevent significant settling in these compartments.

4.3 DC-9 Transfer Function

The overall transfer factors for the DC-9 can be calculated from:

$$OTF = (1 - \eta_e)(1 - \eta_p)(1 - \eta_c)(1 - \eta_s)$$

where:

η_e is the extraction efficiency of the air supply source,

η_p is the extraction efficiency of the air-conditioning pack (which includes a centrifugal cleaner),

η_c is the filtering effect of cockpit and cabin furnishings, and

η_s is the settling effect in the avionics compartment.

This expression defines the transfer of the fibers to the air of the DC-9 avionics compartment with extraction efficiencies as shown in Table 4-2. This approach does not define the effects of "black box" enclosures or the various cooling methods which are used with these units.

The values of η_e given for the P&WA JT8D main engines are judgmental in nature due to the paucity of usable test data. Although numerous tests have been conducted, no data was uncovered to relate contamination at the bleed ports to that at the engine inlet. Values of η_e were therefore selected after careful consideration of pack nozzle erosion experience and a comparison of bleed air extraction features with those of the DC-10 engines. The values chosen are intended to represent a "worst case"; i.e., largest possible amount of CF being left in the bleed air.

From the DC-9 APU, no data applicable to this study was uncovered. It was therefore assumed that this machine is equivalent to the DC-10 and neither concentrates nor extracts CF prior to being bled. Likewise, ground carts for pneumatic air and conditioned air are assumed to have characteristics identical to those used on the DC-10.

The value of η_p includes the effects of the Centrisep bleed air cleaner and water separator bag filtering as a function of air being bypassed on hot and cold day situations. Performance of the Centrisep cleaner is well documented by test data and service experience. Water separator bag filtering efficiency was again assumed to be 90 percent, based on comparison with other filter construction.

The value of η_c was calculated from the known characteristics of the DC-9 cockpit and cabin volumes and airflow rates with a CF settling rate of 0.2 m/s. This factor does not include the effects of re-entrainment or "crack-capture."

The DC-9 avionics compartment should experience some settling of CF fibers because of relatively low velocities in the compartment. The value of η_s was therefore determined from compartment volume and airflow rates without compensation for re-entrainment or "crack-capture." The value of η_S represents the average settling in the compartment; i.e., midway in the compartment between the air inlet and exit.

4.4 Discussion of Data

4.4.1 Main Engine Data

Test data on the P&WA JT9D provides a high level of confidence in analysis associated with this engine. The uncertainties involve the assumption that CF density of 1.7 gm/cm^3 is sufficiently close to "Arizona Road Dust" density of 2.4 gm/cm^3 so that both mediums will behave in the same manner while passing through the engine. It was also assumed that CF fibers would break into relatively short segments analogous to the 5- to 15-micron dust category when passing through high-speed axial and centrifugal compressors and fans. This is basically substantiated by the data supplied by Bionetics on simulated turning vanes.

These data associated with the GE CF6 engine presented some uncertainties but it is believed that this engine is at least as good as the JT9D in foreign matter rejection from the bleed ports. The data used for this engine are therefore conservative.

The values used to the P&WA JT8D are substantiated only by comparison to the JT9D. Since these two engines are substantially different in size and construction, this comparison does not provide a high level of confidence in these numbers.

4.4.2 APU Data

Test data on the DC-10 APU had some argumentative aspects but the results appear to be substantiated by in-service pack nozzle erosion data.

No data was available on the separation efficiency of the DC-9 APU. However, pack nozzle erosion data tends to support the value chosen.

4.4.3 Pneumatic and Conditioned Air Carts

Ground cart manufacturers could provide no data other than judgment as to the filtering to be expected from this equipment. It is expected that pneumatic carts would exhibit a wide range of values due to the various designs used for this task.

4.4.4 Air-Conditioning Packs

The filtering effects of the water separator bags and the centrifugal bleed air cleaner used in the analysis are the same as those in McDonnell Douglas Report MDC J8320, and were based on particulate data of the actual air cleaner and on comparative data for the water separator. The data supplied by Bionetics indicate a higher separation efficiency, for both the water separator and air cleaner, than the values used in this analysis. However, the data were for CF sizes of 1, 3, and 10 mm and it is expected that the CF sizes will be less than 1 mm before reaching the air-conditioning packs. This is substantiated by the Bionetics data on simulated turning vanes which show the carbon fibers are broken up (<1 mm) for air velocities that are present in both the engines and APUs. Therefore, it is believed that the values obtained in MDC J8320 are more representative of the actual case.

4.4.5 Settling, Re-entrainment, and Crack Capture

The interior of an aircraft is a complex maze of wire bundles, cables, structures, equipment racks, seats, carpeting, avionics units, ducts instrumentation, etc., with many airflow origination points and flow paths coupled with the effects of human movements. In addition, settling, re-entrainment, and crack capture will be affected by the length of the carbon fibers. As previously stated, CF passing through high-speed rotary equipment is assumed to be "chopped" while CF passing into avionics areas through open windows and doors will be as initially disseminated.

Since there were no data applicable to this type of construction and environment, the approach used in defining settling, re-entrainment, and crack capture effects was to establish a "worst case" for the combination of the three factors. The actual condition to be encountered on an aircraft may be somewhat better than the values used, but a significant change in values is not expected because the effects of settling and crack capture are opposed by re-entrainment.

4.4.6 Data Summary

The various operating conditions (1 through 6 of Tables 4-1 and 4-2) were sufficient to determine the transfer functions for all operating conditions to be considered. However, the data are reorganized into Tables 4-3, 4-4, and 4-5 to better present the functions considered in the other sections of this report.

TABLE 4-2

TRANSFER FUNCTION FOR CF TO THE AVIONICS COMPARTMENT OF THE DC-9

NO.	OPERATING MODE	η_e	η_p	η_c	η_s	OTF
1	MAIN ENGINES					
	8TH STAGE	(1) −1.5	HOT DAY 0.987	0.454	0.293	0.01255
			COLD DAY 0.664	0.454	0.293	0.32425
	13TH STAGE	(1) 0.5	0.987	0.454	0.293	0.00251
			0.664	0.454	0.293	0.06485
2	APU OR PNEUMATIC	(1) 0	0.987	0.454	0.293	0.00502
3	GROUND CART		0.664	0.454	0.293	0.12970
4	CONDITIONED AIR CART	(2) 0	0	0.454	0.293	0.38602
5	OPEN COCKPIT WINDOWS AND PASSENGER DOORS	0	0	0.454	0.293	0.38602
6	OPEN AVIONICS COMPARTMENT DOOR	0	0	0	0.293	0.70700

(1) IF TRANSFER FUNCTION IS DESIRED FOR FIBERS GREATER THAN 1 MM IN LENGTH, THIS VALUE BECOMES 1.0 AND OTF = 0.0. SEE BIONETICS DATA (REFERENCE NASA CONTRACTOR REPORT 159183).

(2) FOR THE SAME CONDITIONS AS NOTE (1), THIS VALUE SHOULD BE 0.5 AND OTF = 0.19.

TABLE 4-3

DC-10 AVIONICS COMPARTMENT OVERALL TRANSFER FUNCTION

AIRCRAFT POWER	AVIONICS DOOR OPEN				AVIONICS DOOR CLOSED			
	PASSENGER DOORS				PASSENGER DOORS			
	OPEN		CLOSED		OPEN		CLOSED	
	HOT	COLD	HOT	COLD	HOT	COLD	HOT	COLD
ENGINE 70 PERCENT TAKEOFF (8TH STAGE BLEED)	1	1	0.00136	0.00421	0.00136	0.00421	0.00136	0.00421
90 PERCENT TAKEOFF (8TH STAGE BLEED)	1	1	0.00120	0.00372	0.00120	0.00372	0.00120	0.00372
GROUND IDLE (HIGH STAGE BLEED)	1	1	0.00014	0.00043	0.00014	0.00043	0.00014	0.00043
APU OR PNEUMATIC CART	1	1	0.03162	0.09796	0.03162	0.09796	0.03162	0.09796
AIR CONDITIONING CART	1	1	0.69000	0.69000	0.69000	0.69000	0.69000	0.69000
GROUND ELECTRIC	1	1	1	1	0.69000	0.69000	0	0
NONE	0	0	0	0	0	0	0	0

TABLE 4-4

DC-10 CENTER ACCESSORY COMPARTMENT OVERALL TRANSFER FUNCTIONS

AIRCRAFT POWER	CENTER ACCESS DOOR OPEN				CENTER ACCESS DOOR CLOSED			
	PASSENGER DOORS				PASSENGER DOORS			
	OPEN		CLOSED		OPEN		CLOSED	
	HOT	COLD	HOT	COLD	HOT	COLD	HOT	COLD
ENGINE 70 PERCENT TAKEOFF (8TH STAGE BLEED)	(1) 0.69000 / (2) 0	(1) 0.69000 / (2) 0	0.00136	0.00421	0.00136	0.00421	0.00136	0.00421
90 PERCENT TAKEOFF (8TH STAGE BLEED)	0.69000 / 0	0.69000 / 0	0.00120	0.00372	0.00120	0.00372	0.00120	0.00372
GROUND IDLE (HIGH STAGE BLEED)	0.69000 / 0	0.69000 / 0	0.00014	0.00043	0.00014	0.00043	0.00014	0.00043
APU OR PNEUMATIC CART	0.69000 / 0	0.69000 / 0	0.03162	0.09796	0.03162	0.09796	0.03162	0.09796
AIR CONDITIONING CART	0.69000 / 0	0.69000 / 0	0.69000 / 0	0.69000 / 0	0.69000 / 0	0.69000 / 0	0.69000 / 0	0.69000 / 0
GROUND ELECTRIC	0.69000 / 0	0.69000 / 0	0	0	0.69000 / 0	0.69000 / 0	0	0
NONE	0 / 0	0 / 0	0	0	0	0	0	0

(1) AIRPLANES PRIOR TO 242 THAT DRAW AIR FOR THE CAC FAN FROM THE CABIN
(2) AIRPLANES 242 AND SUBS THAT DRAW AIR FOR THE CAS FAN FROM THE SIDE TUNNELS

TABLE 4-5

DC-9 AVIONICS COMPARTMENT OVERALL TRANSFER FUNCTION

AIRCRAFT POWER	AVIONICS DOOR OPEN				AVIONICS DOOR CLOSED			
	PASSENGER DOORS				PASSENGER DOORS			
	OPEN		CLOSED		OPEN		CLOSED	
	HOT	COLD	HOT	COLD	HOT	COLD	HOT	COLD
ENGINE 8TH STAGE	0.70700	0.70700	0.01255	0.32425	0.01255	0.32425	0.01255	0.32425
13TH STAGE	0.70700	0.70700	0.00251	0.06485	0.00251	0.06485	0.00251	0.06485
APU OR PNEUMATIC CART	0.70700	0.70700	0.00502	0.12970	0.00502	0.12970	0.00502	0.12970
AIR CONDITIONING CART	0.70700	0.70700	0.38602	0.38602	0.38602	0.38602	0.38602	0.38602
GROUND ELECTRIC	0.70700	0.70700	0.70700	0.70700	0.38602	0.38602	0	0
NONE	0	0	0	0	0	0	0	0

SECTION 5

TRANSPORT AIRCRAFT EQUIPMENT POTENTIAL FOR EXPOSURE TO CARBON FIBERS

5.1 Introduction

NASA-Langley is assessing the national risk caused by the release of carbon fibers (CF) following accidental fires on aircraft utilizing graphite epoxy composite structural materials. This activity includes contracts to estimate the damage cost of CF exposures at specific sites. NASA also has contracts with the three major domestic airframe manufacturers to evaluate the equipment failures in commercial aircraft exposed to CF releases. The expected number of aircraft in potentially vulnerable operating modes in the vicinity of an accidental CF release incident is required for this evaluation. This report presents the aircraft manufacturers' consolidated estimate of that required data for nine domestic airports.

5.1.1 Inputs to Risk Analysis Models

The risk analysis models to estimate the damage cost of a CF fire are to be used at the following airports:

Chicago O'Hare	(ORD)
New York City Kennedy	(JFK)
St. Louis Lambert	(STL)
New York City LaGuardia	(LGA)
Boston Logan	(BOS)
Philadelphia International	(PHL)
Washington, D.C. National	(DCA)
Atlanta Hartsfield	(ATL)
Miami International	(MIA)

It has been determined that aircraft in flight and aircraft on the ground with all doors closed, operating with no power on or on normal engine power, have an effective transfer function of zero to equipment locations, and need not receive further consideration in the risk analysis. Therefore, major input to these models is the expected number of aircraft on the ground in other operating modes at each of these airports; this input is to be specified according to:

Time of day:

- Daytime (0600-2059)
- Nightime (2100-0559)

Aircraft type (only jet aircraft considered)

- Large (over 250 seats)
- Medium (150 to 250 seats)
- Small (under 150 seats)

Location on the airport:

- At gate being serviced
- At maintenance facility (being serviced or parked)

The probability that a CF cloud will short aircraft electronic equipment is dependent upon the transfer function to the various equipment locations, characterized by the following door status and the aircraft power sources.

Avionic doors:

- open
- closed

Passenger and/or cargo doors:

- open
- closed

Power Source:

- Auxiliary power unit
- Engines running
- Air cart

- Ground electrical
- No power

5.1.2 Aircraft Operations on the Airport

There are three basic locations at an airport where an aircraft is parked with its avionic, passenger, or cargo doors open. These are: passenger terminal, cargo terminal, and maintenance facility. The passenger and all cargo aircraft are analyzed separately, but the results are combined to give the total number of aircraft being serviced at the gate.

An aircraft is being serviced at a gate if it is:

- Being prepared for a flight origin
- Being serviced during an en route stop
- Being serviced after a flight termination

An aircraft has an en route stop if its departure flight number is the same as its arrival flight number. Most flight terminations will stay at the gate and become flight origins; however, many will be towed to a maintenance facility for scheduled work.

An en route stop usually requires less time than a turn (flight destination plus flight origination) because fewer services (particularly cabin cleaning) are performed. Other factors which significantly impact time at the gate include:

- Galley service
- Customs clearance on international flights
- Ground crew availability
- Buffer time to allow for airport delays

The gate times for scheduled service include time for maintenance tasks normally performed during en route and turn operations and for minor problems that keep the aircraft at the gate for a longer time period than planned. In addition, there are often aircraft at the gate during nighttime hours for scheduled or unscheduled maintenance. This includes the extensive overnight cabin cleaning which often requires more than two hours. The aircraft being maintained at the gate during nighttime hours is added to nighttime scheduled service to give the total number of aircraft at the gate. It is assumed that there is no maintenance performed at the gate during the day.

The average number of aircraft at the separate maintenance facility during the daytime and during nighttime has been determined for each airport based upon data from the airlines, airport authorities, and aircraft manufacturers' field representatives. These data are used directly to define the number of aircraft in the maintenance facility.

5.2 Data

5.2.1 Gate Times

Gate time data was obtained from the following airlines: United, American, Ozark, Western, Continental, Delta and Trans World. These data ranged from actual scheduled gate times, to planning guidelines, to discussions of how gate time is impacted by customs, cabin cleaning, or food service. The airline data defined the operations as turns or en route stops.

Table 5-1 presents the average scheduled gate time as a function of aircraft type and type of operation. Gate times for supersonic and two-engine narrow-body aircraft were estimated without any airline data. Gate times for international passenger and all cargo flights were assumed to be five minutes longer than domestic turns.

TABLE 5-1

AVERAGE SCHEDULED GATE TIMES (MINUTES)

TYPE FLIGHT	DOMESTIC PASSENGER				INTERNATIONAL PASSENGER OR FREIGHT	
TYPE SERVICE	EN ROUTE		TURN		TURN	
TYPE OPERATION	ARRIVAL	DEPART	ARRIVAL	DEPART	ARRIVAL	DEPART
SUPERSONIC	–	–	–	–	60 MIN	75 MIN
4 ENGINE WIDE-BODY	23 MIN	38 MIN	37 MIN	53 MIN	52	68
3 ENGINE WIDE-BODY	22	31	35	48	50	63
2 ENGINE WIDE-BODY	21	30	35	47	50	62
4 ENGINE NARROW	21	29	35	45	50	60
3 ENGINE NARROW	20	24	33	39	48	56
2 ENGINE NARROW	19	21	32	37	47	52

5.2.2 Number of Operations

Data on the number of aircraft operations was obtained from the August 1978 Official Airline Guide (OAG) computer tape. These data were extracted to give the number of operations for all combinations of the following:

Airport: each of the nine airports

Time of day:

- Daytime (0600-2059 hours)
- Nighttime (2100-0559 hours)

Aircraft type:

- Supersonic (only at JFK)
- 4-Engine Wide-Body (B747)
- 3-Engine Wide-Body (DC-10, L-1011)
- 2-Engine Wide-Body (A300)
- 4-Engine Narrow-Body (DC-8, B707)
- 3-Engine Narrow-Body (B727)
- 2-Engine Narrow-Body (DC-9, B737, BAC 1-11)

Type of flight:

- Passenger Aircraft
    - Domestic (to or from U.S. airport)
    - International
- All Cargo Aircraft

Type of operation:

- Arrival
- Departure

All four- and three-engine wide-body aircraft are classified as large aircraft (over 250 seats). The two-engine wide-body aircraft and 36.4 percent of the four-engine narrow-body aircraft are classified as medium aircraft

(150 to 250 seats). All other aircraft are classified as small aircraft (under 150 seats). In August 1978, there were 717 daily departures by four-engine narrow-body aircraft with over 150 seats and 1254 daily departures by four-engine narrow-body aircraft with less than 150 seats; hence, 36.4 percent of the four-engine narrow-body aircraft are medium-sized.

The OAG data give the number of arrivals and departures per hour for domestic passenger flights, international passenger flights, and all cargo flights. The data extracted did not identify whether the flight was a turn or en route stop. It was assumed that: JFK, MIA and BOS have 90-percent turns, ORD, DCA, ATL and LGA have 60-percent turns, STL and PHL have 20-percent turns. It was also assumed that an additional two minutes per operation was scheduled for ORD and LGA to give an additional buffer time for airport runway delays.

5.2.3 Aircraft at Maintenance Facility and Overnight Aircraft

The average number of aircraft at the maintenance facility during the daytime and nighttime was obtained from the airlines, airport authorities, and aircraft manufacturers' representatives.

The average number of aircraft which overnight at the gate is used to compute the expected number of exposed aircraft at the gate during nighttime. These numbers are calculated from the total number of aircraft which overnight at the airport and the number of aircraft in the maintenance facility during the daytime and nighttime. The total number of aircraft which overnight are obtained from an analysis of the OAG data and contacts with airlines, airport authorities, and aircraft manufacturers' field representatives.

Data on the number of aircraft at the maintenance facility during the daytime and nighttime and the total number of overnight aircraft were obtained by a coordinated effort of the three aircraft manufacturers. Each manufacturer obtained these data for three airports:

Douglas Aircraft Company

Chicago O'Hare	(ORD)
New York City Kennedy	(JFK)
St. Louis Lambert	(STL)

Boeing Commercial Airplane Company

New York City LaGuardia	(LGA)
Boston Logan	(BOS)
Philadelphia International	(PHL)

Lockheed-California Company

Washington, D.C. National	(DCA)
Atlanta Hartsfield	(ATL)
Miami International	(MIA)

5.2.4 Operating Modes

The probability that a CF cloud will damage aircraft electronic equipment is dependent upon the aircraft's power source and whether the passenger or avionic bay door is open. The aircraft power source and door status (or operating mode) was determined by interviewing airline maintenance and operations personnel, and by on-site surveys to determine the percent of the aircraft in each operating mode.

The percent of the time the aircraft spent in each operating mode was determined by Boeing and Lockheed for the following conditions:

Boeing Commercial Airplane Company

- Gate position daytime
- Gate position nighttime

Lockheed-California Company

- Maintenance facility

The operating mode data are summarized in Table 5-2.

TABLE 5-2

PERCENT OF TIME PER OPERATING MODE

AIRPORT LOCATION AND TIME PERIOD	AIRCRAFT POWER SOURCE	AVIONIC DOORS			
		OPEN		CLOSED	
		PASSENGER DOORS		PASSENGER DOORS	
		OPEN	CLOSED	OPEN	CLOSED
GATE, DAY	AUXILIARY POWER UNIT	1	0	95	0
	ENGINES	0	0	0	0
	AIR CART	0	0	0	0
	GROUND ELECTRIC	0	0	4	0
	NONE	0	0	0	PARK
GATE, NIGHT	AUXILIARY POWER UNIT	0	0	18	0
	ENGINES	0	0	2	0
	AIR CART	0	0	0	0
	GROUND ELECTRIC	30	0	50	0
	NONE	0	0	0	PARK
MAINTENANCE	AUXILIARY POWER UNIT	3.3	0.5	1.0	0.5
	ENGINES	1.0	0	0	1.0
	AIR CART	1.0	0	0	0
	GROUND ELECTRIC	72.7	0	13.8	0
	NONE	1.9	0	3.3	PARK

5.2.5 Transfer Functions

Boeing and Lockheed determined the transfer functions presented in Table 5-3, Boeing developed the transfer functions for small aircraft, and Lockheed developed the transfer functions for medium and large aircraft. All three manufacturers have reviewed these data and have agreed that they adequately characterize their fleets.

Table 5-4 presents the potential exposure factors for the aircraft sizes, equipment location on the aircraft, and aircraft location on the airport. These potential exposure factors were obtained by multiplying the fraction of the time per operating mode by the transfer function for that operating mode and then summing for all operating modes.

5.3 Analysis

5.3.1 Expected Number of Aircraft at the Gate

The expected number of aircraft at the gate is equal to the number in active service (being prepared for a flight origin, during an en route stop, or after a flight destination) plus the number of aircraft receiving extensive maintenance or cabin cleaning at the gate (this only occurs during nighttime). Table 5-5 (one page per aircraft) contains the data and basic calculations to determine the expected number of aircraft at the gate.

The top part of Tables 5-5 through 5-13 presents the OAG data and the calculated gate hours. The OAG data gives the total daily (average day in August 1978) scheduled operations for all combinations of:

- Time period (daytime, nighttime)
- Type of operation (arrival, departure)
- Type of flight (domestic passenger, international passenger or freight)
- Aircraft type (seven types)

The gate hours per aircraft type and time period are obtained by multiplying the number of operations by the gate time per operation (Table 5-1) and summing for all types of operations.

TABLE 5-3

TRANSFER FUNCTIONS

AIRCRAFT SIZE CLASS	ELECTRONIC EQUIPMENT LOCATION	AIRCRAFT POWER SOURCE	AVIONIC DOORS OPEN — PASSENGER DOORS OPEN	AVIONIC DOORS OPEN — PASSENGER DOORS CLOSED	AVIONIC DOORS CLOSED — PASSENGER DOORS OPEN	AVIONIC DOORS CLOSED — PASSENGER DOORS CLOSED
SMALL	AVIONICS BAY	APU	1.0	1.0	0.7	0.0025
		ENG	1.0	1.0	0.7	0.000004
		AIR	0.7	0.7	0.7	0.7
		GR EL	1.0	1.0	0.7	0.7
		NONE	1.0	1.0	0.7	0.0
	FLIGHT DECK	APU	0.7	0.0025	0.7	0.0025
		ENG	0.7	0.0025	0.7	0.000004
		AIR	0.7	0.7	0.7	0.7
		GR EL	0.7	0.7	0.7	0.7
		NONE	0.7	0.0025	0.7	0.0
MED/LARGE	FLIGHT STATION	APU	0.01	0.005	0.01	0.005
		ENG	0.01	0.0008	0.01	0.0008
		AIR	0.01	0.005	0.01	0.005
		GR EL	0.01	0.0	0.01	0.0
		NONE	0.01	0.0	0.01	0.0
	PASSENGER CABIN	APU	0.01	0.0025	0.01	0.0025
		ENG	0.01	0.0004	0.01	0.0004
		AIR	0.01	0.0025	0.01	0.0025
		GR EL	0.01	0.0	0.01	0.0
		NONE	0.01	0.0	0.01	0.0
	FESC/MESC	APU	1.0	1.0	0.0025	0.0025
		ENG	1.0	1.0	0.0004	0.0004
		AIR	1.0	1.0	0.0025	0.0025
		GR EL	1.0	1.0	0.01	0.0
		NONE	1.0	1.0	0.0	0.0

TABLE 5-4

POTENTIAL EXPOSURE FACTOR

$$\sum_{\text{OPERATING MODES}} \text{(FRACTION OF TIME)} \quad \text{(TRANSFER FUNCTION)}$$

AIRCRAFT SIZE	ELECTRONIC EQUIPMENT LOCATION	AIRPORT LOCATION AND TIME PERIOD		
		GATE DAYTIME	GATE NIGHTTIME	MAINTENANCE
SMALL	AVIONICS BAY	0.703	0.79	0.9277
	FLIGHT DECK	0.7	0.7	0.6860
MED/LARGE	FLIGHT STATION	0.01	0.01	0.0098
	PASSENGER CABIN	0.01	0.01	0.0098
	FESC/MESC	0.0128	0.3055	0.7984

TABLE 5-5

CHICAGO O'HARE (ORD)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	9.3	9.1	12.3	9.6	33.3	5.0	3.9	2.0	2.6	10.5
3 ENGINE WIDE-BODY	89.0	3.6	92.3	3.7	114.5	17.0	0.1	13.7	0	17.9
2 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
4 ENGINE NARROW	65.3	21.7	66.2	23.4	116.0	8.0	15.3	6.8	14.6	35.6
3 ENGINE NARROW	352.1	11.1	347.8	11.1	373.6	34.5	4.4	42.6	1.4	44.2
2 ENGINE NARROW	177.0	2.0	177.8	2.0	172.9	17.9	2.0	21.2	2.0	20.1

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	34	9	19	24	8.0
MEDIUM	1	0	1	0	0.0
LARGE	6	2	5	3	1.3

TABLE 5-6

NEW YORK CITY KENNEDY (JFK)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	2.4	–	2.4	5.4	–	–	–	–	–
4 ENGINE WIDE-BODY	11.3	46.5	13.1	40.4	103.9	4.0	5.8	2.0	12.6	23.4
3 ENGINE WIDE-BODY	21.5	11.3	21.3	11.7	51.0	6.9	4.4	7.1	4.0	17.5
2 ENGINE WIDE-BODY	3.0	–	5.0	–	5.4	2.0	–	–	–	1.1
4 ENGINE NARROW	32.3	58.8	34.0	49.2	141.6	9.4	9.5	6.7	18.8	37.0
3 ENGINE NARROW	51.3	9.0	54.3	9.9	76.9	11.1	1.6	9.1	0.7	13.4
2 ENGINE NARROW	24.0	10.9	21.9	11.9	43.8	4.7	2.0	6.8	1.0	8.8

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	20	8	18	10	3.3
MEDIUM	5	0	5	0	0
LARGE	9	2	8	3	1.3

TABLE 5-7

ST. LOUIS LAMBERT (STL)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
3 ENGINE WIDE-BODY	9.0	–	10.0	–	9.7	4.0	–	3.0	–	3.5
2 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
4 ENGINE NARROW	23.9	0.7	24.9	1.4	25.6	3.0	1.4	1.0	0.7	3.7
3 ENGINE NARROW	89.7	0.4	104.6	0.4	84.8	10.9	–	7.0	–	7.6
2 ENGINE NARROW	94.3	–	98.9	–	78.5	13.6	–	9.0	–	9.1

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	14	2	4	12	4.0
MEDIUM	0	0	0	0	0
LARGE	0	0	0	0	0

TABLE 5-8

NEW YORK CITY LAGUARDIA (LGA)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
3 ENGINE WIDE-BODY	9.9	1.0	8.9	1.0	12.9	1.0	–	2.0	–	1.9
2 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
4 ENGINE NARROW	–	–	–	–	–	–	–	–	–	–
3 ENGINE NARROW	167.6	10.7	164.7	11.7	188.5	21.7	0.9	12.4	0.9	18.4
2 ENGINE NARROW	85.6	–	94.8	–	86.5	16.1	–	5.9	–	10.2

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	50	0.1	20	30.1	10.0
MEDIUM	1	0	1	0	0
LARGE	2	0	0	2	0.9

TABLE 5-9

BOSTON LOGAN (BOS)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	2.7	5.0	2.7	2.5	10.1	–	0.1	–	1.9	2.2
3 ENGINE WIDE-BODY	12.4	3.4	14.4	3.4	24.9	5.0	1.0	3.0	1.0	9.6
2 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
4 ENGINE NARROW	16.6	9.4	20.6	5.3	37.8	4.0	1.6	–	5.5	9.1
3 ENGINE NARROW	85.8	5.9	98.6	5.9	115.9	20.8	–	7.0	–	15.2
2 ENGINE NARROW	59.9	6.0	67.4	6.7	84.2	11.2	1.0	2.9	–	8.5

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	51	2.2	13	40.2	13.4
MEDIUM	0	0	0	0	0
LARGE	3	0	1	2	0.9

TABLE 5-10

PHILADELPHIA (PHL)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	2.7	–	2.7	–	3.1	–	–	–	–	–
3 ENGINE WIDE-BODY	17.7	1.0	17.7	1.0	19.9	5.0	–	6.0	–	5.7
2 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
4 ENGINE NARROW	16.1	2.0	18.1	2.7	21.0	3.9	0.7	3.0	–	3.9
3 ENGINE NARROW	56.4	1.3	61.4	2.3	54.0	15.6	1.0	9.6	1.0	12.4
2 ENGINE NARROW	66.3	1.0	72.0	–	57.0	6.6	1.0	3.9	–	5.0

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	22	0.2	0	22.2	7.4
MEDIUM	0	0	0	0	0
LARGE	3	0	0	3	1.3

TABLE 5-11

WASHINGTON NATIONAL (DCA)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
3 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
2 ENGINE WIDE-BODY	–	–	–	–	–	–	–	–	–	–
4 ENGINE NARROW	–	–	–	–	–	–	–	–	–	–
3 ENGINE NARROW	155.2	–	153.0	–	156.0	16.9	–	19.1	–	18.3
2 ENGINE NARROW	82.0	–	83.7	–	79.3	8.3	–	5.6	–	6.6

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	27	0	0	27	9.0
MEDIUM	0	0	0	0	0
LARGE	0	0	0	0	0

TABLE 5-12

ATLANTA HARTSFIELD (ATL)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	0.1	–	0.1	–	0.1	0.1	–	–	–	0.1
3 ENGINE WIDE-BODY	43.7	2.0	49.7	2.0	59.6	17.0	1.0	11.0	1.0	17.8
2 ENGINE WIDE-BODY	2.0	–	2.0	–	2.6	–	–	–	–	–
4 ENGINE NARROW	23.4	5.2	26.6	4.2	37.1	5.9	2.3	4.0	3.3	10.7
3 ENGINE NARROW	204.2	2.3	226.5	2.3	223.1	64.4	–	41.9	–	52.9
2 ENGINE NARROW	217.6	–	229.4	–	214.0	52.7	–	38.7	–	43.2

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	24	10	16	18	6.0
MEDIUM	3	1	1	3	1.3
LARGE	6	2	3	5	2.2

TABLE 5-13

MIAMI INTERNATIONAL (MIA)
AIRCRAFT IN SCHEDULED SERVICE – AUGUST 1978

HOURS	DAYTIME 0600-2059					NIGHTTIME 2100-0559				
STATISTIC	SCHEDULED OPERATIONS				GATE HOURS	SCHEDULED OPERATIONS				GATE HOURS
ARRIVALS OR DEPARTURES	A		D			A		D		
DOMESTIC OR INTERNATIONAL PLUS FREIGHT	D	I, F	D	I, F		D	I, F	D	I, F	
SUPERSONIC	–	–	–	–	–	–	–	–	–	–
4 ENGINE WIDE-BODY	–	2.6	0.1	2.6	5.3	–	0.6	–	0.4	1.0
3 ENGINE WIDE-BODY	20.1	11.9	27.0	11.8	55.2	7.0	1.0	1.1	0.1	6.0
2 ENGINE WIDE-BODY	2.0	2.9	2.0	3.0	8.2	1.0	0.1	1.0	–	1.4
4 ENGINE NARROW	4.8	25.5	8.7	17.1	47.5	3.9	2.5	–	11.5	15.8
3 ENGINE NARROW	95.2	17.4	112.8	14.3	147.0	38.4	2.3	20.8	5.7	40.1
2 ENGINE NARROW	42.4	26.1	51.6	25.0	93.7	13.5	2.9	2.7	3.5	13.7

AIRCRAFT IN MAINTENANCE

AIRCRAFT SIZE	NO. OF OVERNIGHT AIRCRAFT	AVERAGE NO. OF AIRCRAFT AT MAINTENANCE FACILITY		AVERAGE NO. OF OVERNIGHT AIRCRAFT AT GATE	
		DAY	NIGHT	TOTAL	ACTIVE
SMALL	54	4	8	50	16.7
MEDIUM	4	0	2	2	0.9
LARGE	7	3	6	4	1.8

The bottom part of Tables 5-5 through 5-13 presents the data on the average number of aircraft which overnight at the airport and the average number of aircraft at the maintenance facility during the daytime or nighttime. The average number of aircraft being maintained at the gate during nighttime is based upon the following:

1. The number of aircraft at the gate during nighttime equals the number of aircraft which overnight at the airport minus the difference in the (nighttime and daytime) number of aircraft at the airport's maintenance facility.

2. Aircraft at the gate during nighttime have the doors open and/or power on for the following number of hours between 9:00 pm and 6:00 am:

   Small aircraft - 3 hours
   Medium aircraft - 4 hours
   Large aircraft - 4 hours

5.3.2 Average Number of Aircraft per Airport

Table 5-14 summarizes the average number of aircraft per airport. The number of aircraft in maintenance are taken directly from the data at the bottom of Tables 5-6 through 5-13. The number of aircraft at the gate during daytime is based upon the daytime gate hours per aircraft type at the top of those tables. The number of aircraft at the gate during nighttime is based upon the nighttime gate hours per aircraft type at the top of Tables 5-6 through 5-13, plus the average number of active overnight aircraft at the gate from the bottom of those tables. The number of aircraft at DCA, ATL, and MIA are from analysis performed by Lockheed based on the March 1979 scheduled operations. This method estimates 8.5 percent more total aircraft at these three airports than would be calculated from the data in Tables 5-6 through 5-13.

TABLE 5-14

AVERAGE NUMBER OF AIRCRAFT PER AIRPORT

AIRPORT	AIRCRAFT SIZE	DAYTIME		NIGHTTIME	
		GATE	MAINT	GATE	MAINT
ORD	SMALL	41.4	9.0	17.7	19.0
	MEDIUM	2.8	0	1.4	1.0
	LARGE	9.8	2.0	4.5	5.0
JFK	SMALL	40.7	8.0	8.4	18.0
	MEDIUM	3.8	0	1.6	5.0
	LARGE	10.3	2.0	5.8	8.0
STL	SMALL	17.2	2.0	6.1	4.0
	MEDIUM	0.6	0	0.1	0
	LARGE	0.6	0	0.4	0
LGA	SMALL	18.3	0.1	13.2	20.0
	MEDIUM	0	0	0	1.0
	LARGE	0.8	0	1.1	0
BOS	SMALL	14.9	2.2	16.7	13.0
	MEDIUM	0.9	0	0.3	0
	LARGE	2.3	0	1.3	1.0
PHL	SMALL	8.3	0.2	9.6	0
	MEDIUM	0.5	0	0.1	0
	LARGE	1.5	0	1.9	0
DCA	SMALL	16.1	0	9.9	0
ATL	SMALL	30.7	10.0	25.5	16.0
	MEDIUM	2.5	1.0	1.7	1.0
	LARGE	4.1	2.0	3.9	3.0
MIA	SMALL	19.0	4.0	29.7	8.0
	MEDIUM	2.6	0	3.3	2.0
	LARGE	5.9	3.0	5.1	6.0

5.3.3 Potential Exposure per Airport

Table 5-15 summarizes the potential exposure for

- nine airports
- three aircraft size classes
- two (on small aircraft) or three (on medium and large aircraft) locations of the electronic equipment in the aircraft
- two time periods, and the daily average

The Table 5-15 data are the expected number of aircraft per airport (Table 5-14) times the potential exposure factor (Table 5-4) and summed for aircraft at the gate and at maintenance. The daily average potential exposure is weighted according to the length of the daytime and nighttime periods.

5.4 Future Changes in Aircraft Operations

It is expected that the following changes will occur before the end of the century:

1. There will be a small annual increase in aircraft operations. The magnitude of the increase is airport-dependent. The airports are sequenced as follows from the largest to the smallest expected increase: STL, MIA, PHL, ATL, BOS, JFK, ORD, LGA and DCA.

2. There will be a significant shift in aircraft power source from the auxiliary power unit (APU) to ground electrical power.

3. The 1978 aircraft mix at the nine airports by size category is approximately:

   80 percent small (under 150 seats)
   5 percent medium (150-250 seats)
   15 percent large (over 250 seats)

TABLE 5-15

POTENTIAL EXPOSURE PER AIRPORT
(EXPECTED NO. OF AIRCRAFT)(POTENTIAL EXPOSURE FACTOR)

AIRPORT	AIRCRAFT SIZE	ELECTRONIC EQUIPMENT LOCATION	TIME PERIOD		
			DAYTIME	NIGHTTIME	AVERAGE
ORD	SMALL	AVIONICS BAY	50.45	31.61	43.39
		FLIGHT DECK	35.15	25.42	31.50
	MEDIUM	FLIGHT STATION	0.03	0.02	0.03
		PASSENGER CABIN	0.03	0.02	0.03
		FESC/MESC	0.04	0.82	0.33
	LARGE	FLIGHT STATION	0.12	0.09	0.11
		PASSENGER CABIN	0.12	0.09	0.11
		FESC/MESC	1.72	4.05	2.59
JFK	SMALL	AVIONICS BAY	36.03	22.60	30.99
		FLIGHT DECK	33.98	18.23	28.07
	MEDIUM	FLIGHT STATION	0.04	0.06	0.05
		PASSENGER CABIN	0.04	0.06	0.05
		FESC/MESC	0.05	4.01	1.54
	LARGE	FLIGHT STATION	0.12	0.14	0.13
		PASSENGER CABIN	0.12	0.14	0.13
		FESC/MESC	1.73	8.16	4.14
STL	SMALL	AVIONICS BAY	13.95	8.53	11.92
		FLIGHT DECK	13.41	7.01	11.01
	MEDIUM	FLIGHT STATION	0.01	0.00	0.00
		PASSENGER CABIN	0.01	0.00	0.00
		FESC/MESC	0.01	0.03	0.02
	LARGE	FLIGHT STATION	0.01	0.00	0.01
		PASSENGER CABIN	0.01	0.00	0.01
		FESC/MESC	0.01	0.12	0.05
LGA	SMALL	AVIONICS BAY	12.96	28.98	18.97
		FLIGHT DECK	12.88	22.96	16.66
	MEDIUM	FLIGHT STATION	0.00	0.01	0.00
		PASSENGER CABIN	0.00	0.01	0.00
		FESC/MESC	0.00	0.80	0.30
	LARGE	FLIGHT STATION	0.01	0.01	0.01
		PASSENGER CABIN	0.01	0.01	0.01
		FESC/MESC	0.01	0.34	0.13

TABLE 5-15 (CONT)

POTENTIAL EXPOSURE PER AIRPORT
(EXPECTED NO. OF AIRCRAFT)(POTENTIAL EXPOSURE FACTOR)

AIRPORT	AIRCRAFT SIZE	ELECTRONIC EQUIPMENT LOCATION	TIME PERIOD		
			DAYTIME	NIGHTTIME	AVERAGE
BOS	SMALL	AVIONICS BAY	12.52	25.25	17.29
		FLIGHT DECK	11.94	20.61	15.19
	MEDIUM	FLIGHT STATION	0.01	0.00	0.01
		PASSENGER CABIN	0.01	0.00	0.01
		FESC/MESC	0.01	0.09	0.04
	LARGE	FLIGHT STATION	0.02	0.02	0.02
		PASSENGER CABIN	0.02	0.02	0.02
		FESC/MESC	0.03	1.20	0.47
PHL	SMALL	AVIONICS BAY	6.02	7.58	6.61
		FLIGHT DECK	5.95	6.72	6.24
	MEDIUM	FLIGHT STATION	0.01	0.00	0.00
		PASSENGER CABIN	0.01	0.00	0.00
		FESC/MESC	0.01	0.03	0.02
	LARGE	FLIGHT STATION	0.02	0.02	0.02
		PASSENGER CABIN	0.02	0.02	0.02
		FESC/MESC	0.02	0.58	0.23
DCA	SMALL	AVIONICS BAY	11.32	7.82	10.01
		FLIGHT DECK	11.27	6.93	9.64
ATL	SMALL	AVIONICS BAY	30.86	34.99	32.41
		FLIGHT DECK	28.35	28.83	28.53
	MEDIUM	FLIGHT STATION	0.03	0.03	0.03
		PASSENGER CABIN	0.03	0.03	0.03
		FESC/MESC	0.83	1.32	1.01
	LARGE	FLIGHT STATION	0.06	0.07	0.06
		PASSENGER CABIN	0.06	0.07	0.06
		FESC/MESC	1.65	3.59	1.45
MIA	SMALL	AVIONICS BAY	17.07	30.88	22.25
		FLIGHT DECK	16.04	26.28	19.88
	MEDIUM	FLIGHT STATION	0.03	0.05	0.04
		PASSENGER CABIN	0.03	0.05	0.04
		FESC/MESC	0.03	2.60	1.00
	LARGE	FLIGHT STATION	0.09	0.11	0.10
		PASSENGER CABIN	0.09	0.11	0.10
		FESC/MESC	2.47	6.35	3.92

There will be a significant decrease in the percent that are small aircraft, and the medium-sized aircraft will receive most of the growth.

5.5 Summary

Table 5-15 illustrates that the potential exposure per airport is not large, and that the potential exposure is predominantly to small aircraft. The small aircraft have the largest potential exposure because they constitute approximately eighty percent of all aircraft and because they have a significantly higher transfer function than medium/large aircraft. Table 5-4 shows that the potential exposure factor for small aircraft is approximately 70 times the potential exposure factor for the flight station and passenger cabin of medium or large aircraft, or for the forward or middle electronics service center of aircraft at the gate during daytime.

SECTION 6
EQUIPMENT VULNERABILITY ASSESSMENT

An investigation into electrical components potentially vulnerable to carbon fiber (CF) contamination was conducted for the DC-9 and DC-10 aircraft. These components, otherwise known as line replaceable units (LRUs) or black boxes (shortened to just "boxes"), have been categorized by type of design and vulnerability in accordance with NASA criteria.

Vulnerability to CF contamination in electrical/electronic equipment is determined by the type of equipment. For cooling purposes, some equipment is designed to be open so that air can flow through and vent the heat that is generated as the equipment is operated. Small carbon fibers released into the air may gain access to this type equipment with a probability of settling across unprotected terminals or uncoated terminal board leads, causing the equipment to malfunction.

Risk assessment is made by studying present-day aircraft safety and the cost of maintaining the vulnerable aircraft equipment under today's circumstances, and by comparing to corresponding future cost and safety when the use of composite materials becomes more widespread.

Tables 6-1 through 6-6 list the vulnerable LRUs for the DC-10 and DC-9 aircraft, respectively. These lists were categorized into open electrical/electronic boxes having:

Cagegory

- A Coated boards and unprotected terminals
- B Uncoated boards and protected terminals
- C Uncoated boards and unprotected terminals

The LRUs are further classified as to use:

Classification

- D Required for dispatch
- E Passenger convenience
- F Crew convenience (autopilot, etc.)

TABLE 6-1

DC-10 FAILURE RATE AND COST ASSESSMENT – CATEGORY A
CARBON FIBER STUDY
OPEN BOXES, COATED BOARDS, UNPROTECTED TERMINALS
DC-10 DAILY UTILIZATION = 8.56 HOURS (t)

DESCRIPTION	AIRCRAFT REMOVAL RATE λm/1000 FLIGHT HOURS	AVERAGE REPAIR COST IN $ PER REMOVAL	AVERAGE REPAIR COST IN $ PER 1000 FLT HOURS	USAGE CLASSIF	QPA
CONTROLLER, CABIN PRESSURE, STBY	0.114	181.66	20.71	F	1
SWITCH, PRESSURE, ANEROID	0.030	79.51	2.39	F	1
CARGO COMPT TEMP SENSOR	0.036	67.00	2.41	F	3
ZONE TEMP IND SENSOR	0.039	93.00	3.63	F	3
DUCT TEMP IND SENSOR	0.030	91.60	2.75	F	5
FLIGHT GUIDANCE PITCH COMPUTER	2.326	483.83	1125.39	D	2
FLIGHT GUIDANCE ROLL COMPUTER	1.218	520.88	634.43	F	2
FLIGHT GUIDANCE YAW COMPUTER	0.676	236.75	160.04	D	2
HF TRANSCEIVER	1.242	137.33	170.56	D	2
AMPLIFIER, PA	0.854	161.19	137.66	D	2
REPRODUCER, TAPE ANCMT	0.964	81.41	78.48	F	1
MAIN MULTIPLEXER	0.312	188.13	58.70	E	1
SUBMULTIPLEXER	0.442	412.91	182.51	E	2
TIMER/DECODER SECTION	1.848	412.91	763.06	E	8
OVERHEAD DECODER	1.365	82.36	112.42	E	39
1200-VA STATIC INVERTER	0.020	197.38	3.95	D	1
BATTERY CHARGER	0.148	302.39	44.75	D	1
BATTERY VENT PUMP	0.340	50.00	17.00	D	1
TRANSFORMER, INSTRUMENT BUS	0.015	98.00	1.47	D	5
SWITCH ASSY CONTROL, ROLLER	0.240	53.43	53.43	D	2
BATTERY AND LIGHT	0.192	50.00	9.60	D	8
CABIN SMOKE DETECTION IND	0.031	27.60	0.86	D	1
PUMP, AUX AC ELECT. MOTOR DRIVE	0.190	192.11	60.71	D	2
SWITCH, THERMAL	0.054	68.00	3.67	D	1
FLIGHT DATA ENTRY PANEL	0.191	107.30	20.49	D	1
FLIGHT DATA ACQUISITION UNIT	0.200	179.61	35.92	D	1
ANTISKID CONTROL UNIT	0.309	220.12	68.02	F	1
LAMP DIMMER	0.001	86.80	0.09	F	1
CONTROLLER, WARN AND CAUTION	0.252	167.93	42.32	D	1
CENTRAL AIR DATA COMPUTER	1.042	169.18	176.29	D	2
HORIZONTAL SITUATION INDICATOR	2.336	570.83	1333.46	D	2
VERTICAL GYRO	0.557	926.91	516.92	D	1
STANDBY ATTITUDE INDICATOR	0.233	361.14	84.15	D	1
RECEIVER, ILS	0.836	202.49	169.28	D	2
WEATHER RADAR R/T UNIT	2.304	133.73	133.73	D	2
WEATHER RAD IND	0.758	166.59	126.28	D	2
RADIO ALTIMETER R/T UNIT	0.590	240.19	141.71	D	2
INERTIAL SENSOR/NAVIGATION UNIT	1.058	1300.00	1375.40	D	2
INERTIAL SENSOR DISPLAY UNIT	0.181	1000.00	181.00	D	1
VOR/ILS RECEIVER	1.352	151.81	205.25	D	2
VOR/ILS RECEIVER	0.920	278.70	256.40	D	2
VOR RECEIVER	3.252	245.62	798.75	D	2
DME INTERROGATOR	0.778	331.56	257.95	D	2
ADF RECEIVER	0.308	162.62	50.09	D	1
ATC TRANSPONDER	0.946	284.82	269.44	D	2
AINS 70 NAV COMPUTER	1.476	1500.00	2214.00	D	2
CONTROL DISPLAY UNIT	1.470	1000.00	1470.00	D	2
SWITCH, CONTROL	0.081	306.40	24.82	D	3
LIGHT SWITCH	0.081	24.60	1.99	F	3
CONTROLLER, PNEU SYST	0.936	274.01	256.47	D	3
ENGINE IGNITION SWITCH	0.008	175.60	1.40	D	1
	Σλm 35.182		Σ= $13995.34		143

(t) = 8.56 HOURS/DAY

$$\text{EXPECTED NUMBER OF REMOVALS PER DAY PER AIRCRAFT} = \frac{\Sigma\lambda m(t)}{1000}$$

$$\Sigma\lambda m(t) = 35.182 \times 8.56 = \frac{301.159}{1000} = 0.3012$$

$$\text{EXPECTED COST OF REMOVALS PER YEAR PER ACFT} = \frac{\Sigma \text{ REPAIR COST IN \$ PER 1000 FLT HOURS} \times 8.56 \times 365}{1000} = \frac{\$13{,}995.34 \times 8.56 \times 365}{1000}$$

$$= \$43{,}727.04$$

TABLE 6-2

DC-10 FAILURE RATE AND COST ASSESSMENT – CATEGORY B
CARBON FIBER STUDY
OPEN BOXES, UNCOATED BOARDS, PROTECTED TERMINALS
DC-10 DAILY UTILIZATION = 8.56 HOURS (t)

DESCRIPTION	AIRCRAFT REMOVAL RATE λm/1000 FLIGHT HOURS	AVERAGE REPAIR COST IN $ PER REMOVAL	AVERAGE REPAIR COST IN $ PER 1000 FLT HOURS	USAGE CLASSIF	QPA
PASSENGER ADDRESS AMPLIFIER	0.908	161.19	146.36	D	2
AUDIO PANEL CONTROL	1.015	87.32	38.86	D	5
MARKER BEACON RECEIVER	0.162	110.99	4.77	D	1
	Σλm 2.085		Σ= $189.99		8

(t) = 8.56 HOURS/DAY

EXPECTED NUMBER OF REMOVALS PER DAY PER AIRCRAFT = $\frac{\Sigma\lambda m(t)}{1000}$

$\Sigma\lambda m(t) = 2.085 \times 8.56 = \frac{17.848}{1000} = 0.018$

EXPECTED COST OF REMOVALS PER YEAR PER ACFT = $\frac{\Sigma \text{ REPAIR COST IN \$ PER 1000 FLT HOURS} \times 8.56 \times 365}{1000} = \frac{\$189.99 \times 8.56 \times 365}{1000}$

= $593.60

TABLE 6-3

DC-10 FAILURE RATE AND COST ASSESSMENT – CATEGORY C
CARBON FIBER STUDY
OPEN BOXES, UNCOATED BOARDS, UNPROTECTED TERMINALS
DC-10 DAILY UTILIZATION = 8.56 HOURS (t)

DESCRIPTION	AIRCRAFT REMOVAL RATE λm/1000 FLIGHT HOURS	AVERAGE REPAIR COST IN $ PER REMOVAL	AVERAGE REPAIR COST IN $ PER 1000 FLT HOURS	USAGE CLASSIF	QPA
HANDSET	0.332	52.13	17.31	F	1
MARKER BEACON RECEIVER	0.162	110.99	17.98	D	1
	Σλm 0.494		Σ= $35.29		2

EXPECTED NUMBER OF REMOVALS PER DAY PER AIRCRAFT = $\frac{\Sigma\lambda m(t)}{1000}$

$\Sigma\lambda m(t) = 0.494 \times 8.56 = \frac{4.229}{1000} = 0.004$

EXPECTED COST OF REMOVALS PER YEAR PER AIRCRAFT = $\frac{\Sigma \text{ REPAIR COST IN \$ PER 1000 FLT HOURS} \times 8.56 \times 365}{1000} = \frac{\$35.29 \times 8.56 \times 365}{1000}$

= $110.26

TABLE 6-4
DC-9 FAILURE RATE AND COST ASSESSMENT – CATEGORY A
CARBON FIBER STUDY
OPEN BOXES, COATED BOARDS, UNPROTECTED TERMINALS
DC-9 DAILY UTILIZATION = 7.12 HOURS (t)

DESCRIPTION	AIRCRAFT REMOVAL RATE λm/1000 FLIGHT HOURS	AVERAGE REPAIR COST IN $ PER REMOVAL	AVERAGE REPAIR COST IN $ PER 1000 FLT HOURS	USAGE CLASSIF	QPA
HF TRANSCEIVER	1.100	282.00	310.20	D	2
CABIN SPEAKER	0.137	74.00	4.42	D	1
PILOT'S CALL BELL	0.002	102.00	0.20	F	1
MECHANIC'S CALL HORN	0.013	95.00	1.24	F	1
GENERATOR CONTROL PANEL	0.846	232.00	196.27	D	3
BUS CONTROL PANEL	0.598	288.00	171.65	D	1
AC REGULATOR	0.261	214.00	55.85	D	3
BATTERY VENT FAN	0.031	158.00	4.90	D	1
PROX SW CONTROL	0.215	146.00	31.39	D	1
VERTICAL GYRO	1.659	576.00	955.58	D	1
STANDBY HORIZON INDICATOR	0.226	338.00	76.39	D	1
VOR/ILS RECEIVER	1.950	232.00	452.40	D	3
ADF RECEIVER	0.878	172.00	151.02	D	2
ATC TRANSPONDER	0.642	282.00	181.04	D	2
WEATHER RADAR R/T	2.012	326.00	655.91	D	1
WEATHER RADAR INDICATOR	0.657	326.00	214.18	D	1
WEATHER RADAR INDICATOR	0.934	326.00	304.48	D	1
RADIO ALTIMETER R/T UNIT	0.936	204.00	190.94	D	2
	Σλm 13.097		Σ= $3958.06		28

(t) = 7.12 HOURS

EXPECTED NUMBER OF REMOVALS PER DAY PER AIRCRAFT $= \frac{\Sigma\lambda m(t)}{1000}$

$$\Sigma\lambda m(t) = 13.097 \times 712 = \frac{93.251}{1000} = 0.093$$

EXPECTED COST OF REMOVALS PER YEAR PER ACFT $= \frac{\Sigma \text{ REPAIR COST IN \$ PER 1000 FLT HOURS} \times 7.12 \times 365}{1000} = \frac{\$3958.06 \times 7.12 \times 365}{1000}$

$= \$10,286.21$

TABLE 6-5

DC-9 FAILURE RATE AND COST ASSESSMENT – CATEGORY B
CARBON FIBER STUDY
OPEN BOXES, UNCOATED BOARDS, PROTECTED TERMINALS
DC-9 DAILY UTILIZATION = 7.12 HOURS (t)

DESCRIPTION	AIRCRAFT REMOVAL RATE $\lambda m/1000$ FLIGHT HOURS	AVERAGE REPAIR COST IN $ PER REMOVAL	AVERAGE REPAIR COST IN $ PER 1000 FLT HOURS	USAGE CLASSIF	QPA
AUDIO PANEL	0.664	90.00	59.76	F	4
JACK PANEL	0.057	90.00	5.13	F	3
FLIGHT COMPT SPEAKER	0.152	109.00	16.37	D	1
FLIGHT INTERPHONE AMPLIFIER	0.072	120.00	8.64	D	2
FLIGHT DIRECTOR COMPUTER	0.848	198.00	167.90	D	2
MARKER BEACON RECEIVER	0.213	120.00	25.56	D	1
ATC TRANSPONDER	0.642	226.00	145.09	D	2
DME INTERROGATOR	0.452	282.00	170.33	D	2
	$\Sigma\lambda m$ 3.100		Σ = $598.78		17

(t) = 7.12 HOURS/DAY

$$\text{EXPECTED NUMBER OF REMOVALS PER DAY PER AIRCRAFT} = \frac{\Sigma\lambda m(t)}{1000}$$

$$\Sigma\lambda m(t) = 3.100 \times 7.12 = \frac{22.072}{1000} = 0.022$$

$$\text{EXPECTED COST OF REMOVALS PER YEAR PER ACFT} = \frac{\Sigma \text{REPAIR COST IN \$ PER 1000 FLT HOURS} \times 7.12 \times 365}{1000} = \frac{\$598.78 \times 7.12 \times 365}{1000}$$

$$= \$1556.11$$

TABLE 6-6

DC-9 FAILURE RATE AND COST ASSESSMENT – CATEGORY C
CARBON FIBER STUDY
OPEN BOXES, UNCOATED BOARDS, UNPROTECTED TERMINALS
DC-9 DAILY UTILIZATION = 7.12 HOURS (t)

DESCRIPTION	AIRCRAFT REMOVAL RATE λm/1000 FLIGHT HOURS	AVERAGE REPAIR COST IN $ PER REMOVAL	AVERAGE REPAIR COST IN $ PER 1000 FLT HOURS	USAGE CLASSIF	QPA
PASSENGER ADDRESS AMPLIFIER	0.719	148.00	106.41	D	1
WINDSHIELD TEMP CONTROLLER	0.882	183.00	161.41	D	3
MARKER BEACON RECEIVER	0.326	120.00	43.44	D	1
ADF RECEIVER	0.812	226.00	183.51	D	2
	$\Sigma\lambda m$ 2.739		Σ=$494.77		7

(t) = 7.12 HOURS/DAY

EXPECTED NUMBER OF REMOVALS PER DAY PER AIRCRAFT = $\frac{\Sigma\lambda m(t)}{1000}$

$$\Sigma\lambda m(t) = 2.739 \times 7.12 = \frac{19.502}{1000} = 0.020$$

EXPECTED COST OF REMOVALS PER YEAR PER ACFT = $\frac{\Sigma\text{REPAIR COST IN \$ PER 1000 FLT HOURS} \times 7.12 \times 365}{1000} = \frac{\$494.77 \times 7.12 \times 365}{1000}$

= $1285.81

Unscheduled removal rates (λm) have been determined for each LRU based on actual commercial airline experience. Column one, aircraft removal rate λm/1000 flight hours, represents the unscheduled removal rate of the LRU multiplied by the quantity per aircraft (QPA) shown in column five. Column one is summed for each of the categories to show the total unscheduled removal rate for the aircraft, as is column five to show the total number of LRUs involved in the assessment. A survey was conducted to determine the average repair cost involved in an unscheduled removal for each of the LRUs. The cost includes the labor cost to remove and reinstall the unit in the aircraft, the cost to transport to and from the repair facility, and the cost to test and repair the unit as necessary to be serviceable. These costs are listed for each LRU in the second column entitled average cost in dollars per removal and reflect a cost of $10.00 per hour labor and $18.00 per hour burden based on 1979 dollars. Multiplying column one and column two provides the average repair cost in dollars per 1000 flight hours for each LRU and is listed in column three. This column is again summed to show the total repair cost per 1000 flight hours for each category. Dividing through by 1000 flight hours shows the repair cost per flight hour.

The daily utilization (the average length of time per day the aircraft is actually flying) has been determined for the DC-9 as 7.12 hours, and for the DC-10 as 8.56 hours.

Multiplying the repair cost per flight hour by the daily utilization for 365 days per year provides the expected repair cost per year for each category. Summation of the repair cost per year for each category for each aircraft reveals that the annual repair cost for the DC-10 is $44,431, and for the DC-9 is $13,128. These are the costs requested by NASA to be provided to A. D. Little Inc. for use in their computer model to determine cost risk due to carbon fiber contamination. The average repair cost per unscheduled removal is $100.60 for the DC-10 and $120.87 for the DC-9.

During the investigation and identification of DC-9 and DC-10 components considered potentially vulnerable to the effects of CF fallout, an evaluation was made to determine whether any CF-caused failure of these components could result in a hazard on a subsequent flight, particularly any of a nature that could not be coped with using established procedures for accommodating system anomolies. None were found. The reasons for this finding are discussed below.

1. Certification requirements established by the FAA and other regulatory agencies worldwide, as well as the in-house design standards of Douglas and other manufacturers, require that systems be tolerant of functional faults or provide for alternative methods to accomplish the function. All electronically dependent critical functions meet this requirement.

2. Contamination and moisture from various sources have always been present on aircraft and have been dealt with for many years. The sealing/coating protection developed and used on electrical and electronic equipment to control the more common types of contamination work equally well against CR as determined by NASA tests. NASA data show that avionics equipment with conformal coated circuit boards and protected terminals is not vulnerable to CF contamination.

3. NASA data also show that power-generating equipment is not essentially affected by CF contamination. Further, FAA regulations require multiple power sources, fault-clearing ability, and the ability for the aircraft to continue safe flight with all electrical power sources except the battery inoperative for a time sufficient to reconfigure or restart the engines, if that was the cause for electrical power loss. Although CF cannot cause such total loss, this requirement does ensure that the failure of any single electrical item or likely combination of items due to CF (or any other cause) can be tolerated and controlled.

4. No unique failure modes result from CF contamination. As part of the design and certification process, the effects of equipment failure modes are analyzed. Failure effects that are generated by CF fall within the possible failure modes that must be considered in the design of present equipment.

5. Prior to flight, a thorough checklist is completed by the flight crew. If an aircraft is exposed to CF and if any significant system anomoly results, it is unlikely that it would not be detected prior to the next flight.

Consequently, in our view there is no discernible additive risk associated with subsequent operation of an aircraft certified to FAR Part 25 after it has been exposed to CF fallout.

If some postexposure action is nevertheless felt to be prudent, a mandatory cleaning prior to further operation could be imposed. Such action might be shown to be cost-effective since it could reduce the likelihood of incurring subsequent maintenance costs of any vulnerable nonflight significant components. NASA data also indicate that the quanitity of CF that must be present to result in a significant chance of affecting even very vulnerable devices would be visibly apparent and thus amenable to cleaning operations.

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15. Supplementary Notes

Contract Monitor: R. J. Huston, NASA Langley Research Center

16. Abstract

The use of carbon/graphite composite material in aircraft structures is increasing every year. However, concern has been expressed over the potential hazard to electrical and electronic devices should there be a release of free fibers due to a crash and fire; therefore, NASA established a comprehensive study program to estimate the expected dollar loss due to this problem. Work programs were conducted by a variety of firms and Government agencies to acquire exposure and equipment sensitivity data for a risk analysis. Results of the Douglas portions of this program are presented. They consisted of the following: DC-9/DC-10 Electrical/Electronic Component Characterization, DC-9 and DC-10 Fiber Transfer Functions, Potential for Transport Aircraft Equipment Exposure to Carbon Fibers, and Equipment Vulnerability Assessment. Results reflect only a negligible increase in risk for the DC-9 and DC-10 fleets either now or projected to 1993.

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