NASA Contractor Report 159201

CARBON/GRAPHITE FIBER RISK ANALYSIS AND ASSESSMENT STUDY

ASSESSMENT OF THE RISK TO THE LOCKHEED MODEL L-1011 COMMERCIAL TRANSPORT AIRCRAFT

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SUMMARY

This report documents the work performed by Lockheed in assessing the risk to commercial transport aircraft due to the accidental release of carbon/graphite fibers from fire damage to commercial aircraft incorporating advanced composite materials. This work was performed under contract to the National Aeronautics and Space Administration in support of their national risk assessment program. While only small amounts of carbon/graphite composites are in use today on commercial transports, there was concern over the considerable increase in usage projected for the next ten to fifteen years. In response to this concern, the risk to the Lockheed L-1011 Tristar is assessed for conditions projected for the year 1993. This assessment involves identifying the electrical and electronic equipments on the L-1011 that are susceptible to carbon fiber contamination, and computing their probabilities of failure, the associated cost risk and the hazard to continued operation.

The results of the assessment show the risks associated with the use of carbon/graphite composites on commercial transport aircraft are insignificant. The expected annual cost risk for the L-1011 domestic fleet is $25.76 for the year 1993 which is negligible compared to the expected annual costs associated with current sources of equipment failure. Also, current aircraft operational and maintenance practices afford adequate protection from a hazard to continued operation. System failure due to carbon/graphite contamination is such an unlikely occurrence that it need not be considered.

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CHAPTER 1

INTRODUCTION

Composite materials containing carbon/graphite fibers are being used in a wide variety of applications because their high-strength, light-weight structural properties result in considerable cost benefits. These characteristics make them especially attractive for use in aircraft structures. However, there is evidence that the electrically conductive carbon fibers can cause failures in electrical and electronic equipment. Because of their light weight, dissemination of airborne fibers could result in contamination of unprotected electrical equipments.

Since projections indicate a considerable increase in the usage of carbon fiber composite materials, the accidental release of carbon fibers is of concern. To assess the potential risk, the government has undertaken a program involving many of the Federal agencies to deal with different aspects of the problem. The National Aeronautics and Space Administration (NASA) has the responsibility for evaluating the national risk associated with the accidental release of carbon fibers (CF) from civil aircraft and to assess the vulnerability of commercial transport aircraft. It is part of a larger program to evaluate the national risks and hazards .

NASA Langley has established contracts with the three major commercial aircraft manufacturers (Boeing Commercial Airplane Co., Douglas Aircraft Co. and the Lockheed California Co.) to aid in their program. The contracts require the aircraft manufacturers to provide data for the assessment of national risk from the accidental release of carbon fibers (CF) in commercial aircraft, to evaluate the potential for carbon fiber (CF) damage to aircraft equipments and to take part in an ad hoc working group consisting of representatives of the organizations participating in the NASA program.

The role of the airframe manufacturers in the NASA carbon fiber (CF) risk assessment program is illustrated in Figure 1-1. The Task 1 studies have been completed and documented. This report relates to the Task 2 studies and primarily documents the Lockheed efforts in the program.

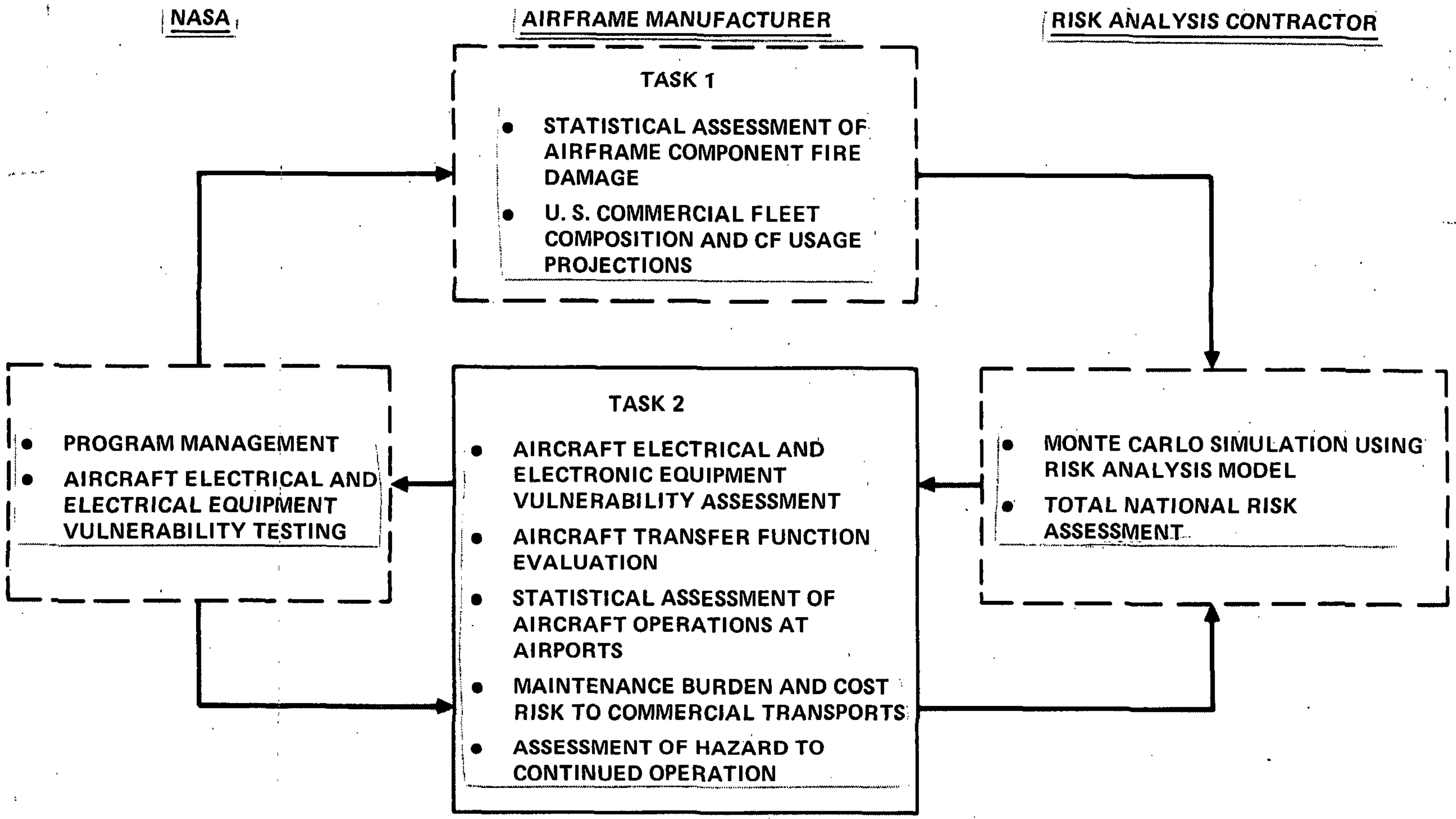


Figure 1-1. Role of Airframe Manufacturer in National Risk Assessment

In Chapter 2 of this report, the electrical and electronic equipment in the L-1011 Tristar which are susceptible to carbon fiber (CF) contamination damage are identified. Chapter 3 discusses the L-1011 transfer functions. Chapter 4 documents the statistical studies performed on aircraft operations and aircraft configurations at airports. In Chapter 5, equipment failure probabilities due to CF exposure are derived. Chapter 6 presents the expected increase in L-1011 equipment failures due to CF contamination for the year 1993. Chapter 7 presents the expected increase in L-1011 maintenance costs due to CF contamination for the year 1993. Chapter 8 discusses the hazard to continued L-1011 operation following the accidental release of carbon fibers. The conclusions are presented in Chapter 9.

This report incorporates data furnished by NASA and other parties under contract to NASA. Suggestions from a number of persons at the Douglas Aircraft Company and the Boeing Commercial Airplane Company have been incorporated throughout this report. In addition, they have furnished a large portion of the data contained in Chapter 4. We would like to acknowledge the team of Bionetics Corporation for providing essential test data on the vulnerability and transfer functions of aircraft equipment. Also we would like to recognize Dr. Joseph Fiksel, Dr. Donald B. Rosenfield, and Mr. Mark Pendrock of Arthur D. Little, Inc. for furnishing the probabilities of aircraft exposure contained in Appendix C. Finally we would like to thank Dr. Wolf Elber, Mr. Jerry L. Humble, and Mr. Robert J. Huston of the NASA Langley Research Center. Dr. Elber provided technical direction during the course of this study, Mr. Humble provided the focal point for a coordinated effort from the airframe manufacturers, and Mr. Huston provided the overall program management.

CHAPTER 2

L-1011 ELECTRICAL AND ELECTRONIC EQUIPMENT VULNERABILITY

This chapter describes the work performed in identifying electrical and electronic equipment in the L-1011 Tristar which are susceptible to carbon fiber (CF) contamination damage. The typical L-1011 Tristar selected for the investigation was one heavily configured with avionic equipment. It was decided to review as many components and assemblies as possible even though some of the items are not normally found on many L-1011 aircraft in airline service.

2.1 IDENTIFICATION OF VULNERABLE EQUIPMENTS

Figure 2-1 illustrates the various phases of work in identifying vulnerable equipment. From over six hundred types of equipments surveyed, two hundred and fifty eight components and assemblies were identified for evaluation of vulnerability to carbon fiber (CF) contamination. The remainder were considered invulnerable due to the requirement for sealed enclosures. Each of these 258 equipments were reviewed for characteristics affecting their vulnerability. Some of the characteristics considered were:

- enclosure construction
- cooling
- internal circuitry construction
- termination types and spacing
- circuit coating
- connectors
- voltage and power ranges
- impedances
- location in aircraft

To ensure a thorough investigation, many of the equipments were physically examined to verify their characteristics.

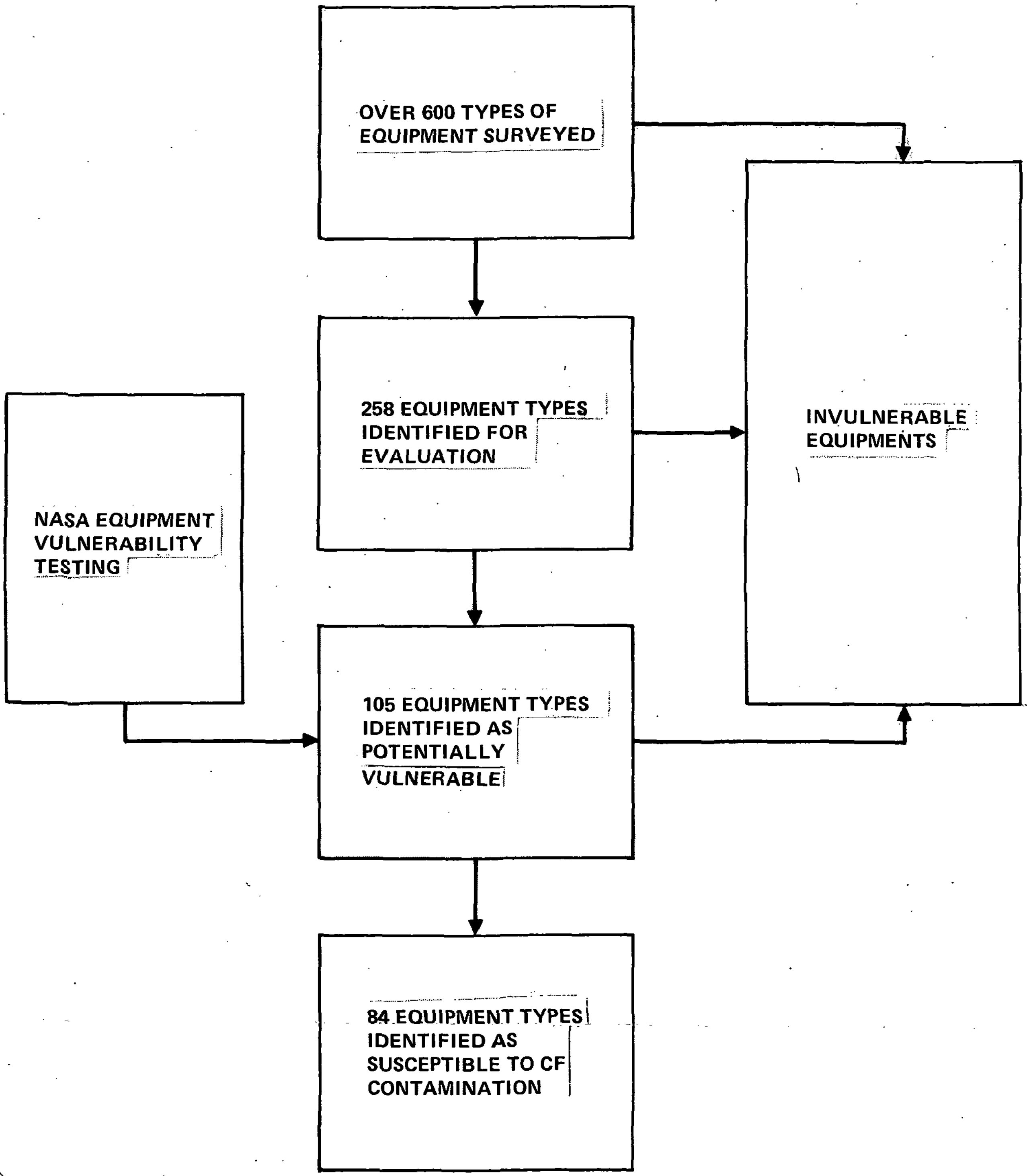


Figure 2-1. Equipment Vulnerability Assessment

One hundred and five out of the original two hundred and fifty eight were found to have some potentially vulnerable characteristic such as an open enclosure, exposed circuitry, etc. These units were reevaluated with respect to vulnerability test data when it was furnished by NASA. As a result, eighty four of the one hundred and five equipments were identified as susceptible to carbon fiber (CF) contamination damage.

2.2 VULNERABILITY CATEGORIES

The eighty four susceptible equipments were assigned to different vulnerability categories based on the criteria derived from the test data. Table 2-1 presents the seven vulnerability categories that were established and their mean exposure-to-failure values. For the first two categories, θ and β, it was necessary to establish sub-categories because of the wide variation in internal circuitry. Three of the categories, δ , τ and ψ are listed in the table even though they were found to be invulnerable to carbon fiber (CF) contamination damage. The last column in the table lists how many of the eighty four equipment types are in each vulnerability category. It is seen that no L-1011 equipment items were under category γ (open boxes with uncoated boards and protected terminals).

2.3 EQUIPMENT CATEGORIZATION

A listing of the eighty four vulnerable equipments is shown in Table 2-2. The system usage and the quantity per aircraft for each item is listed. The total quantity per aircraft for all the equipments is two hundred and eighty one. The equipments are located in one of three designated locations:

- Flight Station
- Passenger Cabin
- Avionic Centers

The avionic centers on the L-1011 Tristar consist of the forward electronic service center and the middle electrical service center. The estimated number of exposed contracts for each equipment and its vulnerability category (from Table 2-1) are also shown.

TABLE 2-1. EQUIPMENT VULNERABILITY CATEGORIES

VULNERABILITY CATEGORY	DESCRIPTION	MEAN EXPOSURE TO FAILURE ($\bar{E}$) FIBER-SECONDS PER CUBIC METER	NUMBER OF L-1011 EQUIPMENT TYPES
θ	Open boxes with coated boards and unprotected terminals	θ_1: $\bar{E} = 1.5 \times 10^7$ θ_2: $\bar{E} = 1.0 \times 10^8$	7 38
β	Open boxes with uncoated boards and unprotected terminals	β_1: $\bar{E} = 1.5 \times 10^7$ β_2: $\bar{E} = 1.0 \times 10^8$	4 12
γ	Open boxes with uncoated boards and protected terminals	$\bar{E} = 1.0 \times 10^8$	0
δ	Open boxes with coated boards and protected terminals	Invulnerable	--
ϵ	Open boxes with unprotected terminals (no boards)	$E = 1.0 \times 10^8$	23
τ	Open boxes with protected terminals (no boards)	Invulnerable	--
ψ	Closed boxes	Invulnerable	--

2.4 CURRENT SOURCE DATA

Having identified the vulnerable equipments, it was necessary to compile reliability and maintenance cost data for analyses in subsequent chapters. These data will be used to assess the cost risk and to determine whether any equipments have a significantly greater probability of failure resulting from carbon fiber (CF) exposure. The compilation of reliability and maintenance cost data from current sources is presented in Appendix A.

TABLE 2-2. VULNERABLE EQUIPMENTS LIST

EQUIPMENT NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT*	LOCATION IN AIRCRAFT	NUMBER OF EXPOSED CONTACTS	VULNERABILITY CATEGORY
1	Air Conditioning	1	Avionic Centers	300	θ_2
2	Air Conditioning	5	Avionic Centers	128	θ_2
3	Air Conditioning	3	Avionic Centers	176	θ_2
4	Auto Flight	1	Flight Station	50	ϵ
5	Auto Flight	1	Avionic Centers	40	ϵ
6	Auto Flight	2	Avionic Centers	3000	θ_1
7	Auto Flight	2	Avionic Centers	3000	θ_1
8	Auto Flight	2	Avionic Centers	3000	θ_1
9	Auto Flight	1	Avionic Centers	3000	θ_1
10	Auto Flight	1	Avionic Centers	3000	θ_1
11	Auto Flight	1	Avionic Centers	2100	θ_1
12	Radio Communications	2	Avionic Centers	100	θ_2
13	Radio Communications	3	Avionic Centers	2500	β_2
14	Passenger Service	2	Avionic Centers	190	θ_2
15	Passenger Service	1	Flight Station	8	ϵ
16	Passenger Service	1	Avionic Centers	180	θ_2
17	Passenger Service	1	Avionic Centers	320	θ_2
18	Passenger Service	3	Passenger Cabin	50	θ_2

TABLE 2-2. VULNERABLE EQUIPMENTS LIST (Continued)

EQUIPMENT NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT*	LOCATION IN AIRCRAFT	NUMBER OF EXPOSED CONTACTS	VULNERABILITY CATEGORY
19	Passenger Service	4	Passenger Cabin	60	θ_2
20	Passenger Service	1	Avionic Centers	850	θ_2
21	Passenger Service	1	Passenger Cabin	50	ϵ
22	Passenger Service	1	Passenger Cabin	90	ϵ
23	Passenger Service	2	Avionic Centers	200	β_2
24	Passenger Service	1	Avionic Centers	32	θ_2
25	Passenger Service	2	Flight Station	-	θ_2
26	Passenger Service	2	Avionic Centers	120	θ_2
27	Electrical Power	1	Flight Station	120	ϵ
28	Electrical Power	1	Avionic Centers	450	θ_2
29	Electrical Power	4	Avionic Centers	500	θ_2
30	Electrical Power	1	Avionic Centers	85	β_2
31	Electrical Power	1	Avionic Centers	24	θ_2
32	Electrical Power	1	Flight Station	420	ϵ
33	Electrical Power	1	Flight Station	368	ϵ
34	Electrical Power	1	Flight Station	566	ϵ
35	Electrical Power	1	Avionic Centers	240	ϵ
36	Electrical Power	1	Avionic Centers	170	ϵ

TABLE 2-2. VULNERABLE EQUIPMENTS LIST (Continued)

EQUIPMENT NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT*	LOCATION IN AIRCRAFT	NUMBER OF EXPOSED CONTACTS	VULNERABILITY CATEGORY
37	Electrical Power	1	Avionic Centers	117	ϵ
38	Electrical Power	3	Avionic Centers	226	ϵ
39	Electrical Power	1	Avionic Centers	50	ϵ
40	Fire Extinguisher	1	Flight Station	24	ϵ
41	Slat Control	2	Avionic Centers	50	θ_2
42	Windshield Heat	2	Avionic Centers	50	θ_2
43	Windshield Heat	1	Flight Station	28	ϵ
44	Water Waste	1	Flight Station	40	ϵ
45	Proximity Sensing	1	Avionic Centers	50	θ_2
46	Aural Warning	1	Flight Station	20	β_2
47	Flight Data	1	Avionic Centers	30	θ_2
48	Flight Data	1	Flight Station	50	θ_2
49	AIDS	1	Avionic Centers	100	θ_2
50	AIDS	1	Avionic Centers	50	θ_2
51	AIDS	3	Avionic Centers	30	θ_2
52	Weight & Balance	1	Flight Station	40	θ_2
53	Instrument Lights	2	Avionic Centers	Various	β_2
54	Warning Lights	1	Avionic Centers	4000	θ_1

TABLE 2-2. VULNERABLE EQUIPMENTS LIST (Continued)

EQUIPMENT NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT*	LOCATION IN AIRCRAFT	NUMBER OF EXPOSED CONTACTS	VULNERABILITY CATEGORY
55	Cabin Lighting	22	Passenger Cabin	66	β_2
56	Cabin Lighting	4	Passenger Cabin	44	β_2
57	Cabin Lighting	120	Passenger Cabin	36	β_2
58	Cabin Lighting	1	Avionic Centers	45	β_2
59	Cabin Lighting	3	Avionic Centers	58	β_2
60	Cabin Lighting	10	Avionic Centers	215	β_1
61	Navigation	2	Flight Station	40	ϵ
62	Navigation	2	Avionic Centers	200	θ_2
63	Navigation	2	Avionic Centers	86	θ_2
64	Navigation	2	Avionic Centers	1500	β_1
65	Navigation	2	Avionic Centers	1800	β_1
66	Navigation	1	Flight Station	140	θ_2
67	Navigation	1	Avionic Centers	50	θ_2
68	Navigation	1	Avionic Centers	50	θ_2
69	Navigation	1	Flight Station	50	θ_2
70	Navigation	2	Avionic Centers	75	θ_2
71	Navigation	2	Avionic Centers	1750	β_2
72	Navigation	2	Flight Station	75	θ_2

TABLE 2-2. VULNERABLE EQUIPMENTS LIST (Continued)

EQUIPMENT NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT*	LOCATION IN AIRCRAFT	NUMBER OF EXPOSED CONTACTS	VULNERABILITY CATEGORY
73	Navigation	2	Avionic Centers	125	θ_2
74	Navigation	2	Avionic Centers	60	θ_2
75	Navigation	2	Avionic Centers	1800	β_1
76	Navigation	1	Avionic Centers	48	θ_2
77	Navigation	2	Avionic Centers	100	θ_2
78	Airborne Aux Pwr	1	Passenger Cabin	75	θ_2
79	Airborne Aux Pwr	1	Passenger Cabin	200	ϵ
80	Fuel Flow	1	Flight Station	20	ϵ
81	Fuel Flow	1	Flight Station	75	ϵ
82	Engine Ignition	1	Flight Station	75	ϵ
83	Engine Indicating	1	Avionic Centers	700	β_2
84	Engine Indicating	1	Flight Station	32	ϵ

*Note - Total quantity per aircraft equals 281.

CHAPTER 3

L-1011 TRANSFER FUNCTIONS

The term TRANSFER FUNCTION (TF) is used in the context of this study to express a carbon fiber (CF) exposure ratio. Specifically, it is the ratio of the CF concentration at the locations of a piece of electrical or electronic equipment on the L-1011 aircraft to the CF concentration in the aircraft external environment.

Carbon fiber can only infiltrate the aircraft and contaminate potentially vulnerable electrical and electronic components through the Integrated Pneumatic System (IPS) or through certain open external doors. Whenever the aircraft is parked with all doors closed, the IPS not operating, and no external electrical power supplied, CF infiltration is not possible and the TF is zero.

3.1 CARBON FIBER DISTRIBUTION

Depending on the operating configuration of the aircraft, air containing CF can be ingested through several sources, filtered, conditioned, distributed throughout the aircraft and finally exhausted overboard. The various distributions paths are shown schematically in Figure 3-1, and each is discussed in the following sections.

Sources

The L-1011 Integrated Pneumatic System (IPS) supplies the airplane air conditioning and pressurization and provides cooling air to the electronic equipment bays. It consists of an efficient engine bleed air system for inflight operations and an auxiliary power unit (APU) for ground and backup inflight use. The two systems normally operate independently (APU and engine bleedair are not mixed) and are each a potential source of CF. The ground carts that provide high pressure air for engine starting and low pressure, preconditioned air for air conditioning and equipment cooling are additional CF sources. The airplane could also be exposed when avionic center or passenger doors are open. With ground electrical power supplied, the avionics bay exhaust fans would draw air in through the open doors. These sources are discussed in more detail below.

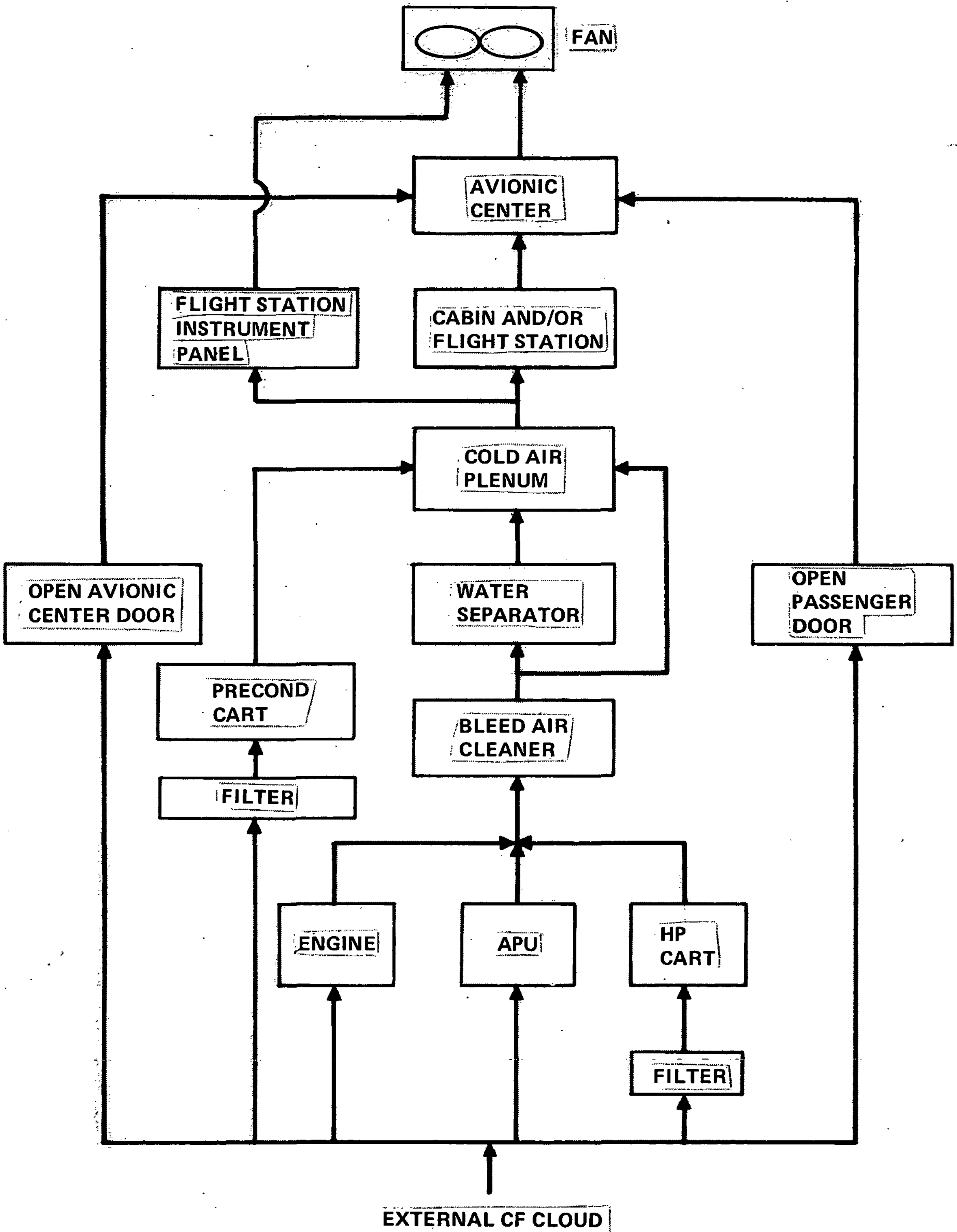


Figure 3-1. L-1011 CF Distribution Paths

The engine bleed air system supplies air to the pneumatic and air conditioning systems. Air is bled from the engine 8th compressor stage (intermediate pressure) of each of the three Rolls Royce RB211 engines during normal flight operation. This air is supplemented, as needed, by high pressure, 13th compressor stage air. The 8th stage bleed air offtakes are located near the outside (O.D.) of the annulus. The 13th stage offtakes are located in the inside wall (I.D.) of the annulus.

The O.D. offtake design of the intermediate pressure port is most efficient for extracting air from the engine. Unfortunately, any dust, debris or carbon fibers that may have been ingested by the engine, will be concentrated along the outer perimeter of the annulus. That this location is more efficient at collecting foreign particles along with engine bleedair than the high pressure port is illustrated by the results of the cabin air dust ingestion tests performed on the engines by Rolls Royce. In the tests, it was found that the efficiency of both ports for sampling fine particles ($<40\mu m$) was similar (59% for the IP system versus 70% for the HP system). However, the IP system was much more efficient at sampling coarse particles (an average of 17% in two tests compared to .8% for the HP port in one test).

The APU driven load compressor has sufficient capacity to operate the entire air conditioning system at optimum capacity. Although the system is capable of being operated at altitudes up to 31,000 feet, its primary function is to provide ground self-sufficiency for the L-1011. The APU takes air from an inlet, about 30 feet above the ground, and compresses it in an engine driven turbo compressor. Any CF collected at the inlet will be delivered to the pneumatic system.

The commercial airlines use a variety of ground carts, both high and low pressure, for various ground operations with their airliners. High pressure carts are normally used for engine starting. However, they also have sufficient capacity to permit their use to run the air conditioning system. In conversations with several suppliers of high pressure carts, it was revealed that some cart manufacturers incorporate filters in their cart designs, and some do not.

Pre-conditioned air (PC) carts are used by the airlines, to provide cart conditioned air to the airplane, thereby obviating the need for the use of onboard refrigeration packs during air terminal operations. When used with the L-1011, such carts supply low pressure air directly to the cold air plenum. Pre-conditioned air carts usually incorporate several filters in their compressor inlet ducts.

Whenever there is electrical power supplied to the aircraft, exhaust fans extract air from the avionic centers which results in air being ingested through any open door in the avionic center or the passenger cabin. When an avionic center door is open, CF contaminated air would be ingested directly into the compartment with sufficient velocity to allow CF to reach the equipment in the compartment with little attenuation. However, CF contaminated air ingested through a passenger door would be heavily attenuated by settling and entrapment in the cabin furnishings and carpet. The extremely low airflow velocity as compared to the fibers fall rate would produce a further attenuation of airborne fibers as they pass through the many interconnected compartments below the passenger floor.

Internal Distribution and Filtering

Dust (and CF) bearing air supplied by the engine bleed ports, the APU or high pressure carts, is ducted to the air distribution manifold. From there three ducts take it through the three bleed air cleaners where most of the particulate matter is removed. It then travels to the three ECS air cycle machines. The distribution manifold system incorporates three duct crossbleed isolation valves that enable division of the manifold into isolated sections. The valves provide operational flexibility for all three refrigeration packs. Each source (any engine, the APU or high pressure cart) can supply air to any or all air cycle machines. Air leaving the ECS refrigeration packs is ducted to the cold air plenum for distribution throughout the air vehicle. When pre-conditioned air carts are in use, the low pressure, conditioned air is ducted directly to the cold air plenum.

In early serial aircraft, silica and other fine particulate matter in the engine bleed air supplied to the refrigeration packs was greatly reducing compressor life. It became necessary to develop a means of removing the particles and centrifugal bleedair cleaners were incorporated. The cleaners remove more than 90% of the dust particles from the airstream and should be equally effective at removing CF.

The functions of the environmental control system (ECS) are to control the supply of conditioned air to the cabin, flight station, galleys, lavatories, and aft cargo compartment; to provide proper occupied area ventilation and cooling; to provide cabin pressurization; to heat the cargo compartments; and to supply cooling air for the forward electronics and mid-electrical service centers. The air conditioning system, using a high pressure source (APU or engine bleed air) conditions the air for cooling or heating as required by the automatic temperature control system and regulates the air flow rate to the cabin. This system consists of three independent refrigeration packs which are manifolded together downstream for greater flexibility and reliability. Each pack contains a water separator, located downstream of the air conditioning unit, consisting of a coalescer, a vortex generator, a moisture collector, and a bypass valve. The water separator is effective in extracting both entrained moisture and solid particles from the air. A portion of the output from each pack bypasses the water separator to provide zone trim air to the cabin distribution system.

Air from the three Environmental Control System packs, or pre-conditioned air carts, passes into the cold air plenum for distribution to the occupied portion of the fuselage (passenger cabin, flight stations, and galley). From these areas, it is exhausted from the cabin through floor-level vents in the sidewall to many underfloor compartments and finally discharged from the fuselage through the forward and mid avionic centers by the exhaust fans. In addition, cooling air is ducted directly from the cold air plenum to the flight station instruments and is discharged through the forward avionics center exhaust fan.

3.2 TRANSFER FUNCTION MODELS FOR FORCED AIR FLOW

The airflow distributions are well known for all Integrated Pneumatic System (IPS) operating configurations. While no test data exist on CF extraction efficiencies for the IPS components, standard road dust test data can be used to compute CF transfer functions with reasonable accuracy. A model, based on conservation of mass flow, is described for each IPS flow pack shown in Figure 3-1.

The following nomenclature is used for the remainder of Chapter 3.

Q_e = Engine total inflow rate

Q_{APU} = APU airflow rate

Q_{HP} = High pressure cart airflow rate

Q_{PC} = Preconditioned cart airflow rate

α_i = Air flow rates ratio across component i

$$\alpha_i = \frac{\text{Air mass flow rate from component i}}{\text{Air mass flow rate into component i}}$$

ϕ_i = CF flow mass ratio across component i

ϕ_i = $\dfrac{\text{CF mass flow rate out of component i}}{\text{CF mass flow rate into component i}}$

η_i = CF or dust filtering efficiency of component i

E_o = External CF exposure, fibers - sec/m^3

E_i = Internal CF exposure, fibers - sec/m^3

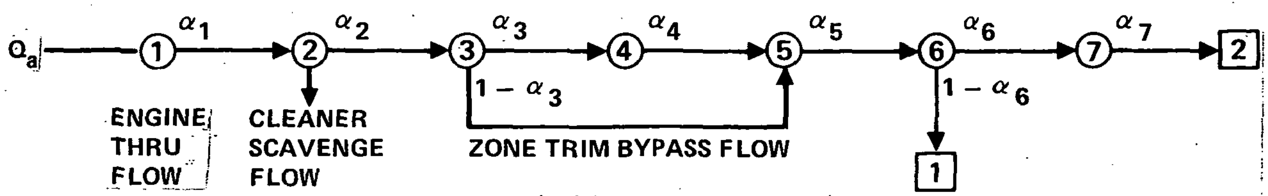
C_o = External CF concentration, fibers/m^3

C_i = Internal CF concentration, fibers/m^3

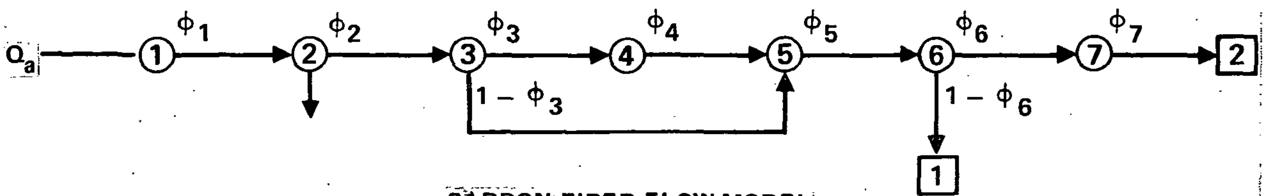
TF = CF transfer function = $E_i/E_o = C_i/C_o$

Note for filters and cleaners: $\phi_i = 1 - \eta_i$

ENGINE BLEED AIR MODEL



ENGINE BLEED AIRFLOW MODEL



CARBON FIBER FLOW MODEL

1 – ENGINES

2 – BLEED AIR CLEANER

3 – ZONE TRIM BYPASS VALVE

4 – WATER SEPARATOR

5 – COLD AIR PLENUM

6 – COLD AIR PLENUM

7 – CABIN AND FLIGHT STATION

$\boxed{1}$ – FLIGHT STATION INSTRUMENT PANEL

$\boxed{2}$ – PASSENGER CABIN AND AVIONIC CENTER

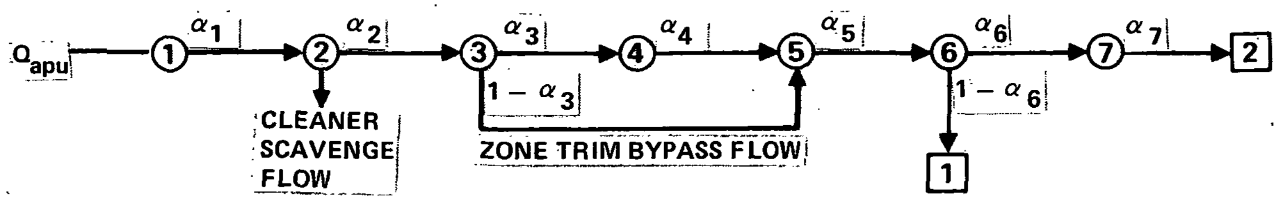
PASSENGER CABIN AND AVIONIC CENTERS

$$TF = \frac{\phi_1\ \phi_2\ \phi_5\ \phi_6\ \phi_7\ (\phi_3\ \phi_4 + 1 - \phi_3)}{\alpha_1\ \alpha_2\ \alpha_5\ \alpha_6\ \alpha_7\ (\alpha_3\ \alpha_4 + 1 - \alpha_3)}$$

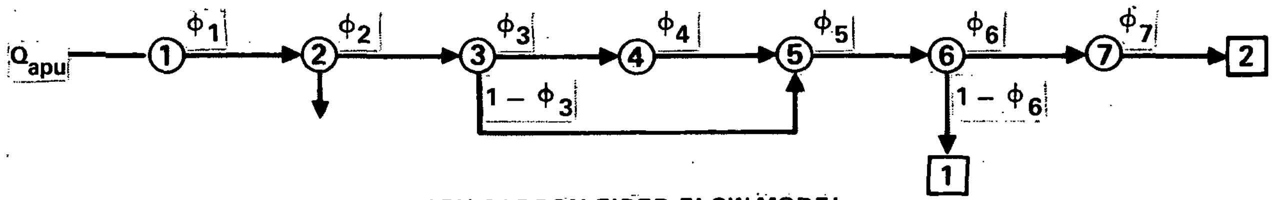
FLIGHT STATION INSTRUMENT PANEL

$$TF = \frac{\phi_1\ \phi_2\ \phi_5\ (1 - \phi_6)\ (\phi_3\ \phi_4 + 1 - \phi_3)}{\alpha_1\ \alpha_2\ \alpha_5\ (1 - \alpha_6)\ (\alpha_3\ \alpha_4 + 1 - \alpha_3)}$$

AUXILIARY POWER UNIT (APU) MODEL



APU AIRFLOW MODEL



APU CARBON FIBER FLOW MODEL

①	– APU	⑤	– COLD AIR PLENUM
②	– BLEED AIR CLEANER	⑥	– COLD AIR PLENUM
③	– ZONE TRIM BYPASS VALVE	⑦	– CABIN AND FLIGHT STATION
④	– WATER SEPARATOR		

1	– FLIGHT STATION INSTRUMENT PANEL
2	– PASSENGER CABIN AND AVIONIC CENTER

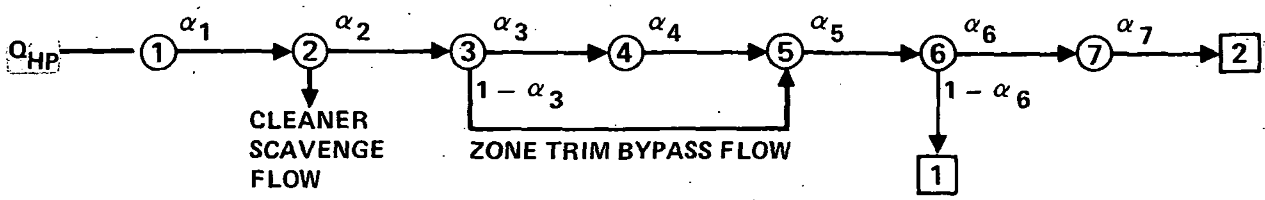
PASSENGER CABIN AND AVIONIC CENTERS

$$TF = \frac{\phi_1\ \phi_2\ \ {}_5\ \phi_6\ \phi_7\ (\phi_3\ \phi_4\ +1-\phi_3)}{\alpha_1\ \alpha_2\ \alpha_5\ \alpha_6\ \alpha_7\ (\alpha_3\ \alpha_4\ +1-\alpha_3)}$$

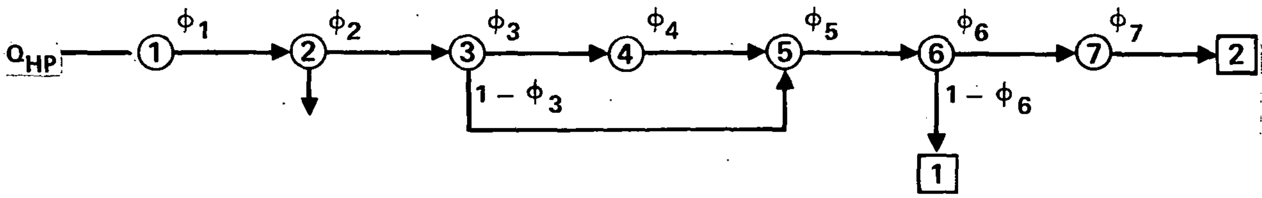
FLIGHT STATION INSTRUMENT PANEL

$$TF = \frac{\phi_1\ \phi_2\ \phi_5\ (1-\phi_6)\ (\phi_3\ \phi_4\ +1-\phi_3)}{\alpha_1\ \alpha_2\ \alpha_5\ (1-\alpha_6)\ (\alpha_3\ \alpha_4\ +1-\alpha_3)}$$

HIGH PRESSURE CART (HP) MODEL



HIGH PRESSURE CART AIRFLOW MODEL



HIGH PRESSURE CART CARBON FIBER FLOW MODEL

(1) – HIGH PRESSURE GROUND CART

(2) – BLEED AIR CLEANER

(3) – ZONE TRIM BYPASS VALVE

(4) – WATER SEPARATOR

(5) – COLD AIR PLENUM

(6) – COLD AIR PLENUM

(7) – CABIN AND FLIGHT STATION

[1] – FLIGHT STATION INSTRUMENT PANEL

[2] – PASSENGER CABIN AND AVIONIC CENTER

PASSENGER CABIN AND AVIONIC CENTERS

$$TF = \frac{\phi_1\ \phi_2\ \phi_5\ \phi_6\ \phi_7\ (\phi_3\ \phi_4 + 1 - \phi_3)}{\alpha_1\ \alpha_2\ \alpha_5\ \alpha_6\ \alpha_7\ (\alpha_3\ \alpha_4 + 1 - \alpha_3)}$$

FLIGHT STATION INSTRUMENT PANEL

$$TF = \frac{\phi_1\ \phi_2\ \phi_5\ (1-\phi_6)\ (\phi_3\ \phi_4 + 1 - \phi_3)}{\alpha_1\ \alpha_2\ \alpha_5\ (1-\alpha_6)\ (\alpha_3\ \alpha_4 + 1 - \alpha_3)}$$

Air Flow Mass Ratios (α)

The following air flow mass ratios are used in the IPS transfer function models. The full flow entering the APU, HP cart, and PC cart is injected into the system. When the source is the engine, two percent of the total engine air flow is bled for IPS supply during engine idle. Therefore:

$$\alpha_1 = \begin{cases} 0.02 & \text{(engine)} \\ 1.0 & \text{(APU, HP cart, PC cart)} \end{cases}$$

The air cleaner operates with a force percent scavenge flow. Therefore:

$$\boxed{\alpha_2 = 0.96}$$

Two of the three refrigeration packs incorporate bypass flow capabilities. The amount of bypass flow depends on the zone temperature trim requirements; however, a typical value is 0.091 kg/s from each of two packs or 0.182 kg/s total. The total output from this three packs is 3.402 kg/s. Therefore, for the water separator:

$$\boxed{\alpha_3 = \left\{ \frac{3.402 - 0.182}{3.402} = 0.947 \right.}$$

and the bypass

$$\boxed{1 - \alpha_3 = 0.053}$$

The total flow for APU operation is 2.990 kg/s; however, the bypass flow would be reduced proportionally and α_3 would be the same.

The air loss from the water separator and the cold air plenum is negligible. Therefore:

$$\alpha_4 = 1.0$$
$$\alpha_5 = 1.0$$

The cold air plenum receives the total output from the three packs. Of this, 0.178 kg/s is ducted directly to the flight station instrument panel and the remainder is ejected into the passenger cabin and flight station. Therefore to the passenger cabin and flight station:

$$\alpha_6 = \begin{cases} \dfrac{3.402 - 0.178}{3.402} = .948 \text{ (Engine, HP cart, PC cart)} \\[2ex] \dfrac{2.990 - 0.178}{2.990} = .940 \text{ (APU)} \end{cases}$$

and to the flight station instrument panel

$$1 - \alpha_6 = \begin{cases} .052 \text{ (Engine, HP cart, PC cart)} \\ .060 \text{ (APU)} \end{cases}$$

The air loss from the passenger cabin and flight station is negligible. Therefore:

$$\alpha_7 = 1.0$$

The mass flow ratios are summarized in Table 3-1.

Carbon Fiber Particle Size and Shape

The test data on particle extraction efficiencies of L-1011 components are for a spectrum of sizes of road dust. In order to apply these data to CF, the characteristics of CF must be related to the characteristics of road dust. The three primary characteristics that affect the extraction efficiencies are size, shape, and density. They affect filter efficiencies and dynamic forces (centrifugal, coriolis, aerodynamic drag, and gravity) which are important in assessing the attenuation of the components employing centrifugal extraction and in settling. NASA studies and tests have added a limited amount of CF data to the data base and will be used, where applicable, to substantiate the extraction efficiencies derived in the following section.

TABLE 3-1. SUMMARY OF MASS FLOW RATIOS

QUANTITY	SOURCE			
	ENGINES	APU	HP CART	PC CART
α_1	0.02	1.0	1.0	1.0
α_2	0.96	0.96	0.96	NA
α_3	0.947	0.947	0.947	NA
α_4	1.0	1.0	1.0	NA
α_5	1.0	1.0	1.0	NA
α_6	0.948	0.940	0.948	0.948
α_7	1.0	1.0	1.0	1.0
ϕ_1	0.003	1.0	1.0	0.005
ϕ_2	0.05	0.05	0.05	NA
ϕ_3	0.947	0.947	0.947	NA
ϕ_4	0.04	0.04	0.04	NA
ϕ_5	1.0	1.0	1.0	NA
ϕ_6	0.948	0.940	0.948	0.948
ϕ_7	0.5	0.5	0.5	0.5

NA - Not Applicable

NASA composite burn tests and equipment vulnerability tests have shown that CF length between one and ten millimeters constitute the range of concern. Very few released fibers exceed 10 mm and fibers less than 1 mm pose little, if any, hazard to electrical equipment. Since particle extraction efficiencies increase with the size of the particle, a single CF length at the lower end of the spectrum, 1.5 mm, is conservatively selected for the derivation of the transfer functions.

Since free CF are flexible, their straight cylindrical shape will be deformed in unknown ways under the high forces imposed by the high flow rates through the IPS. Therefore it is reasonable to assume a 7.5μm diameter by 1500μm long fiber can be represented by an equal volume 50.2μm diameter sphere.

The settling rate for 50μm road dust is 8-10 m/min compared to 1.92 m/min average settling rate for CF. Since the extraction efficiency of centrifugal filters increases with density for particles of equal size and shape and settling rate also increases with density, the extraction efficiency for road dust should be greater than for CF. However, NASA studies show that fibers disintegrate under the high forces imposed by a centrifugal air cleaner which would more than compensate for the lower extraction efficiency. Therefore CF mass flow ratios are derived from 50μm road dust test data.

CF Mass Flow Ratios (ϕ)

The following CF mass flow ratios are used in the IPS transfer function models. Road dust ingestion test results on L-1011 engines at idle show that an average of 17% of the ingested coarse (<40μm) dust mass per unit bleed air flow mass would be ejected into the bleed air system. Since the bleed air supply is 2% of the engine air flow:

$$\phi_1 = 0.17 \times 0.02 = 0.003 \text{ (Engine)}$$

This value assumes no change in the spectrum of CF lengths. Studies conducted by NASA concluded that CF is too fragile to withstand the high forces imposed on them during the passage through the engine compressor stages. The fibers would disintegrate into lengths too short to cause equipment failures and therefore the transfer function through an engine would be zero.

The APU supply has no filtering. Therefore:

$$\phi_1 = 1.0 \quad \text{(APU)}$$

The HP carts have a wide range of extraction efficiencies, varying from filter efficiencies of 0.998 for 50μm road dust to no filters. For this analysis a worst case is used. Therefore:

$$\phi_1 = 1.0 \quad \text{(HP cart)}$$

A preconditioned air (PC) cart used by several L-1011 operators contains a series of four filters in the inlet. Based on the work on filter efficiencies published under Phase I of this program, it is estimated that this PC cart has a CF extraction efficiency of at least 0.995. Therefore:

$$\phi_1 = 0.005 \text{ (PC cart)}$$

Tests on the bleed air cleaner show that the extraction efficiency for particles in 40μm - 60μm range is 95%. Therefore:

$$\phi_2 = 0.05$$

Tests conducted by NASA on a different air cleaner show the extraction efficiency for 1-3 mm long CF is greater than 99.5%.

Dust extraction tests were not conducted on the water separator. A fabric filter collects water in the coalescer which is separated from the airstream by centrifugal force in the vortex generator. Test data show the average droplet size of the water emerging from the coalescer is 25μm and the water extraction efficiency is 96%. It is estimated that the water separator is at least as effective in removing 50μm solid particles. The bypass flow is not filtered. Therefore to the water separator:

$$\phi_3 = \alpha_3 = 0.947$$

and the bypass:

$$1 - \phi_3 = 0.053$$

and for the water separator:

$$\phi_4 = 0.04$$

Tests conducted by NASA on a similar water separator show the extraction efficiency for 1-3 mm long CF is greater than 99.3%.

The high velocities in the cold air plenum and duct to the flight station instrument panel would produce negligible CF attenuation. Therefore

$$\phi_5 = \alpha_5 = 1.0$$

$$\phi_6 = \alpha_6 = \begin{cases} 0.948 \text{ (Engine, HP cart, PC cart)} \\ 0.940 \text{ (APU)} \end{cases}$$

$$1 - \phi_6 = \begin{cases} 0.052 \text{ (Engine, HP cart, PC cart)} \\ 0.060 \text{ (APU)} \end{cases}$$

The air from the cold air plenum is more or less uniformly distributed to all areas of the passenger cabin and flight station. The flow is sufficient to displace the encapsulated air every five to six minutes generating air velocities that are seldom less than six meters per minute. Since the CF settling rate is approximately one third of the air velocity, CF would tend to remain airborne. However, the airflow forms circular patterns and many CF would be entrapped in the carpets and interior furnishings prior to infiltrating electrical and electronic equipments in these compartments which are located behind shrouds. The air is ejected to the underfloor compartments through vents located in the cabin sidewalls at the floor line. It is estimated that at least 50% of the CF would be entrapped in the passenger cabin. Therefore:

$$\boxed{\phi_7 = 0.5}$$

The CF mass flow ratios are summarized in Table 3-1.

3.3 TRANSFER FUNCTION ESTIMATES FOR OPEN EXTERNAL DOORS

A normal operating configuration, particularly during maintenance, consists of supplying external electrical power to aircraft while various external doors are open. Whenever electrical power is supplied, exhaust fans discharge air directly from the avionic service centers to provide convective cooling for the equipment. This generates a flow through all the many interconnected compartments in the fuselage both above and below the passenger cabin floor resulting in air ingestion through open doors. The precise distribution of airflow throughout the aircraft has never been investigated for this configuration, or more accurately configurations since it would be affected by which combination of eight passenger and two avionic center doors are open and the external wind velocity and direction. Without precise knowledge of the airflow distribution, the transfer functions cannot be calculated accurately. However, the transfer functions can be estimated from certain data that are available.

Avionic Center Doors Open

With the avionic center doors open, air is ingested directly into the compartment and exhausted through the equipment. The flow rates are high so there will be little attenuation of CF for equipment within the avionic centers. However, very little ingested air will circulate through the passenger cabin and flight station and any CF would settle before the equipment in these areas could be contaminated. Therefore a reasonable estimate for the purpose of this study is transfer functions of one for the avionic centers and zero for the passenger cabin and flight station.

Passenger Cabin Doors Open

Measured temperature decay rates in the avionic service centers show that air ingested through the passenger doors mixes very slowly with the encapsulated air. This indicates that most of the ingested air distributes throughout the length of the passenger cabin before passing through the floor at the sidewall vents into the many underfloor compartments before finally being exhausted from the avionic service centers. Since the capacities of the exhaust fans would require approximately twenty-five minutes and fifty minutes, respectively, for the forward and aft fans to displace the volume of encapsulated air, the flow rates would be very low compared to the settling rate of CF. Therefore, CF would be heavily attenuated by settling and entrapment by the carpet and furnishings of the passenger cabin. Additional attenuation would result from obstructions (structure, installations, insulation, etc.) in the below floor compartments. It is estimated that less than one percent of the air could reach the service centers with any appreciable amount of CF. Therefore, a transfer function of 0.01 is considered a realistic estimate for the avionic service centers.

Since essentially all potentially vulnerable equipment in the passenger cabin and flight stations are located behind shrouds in the upper portion of the compartment, the exposure to these components will be minimal due to the settling rate of the fibers. A transfer function of 0.01 is used for the entire aircraft with open passenger doors.

Cargo and Galley Doors Open

The cargo compartments on the L-1011 are sealed to prevent the flow of oxygen to sustain a fire. Any CF ingested through an open cargo door would be contained within the cargo compartment and the transfer function would essentially be zero. No further consideration is given to this configuration.

There are two means of access to the mid avionics service center, through the avionics center door and through an internal door from the galley. Access through the galley is the means normally used on the L-1011 and when the external galley door is also open, there would be little attenuation of CF. For the purpose of this study, either configuration is considered to have a transfer function equal to one and is categorized as an "avionic service center door open" configuration. When the internal door between the galley and the avionic service center is closed and its external galley door open, the transfer function would be similar to that for an open passenger door and is included in that configuration.

3.4 SUMMARY OF TRANSFER FUNCTIONS

The transfer functions calculated by the forced air flow models of Section 3.2 and estimated in Section 3.3 are summarized in Table 3-2. These values were derived considering a single source of CF ingestions. During ground operation, the aircraft will often be subject to CF ingestion from more than one source (e.g., APU operating with passenger doors open, both avionic center and passenger doors open, etc.). For multiple source configurations, the largest transfer function from any single source is conservatively used in the risk assessment. The actual value is between the values for the single sources. The multiple source transfer functions tabulated in Table 3-3 are used for the risk assessments of this report.

TABLE 3-2. L-1011 TRANSFER FUNCTIONS

CF SOURCE	AIRCRAFT LOCATION		
	AVIONIC CENTERS	PASSENGER CABIN	FLIGHT STATION PANEL
Engine	0.0004	0.0004	0.0008
APU	0.0025	0.0025	0.0050
HP Cart	0.0024	0.0024	0.0047
PC Cart	0.0025	0.0025	0.0050
Avionic Doors Open	1.0	0	0
Passenger Doors Open	0.01	0.01	0.01

TABLE 3-3. TRANSFER FUNCTIONS FOR MULTIPLE INGESTION SOURCES

AIRCRAFT LOCATION	AIRCRAFT POWER	AVIONIC CENTER DOORS			
		OPEN		CLOSED	
		PASSENGER DOORS			
		OPEN	CLOSED	OPEN	CLOSED
Avionic Centers	Engine	1.0	1.0	0.01	0.0004
	APU	1.0	1.0	0.01	0.0025
	Air Cart	1.0	1.0	0.01	0.0025
	Ground Elec.	1.0	1.0	0.01	0
	None	1.0	1.0	0.01	Parked
Passenger Cabin	Engine	0.01	0.0004	0.01	0.0004
	APU	0.01	0.0025	0.01	0.0025
	Air Cart	0.01	0.0025	0.01	0.0025
	Ground Elec.	0.01	0	0.01	0
	None	0.01	0	0.01	Parked
Flight Station	Engine	0.01	0.0008	0.01	0.0008
	APU	0.01	0.0050	0.01	0.0050
	Air Cart	0.01	0.0050	0.01	0.0050
	Ground Elec.	0.01	0	0.01	0
	None	0.01	0	0.01	Parked

Note: Air Cart applies to either HP Cart or PC Cart.

CHAPTER 4

STATISTICAL ASSESSMENT OF AIRCRAFT OPERATIONS AT AIRPORTS

This assessment provides data required to evaluate the risk to commercial transport aircraft. The first part of this study estimates the population of aircraft at airports as a function of aircraft size, time of day and operational mode. These data form the basis for establishing the probabilities of aircraft exposure contained in Appendix C. The second part of this study estimates the time distribution of aircraft configurations within the operational mode as the basis for establishing aircraft transfer function distributions.

The burden of this study was shared by the airframe manufacturers. The work performed by Lockheed is documented in this chapter along with a summary of the results from the other manufacturers.

4.1 AIRCRAFT POPULATIONS IN AIRPORT OPERATIONAL MODES

Nine airports were analyzed to provide a statistical data base for the simulation analysis contained in Appendix C. The airports are:

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

The first three airports were analyzed by Lockheed, the next three were analyzed by the Douglas Aircraft Company and the last three by the Boeing commercial Airplane Company.

The expected number of aircraft on the ground at these airports was required for input to the simulation model. The three airports analyzed by Lockheed are described in the following section.

4.1.1 Analysis of Operations at Three Airports

It was required that the data on aircraft populations at airports be developed by time of day, aircraft size and operational mode. To ensure compatibility of results for all nine airports, the following definitions were established:

Time of Day

Day - 6 AM to 9 PM (0601-2100)

Night - 9 PM to 6 AM (2101-0600)

Aircraft Size

Large - 747, DC-10, L-1011

Medium - A300, DC-8-60 (Series)

Small - All other commercial jets not included above.

(Note: Propellor driven aircraft and small non-commercial jets are excluded.)

Operating Modes

In maintenance

At the Gate (Ramp)

Parked

Aircraft In Maintenance

Existing data on aircraft in maintenance were insufficient. Therefore, it was necessary to contact airport officials, airline maintenance personnel and resident field service representatives to establish the populations of aircraft in maintenance. Table 4-1 shows the number of aircraft in maintenance that were estimated for the three airports analyzed. The estimates are given for the day and night periods and by aircraft size. Washington National Airport operations are restricted to small aircraft and no significant maintenance is performed.

TABLE 4-1. AVERAGE AIRCRAFT POPULATIONS IN MAINTENANCE AT THREE AIRPORTS

PERIOD	SIZE CATEGORY	AIRPORT		
		WASHINGTON NATIONAL	ATLANTA	MIAMI
Day (0601-2100)	Small	-0-	10	4
	Medium	---	1	-0-
	Large	---	2	3
Night (2101-0600)	Small	-0-	16	8
	Medium	---	1	2
	Large	---	3	6

Aircraft Movements

Aircraft movements at each airport were available from a computer print-out of an official Airline Guide tape. It contained the arrival and departure times of scheduled flights by aircraft type and airline. For this study, movements through each airport during one typical day were analyzed. The information evaluated at each airport is summarized in Table 4-2. The total movements (arrivals and departures) scheduled on each date are shown along with the percentabe of the total for the day and night periods. The number of aircraft movements applicable to this analysis are shown by size category. As noted earlier, propeller driven aircraft and small non-commercial jets are not included in this study.

Table 4-3 lists the applicable aircraft types found at each airport. At the present time, operators are restricted to small aircraft at Washington National Airport.

In analyzing movements of applicable aircraft, the ground times were calculated for through flights and for turnaround flight. The ground time of through flights is the difference between their arrival and departure times. However, turnaround flights change flight numbers. Therefore, ground times were calculated by matching arrivals and departures according to aircraft type and airline on a "first in, first out" basis. These calculations established the time interval each aircraft was on

TABLE 4-2. AIRCRAFT MOVEMENTS AT THREE AIRPORTS

		AIRPORT		
		WASHINGTON NATIONAL	ATLANTA	MAIMI
Date		Feb. 15, 1979	Feb. 16, 1979	Feb. 17, 1979
Total Aircraft Movements		726	1527	851
Percent	Day (0601-2100)	91.1%	84.2%	84.5%
	Night (2101-0600)	8.9%	15.8%	15.5%
Applicable Aircraft Movements(1)		550	1304	728
Size	Small	550	1124	554
	Medium	---	56	48
	Large	---	124	126

(1)Propeller aircraft and small business jets excluded.

on the ground. The number for each aircraft size category were counted at fifteen minute intervals for the entire 24-hour period to obtain average populations by hour and for the day and night periods.

When an airplane moves through an airport, the time on the ground is spent "at the gate." If an aircraft remains at an airport for an extended period of time, it will very likely be "parked" for some portion of the time, especially aircraft that remain overnight. The number of overnight aircraft at each airport is shown in Table 4-4. In this analysis, the overnights and long afternoon stays had their ground times allocated between time "at the gate" and "parked." The allocation for each airport is discussed below along with results of the analysis.

TABLE 4-3. TYPES OF AIRCRAFT AT THREE AIRPORTS

AIRPORT	AIRCRAFT SIZE		
	SMALL	MEDIUM	LARGE
Washington National	BAC-111 DC-9 727 737	-None	-None-
Hartsfield-Atlanta International	707 727 737 DC-8 (excl -60) DC-9	A300 DC-8-60 (series)	L-1011
Miami International	BAC-111 707 720 727 737 DC-8 (excl -60) DC-9	A300 DC-8-60 (series)	747 L-1011 DC-10

TABLE 4-4. OVERNIGHT AIRCRAFT POPULATIONS AT THREE AIRPORTS

SIZE	AIRPORT		
	WASHINGTON NATIONAL	ATLANTA	MAIMI
Small	27	24	52
Medium	--	3	4
Large	00	6	7
TOTAL	27	33	63

SUMMARY OF RESULTS

Table 4-5 presents a summary of the results of the analyses for the three airports. The average number of aircraft during the day and night periods are shown by aircraft size and operational mode. These averages were determined from hourly tabulations contained in Appendix B.

Only small aircraft operate at Washington National Airport, due to a current aircraft size restriction. Another restriction at Washington National Airport is an operating curfew between the hours of 11 PM (2300) and 7 AM (0700).

TABLE 4-5. AVERAGE AIRCRAFT POPULATIONS AT THREE AIRPORTS

		PERIOD					
		DAY (0601 - 2100)			NIGHT (2101 - 0600)		
		OPERATIONAL MODE					
AIRPORT	AIRCRAFT SIZE	GATE	MAINT.	PARKED	GATE	MAINT.	PARKED
Washington National	Small	16.05	0.00	0.93	9.86	0.00	16.17
	Medium	---	---	---	---	---	---
	Large	---	---	---	---	---	---
Atlanta	Small	30.73	10.00	1.25	25.50	16.00	5.83
	Medium	2.47	1.00	0.20	1.67	1.00	0.00
	Large	4.10	2.00	0.00	3.86	3.00	0.00
Miami	Small	19.03	4.00	5.43	29.75	8.00	12.08
	Medium	2.60	0.00	0.00	3.33	2.00	0.00
	Large	5.88	3.00	0.92	5.11	6.00	1.44

This restriction results in twenty-seven (27) overnights that spend part of the time "at the gate" and the remainder of the time "parked." To account for this effect, it was estimated that a small size aircraft would spend thirty (30) minutes at the gate after its arrival to unload passengers and baggage plus thirty (30) minutes before its departure to load passengers and baggage. In addition, it was estimated that three (3) hours were spent during the night to service each aircraft and the remainder of the time the aircraft was in a "parked" condition. The time "at the gate" for arrivals and departures is identified by the schedule but the time "at the gate" for servicing was spread equally between 10 PM and 7 AM.

The approach used for Hartsfield-Atlanta Airport was essentially the same as Washington National Airport except that overnights and long stays at this airport were treated somewhat differently because of the more extensive maintenance capabilities at this airport and the existence of medium and large size aircraft. Small size aircraft were still allocated thirty (30) minutes on the ramp after their arrival for unloading passengers and baggage plus thirty (30) minutes before their departure for loading passengers; but medium and large size aircraft were allowed sixty (60) minutes in each case. However, all size aircraft staying overnight or having a long stay during the day would be allowed four (4) hours of servicing. Since the airport is operating every hour, the usual maintenance practice would be to service the aircraft immediately after debarking passengers and then place the aircraft in a parked condition until preparation for departure.

The data for Miami International Airport were developed in the same manner as Hartsfield-Atlanta International Airport.

4.1.2 Summary of Operations at Nine Airports

The results for all nine airports are summarized in Table 4-6. Since parked aircraft are closed shut and invulnerable to carbon fiber (CF) contamination damage they have not been included in this summary.

TABLE 4-6. AVERAGE AIRCFAFT POPULATIONS AT NINE AIRPORTS

AIRPORT	AIRCRAFT SIZE	DAYTIME GATE	DAYTIME MAINT.	NIGHTTIME GATE	NIGHTTIME 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
JKF	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

4.2 AIRCRAFT CONFIGURATIONS WITHIN OPERATIONAL MODES

Time distributions of potentially vulnerable aircraft configurations within the operational modes are required to establish transfer function distributions for the aircraft risk assessments. This work was divided between Boeing and Lockheed. Boeing analyzed the gate mode and Lockheed analyzed the maintenance mode which is described in the following section.

4.2.1 Analysis of Configurations in Maintenance Mode

Maintenance operations at Los Angeles International Airport (LAX) are considered representative of airports with major maintenance facilities. No significant difference between day and night maintenance practices could be identified that could result in a difference in the distribution of maintenance configurations, even though there would be a difference in the number of aircraft during these periods. Therefore, the time distributions derived in this section are applicable to the maintenance mode for both day and night operations.

Two surveys were conducted at LAX to analyze maintenance modes. The first was to observe and record aircraft configurations during periodic trips to the various maintenance facilities at the airport. The second survey consisted of obtaining estimates of configuration distributions from maintenance personnel at four airlines.

For the first survey, two hundred and twenty-one observations were made of aircraft inside of or in the immediate vicinity of maintenance hangers. These observations were made at various times of the day and night over a four day period. The sample shown in Table 4-7 consists of various combinations of the following parameters affecting the distribution of aircraft configurations.

aircraft size	small, large
hanger location	inside, outside
avionic doors	open, closed
passenger doors	open, closed
power to aircraft	ground electrical, APU operating engine operating, no power

No medium size aircraft were observed during the times the sample was taken. Also, no air carts were seen providing power to an aircraft. Therefore these parameters were not included in Table 4-7.

TABLE 4-7. STATISTICAL SAMPLE OF AIRCRAFT CONFIGURATIONS IN MAINTENANCE MODE

POWER TO AIRCRAFT	AVIONIC DOORS	AIRCRAFT SIZE							
		SMALL				LARGE			
		HANGAR LOCATION							
		INSIDE		OUTSIDE		INSIDE		OUTSIDE	
		PASSENGER DOORS							
		OPEN	CLOSED	OPEN	CLOSED	OPEN	CLOSED	OPEN	CLOSED
Grd Elect Open	Open	51	0	58	0	13	0	33	0
	Closed	3	0	17	0	2	0	7	0
APU Open	Open	X	X	3	0	X	X	4	1
	Closed	X	X	0	0	X	X	2	1
Eng Open	Open	X	X	1	0	X	X	1	0
	Closed	X	X	0	2	X	X	0	0
No Pwr	Open	1	0	0	0	1	0	2	0
	Closed	2	0	2	6	1	0	2	5

SAMPLE TOTAL: 221 observations

The second survey was conducted during the same four day period that the samples observations were taken. Four airlines, having major maintenance facilities at LAX were contacted. The estimates for fraction of time in various aircraft configurations obtained from maintenance personnel at each airline are shown in Table 4-8.

TABLE 4-8. AIRLINE PERSONNEL ESTIMATES OF AIRCRAFT CONFIGURATIONS IN MAINTENANCE MODE

CONDITION	HANGAR AREA	ESTIMATED PERCENTAGE			
		AIRLINE			
		A	B	C	D
Pass. Doors Open	Inside	100%	100%	100%	95%
	Outside	100%	100%	100%	95%
Ground Elect. Power	Inside	100%	100%	100%	100%
	Outside	90%	85%	85-90%	93-94%
Avionic Doors Open	Inside	10% Large 100% Small	100%	100%	90%
	Outside	10% Large 100% Small	75%	90%	90%
APU Operating	Inside	0%	0%	0%	0%
	Outside	<10% Large 60% Small	15%	10-15%	6-7%
Engines Operating	Inside	0%	0%	0%	0%
	Outside	5%	< 5%	1%	1%
HP Cart	Inside	0%	0%	0%	0%
	Outside	< 5%	< 1%	0%	0%
LP Cart	Inside	0%	0%	0%	0%
	Outside	0%	< 1%	0%	0%

Using the two surveys as a basis, the fraction of time for various aircraft configurations in the maintenance mode was established and is summarized in Table 4-9. Only the parameters, avionic doors, passenger doors and power to aircraft are included in the table. Aircraft size and hangar area are statistically insignificant in establishing the configuration time distributions.

4.2.2 Summary of Configurations in All Modes

The information in Table 4-9 along with the results obtained by Boeing for the gate mode, are summarized in Table 4-10. In the case of the gate mode, the day and night periods show a significant difference in the configuration distributions.

TABLE 4-9. TIME DISTRIBUTION OF AIRCRAFT CONFIGURATIONS IN MAINTENANCE MODE

FRACTION OF TIME

POWER TO AIRCRAFT	AVIONIC DOORS: OPEN		AVIONIC DOORS: CLOSED	
	PASSENGER DOORS: OPEN	PASSENGER DOORS: CLOSED	PASSENGER DOORS: OPEN	PASSENGER DOORS: CLOSED
APU	0.033	0.005	0.010	0.005
Engines	0.010	-0-	-0-	0.010
Air Cart	0.010	-0-	-0-	-0-
Elect Cart	0.727	-0-	0.138	-0-
None	0.019	-0-	0.033	Parked

TABLE 4-10. SUMMARY OF TIME DISTRIBUTIONS OF AIRCRAFT CONFIGURATIONS FOR ALL OPERATIONAL MODES

FRACTION OF TIME PER OPEATIONAL MODE

OPERATIONAL MODE	POWER TO AIRCRAFT	AVIONIC DOORS			
		OPEN		CLOSED	
		PASSENGER DOORS			
		OPEN	CLOSED	OPEN	CLOSED
Gate, Day	APU	0.01	-0-	0.95	-0-
	Engine	-0-	-0-	-0-	-0-
	Air Cart	-0-	-0-	-0-	-0-
	Ground Elect	-0-	-0-	0.04	-0-
	None	-0-	-0-	-0-	Parked
Gate, Night	APU	-0-	-0-	0.18	-0-
	Engine	-0-	-0-	0.02	-0-
	Air Cart	-0-	-0-	-0-	-0-
	Ground Elect	0.30	-0-	0.50	-0-
	None	-0-	-0-	-0-	Parked
Maintenance	APU	0.033	0.005	0.010	0.005
	Engine	0.010	-0-	-0-	0.010
	Air Cart	0.010	-0-	-0-	-0-
	Ground Elect	0.727	-0-	0.138	-0-
	None	0.019	-0-	0.033	Parked

Using the results shown in Table 3-3 and Table 4-10, the distribution of time for the carbon fiber (CF) transfer functions for each location in the aircraft was determined. Tables 4-11, 4-12, and 4-13 show, respectively, the time distributions for the avionic centers, passenger cabin and flight station areas. These tables will be used in the following chapter.

TABLE 4-11. TIME DISTRIBUTION OF CF TRANSFER FUNCTIONS FOR AVIONIC CENTERS

OPERATIONAL MODE / TRANSFER FUNCTION	FRACTION OF TIME		
	GATE-DAY	GATE-NIGHT	MAINTENANCE
1.0	0.010	0.300	0.804
0.01	0.040	0.700	0.138
0.0025	0.950	-0-	0.048
0.0004	-0-	-0-	0.010

TABLE 4-12. TIME DISTRIBUTION OF CF TRANSFER FUNCTIONS FOR PASSENGER CABIN

OPERATIONAL MODE / TRANSFER FUNCTION	FRACTION OF TIME		
	GATE-DAY	GATE-NIGHT	MAINTENANCE
0.01	1.0	1.0	0.98
0.0025	0	0	0.01
0.0004	0	0	0.01

TABLE 4-13. TIME DISTRIBUTION OF CF TRANSFER FUNCTIONS FOR FLIGHT STATION

OPERATIONAL MODE / TRANSFER FUNCTION	FRACTION OF TIME		
	GATE-DAY	GATE-NIGHT	MAINTENANCE
0.01	1.0	1.0	0.98
0.005	0	0	0.01
0.0008	0	0	0.01

CHAPTER 5

PROBABILITY OF ELECTRICAL AND ELECTRONIC EQUIPMENT FAILURES CONDITIONAL ON AIRCRAFT EXTERNAL CF EXPOSURE

Each of the potentially vulnerable pieces of electrical and electronic equipment, identified in Chapter 2, presents a risk of failing wherever the L-1011 is subjected to an external CF exposure. The level of risk depends on the conditional probabilities that the equipments fail given the exposure. These probabilities are a function of the following variables:

- The magnitude of the external exposure, E
- The vulnerability of the individual piece of equipment indicated by its mean exposure for failure, $\bar{E}$
- The location of the equipment in the aircraft and the operating configuration of the aircraft to establish the CF transfer function to the equipment, TF
- The operational mode of the aircraft to define the time distribution of transfer functions within each operational mode.

The conditional probabilities of failure can easily be calculated from the data developed in Chapters 2 - 4.

Analysis of data compiled from equipment vulnerability tests, conducted under the direction of NASA, has shown that it is reasonable to represent the CF exposure level at the equipment causing failure as an exponentially distributed random variable characterized by the mean exposure to failure. Also the exposure at the equipment is related to the aircraft external exposure by the transfer function associated with the specific aircraft configuration. Therefore, each equipment in the same aircraft location with the same mean exposure to failure will have the same probability of failure under identical conditions of aircraft configuration and external exposure. Since the same aircraft location and mean exposure to failure were necessary conditions for establishing the equipment groups in Appendix A, the probability of failure is described by:

$$p_{ijk} = 1 - e^{-\left[(TF)_{ik}\, E_j/\overline{E}_i\right]}$$

where:

$\overline{E}_i$ = mean exposure to failure for equipment in group i ~ fiber-sec/in^3

E_j = a discrete aircraft external exposure ~ fiber-sec/in^3

$(TF)_{ik}$ = the transfer function for group i associated with the specific aircraft configuration k

therefore:

p_{ijk} = the probability of failure for each equipment in group i conditional on the aircraft being in configuration k and exposed to the discrete exposure E_j.

The time distribution of transfer functions, derived in Section 4.3, can readily be combined with the above conditional probabilities to produce the probability of equipment failure conditional on the aircraft external exposure for each of the aircraft operational modes described in Section 4.1. This is described by:

$$P_{ij} = \sum_k \overline{p}_k \, p_{ijk}$$

where:

$\overline{p}_k$ = the fraction of time the aircraft is in the configuration k that defines the transfer function $(TF)_{ik}$ for the equipment group i. The set of all k within an operational mode produces a mutually exclusive exhaustive set of probabilities.

Therefore:

P_{ij} = the probability of failure for each equipment in group i conditional on the aircraft being exposed to the discrete exposure E_j within an operational mode.

For each of the three airport operational modes (gate-day, gate-night, maintenance), the conditional probabilities, P_{ij}, are listed in Tables 5-1, 5-2, and 5-3 for several levels of aircraft external exposure. These probabilities are used in risk analyses contained in the following chapters.

TABLE 5-1. PROBABILITY OF EQUIPMENT FAILURE CONDITIONAL ON AIRCRAFT EXTERNAL CF EXPOSURE IN GATE-DAY MODE

EQUIP GROUP $\bar{E}$	TRANSFER FUNCTION DISTRIBUTION	PROBABILITY OF FAILURE: GATE - DAY				
		EXPOSURE LEVEL - E				
		3.2×10^{3}	3.2×10^{4}	3.2×10^{5}	3.2×10^{6}	3.2×10^{7}
Group A Avionic Centers $\bar{E}=1.5\times10^{7}$	Table 4-11	2.72×10^{-6}	2.72×10^{-5}	2.70×10^{-4}	2.51×10^{-3}	1.47×10^{-2}
Group B Flight Station $\bar{E}=1.0\times10^{8}$	Table 4-12	3.20×10^{-7}	3.20×10^{-6}	3.20×10^{-5}	3.20×10^{-4}	3.19×10^{-3}
Groups C&D Passenger Cabin $\bar{E}=1.0\times10^{8}$	Table 4-13	3.20×10^{-7}	3.20×10^{-6}	3.20×10^{-5}	3.20×10^{-4}	3.19×10^{-3}
Groups E-H Avionic Centers $\bar{E}=1.0\times10^{8}$	Table 4-11	4.09×10^{-7}	4.09×10^{-6}	4.08×10^{-5}	4.04×10^{-4}	3.63×10^{-3}

TABLE 5-2. PROBABILITY OF EQUIPMENT FAILURE CONDITIONAL ON AIRCRAFT EXTERNAL CF EXPOSURE IN GATE - NIGHT MODE

EQUIP GROUP $\overline{E}$	TRANSFER FUNCTION DISTRIBUTION	PROBABILITY OF FAILURE: GATE - NIGHT				
		EXPOSURE LEVEL - E				
		3.2×10^{3}	3.2×10^{4}	3.2×10^{5}	3.2×10^{6}	3.2×10^{7}
Group A Avionic Centers $\overline{E}=1.5 \times 10^{7}$	Table 4-11	6.54×10^{-5}	6.54×10^{-4}	6.48×10^{-3}	5.91×10^{-2}	2.79×10^{-1}
Group B Flight Station $\overline{E}=1.0 \times 10^{8}$	Table 4-12	3.20×10^{-7}	3.20×10^{-6}	3.20×10^{-5}	3.20×10^{-4}	3.19×10^{-3}
Groups C&D Passenger Cabin $\overline{E}=1.0 \times 10^{8}$	Table 4-13	3.20×10^{-7}	3.20×10^{-6}	3.20×10^{-5}	3.20×10^{-4}	3.19×10^{-3}
Groups E-H Avionic Centers $\overline{E}=1.0 \times 10^{8}$	Table 4-11	9.82×10^{-6}	9.82×10^{-5}	9.79×10^{-4}	9.67×10^{-3}	8.44×10^{-2}

TABLE 5-3. PROBABILITY OF EQUIPMENT FAILURE CONDITIONAL ON AIRCRAFT EXTERNAL CF EXPOSURE IN MAINTENANCE MODE

EQUIP GROUP	TRANSFER FUNCTION	PROBABILITY OF FAILURE: MAINTENANCE				
		EXPOSURE LEVEL - E				
$\overline{E}$	DISTRIBUTION	$3.2x10^3$	$3.2x10^4$	$3.2x10^5$	$3.2x10^6$	$3.2x10^7$
Group A Avionic Centers $\overline{E}=1.5x10^7$	Table 4-11	$1.72x10^{-4}$	$1.72x10^{-3}$	$1.70x10^{-2}$	$1.55x10^{-1}$	$7.12x10^{-1}$
Group B Flight Station $\overline{E}=1.0x10^8$	Table 4-12	$3.15x10^{-7}$	$3.15x10^{-6}$	$3.15x10^{-5}$	$3.15x10^{-4}$	$3.14x10^{-3}$
Groups C&D Passenger Cabin $\overline{E}=1.0x10^8$	Table 4-13	$3.15x10^{-7}$	$3.15x10^{-6}$	$3.15x10^{-5}$	$3.15x10^{-4}$	$3.14x10^{-3}$
Groups E-H Avionic Centers $\overline{E}=1.0x10^8$	Table 4-11	$2.58x10^{-5}$	$2.58x10^{-4}$	$2.57x10^{-3}$	$2.54x10^{-2}$	$2.21x10^{-1}$

CHAPTER 6

EXPECTED INCREASE IN EQUIPMENT FAILURES DUE TO CF CONTAMINATION

The probabilities of equipment failure conditional on the CF exposure from the previous chapter can be combined with the expected frequency the L-1011 fleet will experience various CF exposure levels to determine the expected number of electrical and electronic equipment failures resulting from CF contamination. The expected number of failures due to CF containimation can be compared to the expected number of failures due to current sources to assess the relative impact on the equipment failure burden for L-1011 operators. Since the source of CF contamination is free fibers released from fires on commercial transport aircraft incorporating CF composite materials, the frequency and magnitude of CF exposures is directly related to the utilization of composite materials. Only small quantities of this material are incorporated on a small portion of the commercial fleet at this time. However, airframe manufacturers project dramatic increased use of composite materials in the next ten to fifteen years. To reflect this phenomena, the analyses in this and subsequent chapters are based on the U.S. commercial transport fleet projected for the year 1993.

Appendix C contains the expected number of aircraft exposed to various discrete CF exposure levels for the year 1993. This analysis, conducted by Arthur D. Little, Inc., employed a Monte Carlo simulation using a CF dispersion and risk analysis model. The simulation was performed for the nine major U.S. airports described in Section 4.1 and incorporated data on the aircraft populations at these airports, contained in Table 4-6 along with the airframe manufacturer's projected utilization of composite materials for the 1993 U.S. commercial transport fleet. Table 22 of Appendix C presents the total number of aircraft exposed to various exposure levels annually. In order to apply the data in Table 22, Appendix C to the analysis of the L-1011 fleet, the fraction of total fleet exposures expected to be L-1011's is determined from the projected fleet composition for the year 1993. Forcasts of U.S. fleet requirements for 1993 show the need for 2740 total aircraft of which 1400 are large aircraft. It is estaimated that one third, or 467, of the large aircraft will be L-1011's. Therefore, the expected number of total fleet exposures in Table 22 of Appendix C is reduced by the ratio 467/2740 to produce the expected number of L-1011 fleet exposure. The annual expected number of exposures in the year 1993 for the L-1011 U.S. fleet are listed in Table 6-1 for the aircraft operational modes susceptible to CF contamination; gate-day, gate-night and maintenance. The exposure levels in this Table range from 10^3 - 10^8 fiber-seconds per cubic meter, the discrete value 3.2×10^R representing the geometric mean of the range $10^R - 10^{R+1}$. Equipment is considered invulnerable to exposures less than 10^3 and the simulation produced no exposures greater than 10^8.

The expected number of electrical and electronic equipment failures due to CF contamination can readily be computed from the probabilities of failure conditional on the aircraft external exposure from Chapter 5.0 and the expected number of aircraft exposed from Table 6-1. For each of the three operational modes, the expected number of equipment failures can be described by:

$$X_i = M_i \sum_j P_{ij} Y_j$$

where:

P_{ij} = the probability of failure for each equipment in group i conditional on the aircraft being exposed to the discrete exposure E_j within an operational mode.

Y_j = the expected number of L-1011's exposed to the discrete exposure E_j annually.

M_i = the quantity of equipments contained in group i per aircraft

therefore:

X_i = the expected numbers of equipment failures per year for equipment group i within an operational mode.

The quantities X_i can be summed over all equipment groups and/or over all operational modes to obtain the annual expected number of failures by group, by operational mode, and the total. The results of these computations for the year 1993 are presented in Table 6-2 which show that the total expected number of equipment failures is approximately 0.1 due to CF contaimination.

In Appendix A, page A-14, the annual expected number of failures from current sources for the 281 pieces of equipment susceptible to CF contamination is 33,475

TABLE 6-1. EXPECTED NUMBER OF L-1011 AIRCRAFT EXPOSED TO DISCRETE CF EXPOSURES IN 1993

OPERATIONAL MODE	DISCRETE CF EXPOSURES - E FIBER-SECONDS PER CUBIC METER				
	3.2×10^3	3.2×10^4	3.2×10^5	3.2×10^6	3.2×10^7
Gate - Day	.05455	.06031	.02700	.02468	.00553
Gate - Night	.00812	.00984	.00484	.00328	.00090
Maintenance	.03684	.02133	.01754	.00834	.00019

TABLE 6-2. EXPECTED NUMBER OF EQUIPMENT FAILURES IN THE L-1011 FLEET DUE TO CF CONTAMINATION in 1993

EQUIP GROUP	QPA	OPERATIONAL MODE			TOTALS
		GATE-DAY	GATE-NIGHT	MAINTENANCE	
A	26	.00396	.01257	.04599	.06252
B	24	.00064	.00010	.00009	.00083
C	153	.00407	.00063	.00059	.00529
D	4	.00011	.00002	.00002	.00015
E	65	.00204	.00738	.01985	.02927
F	3	.00009	.00034	.00092	.00135
G	2	.00006	.00023	.00061	.00090
H	4	.00013	.00045	.00122	.00180
TOTAL	281	.01110	.02172	.06929	.10211

for a 467 aircraft L-1011 fleet. Therefore CF contamination would only increase the expected number of failures for these 281 pieces of equipment by 0.0003 percent which is negligible.

CHAPTER 7

EXPECTED INCREASE IN MAINTENANCE COSTS DUE TO CF CONTAMINATION

The expected annual maintenance costs due to CF contamination is readily obtained by combining the expected number of failures with the average cost per failure for each of the equipment groups. This is described by:

$$C_i = c_i \bar{X}_i$$

where:

c_i = the average cost per failure for equipment in group i

$\bar{X}_i$ = the expected number of equipment failures per year for equipment group i for all operational modes

Therefore:

C_i = the expected annual maintenance cost for all equipment in group i.

The quantities C_i can be summed for all equipment groups to obtain the total expected annual costs for the L-1011 fleet. The results of these computations, obtained from the expected number of failures from Table 6-2 and the average cost per failure from Appendix A, Table A-3, are presented in Table 7-1. These results for the year 1993 show the total expected annual cost is $25.76 due to electrical and electronic equipment failures caused by CF contamination.

From Appendix A, Table A-4, the expected annual cost for the 281 pieces of equipment susceptible to CF contamination is $14,647,922 due to current sources of failure for a 467 aircraft L-1011 fleet. Therefore, CF contaimination would only increase the maintenance cost by 0.0002 percent which is negligible.

TABLE 7-1. EXPECTED ANNUAL COST OF EQUIPMENT FAILURES IN THE L-1011 FLEET DUE TO CF CONTAMINATION FOR 1993

EQUIPMENT GROUP	EXPECTED NUMBER OF CF FAILURES IN 1993	COST PER FAILURE (1978 DOLLARS)	EXPECTED ANNUAL COST (1978 DOLLARS)
A	.06252	216	13.50
B	.00083	221	0.18
C	.00529	177	0.94
D	.00015	249	0.04
E	.02927	212	6.21
F	.00135	530	0.72
G	.00090	1297	1.17
H	.00180	1665	3.00
TOTALS	.10211		25.76

CHAPTER 8

ASSESSMENT OF HAZARD TO CONTINUED OPERATION

Commercial transport aircraft are designed and certified to extremely severe criteria for equipment and systems essential to the safe operation. To state this criteria in the most basic terms:

> The aircraft must be capable of continued safe flight and landing following any single failure or any combination of failures not shown to be extremely improbable.

The term "extremely improbable" refers to events so unlikely to occur that they need not be considered. These requirements are fulfilled by a variety of design considerations such as:

- High equipment reliability obtained by the specification of stringent design and qualification requirements for endurance and protection from environmental contamination.
- System design employing component redundancy.
- Alternate means to accomplish required functions.
- Continuous or periodic equipment and system function monitoring.

Systems, whose function is essential to the safe operation of aircraft, usually incorporate all the above design considerations. It can readily be shown that aircraft systems designed to the above criteria also provide adequate protection from CF contamination. The following rationale is offered in substantiation of this statement.

Since the design criteria for essential systems requires that no single failure must present a hazard to continued safe operation, it follows that at least two equipment failures must result from a single CF exposure to cause the system failure. Consider a hypothetical system configuration consisting of two parallel channels with three of the most vulnerable equipments in each channel. The loss of function of a channel is defined as the failure of any one of these pieces of equipment in that channel and system faiure is defined as loss of function of both channels. This hypothetical configuration is more vulnerable to CF contamination than any essential system on the L-1011. Therefore substantiation that the hazard to continued aircraft operation based on the assessment of this hypothetical system configuration is a sufficient condition to substantiate that the hazard to the L-1011 is negligible.

From Tables 5-1 through 5-3, it is obvious that the equipment in Group A is most vulnerable to CF contamination. Then if all six equipments in the hypothetical system are in Group A, the conditional probability of system failure can be described by:

$$\overline{P}_j = \left[1 - (1-P_{Aj})^3\right]^2$$

where:

P_{Aj} = the probability of failure for each equipment in Group A conditional on the aircraft being exposed to the discrete exposure E_j within an operational mode. (From Tables 5-1 through 5-3.)

Therefore:

$\left[1-(1-P_{Aj})^3\right]$ = the probability of loss of function of one channel caused by the failure of at least one of the three equipments in that channel conditional on E_j within an operational mode.

$\overline{P}_j$ = the probability of system failure caused by loss of function of both channels conditional on E_j within an operational mode.

The expected number of system failures is described by:

$$Z = \sum_j \overline{P}_j \, Y_j$$

where:

Y_j = the expected number of L-1011's exposed to the discrete exposure E_j annually. (From Table 6-1.)

Therefore:

Z = the expected number of failures of the hypothetical system per year within an operational mode.

Performing the above computation using the data contained in Tables 5-1 through 5-3 and 6-1, the values of Z are 0.00001, 0.00045 and 0.00154 for the gate-day, gate-night and maintenance modes, respectively, or a total of 0.002 expected failures of the hypothetical system for the year 1993 in the 467 aircraft L-1011 fleet. This is equivalent to expecting one failure in the fleet every 500 years which is so unlikely to occur that it need not be considered a hazard to continued operation. Even if the failure of an essential system would occur, it is very unlikely that it would present a hazard to continued operation. The integral and pre-flight monitoring for these systems have a high probability of detecting malfunctions or failures. Since aircraft are considered potentially vulnerable to CF contamination only while on the ground, the system malfunction or failure would be corrected prior to flight. Elimination of flight as a potentially vulnerable mode is justified by the following considerations:

- Due to the short period of time the aircraft would be immersed in a concentration, the total external exposure level would be much lower than if the aircraft remained in a static ground position.

- The only source of CF infiltration is through the engines and bleed air system. The transfer function for this ingestion path is very low due to filtering. In addition, NASA studies have shown that the fibers are too fragile to withstand the high forces associated with passage through the engine compressor stages. They disintegrate into lengths too short to cause failures in electrical and electronic equipment.

CHAPTER 9

CONCLUSIONS

The risk associated with electrical and electronic equipment contamination on the Lockheed L-1011 due to free carbon/graphite fibers (CF) being released from fires on commercial transport aircraft incorporating CF composite materials has been assessed. This assessment is based on projections of the greatly increased usage of CF composite materials in commercial transport in the next 10-15 years and a 467 aircraft domestic L-1011 fleet for the year 1993. The major results of this assessment are:

- The L-1011 contains 281 pieces of electrical and electronic equipment of 84 different types that susceptible to CF contamination.

- *The expected number of equipment failures due to CF contamination is* 0.1 for the L-1011 fleet in 1993. This is only 0.0003 percent of the expected failures due to current sources of failure for the same 281 pieces of equipment.

- The expected annual cost due to CF contamination is $25.76 for the L-1011 fleet in 1993. This is only 0.0002 percent of the expected annual cost due to current sources for the same 281 pieces of equipment.

- The risk to continued aircraft operation due to CF contamination for all ground and flight operational modes is so unlikely that it need not be considered.

These results clearly show that the economic and hazard risks associated with CF contaimination of electrical and electronic equipment are negligible for the projected usage of CF composite materials on commercial transport aircraft. Therefore, present design, maintenance, and operational practices provide adequate protection for this phenomena. Any imposed change in these practices would be far more costly than the risk.

APPENDIX A

ELECTRICAL AND ELECTRONIC EQUIPMENT RELIABILITY AND MAINTENANCE COST DATA

APPENDIX A

ELECTRICAL AND ELECTRONIC EQUIPMENT RELIABILITY AND MAINTENANCE COST DATA

INTRODUCTION

This appendix presents current source reliability and maintenance cost data on the eighty-four L-1011 equipment types identified as susceptible to carbon fiber (CF) contamination damage in Chapter 2 of this report. These data are used in Chapters 6 and 7 to establish the cost risk associated with CF contamination and to provide a basis for assessing the impact of this risk on the maintenance burden associated with current sources of equipment failure.

EQUIPMENT RELIABILITY/MAINTENANCE COSTS

Table A-1 summarizes the reliability and maintenance cost data from current sources. The first five columns reproduced from Tables 2-1 and 2-2 are included in this table for ease of reference. The next two columns show the basic failure rate and the unscheduled removal rate for equipment item. These rates are related by

Unscheduled Removals = Basic (or confirmed) failures
plus
Unconfirmed failures

The failure and removal rates were based primarily on the experience of an L-1011 customer airline covering the period from 1 May 1978 through 30 April 1979. Where airline data were not available, estimates were made utilizing MIL-HDBK-217C. In certain instances, special studies where airlines retrieved data on specific items were used.

The next column in Table A-1 shows the cost per basic failure in 1978 dollars. This cost is derived in Table A-2. It includes on-aircraft and shop direct labor, material expenditure, and an allowance for burden/overhead costs. The on-aircraft direct manhours were estimates from Lockheed flight operators maintenance personnel based on their experience in maintaining L-1011 Tristar aircraft during pre-delivery flight test operations. The shop direct manhours were primarily obtained from airline records. For the direct labor cost, ten dollars per hour was used as the base rate. The burden expenses was 180% of the direct labor cost, which is the Air Transport Association (ATA) standard used in estimating maintenance costs. The shop material costs were based on the in-service experience of several airlines, supplier data, and from existing data on similar equipment.

The cost per unscheduled removal was essentially derived using the information from the basic failure costs. Material costs on unconfirmed failures are negligible and therefore ignored. From airline experience, shop direct manhours were, on the average, 30% less than the basic or confirmed failures. With all else being the same, the cost per unconfirmed failure was determined. The cost per unscheduled removal was established by proportioning the costs in accordance with the confirmed and unconfirmed failure rates.

EQUIPMENT GROUPS

The last column in Table A-1 places each equipment in an equipment group. This reduces the computation burden required for the risk assessment. The criteria for grouping are that all equipment in a group have the same mean exposure-to-failure ($\bar{E}$), be in the same location in the aircraft, and have the same approximate cost per failure. Eight distinct equipment groups (A through H) were established and are shown in Table A-3. The average cost per failure in Table A-3 is the weighted average cost for all equipments in the group.

FAILURES/COST PER YEAR

Table A-4 shows the expected failures, unscheduled removals and costs per aircraft per year for each equipment group due to current sources of equipment failure. Directly below the totals, projections of equipment failures and annual costs for 1993 are shown. The values in Table A-4 are based on 3000 flight hours per aircraft per year and a projected L-1011 domestic fleet of 467 aircraft for 1993.

TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\overline{E}$	BASIC FAILURES PER 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULED REMOVAL	EQUIP. GROUP
1	Air Conditioning	1	Avionic Centers	1.0×10^8	0.0956	0.4914	246	131	E
2	Air Conditioning	5	Avionic Centers	1.0×10^8	0.0273	0.0921	279	169	E
3	Air Conditioning	3	Avionic Centers	1.0×10^8	0.0273	0.0921	290	169	E
4	Auto Flight	1	Flight Station	1.0×10^8	0.0050	0.0067	225	205	B
5	Auto Flight	1	Avionic Centers	1.0×10^8	0.1000	0.1333	323	305	E
6	Auto Flight	2	Avionic Centers	1.5×10^7	0.2525	0.3823	189	166	A
7	Auto Flight	2	Avionic Centers	1.5×10^7	0.0067	0.0341	261	195	A
8	Auto Flight	2	Avionic Centers	1.5×10^7	0.1706	0.6897	249	188	A
9	Auto Flight	1	Avionic Centers	1.5×10^7	0.3823	3.7594	160	124	A
10	Auto Flight	1	Avionic Centers	1.5×10^7	0.2730	1.7606	240	172	A
11	Auto Flight	1	Avionic Centers	1.5×10^7	0.0955	1.0787	197	150	A
12	Radio Communications	2	Avionic Centers	1.0×10^8	0.0205	0.0410	129	95	E
13	Radio Communications	3	Avionic Centers	1.0×10^8	0.2684	0.5277	148	122	E

*1978 Dollars

TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES (Continued)

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\overline{E}$	BASIC FAILURES PER 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULED REMOVAL	EQUIP. GROUP
14	Passenger Service	2	Avionic Centers	1.0×10^8	1.1123	1.4065	208	181	E
15	Passenger Service	1	Flight Station	1.0×10^8	0.0050	0.0067	239	219	B
16	Passenger Service	1	Avionic Centers	1.0×10^8	0.3823	0.4778	134	124	E
17	Passenger Service	1	Avionic Centers	1.0×10^8	0.1365	0.4914	218	164	E
18	Passenger Service	3	Passenger Cabin	1.0×10^8	0.0637	0.1820	235	177	C
19	Passenger Service	4	Passenger Cabin	1.0×10^8	0.1000	0.2227	222	187	C
20	Passenger Service	1	Avionic Centers	1.0×10^8	0.3686	0.9960	300	182	E
21	Passenger Service	1	Passenger Cabin	1.0×10^8	0.0400	0.0500	278	255	D
22	Passenger Service	1	Passenger Cabin	1.0×10^8	0.0200	0.0556	217	180	D
23	Passenger Service	2	Avionic Centers	1.0×10^8	0.0273	0.0990	102	71	E
24	Passenger Service	1	Avionic Centers	1.0×10^8	0.0833	0.1933	586	482	F
25	Passenger Service	2	Flight Station	1.0×10^8	0.0341	0.0546	89	71	B
26	Passenger Service	2	Avionic Centers	1.0×10^8	0.0273	0.0990	105	72	E

*1978 Dollars

TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES (Continued)

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\overline{E}$	BASIC FAILURES PER 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULED REMOVAL	EQUIP. GROUP
27	Electrical Power	1	Flight Station	1.0×10^8	0.1667	0.2000	200	189	B
28	Electrical Power	1	Avionic Centers	1.0×10^8	0.1775	0.5187	311	204	E
29	Electrical Power	4	Avionic Centers	1.0×10^8	0.1229	0.5528	253	185	E
30	Electrical Power	1	Avionic Centers	1.0×10^8	0.0034	0.0171	154	91	E
31	Electrical Power	1	Avionic Centers	1.0×10^8	0.1911	0.4505	267	173	E
32	Electrical Power	1	Flight Station	1.0×10^8	0.8333	1.0000	345	302	B
33	Electrical Power	1	Flight Station	1.0×10^8	0.5000	0.6667	279	267	B
34	Electrical Power	1	Flight Station	1.0×10^8	0.8333	1.0000	487	476	B
35	Electrical Power	1	Avionic Centers	1.0×10^8	0.4000	0.5000	424	417	E
36	Electrical Power	1	Avionic Centers	1.0×10^8	0.4000	0.5000	424	417	E
37	Electrical Power	1	Avionic Centers	1.0×10^8	0.1667	0.2000	1702	1683	H
38	Electrical Power	3	Avionic Centers	1.0×10^8	0.1333	0.1667	1653	1634	H
39	Electrical Power	1	Avionic Centers	1.0×10^8	0.1667	0.2000	238	227	E

*1978 Dollars

TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES (Continued)

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\overline{E}$	BASIC FAILURES PER 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULED REMOVAL	EQUIP. GROUP
40	Fire Extinguisher	1	Flight Station	1.0×10^8	0.0025	0.0033	141	131	B
41	Slat Control	2	Avionic Centers	1.0×10^8	0.1024	0.3617	162	116	E
42	Windshield Heat	2	Avionic Centers	1.0×10^8	0.0341	0.2662	119	66	E
43	Windshield Heat	1	Flight Station	1.0×10^8	0.0040	0.0050	230	218	B
44	Water Waste	1	Flight Station	1.0×10^8	0.0167	0.0200	164	156	B
45	Proximity Sensing	1	Avionic Centers	1.0×10^8	0.0133	0.0410	80	60	E
46	Aural Warning	1	Flight Station	1.0×10^8	0.0100	0.0273	114	75	B
47	Flight Data	1	Avionic Centers	1.0×10^8	0.3003	0.6414	274	225	E
48	Flight Data	1	Flight Station	1.0×10^8	0.0683	0.0683	107	107	B
49	AIDS	1	Avionic Centers	1.0×10^8	0.3333	0.6667	263	213	E
50	AIDS	1	Avionic Centers	1.0×10^8	0.4000	0.9737	181	137	E
51	AIDS	3	Avionic Centers	1.0×10^8	0.0823	0.2033	334	268	E
52	Weight and Balance	1	Flight Station	1.0×10^8	0.1389	0.3466	162	135	B

*1978 Dollars

TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES (Continued)

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\overline{E}$	BASIC FAILURES PER 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULED REMOVAL	EQUIP. GROUP
53	Instrument Lights	2	Avionic Centers	1.0×10^8	0.0751	0.1433	195	169	E
54	Warning Lights	1	Avionic Centers	1.5×10^7	1.1737	1.8975	249	189	A
55	Cabin Lighting	22	Passenger Cabin	1.0×10^8	0.0292	0.0292	183	183	C
56	Cabin Lighting	4	Passenger Cabin	1.0×10^8	0.0100	0.0192	84	71	C
57	Cabin Lighting	120	Passenger Cabin	1.0×10^8	0.0025	0.0028	176	171	C
58	Cabin Lighting	1	Avionic Centers	1.0×10^8	0.7097	0.8190	190	181	E
59	Cabin Lighting	3	Avionic Centers	1.0×10^8	0.0036	0.0091	84	66	E
60	Cabin Lighting	10	Avionic Centers	1.5×10^7	0.0846	0.1106	192	165	A
61	Navigation	2	Flight Station	1.0×10^8	0.0200	0.0250	293	277	B
62	Navigation	2	Avionic Centers	1.0×10^8	0.0683	0.2593	169	114	E
63	Navigation	2	Avionic Centers	1.0×10^8	0.1911	0.2320	213	199	E
64	Navigation	2	Avionic Centers	1.5×10^7	0.2116	0.5325	340	250	A
65	Navigation	2	Avionic Centers	1.5×10^7	0.1160	0.3275	235	205	A

*1978 Dollars

TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES (Continued)

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\bar{\bar{E}}$	BASIC FAILURES PRR 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULE REMOVAL	EQUIP. GROUP
66	Navigation	1	Flight Station	1.0×10^8	0.0410	0.1229	127	69	B
67	Navigation	1	Avionic Centers	1.0×10^8	0.0025	0.0033	477	445	F
68	Navigation	1	Avionic Centers	1.0×10^8	0.0080	0.0100	168	155	E
69	Navigation	1	Flight Station	1.0×10^8	0.0080	0.0100	246	217	B
70	Navigation	2	Avionic Centers	1.0×10^8	0.0769	0.1919	1297	832	G
71	Navigation	2	Avionic Centers	1.0×10^8	0.4369	1.0718	345	252	E
72	Navigation	2	Flight Station	1.0×10^8	0.5187	0.8190	246	213	B
73	Navigation	2	Avionic Centers	1.0×10^8	0.4163	0.9416	160	116	E
74	Navigation	2	Avionic Centers	1.0×10^8	0.1638	0.3482	135	100	E
75	Navigation	2	Avionic Centers	1.5×10^7	0.2252	0.8053	158	95	A
76	Navigation	1	Avionic Centers	1.0×10^8	0.0400	0.0500	527	496	F
77	Navigation	2	Avionic Centers	1.0×10^8	0.0500	0.0067	159	144	E

*1978 Dollars

TABLE A-2. MAINTENANCE COST - BASIC FAILURES (Continued)

EQUIP. NO.	EQUIPMENT SYSTEM USAGE	ON-AIRCRAFT DIRECT MANHOURS	SHOP DIRECT MANHOURS	TOTAL DIRECT MANHOURS	DIRECT LABOR COST	BURDEN EXPENSE	SHOP MATERIAL COST	TOTAL COST*
22	Passenger Service	2.0	4.2	6.2	62.00	111.60	43.76	217.36
23	Passenger Service	0.8	1.9	2.7	27.00	48.60	25.97	101.57
24	Passenger Service	6.0	12.0	18.0	180.00	324.00	81.50	585.50
25	Passenger Service	0.8	1.0	1.8	18.00	32.40	38.74	89.14
26	Passenger Service	0.8	1.9	2.7	27.00	48.60	29.22	104.82
27	Electric Power	1.5	4.5	6.0	60.00	108.00	32.18	200.18
28	Electric Power	1.0	6.2	7.2	72.00	129.60	109.62	311.22
29	Electric Power	0.5	7.7	8.2	82.00	147.60	23.31	252.91
30	Electric Power	0.5	3.1	3.6	36.00	64.80	52.87	153.69
31	Electric Power	0.8	4.1	4.9	49.00	88.20	129.20	266.40
32	Electric Power	8.0	3.3	11.3	113.00	203.40	28.37	344.77
33	Electric Power	6.0	3.1	9.1	91.00	163.80	24.60	279.40
34	Electric Power	12.0	4.3	16.2	163.00	293.40	30.59	486.99
35	Electric Power	12.0	2.5	14.5	145.00	261.00	18.13	424.13
36	Electric Power	12.0	2.5	14.5	145.00	261.00	18.13	424.13
37	Electric Power	52.0	6.4	58.4	584.00	1051.20	67.23	1702.43
38	Electric Power	52.0	5.2	57.2	572.00	1029.60	51.40	1653.00
39	Electric Power	4.0	3.2	7.2	72.00	129.60	36.00	237.60
40	Fire Extinguisher	2.0	2.2	4.2	42.00	75.60	23.53	141.13
41	Slat Control	1.0	3.5	4.5	45.00	81.00	35.71	161.71
42	Windshield Heat	0.8	1.9	2.7	27.00	48.60	42.90	118.50

*1978 Dollars

TABLE A-2. MAINTENANCE COST - BASIC FAILURES (Continued)

EQUIP. NO.	EQUIPMENT SYSTEM USAGE	ON-AIRCRAFT DIRECT MANHOURS	SHOP DIRECT MANHOURS	TOTAL DIRECT MANHOURS	DIRECT LABOR COST	BURDEN EXPENSE	SHOP MATERIAL COST	TOTAL COST*
43	Windshield Heat	4.0	3.0	7.0	70.00	126.00	84.00	230.00
44	Water Waste	3.0	1.8	4.8	48.00	86.40	29.21	163.61
45	Proximity Sensing	1.0	1.2	2.2	22.00	39.60	18.40	80.00
46	Aural Warning	1.0	1.3	2.3	23.00	41.40	49.44	113.84
47	Flight Data	0.8	8.1	8.9	89.00	160.20	24.14	273.64
48	Flight Data	0.8	1.4	2.2	22.00	39.60	45.36	106.96
49	AIDS	0.8	7.2	8.0	80.00	144.00	38.76	262.76
50	AIDS	0.8	4.3	5.1	51.00	91.80	38.08	180.88
51	AIDS	0.8	10.1	10.9	109.00	196.20	29.04	334.24
52	Weight and Balance	1.5	3.9	5.4	54.00	97.20	10.95	162.15
53	Instrument Lights	2.0	4.3	6.3	63.00	113.40	18.12	194.52
54	Warning Lights	2.0	1.8	3.8	38.00	68.40	142.30	248.70
55	Cabin Lighting	1.0	5.0	6.0	60.00	108.00	15.40	183.40
56	Cabin Lighting	1.0	1.4	2.4	24.00	43.20	17.00	84.20
57	Cabin Lighting	1.0	5.0	6.0	60.00	108.00	7.92	175.92
58	Cabin Lighting	1.0	4.7	5.7	57.00	102.60	30.59	190.19
59	Cabin Lighting	1.0	1.3	2.3	23.00	41.40	20.00	84.40
60	Cabin Lighting	0.8	2.8	3.6	36.00	64.80	91.45	192.25
61	Navigation	4.0	5.1	9.1	91.00	163.80	38.06	292.86
62	Navigation	1.5	3.3	4.8	48.00	86.40	34.24	168.64
63	Navigation	0.8	5.7	6.5	65.00	117.00	31.19	213.19

*1978 Dollars

TABLE A-2. MAINTENANCE COST - BASIC FAILURES (Continued)

EQUIP. NO.	EQUIPMENT SYSTEM USAGE	ON-AIRCRAFT DIRECT MANHOURS	SHOP DIRECT MANHOURS	TOTAL DIRECT MANHOURS	DIRECT LABOR COST	BURDEN EXPENSE	SHOP MATERIAL COST	TOTAL COST*
64	Navigation	0.8	8.5	9.3	93.00	167.40	79.54	339.94
65	Navigation	0.8	5.7	6.5	65.00	117.00	53.10	335.10
66	Navigation	0.8	0.8	1.6	16.00	28.80	82.22	127.02
67	Navigation	6.0	9.1	15.1	151.00	271.80	54.19	476.97
68	Navigation	0.8	4.1	4.9	49.00	88.20	30.85	168.05
69	Navigation	1.5	3.2	4.7	47.00	84.60	114.21	245.81
70	Navigation	1.0	25.1	26.1	261.00	469.80	565.91	1296.71
71	Navigation	1.0	8.1	9.1	91.00	163.80	70.00	344.80
72	Navigation	1.5	5.9	7.4	74.00	133.20	39.13	246.33
73	Navigation	0.8	3.0	3.8	38.00	68.40	53.40	159.80
74	Navigation	0.5	2.8	3.3	33.00	59.40	42.14	134.54
75	Navigation	0.5	2.9	3.4	34.00	61.20	62.42	157.62
76	Navigation	6.0	10.3	16.3	163.00	293.40	70.95	527.35
77	Navigation	0.5	4.3	4.8	48.00	86.40	24.72	159.12
78	Airborne Aux Pwr	0.8	3.7	4.5	45.00	81.00	113.92	239.92
79	Airborne Aux Pwr	4.0	4.1	8.1	81.00	145.80	32.94	259.74
80	Fuel Flow	2.0	3.8	5.8	58.00	104.40	30.21±	192.68
81	Fuel Flow	2.0	4.0	6.0	60.00	108.00	31.29	199.29
82	Engine Ignition	6.0	3.4	9.4	94.00	169.20	40.00	303.20
83	Engine Indicating	1.0	2.8	3.8	38.00	68.40	86.69	193.09
84	Engine Indicating	4.0	4.2	8.2	82.00	147.60	38.43	268.03

*1978 Dollars

TABLE A-3. SUMMARY TABLE FOR EQUIPMENT GROUPS

EQUIPMENT GROUP	QUANTITY PER AIRCRAFT (QPA)	MEAN EXPOSURE TO FAILURE ($\bar{E}$)	LOCATION IN AIRCRAFT	AVERAGE MAINTENANCE COST PER FAILURE (1978 DOLLARS)
A	26	1.5×10^7	Avionic Centers	216
B	24	1.0×10^8	Flight Station	221
C	153	1.0×10^8	Passenger Cabin	177
D	4	1.0×10^8	Passenger Cabin	249
E	65	1.0×10^8	Avionic Centers	212
F	3	1.0×10^8	Avionic Centers	530
G	2	1.0×10^8	Avionic Centers	1297
H	4	1.0×10^8	Avionic Centers	1665

TABLE A-4. ANNUAL RATES/COSTS - CURRENT SOURCES

EQUIP GROUP	QUANTITY PER AIRCRAFT	EXPECTED* NUMBER OF BASIC FAILURES PER AIRCRAFT PER YEAR	EXPECTED* NUMBER OF UNSCHEDULED REMOVALS PER AIRCRAFT PER YEAR	COST PER UNSCHEDULED REMOVAL (1978 DOLLARS)	EXPECTED* UNSCHEDULED REMOVAL COST PER AIRCRAFT PER YEAR (1978 DOLLARS)
A	26	14.2071	45.4350	192	8724
B	24	13.7925	18.9120	200	3782
C	153	4.7205	7.4760	171	1278
D	4	1.7001	7.2540	202	1465
E	65	34.7214	72.3004	157	11351
F	3	0.3774	.7398	474	351
G	2	0.4614	1.1514	832	958
H	4	1.6998	2.1003	1646	3457
TOTALS	281	71.6802	155.3689	-	31366

*Based on 3000 Flight hours/Aircraft/Year

For 1993 - Projected L-1011 Fleet Size = 467 Aircraft
Expected Number of Equipment Failures = 33,475
Expected Annual Cost = $14,647,922

APPENDIX B

AIRCRAFT POPULATIONS BY HOUR AT THREE AIRPORTS

APPENDIX B

AIRCRAFT POPULATIONS BY HOUR AT THREE AIRPORTS

This appendix contains seven tables of aircraft populations at Washington National, Hartsfield - Atlanta and Miami International Airports. The tables give the average number of aircraft in each operational mode by hour of day. They are listed by airport and size category as follows:

B-1 - Washington National; small
B-2 - Hartsfield - Atlanta; small
B-3 - Hartsfield - Atlanta; medium
B-4 - Hartsfield - Atlanta; large
B-5 - Miami International; small
B-6 - Miami International; medium
B-7 - Miami International; large

The methodology and sources of data for deriving the results contained in these tables are described in Chapter 4.

TABLE B-1

AIRPORT: Washington National SIZE: Small

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	9.00	0.00	18.00	27.00
0101 - 0200	9.00	0.00	18.00	27.00
0201 - 0300	9.00	0.00	18.00	27.00
0301 - 0400	9.00	0.00	18.00	27.00
0401 - 0500	9.00	0.00	18.00	27.00
0501 - 0600	9.00	0.00	18.00	27.00
0601 - 0700	16.00	0.00	11.00	27.00
0701 - 0800	18.75	0.00	0.25	19.00
0801 - 0900	13.00	0.00	0.15	13.25
0901 - 1000	17.50	0.00	0.00	17.50
1001 - 1100	15.25	0.00	0.00	15.25
1101 - 1200	16.25	0.00	0.00	16.25
1201 - 1300	14.50	0.00	0.00	14.50
1301 - 1400	14.50	0.00	0.00	14.50
1401 - 1500	16.25	0.00	0.00	16.25
1501 - 1600	15.50	0.00	0.00	15.50
1601 - 1700	15.25	0.00	0.00	15.25
1701 - 1800	16.75	0.00	0.00	16.75
1801 - 1900	16.75	0.00	0.00	16.75
1901 - 2000	17.25	0.00	0.25	17.50
2001 - 2100	17.25	0.00	2.25	19.50
2101 - 2200	13.25	0.00	6.00	19.25
2201 - 2300	12.50	0.00	14.50	27.00
2301 - 2400	9.00	0.00	18.00	27.00
Average	13.73	0.00	6.64	20.37
Day Average (1)	16.05	0.00	0.93	16.98
Night (2) Average	9.86	0.00	16.17	26.03

(1) DAY - 0601-2100; (2) NIGHT - 2101-0600.

TABLE B-2

AIRPORT: Hartsfield-Atlanta SIZE: Small

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	42.50	16.00	1.00	59.50
0101 - 0200	23.50	16.00	2.00	41.50
0201 - 0300	21.75	16.00	4.25	42.00
0301 - 0400	17.00	16.00	8.75	41.75
0401 - 0500	6.25	16.00	19.75	42.00
0501 - 0600	20.00	16.00	16.00	52.00
0601 - 0700	14.75	10.00	4.75	29.50
0701 - 0800	4.25	10.00	3.00	17.25
0801 - 0900	14.50	10.00	3.00	27.50
0901 - 1000	42.50	10.00	2.75	55.25
1001 - 1100	32.75	10.00	2.00	44.75
1101 - 1200	44.25	10.00	2.00	56.25
1201 - 1300	33.50	10.00	1.25	44.75
1301 - 1400	23.50	10.00	0.00	33.50
1401 - 1500	38.25	10.00	0.00	48.25
1501 - 1600	45.50	10.00	0.00	55.50
1601 - 1700	24.25	10.00	0.00	34.25
1701 - 1800	42.25	10.00	0.00	52.25
1801 - 1900	33.25	10.00	0.00	43.25
1901 - 2000	42.00	10.00	0.00	52.00
2001 - 2100	25.50	10.00	0.00	35.50
2101 - 2200	26.50	16.00	0.00	42.50
2201 - 2300	29.00	16.00	0.00	45.00
2301 - 2400	43.00	16.00	0.75	59.75
Average	28.77	12.25	2.97	43.99
Day Average(1)	30.73	10.00	1.25	41.98
Night Average(2)	25.50	16.00	5.83	47.33

(1) DAY - 0601-2100; (2) NIGHT - 2101-0600.

TABLE B-3

AIRPORT: Hartsfield-Atlanta SIZE: Medium

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	2.25	1.00	0.00	3.25
0101 - 0200	1.00	1.00	0.00	2.00
0201 - 0300	1.00	1.00	0.00	2.00
0301 - 0400	1.00	1.00	0.00	2.00
0401 - 0500	1.25	1.00	0.00	2.25
0501 - 0600	4.25	1.00	0.00	5.25
0601 - 0700	3.25	1.00	0.00	4.25
0701 - 0800	1.00	1.00	0.00	2.00
0801 - 0900	1.00	1.00	0.00	2.00
0901 - 1000	1.75	1.00	0.00	2.75
1001 - 1100	0.50	1.00	0.00	1.50
1101 - 1200	1.25	1.00	0.00	2.25
1201 - 1300	2.00	1.00	0.00	3.00
1301 - 1400	2.50	1.00	0.00	3.50
1401 - 1500	4.00	1.00	0.00	5.00
1501 - 1600	5.75	1.00	0.00	6.75
1601 - 1700	3.25	1.00	0.00	4.25
1701 - 1800	3.50	1.00	1.00	5.50
1801 - 1900	1.00	1.00	1.00	3.00
1901 - 2000	3.25	1.00	1.00	5.25
2001 - 2100	3.00	1.00	0.00	4.00
2101 - 2200	1.00	1.00	0.00	2.00
2201 - 2300	1.00	1.00	0.00	2.00
2301 - 2400	2.25	1.00	0.00	3.25
Average	2.17	1.00	0.13	3.29
Day Average (1)	2.47	1.00	0.20	3.67
Night Average (2)	1.67	1.00	0.00	2.67

(1) DAY - 0601-2100; (2) NIGHT - 2101-0600.

TABLE B-4

AIRPORT: Hartsfield-Atlanta SIZE: Large

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	7.50	3.00	0.00	10.50
0101 - 0200	3.00	3.00	0.00	6.00
0201 - 0300	3.50	3.00	0.00	6.50
0301 - 0400	3.75	3.00	0.00	6.75
0401 - 0500	4.75	3.00	0.00	7.75
0501 - 0600	6.75	3.00	0.00	9.75
0601 - 0700	4.25	2.00	0.00	6.25
0701 - 0800	2.00	2.00	0.00	4.00
0801 - 0900	2.00	2.00	0.00	4.00
0901 - 1000	7.50	2.00	0.00	9.50
1001 - 1100	5.25	2.00	0.00	7.25
1101 - 1200	4.00	2.00	0.00	6.00
1201 - 1300	2.00	2.00	0.00	4.00
1301 - 1400	1.50	2.00	0.00	3.50
1401 - 1500	3.25	2.00	0.00	5.25
1501 - 1600	5.50	2.00	0.00	7.50
1601 - 1700	4.00	2.00	0.00	6.00
1701 - 1800	6.25	2.00	0.00	8.25
1801 - 1900	2.50	2.00	0.00	4.50
1901 - 2000	8.50	2.00	0.00	10.50
2001 - 2100	3.00	2.00	0.00	5.00
2101 - 2200	0.75	3.00	0.00	3.75
2201 - 2300	0.50	3.00	0.00	3.50
2301 - 2400	4.25	3.00	0.00	7.25
Average	4.01	2.38	0.00	6.39
Day Average (1)	4.10	2.00	0.00	6.10
Night Average (2)	3.86	3.00	0.00	6.86

(1) DAY - 0601-2100; (2) NIGHT - 2101 - 0600.

TABLE B-5

AIRPORT: Miami International SIZE: Small

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	42.50	8.00	4.25	54.75
0101 - 0200	36.75	8.00	9.25	54.00
0201 - 0300	41.25	8.00	12.00	61.25
0301 - 0400	36.25	8.00	17.00	61.25
0401 - 0500	29.00	8.00	23.75	60.75
0501 - 0600	17.50	8.00	36.00	61.50
0601 - 0700	16.75	4.00	33.25	54.00
0701 - 0800	15.25	4.00	21.75	41.00
0801 - 0900	8.75	4.00	11.00	23.75
0901 - 1000	9.00	4.00	4.50	17.50
1001 - 1100	6.50	4.00	4.00	14.50
1101 - 1200	22.50	4.00	1.50	28.00
1201 - 1300	32.50	4.00	0.75	37.25
1301 - 1400	25.75	4.00	0.00	29.75
1401 - 1500	27.50	4.00	0.00	31.50
1501 - 1600	26.25	4.00	0.00	30.25
1601 - 1700	27.50	4.00	0.50	32.00
1701 - 1800	16.75	4.00	1.00	21.75
1801 - 1900	16.25	4.00	1.00	21.25
1901 - 2000	16.00	4.00	1.00	21.00
2001 - 2100	18.25	4.00	1.25	23.50
2101 - 2200	27.25	8.00	2.00	37.25
2201 - 2300	17.50	8.00	2.00	27.50
2301 - 2400	19.75	8.00	2.50	30.25
Average	23.05	5.50	7.93	36.48
Day Average (1)	19.03	4.00	5.43	28.46
Night Average (2)	29.75	8.00	12.08	49.83

(1) DAY - 0601-2100; (2) NIGHT - 2101-0600.

TABLE B-6

AIRPORT: Miami International SIZE: Medium

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	2.00	2.00	0.00	4.00
0101 - 0200	4.50	2.00	0.00	6.50
0201 - 0300	5.75	2.00	0.00	7.75
0301 - 0400	5.25	2.00	0.00	7.25
0401 - 0500	3.75	2.00	0.00	5.75
0501 - 0600	3.75	2.00	0.00	5.75
0601 - 0700	2.75	0.00	0.00	2.75
0701 - 0800	2.00	0.00	0.00	2.00
0801 - 0900	2.75	0.00	0.00	2.75
0901 - 1000	1.00	0.00	0.00	1.00
1001 - 1100	1.50	0.00	0.00	1.50
1101 - 1200	3.00	0.00	0.00	3.00
1201 - 1300	3.50	0.00	0.00	3.50
1301 - 1400	1.50	0.00	0.00	1.50
1401 - 1500	2.00	0.00	0.00	2.00
1501 - 1600	3.50	0.00	0.00	3.50
1601 - 1700	6.00	0.00	0.00	6.00
1701 - 1800	4.50	0.00	0.00	4.50
1801 - 1900	1.25	0.00	0.00	1.25
1901 - 2000	1.25	0.00	0.00	1.25
2001 - 2100	2.50	0.00	0.00	2.50
2101 - 2200	3.00	2.00	0.00	5.00
2201 - 2300	1.00	2.00	0.00	3.00
2301 - 2400	1.00	2.00	0.00	3.00
Average	2.28	0.75	0.00	3.63
Day Average (1)	2.60	0.00	0.00	2.60
Night Average (2)	3.33	2.00	0.00	5.33

(1) DAY - 1601-2100; (2) NIGHT - 2101-0600.

TABLE B-7

AIRPORT: Miami International SIZE: Large

HOURLY PERIOD	AVERAGE NUMBER OF AIRCRAFT			
	GATE	MAINTENANCE	PARKED	AIRPORT TOTAL
0001 - 0100	7.50	6.00	0.00	13.50
0101 - 0200	8.75	6.00	0.00	14.75
0201 - 0300	7.00	6.00	1.00	14.00
0301 - 0400	8.00	6.00	1.50	15.50
0401 - 0500	4.75	6.00	4.00	14.75
0501 - 0600	1.50	6.00	6.50	14.00
0601 - 0700	4.25	3.00	5.50	12.75
0701 - 0800	5.25	3.00	4.00	12.25
0801 - 0900	8.25	3.00	2.00	13.25
0901 - 1000	4.75	3.00	1.50	9.25
1001 - 1100	5.25	3.00	0.75	9.50
1101 - 1200	6.25	3.00	0.00	9.25
1201 - 1300	10.00	3.00	0.00	13.00
1301 - 1400	9.25	3.00	0.00	12.25
1401 - 1500	2.25	3.00	0.00	5.25
1501 - 1600	5.25	3.00	0.00	8.25
1601 - 1700	12.50	3.00	0.00	15.50
1701 - 1800	8.00	3.00	0.00	11.00
1801 - 1900	2.50	3.00	0.00	5.50
1901 - 2000	2.75	3.00	0.00	5.75
2001 - 2100	1.25	3.00	0.00	4.25
2101 - 2200	1.75	6.00	0.00	7.75
2201 - 2300	2.75	6.00	0.00	8.75
2301 - 2400	4.00	6.00	0.00	10.00
Average	5.59	4.13	1.11	10.83
Day Average (1)	5.88	3.00	0.92	9.80
Night Average (2)	5.11	6.00	1.44	12.55

(1) DAY - 0601-2100; (2) NIGHT - 2101-0600.

APPENDIX C

PROBABILITIES OF EXPOSURE OF JET AIRCRAFT AT MAJOR U.S. AIRPORTS

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PROBABILITIES OF EXPOSURE OF JET AIRCRAFT AT MAJOR U.S. AIRPORTS

I. INTRODUCTION

The purpose of this memorandum is to summarize an analysis performed of potential carbon fiber exposures at major U.S. airports. The results of this analysis will be utilized in conjunction with a safety analysis and a risk analysis of electronic components within U.S. aircraft. The analysis was performed by Monte Carlo simulation using Arthur D. Little's carbon fiber dispersion and risk analysis model.

The major finding of the analysis is that probabilities of exposure that can reasonably affect the electronic systems of U.S. jet aircraft are extremely small. The probability of a fire accident resulting in an exposure of 10^3 fs/m^3 at either the gate or maintenance area of a major airport is 2.2% per accident. The corresponding probabilities of exposures in excess of 10^4, 10^5, 10^6, and 10^7 are 1.4%, .7%, .3%, and .04% respectively. The probabilities of these exposures affecting given numbers of aircraft, and breakdowns by day and night and by maintenance and gate areas are presented in Section III.

The conclusions were based on certain assumptions and simplifications. The major assumption was that all of the aircraft in either the gate or maintenance area would experience the identical exposure in any fire accident. Another way of looking at this is that we assumed that aircraft were for the purposes of the model located at the same point. Exposure probabilities were computed analyzing exposures at one maintenance point and two gate points. A second major assumption was that at any given point during the day or night the number of aircraft on the ground would be equal to the average for the day or night period. Thus, the probabilities were computed by determining exposure probabilities at given locations and then assuming that all the aircraft in the gate or maintenance area were located at these locations. These assumptions lower the probability of any aircraft experiencing a given exposure but increase the probability that all planes experience the given exposure.

It was also assumed within the context of the ADL dispersion model that the direction and velocity of the wind would not change in the course of the dispersion. This assumption has the practical affect of causing a thin cloud to disperse in a given direction without any variation or changes in direction. In actuality, a fire or explosion on or near the airport may be subject to some variation in speed and direction. However, even allowing for error due to these assumptions, it is clear that significant exposures at airport locations are highly unlikely.

There are two major reasons why the exposure probabilities at airport locations are extremely small. First, under the most likely set of release conditions a plume release does not result in substantial exposures at locations close to the source of the plume. Cases analyzed by Arthur D. Little previously show that distance to the beginning of the 10^3 contour is usually several thousand meters. If, as in the case of most aircraft accidents, the location of the fire is close to the airport then the plume cloud will not result in high exposures at the airport. The second reason is that even in the case of an explosive release, the width of the cloud is quite narrow at locations close to the source of the accident. Thus, it is very unlikely that an explosive release will affect a particular location. This event will only occur if the wind direction is precisely in the direction of that location. Our model simplifies the true situation bv locating all of the aircraft at a small number of points. Actual probabilities of any aircraft being covered by a given exposure might be higher than estimated. To compensate for this, we assume that all the aircraft are exposed if any are.

The results presented in this memorandum are aggregated over all sizes of aircraft because there is a great deal of correlation in the exposure probabilities for small, medium and large aircraft. It is not very meaningful to present probabilities of exposure for small, medium, and large aircraft taken separately.

II. METHODOLOGY

The analysis was performed in the following steps:

- For each of 9 major airports we computer coded the location of the maintenance area and two central gate points

- We executed the Arthur D. Little carbon fiber dispersion and risk analysis model to compute the probability of exposure at various levels at the particular locations.

- For each airport, we evaluated the probability of a given number of aircraft being exposed during the day and night operations by assuming that the average number of planes on the ground are all located at a single point representative of the sample points used in the program.

- We computed the national probability of exposure for a given number of planes by mixing the individual airport probabilities according to the number of estimated operations of aircraft carrying carbon fibers. As noted, the assumption that all of the aircraft are located at a given point overestimates the probability that any plane will be covered by a given exposure. On the other hand, it underestimates the probability that all of either the gate or maintenance aircraft can experience a given exposure.

The gate and maintenance area coordinates were determined from airport maps and were computed in relation to the centroid of the airports runways. The precise distances were extremely important in the analysis and hence the assumptions of accident locations in the risk analysis model should be reviewed. For each airport, a probability distribution for the given runway was input and accidents taking place off the runway were located according to a model based on historical data. Takeoff and landing accidents taking place on or near the airport were assumed to take place at the center of the appropriate runway. Static and taxi accidents were assumed to take place near the gate area and were therefore located between the two gate locations utilized for exposure sampling.

The dispersion model is the modified model being utilized by Arthur D. Little in its national risk assessment being performed for NASA. This model is the same as the model presented in a previous report except for the following modifications:

- Time of burn, percent of fuel burned and percent of carbon fiber structures consumed are based on a probabilistic distribution constructed from a data base of 92 fire and explosion accidents compiled by Lockheed, Douglas, and Boeing. Correlations among these variables were implemented and the distribution for percent of carbon fiber structures consumed is consistent with a structural damage model developed by Lockheed.

- Carbon fiber usage on aircraft is consistent with the production forecasts up to an including 1993 by the three airframe manufacturers. Fleets of aircraft that use carbon fibers are assumed to be split equally among the airframe manufacturers appropriate for each size of aircraft.

- Maximum percentage of carbon fibers released is assumed to be 1% and 4% for plume and explosive releases respectively.

- Maximum fuel loads are consistent with the types of aircraft that are dominating the 1993 fleet mix.

- Probability of explosive release is conservatively estimated to be 15%. This is consistent with the 92 fire and explosion accidents compiled by Lockheed, Douglas, and Boeing. This estimate is conservative in a sense that not all of these explosions represent burns followed by an explosion. The probability of an explosive release is higher than 15% for take-off accidents taking place on or near the runway and slightly lower than 15% for landing accidents.

In the next step of the analysis, probability distributions were estimated using the model for each of the nine airports at the maintenance and the gate areas conditional on there being a fire accident. These conditional distributions are presented in Table 1.

In the next step of the analysis the conditional distributions represented in Table 1 were combined with the statistics of the number of planes at each airport during the day and night in the gate and maintenance area to produce a distribution of number of planes being exposed to a given exposure.

In the final step of the analysis we assumed that every fire accident will occur at one of the nine airports. By making this assumption we can use the nine airports to project a national risk profile. In order to perform the final step, it was necessary to compute the conditional probability that an accident occurred at a particular one of these nine airports given that it occurred at one of the nine airports. The equation utilized in computing these probabilities is

$$\text{Prob } C_i \text{ is proportional to(estimated 1993 operations) x}$$
$$\text{(weather factor) x (percent CF)}$$

Derivation of the weather factor and the estimated 1993 operation are presented in the Arthur D. Little report for Phase 1. The percentage of CF represents the percentage of operations at a given airport in 1993 that will involve aircraft utilizing CF. These percentages were estimated utilizing the airframer estimates for percent of 1993 fleets carrying CF and projections of operations mixes by aircraft type at each given airport. Factors utilized in the computation and the conditional probability of each major city are presented in Table 2.

To estimate the conditional probability that an accident occurs during the day and night operations, we examined operations statistics at three airports and accident times for the 92 accidents cited previously. For Boston, the percentage of operations taking place during the night hours is 6% and for Washington, D.C. and Atlanta the percentages are 3.5% and

22% respectively. The percentage of night accidents in the data base is 25%. (These were the only data available). We, therefore, equate the nighttime probability of an accident at Washington to be 3.5% x the probability of an accident. For Boston, and for other cities that we judged to be mainly daytime airports we estimated the probability of an accident occurring during the nighttime hours as 6% x the probability of an accident. These cities included Boston, LaGuardia, Philadelphia, and St. Louis. For the other airports, Atlanta, Chicago, Kennedy, and Miami, which we judged to be active 24 hour airports we estimated that the probability of an accident taking place during the night hours is 25% x the probability of an accident. This estimate is consistent with the statistics from the 92-accident data base and the operations data from Atlanta. We used the 25% figure rather than 22% since there seems to be some evidence that night operations involve slightly more risk.

The conditional probability that an accident takes place at a given airport along with the day-night probabilities were utilized in constructing the overall distributions. These are presented in the next section.

III. RESULTS

The aggregate distributions for the number of aircraft experiencing a given exposure value are presented in Table 3 through 6. These tables represent the four conditions of interest which are day and night for gate and maintenance. Tables 7 through 10 present the aggregated and maintenance distributions and Table 11 represents the overall distributions. As noted previously, the conditional probability of aircraft being exposed to moderate exposure values is very low.

To convert these probabilities to annual values, each of the probabilities should be multiplied by 3.2 to represent the number of accidents occurring in a year. Thus, for example, the conditional probability of 10 or more planes being exposed to an exposure of 10^5 or greater is .69%. The annual probability of exposing 10 planes or greater to 10^5 or greater exposure is 3.2 x .69% or 2.2%. Table 12 through 20 are the analog of Tables 3 through 11 on an annual basis.

In order to estimate the size of the aircraft involved Table 21 presents the average fleet mix for aircraft exposed for each of the different situations.

Table 22 presents summaries of Tables 12 through 20 by presenting the average number of planes experiencing exposures in each interval for the various cases. The logarithmic average was chosen as the exposure value for each interval.

TABLE 1

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: JFK

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability that Gate Exposure Exceeds Value
10^3	.014	.0125
10^4	.008	.0080
10^5	.004	.0030
10^6	.0015	.0015
10^7	0	0

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: Chicago

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability that Gate Exposure Exceeds Value
10^3	.0165	.0105
10^4	.0085	.0080
10^5	.0040	.0045
10^6	.0005	.0030
10^7		.005

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: Miami

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Excceds Value
10^3	.022	.0118
10^4	.0115	.0063
10^5	.005	.0033
10^6	.0025	.0008
10^7	.0005	.0003

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: Atlanta

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Exceeds Value
10^3	.016	.0118
10^4	.0105	.0078
10^5	.007	.0033
10^6	.003	.0008
10^7		.0003

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: LaGuardia

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Exceeds Value
10^3	.0075	.0103
10^4	.0045	.0073
10^5	.0030	.0048
10^6	.0015	.0023
10^7		.0008

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: DC National

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Excceds Value
10^3	.017	.014
10^4	.011	.0095
10^5	.010	.0070
10^6	.0055	.0040
10^7		.0005

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: Boston

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Excceds Value
10^3	.006	.0009
10^4	.004	.0006
10^5	.002	.0005
10^6		.0001
10^7		.000025

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: Philadelphia

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Exceeds Value
10^3	.0165	.0105
10^4	.0090	.0065
10^5	.0035	.0060
10^6	.0005	.0030
10^7		.0010

TABLE 1 (CONTINUED)

CONDITIONAL EXPOSURE DISTRIBUTIONS AT GATE AND MAINTENANCE AREAS FOR NINE AIRPORTS

Airport: St. Louis

Exposure (fs/m^3)	Probability That Maintenance Exposure Exceeds Value	Probability That Gate Exposure Exceeds Value
10^3	.0105	.0075
10^4	.008	.0045
10^5	.0055	.0015
10^6	.0015	.0005
10^7		

TABLE 4

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Gate Night

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.002034	.001426	.000681	.000337	.000065
4	.002034	.001426	.000681	.000337	.000065
7	.002034	.001426	.000681	.000337	.000065
10	.002014	.001412	.000676	.000335	.000065
11	.001984	.001392	.000662	.000327	.000065
12	.001984	.001392	.000662	.000327	.000065
13	.001954	.001372	.000642	.000318	.000062
14	.001954	.001372	.000642	.000318	.000062
16	.001904	.001332	.000622	.000306	.000058
18	.001404	.001032	.000502	.000246	.000058
19	.001400	.001030	.000500	.000246	.000058
20	.001400	.001030	.000500	.000246	.000058
21	.001400	.001030	.000500	.000246	.000058
24	.001400	.001030	.000500	.000246	.000058
25	.000700	.000430	.000200	.000046	.000018
28	.000700	.000430	.000200	.000046	.000018
31	.000700	.000430	.000200	.000046	.000018
37	.000200	.000130	.000070	.000016	.000006
38	.000200	.000130	.000070	.000016	.000006
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 5

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Maintenance Day

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.009100	.005160	.002800	.000920	.000030
4	.008200	.004500	.002400	.000850	.000030
7	.008200	.004500	.002400	.000850	.000030
10	.006900	.003900	.002100	.000700	.000000
11	.005300	.003000	.001600	.000500	.000000
12	.001900	.001200	.000800	.000400	.000000
13	.001900	.001200	.000800	.000400	.000000
14	.000000	.000000	.000000	.000000	.000000
16	.000000	.000000	.000000	.000000	.000000
18	.000000	.000000	.000000	.000000	.000000
19	.000000	.000000	.000000	.000000	.000000
20	.000000	.000000	.000000	.000000	.000000
21	.000000	.000000	.000000	.000000	.000000
24	.000000	.000000	.000000	.000000	.000000
25	.000000	.000000	.000000	.000000	.000000
28	.000000	.000000	.000000	.000000	.000000
31	.000000	.000000	.000000	.000000	.000000
37	.000000	.000000	.000000	.000000	.000000
38	.000000	.000000	.000000	.000000	.000000
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 6

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Maintenance Night

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.002870	.001640	.000915	.000283	.000010
4	.002870	.001640	.000915	.000283	.000010
7	.002840	.001620	.000895	.000278	.000010
10	.002840	.001620	.000895	.000278	.000010
11	.002840	.001620	.000895	.000278	.000010
12	.002840	.001620	.000895	.000278	.000010
13	.002840	.001620	.000895	.000278	.000010
14	.002840	.001620	.000895	.000278	.000010
16	.002340	.001320	.000785	.000228	.000000
18	.002340	.001320	.000785	.000228	.000000
19	.002340	.001320	.000785	.000228	.000000
20	.002340	.001320	.000785	.000228	.000000
21	.001740	.000920	.000485	.000108	.000000
24	.001700	.000900	.000470	.000100	.000000
25	.001700	.000900	.000470	.000100	.000000
28	.000500	.000300	.000170	.000060	.000000
31	.000500	.000300	.000170	.000060	.000000
37	.000000	.000000	.000000	.000000	.000000
38	.000000	.000000	.000000	.000000	.000000
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 7

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE
PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Day

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.017600	.010920	.005800	.002370	.000342
4	.016700	.010260	.005400	.002300	.000342
7	.016700	.010260	.005400	.002300	.000342
10	.015400	.009660	.005100	.002150	.000312
11	.013200	.008360	.004400	.001850	.000262
12	.009800	.006560	.003600	.001750	.000262
13	.009800	.006560	.003600	.001750	.000262
14	.007900	.005360	.002800	.001350	.000262
16	.007900	.005360	.002800	.001350	.000262
18	.007000	.004760	.002300	.001150	.000232
19	.006600	.004500	.002200	.001120	.000230
20	.005800	.003900	.001800	.000920	.000170
21	.005800	.003900	.001800	.000920	.000170
24	.005800	.003900	.001800	.000920	.000170
25	.005800	.003900	.001800	.000920	.000170
28	.005800	.003900	.001800	.000920	.000170
31	.005100	.003500	.001600	.000870	.000150
37	.005100	.003500	.001600	.000870	.000150
38	.003700	.002600	.001200	.000770	.000110
54	.003700	.002600	.001200	.000770	.000110
55	.001500	.000900	.000300	.000170	.000000

TABLE 8

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Night

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.004904	.003066	.001596	.000620	.000075
4	.004904	.003066	.001596	.000620	.000075
7	.004874	.003046	.001576	.000615	.000075
10	.004854	.003032	.001571	.000613	.000075
11	.004824	.003012	.001557	.000605	.000075
12	.004824	.003012	.001557	.000605	.000075
13	.004794	.002992	.001537	.000596	.000072
14	.004794	.002992	.001537	.000596	.000072
16	.004244	.002652	.001407	.000534	.000058
18	.003744	.002352	.001287	.000474	.000058
19	.003740	.002350	.001285	.000474	.000058
20	.003740	.002350	.001285	.000474	.000058
21	.003140	.001950	.000985	.000354	.000058
24	.003100	.001930	.000970	.000346	.000058
25	.002400	.001330	.000670	.000146	.000018
28	.001200	.000730	.000370	.000106	.000018
31	.001200	.000730	.000370	.000106	.000018
37	.000200	.000130	.000070	.000016	.000006
38	.000200	.000130	.000070	.000016	.000006
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 9

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Gate

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.010534	.007186	.003681	.001787	.000377
4	.010534	.007186	.003681	.001787	.000377
7	.010534	.007186	.003681	.001787	.000377
10	.010514	.007172	.003676	.001785	.000377
11	.009884	.006752	.003462	.001677	.000327
12	.009884	.006752	.003462	.001677	.000327
13	.009854	.006732	.003442	.001668	.000324
14	.009854	.006732	.003442	.001668	.000324
16	.009804	.006692	.003422	.001656	.000320
18	.008404	.005792	.002802	.001396	.000290
19	.008000	.005530	.002700	.001366	.000288
20	.007200	.004930	.002300	.001166	.000228
21	.007200	.004930	.002300	.001166	.000228
24	.007200	.004930	.002300	.001166	.000228
25	.006500	.004330	.002000	.000966	.000188
28	.006500	.004330	.002000	.000966	.000188
31	.005800	.003930	.001800	.000916	.000168
37	.005300	.003630	.001670	.000886	.000156
38	.003900	.002730	.001270	.000786	.000116
54	.003700	.002600	.001200	.000770	.000110
55	.001500	.000900	.000300	.000170	.000000

TABLE 10

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Maintenance

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.011970	.006800	.003715	.001203	.000040
4	.011070	.006140	.003315	.001133	.000040
7	.011040	.006120	.003295	.001128	.000040
10	.009740	.005520	.002995	.000978	.000010
11	.008140	.004620	.002495	.000778	.000010
12	.004740	.002820	.001695	.000678	.000010
13	.004740	.002820	.001695	.000678	.000010
14	.002840	.001620	.000895	.000278	.000010
16	.002340	.001320	.000785	.000228	.000000
18	.002340	.001320	.000785	.000228	.000000
19	.002340	.001320	.000785	.000228	.000000
20	.002340	.001320	.000785	.000228	.000000
21	.001740	.000920	.000485	.000108	.000000
24	.001700	.000900	.000470	.000100	.000000
25	.001700	.000900	.000470	.000100	.000000
28	.000500	.000300	.000170	.000060	.000000
31	.000500	.000300	.000170	.000060	.000000
37	.000000	.000000	.000000	.000000	.000000
38	.000000	.000000	.000000	.000000	.000000
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 11

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT *n* OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

<u>Case: Aggregate Overall</u>

Number of Planes n	Exposure E (fs/m^3) 10^3	10^4	10^5	10^6	10^7
2	.022400	.014010	.007355	.003018	.000417
4	.021500	.013350	.006955	.002948	.000417
7	.021470	.013330	.006935	.002943	.000417
10	.020170	.012630	.006635	.002793	.000387
11	.017970	.011330	.005935	.002493	.000337
12	.014570	.009530	.005135	.002393	.000337
13	.014540	.009510	.005115	.002384	.000334
14	.012640	.008310	.004315	.001984	.000334
16	.012140	.008010	.004185	.001924	.000320
18	.010740	.007110	.003585	.001674	.000290
19	.010340	.006850	.003485	.001594	.000288
20	.009540	.006250	.003085	.001394	.000228
21	.008940	.005850	.002785	.001274	.000228
24	.008900	.005830	.002770	.001266	.000228
25	.008200	.005230	.002470	.001066	.000188
28	.007000	.004630	.002170	.001026	.000188
31	.006300	.004230	.001970	.000976	.000168
37	.005300	.003630	.001670	.000886	.000156
38	.003900	.002730	.001270	.000786	.000116
54	.003700	.002600	.001200	.000770	.000110
55	.001500	.000900	.000300	.000170	.000000

TABLE 12

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Gate Day

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.027200	.018432	.009600	.004640	.000998
4	.027200	.018432	.009600	.004640	.000998
7	.027200	.018432	.009600	.004640	.000998
10	.027200	.018432	.009600	.004640	.000998
11	.025280	.017152	.008960	.004320	.000838
12	.025280	.017152	.008960	.004320	.000838
13	.025280	.017152	.008960	.004320	.000838
14	.025280	.017152	.008960	.004320	.000838
16	.025280	.017152	.008960	.004320	.000838
18	.022400	.015232	.007360	.003680	.000742
19	.021120	.014400	.007040	.003584	.000736
20	.018560	.012480	.005760	.002944	.000544
21	.018560	.012480	.005760	.002944	.000544
24	.018560	.012480	.005760	.002944	.000544
25	.018560	.012480	.005760	.002944	.000544
28	.018560	.012480	.005760	.002944	.000544
31	.016320	.011200	.005120	.002784	.000480
37	.016320	.011200	.005120	.002784	.000480
38	.011840	.008320	.003840	.002464	.000352
54	.011840	.008320	.003840	.002464	.000352
55	.004800	.002880	.000960	.000544	.000000

TABLE 13

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Gate Night

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.006509	.004563	.002179	.001080	.000209
4	.006509	.004563	.002179	.001080	.000209
7	.006509	.004563	.002179	.001080	.000209
10	.006445	.004518	.002163	.001073	.000209
11	.006349	.004454	.002118	.001048	.000208
12	.006349	.004454	.002118	.001048	.000208
13	.006253	.004390	.002054	.001019	.000199
14	.006253	.004390	.002054	.001019	.000199
16	.006093	.004262	.001990	.000980	.000186
18	.004493	.003302	.001606	.000788	.000186
19	.004480	.003296	.001600	.000787	.000186
20	.004480	.003296	.001600	.000787	.000186
21	.004480	.003296	.001600	.000787	.000186
24	.004480	.003296	.001600	.000787	.000186
25	.002240	.001376	.000640	.000147	.000058
28	.002240	.001376	.000640	.000147	.000058
31	.002240	.001376	.000640	.000147	.000058
37	.000640	.000416	.000224	.000051	.000019
38	.000640	.000416	.000224	.000051	.000019
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 14

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Maintenance Day

		Exposure (fs/m^3)				
		10^3	10^4	10^5	10^6	10^7
Number of Planes n	2	.029120	.016512	.008960	.002944	.000096
	4	.026240	.014400	.007680	.002720	.000096
	7	.026240	.014400	.007680	.002720	.000096
	10	.022080	.012480	.006720	.002240	.000000
	11	.016960	.009600	.005120	.001600	.000000
	12	.006080	.003840	.002560	.001280	.000000
	13	.006080	.003840	.002560	.001280	.000000
	14	.000000	.000000	.000000	.000000	.000000
	16	.000000	.000000	.000000	.000000	.000000
	18	.000000	.000000	.000000	.000000	.000000
	19	.000000	.000000	.000000	.000000	.000000
	20	.000000	.000000	.000000	.000000	.000000
	21	.000000	.000000	.000000	.000000	.000000
	24	.000000	.000000	.000000	.000000	.000000
	25	.000000	.000000	.000000	.000000	.000000
	28	.000000	.000000	.000000	.000000	.000000
	31	.000000	.000000	.000000	.000000	.000000
	37	.000000	.000000	.000000	.000000	.000000
	38	.000000	.000000	.000000	.000000	.000000
	54	.000000	.000000	.000000	.000000	.000000
	55	.000000	.000000	.000000	.000000	.000000

TABLE 15

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Maintenance Night

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.009184	.005248	.002928	.000906	.000032
4	.009184	.005248	.002928	.000906	.000032
7	.009088	.005184	.002864	.000890	.000032
10	.009088	.005184	.002864	.000890	.000032
11	.009088	.005184	.002864	.000890	.000032
12	.009088	.005184	.002864	.000890	.000032
13	.009088	.005184	.002864	.000890	.000032
14	.009088	.005184	.002864	.000890	.000032
16	.007488	.004224	.002512	.000730	.000000
18	.007488	.004224	.002512	.000730	.000000
19	.007488	.004224	.002512	.000730	.000000
20	.007488	.004224	.002512	.000730	.000000
21	.005568	.002944	.001552	.000346	.000000
24	.005440	.002880	.001504	.000320	.000000
25	.005440	.002880	.001504	.000320	.000000
28	.001600	.000960	.000544	.000192	.000000
31	.001600	.000960	.000544	.000192	.000000
37	.000000	.000000	.000000	.000000	.000000
38	.000000	.000000	.000000	.000000	.000000
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 16

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Day

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.056320	.034944	.018560	.007584	.001094
4	.053440	.032832	.017280	.007360	.001094
7	.053440	.032832	.017280	.007360	.001094
10	.049280	.030912	.016320	.006880	.000998
11	.042240	.026752	.014080	.005920	.000838
12	.031360	.020992	.011520	.005600	.000838
13	.031360	.020992	.011520	.005600	.000838
14	.025280	.017152	.008960	.004320	.000836
16	.025280	.017152	.008960	.004320	.000838
18	.022400	.015232	.007360	.003680	.000742
19	.021120	.014400	.007040	.003584	.000736
20	.018560	.012480	.005760	.002944	.000544
21	.018560	.012480	.005760	.002944	.000544
24	.018560	.012480	.005760	.002944	.000544
25	.018560	.012480	.005760	.002944	.000544
28	.018560	.012480	.005760	.002944	.000544
31	.016320	.011200	.005120	.002784	.000480
37	.016320	.011200	.005120	.002784	.000480
38	.011840	.008320	.003840	.002464	.000352
54	.011840	.008320	.003840	.002464	.000352
55	.004800	.002880	.000960	.000544	.000000

TABLE 17

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Night

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.015693	.009811	.005107	.001985	.000241
4	.015693	.009811	.005107	.001985	.000241
7	.015597	.009747	.005043	.001969	.000241
10	.015533	.009702	.005027	.001963	.000241
11	.015437	.009638	.004982	.001937	.000240
12	.015437	.009638	.004982	.001937	.000240
13	.015341	.009574	.004918	.001908	.000231
14	.015341	.009574	.004918	.001908	.000231
16	.013581	.008486	.004502	.001710	.000186
18	.011981	.007526	.004118	.001518	.000186
19	.011968	.007520	.004112	.001517	.000186
20	.011968	.007520	.004112	.001517	.000186
21	.010048	.006240	.003152	.001133	.000186
24	.009920	.006176	.003104	.001107	.000186
25	.007680	.004256	.002144	.000467	.000058
28	.003840	.002336	.001184	.000339	.000058
31	.003840	.002336	.001184	.000339	.000058
37	.000640	.000416	.000224	.000051	.000019
38	.000640	.000416	.000224	.000051	.000019
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 18

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Gate

Exposure E (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.033709	.022995	.011779	.005720	.001207
4	.033709	.022995	.011779	.005720	.001207
7	.033709	.022995	.011779	.005720	.001207
10	.033645	.022950	.011763	.005713	.001207
11	.031629	.021606	.011078	.005368	.001046
12	.031629	.021606	.011078	.005368	.001046
13	.031533	.021542	.011014	.005339	.001037
14	.031533	.021542	.011014	.005339	.001037
16	.031373	.021414	.010950	.005300	.001024
18	.026893	.018534	.008966	.004468	.000928
19	.025600	.017696	.008640	.004371	.000922
20	.023040	.015776	.007360	.003731	.000730
21	.023040	.015776	.007360	.003731	.000730
24	.023040	.015776	.007360	.003731	.000730
25	.020800	.013856	.006400	.003091	.000602
28	.020800	.013856	.006400	.003091	.000602
31	.018560	.012576	.005760	.002931	.000538
37	.016960	.011616	.005344	.002835	.000499
38	.012480	.008736	.004064	.002515	.000371
54	.011840	.008320	.003840	.002464	.000352
55	.004800	.002880	.000960	.000544	.000000

TABLE 19

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Maintenance

Number of Planes n	Exposure E (fs/m^3) 10^3	10^4	10^5	10^6	10^7
2	.038304	.021760	.011888	.003850	.000128
4	.035424	.019648	.010608	.003626	.000128
7	.035328	.019584	.010544	.003610	.000128
10	.031168	.017664	.009584	.003130	.000032
11	.026048	.014784	.007984	.002490	.000032
12	.015168	.009024	.005424	.002170	.000032
13	.015168	.009024	.005424	.002170	.000032
14	.009088	.005184	.002864	.000890	.000032
16	.007488	.004224	.002512	.000730	.000000
18	.007488	.004224	.002512	.000730	.000000
19	.007488	.004224	.002512	.000730	.000000
20	.007488	.004224	.002512	.000730	.000000
21	.005568	.002944	.001552	.000346	.000000
24	.005440	.002880	.001504	.000320	.000000
25	.005440	.002880	.001504	.000320	.000000
28	.001600	.000960	.000544	.000192	.000000
31	.001600	.000960	.000544	.000192	.000000
37	.000000	.000000	.000000	.000000	.000000
38	.000000	.000000	.000000	.000000	.000000
54	.000000	.000000	.000000	.000000	.000000
55	.000000	.000000	.000000	.000000	.000000

TABLE 20

ANNUAL PROBABILITY THAT n OR MORE PLANES ARE EXPOSED
TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Overall

Exposure (fs/m^3)

Number of Planes n	10^3	10^4	10^5	10^6	10^7
2	.071680	.044832	.023536	.009658	.001334
4	.068800	.042720	.022256	.009434	.001334
7	.068704	.042656	.022192	.009418	.001334
10	.064544	.040416	.021232	.008928	.001238
11	.057504	.036256	.018992	.007978	.001078
12	.046624	.030496	.016432	.007658	.001078
13	.046528	.030432	.016368	.007629	.001064
14	.040448	.026592	.013808	.006349	.001069
16	.038848	.025632	.013392	.006157	.001024
18	.034368	.022752	.011472	.005197	.000928
19	.033088	.021920	.011152	.005101	.000922
20	.030528	.020000	.009872	.004461	.000730
21	.028608	.018720	.008912	.004077	.000730
24	.028480	.018656	.008864	.004051	.000730
25	.026240	.016736	.007904	.003411	.000602
28	.022400	.014816	.006944	.003283	.000602
31	.020160	.013536	.006304	.003123	.000538
37	.016960	.011616	.005344	.002835	.000499
38	.012480	.008736	.004064	.002515	.000371
54	.011840	.008320	.003840	.002464	.000352
55	.004800	.002880	.000960	.000544	.000000

TABLE 21

AVERAGE FLEET MIX FOR AIRCRAFT EXPOSED IN ACCIDENTS

	% Small	% Medium	% Large
Maintenance Day	79.2	2.1	18.7
Maintenance Night	70.5	8.2	21.3
Gate Day	79.2	5.5	15.3
Gate Night	75.2	6.6	18.2
Maintenance Overall	75.5	4.7	19.8
Gate Overall	78.7	5.7	15.6
Day Overall	79.2	5.0	15.8
Night Overall	72.9	7.4	19.7
Overall	78.0	5.4	16.6

TABLE 22

EXPECTED NUMBER OF PLANES EXPOSED TO A
A GIVEN EXPOSURE ANNUALLY

Case	3.2×10^3	3.2×10^4	3.2×10^5	3.2×10^6	3.2×10^7
Total	.58387	.53673	.28974	.21301	.03884
Day	.44512	.42688	.21478	.17451	.03310
Night	.13875	.10985	.07495	.03849	.00574
Gate	.36774	.41156	.18680	.16408	.03772
Maintenance	.21613	.12517	.10293	.04892	.00112
Gate-Day	.32006	.35386	.15843	.14482	.03243
Gate-Night	.04767	.05771	.02837	.01927	.00530
Maintenance-Day	.12506	.07302	.05635	.02970	.00067
Maintenance-Night	.09107	.05214	.04658	.01923	.00045

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16. ABSTRACT

This report was prepared under contract to NASA in support of their program to assess the national risk associated with the accidental release of carbon/graphite fibers (CF) from fires on commercial transport aircraft incorporating composite materials. Data are developed to evaluate the potential for CF damage to electrical and electronic equipment, assess the cost risk, and evaluate the hazard to continued operation. The subjects covered include identification of susceptible equipments, determination of infiltration transfer functions, analysis of airport operations, calculation of probabilities of equipment failures, assessment of the cost risk, and evaluation of the hazard to continued operation. The results of this study show the risks associated with CF contamination are negligible through 1993.

17. KEY WORDS (SUGGESTED BY AUTHOR(S))
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TABLE A-1. EQUIPMENT RELIABILITY/MAINTENANCE COST - CURRENT SOURCES (Continued)

EQUIP. NO.	SYSTEM USAGE	QUANTITY PER AIRCRAFT	LOCATION IN AIRCRAFT	$\overline{E}$	BASIC FAILURES PER 1000 HRS	UNSCHEDULED REMOVALS PER 1000 HRS	COST* PER BASIC FAILURE	COST* PER UNSCHEDULED REMOVAL	EQUIP. GROUP
78	Airborne Aux Pwr	1	Passenger Cabin	1.0×10^8	0.4234	2.2124	240	123	D
79	Airborne Aux Pwr	1	Passenger Cabin	1.0×10^8	0.0833	0.1000	260	249	D
80	Fuel Flow	1	Flight Station	1.0×10^8	0.0025	0.0033	193	178	B
81	Fuel Flow	1	Flight Station	1.0×10^8	0.4000	0.5000	199	186	B
82	Engine Ignition	1	Flight Station	1.0×10^8	0.0167	0.0200	303	292	B
83	Engine Indicating	1	Avionic Centers	1.0×10^8	0.1638	0.4505	193	124	E
84	Engine Indicating	1	Flight Station	1.0×10^8	0.4000	0.5000	268	253	B

*1978 Dollars

TABLE A-2. MAINTENANCE COST - BASIC FAILURES

EQUIP. NO.	EQUIPMENT SYSTEM USAGE	ON-AIRCRAFT DIRECT MANHOURS	SHOP DIRECT MANHOURS	TOTAL DIRECT MANHOURS	DIRECT LABOR COST	BURDEN EXPENSE	SHOP MATERIAL COST	TOTAL COST*
1	Air Conditioning	1.0	3.9	4.9	49.00	88.20	108.65	245.85
2	Air Conditioning	1.0	4.8	5.8	58.00	104.40	170.60	279.25
3	Air Conditioning	0.8	4.8	5.6	56.00	100.80	132.75	289.55
4	Auto Flight	1.5	5.4	6.9	69.00	124.20	31.52	224.75
5	Auto Flight	6.0	4.2	10.2	102.00	183.60	37.45	323.05
6	Auto Flight	1.8	3.5	5.3	53.00	95.40	40.55	188.95
7	Auto Flight	1.8	6.4	8.2	82.00	147.60	31.16	260.76
8	Auto Flight	1.8	6.0	7.8	78.00	140.40	30.62	249.02
9	Auto Flight	1.8	3.5	5.3	53.00	95.40	11.90	160.30
10	Auto Flight	1.8	5.6	7.4	74.00	133.20	32.67	239.87
11	Auto Flight	1.8	4.8	6.6	66.00	118.80	12.65	197.45
12	Radio Communications	1.0	1.7	2.7	27.00	48.60	53.77	129.37
13	Radio Communications	1.0	3.4	4.4	44.00	79.20	24.72	147.92
14	Passenger Service	1.0	2.5	3.5	35.00	63.00	110.07	208.04
15	Passenger Service	2.0	5.3	7.3	73.00	131.40	34.70	239.10
16	Passenger Service	1.0	2.8	3.8	38.00	68.40	27.68	134.08
17	Passenger Service	2.0	4.4	6.4	64.00	115.20	38.53	217.73
18	Passenger Service	2.0	4.5	6.5	65.00	117.00	52.50	234.50
19	Passenger Service	3.0	3.9	6.9	69.00	124.20	28.67	221.87
20	Passenger Service	0.8	4.5	5.3	53.00	95.40	151.63	300.23
21	Passenger Service	2.0	5.5	7.5	25.00	135.00	68.03	278.03

*1978 Dollars

TABLE 2

COMPUTATION OF THE CONDITIONAL PROBABILITY OF A CITY

	Estimated 1993 Op	Weather Factor	% CF	Probability
Atlanta	433,434	1.09	.54	.159
Boston	171,897	1.06	.63	.072
Chicago	599,339	1.04	.72	.280
Kennedy	289,275	1.05	.81	.154
LaGuardia	213,724	1.05	.61	.085
Miami	249,330	.65	.78	.079
Philadelphia	138,520	1.04	.60	.054
St. Louis	165,764	.99	.50	.051
Washington	189,295	.87	.64	.066

TABLE 3

PROBABILITY CONDITIONAL ON AN ACCIDENT THAT n OR MORE PLANES ARE EXPOSED TO AN EXPOSURE OF E OR LARGER

Case: Aggregate Gate Day

Number of Planes n	Exposure E (fs/m^3) 10^3	10^4	10^5	10^6	10^7
2	.008500	.005700	.003000	.001450	.000312
4	.008500	.005700	.003000	.001450	.000312
7	.008500	.005700	.003000	.001450	.000312
10	.008500	.005700	.003000	.001450	.000312
11	.007900	.005360	.002800	.001350	.000262
12	.007900	.005360	.002800	.001350	.000262
13	.007900	.005360	.002800	.001350	.000262
14	.007900	.005360	.002800	.001350	.000262
16	.007900	.005360	.002800	.001350	.000262
18	.007000	.004760	.002300	.001150	.000232
19	.006600	.004500	.002200	.001120	.000230
20	.005800	.003900	.001800	.000920	.000170
21	.005800	.003900	.001800	.000920	.000170
24	.005800	.003900	.001800	.000920	.000170
25	.005800	.003900	.001800	.000920	.000170
28	.005800	.003900	.001800	.000920	.000170
31	.005100	.003500	.001600	.000870	.000150
37	.005100	.003500	.001600	.000870	.000150
38	.003700	.002600	.001200	.000770	.000110
54	.003700	.002600	.001200	.000770	.000110
55	.001500	.000900	.000300	.000170	.000000