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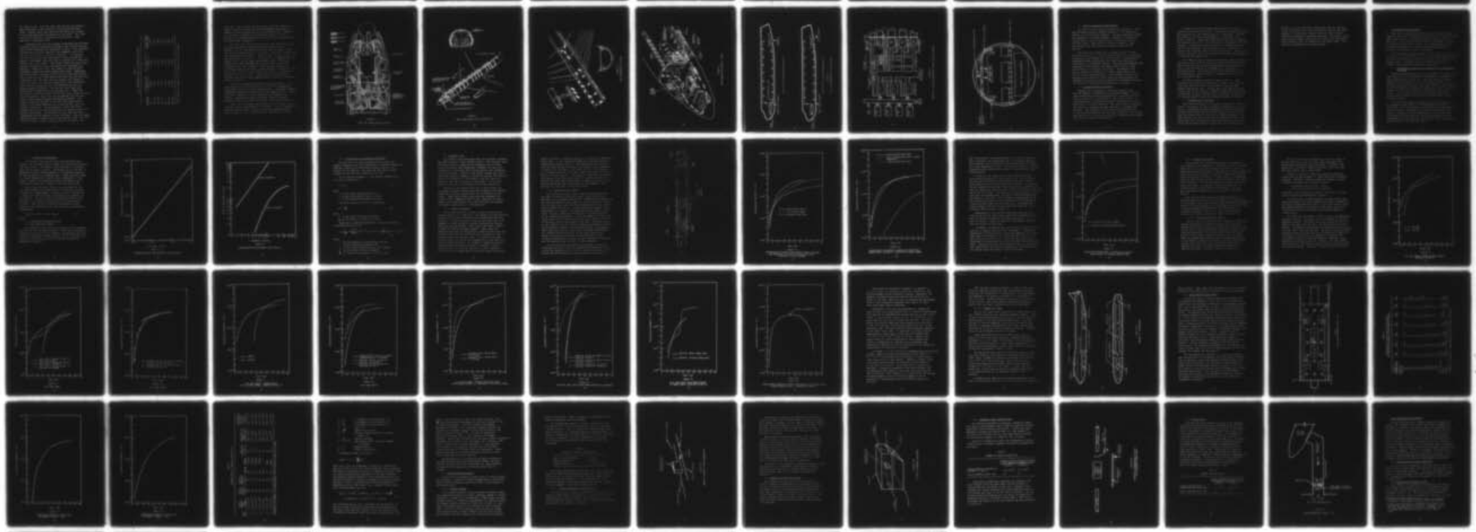

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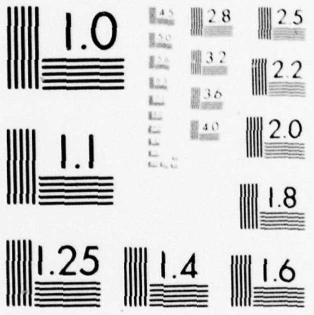

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LEVEL II

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EVALUATING SENSITIVITY REQUIREMENTS OF EXPLOSIVE VAPOR DETECTOR SYSTEMS

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16\. Abstract

The sensitivity requirements for bomb chemosensors in air transportation facilities depend in part on the extent of vapor attenuation that occurs between the point where bomb-characteristic vapors escape from the bomb enclosure and the site of the chemosensor. The magnitudes of this attenuation parameter for various possible bomb locations were explored using Freon 12 as the bomb vapor simulator and a halogen leak detector. The facilities tested included: the passenger cabin, luggage space, and the lavatories of DC-8's and 707's with the aircraft parked and while the aircraft were taxied. Also, tested were the cabin of the 747, a mobile lounge, a passenger jetway and check-in counter, a baggage conveyor and baggage containers. The exact location of the chemosensor in the DC-8, 707 and mobile lounge was not found to be critical and the detection should be possible in 10 minutes or less. In the 747, chemosensing will be needed in several locations. The jetway appears to be a preferable location for passenger walk-by screening. Chemosensing of bombs in baggage or on conveyor belts requires elimination of major drafts and may present a response speed problem. Baggage loading containers present no special problem. The above assessments apply to detectors of reasonable sensitivity.

17\. Key Words

Explosives, Sabotage, Vapor Detection

18\. Distribution Statement

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EVALUATING SENSITIVITY REQUIREMENTS OF EXPLOSIVE VAPOR DETECTOR SYSTEMS

1. BACKGROUND AND OBJECTIVE

Current bomb detection systems depend on identifying trace quantities of vapors emitting from explosives. The sensitivities of various experimental detectors can be established; still to be determined is the sensitivity actually required for practical applications aboard aircraft or in baggage handling systems. Similarly, the optimum location of the detector aboard aircraft or at airport facilities has not been determined. Thus, it was the objective of this study to gather the information necessary to establish the engineering specifications of workable detection systems.

In bomb detection by chemosensors, three factors control the concentration of the detectable vapor: the rate of emission of the particular vapor from the explosive proper, the extent by which various barriers (wrappings, suitcases, etc.) hinder these vapors from reaching freely moving air and the extent to which the vapors which left the containers are further attenuated in air before reaching the detector site. The first two are specific to the explosive and the geometry and tightness of the container. The attenuation which occurs by a dilution in turbulent eddying air is not significantly species-specific. The work, as requested by the contract, dealt with establishing the extent of attenuation of vapors in several air transportation related facilities.

Since the attenuation of vapors in bulk air is not species-specific, it could be explored using a non-toxic non-explosive simulant (tracer) gas, Freon 12, instead of experimenting with explosives which would have introduced extreme operational difficulties.

Specifically, this program was directed toward evaluating four facilities:

1. Aircraft such as 747 and 707 size
2. Mobile lounges at Dulles Airport
3. Typical baggage handling systems, both open and enclosed type
4. Boarding gate positions.

2. EXPERIMENTAL EQUIPMENT

The technique used in the program was relatively simple, safe and straightforward. The vapor emitting from an explosive was simulated by releasing Freon 12 gas at selected rates. Two small cylinders of Freon 12 were utilized as the Freon source. One cylinder was attached to a pre-calibrated flow meter and positioned inside a typical attache case. A needle valve provided flow adjustment at the desired rate; the Freon exhausted through a small tube slightly protruding from the bottom of the case. This cylinder was used in some baggage tests and in the passenger gate tests. The second cylinder was enclosed in a small, cardboard box. The Freon was released through a tube protruding from the side of the box. The flow rate was preset by adjusting a needle valve; a block valve permitted rapid on-off control. This package was used in the majority of the aircraft tests and in some baggage handling tests. It would fit underneath an aircraft seat or could be placed in the overhead luggage rack.

A standard halogen leak detector simulated the bomb detector. This instrument, General Electric Model No. H-2, gun detector and control unit is designed to detect small changes in current flowing through a heated sensing element. This current increases in direct proportion to the amount of halogen gas drawn through the sensing element by a small pump. An electronic circuit amplifies the current and converts it into a direct read-out as concentration. A range selection switch permits concentrations as low as 1 PPHM to be monitored. This instrument was operated in the IITRI laboratories to determine its response time, calibration, drift and any operational pecularities. The calibration and sensitivity over several ranges were measured experimentally as follows: the sensing element was placed in a cubical, stainless steel tank having a volume of 10^6 ml. A small fan constantly circulated the air within the tank. After the tank background concentration was recorded quantities of Freon 12 - ranging from 0.01 to 50 ml - were injected into the tank. Thus response time and a calibration over several ranges were obtained. In addition, the effects of high humidity, electronic adjustments, and circulating air velocity were determined and could be used for interpretation of data obtained in field tests.

The leak detector is designed to operate with a 100 Vac 60 Hz power source. Available power aboard aircraft varies from 28VDC to 110 VAC 400 Hz. To provide complete mobility and flexibility in the test program, a portable power source consisting of a 12 volt battery and an inverter was assembled. The power source and the detector were mounted on a two wheel hand truck for mobility.

3. EXPERIMENTAL WORK

Through the cooperation of four airlines, AA, NW, TWA and UAL, testing procedures were developed and refined into workable techniques which were used at the four facilities to obtain valid data.

3.1 Aircraft

Initial tests were conducted aboard a DC-8 located in or adjacent to a hangar. Ground power was utilized to operate the aircraft equipment and to supply operating power for the Halogen detector. A typical test consisted of positioning the Freon source beneath one of the seats in the First Class Lounge. The detector was placed on a portable cart at the aft end of the cabin. With the planes recirculating fans on, the background or ambient Freon concentration in the cabin was measured and allowed to reach equilibrium. At time zero, the Freon gas was released at a measured rate. Time and concentration levels were recorded at the extreme rear of the passenger cabin. When the concentration reached a constant value at this location, the detector was moved forward and concentration levels measured at many other points throughout the cabin. Several variations of this technique were employed to gather data with the Freon leak in different locations. One limitation to this technique became obvious: there was not enough ground power available to operate all the aircraft air circulation systems in their normal, pretakeoff manner. Thus, the tests were not truly indicative of the actual situation commonly expected aboard an aircraft awaiting takeoff.

A second testing procedure was developed and was used to conduct further tests on aircraft operating under their own power. Regularly, airplanes are taxied between the terminal and hangar area. These aircraft have full power available and the air circulation system could be operated in any desired fashion. The taxi runs varied from 10 to 60 min. duration; arbitrarily, the tests were directed towards obtaining data in the first 10 min. Both the Freon leak and the leak detector were positioned at many different locations during these tests. Several tests were made with the Freon leak located in the cargo space and the detector in the cabin. Two "live" tests were conducted on occupied aircraft prior to their departure on scheduled trips.

Concurrent with the test program, information was obtained concerning the air circulation systems of the various aircraft. Some of this information is presented in Table 1; the remaining information on aircraft operation and equipment variations does not fit into any consistent tabulation. For instance, all the 707's do not have recirculating fans, instead they depend on the Gasper (eye ball) fan to circulate air while the aircraft is on the ground. This blower system may have a small capacity and does not truly recirculate air throughout the fuselage. Some DC-8's carry the luggage in semi-enclosed containers; others have hand loaded cargo areas. Supposedly, the cargo areas of the jets do not have air circulated within them; rather the air flows between the outer skin and the cargo compartment wall and thus would not support any combustion among the cargo. But the seal between the cargo compartment wall and the circulating air is not complete and can vary among individual aircraft. All aircraft have radio rack exhaust fans to keep the electronic gear cool. These fans will directly exhaust as much as 1000 CFM of air while the plane is on the ground. Since this air is supplied from the main cabin it does present unusual circulation problems. (In flight the air is returned to the main circulation ducts.) Finally, the ground operation of an aircraft will vary with seasonal conditions. In warm weather a plane with Freon coolers will use the recirculating fans to keep the cabin cool while on the ground. If the plane is cold, then the turbo compressors will be operated to heat the cabin: this air making one pass through the plane and out the outflow valve. On 707's and DC-8's both of these systems cannot be operated at the

Table 1

AIR CIRCULATION RATES OF SELECTED AIRCRAFT

Aircraft	Fuselage Volume, Cu Ft	Fresh Air Inflow,* CFM	Recirculation Rate, CFM
747	26,000	8,200	2,500
707-120	8,600	1,000	1,600
707-320	9,100	1,000	1,600
707-720	7,600	1,000	1,600
DC-8	9,300	1,000	4,200
DC-8-62	11,000	1,000	5,600
DC-8-61	12,000	1,000	5,600

*While taxiing, engines at or slightly above idle speed.

same time. The ductwork within the plane does not contain one common location in which air could be sampled regardless of whether it was recirculating air or discharging air. Figures 1 to 4 present the design air circulation system of a DC 8. Figure 5 is a simplified sketch of the air flow of this aircraft in either mode of operation.

The 747 is the only aircraft in which the fresh air system and the recirculating system can operate simultaneously. However, the air flow patterns are such that the recirculated air is in the upper portion of the cabin, little or no recirculated air reaches the cabin deck. Figures 6 and 7 outline the design air flow pattern for the 747. The size of the fuselage required separation of the air supply system into zones. This large volume of air also required two outflow valves, each valve exhausting air from a portion of the fuselage. The four recirculating fans do not feed a common manifold and thus thoroughly mix the air, rather the only mixing that occurs is caused by diffusion within the cabin. Thus, the air flowing from one outflow valve is not truly representative of the air circulating within its zones.

The above information complicated the test program. The air velocity at the outflow valve is too high for dependable measurements with the Halogen leak detector. The plenum chamber immediately upstream of the outflow valve appears to be a logical place for a detector but this area was not accessible for testing. Measurements made outside the aircraft could be suspect because of interferring exhaust gases from the engines.

Thus, we have reached a point where no one optimum detector location can be recommended for all types of aircraft operated in all the various modes. However, those tests which produced positive data in certain situations are discussed in Section 4.

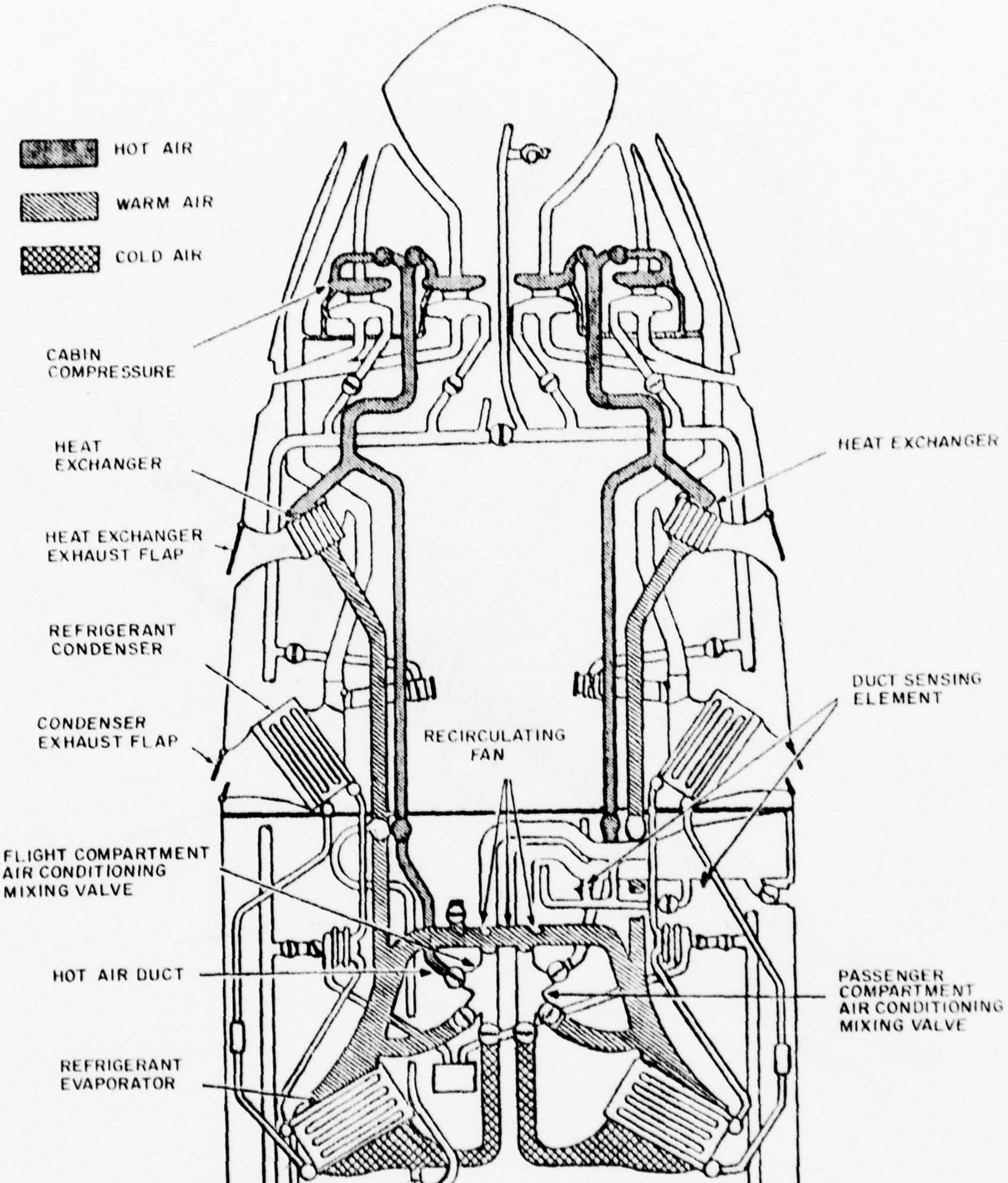


Figure 1

DC-8 AIR CONDITIONING SYSTEM

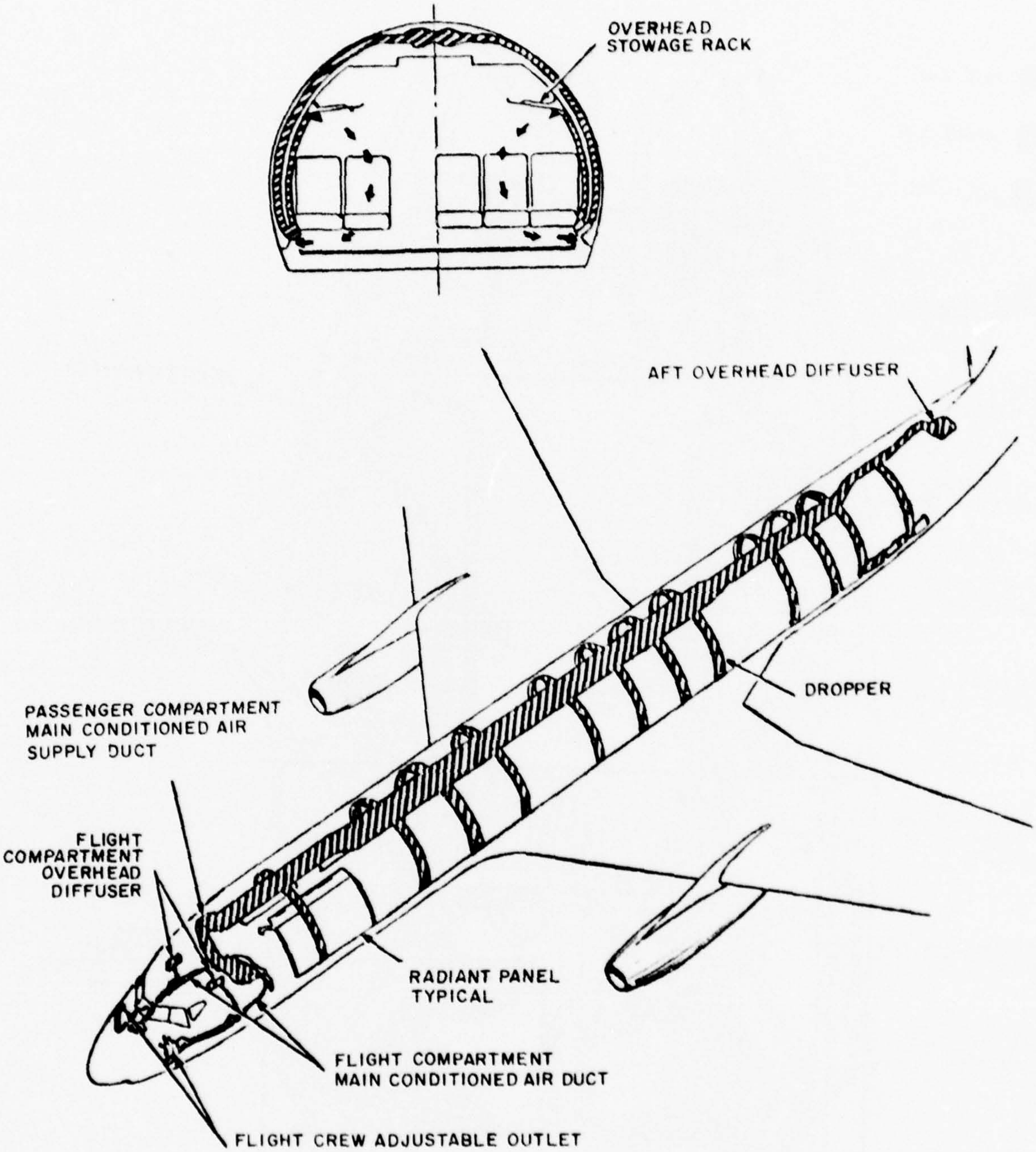


Figure 2

DC-8 CONDITIONED AIR DISTRIBUTION

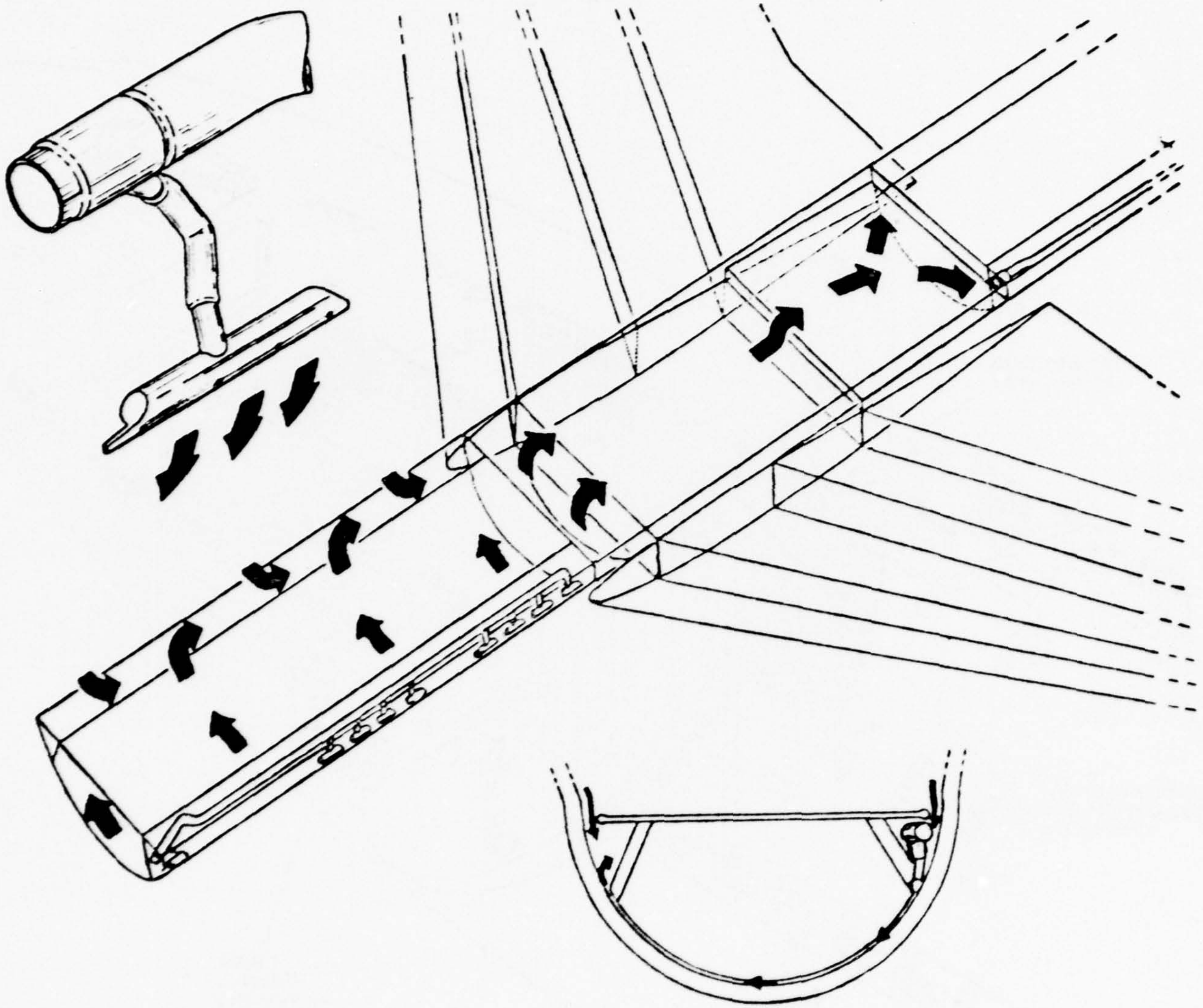


Figure 3

DC-8 UNDERFLOW AIR FLOW

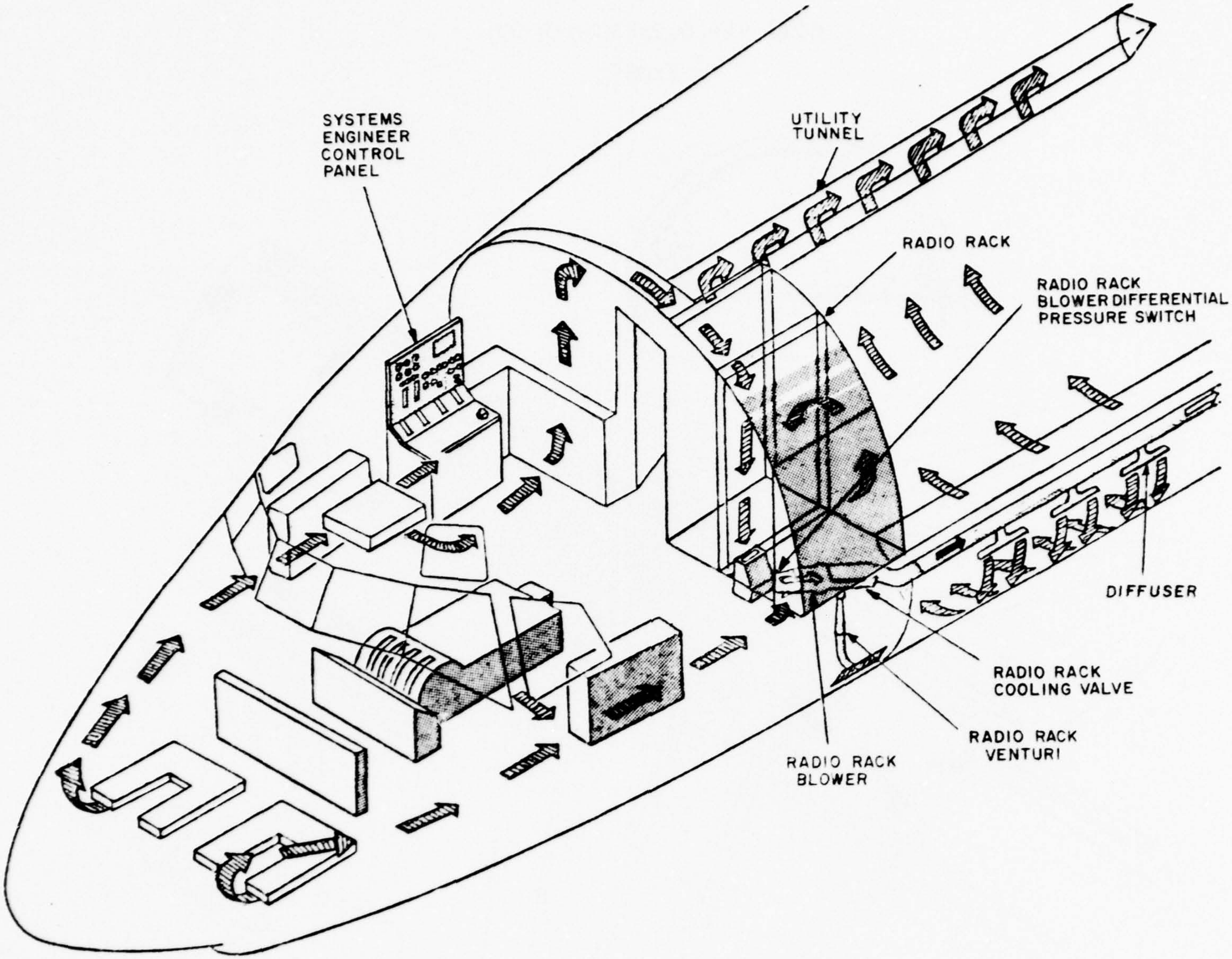
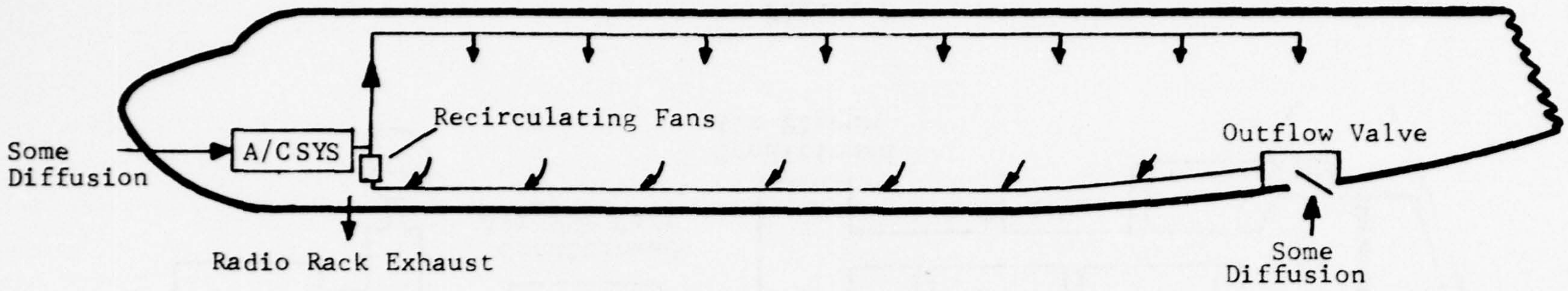
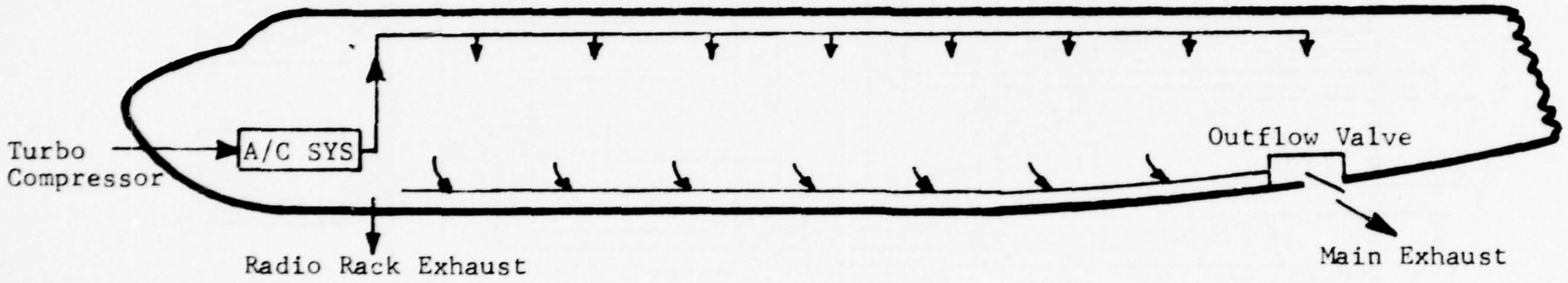


Figure 4

DC-8 RADIO RACK COOLING SYSTEM



Air Flow with Recirculating Fans On



Air Flow with Turbo-Compressors On

Figure 5

DC-8 AIR CIRCULATION WHILE TAXIING

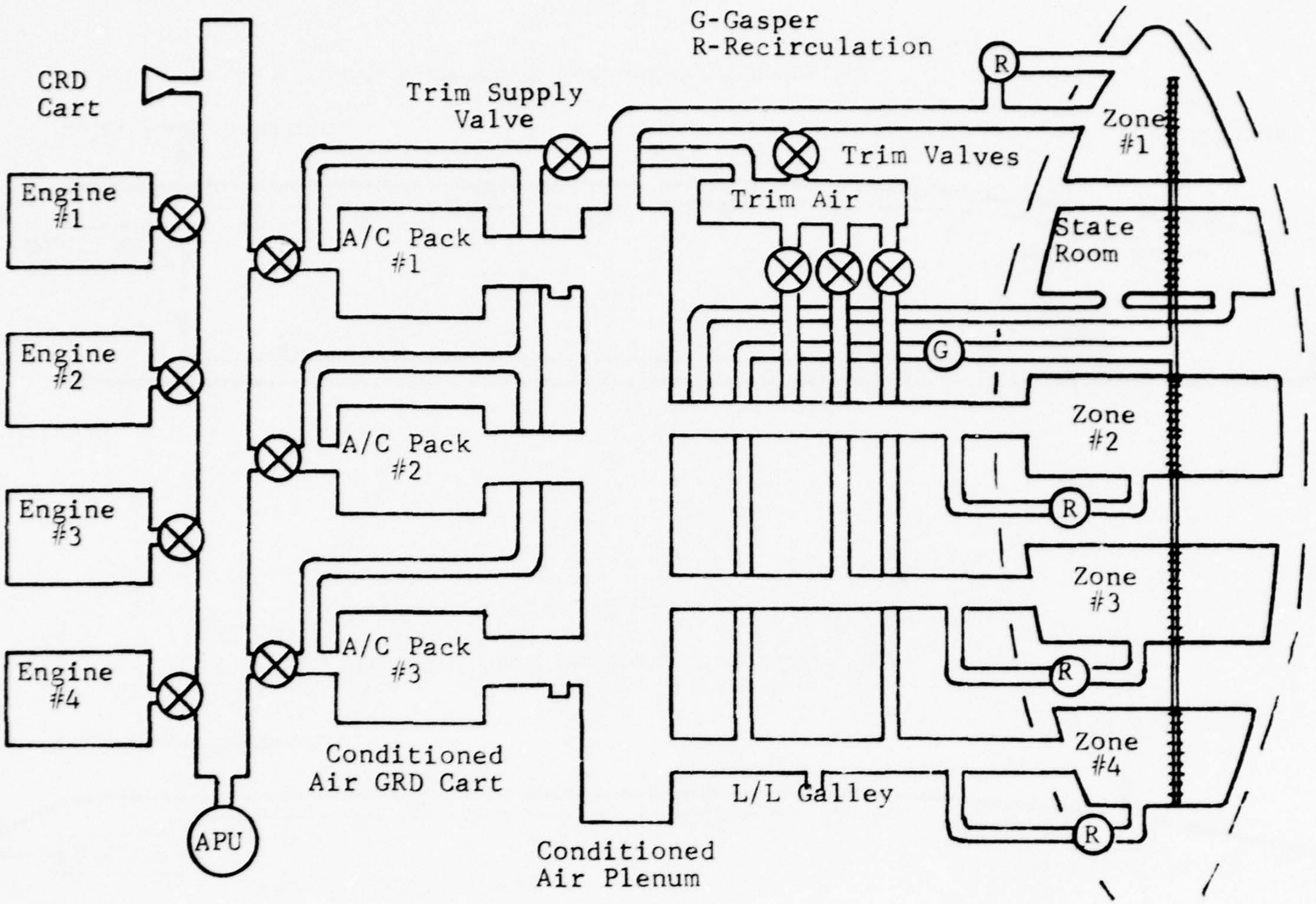


Figure 6

BOEING 747 AIR CONDITIONING SYSTEM BLOCK DIAGRAM

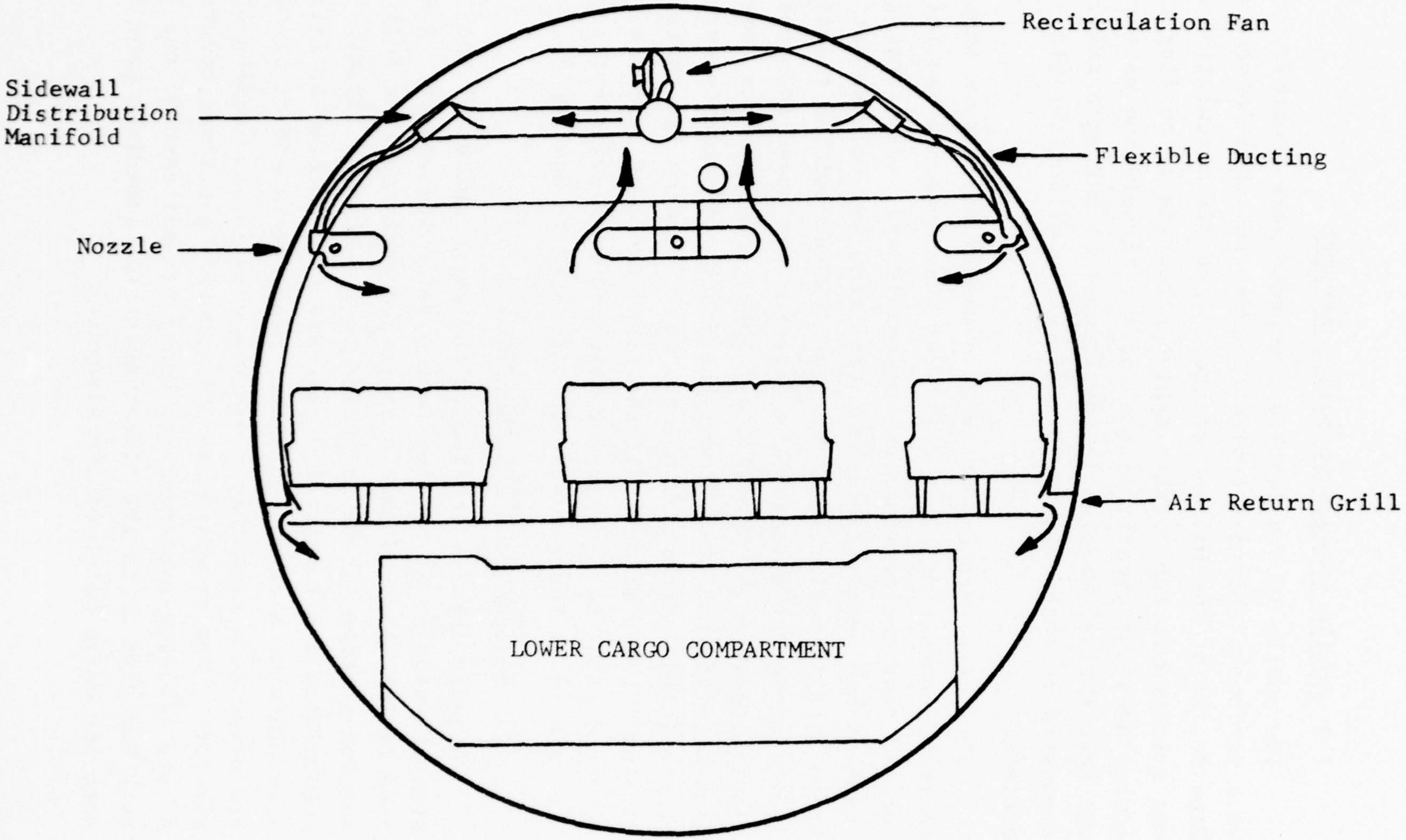


Figure 7

AIR DISTRIBUTION PASSENGER CABIN CROSS SECTION - BOEING 747

3.2 Mobile Lounges at Dulles Airport

The mobile lounge testing proceeded very smoothly. Tests were performed aboard a typical lounge (No. 126) located at Gate No. 21 at the Dulles terminal. The air circulation system was operated in the normal fashion - heating or cooling the lounge does not greatly effect the air circulation pattern. One test series, made while the lounge was making a trip, demonstrated that motion did not greatly effect the air pattern.

The tests were conducted in a manner similar to those performed on aircraft. The Halogen leak detector was initially located near the terminal end of the lounge. After background readings had been established, the Freon was released at a known rate in a different location. When positive readings were indicated on the detector the detector was moved to other sample stations throughout the lounge. Measurements were made at different elevations; the final measurements were at the initial detection point. After opening the doors and purging out the majority of the Freon the test sequence was repeated with the Freon being released in a different location. The results of these tests are discussed in Section 4.

3.3 Baggage Handling Equipment

Baggage that is carried in the cargo spaces of the aircraft usually is handled in the following manner. A suitcase is labelled and then transferred on a conveyor belt to a sorting station for distribution to the correct flight. It accumulates until sufficient baggage is collected to fill an open truck or a cargo container. The trucks and/or containers are moved to a temporary storage area prior to loading the aircraft. One exception to this routine sometimes occurs. A late arriving passenger may bring his suitcase to the loading gate and give it to the ticket agent for immediate hand loading into the cargo hatch of the aircraft.

A series of tests were performed adjacent to an open conveyor belt moving at 2 ft/sec. Freon was continually released from the bottom of the attache case at a known rate. The case was placed on the belt approximately 10 ft upstream of the detector station. Times and concentration levels were measured for numerous situations. This conveyor was located in the O'Hare terminal - consistent results could only be obtained when the outside doors remained closed during a test. No tests were made on open conveyors used to hand load aircraft. Shifting air currents or blasts from moving aircraft precluded the possibility of obtaining any useful data.

Two types of cargo containers are commonly used. The type used with 707's and DC-8's can be considered semi-closed in as much as they have two or three fixed sides and a fixed bottom. The top and one side may be a tarpaulin or a section of perforated metal. Since this type is well ventilated it can be considered as one large piece of luggage and the conveyor belt data should apply.

A totally closed container is used on the 747. This container has a fixed top, bottom and 2 sides. The other two sides are rigid and hinged in the middle to permit rapid opening from either side. Several tests were made by placing a Freon leak in the container, rapidly closing the access side and probing the outer perimeter with the Halogen leak detector. All baggage handling tests are discussed further in Section 4.

3.4 Boarding Gate Positions

Tests were conducted in the waiting area and in a typical jetway. One series of tests consisted of positioning the leak detector immediately behind the passenger agent's station and carrying the attache case with Freon flowing from the bottom past the ticket counter. The time to maximum response of the leak detector was the critical factor measured in these tests. Other tests were performed with the leak detector located in the jetway and again in the attache case was carried past the detector. It was observed in these tests that the location of the ventilating ducts near the detector station was highly important - as expected a general air flow away from the detector eliminated any positive responses. The jetway, being tunnel like in shape, limited the air flow to two directions. More consistent data was gathered in the jetway tests. The results are presented in the next section.

4. DATA REDUCTION AND ANALYSIS

This section presents the methods of calibration and data reduction along with the results and analysis of the data obtained under this contract. The detector used to simulate a bomb detector is a leak detector which must be calibrated to be able to determine concentration levels. Once concentration levels have been obtained, the attenuation parameter determining sensitivity requirements may be calculated.

The attenuation parameter, which is the ratio of concentration of Freon 12 to the emission rate, is a time varying function since the Freon concentration varies with time while the emission rate remains fixed. In general then, the data are presented as graphs of the attenuation parameter versus time.

4.1 Instrument Calibration and Calculation of Attenuation Parameter

Before any data analysis can be performed, the output of the leak detector must be calibrated to determine its response to a known concentration of Freon 12. The data taken are leak rate readings and differences in leak rate readings reflect the changes in concentration due to the Freon used as a bomb simulant. We are interested in obtaining the change in concentration with respect to an initial background concentration due to our Freon source. In the testing we had to contend with background concentrations arising from leaking air conditioning systems and air pollution.

The flow meters used to regulate the flow of Freon had to be calibrated with Freon 12 so that emission rates can be calculated. Once the changes in concentration and the emission rates of Freon 12 are known, the attenuation parameter, the object of interest in this investigation, can be calculated. The method of calculating the attenuation parameter from the background leak rate readings, the "current" leak rate readings, and the Freon 12 flow rate are shown.

4.1.1 Calibration Techniques

The detector used for the tests performed under this contract was a General Electric Model H-2 halogen leak detector and control unit. The output of this detector is a halogen leak rate in units of cc/sec. The sensitivity of the unit is dependent upon the voltage applied to the sensitive element of the unit and the air sampling rate. These were kept fixed at a meter reading of 6.0 and 4 cc/sec respectively. The actual voltage to the sensitive element is unknown, but an indication is given by a reading on the leak rate meter.

Calibration of the leak detector and conversion of the leak rate readings to concentrations of Freon were obtained by injecting a known amount of Freon gas with a syringe into a container of 10^6 cm^3 volume and observing the response of the detector. Figure 8 gives the calibration curve of the response of the detector versus increase in concentration of Freon. This curve was fitted by the method of least squares to the calibration data and can best be described by the equation:

$$\log_{10} C = 2.331 + 1.171 \log_{10} R \qquad (1)$$

where

C is the Freon concentration and
R is the leak rate reading.

Two rotameters were used in the various tests to measure the flow rate of the Freon released. These were calibrated by setting the flow rate on the rotameter and measuring the time required to displace a known volume of water. The calibration curves of Freon flow rate versus rotameter settings are presented in Figure 9.

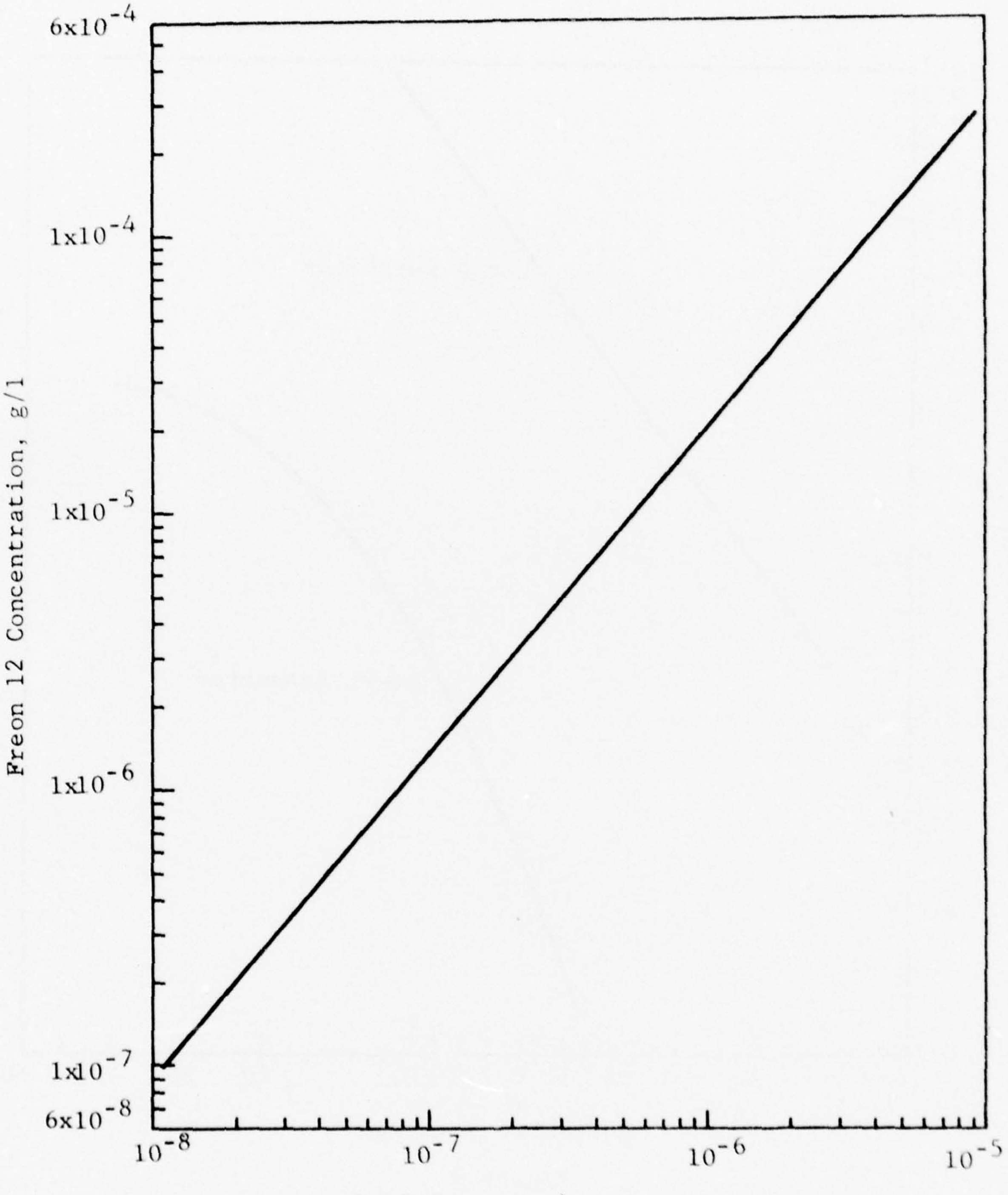


Figure 8

CALIBRATION CURVE FOR HALOGEN LEAK DETECTOR

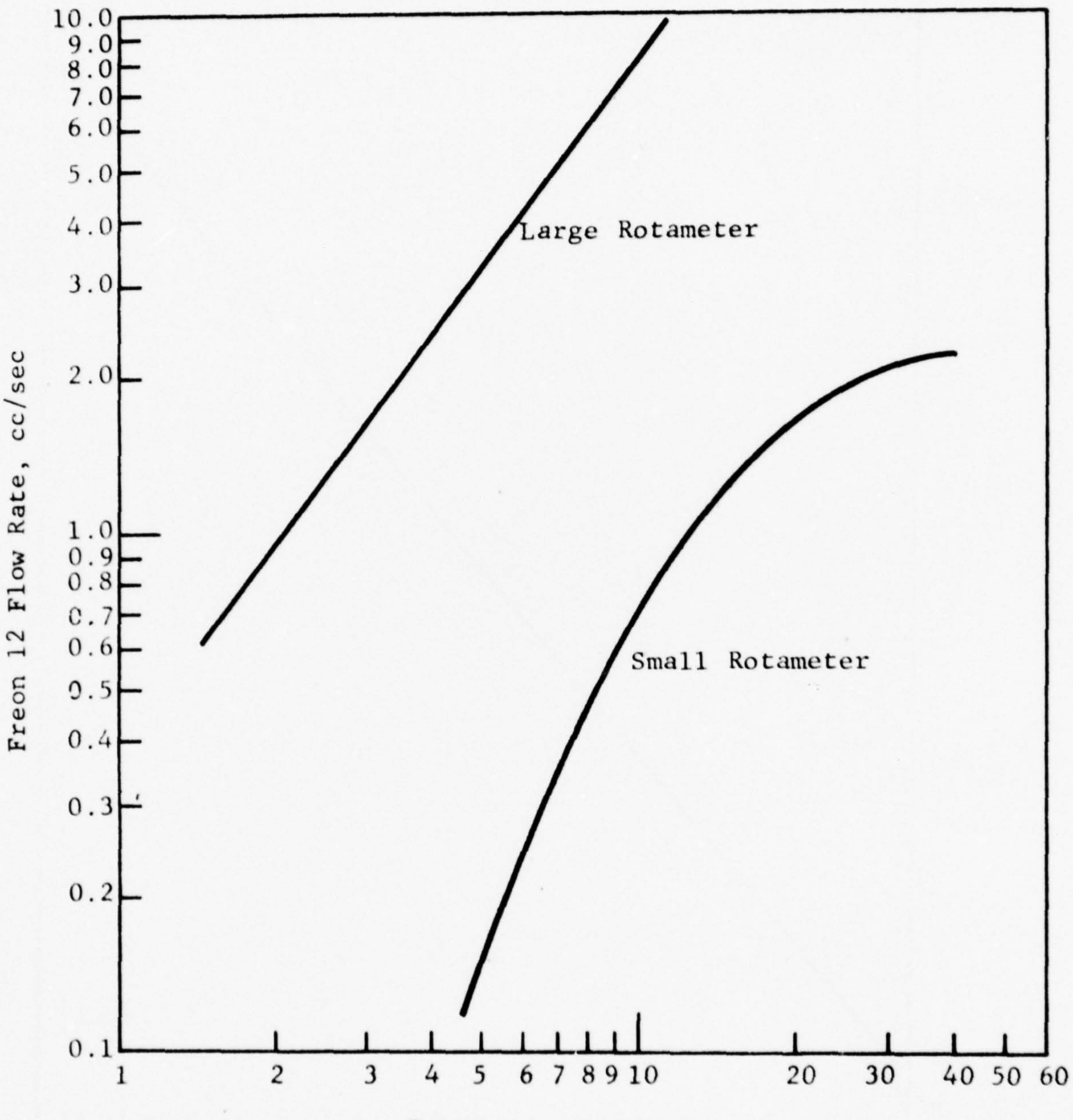


Figure 9

CALIBRATION OF FLOW-METERS WITH FREON 12

4.1.2 Calculation of Attenuation Parameter

For each test, the data recorded were the sensitive element voltage setting on the detector, the ambient background leak-rate reading, the Freon bomb simulant location, the location of the detector, the time from the start of Freon release and the leak rate reading at that time.

The attenuation parameter r, the quantity desired from the tests, is defined by

$$C = r \cdot Q \tag{2}$$

where

C is the Freon concentration in g/l

Q is the Freon emission rate, in g/sec

r is the attenuation parameter in sec/l.

The Freon emission rate, Q, is obtained by:

$$Q = F \cdot \rho \tag{3}$$

where

F is the Freon flow rate in cm^3/sec

ρ is the density of Freon 12 in g/cm^3.

Therefore by combining Equations 1, 2 and 3 we obtain r, the attenuation factor by:

$$r = \frac{\Delta C}{F \cdot \rho} = \frac{10^{2.331}}{.005F} \left(R^{1.171} - R_o^{1.171}\right) = \frac{42860}{F} \left(R^{1.171} - R_o^{1.171}\right) \tag{4}$$

where

ΔC is the increase in concentration over the initial background concentration

R_o is the initial background leak rate reading

R is the current leak rate reading

ρ for Freon 12 is assumed to be 0.005 g/cm^3.

4.2 Aircraft Tests

The aircraft tests performed under this contract represent the major portion of this research effort. The aircraft, after the cargo has been loaded and the passengers are on board, is the only place where passengers, baggage, and cargo are confined to a relatively small volume and air flow conditions can be controlled. Ideally a bomb detector based upon vapor "sniffing" should be capable of detection between the time the aircraft is closed up at the terminal, and the time it is ready for take-off at the end of the runway. It was this period of time that this research effort was directed to.

Aircraft of the 707/DC-8 and the 747/DC-10 sizes were the primary aircraft tested since these represent the largest investment in money and human life in the event of a bomb threat. Additionally since these aircraft represent the largest of the commercial jets in size, detection of dilute vapors from a bomb should be the most difficult and require the highest sensitivity of a bomb detector.

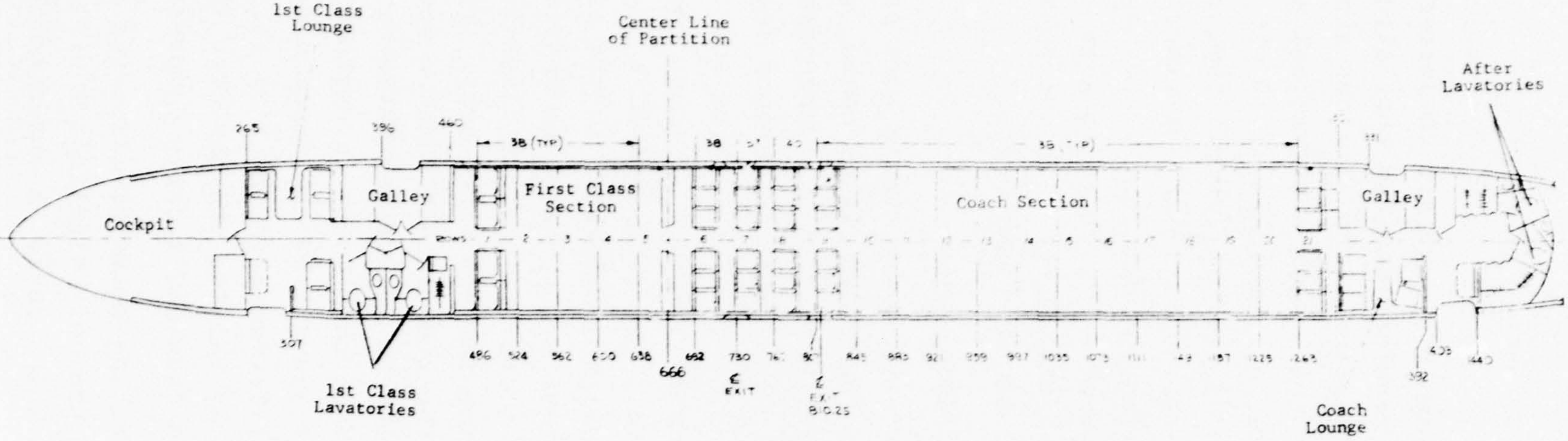
4.2.1 Testing Procedure

The original plan for testing on board aircraft was to release Freon 12 at a known rate, and measure the concentration buildup with the leak rate meter until equilibrium had been achieved. Various locations on the aircraft were then to be sampled to locate regions of optimal concentration buildup. This plan was used during "static tests" performed on DC-8's without the aircraft engines running. Under these test conditions the only air circulation system available were the aircraft recirculation fans which only circulate air that is already within the aircraft cabin. No fresh air is drawn into the cabin, nor is any air exhausted as in the case with aircraft power available. An attempt at simulating the air-flow with aircraft power was made by attaching a turbine starter truck to a DC-8 and operating a cabin compressor from it but this attempt was not successful since the turbine starter is unable to supply enough air to operate the compressors effectively. It was therefore decided that aircraft should be tested while actually taxiing. The airlines shuttle aircraft back and forth between the hangar and terminal areas frequently. A typical taxi run takes on the order of 10 min and therefore is of similar duration as the pre takeoff taxi run of a departing flight at O'Hare airport. This length of times does not permit the testing of many different detector locations on board the aircraft but does allow enough time to measure the rate of concentration buildup with the detector in one position. This has been the test plan of the "taxi tests."

4.2.2 Aircraft Static Tests

In the aircraft static tests, tests were performed with the Freon 12 source in the first class, coach, and baggage sections of two standard size DC-8's. Concentration measurements with the leak detector were taken at various locations throughout the first class and coach class cabins and the main outflow valve outside the aircraft. Figure 10 shows the general cabin arrangement of a typical, standard size DC-8 as used in these tests. Figure 11 shows the difference in the time response of the attenuation parameter, r, with the detector in the coach lounge, and the Freon source in the 1st class lounge, in row 10 of the cabin, and in the forward cargo area. From this figure one may observe that the rise in attenuation parameter increases as the distance between the source and detector is decreased. This arises from the fact that there is neither instantaneous nor complete mixing of the air by the recirculating fans. Figure 12 shows the differences in the time rise of the attenuation parameter by varying the air circulation conditions with the recirculation fans and a cabin compressor.

In all tests where the detector was moved to locations throughout the cabin, the only significant differences in the attenuation parameter which could be observed were due to the spatial distance between the Freon source and the detector.



(5 ROWS FIRST CLASS 16 ROWS TOURIST)

Figure 10

STANDARD DC-8

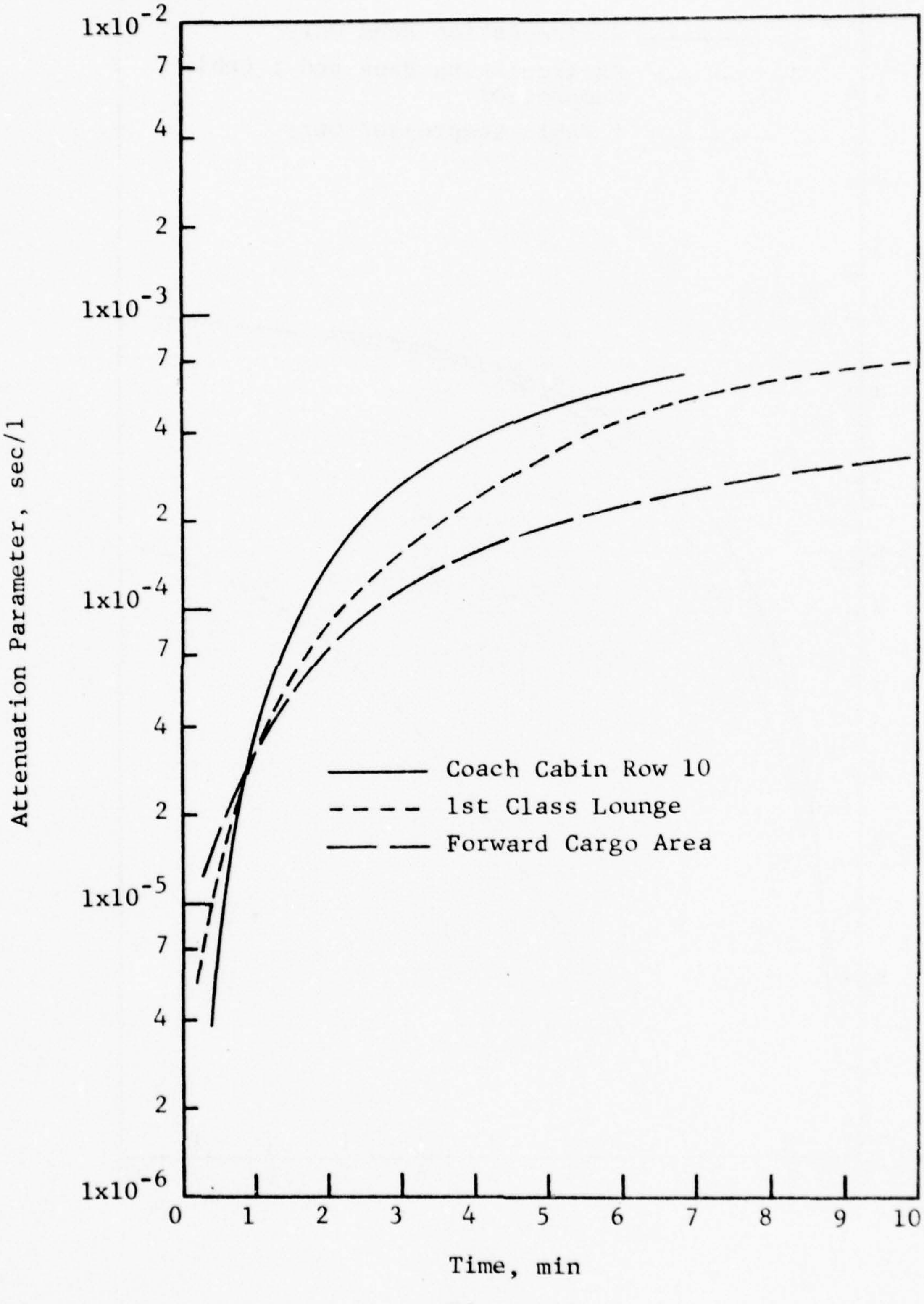


Figure 11

COMPARISON OF RESPONSE WITH FREON SOURCE POSITION FOR STANDARD DC-8 WITH RECIRCULATION FANS - DETECTOR IN COACH LOUNGE

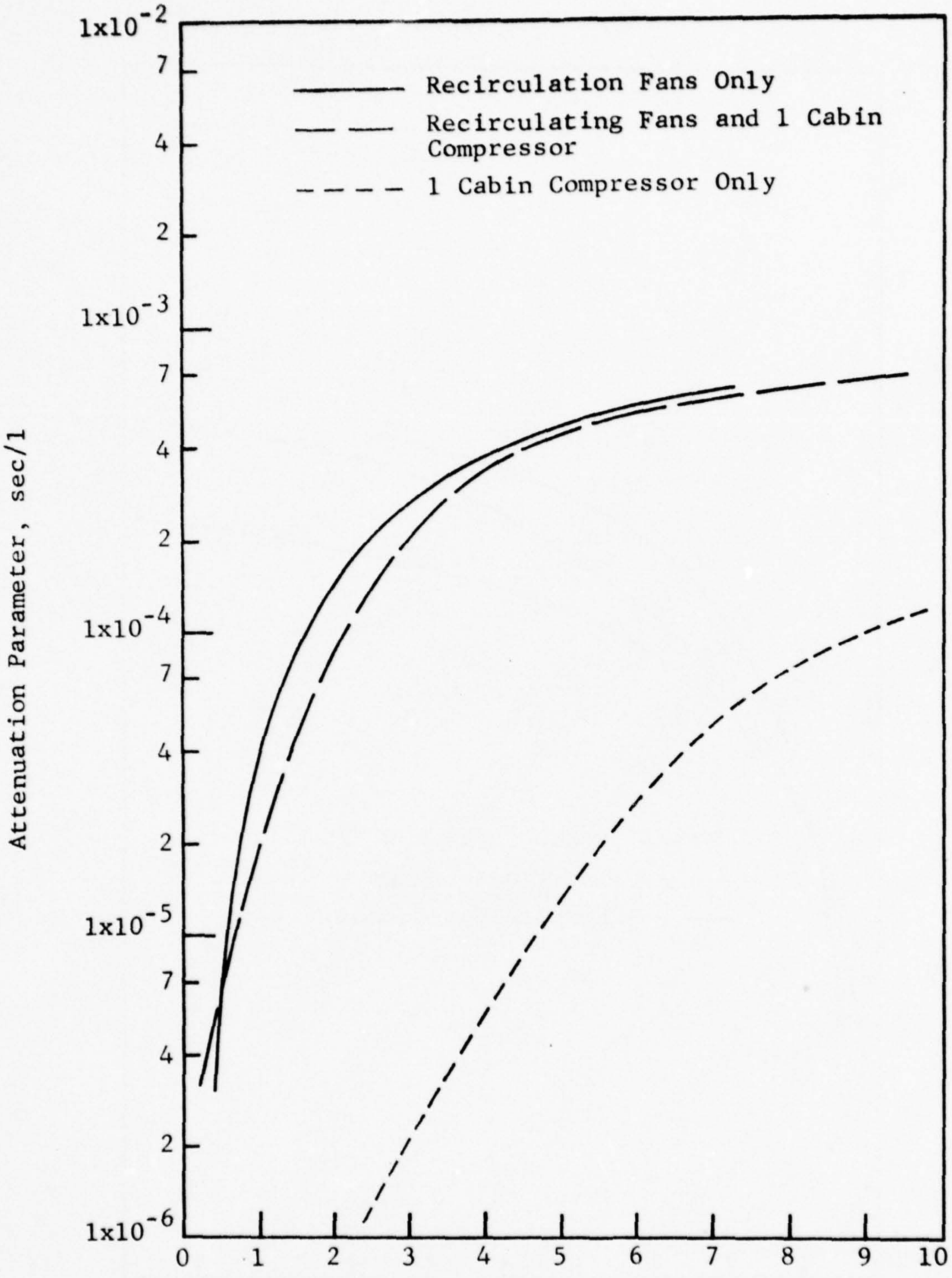


Figure 12

COMPARISON OF DIFFERENT CIRCULATION CONDITIONS - FREON SOURCE IN ROW 10, DETECTOR IN COACH LOUNGE

Near "equilibrium" (true equilibrium in the static tests was never attained), the differences due to the spatial distance were minimized and at distances greater than about 10 ft were all within experimental error. No particular detector location indicated either significantly higher or significantly lower concentrations.

In the aircraft used for the static tests, when the Freon source was placed in the forward cargo area, the Freon was detectable in both the cabin area and the main outflow valve while the recirculation fans were running. In Figure 11 one may compare the increase in the attenuation parameter with time for conditions where the Freon source is located in the cabin and in the cargo area. The values of r with the source in the cargo area are approximately one half of those obtained with the source in the cabin. With the detector positioned at the main outflow valve the rate of increase and the magnitude of r with the Freon source in the cargo area, are comparable to those obtained with both the source and the detector in the aircraft cabin as shown in Figure 13.

Measurements at the outflow valve were taken with the Freon source in the coach cabin, while the recirculation fans were on, produced attenuation parameters of about 5×10^{4} sec/l in 10 min. These are similar to the results obtained with the detector in the cabin.

In summary, it appears that, with recirculation fans only, there is no detector location that is optimal. Attenuation parameters for Freon sources in the cabin appear to be of the same order if the detector is located in the cabin or at the main outflow valve of DC 8's. Freon sources in the cargo areas were also detectable from both the cabin and the outflow valve. These static tests are indicative only of a situation that exists while the aircraft is parked at the boarding gate with engine power off during loading and boarding.

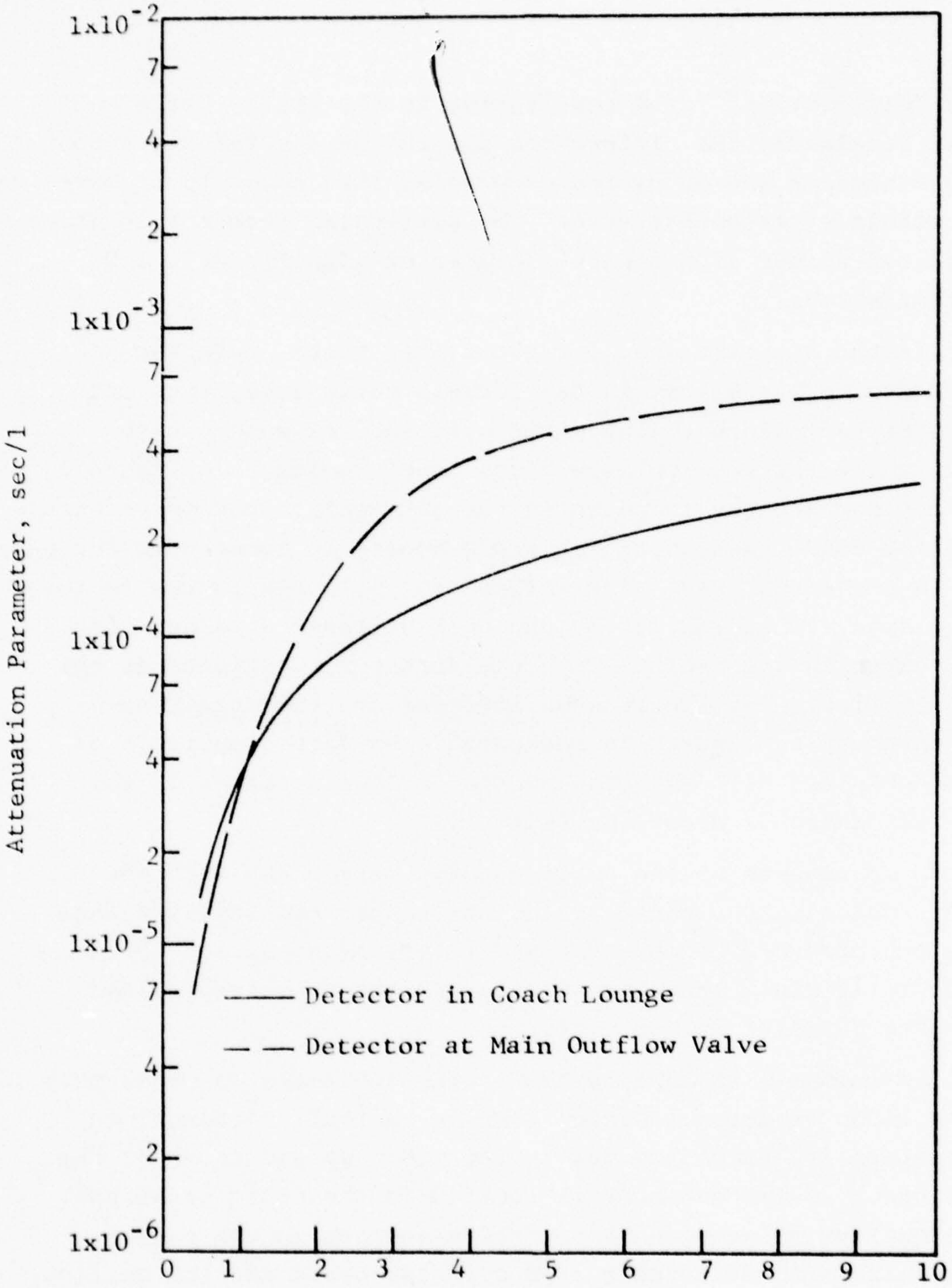


Figure 13

COMPARISON FOR RESPONSE TO DETECTOR LOCATION - FREON SOURCE IN FORWARD BAGGAGE AREA

4.2.3 Aircraft Taxi Tests

The aircraft taxi tests were prompted by the need for more realistic test conditions. Aircraft connected to ground power only do not have enough power available to run the circulation systems necessary to simulate pre-takeoff conditions. Since aircraft are regularly shuttled between hangar service areas and terminal locations at O'Hare airport, arrangements were made with United Airlines, American Airlines, and Trans World Airlines to ride on the aircraft and make tests during these taxi trips. In addition, with the cooperation of United Airlines and Northwest Orient Airlines, two tests were made aboard loaded aircraft on regularly scheduled flights.

The aircraft taxi tests are grouped essentially by aircraft type with DC-8's and 707's being of one class, the 747 as another, and other aircraft which were tested incidentally. Boeing 707's and Douglas DC-8's are similar in size (at least in their standard configurations) and have similar air circulation systems. The 747 is a much larger aircraft with air circulation systems much like 727's and 737's.

4.2.3.1 DC-8 and Boeing 707 Tests

The DC-8 and 707 taxi tests were conducted on trips made between the hangar and terminal areas at O'Hare airport. Because of the short duration of these trips (typically less than 10 min), a testing procedure different from the "static" tests was developed. For each test the Freon source was placed at one location while the detector was at another. When the engines were turned on and the background reading of the detector allowed to stabilize, the Freon source was turned on at "time zero" and the readings were taken at selected intervals. If enough time was available, the detector was moved to several locations in the cabin.

The taxi tests were conducted with the Freon source at several locations in the 1st class cabin and coach cabin, the cockpit, lavatories, and cargo areas. Similarly, the detector was located at several locations in the 1st class and coach cabins, and in the cockpit.

Figures 14 through 21 show the attenuation parameter versus time for tests typical of those which show a positive response. Failure to achieve a positive response occurred on several occasions due to several factors:

1. Background level too high, and/or
2. Flow rate too low for the conditions.

Indicated on each figure is the type of aircraft, the Freon source location and the detector location.

In those tests, in which several locations in the cabin could be sampled, the Freon concentration always increased as the detector approached the source. As in the "static" tests described previously no particular "dead" spots were found nor were any locations of higher than average changes in concentrations.

Two tests were performed on board aircraft with passengers, luggage, and cargo. The first was on a standard DC-8 with 45 passengers aboard. The Freon source was located on the floor beneath the window seat of row 6, the first row of the coach section. The detector was located on the window seat of row 21, the last row in the coach section. The plot of the attenuation parameter versus time for this test is presented in Figure 22. The captain on this flight was requested to operate the recirculation fans but otherwise maintain completely normal operating conditions, to which he complied. The Freon source was turned on at the time the captain turned on the fans after starting the engines. The start of take-off was 8 min later.

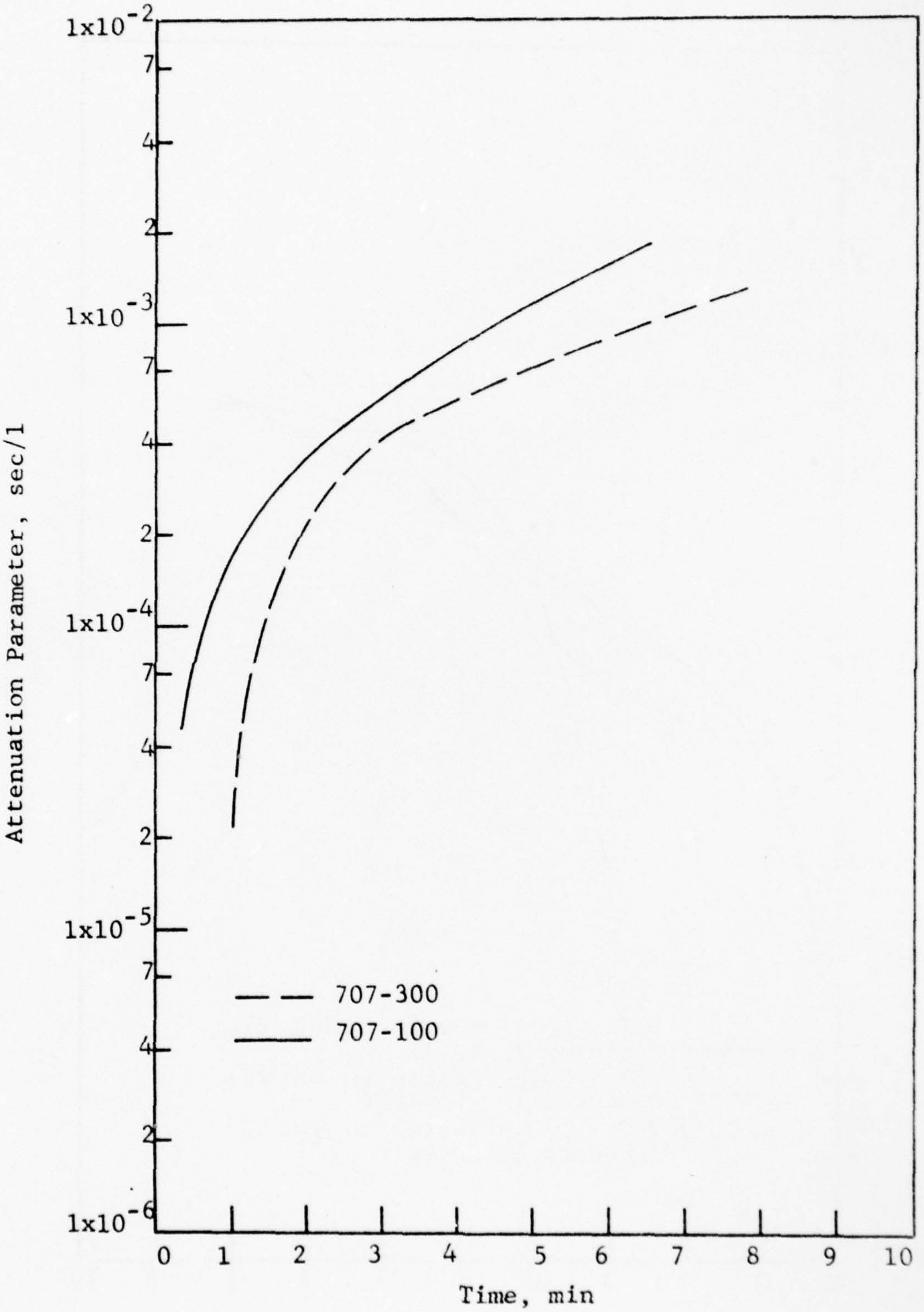


Figure 14

707 TAXI TESTS - FREON SOURCE IN ROW 1,
DETECTOR IN ROW 27

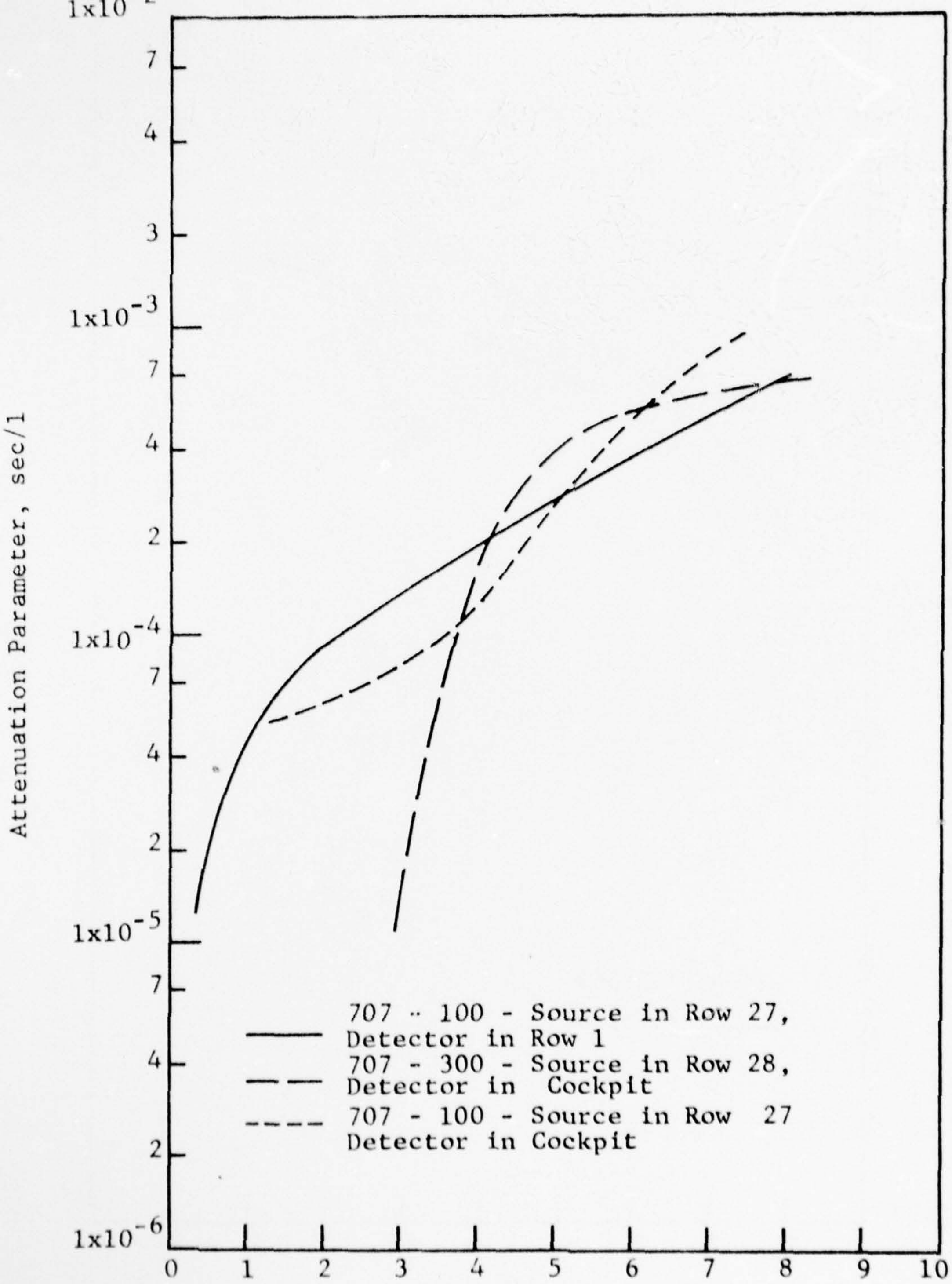


Figure 15

707 TAXI TESTS

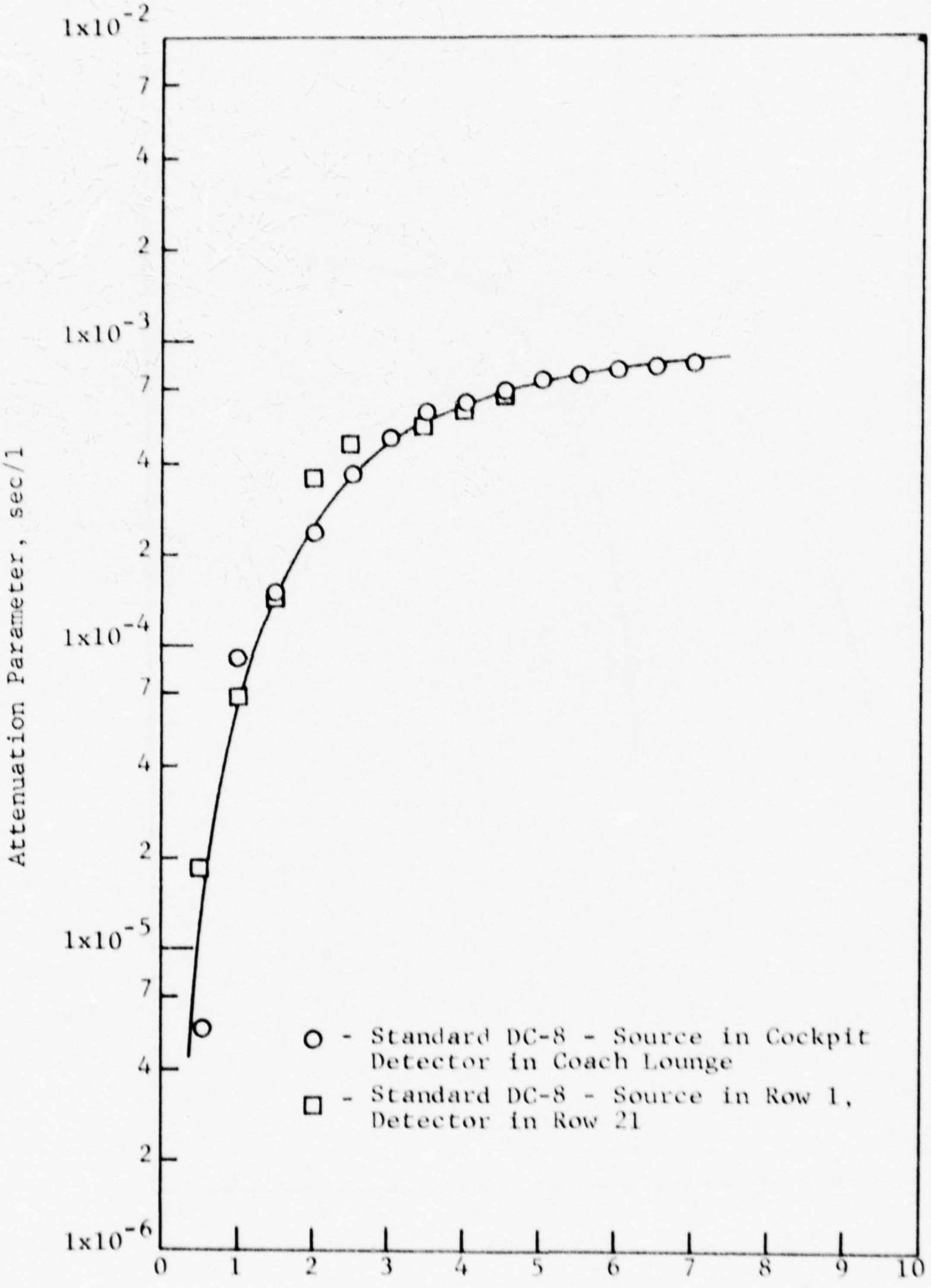


Figure 16

DC-8 TAXI TESTS

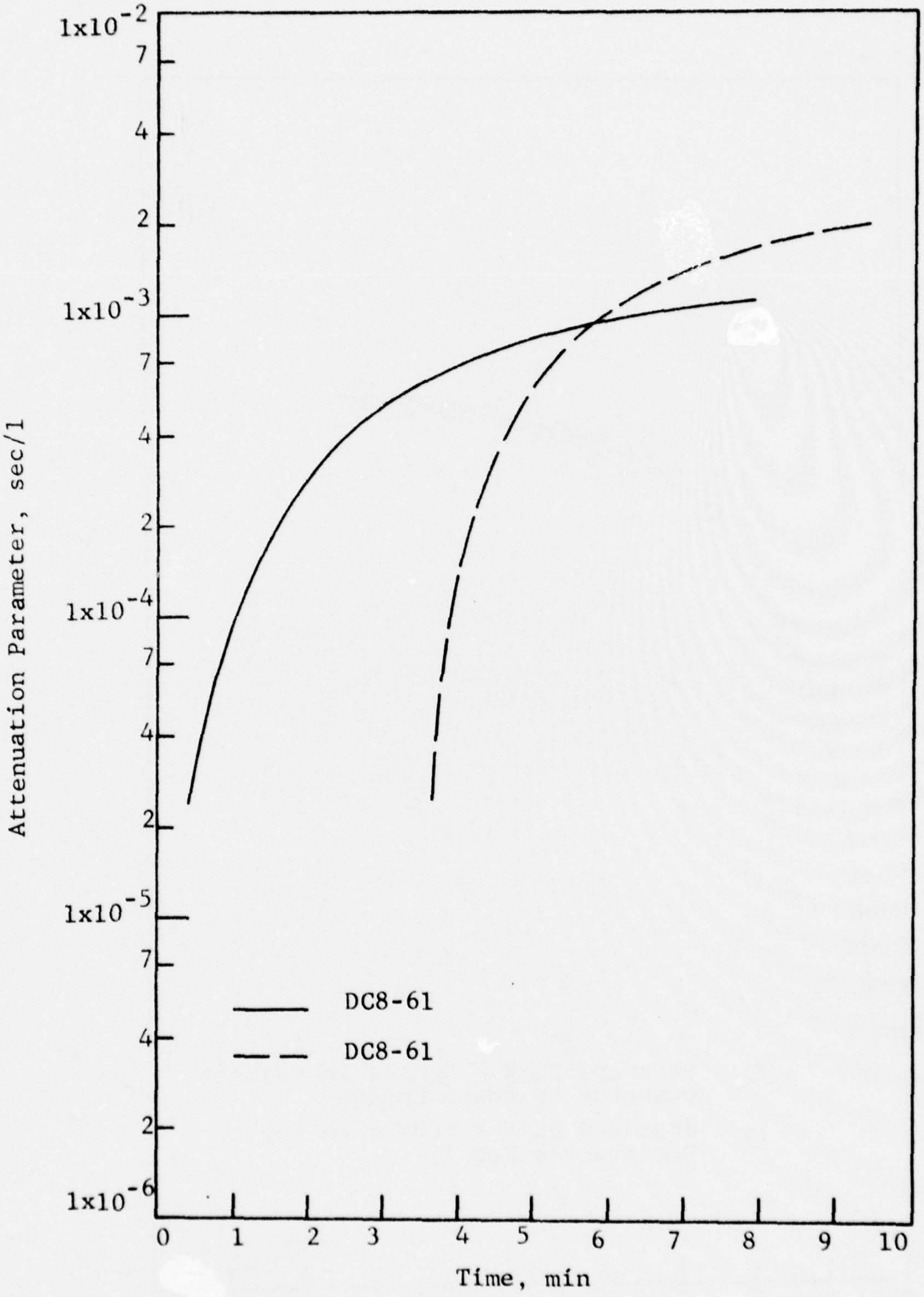


Figure 17

DC8 TAXI TESTS - FREON SOURCE
IN 1st CLASS LOUNGE, DETECTOR IN ROW 35

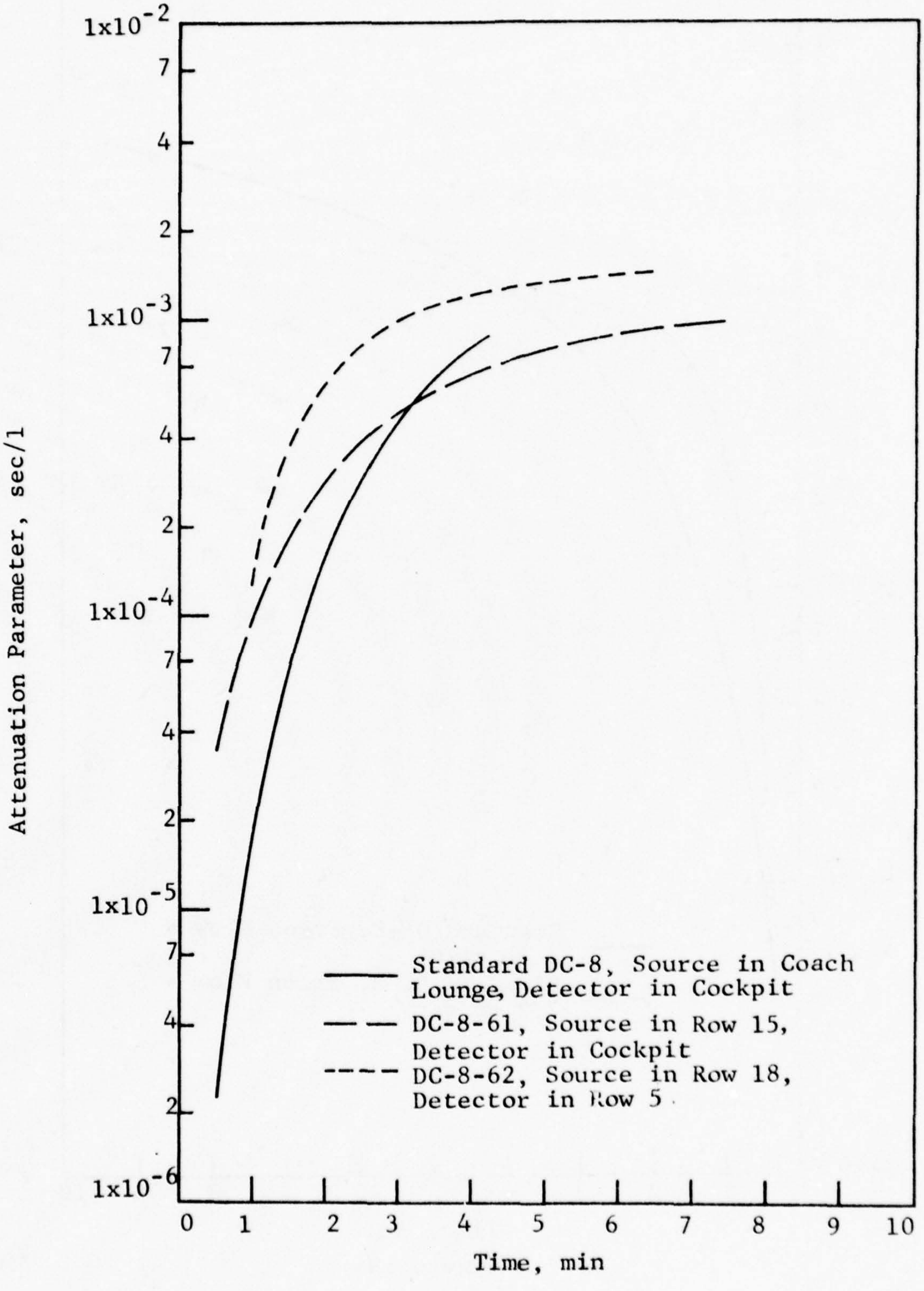


Figure 18

DC-8 TAXI TESTS

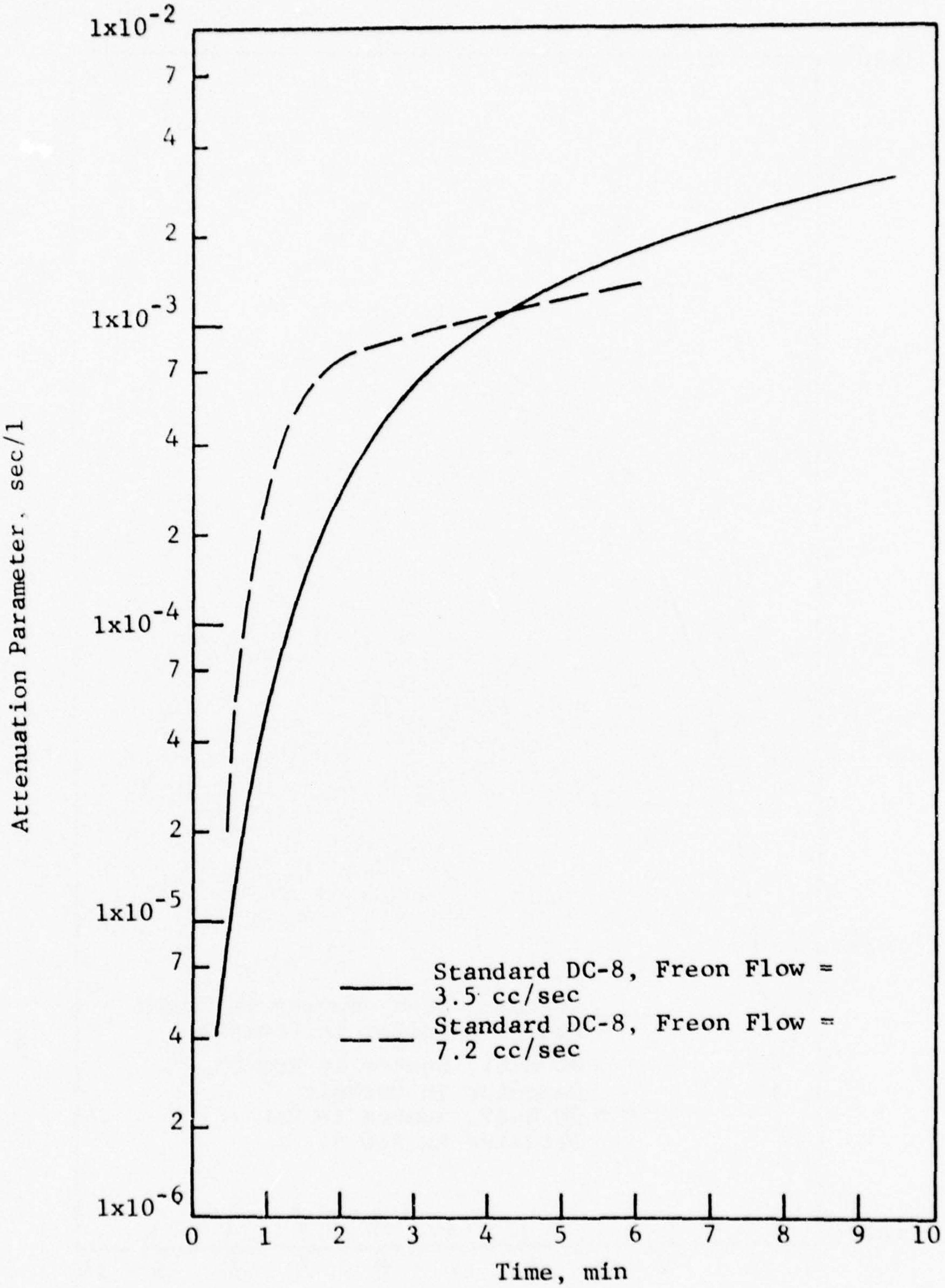


Figure 19

DC-8 TAXI TESTS, VARYING FREON FLOW RATE WITH SOURCE IN ROW 13, DETECTOR IN 1st CLASS LOUNGE

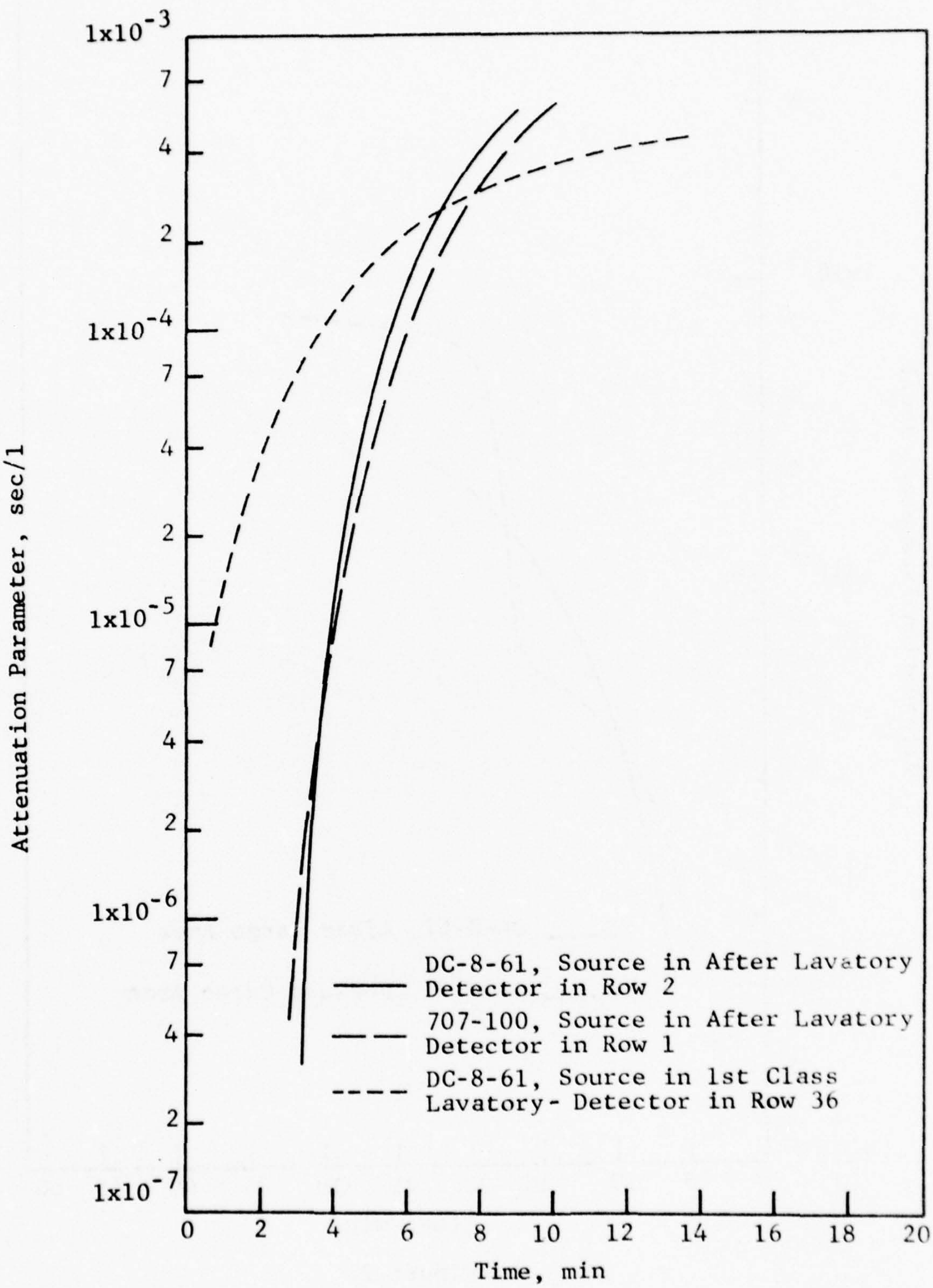


Figure 20

DC-8/707 TAXI TESTS WITH FREON SOURCE IN LAVATORIES

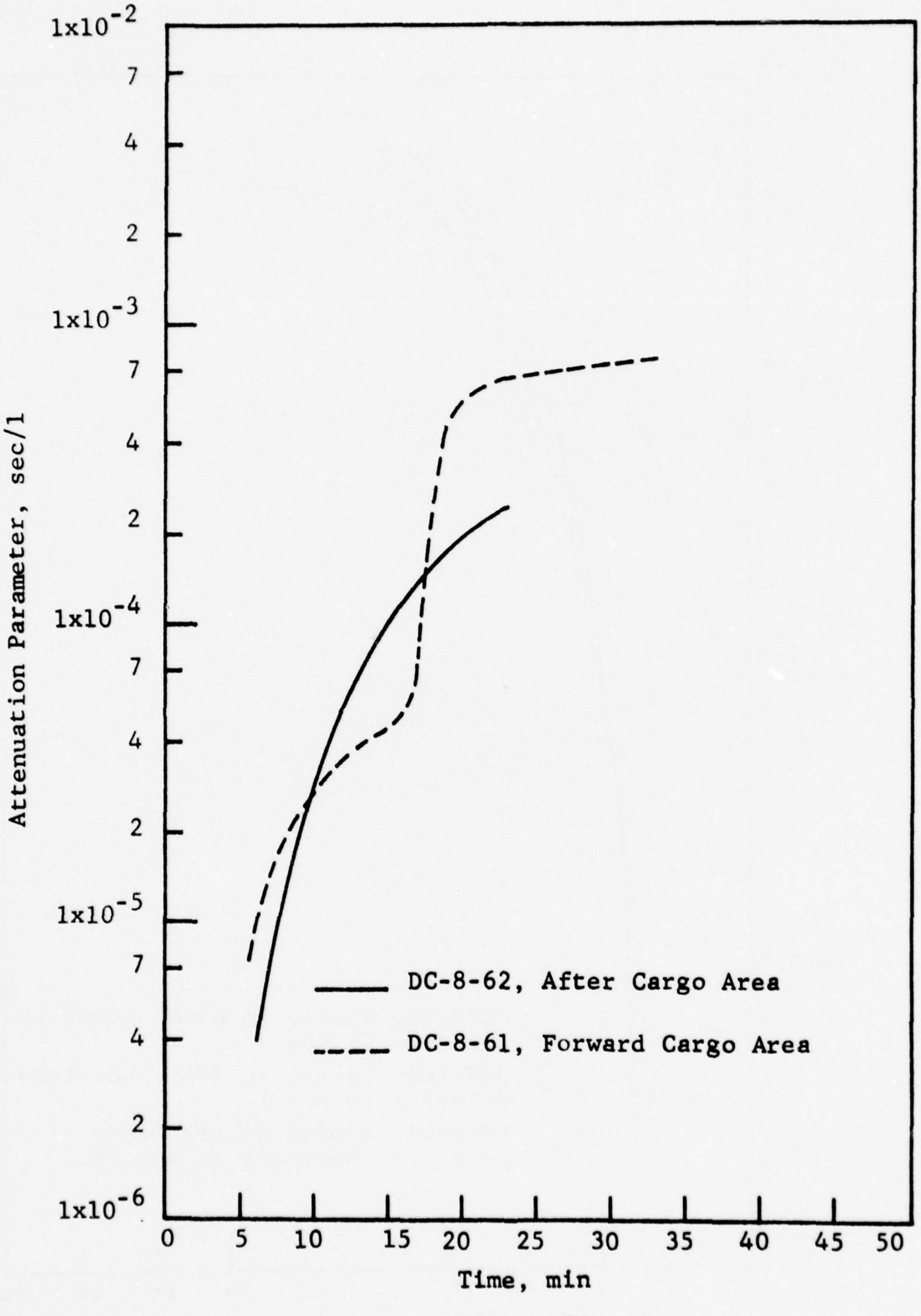


Figure 21

DC-8 TAXI TESTS WITH FREON SOURCE IN CARGO AREAS, DETECTOR IN ROW 36

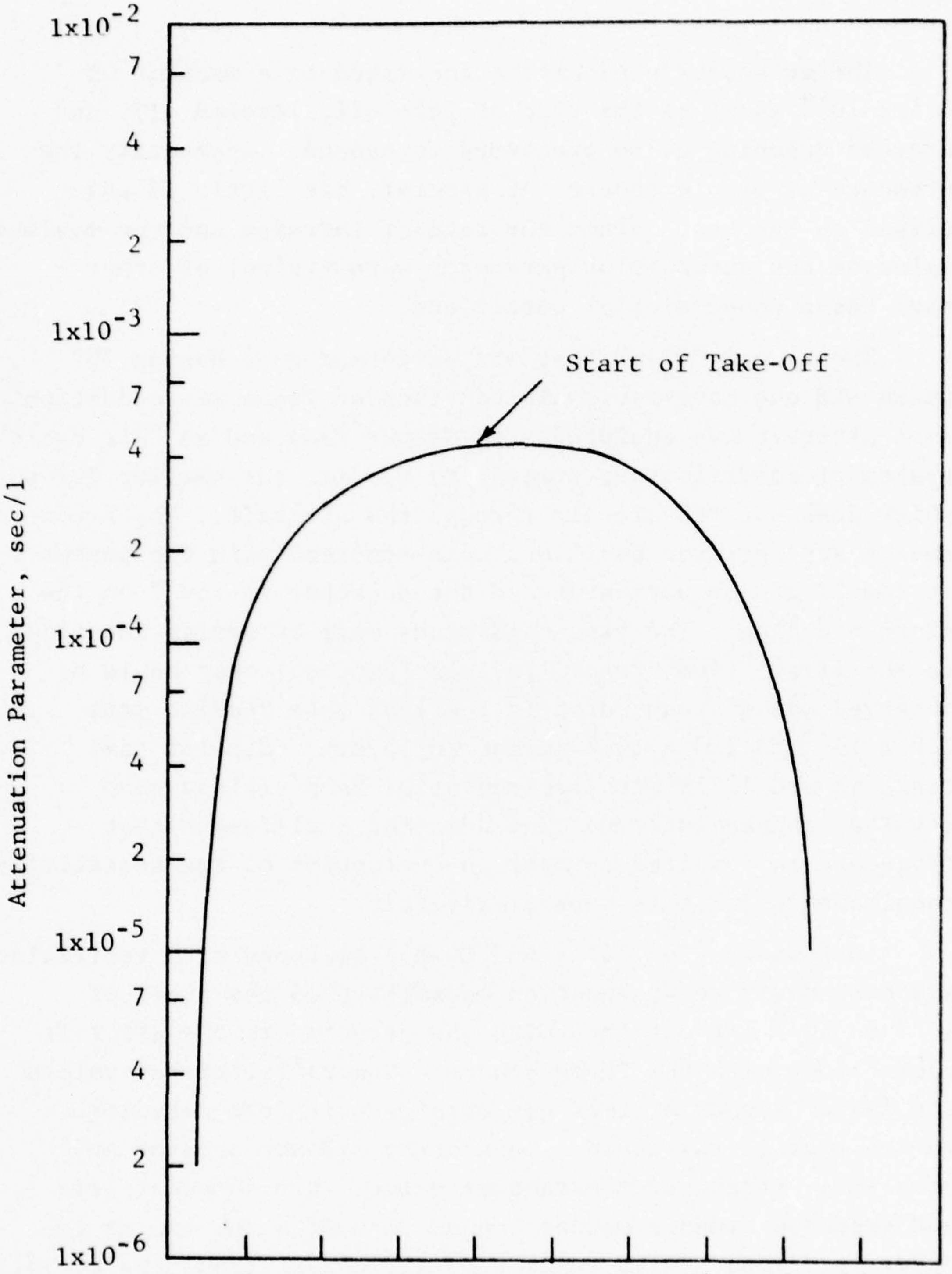


Figure 22

ATTENUATION PARAMETER VERSUS TIME FOR DC-8 LIVE TAXI TEST - FREON SOURCE IN ROW 6, DETECTOR IN ROW 21

The attenuation parameter increased to a maximum of 4.4×10^{-4} sec/l at the time of take-off, leveled off, and started dropping as we proceeded to ascend. Apparently the presence of people aboard the aircraft had little if any effect on the test, since the rate of increase and the maximum value of the attenuation parameter were typical of other taxi tests under similar conditions.

The second "live" test was performed on a Boeing 707 which did not have recirculation fans or Freon air conditioning. This aircraft was equipped with Gasper fans and an "air cycle" system of conditioning, similar to the 747 and smaller 727's, which does not recycle air through the aircraft. The Freon source and detector positions were reversed with the source at row 27 on the port side and the detector in row 7 on the starboard side. The test conditions were otherwise identical to the first "live" test. In this test, all that could be observed was a steady drop in the leak rate reading from 7.0×10^{-8} to 2.3×10^{-8} cc/sec in 15 min. Similar taxi tests aboard 707's with recirculation fans yielded good results, consequently we conclude that a different test procedure is required to make an evaluation of the sensitivity requirements for this type of aircraft.

In summary, for 707's and DC-8's equipped with recirculation systems, positive attenuation parameters on the order of 10^{-4} to 10^{-3} are obtained with the detector in the aircraft cabin along with the Freon source. Generally, higher values and faster response times are obtained with the detector in the rear of the cabin. Lavatories did not present any problems. Attenuation parameter values were somewhat less and response times somewhat longer than with the source in other locations. With respect to air circulation, the cockpit of these aircraft (707's and DC-8's) appears to be an extension of the passenger cabin and similar results are obtained.

When the Freon source is placed in either of the cargo areas the results obtained are less than predictable due to variations in "leakability" of these areas. The cargo areas are supposed to be "sealed" to prevent air circulation in case of a fire. Perhaps sampling the main out flow valve as in the "static" tests would produce reproducible positive results but this type of testing could not be performed.

4.2.3.2 Boeing 747 Tests

The 747 taxi tests were conducted in a manner similar to the 707/DC-8 tests but with entirely different results. There is very little recirculated air in the 747, and that which is recirculated is only recirculated within zones. The large majority of the air supplied to the cabin is fresh so that the air is completely changed once every three minutes when the aircraft is either on the ground or in the air. Figure 23 shows the main features of the 747 interior.

Tests performed with both the Freon source and the detector in the coach cabin produced a maximum attenuation parameter of 4×10^{-5} sec/l from as near as 8 rows separating the source and the detector. Under these conditions, the Freon source was detectable from as far as about 20 rows with attenuation parameters of about 2×10^{-6}.

One particular test, with the Freon source at row 30 in the coach cabin and the detector in the after buffet on the lower level, yielded an attenuation parameter of as high as 1.61×10^{-4} sec/l in six minutes. But the reading was fluctuating constantly with more typical values averaging between 8×10^{-5} and 1.2×10^{-4} sec/l. It must also be noted that in this test the source and detector were nearly at the same location but on different levels of the aircraft.

It appears that desirable locations are probably at the main out-flow valves since all air in the aircraft is constantly

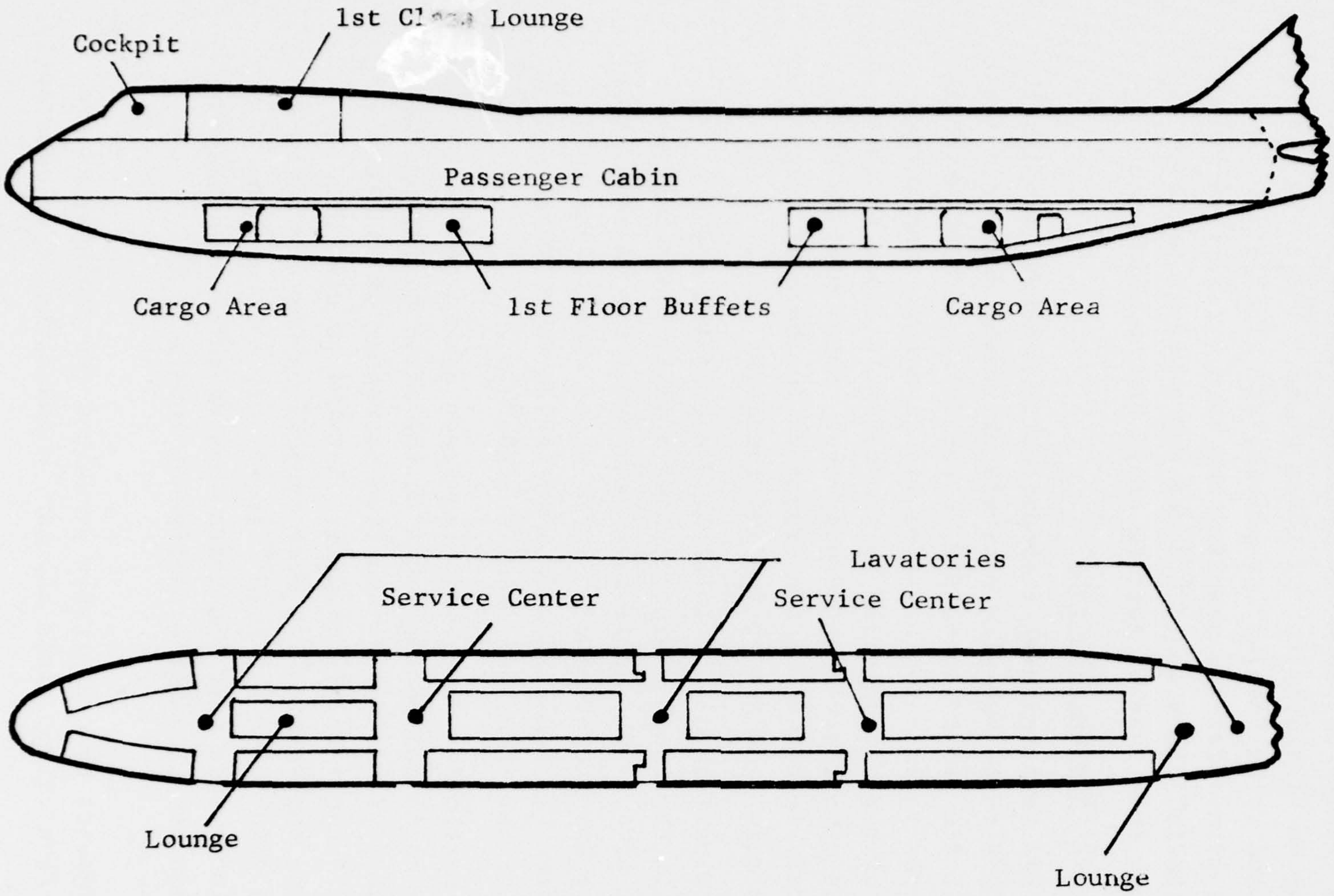


Figure 23

BOEING 747 ARRANGEMENT

being changed. These areas were inaccessible to us for testing, therefore, this must remain as conjecture for the time being.

4.3 Dulles Mobile Lounge Tests

The mobile lounges at Dulles International Airport are considerably more simple in layout than any of the aircraft tested since the passenger compartment is rectangular in shape and is not compartmentalized. Figure 24 shows schematically the interior arrangement and the testing plan for the mobile lounge. The detector was located at positions D1 through D15 for taking readings and the Freon source located at P1 through P5. For all tests on the lounge, the source was located on the floor since there is no other provision for luggage carrying. Table 2 gives specifically the source location and the sequence of detector positions of each test. For those tests in which the Freon concentration was measured at different heights, the sequence went from ceiling to floor. Figures 25 and 26 present graphically the attenuation parameter versus time data obtained for tests 2 and 3. These tests are typical of relatively large distances between the Freon source and the detector. Table 3 presents a summary of all the mobile lounge tests. The attenuation parameter at the time equal to 5 min is shown since this is the average duration of the trip between the terminal and the aircraft.

For the purposes of analysis, x, y, and z coordinates were assigned each of the detector and Freon source locations from an arbitrary origin and distances between detector and source were calculated. The variables of lounge speed and damper setting were assigned numerical values of 0 and 1 for the lounge not moving and moving, and the damper being closed and open respectively. The logarithm of the attenuation parameter was treated as the dependent variable by analysis of variance and multiple regression with the following as independent variables:

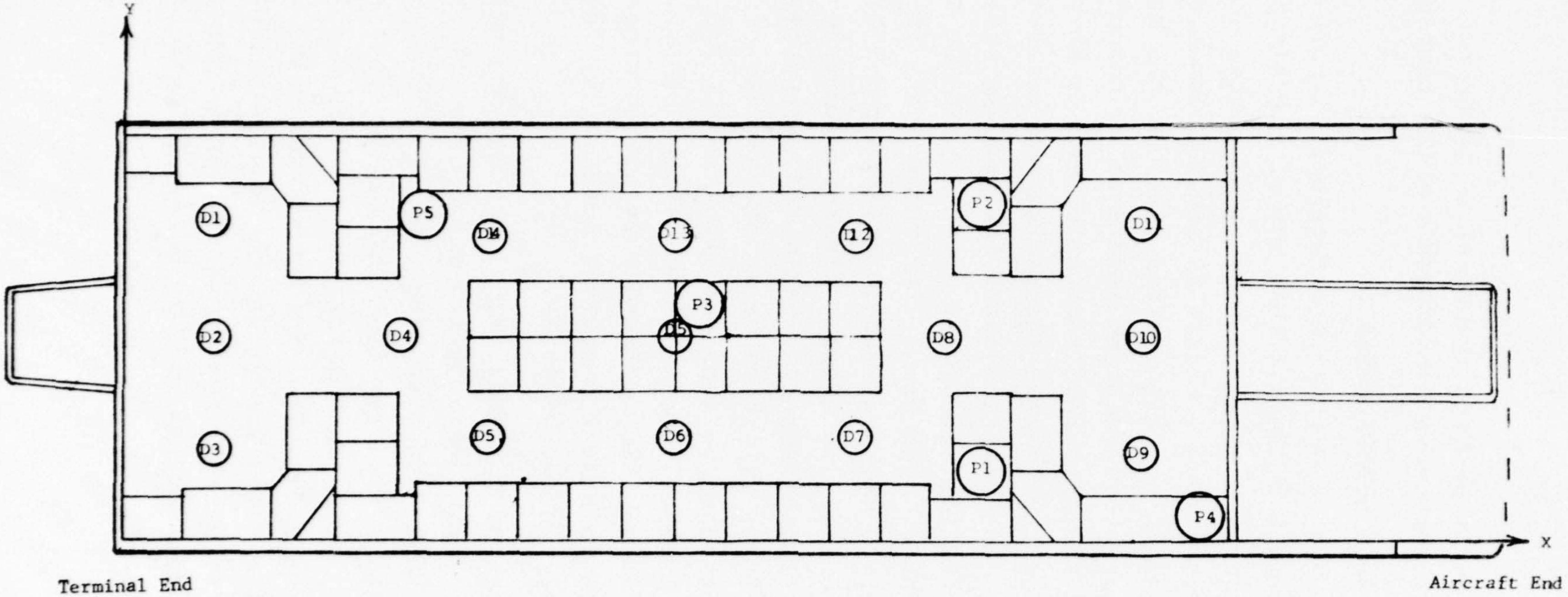


Figure 24

INTERIOR FLOOR ARRANGEMENT OF MOBILE LOUNGE

Table 2

CONDITIONS OF EACH TEST AND SEQUENCE OF TESTING POSITIONS IN THE MOBILE LOUNGE

Test No.	1	2	3	4	5	6	7
Package Pos.	P1	P2	P2	P3	P4	P1	P5
Detector Position							
D1	1,16	1,16	1,16	1,15	1,15	1,15	9
D2	2	2	2	2	2	2	10
D3	3	3	3	3	3	3	11
D4	4	4	4	4	4	4	8,12
D5	5	5	5	5	5	5	13
D6	6	6	6	6	6	6	14
D7	7	7	7	7	7	7	15
D8	8	8	8	8	8	8	4,16
D9	9	9	9	9	9	9	1,17
D10	10	10	10	10	10	10	2
D11	11	11	11	11	11	11	3
D12	12	12	12	12	12	12	5
D13	13	13	13	13	13	13	6
D14	14	14	14	14	14	14	7
D15	15	15	15				
Flow, cc/sec	9.25	9.5	5.0	5.0	5.0	5.0	4.7
Motion	None	None	None	None	Moving	None	None
Damper	Closed	Closed	Closed	Closed	-*	Open	Open

*Position of damper is indeterminant while lounge is moving.

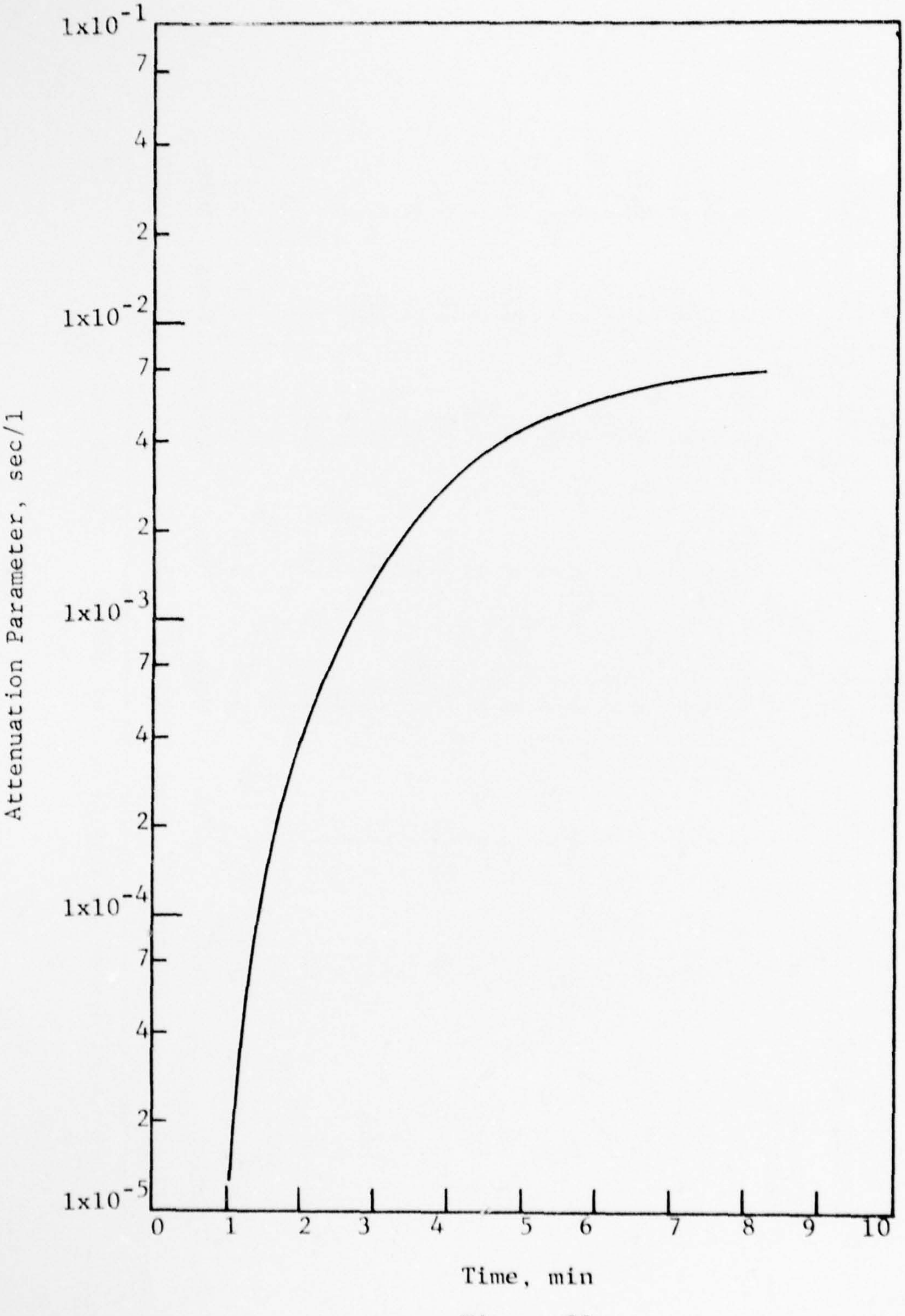


Figure 25

ATTENUATION PARAMETER VERSUS TIME
FOR MOBILE LOUNGE - TEST 2

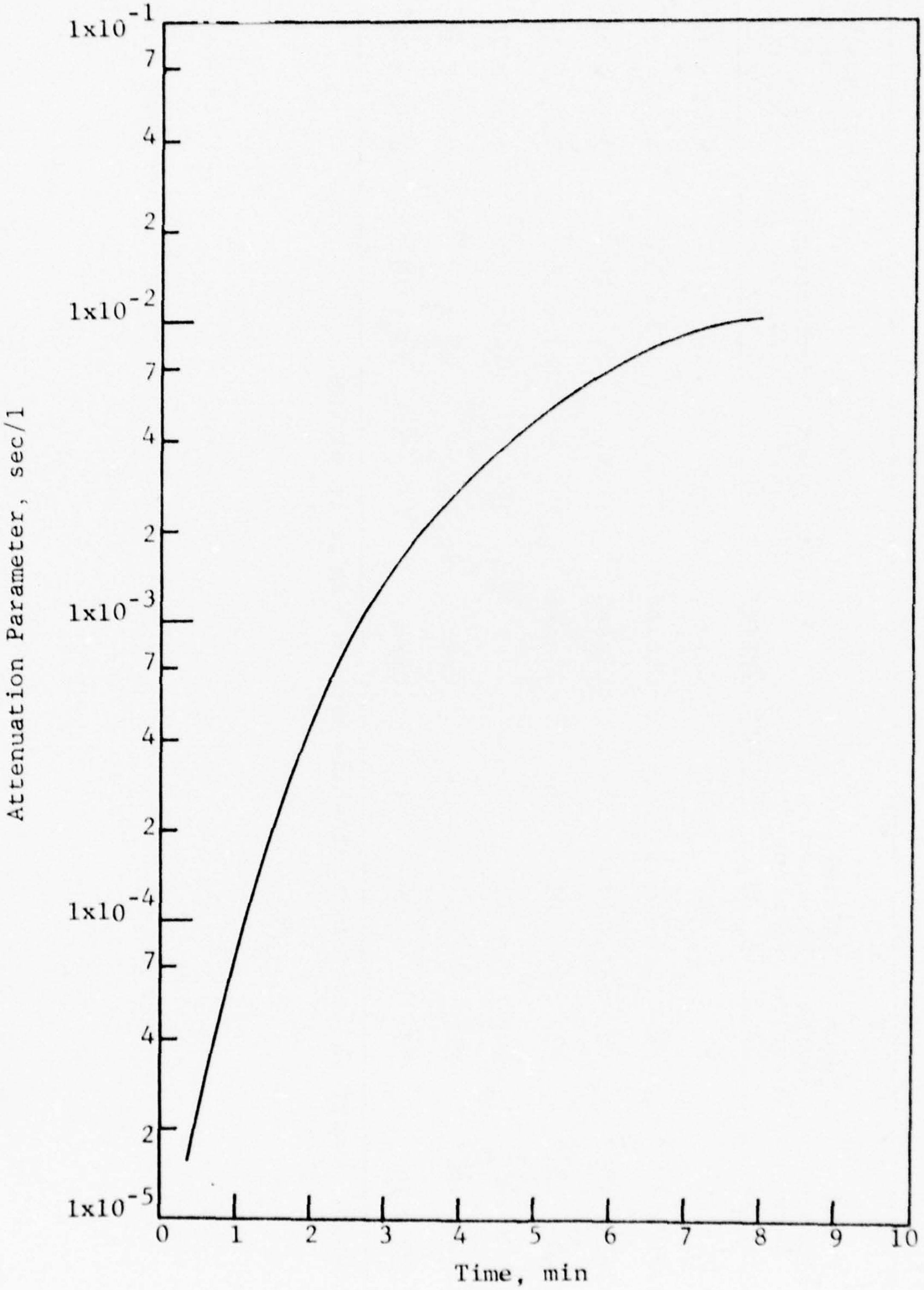


Figure 26

ATTENUATION PARAMETER VERSUS TIME
FOR MOBILE LOUNGE - Test 3

Table 3

SUMMARIZATION OF MOBILE LOUNGE DATA

Test No.	Freon Emission Rate g/sec	Freon Source Position No.	Initial Detector Position No.	Motion	Damper	Distance (Initial), ft	Concentration Increase in 5 Min, g/l	Attenuation Parameter at 5 Min (Initial Pos.)
1	3.7×10^{-2}	P1	D1	No	Closed	29	245×10^{-6}	6.62×10^{-3}
2	3.85×10^{-2}	P2	D1	No	Closed	27.5	170×10^{-6}	4.42×10^{-3}
3	1.65×10^{-2}	P2	D1	No	Closed	27.5	65×10^{-6}	3.94×10^{-3}
4	1.65×10^{-2}	P3	D1	No	Closed	18	85×10^{-6}	5.15×10^{-3}
5	2.1×10^{-2}	P4	D1	Yes	-*	37	145×10^{-6}	6.91×10^{-3}
6	1.65×10^{-2}	P1	D1	No	Open	29	80×10^{-6}	4.85×10^{-3}
7	1.50×10^{-2}	P5	D9	No	Open	29	33×10^{-6}	2.20×10^{-3}

*Position of damper is indeterminant while mobile lounge is moving.

1.	X_d	x coordinate of the detector, ft
2.	Y_d	y coordinate of the detector, ft
3.	Z_d	Z coordinate of the detector, ft
4.	t	time, min
5.	$\sqrt{t}$	square root of time
6.	d	distance between detector and Freon source, ft
7.	d^2	distance squared
8.	$e^{-0.1\cdot d}$	exponiential decay term with respect to distance
9.	D	damper position
10.	M	mobile lounge motion

A regression model of the form:

$$\log_{10} r = \beta_o + \sum_{i=1}^{10} \beta_i X_i$$

where the X_i are the independent variables as listed above, and each of the β's are the fitted parameters, was considered. This model is intended to be more of a qualitative rather than an accurate quantitative description of the data obtained, but should be accurate enough to allow the estimation of any significant effects. Equation 4 presents the final regression equation. Each of the coefficients (fitted parameters) is significant at the .0005 level, i.e., there is little chance that the coefficients are zero.

$$\log_{10} r = -5.988 - 0.00578\, X_d - 0.339\, t + 2.290 \sqrt{t} + 0.000242\, d^2 + 0.563\, e^{-0.1d} - 0.091\, D. \tag{4}$$

The term involving X_d, the x coordinate of the detector, is due to the fact that most of the tests were performed with the Freon source near the aircraft end of the mobile lounge and does not necessarily mean that higher concentrations will be found near the aircraft end. The terms involving t and $\sqrt{t}$ are a qualitative description of the time response of the attenuation parameter. That the attenuation parameter decreases non-linearly with increasing distance between the detector and the Freon source is shown qualitatively by the terms involving d^2 and $e^{-0.1d}$. The term of importance resulting from this study is that involving the damper position. Lower Freon concentrations and hence smaller attenuation parameters were observed with the damper open. However, this effect should be put in proper perspective. The magnitude of the effect of the damper is smaller than the residual standard deviation of the data about the regression. Consequently this term is of little practical significance until more refined data have been obtained.

The magnitude of the attenuation parameters obtained in the mobile lounge study are significantly higher than were obtained from aircraft tests indicating that vapor detection of bombs should be easier on the mobile lounge than on aircraft.

4.4 Baggage Handling Systems

Two areas of the baggage handling system at O'Hare airport were studied: a conveyor on which baggage moves to be sorted, and the aluminum baggage containers as used on the Boeing 747 and Douglas DC-10.

4.4.1 Conveyor System

At the O'Hare terminal there are numerous conveyors which move baggage and parcels at several different speeds to various locations. We chose, for the purposes of these tests, an open conveyor moving at a speed of approximately two feet per second. The baggage handling systems at O'Hare are located on a level below the boarding gates to the aircraft and are at ground level. Typical of all the baggage handling areas at O'Hare, are a high vehicular traffic movement and open doors during mild weather, and doors opening and closing almost constantly during cold weather. Thus, no degree of consistency in the testing conditions could be obtained.

The halogen leak detector was kept at about 2 ft from the center line of the moving conveyor, and at a level about 6 inches above it. Thus, a suitcase or briefcase would move past the detector at a minimum distance of approximately 1 ft. Figure 27 illustrates the basic details of the test arrangement and Table 4 presents a summary, representing an average, of the results obtained under these non-controllable test conditions.

Table 4

SUMMARY OF BAGGAGE CONVEYOR DATA

Time to First Detection	:	6.5 sec
Time to Maximum r	:	16 sec
Maximum Value of r	:	7.1×10^{-4} sec/l

The times presented are taken with "time zero" being the moment the Freon source passed the detector. These times are given only as an indication of what might be expected since they are more representative of the response time of the particular detector being used rather than the time necessary for the transport of the Freon through the air.

4.4.2 747/DC-10 Baggage Container Tests

For the 747/DC-10 baggage container tests we obtained an empty container which was located in a relatively little used corridor in the O'Hare terminal. The circulation of air in this corridor was minimal; thus the air inside of the container, when closed, was essentially stagnant.

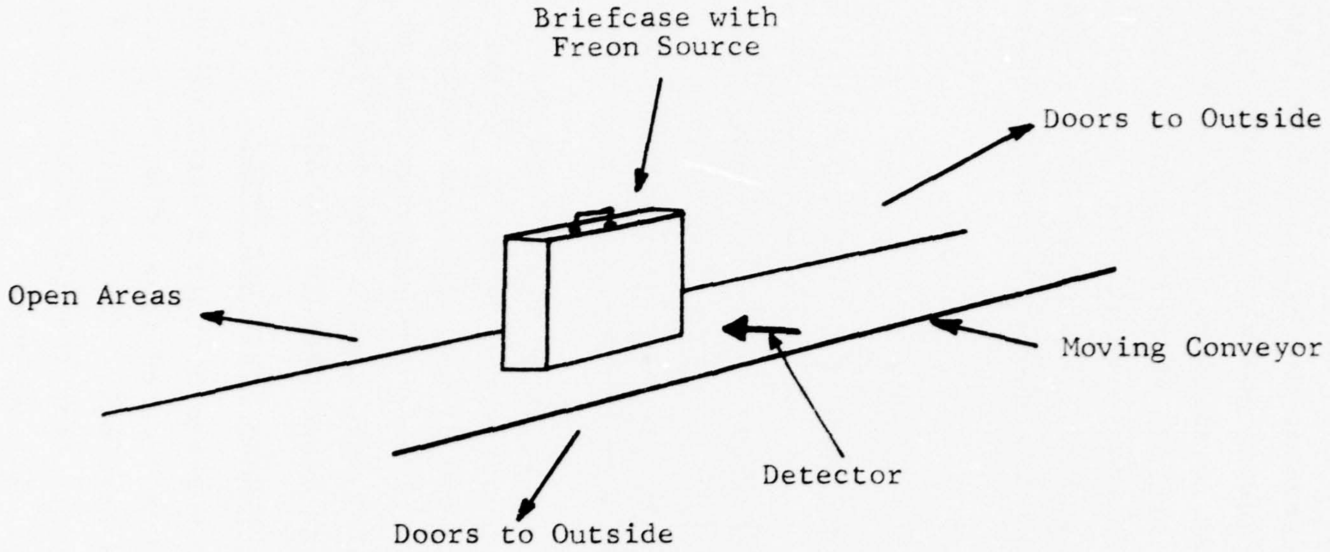


Figure 27

BAGGAGE CONVEYOR TEST ARRANGEMENT

The baggage container may be described as essentially a box with a shelf and two hinged sides to permit the loading and unloading of baggage. For our tests, a briefcase containing the Freon source was placed on the center of the shelf. This placement located the source at approximately the center of the container as shown in Figure 28. The Freon flow rate was set at 0.4 cc/sec.

Freon concentrations were observed to vary from about 2×10^{-6} to about 2×10^{-4} g/l after 5 minutes. The higher levels of concentration were located at the bottom and shelf levels of the container since Freon 12 is more dense than air. The lowest levels of concentration were located at the top corners of the container, which substantiates the premise that there is little air circulation within the container. The levels of concentration measured correspond to values of the attenuation parameter of about 1×10^{-3} to 1×10^{-1} sec/l at the lower and upper limits respectively.

The levels of the attenuation parameter obtained in these tests pertain to an essentially empty baggage container. We were not able to obtain a loaded container for testing which would have been a more realistic and desirable situation.

4.5 Passenger Boarding Area Tests

The passenger boarding area tests were similar in nature to those tests performed with the baggage conveyor, in that the detector was located at one place in essentially free space, and the Freon source moves past the detector. Tests were performed at the passenger agent check-in desk and in the "Jetway" leading to aircraft at O'Hare airport. The testing procedure used was to have a person walk by the detector location while carrying the Freon source enclosed in a briefcase.

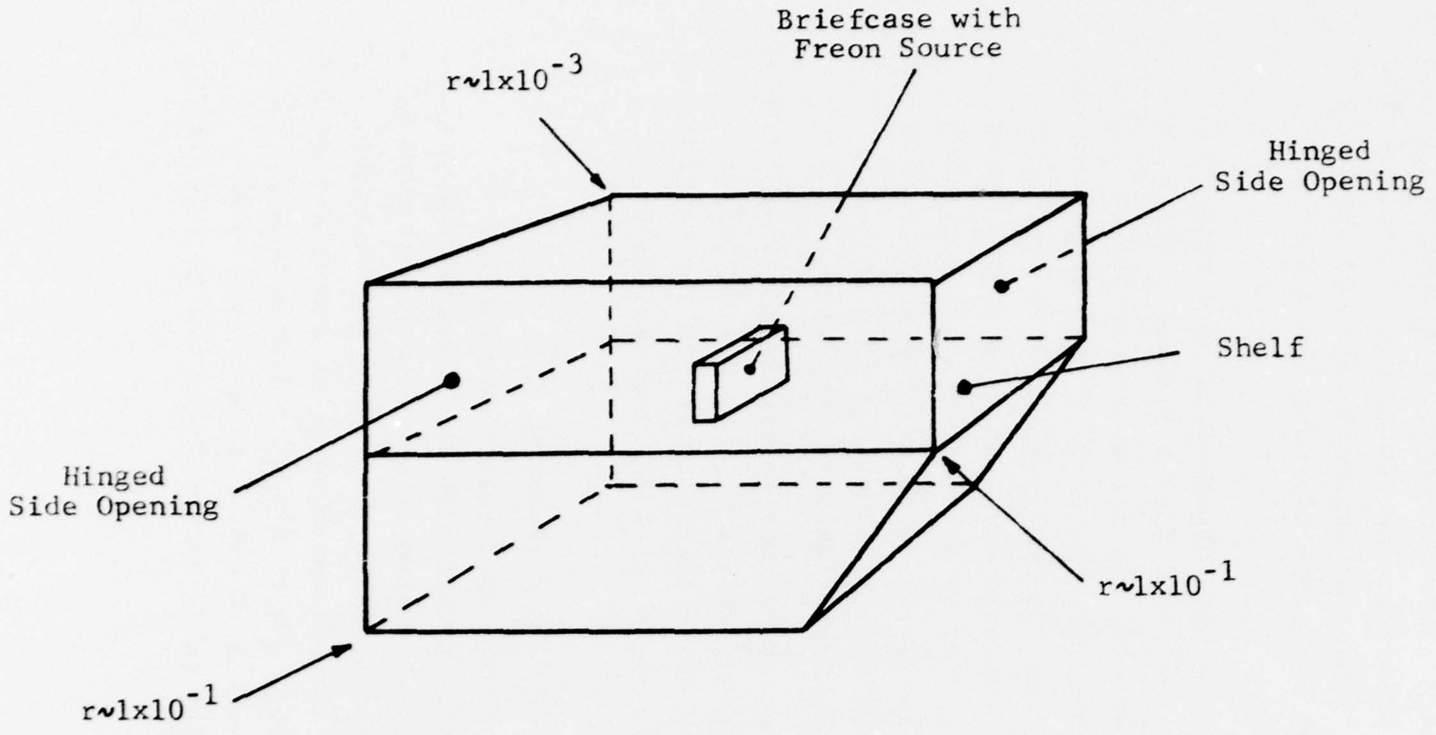


Figure 28

747/DC-10 BAGGAGE CONTAINER

4.5.1 Passenger Agent Check-In Desk

All boarding passengers of regularly scheduled flights must stop at the passenger agent's desk for check-in and seat assignment before boarding the aircraft. These tests were designed to examine the feasibility of a bomb detector in this area for the detection of a bomb that might be carried in hand carried luggage, or hidden in one's clothing.

Figure 29 schematically shows the arrangement as used at O'Hare airport and Table 5 presents the results obtained from the tests.

Table 5

SUMMARY OF CHECK-IN DESK DATA

	Average Minimum Distance Between Freon Source and Detector, Ft	
	1.0	2.5
Average Maximum Attenuation Parameter r, sec/l	8.8×10^{-4}	6.3×10^{-4}
Time to Maximum Value, sec	10	14

These data as presented, represent the average of the data obtained since they were quite variable because of uncontrolled air circulation in the area. Because of the variable air current readings above the background could not be obtained from tests on the far side of the desk. The two minimum distances presented are the typical distances for a passenger carrying a briefcase in his right or left hand as he passes the detector on the near side of the desk (as shown in Figure 29).

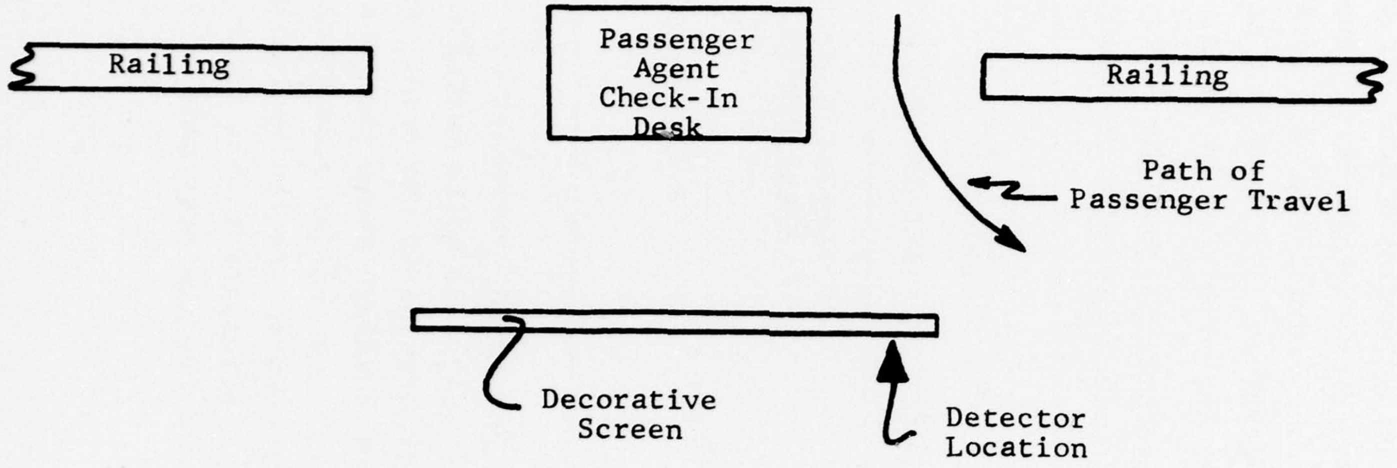


Figure 29

SCHEMATIC ARRANGEMENT OF TESTS AT PASSENGER AGENT DESK

4.5.2 Jetway Tests

Since the air flow patterns in the area of the passenger agent check-in desk were variable and uncontrolled, we were prompted to test the Jetway leading to aircraft at the boarding gates. The general air movement inside the Jetway was from the aircraft to the terminal waiting area. The detector was stationed in the Jetway corridor at one side, as shown in Figure 30, at a distance of 2 feet above the floor. An article of luggage carried in the right hand of a boarding passenger would pass the detector at an average minimum distance of about 3.5 feet. Similarly, an article carried in the left hand would pass at about 2 feet. These were the conditions under which the Freon source was carried past the detector while enclosed in a briefcase. Table 6 presents a summarization of the data obtained. The maximum values of the attenuation parameter are similar to those obtained at the passenger agent desk, while the times required for the detector to reach its maximum reading were somewhat longer.

Table 6

SUMMARY OF JETWAY TESTS

	Average Minimum Distance Between Freon Source and Detector, Ft	
	2.0	3.5
Average Maximum Value of Attenuation Parameter, sec/l	6.4×10^{-4}	5.9×10^{-4}
Time to Maximum Value, sec	17	18

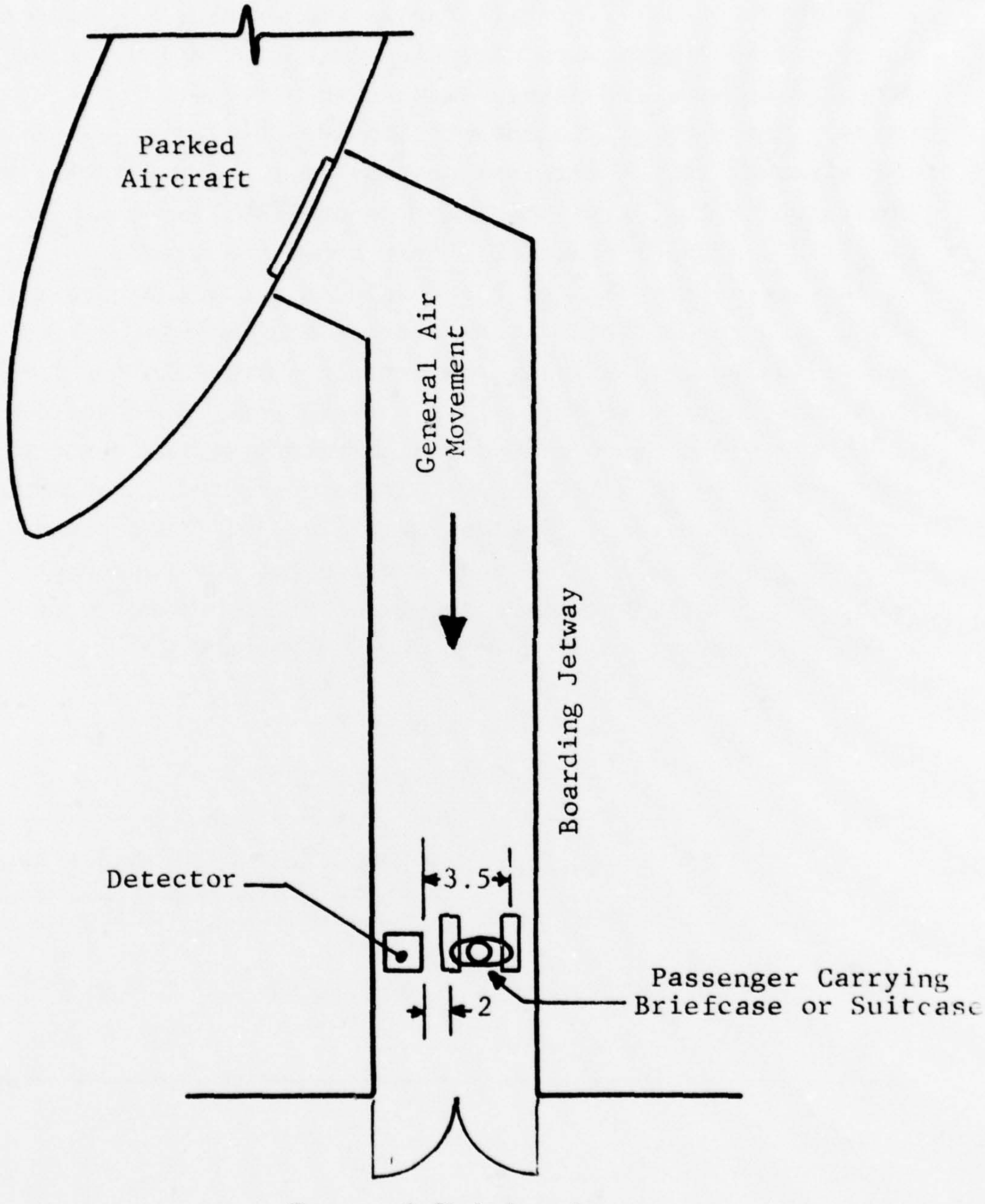


Figure 30

CONFIGURATION OF JETWAY TESTS

5. VAPOR DETECTABILITY ESTIMATES

The data obtained in the present work and combined with earlier vapor pressure data on some explosives, together with estimates of diffusion and emission rates from principles of physical chemistry and chemical engineering, permit calculating some typical explosives vapor concentrations that may be expected in several facilities from openly exposed explosives. Since the degree of vapor emission reduction effected by concealment was not studied and suitable data are not available, the more realistic situation of a hidden bomb cannot be properly calculated. The calculated values are the highest concentrations that can be expected. However, any detector that does not reach these sensitivities is obviously inadequate, at least in the absence of pressurizing/depressurizing cycles designed to produce a pumping effect on the vapors in bomb-carrying containers.

5.1 Vapor Pressures of Some Explosives

Data on the vapor pressure of some explosives, taken from earlier work at IITRI under a FAA contract* and more recent BRL data** are tabulated in Table 7. Since the explosives do not consist of pure compounds, the vapor pressure of each component, e.g. ethylene glycol dinitrate in dynamite, is lower than in the pure form.

5.2 Diffusion Coefficients in Air

After leaving the surface of an explosive, the vapors of the explosive first migrate through a non-turbulent boundary film of air, usually estimated as an air film of a nominal thickness of 0.1-0.2 cm. The non-turbulent diffusion coefficients for the vapors of explosives in air have not been

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*FAA-ADS-34, Bomb Detection System Study, IIT Research Institute, A. Dravnieks, Contract FA-WA-4782 (1965).

**Thermal and Mass Spectral Analyses of the Vapors and Decomposition Products and the Vapor Pressures of Some Military Explosives, A.D. Coates, E. Freedman, and L.E. Kuhn, BRL, Aberdeen Proving Grounds, Report, (1969).

Table 7

VAPOR PRESSURES OF TYPICAL EXPLOSIVES

Compound	Form	Vapor Pressure at 25° ±3°C in Torr (mm Hg)
Ethylene glycol dinitrate	Pure	8×10^{-2}
Ethylene glycol dinitrate	in Gelobel C	1.8×10^{-2}
Nitroglycerin	Pure	5×10^{-4}
Nitroglycerin	in Gelobel C	(3×10^{-5})(Estimated)
2,4-Dinitrobenzene	Pure	1.6×10^{-2} (BRL)
2,4-Dinitrobenzene	Pure	2.1×10^{-2} (IITRI)
2,4-Dinitrobenzene	Above block on Composition B	3.5×10^{-4}
2,4-Dinitrobenzene	in "purified" TNT	4.3×10^{-4}
TNT	Pure	1.3×10^{-6} (BRL)
TNT	Pure	2×10^{-5} (IITRI)

reported, but estimates can be made from Chapman-Enskog equations*

$$D_{AB} = 0.0018583 \frac{\sqrt{T^3 \left(\frac{1}{M_A} + \frac{1}{M_B} \right)}}{p \sigma_{AB}^2 \Omega_{D,AB}} \qquad (5)$$

Here D is the diffusion constant, in gas consisting of A and B substance, cm^2 sec^{-1}; T is the temperature, °Kelvin; M_A and M_B are the molecular weights of A (explosive) and B (air); p, the pressure, in atm. (1 atm); σ_{AB} is the approximate average diameter of the A and B molecules; in Angstroms (1Å = 10^{-8} cm) and Ω is an averaged "temperature" parameter dependent on the intermolecular interaction forces between A and B.

The value of σ, 3.62 Å is given in the same reference. The values for the four explosive components considered were estimated by calculating the molvolumes from Kopps rule on molvolume additivity, and assuming that the molecules are reasonably spherical so that mensuration rules apply. The value of Ω for air is 97°K. Its values for explosives are unknown, but since it is not a very sensitive function of molecular structure and size (nonane, 324; chloromethane, 855; CS_2, 488), the range between 500 and 2000 should be more than ample to accomodate its values for the explosives. Calculations for the example on 1/ 512 of Bird's reference, using the above assumptions for air/explosive mixtures, give values in the range of 1.2 to 1.8. Thus, only relatively little error is inherent in estimating the value of this parameter. The following diffusion constants, were then calculated for the four vapors at room temperature in air,

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*cf Transport Phenomena, p. 510-511, R.B. Bird, W.E. Stewart and E.N. Lightfoot, John Wiley & Sons, Inc., New York, 1960.

Ethyleneglycoldinitrate	0.038 cm^2 sec^{-1}
Nitroglycerine	0.032
2,4-Dinitrobenzene	0.037
TNT	0.033

In essence, a conservative value of 0.03 cm^2 sec^{-1} should reasonably well apply to all four vapors.

5.3 Emission Rates from Openly Exposed Explosives

From an explosive openly exposed to bulk air, the rate of vapor emission per cm^2 of geometrically measured surface can be approximated from Fick's law

$$J = A \cdot D \cdot \frac{n_c - n_a}{d} \qquad (6)$$

Here J is the emission flux, e.g. molecules/sec; A is the exposed area, 1 cm^2; D is the diffusion constant of vapor in air 0.03 cm^2 sec^{-1} for explosives vapors; n_c is the concentration of the vapor in equilibrium with the explosive, and can be calculated from its vapor pressure in the explosive; n_a is the vapor's concentration in air, and can be assumed as negligible ($n_a = 0$) and d is the formal thickness, cm of the non-turbulent air film at the surface of the explosive, with a typical value of 0.2 cm.

Putting in the estimated values,

$$J = 0.15\, n_c \qquad (7)$$

After conversion to partial pressure and gravimetric terms ($n_c = 3.3 \cdot 10^{16}$ p, with p in mm Hg; $J \cdot M/6.03 \cdot 10^{23}$, flux in g/sec)

$$Q = 8.2 \cdot 10^{-9}\, pM \qquad (8)$$

Q = emission, $g \cdot sec^{-1}$, per cm^2 of explosive

p = vapor pressure of vapor, mm Hg in explosive at ambient temperature

M = molecular weight of vapor, grams.

Table 8 gives the emission rates for several explosives of Table 7. These values multiplied by the exposed surface

Table 8

ESTIMATED EMISSION RATES OF
SEVERAL EXPLOSIVES OPENLY EXPOSED TO OPEN AIR

Vapor and Explosive	Emission rate, grams per second, per cm^2 of freely exposed surface of the explosive
EGDN in Gelobel C (a dynamite)	$2.2 \cdot 10^{-8}$
Nitroglycerin in Gelobel C (a dynamite)	$6.5 \cdot 10^{-11}$
DNT above a block of Composition B	$4.8 \cdot 10^{-10}$
TNT pure	$2.3 \cdot 10^{-12}$

area of the corresponding explosive, and further multiplied by the attenuation factors obtained and quoted in the present work, would give concentrations in (g/liter) of the corresponding vapors available at the detector site if the explosive were fully exposed to air. Since any concealment results in an additional reduction in emission into the free air, such values represent the maximum concentration of the corresponding vapors that may be ever expected.

As an example, assume 200 cm^2 as a reasonable surface area for an explosive (a dynamite stick has ~180 cm^2 of paper-wrapped surface). If $r = 10^{-4}$, a value frequently found in this study,

$$200 \times 6.5 \times 10^{-11} \times 10^{-4} = 1.3 \times 10^{-12} \text{ g/liter}$$

would be available.

Any concealment would reduce these values to an extent that cannot be estimated without knowing the "barrier" factor the factor which represents the degree of the concealment in terms of reduction of free-air emission.

5.4 Typical Available Concentration Levels

Because of the unknown "barrier" factors, the bomb-generated concentration levels for bombs hidden in packages and suitcases cannot be estimated. Table 9 gives expected EGDN concentrations that may be obtained from three side-by-side triangularly arranged 1" x 9" dynamite sticks in free air. The free area of such a bomb is of the order of 360 cm^2, and the calculated EGDN emission rate is:

$$360 \times 2.2 \times 10^{-8} = 792 \times 10^{-8} \approx 8 \times 10^{-6} \text{ g/sec.}$$

Other values are of the order of 10^{-8} g/l in a mobile lounge, 10^{-9} in cabins and in walk-by or move-by situations, and 10^{-10} for cases where the detector is in the cabin but the bomb is in the baggage compartment or a lavatory in the smaller plane. In the 747, the value is of the order of 10^{-9}

when the detector is in the same air movement module, and much lower in the adjoining module. Thus, in a 747, several detector sites, or manifolding from several locations to the same detector may be necessary.

It is likely that the vapor transport barrier imposed by wrappings etc. may decrease these values by several orders of magnitude. An urgent need exists to experimentally determine the barrier factors for various typical types of concealment.

A system in which a pressure/depressure cycle is used to bring vapors out of the containers into freely moving air should reduce the significance of the barrier factor.

Table 9

ESTIMATES (WITHOUT BARRIER FACTOR) OF EGDN CONCENTRATION IN AIR: 3-STICK DYNAMITE BOMB EXPOSED TO AIR

Facility	Bomb Location	Detector Location	Time, Min. After Exposing the Bomb	Attenuation Factor	Expected EGDN Concentration, g/Liter	Reference Figure in Text
DC-8	Coach cabin with passengers	Coach cabin	5	3.4×10^{-4}	2.7×10^{-9}	Fig. 21
DC-8	Baggage compartment	Coach cabin	10	2.8×10^{-5}	0.2×10^{-9}	Fig. 20
747	Cabin row 30	After buffet	6	1.6×10^{-4}	1.3×10^{-9}	cf Text
707	Aft lavatory	1st class cabin	5	4.2×10^{-5}	0.3×10^{-9}	Fig. 19
Mobile Lounge	(Test 2)		5	4.4×10^{-3}	35×10^{-9}	Table 3
Jetway	Walk by	Side	Max	5.9×10^{-4}	4.7×10^{-9}	Table 4
Baggage Conveyor	Move-by	Side	Max	7.1×10^{-4}	5.7×10^{-9}	Table 4

6. SUMMARY AND CONCLUSIONS

Estimates on the chemosensor sensitivity needed to detect explosives by detection of characteristic vapors emitted by explosives require knowing the rate of emission of such vapors from contained explosives and the extent of attenuation that occurs with these vapors in air between the bomb and the chemosensor locations. The emission rate from containers depends on the explosive and the degree of its concealment, and thus requires study for specific cases. The extent of the attenuation in air is essentially species-nonspecific. The objective of the reported work was to assess the degree of attenuation in various air-transport-related facilities. Freon 12 vapor and a halogen-gas detector were used to measure the attenuation, which was expressed in terms of a parameter r. This permits calculating concentrations of vapor, g/liter of air, expected to occur at the various chemosensor sites for any proposed bomb vapor emission rate, g/sec, through the bomb enclosure.

The following findings resulted:

(1) In smaller aircraft (DC-8, 707), air movements under recirculation are sufficiently effective to conclude that under proper taxiing conditions the chemosensor placement site is not very critical. Attenuation factors of the order of 10^{-4} were reached within minutes after the simulated bomb was placed; they were reasonably uniform throughout the cabin. Attenuation factors of the order of 10^{-5} were observed when the simulated bomb was placed in the baggage compartment or the lavatory and the detector in the cabin. There was no significant difference between taxiing an empty or an occupied aircraft.

(2) In larger aircraft (747), where air streams are channeled, attenuation factors of the order of 10^{-4} were observed when the detector was in the same air movement channel as the simulated bomb. When the bomb and the detector were in separate air movement channels, r was less than 10^{-6}. A bomb detector would have to sample separately each of the air currents.

(3) In the mobile lounge, the attenuation factors were of the order of 10^{-3}, so that the detection would be possible with a less sensitive detector than in the aircraft. Again, the vapor concentration was relatively uniform throughout the lounge, so that the bomb detector placement site is not critical.

(4) In the walk-by situations, the jetway location was more favorable than the ticketing desk site; a vapor attenuation pulse equivalent to the attenuation factor of the order of 10^{-4} was observed.

(5) In the conveyor-moved baggage, a vapor pulse of the order of 10^{-4} was observed if major air drafts were eliminated.

(6) In baggage handling containers, holes or slots existed through which a bomb sniffer's inlet nozzle could be inserted. Attenuation factors of the order of 10^{-1} to 10^{-3} were observed.

(7) The above sensitivity estimates permit calculating the chemical sensitivity required from a bomb chemosensor if the chemical species, its vapor pressure in the explosive, and its retardation by a bomb enclosure are specified. Conversely, certain situations can be identified where a chemosensor with a defined, but limited, sensitivity could perform satisfactory.