GROUND-BASED WARM FOG DISPERSAL SYSTEMS

TECHNIQUE SELECTION AND FEASIBILITY DETERMINATION WITH COST ESTIMATES

FEDERAL AVIATION ADMINISTRATION

NOVEMBER 1975

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Prepared by

FAA Systems Research and Development Service

Fog Dispersal Task Team

November 1975

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16. Abstract

This engineering study determines the feasibility of and prepares a conceptual design for a ground-based warm fog dispersal system at a selected airport which has a high frequency of fog and a large air traffic volume that is adversely affected by fog. Los Angeles International Airport (LAX) was selected as the airport for study.

The study considers and includes a brief review of warm fog dispersal mechanisms. The results indicate that heat is presently the only reliable technique for warm fog dispersal. Two methods of applying heat to fog are examined in detail, namely, the Thermokinetic and Modified Passive Thermal. Engineering costs estimates are developed. The results of the study indicate that both systems would be cost-effective at Los Angeles International Airport. For improving the visibility in fog to CAT II minimums, the 12-year benefit-to-cost ratio of the Thermokinetic Fog Dispersal System which uses natural gas for fuel is 8.7 to 1 while the Modified Passive Thermal Fog Dispersal System has a ratio of 4.8 to 1. The study concludes that a Thermal Fog Dispersal System at LAX is both feasible and cost effective.

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Fog Dispersal, Warm Fog, Los Angeles International Airport, Thermokinetic Modified Passive Thermal Fog Dispersal System

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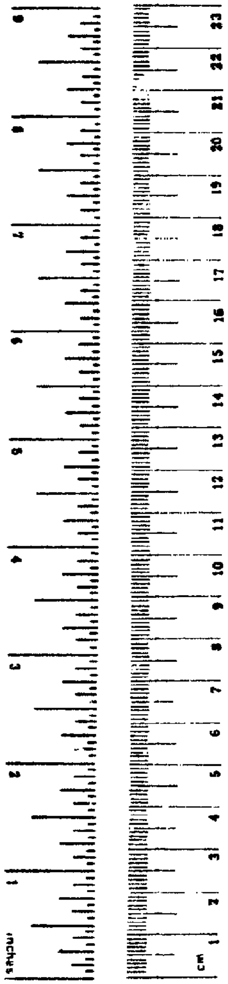
NOTICE

METRIC CONVERSION FACTORS

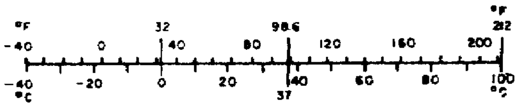
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.036	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

PREFACE

This technical report is an FAA in-house engineering study to determine the feasibility of a ground-based warm fog dispersal system for a selected United States airport.

The completion of this report is the result of the efforts of the following individuals from the Systems Research and Development Service who constituted the in-house task team: R. Conway (Air Traffic Control Systems Division); J. Hendrickson, S. Millington (Navigation Division); C. Ball, J. Chen, M. Coggins, F. Coons, J. Link, F. Melewicz (Chairman), W. Smith, R. Pierre, L. Goodwin, E. Van Vlaanderen, C. Workman, E. Mandel (Airport Division); and A. Hermie (Analysis Division).

The comments and suggestions of Dr. James E. Jiusto, Atmospheric Sciences Research Center, State University of New York at Albany, are gratefully appreciated.

In addition, appreciation for the valuable assistance of Arlene Kline during preparation of the manuscript is expressed.

SUMMARY

This engineering study was made to determine the feasibility of, and prepare a conceptual design and cost estimates for a ground-based warm fog dispersal system at a selected airport.

The first step was to establish reasonable fog dispersal system operational and functional requirements. Two operational possibilities exist for the system and were studied to determine the most feasible operation. These are; (1) a system which would improve the visibility in fog to CAT I minimums, and (2) one which would improve visibility in fog to CAT II minimums. The volume of fog clearance required in each case was determined.

Functionally, the actual mechanisms which produce fog clearings had to be both theoretically and operationally sound before this study would consider a particular system or technique. Of the several techniques for fog dispersal referred to in this report, only the thermal techniques meet these criteria. Therefore, preliminary designs, installation and operational cost estimates have been made for:

(1) A modified passive thermal fog dispersal system, and

(2) A thermokinetic fog dispersal system.

Cost estimates were developed in order to determine feasibility and approximate benefit/cost ratios for use in comparing the two systems. The costs are representative of actual costs in as much as the limited scope of this report allowed them to be. Variations in the costs quoted in this report from actual costs may reasonably be expected to exist. Estimations of costs for the thermokinetic system were particularly troublesome to determine. Attempted verification of our estimates with French manufacturers indicate that our costs may be slightly low.

Another responsibility of the task team was to select the airport to receive the system. Airport selection was based on both a high air traffic density and high fog frequency, the factors which determine the probability of a fog dispersal system's ability to impart a large benefit for the airlines and passengers. Los Angeles International Airport (LAX) was selected from among the major airports in the United States as the airport which would derive the highest potential benefit from a fog dispersal system.

For improving visibility in fog to CAT II minimums, the results of this study show that the Thermokinetic Fog Dispersal System which uses natural gas for fuel has a 12 year benefit-to-cost ratio of 8.7 to 1, while the Modified Passive Thermal Fog Dispersal System has a ratio of 4.8 to 1. This study concludes that a thermal fog dispersal system which will improve visibility in fog from CAT III conditions to CAT II minimums at LAX in order to land CAT II certificated aircraft and aircrews is both feasible and cost-effective.

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LIST OF ABBREVIATIONS AND ACRONYMS

ARTCC	Air Route Traffic Control Center
ATA	Air Transport Association
ALPA	Airline Pilots Association
ATC	Air Traffic Control
CAT I	*An instrument approach procedure which provides for approaches to a decision height (DH) of not less than 200 feet and visibility of not less than 1/2 mile or RVR 2400 (RVR 1800 with operative touchdown zone and runway centerline lights).
CAT II	*An instrument approach procedure which provides approaches to minima of less than DH 200 feet/RVR 2400 to as low as DH 100 feet/RVR 1200.
CAT IIIA	*Operation with no decision height limitations to and along the surface of the runway with RVR not less than 700 feet.
CAT IIIB	*Operation with no decision height limitations to and along the surface of the runway and with RVR not less than 150 feet.
CAT IIIC	*Operation with no decision height limitations to and along the surface of the runway and taxiways without reliance on external visual reference.
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
ILS	Instrument Landing System
LAX	Los Angeles International Airport
RVR	Runway Visual Range
THERM	Quantity of heat equivalent to 100,000 British Thermal Units (BTU's)
TRACON	Terminal Radar Control Facility (FAA)

*Ref. 10.

CHAPTER 1

INTRODUCTION

The purpose of this engineering study is to determine the feasibility of and to prepare a conceptual design for a ground-based fog dispersal system. The system will be analyzed as if it were located at a selected airport which has a high frequency of fog and high air traffic density. This approach will allow system cost estimates to be developed so that a comparison between these costs and benefits can be assessed.

During the past three decades, attempts to disperse fog by artificial means have met with varying degrees of success. Numerous techniques and systems have been tried based on such principles as heat, electrostatics, sound, chemical and physical additives, mechanical mixing, etc. Some techniques have been engineered into operational systems (e.g., ground-based cold fog dispersal systems using propane; thermokinetic systems for warm fog). The optimization of several of these techniques and systems can lead to favorable benefit-to-cost ratios for installation and operation of fog dispersal systems at certain airports. The objective of fog dispersal is visibility improvement; i.e., to provide a pilot with the visibility needed for visual ground reference* in the approach, touchdown and rollout zones of the runway.

The function of the fog dispersal system complements the instrument landing system function; the ILS provides a precision approach while visual ground reference is provided by the fog dispersal system. Under low visibility conditions, aircraft need ILS to navigate to the region cleared by the fog dispersal system. Likewise, at otherwise fog closed airports the fog dispersal system provides the landing minimums required for a Category II or Category I approach as the case may be. While the latest high performance ILS and future MLS systems provide the precision necessary for Category III A and B approaches, the fog dispersal system enhances the safety of such operations by enabling the pilot to have good visual ground reference.

Although fogs at United States airports occur on the average of only one to two percent of the time, they are, nevertheless, responsible for the loss in revenues of approximately $100 million annually (ATA estimate) due to air carrier flight cancellations, delays, and diversions. As a result, the United States and other countries are seeking methods to minimize the impact of fog on aircraft operations and also to increase airport capacity and improve aviation safety through the development of operationally reliable fog dispersal systems.

The dissipation of cold fogs (temperature below 32° F.) by seeding with dry ice or liquid propane as nucleating agents is already operationally established. This report will concern itself with warm fog (temperature above 32° F.) dispersal. In the United States, warm fogs occur approximately 95% of the time while cold fogs occur approximately 5% of the time when fog conditions exist.

*ALPA recommends research to disperse fog to the extent that the threshold and touchdown zone are clearly visible to the pilot at decision height. (Subcommittee on Advanced Research and Technology, Committee on Science and Astronautics, House of Representatives, January 20, 1972).

The approach taken in this study is as follows:

1) Delineation of the operational requirements and capabilities for a ground-based warm fog dispersal system.
2) Analysis of known fog dispersal techniques and selection of the operationally feasible technique(s), along with rationale for selection.
3) Preliminary system design and selection of airport for system installation.
4) Determination of cost estimates to install and operate a fog dispersal system using the selected technique at the selected airport.

CHAPTER 2

FOG DISPERSAL SYSTEM OPERATIONAL AND FUNCTIONAL REQUIREMENTS

The following fog dispersal system functional and operational requirements for CAT I and CAT II conditions* are identified and will be used as criteria for developing the system design:

2.1 FOR CAT I

The system must increase and maintain visibility to 1/2 mile equivalent (RVR 2,400 feet) or more in the approach, touchdown and rollout zones of the prime instrument runway in fog with surface wind speed 0 to 8 knots inclusive from any direction.

2.1.1 DIMENSIONS OF ZONE OF INCREASED VISIBILITY

The fog dispersal system must provide for a visible path from middle marker or CAT I decision height in general to touchdown and rollout. The rollout zone is 5,000 feet long.** The width of the zone of increased visibility is the runway width (200 feet) plus 75 feet on each side of the runway. The width of the cleared zone at the decision height is 1,000 feet. The height over the runway is 75 feet to allow for the pilot's eye position which is 45 to 50 feet above the landing gear in large jet aircraft. The height of the cleared zone at decision height is 325 feet (200 feet decision height plus 50 feet for the pilot's eye position with an added 75 feet as a safety margin). The volume of fog dispersed to permit CAT I operations is approximately 6.3 x 10^8 cubic feet. (See Figure 2.1.)

2.2 FOR CAT II

The system must increase and maintain visibility to 1,200 feet RVR or more in the approach, touchdown and rollout zones of the prime instrument runway in fog with surface wind velocity 0 to 8 knots inclusive from any direction.

2.2.1 DIMENSIONS OF ZONE OF INCREASED VISIBILITY

The fog dispersal system must provide for a visible path from the Inner Marker or CAT II decision height in general to touchdown and rollout. The rollout zone is 5,000 feet long. The width of the CAT II zone of increased visibility is the runway width plus 75 feet on each side of the runway. At

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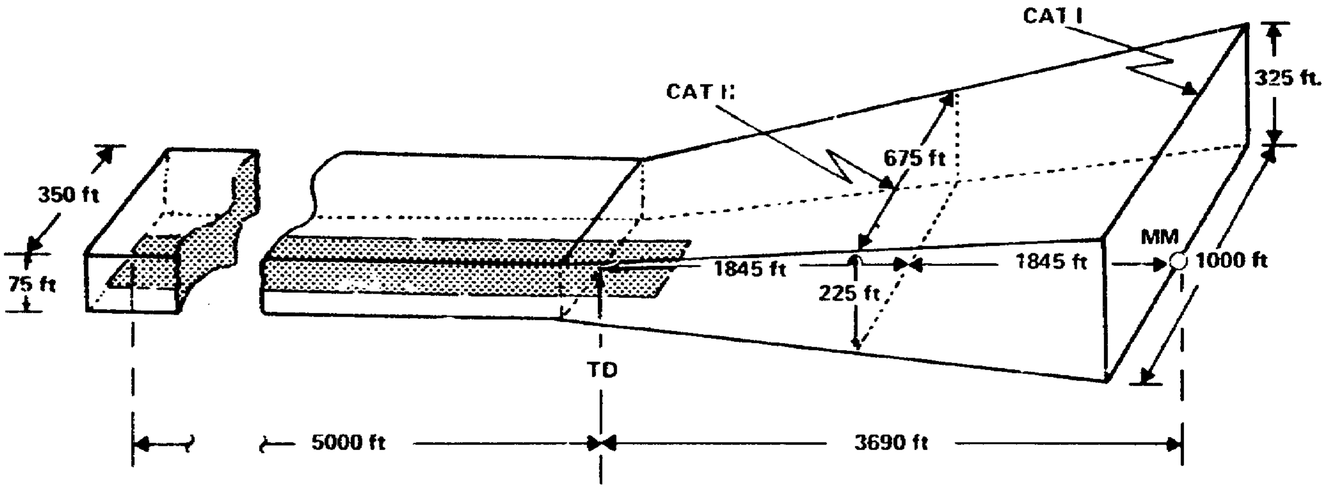
* See List of Abbreviations and Acronyms for definition

** 5000 feet approximates the rollout distance of a large heavy jet aircraft with all systems functioning properly.

FIG. 2.1 Proposed Region of Fog Clearance *



CAT I VOL $= 6.3 \times 10^8$ cu ft
CAT II VOL $= 2.7 \times 10^8$ cu ft

* not to scale

the CAT II decision height, the width of the zone is approximately 1/2 the width of the CAT I zone at its decision height. The height over the runway is 75 feet to allow for the pilot's eye position which is 45 to 50 feet above the wheels in large jet aircraft. The extra 25 feet is a safety margin. The height of the cleared zone at the CAT II decision height is the decision height (100 feet) plus 50 feet to allow for the pilot's eye position above landing gear height in the aircraft plus a safety margin of 75 feet for a total of 225 feet. The volume of fog dispersed to permit CAT II operations is 2.7 x 10^8 cubic feet (see Figure 2.1).

CAT I operations require that either CAT III or CAT II conditions be improved to CAT I, and CAT II operations require that CAT III conditions be improved to CAT II. However, CAT III is divided into three levels, and under the lowest of these conditions, CAT IIIC, (zero visibility) aircraft cannot taxi and the system cannot be used. Therefore, CAT IIIC conditions will not be considered amenable to fog dispersal operations and any system costs or benefits due to CAT IIIC will not be included in the analyses.

The dimensions shown in Figure 2.1 will be used only to determine costs for the systems and do not represent standard requirements for FAA certification of fog dispersal systems.

CHAPTER 3

ANALYSIS OF FOG DISPERSAL TECHNIQUES

3.1 HEAT TECHNIQUES

3.1.1 THERMOKINETICS

The thermokinetic technique for fog dispersal uses jet engines (usually placed underground) to heat and mix foggy air over the runway 2° to 3° F above ambient temperature, thereby causing evaporation of the fog and improving the visibility from CAT III minimums up to CAT II minimums. The thermokinetic technique provides rapid and reliable defogging action in about one to two minutes. The method of transporting the heated air into the fog is primarily by thrust, or kinetic energy, hence the name thermokinetic. The technique does produce light turbulence, but not to a disqualifying degree. Therefore, it is considered a candidate technique for a fog dispersal system design.

3.1.2 MODIFIED PASSIVE THERMAL FOG DISPERSAL

Heat can be applied to fog by heat generators placed alongside a runway and in the approach zone (British FIDO system of the 1940's, Ref. 5). The natural convective forces of the heated atmosphere and the winds in the fog are relied on to transport and mix the heat energy throughout the fog. This is followed by a reduction in relative humidity and subsequent evaporation of existing fog droplets thereby causing visibility improvement. No additional expenditure of energy over that needed to produce the hot air plumes is required for the buoyant plumes to rise and mix with the fog except at runway intersections and taxiways where it may be necessary to install blowers in the heating units in order to counteract fog intrusion; hence the name modified passive thermal fog dispersal system. The heat output needed for fog dispersal will require the development of safe, clean and efficient burners. The system is wind sensitive. Therefore, more heat energy will be required to disperse fog when accompanied by the higher wind speeds than when dissipating fog under calm or lighter wind conditions (Table 5.3). The modified passive thermal fog dispersal technique is also considered a candidate for a system design.

3.2 ELECTROSTATIC TECHNIQUES

Electrostatic techniques of fog dispersal require charging of the drops making up the fog and creation of a high electric field in the fog. The electric field imparts a force on the charged fog drops which accelerates the fallout of the drops and thereby improves visibility.

A mechanism to produce the very high electric field necessary for significant acceleration of fog drop fallout has not yet been satisfactorily demonstrated. Therefore, at this time, this technique is not considered feasible for operational application and is not considered as a candidate.

3.3 SEEDING WITH HYGROSCOPIC PARTICLES

There has been periodic interest in modifying fogs with hygroscopic materials, such as salt, beginning with the promising work at M. I. T. in the 1930's. An improved version of this early method has been investigated by NASA and its contractors (Reference 9). In essence, dry salt particles of carefully prescribed sizes (about 10-20 μ) are injected into fogs with only slight reductions in relative humidity sought. The natural fog drops then evaporate at the expense of growing and sedimenting saline drops with a subsequent increase in visibility.

While laboratory experiments and field tests in thin radiation fogs were successful, the method is considered marginal. Limited effectiveness in thick or turbulent fogs, problems of vectoring the seeding material over the airport and environmental impact considerations reduce its applicability. Due to these limitations, this technique is not considered as a candidate.

3.4 OTHER TECHNIQUES

Other techniques such as ultrasonics, laser beams, solar energy, and mechanical separation of fog droplets have been considered and determined to be impractical for development into airport fog dispersal systems (Table 3.1) at this time.

3.5 TECHNIQUE SELECTION

Heat has been demonstrated to be an effective and reliable technique for dispersing natural fog more so than any other of the above described or known techniques. For purposes of this study, two heat techniques, thermokinetic and modified passive thermal, will be considered as candidates for a ground-based fog dispersal system design.

These two systems represent extremes in thermal techniques. The thermokinetic system depends on the high thrust of jet engines while the modified passive system relies primarily on high heat output rather than thrust. Data on reliability and approximate operating requirements exist since both systems are or have been operational - the passive technique used in the British FIDO system of the 1940's, thermokinetic technique currently used in the French Turboclair system.

It should be recognized that a system which optimizes the ratio of heat to thrust for the specific wind conditions may indeed represent a more cost effective system than the two we will study. The design and cost estimates for such a system were not attempted since the amount of intensive research and scientific study required for consideration of this specific system were beyond the scope of this task.

TABLE 3.1 OTHER FOG DISPERSAL TECHNIQUES

TECHNIQUE	PRINCIPLE OF OPERATION	EVALUATION
THERMAL		
Laser Beams	Evaporation	Expensive power requirements (500 Megawatts).
Infra-red radiation by electric heating.	Evaporation	Expensive power requirements (500 Megawatts).
Solar Energy	Evaporation	Unproven heat storage units.
MECHANICAL		
Vertical Mixing by Fans, Helicopters	Evaporation by mixing foggy air with drier air.	Some sucess with shallow radiation fog (75 ft.). Impractical installation for airports.
Removal of fog droplets by impact on fans, sieves, etc.	Separation of fog droplets by centrifugal force or screens.	Negligible effect on fog. Inefficient and impractical.
SOUND		
Ultrasonic	Coalescence of fog droplets by high frequency sound waves with resultant fallout of droplets and improved visibility.	Impractical power requirements. Not proven effective in field trials.

TABLE 3.1 OTHER FOG DISPERSAL TECHNIQUES (CONTINUED)

TECHNIQUE	PRINCIPLE OF OPERATION	EVALUATION
ELECTRICAL		
Electrostatic	Downward force imparted on charged fog drops by electric field resulting in fallout and improved visibility.	Not considered feasible for practical application.
CHEMICAL		
Hygroscopic	Sodium Chloride and other hygroscopic chemicals absorb water vapor as they fall through fogs thereby lowering humidity to the point where suspended fog liquid droplets evaporate.	Corrosive effects make some hygroscopic chemicals (such as salt) impractical for airports. Other hygroscopic chemicals such as glycerine and urea have shown some sucess when used in large quantities. However, proper targeting of the cleared area over the desired runway is difficult.

CHAPTER 4

AIRPORT SELECTION

4.1 CRITERIA

Major U.S. airports which have a high air traffic count and are scheduled for CAT II ILS installation (or already have CAT II ILS installed) were screened to determine which ones would benefit from the installation and operation of a ground-based warm fog dispersal system. Since many airports would gain benefits from an effective fog dispersal system, it was decided to select, for a more detailed engineering study, that airport which would derive the highest potential benefit from the installation and operation of a warm fog dispersal system.

Screening factors for each airport included the following: average annual number of hours of CAT II and CAT III weather due to fog; air traffic projections for 1981; projected economic losses due to cancellations, diversions, and delays of scheduled arrivals of U.S. certificated route air carriers because of CAT II and CAT III weather due to fog; and the capability of the airport to accept fog dispersal systems of the types considered.

4.2 SELECTION PROCESS

In selecting an airport, it was considered necessary that the airport have a high annual occurrence of fog and a high air traffic density during the hours of fog in order for the fog dispersal system to be cost-effective. The more aircraft that a fog dispersal system permits to land and take-off, when otherwise the airport would be closed due to fog, the greater will be the benefit to airlines and passengers. Tables 4.1 and 4.2* list the airports which were screened in this study as potential candidates for a fog dispersal system installation. The average number of hours of CAT II and CAT IIIA and B weather** due to fog is listed based on a ten year period from Jan. 1, 1956, to Dec. 31, 1965.*** Also, this table shows estimated airline and passenger costs, projected for 1981, associated with disruptions of scheduled arrivals

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* 1975 dollars are used throughout the report as a standard in both system costs and benefits for comparison purposes. The 1970 dollar figures in potential economic benefit study (Ref. 2) were upgraded to 1975 dollars using the consumer price index as the scaling factor.

** Ref. 6.

*** Data from this period was used to insure compatibility with the potential benefit study (Ref. 2) which used the same ten year period in forecasting future benefits.

Table 4.1 Estimated Costs Due to CAT III A&B Fog

Cost - These columns are the estimated cost (1981) associated with disruptions of scheduled arrivals of aircraft of first and second level U.S. certificated route air carriers due to CAT III A&B weather due to fog.

City*	Airport	Annual No. of Hours CAT III A&B Fog	Cost to Airlines & Pass. in 1975 Dollars ($1000)	Cost to Airlines in 1975 Dollars ($1000)
Los Angeles	International	79.1	10,816	2,306
Seattle	Seattle-Tacoma Int'l.	147.0	9,660	2,062
New York	John F. Kennedy Int'l.	32.4	5,169	1,186
Chicago	O'Hare International	26.2	5,157	1,154
Atlanta	The Wm. B. Hartsfield Atl. Int'l.	31.4	3,665	878
Portland, Oregon	International	104.5	3,281	777
Washington	Dulles International	51.0	3,188	782
San Francisco	International	31.2	2,870	721
Baltimore	Baltimore-Washington Int'l.	41.1	2,855	645
Detroit	Detroit Met.-Wayne County	46.6	2,776	627
Philadelphia	International	32.4	2,048	506
New Orleans	International	57.7	1,928	522
Boston	Gen. E. L. Logan International	23.2	1,795	477
Newark	Newark	16.7	1,180	290
New York	La Guardia	16.2	1,137	281
Milwaukee	General Mitchell Field	44.7	1,132	270
Kansas City	Mid-Continent International	24.4	1,117	197
Salt Lake City	Municipal No. 1	35.8	997	284
Covington	Greater Cincinnati	36.8	829	208
Miami	International	11.2	738	190
Cleveland	Cleveland-Hopkins International	21.2	703	200
Pittsburgh	Greater Pittsburgh International	25.8	680	177
Indianapolis	Weir Cook	26.3	645	166
St. Louis	Lambert-St. Louis Municipal	11.9	586	155
Washington	National	15.9	551	137
Buffalo	Greater Buffalo Int'l.	22.0	532	144
Minneapolis	Minneapolis-St. Paul Int'l.	14.4	532	141
Hartford	Bradley Int'l. (Windsor Locks)	43.0	530	121
Columbus	Port Columbus Int'l.	27.4	429	103
Dayton	James M. Cox Municipal	32.8	395	97
Oakland	Metropolitan Oak. Int'l.	36.0	371	90
Anchorage	International	43.5	298	86
Denver	Stapleton International	7.5	230	70
Nashville	Metropolitan	23.3	244	63
Louisville	Standiford Field	16.3	227	58
Rochester	Rochester-Monroe County	15.4	206	53
Birmingham	International	12.4	105	29
Syracuse	Clarence E. Hancock	8.9	92	26

*Both Dallas and Houston have had recent changes in airport location. Consequently, there is no long term climatology of the type used for the other airports to determine the occurrence of fog at these locations. Therefore, Dallas and Houston have not been included in the analyses.

Table 4.2 Estimated Costs Due to CAT II and III A&B Fog

Cost - These columns are the estimated cost (1981) associated with disruptions of scheduled arrivals of aircraft of first and second level U.S. certificated route air carriers due to CAT II and III A&B weather due to fog.

City*	Airport	Annual No. of Hours CAT II & III A&B Fog	Cost to Airlines & Pass. in 1975 Dollars ($1000)	Cost to Airlines in 1975 Dollars ($1000)
Los Angeles	International	121.7	16,647	3,548
Seattle	Seattle-Tacoma International	198.7	13,057	2,787
New York	John F. Kennedy International	69.7	11,109	2,551
Chicago	O'Hare International	46.3	9,109	2,037
Atlanta	The Wm. B. Hartsfield Atl. Int'l.	72.0	8,405	2,013
Washington	Dulles International	101.1	6,316	1,549
Portland, Oregon	International	157.2	4,935	1,169
Baltimore	Baltimore-Washington Int'l.	68.4	4,748	1,073
San Francisco	International	48.5	4,459	1,119
Detroit	Detroit Met.-Wayne County	67.2	4,005	904
New Orleans	International	103.5	3,457	936
Philadelphia	International	53.9	3,413	843
Boston	Gen. E. L. Logan International	43.7	3,373	896
Newark	Newark	31.9	2,248	555
New York	La Guardia	31.8	2,233	552
Kansas City	Mid-Continent International	45.6	2,088	370
Milwaukee	General Mitchell Field	69.5	1,760	419
Salt Lake City	Municipal No. 1	49.4	1,378	392
Covington	Greater Cincinnati	58.7	1,322	333
Miami	International	19.1	1,256	325
Pittsburgh	Greater Pittsburgh International	43.8	1,156	300
St. Louis	Lambert-St. Louis Muncipal	23.5	1,154	306
Washington	National	32.6	1,132	281
Minneapolis	Minneapolis-St. Paul Int'l.	28.2	1,044	277
Indianapolis	Weir Cook	42.5	1,043	269
Cleveland	Cleveland-Hopkins Int'l.	30.1	996	284
Hartford	Bradley Int'l. (Windsor Locks)	72.2	889	203
Buffalo	Greater Buffalo International	36.3	877	237
Anchorage	International	97.8	648	195
Columbus	Port Columbus International	41.0	641	153
Denver	Stapleton International	16.6	575	155
Dayton	James M. Cox Muncipal	47.6	573	141
Oakland	Metropolitan Oakland Int'l.	53.8	555	136
Nashville	Metropolitan	35.4	371	96
Rochester	Rochester-Monroe County	27.8	370	97
Louisville	Standiford Field	25.6	356	90
Birmingham	International	21.6	184	49
Syracuse	Clarence E. Hancock	13.9	141	41

*Both Dallas and Houston have had recent changes in airport location. Consequently, there is no long term climatology of the type used for the other airports to determine the occurrence of fog at these locations. Therefore, Dallas and Houston have not been included in the analyses.

of aircraft of first and second level U.S. certificated route air carriers in domestic and international passenger service due to CAT II and CAT III A&B weather due to fog. These costs are measures of the potential economic benefits the airport users would realize if the adverse effects of fog on aircraft landings were eliminated by a fog dispersal system. A further increase in these benefits not considered in this study would be realized by operation of the fog dispersal system during fog to obtain field minimums for aircraft take-offs.

Not considered are potential benefits accruing to foreign flag carriers, general aviation aircraft, military aircraft and cargo service aircraft.

Table 4.3 is a summary of the top seven airports which have the highest projected costs for 1981 (and therefore would realize the highest potential benefit from a fog dispersal system) together with the projected number of aircraft arrivals during CAT II and CAT IIIA and B fog conditions (Ref. 2).

4.3 SELECTION OF AIRPORT

From the list of airports considered in Tables 4.1, 4.2, and 4.3 Los Angeles International Airport (LAX) appears to be that airport which, in 1981, would gain the highest potential benefit from a fog dispersal system with annual savings of $16.6 million for CAT II and IIIA and B and $10.8 million for CAT IIIA and B weather due to fog. LAX is scheduled to have two CAT II ILS runways, 25L and 24R by 1981, of which 25L will be the preferred runway. A fog dispersal system located along the CAT II ILS runway can change CAT IIIA and B fog conditions to CAT II minimums thereby permitting CAT II-equipped aircraft and CAT II certificated pilots and crews to land when otherwise the airport would be below landing minimums.

This engineering study will determine the feasibility of, and prepare a conceptual design for a ground-based thermal fog dispersal system for Los Angeles International Airport, runway 25L, enabling an estimate of system cost to be made to determine the benefit-to-cost ratio. Additionally, a cost/benefit comparison will be made between the thermokinetic and modified passive thermal fog dispersal systems.

Table 4.3 Projected Annual Cost of Disruption of Scheduled Arrivals of U.S. Certificated Route Air Carriers Due to CAT II and CAT III A&B Weather Due to Fog (1981).

Airport	CAT II AND III A&B				CAT III A&B			
	Cost ($Million)*		Annual Hrs. Fog	No. Aircraft Arrivals Affected	Cost ($Million)*		Annual Hrs. Fog	No. Aircraft Arrivals Affected
	With Pass. Benefit	Without			With Pass. Benefit	Without		
Los Angeles	16.6	3.5	122	2,191	10.8	2.3	79	1,423
Seattle-Tacoma	13.1	2.8	199	1,778	9.7	2.1	147	1,315
New York (JFK)	11.1	2.6	70	1,348	5.2	1.2	32	627
Chicago (ORD)	9.1	2.0	46	1,339	5.2	1.2	26	758
Atlanta	8.4	2.0	72	1,684	3.7	.9	31	734
Washington, Dulles	6.3	1.5	101	872	3.2	.8	51	440
Portland, Ore.	4.9	1.2	157	1,197	3.2	.8	105	796

Note: The factors (other than the number of aircraft affected) which determine the cost of disruption include, among other things, the estimated family income of the affected passengers, the number of passengers per scheduled arrival and the relative proportion of flight delays, diversions and cancellations for that particular airport. As a result, Dulles, for example, has a higher annual cost of disruption than Portland even though more aircraft at Portland are affected by CAT II and CAT III A&B weather due to fog than at Dulles.

*1975 Dollars

CHAPTER 5

DESIGN CONSIDERATIONS OF A MODIFIED PASSIVE THERMAL FOG DISPERSAL SYSTEM

5.1 ENERGY REQUIREMENT ANALYSIS FOR THE ZONE OF INCREASED VISIBILITY

Figure 2.1 delineates the fog volumes to be cleared to reach CAT II and CAT I minimums. The amount of heat required and its proper distribution through the specified volumes can be determined by applying available heat plume technology. A computer program was used to calculate the various heat outputs under various crosswind speeds (normal to runway) in order to determine the horizontal and vertical extent of the heat plumes under these conditions. Appendix B shows examples of the graphs which were used to determine the positioning of the thermal or burner lines in the modified passive thermal fog dispersal system design and also to calculate the amount of heat energy (in therms per yard hour) needed in various segments of the burner lines to bring about clearing of fog as related to ambient wind conditions. Additionally, the width of the clearance zone over the approach and runway specified volumes was determined. The graphs were derived from equations developed by Hunter Rouse and Associates at the Iowa Institute of Hydraulic Research who investigated the thermal effects produced by a line of burners in a crosswind (Reference 3). The equations have proved essentially correct in field tests of heat plumes (Reference 5). The 3° F. isotherm was used as the limiting isotherm for defining the height and downwind distance of the cleared zone in fog.

The variation of fog (visibility $<$ 1/2 mile, CAT IIIC included) at LAX over 10 years is shown in Figure 5.1. These values ranged from a low fog year of 73 hours in 1964 to a high fog year of 252 hours in 1962 and represent an annual average of 148 hours of fog, 98 hours producing CAT IIIA, B, and C conditions. CAT II and CAT IIIA and B fog conditions occur at an annual rate of 121.7 hours/year, 79.1 of which are due to CAT IIIA and B.

The percent frequency of occurrence of both wind speed and direction in LAX fog has been computed and shown in Tables 5.1 and 5.2. The number of therms (1 therm = 100,000 BTU's) required to disperse fog for a particular wind direction and speed was calculated for the approach, touchdown and rollout zones of the CAT I and CAT II volumes as specified for runway 25L. The number of therms per yard hour required and the location of the burner lines relative to runway 25L is depicted in Figure 5.2. Since the number of therms required per yard hour is directly related to the wind in fog conditions, Tables 5.1 and 5.2 show that the modified passive thermal fog dispersal system must be capable of generating heat in the CAT I volume (6.3×10^8 cubic feet) ranging from 24,000 therms per hour for the two knot crosswind to runway 25L up to 183,000 therms per hour for the eight knot wind parallel to the runway. For the CAT II volumes (2.7×10^8 cubic feet) the low and high thermal values are 13,874 and 92,600 therms per hour respectively.

The burner line system layout is shown in Figure 5.2. The burner lines are separated by 600 feet in the rollout portion (line section A). For calm conditions, which occur 21.2% of the time at LAX, line section A will be required to produce 15 therms per linear yard per hour of fog. Line section B will be required to

FIG. 5-1 NUMBER OF FOG HOURS BY YEAR (VISIBILITY ≤ ½ MILE)

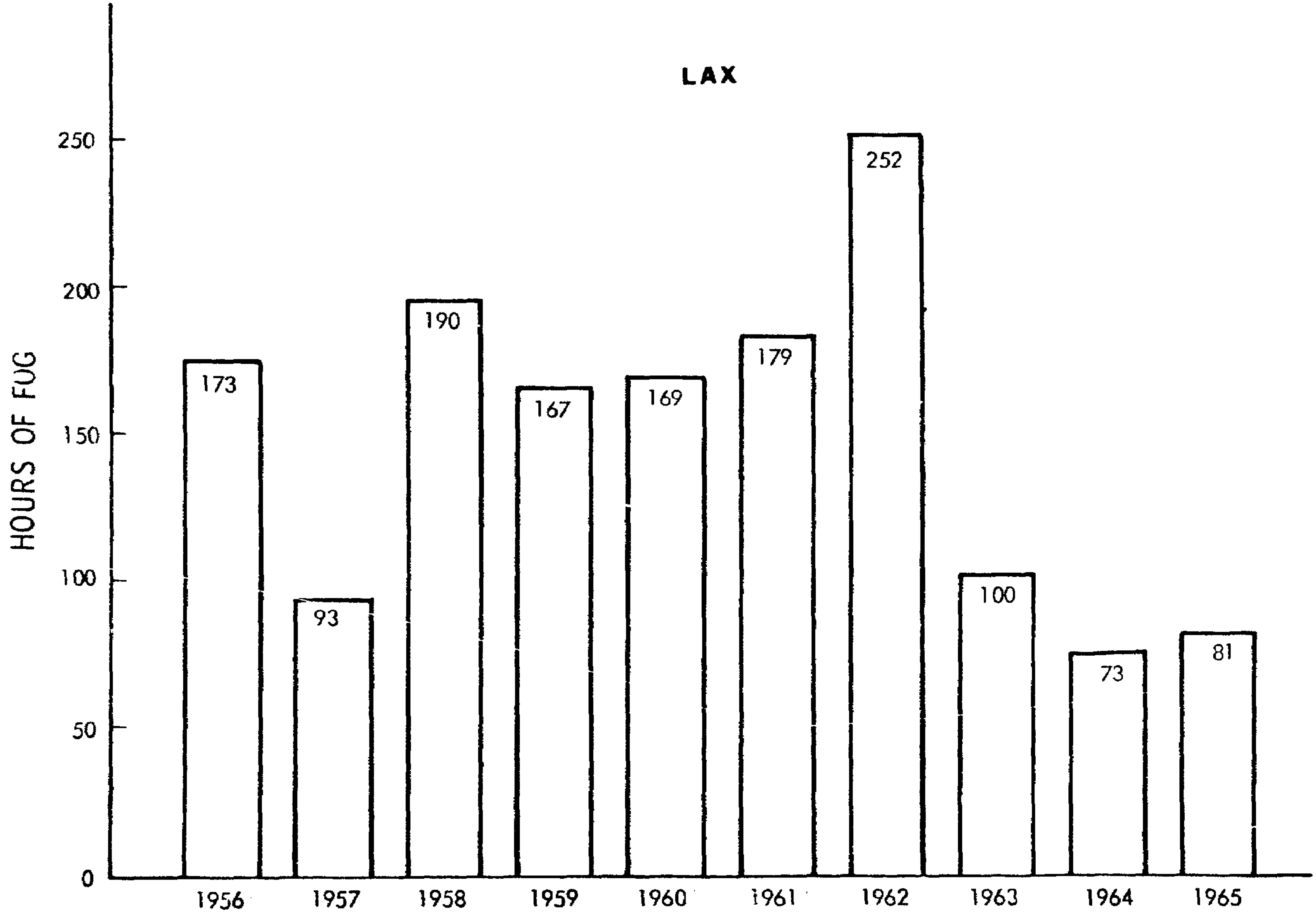


Table 5.1 Energy Requirements/Costs for a Modified Passive Thermal Ground-Based Fog Dispersal System as Related to Wind Data in CAT II and III A&B Fog at Los Angeles International Airport (Single Line Generator System), CAT II Volume (6.3×10^8 cubic feet).

Average Fog Wind (kts.) (Ref. 4)	No. of Therms Per Hour	Percent Occurrence (True Direction)				Total Percent	No. of Hours Fog Per Year (Average)	Total* Cost @ 7¢ Per Therm/ Hour	Total Cost of Fog Dispersal Per Year	Remarks
Calm	107,872					21.2	25.8	$7,551	$194,816	
Crosswind		N,NNW, NNE	S,SSW, SSE							
2	24,340	2.2	2.7			4.9	6.0	$1,704	10,224	
5	53,605	2.3	3.9			6.2	7.6	3,752	28,515	
8	145,428	.1	.3			.4	.5	10,180	5,090	
Parallel Wind		E,ENE ESE	W,WNW WSW							
2	120,445	7.7	4.1			11.8	14.3	$8,431	120,563	
5	139,305	21.0	12.0			33.0	40.1	9,751	391,015	
8	183,312	3.3	4.1			7.4	9.0	12,832	115,488	
Diagonal Wind		NE	NW	SE	SW					
2	23,688	1	1.3	1.7	.7	4.7	5.8	$1,658	9,616	
5	41,580	1.8	1.4	4.3	1.0	8.5	10.4	2,911	30,274	
8	73,623	.1	0	.5	.1	.7	.9	5,154	4,639	
Fogs With Higher Wind Speeds						1.2	1.4			Not Considered
Totals						100%	121.7		$910,240 (for 100% efficiency)	For 99% Fog Dispersal

NOTE:

1. Assume 80% burner efficiency, fuel cost is $1,137,800 for 99% fog dispersal/yr.
2. If 8 kt. wind/Therm requirement is eliminated, fuel cost/yr. is $981,280 for 90% fog dispersal (109.5 hrs/yr. average). Assume 80% burner efficiency.
3. Crosswind is 90° to runway heading; diagonal wind is 45° to runway heading; parallel wind is parallel to runway.
4. Calculations based on average temperature increase of 3°F. corresponding to a total clearing of the fog within the region of clearance. Fuel estimates are conservative since the visibility inside the region will be greater than required. Therefore, the system fuel requirements can be reduced and still perform to specifications.

* Rates for natural gas (as of July 1975) supplied by Southern California Gas Co., Los Angeles, California.

Table 5.2 Energy Requirements/Costs For a Modified Passive Thermal Ground-Based Fog Dispersal System as Related to Wind Data in CAT III A&B Fog at Los Angeles International Airport (Single Line Generator System), CAT II Volume (2.7×10^8 cubic feet).

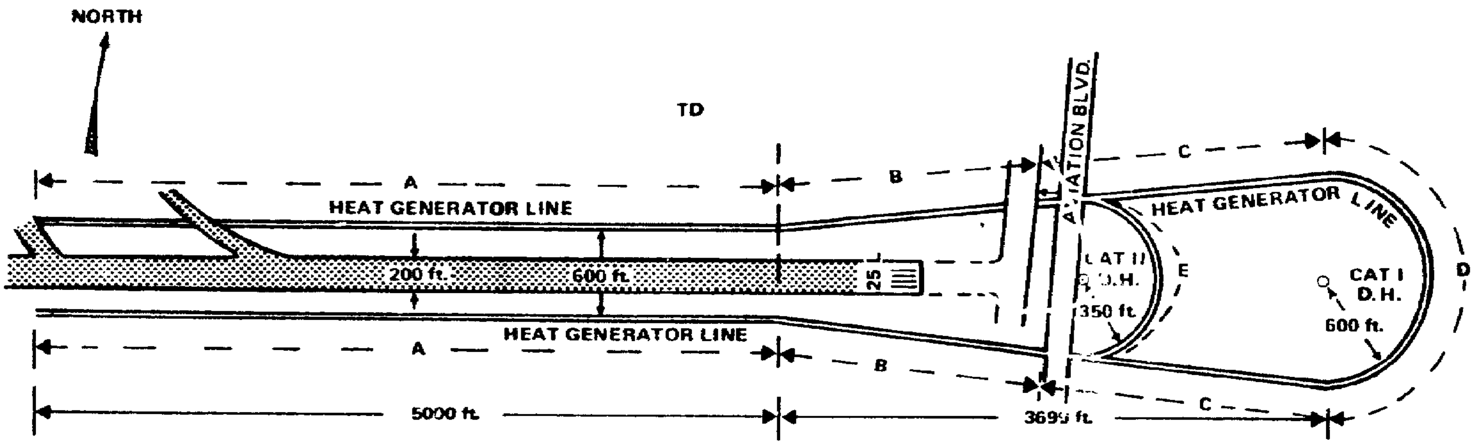
Average Fog Wind (kts.) (Ref. 4)	No. of Therms Per Hour	Per Cent Occurrence (True Direction)				Total Per Cent	No. of Hours Fog Per Year (Average)	Total* Cost @ 7¢ Per Therm/ Hour	Total Cost of Fog Dispersal Per Year	Remarks
Calm	70,933					21.2	16.8	$4965	$83,412	
Crosswind		N,NNW, NNE	S,SSW, SSE							
2	13,874	2.2	2.7			4.9	3.9	$ 971	$ 3,787	
5	28,979	2.3	3.9			6.2	4.9	2029	9,942	
8	83,862	.1	.3			.4	.3	5870	1,761	
Parallel Wind		E,ENE, ESE	W,WNW WSW							
2	74,460	7.7	4.1			11.8	9.3	$5212	$48,472	
5	79,073	21.0	12.0			33.0	26.1	5535	144,464	
8	92,639	3.3	4.1			7.4	5.9	6885	40,622	
Diagonal Wind		NE	NW	SE	SW					
2	16,480	1	1.3	1.7	.7	4.7	3.7	$1154	$ 4,268	
5	37,590	1.8	1.4	4.3	1.0	8.5	6.7	2631	17,630	
8	56,607	.1	0	.5	.1	.7	.6	3962	2,377	
Fogs With Higher Wind Speeds						1.2	1.0			Not Considered
Totals						100%	79.1		$356,735 (for 100% efficiency)	For 99% Fog Dispersal

NOTE:

1. Assume 80% burner efficiency, fuel cost is $445,920 for 99% fog dispersal/yr.
2. If 8 kt. wind/Therm requirement is eliminated, fuel cost/year is $390,000 for 90% fog dispersal (71.2 hrs.). Assume 80% burner efficiency.
3. Crosswind is 90° to runway heading; diagonal wind is 45° to runway heading; parallel wind is parallel to runway.
4. Calculations based on average temperature increase of 3°F. corresponding to a total clearing of the fog within the region of clearance. Fuel estimates are conservative since the visibility inside the region will be greater than required. Therefore, the system fuel requirements can be reduced and still perform to specifications.

* Rates for natural gas (as of July 1975) supplied by Southern California Gas Co., Los Angeles, California.

FIG. 5.2 Preliminary Configuration of Single Line of Burners



LAX - RUNWAY 25L

LINE SECTION	HEAT GENERATOR OUTPUT (Therms/Yd. Hr.)
A - 5000 ft.	5 to 30
B - 1847 ft.	9 to 55
C - 1847 ft.	17 to 100
D - 1855 ft.	20 to 120
E - 814 ft.	13 to 80

D.H. = Decision Height

TOTAL HEAT GENERATOR LINE LENGTH - 19274 ft. for CAT I, line sections A, B, C, D.
14504 ft. for CAT II, line sections A, B, E.

produce 17 therms per yard hour, while line section C must produce 30 therms per yard hour. Table 5.3 shows the heat requirements for various sections of the heat generator line in therms per yard hour for other wind conditions using the modified passive thermal fog dispersal system at LAX. Thus, the heat generator line must be capable of generating a variable quantity of heat over its entire length. The heat output into the fog would be related to the wind speed and direction. For example, for a crosswind to runway 25L, only the upwind burner line will be energized. For wind parallel to the runway, the lines on both sides of the runway must be activated. For easterly winds, the transverse burner line (section D, Figure 5.2) at the decision height point must be activiated to provide the necessary clearance zone height (325 feet) when clearing the CAT I volume. For the CAT II volume, section E, Figure 5.2 must be activated when the wind is from an easterly direction in order to obtain the necessary visibility at CAT II decision height (225 feet), Figure 5.3.

Figures 5.4 and 5.5 show a more detailed view of the airport where the heat generator line would be constructed.

5.2 COST ESTIMATES FOR THE MODIFIED PASSIVE THERMAL GROUND - BASED FOG DISPERSAL SYSTEM AT LOS ANGELES INTERNATIONAL AIRPORT

The length of the heat generator line to clear the LAX fog in the CAT I specified volume is 19274 feet. This line will require site survey, excavation, construction, tunneling, etc. Along the North side of runway 25L, the line is broken by two concrete taxiways. In the approach zone, the line is broken by the Atcheson, Topeka & Santa Fe (AT & SF) Railroad and Aviation Blvd. in both the northern and southern half of the heat generator line. It is suggested that where the burner line intersects taxiways, the individual heat generators in the line be provided with blowers to force the heated air onto the taxiways. The use of blowers is also proposed for the points where the heat generator line crosses Aviation Blvd. and the AT & SF Railroad. The remainder of the line will be on soil/grass surface.

Specialized heat generators to provide the required heat output for the various fog winds have to be developed and specially manufactured. Essentially, these units would be composed of a large combustion chamber (approximately 5 feet in diameter), fuel distribution and ignition system, a control system, etc. Additionally, the heat generators in close proximity to taxiways will have to be equipped with blowers. All units must have a high mass flow and satisfy the energy requirements as specified (5 to 120 therms/yd. hr.). The heat generators will be installed in underground reinforced concrete trenches (Figure 5.2, line sections A and B) and covered by a grating flush with the ground level along each side of runway 25L. In the approach zone, line sections C, D, and E, the heat generator line will be constructed above ground thereby saving the cost of underground construction. Engineering cost estimates for a modified passive thermal ground-based fog dispersal system for LAX have been developed for both the CAT I volume and the CAT II volume as follows:

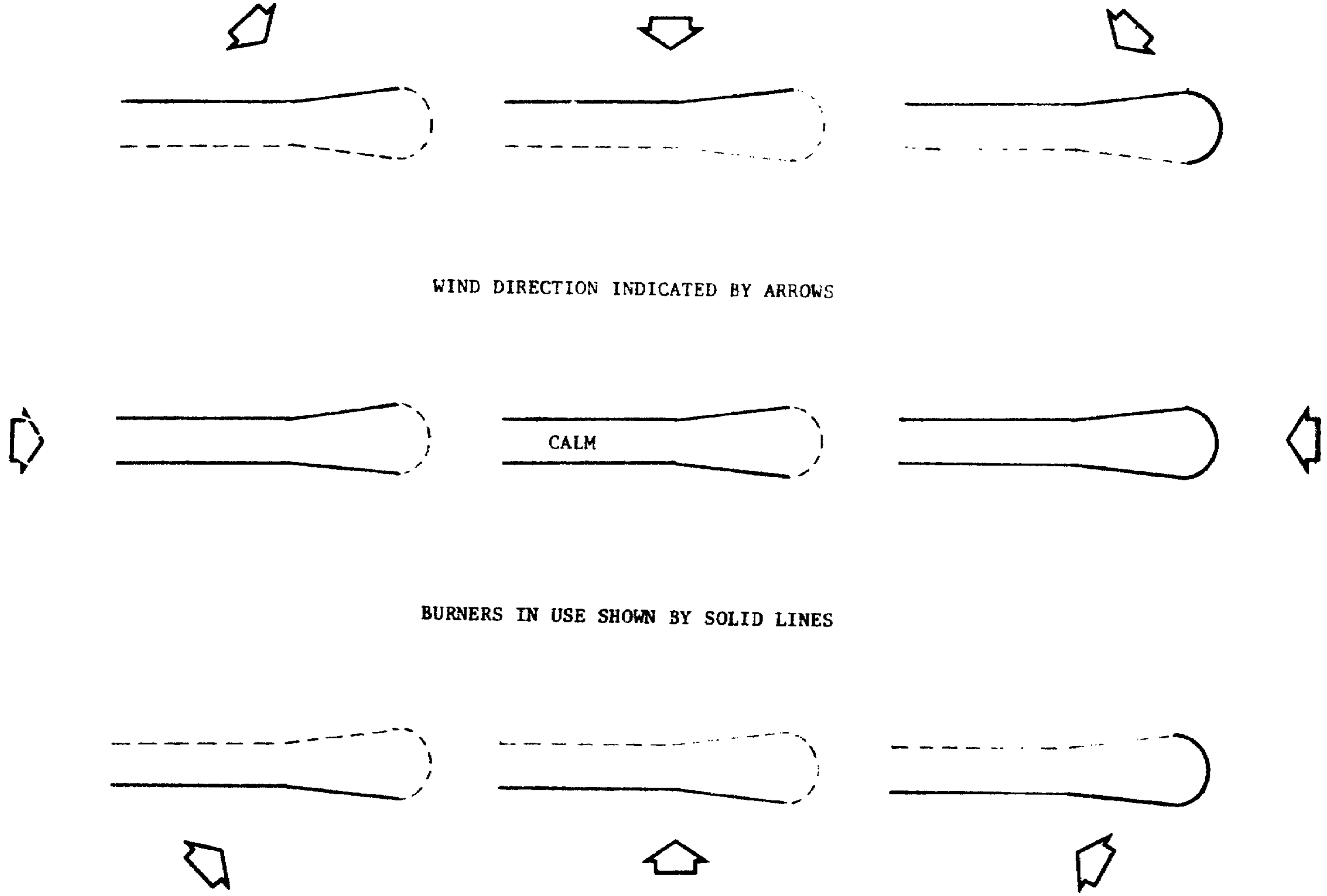
Table 5.3 Heat Requirements For Various Sections of the Heat Generator Line (Therms/Yd. Hr.), Modified Passive Thermal Fog Dispersal System.

Line sec. / Wind Component	A	B	C	D	E
Calm	15	17	30		
Crosswind 2 knot	5	9	17		
Crosswind 5 knot	10	20	40		
Crosswind 8 knot	30	55	100		
Parallel Wind 2 knot	15	17	30	20*	13*
Parallel Wind 5 knot	16	18	32	50*	30*
Parallel Wind 8 knot	17	19	34	120*	80*

* Lines D or E activated for parallel winds from east only

NOTE: Winds from any direction may be broken down into their components - parallel and crosswinds - for the purposes of analysis.

FIGURE 5.3. BURNER LINES FOR VARIOUS WINDS



WIND DIRECTION INDICATED BY ARROWS

BURNERS IN USE SHOWN BY SOLID LINES

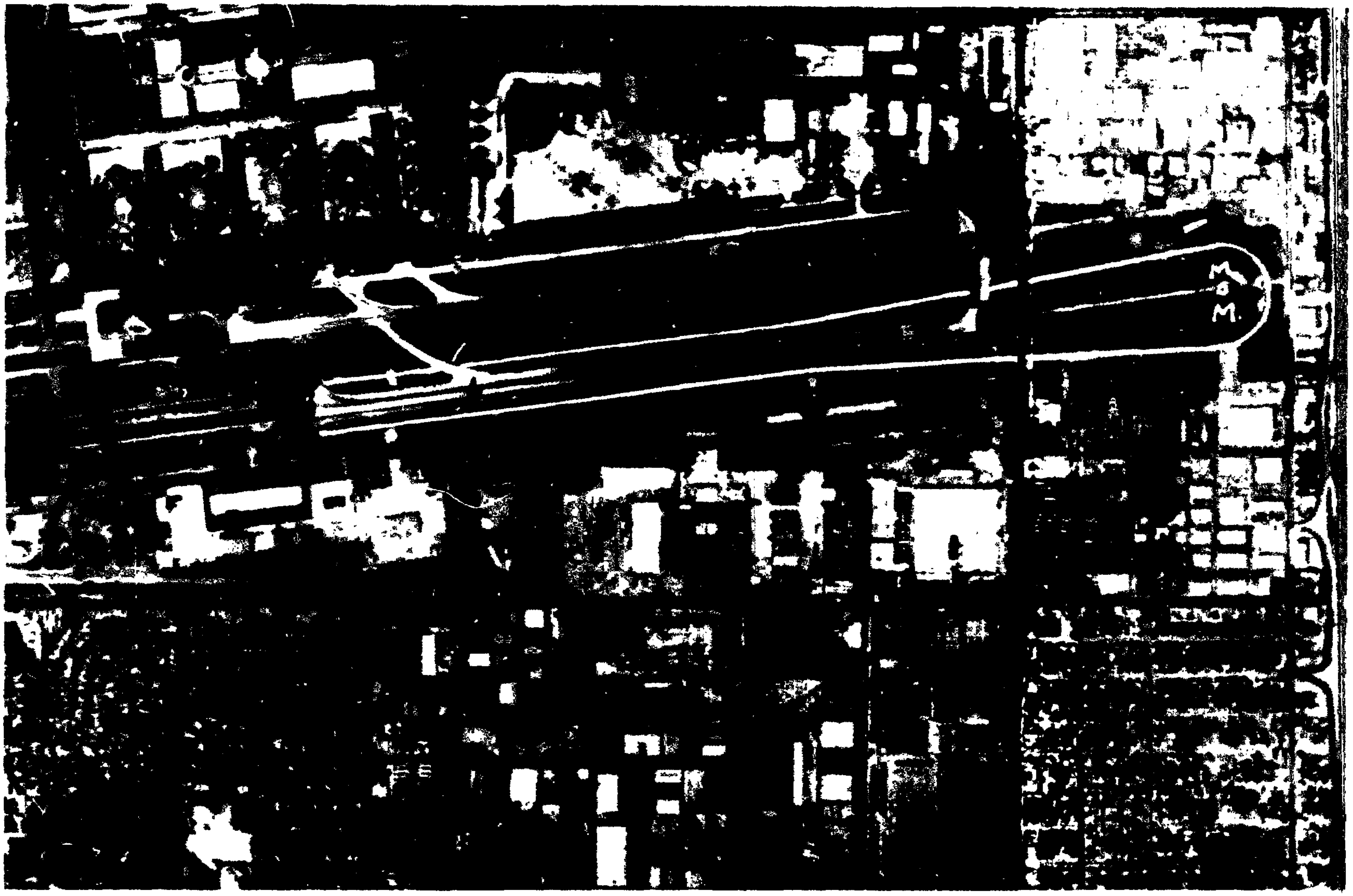


Figure 3.4 Modified Passive Thermal Fog Dispersal System Design showing location of heat generator line, runway 25L for CAT I volume (6.5×10^8 cu. ft.) Los Angeles International Airport

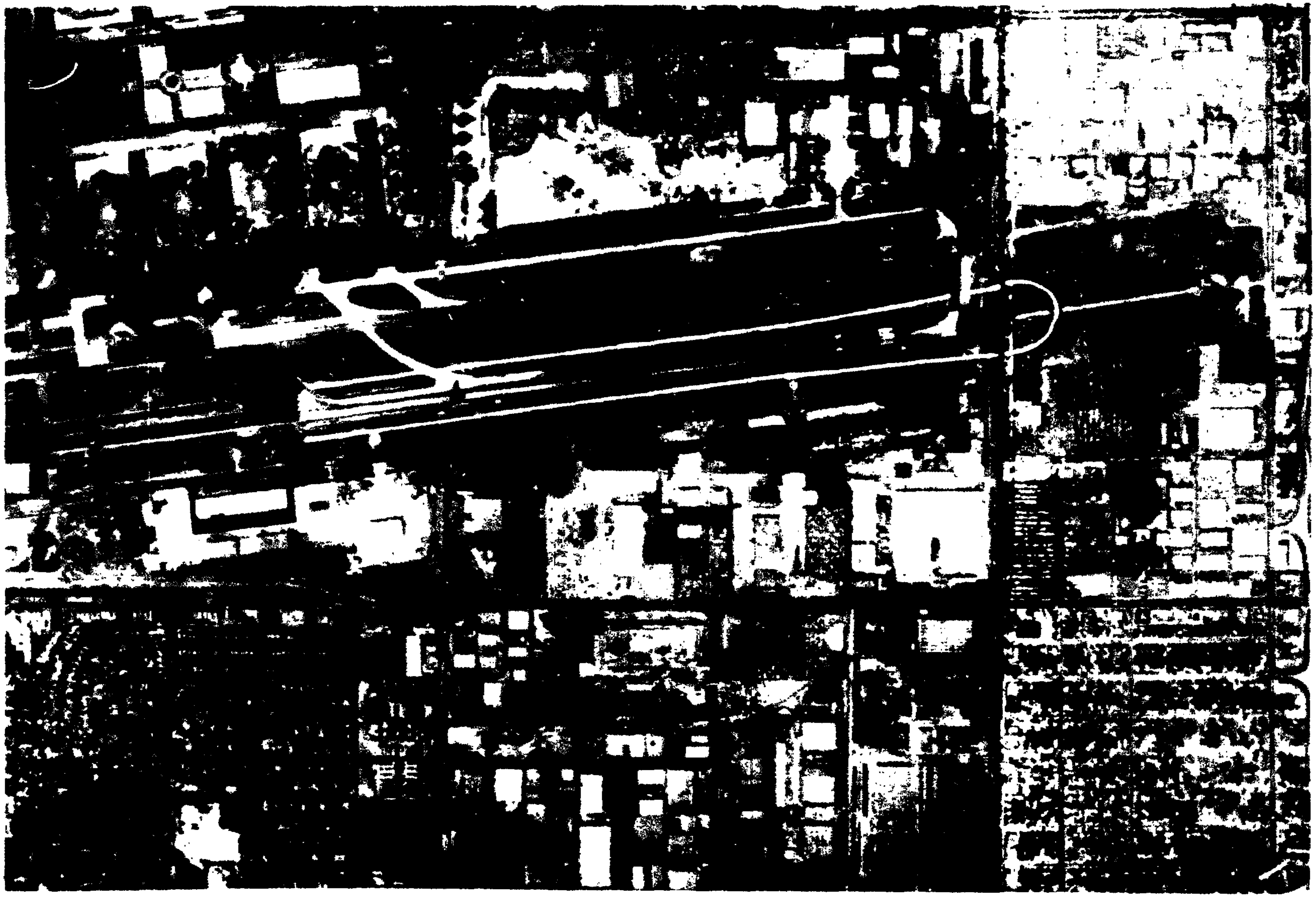


Figure 5.5 Modified Passive Thermal Fog Dispersal System Design showing location of heat generator line runway 25L for CAT II volume (2.2 x 10^8 cu. ft.) Los Angeles International Airport

COST ESTIMATE FOR A MODIFIED PASSIVE THERMAL FOG DISPERSAL SYSTEM FOR LAX (1975 DOLLARS)

	CAT I Vol.	CAT II Vol.
CONSTRUCTION		
Excavation and foundation for reinforced concrete trenchway to house a continuous line of generator units.		
Inner dimensions of trenchway: 6 ft. x 6 ft. x 13,694 ft. (line sec. A and B, Fig. 5.2)		
Thickness of reinforced concrete walls and floor: 1 ft.		
Excavation @ $7/cu. yd.	$ 149,000	$ 149,000
Reinforced concrete @ $100/cu. yd.	1,014,000	1,014,000
Subgrade preparation, grating material, drainage system, and service road @ $25/ft.	342,000	342,000
	$1,505,000	$1,505,000
Above-ground construction (5580 ft.) in the approach zone (line sections C & D, Fig. 5.2) @ $20 per linear foot.	112,000	
Total	1,617,000	
10% architectural/engineering	161,700	
Total CAT I Vol. System Construction Cost.....	1,779,000	
Above-ground construction cost (line sec. E, Fig. 5.2), 814 ft. @ $20 per linear foot		16,280
Total		1,522,000
10% architectural/engineering		152,000
Total CAT II Vol. System Construction Cost.................		$1,674,000
HEAT GENERATORS		
Individual heat generators, 5 ft. in diameter, will be needed which are capable of producing the variable no. of therms as specified (Fig. 5.2 and Table 5.3). For the CAT I volume, 3,854 heat generators are required at an estimated procurement cost of $1000 per unit. Total	$3,854,000	
Installation cost assumed at 50% of procurement cost	1,927,000	
For the CAT II volume, 2901 heat generators are required at an estimated procurement cost of $1000 per unit. Total		$2,901,000
Installation cost assumed at 50% of procurement cost		1,451,000
Fuel distribution and control system	500,000	376,000
Total..................................	$6,281,000	$4,728,000

RELATED COST ASSUMPTIONS

	CAT I Vol.	CAT II Vol.
Control Panel and Telemetering	$ 533,000	$ 400,000
Electric Power Supply	253,000	160,000
Assembly	177,000	133,000
Two Transmissometer Systems	100,000	100,000
Research and Planning	200,000	200,000
Control Building	40,000	40,000
Service Road	77,000	58,000
Contingency, 20% (A & B)	1,582,000	1,250,000
Total	$2,962,000	$2,341,000

SUMMARY OF COSTS

	CAT I Vol.	CAT II Vol.
Construction/Excavation (A)	$1,779,000	$1,674,000
Heat Generators (B)	6,281,000	4,728,000
Related Costs	2,962,000	2,341,000
Total (one time cost)	$11,020,000	$8,743,000

ANNUAL OPERATIONAL COST

Because of its clean-burning qualities and current availability, it is planned to use natural gas as the fuel for the modified passive heat generators. The gas will be piped onto the airport from an outside source. Consequently, no fuel storage costs are incurred. Gas lines are now on the airport since the whole airport complex uses natural gas for heating its buildings. Gas was selected as the fuel to burn in the modified passive thermal fog dispersal system because it is economical (7¢/therm, 1975 rates), has no adverse pollution effects and does not require storage facilities on airport property.

	CAT I Vol.	CAT II Vol.
The average annual cost of natural gas for a 90% fog dispersal capability (Tables 5.1 and 5.2) is	$981,000	$ 390,000
Maintenance (1% of Procurement/Installation)	110,000	87,000
Personnel	60,000	60,000
Total (annual operational cost)	$1,151,000	$ 537,000

5.3 DERIVATION OF BENEFIT TO COST RATIOS

Conservative calculations of benefit to cost ratios are based on an installation period of approximately 2 years, expected fog dispersal system life of 10 years, and an annual interest rate of 10%. The installation and procurement cost is assumed to be equally divided during the 2 year installation period, one half the total cost for the first year, one half for the second year. System benefits are based on the projected 1981 level of traffic throughout the conservative 10 year life expectancy of the fog dispersal system (Tables 4.1 and 4.2). It should be noted that the benefit/cost figures become larger as the life of the system exceeds the 10 year figure.

The operating costs and benefits are for a system capable of effecting clearings in approximately 90% of all occurrences of fog. The format for these calculations is presented below and is done in accordance with the Office of Management and Budget Circular No. A-94.

MODIFIED PASSIVE CAT I SYSTEM AT LAX
($1000)

Year Since Initiation	Expected Yearly Cost	Expected Yearly Benefit		Discount Factor for 10%	Present Value Cost	Present Value Benefit	
		(3)				Col. (3)x(4)	
(1)	(2)	With Pass. Benefit	Without Pass. Benefit	(4)	Col. (2)x(4)	With Pass. Benefit	Without Pass. Benefit
1	$5,510	0	0	.909	$5,009	0	0
2	5,510	0	0	.826	4,551	0	0
3	1,151	$14,982	$3,193	.751	864	$11,251	$2,398
4	1,151	14,982	3,193	.683	786	10,233	2,181
5	1,151	14,982	3,193	.621	715	9,304	1,983
6	1,151	14,982	3,193	.564	649	8,450	1,801
7	1,151	14,982	3,193	.513	590	7,686	1,638
8	1,151	14,982	3,193	.467	538	6,997	1,491
9	1,151	14,982	3,193	.424	488	6,353	1,354
10	1,151	14,982	3,193	.386	444	5,783	1,232
11	1,151	14,982	3,193	.350	403	5,244	1,118
12	1,151	14,982	3,193	.319	367	4,779	1,019
					$15,404	$76,080	$16,215

12 year expected value cost:	$15,404,000
12 year expected value benefit:	$76,080,000 (including passenger benefit)
	$16,215,000 (without passenger benefit)

Benefit to cost ratios:

4.9 to 1 for airlines and passengers
1.1 to 1 for airlines

MODIFIED PASSIVE CAT II SYSTEM AT LAX
($1000)

Year Since Initiation	Expected Yearly Cost	Expected Yearly Benefit		Discount Factor for 10%	Present Value Cost	Present Value Benefit	
		(3)				Col. (3)x(4)	
(1)	(2)	With Pass. Benefit	Without Pass. Benefit	(4)	Col. (2)x(4)	With Pass. Benefit	Without Pass. Benefit
1	$4,372	0	0	.909	$3,974	0	0
2	4,372	0	0	.826	3,611	0	0
3	537	$9,734	$2,075	.751	403	$7,311	$1,559
4	537	9,734	2,075	.683	367	6,649	1,417
5	537	9,734	2,075	.621	333	6,045	1,289
6	537	9,734	2,075	.564	303	5,490	1,171
7	537	9,734	2,075	.513	275	4,993	1,065
8	537	9,734	2,075	.467	251	4,547	969
9	537	9,734	2,075	.424	228	4,127	880
10	537	9,734	2,075	.386	207	3,757	801
11	537	9,734	2,075	.350	188	3,407	726
12	537	9,734	2,075	.319	171	3,105	662
					$10,311	$49,431	$10,539

12 year expected value cost: $10,311,000
12 year expected value benefit: $49,431,000 (including passenger benefit)
$10,539,000 (without passenger benefit)

Benefit to cost ratios:

4.8 to 1 for airlines and passengers
1.02 to 1 for airlines

CHAPTER 6

PRELIMINARY DESIGN OF A THERMOKINETIC FOG DISPERSAL SYSTEM

6.1 SYSTEM DESCRIPTION AND INSTALLATION CRITERIA

The installation and operation of a thermokinetic system at LAX is also considered feasible for fog dispersal. The system employs turbojet engines, installed underground, to produce heat and kinetic energy which heats and mixes the foggy air over the runway to evaporate the fog and improve visibility. Considerable open real estate is available on both the north and south sides of runway 25L for installation of the underground jet engines. The thermokinetic fog dispersal system at LAX can improve visibility in fog from CAT III conditions to at least CAT II minimums in the specified CAT II volume of 2.7×10^8 cu. ft. Thus, the thermokinetic system for runway 25L is designed to clear to CAT II minimums an approach region that extends 1,845 feet from touchdown at a decision height of 225 ft.* The rollout zone of clearance is 5,000 ft. long, 350 ft. wide, and 75 ft. in height.

It is estimated that twenty turbojet engine installations are required to clear the above volume of foggy air to CAT II minimums. They must be spaced 300 ft. apart along runway 25L, each installation being 300 ft. from the runway centerline. Figure 6.1 shows the proposed thermokinetic unit installation locations at LAX. These units are located on the south side of runway 25L. Twenty medium-thrust jet engines will be required, each engine rated at approximately 8,000 to 10,000 lbs. thrust at sea level. Engineering cost estimates (1975 dollars) for the procurement, installation, operation, and maintenance of a thermokinetic fog dispersal system at LAX capable of improving CAT III fog conditions to CAT II minimums (or better) in the specified volume of 2.7×10^8 cu. ft. have been developed as follows:

6.2 COST ESTIMATE FOR A THERMOKINETIC FOG DISPERSAL SYSTEM FOR LAX (1975 Dollars)

Construction	CAT II Vol.
Excavation and foundation for reinforced concrete underground pits (62 ft. x 16 ft. x 18 ft. or 661 cu. yds.) to house the turbojet engines. Excavation @ $10.00/cu. yd.	$6,610

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*Although there is a lack of a quantitative way of supporting the claim that the thermokinetic system with the configuration we have considered in this report can clear up to 225 ft., it is the opinion of this task team that deflection vanes or hot gas exhaust nozzles can be specifically developed to achieve clearings to this height for those units which are required to do so.

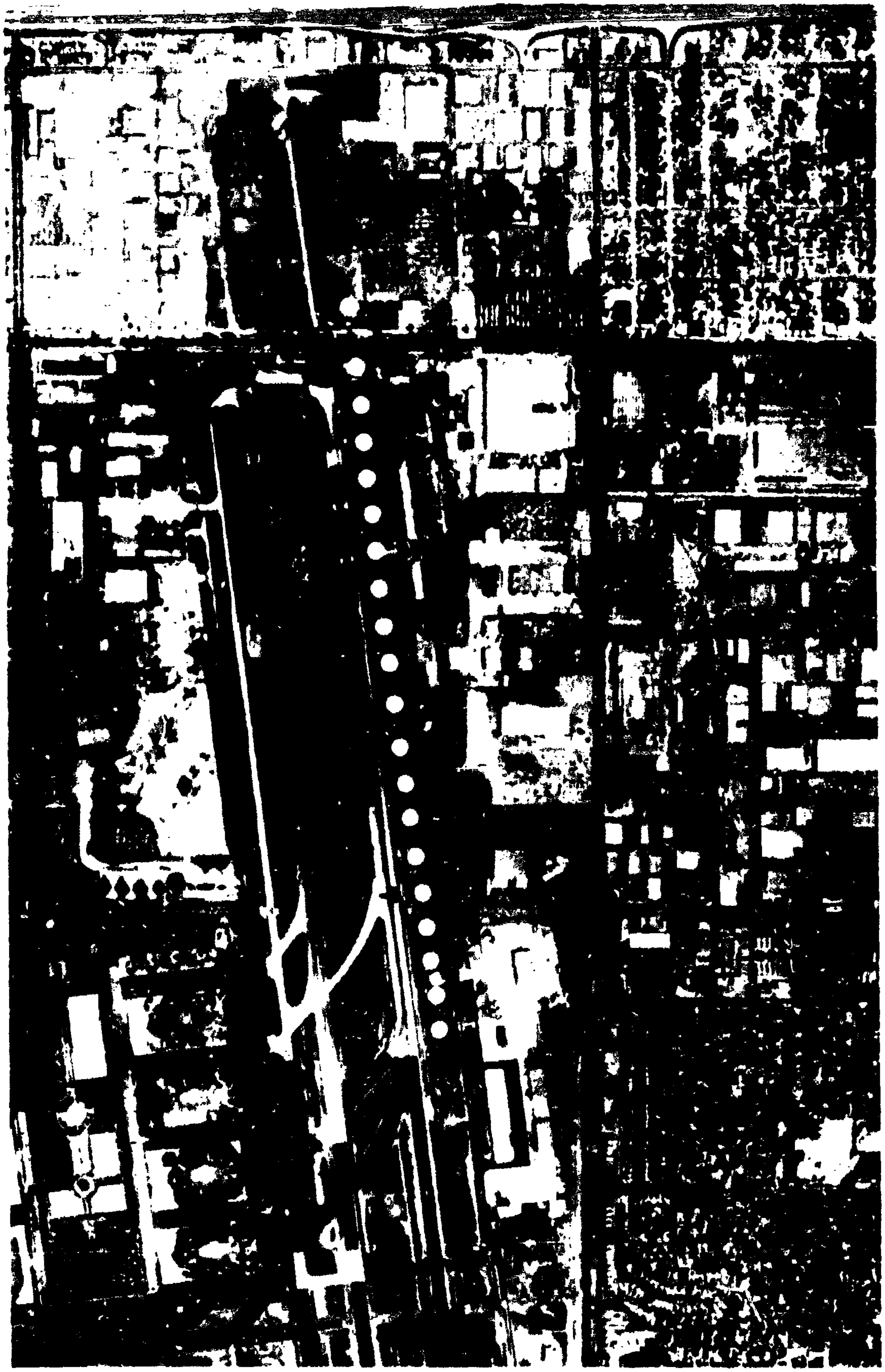


Fig. 6.1 Proposed Location of Thermokinetic Underground Jet Engine Units at LAX Runway 25 L

Reinforced concrete (roof and walls 1 ft. thick, floor 1.5 ft. thick). 278 cu. yds. of concrete needed @$100.00 per cu. yd.	$ 27,800
Drainage	500
Noise insulation	200
Total	35,100
10% architectural engineering cost	3,500
Total cost per pit	38,600
Total cost 20 pits	$772,400

Turbojet Engines

20 turbojet engines (each rated about 10^4 lbs. thrust will be needed. It is recommended that used jet engines be purchased. The cost of a used jet engine depends on the number of hours that the engine has been used. A cost of 15% of the price of a new jet engine is assumed to be a fair estimate. Reasonable engine specification estimates are : length 12 ft., diameter 4 ft., and fuel consumption of 1000 gal. per hour at sea level. A used engine is estimated to cost $75,000. For 20 engines @ $75,000 per engine, the procurement cost is	$ 1,500,000
Installation cost	500,000
Total cost for 20 engines.............	$ 2,000,000

Blast Pads and Deflection Vanes

Each engine pit installation will require a semi-circular concrete blast pad, 60 ft. in diameter. Engineering cost of excavation, 523 cu. yds. at $7.00/cu. yd.	$ 3,660
Reinforced concrete at $70 per cu. yd.	36,600
Total cost of blast pads	$40,300
20 electrically-operated deflection vanes are needed to direct the jet exhaust plume onto the runway. The assumed procurement and installation cost for each vane is $3,000. Total cost is	$60,000
Total cost of blast pads and deflection vanes	$100,300

Fuel Tanks

Each engine uses 1000 gal. Jet-A fuel per hour. Therefore, 20 engines use 20,000 gal./hour. The maximum duration of fog (visibility less than 1/2 mile) at LAX is 20 hours (Ref. 8). For 20 hours continuous, 20 engines will need a minimum of 20 x 20,000 gal./hr. or 400,000 gal. of fuel. It is proposed to install 4 tanks (each tank supplying 5 engines) of 150,000 gal. capacity. The procurement cost for one fuel storage tank (150,000 gallons) is	$ 60,000
Engineering costs (excavation and foundation)	10,000
Fuel transfer system	30,000
Total	$100,000
Total procurement/installation (4 fuel tanks)	$400,000

Related Cost Assumptions

	CAT II Vol.
Control Panel and Telemetering	$ 400,000
Electric Power Supply	160,000
Assembly	133,000
2 Transmissometer systems to determine RVR in the cleared zone since present transmissometers at LAX are outside of the proposed fog-cleared zone.	100,000
Research and Planning	200,000
Control building engineering costs of excavation and construction. Building to be 30 ft. x 30 ft. x 10 ft. and located between runways 25L and 25R.	40,000
Service road to service the 20 jet engine pits and control building. Road length 7000 ft., width 12 ft. Road to be constructed of crushed stone. Excavation cost (sand soil) for 1555 cu. yds. at $ 7.00 per cu. yd. = $10,900; 1555 cu. yds. of crushed stone at $14 per ton = $43,500; Labor cost =$2,000.	
Total for Service Road	56,000
Contingency, 20% (a + b)	655,000
Total..	$1,744,000

Summary of Costs

Construction/Excavation (a)	$ 772,400
Turbojet Engines, blast pads, deflection vanes and fuel tanks (b)	2,500,000
Related Costs	1,744,000
Total (one time cost)	$5,016,000

Annual Operational Cost

Each jet engine burns 1000 gal. per hour jet fuel (JET-A). For 20 jet engines used in the thermokinetic fog dispersal system the fuel consumption is 20,000 gal. per hour. The thermokinetic system will raise CAT III conditions due to fog to CAT II minimums (or better). LAX has an annual average of 79.1 hours of CAT III A&B fog. For 90% CAT III fog dispersal (71.2 hrs.) to CAT II minimums, the total annual jet fuel consumption is 1,423,800 gal. The current price (1975) of JET-A fuel in the U.S. is 26.69¢/gal. Total annual average fuel cost is $1,423,800 x .2669 .... $380,000

A reduction in fuel cost can be obtained by using natural gas instead of JET-A fuel since the former is cheaper and available at LAX. Jet engines can be modified to burn natural gas at a conversion cost of $10,000 per engine. The total cost of conversion of 20 jet engines is $200,000

One gallon of jet fuel (JET-A) produces 1.2 therms (120,000 BTU's). The annual consumption of 1,423,800 gal. of jet fuel produces 1,708,560 therms. At LAX, the cost of natural gas is 7¢ per therm. Therefore, the total average annual natural gas cost is 1,708,560 x .07 .... $119,600

The following summarizes the annual operational cost of the thermokinetic fog dispersal system proposed for LAX:
Annual fuel cost for 90% CAT III

	CAT II Vol. (Using Jet Fuel)	CAT II Vol. (Using Natural Gas
Annual Operational Cost (Continued)		
fog dispersal to CAT II minimums.	$ 380,000	$ 119,600
Maintenance (1% of procurement/installation)	50,000	52,000
Personnel	60,000	60,000
Total (annual operational cost)	$ 490,000	$ 231,600

6.3 DERIVATION OF BENEFIT TO COST RATIOS

Conservative calculations of benefit to cost ratios are based on an installation period of approximately 2 years, expected fog dispersal system life of 10 years, and an annual interest rate of 10%. The installation and procurement cost is assumed to be equally divided during the 2 year installation period, one half the total cost for the first year, one half for the second year. System benefits are based on the projected 1981 level of traffic throughout the conservative 10 year life expectancy of the fog dispersal system (Tables 4.1 and 4.2). It should be noted that the benefit/cost figures become larger as the life of the system exceeds the 10 year figure.

The operating costs and benefits are for a system capable of effecting clearings in approximately 90% of all occurrences of fog. The format for these calculations is presented below and is done in accordance with the Office of Management and Budget Circular No. A-94.

THERMOKINETIC CAT II SYSTEM AT LAX USING JET FUEL
($1000)

Year Since Initiation	Expected Yearly Cost	Expected Yearly Benefit		Discount Factor for 10%	Present Value Cost	Present Value Benefit	
(1)	(2)	(3)		(4)	Col. (2)x(4)	Col. (3)x(4)	
		With Pass. Benefit	Without Pass. Benefit			With Pass. Benefit	Without Pass. Benefit
1	$2,508	0	0	.909	$2,280	0	0
2	2,508	0	0	.826	2,072	0	0
3	490	$9,734	$2,075	.751	368	$7,311	$1,559
4	490	9,734	2,075	.683	335	6,649	1,417
5	490	9,734	2,075	.621	304	6,045	1,289
6	490	9,734	2,075	.564	276	5,490	1,171
7	490	9,734	2,075	.513	251	4,993	1,065
8	490	9,734	2,075	.467	229	4,547	969
9	490	9,734	2,075	.424	208	4,127	880
10	490	9,734	2,075	.386	189	3,757	801
11	490	9,734	2,075	.350	172	3,407	726
12	490	9,734	2,075	.319	156	3,105	662
					$6,840	$49,431	$10,539

12 year expected value cost:	$6,840,000	
12 year expected value benefit:	$49,431,000	(including passenger benefit)
	$10,539,000	(without passenger benefit)

Benefit to cost ratios:

7.2 to 1 for airlines and passengers
1.5 to 1 for airlines

THERMOKINETIC CAT II SYSTEM AT LAX USING NATURAL GAS
($1000)

Year Since Initiation	Expected Yearly Cost	Expected Yearly Benefit		Discount Factor for 10%	Present Value Cost	Present Value Benefit	
		(3)				Col. (3)x(4)	
(1)	(2)	With Pass. Benefit	Without Pass. Benefit	(4)	Col. (2)x(4)	With Pass. Benefit	Without Pass. Benefit
1	$2,608	0	0	.909	$2,371	0	0
2	2,608	0	0	.826	2,154	0	0
3	232	$9,734	$2,075	.751	174	$7,311	$1,559
4	232	9,734	2,075	.683	158	6,649	1,417
5	232	9,734	2,075	.621	144	6,045	1,289
6	232	9,734	2,075	.564	131	5,490	1,171
7	232	9,734	2,075	.513	119	4,993	1,065
8	232	9,734	2,075	.467	108	4,547	969
9	232	9,734	2,075	.424	98	4,127	880
10	232	9,734	2,075	.386	90	3,757	801
11	232	9,734	2,075	.350	81	3,407	726
12	232	9,734	2,075	.319	74	3,105	662
					$5,702	$49,431	$10,539

12 year expected value cost: $5,702,000
12 year expected value benefit: $49,431,000 (including passenger benefit)
$10,539,000 (without passenger benefit)

Benefit to cost ratios:

8.7 to 1 for airlines and passengers
1.8 to 1 for airlines

CHAPTER 7

THERMAL FOG DISPERSAL SYSTEM COMPARISON FOR LAX

A comparison of the thermal fog dispersal systems (Table 7.1) shows that the modified passive systems which improve visibility to CAT II and CAT I minimums are cost beneficial to the airlines. Over a 12-year period, the benefits exceed the costs by 2% and 10% respectively. The benefit-to-cost ratio for passengers is 3.8 to 1 for the CAT I and CAT II systems so that the overall total 12-year benefit-to-cost ratios are 4.9 to 1 and 4.8 to 1 respectively. Thus, the passengers account for 79% of the total benefit and the airlines accrue the remaining 21%.

The modified passive thermal fog dispersal system which clears fog in the CAT I volume has been considered in this study for those situations which might require CAT I volume clearings. A corresponding thermokinetic fog dispersal system which clears fog in the CAT I volume has not been considered for comparison purposes because, with the data presently available and for the type of engines and system layout considered in this design, it cannot be shown that the thermokinetic system is consistently able to clear fog up to 325 feet in the approach zone as required for the CAT I volume. The turbulence generated by such a system might also be a problem.

The thermal fog dispersal system which clears fog in the CAT II volume is operated in conjunction with the CAT II instrument landing system for landing CAT II certificated aircraft and aircrews.

The thermokinetic fog dispersal system (using natural gas for fuel) which clears fog in the CAT II volume has a higher benefit-to-cost ratio than the corresponding modified passive system. It is cost-beneficial to both airlines (1.8 to 1) and passengers (6.9 to 1) with 79% of the total benefit accruing to the passengers and 21% to the airlines. Of the two fuels considered for use in the thermokinetic system, Jet-A and natural gas, the thermokinetic fog dispersal system using natural gas has the highest total benefit-to-cost ratio (8.7 to 1) when considering both airlines and passengers.

Compatability of either fog dispersal system with instrument landing systems at LAX can be insured by placing all metal components of the fog dispersal system underground or flush to the ground when these components must be located in the critical areas of the glide slope or localizer. Our conceptual designs have allowed for these accommodations; i.e., the possible use of non-metallic deflection vanes for the thermokinetic system and underground construction of the large majority of the modified passive burner line.

Table 7-1 Thermal Fog Dispersal System Cost Comparison for LAX - 1975 Dollars ($1000)

Fog Dispersal System	Modified Passive		Thermokinetic	
Fog Visibility Improved to These Minimums	CAT I	CAT II	CAT II	CAT II
Fuel Used	Natural Gas	Natural Gas	JET-A	Natural Gas
Fog Volume to be Cleared (cu.ft.)	6.3×10^8	2.7×10^8	2.7×10^8	2.7×10^8
Procurement and Installation Cost	11,020	8,743	5,016	5,216
Annual Operational Cost	1,151	537	490	232
Annual Passenger Benefit*	11,800	7,660	7,660	7,660
12-yr. Benefit-to-Cost Ratio (passenger)	3.8	3.8	5.7	6.9
Annual Airline Benefit*	3,193	2,075	2,075	2,075
12-yr. Benefit-to-Cost Ratio (Airlines)	1.1	1.02	1.5	1.8
Annual Benefit* (Passengers and Airlines)	15,000	9,700	9,700	9,700
12-yr. Benefit-to-Cost Ratio (Passengers and Airlines)	4.9	4.8	7.2	8.7

*For 90% fog dispersal system design capability and excluding CAT III C.

CHAPTER 8

PROPOSED FOG DISPERSAL SYSTEM OPERATIONS AND AIR TRAFFIC CONTROL

The decision to operate the Fog Dispersal System should be made by the airport manager, based on current and forecast meteorological conditions received from the National Weather Service.

The operation of the Fog Dispersal System should not affect or be cause for change to the procedures for the control of traffic on and about the airport. Operation of the system should be a direct responsibility of the airport operator or his designated representative. It should be his responsibility to provide appropriate notification of the system characteristics and the periods of time and conditions of expected operation to airport users. He should keep the Air Traffic Control Tower advised of the operational status of the system at all times.

Experience gained under actual operation of the Fog Dispersal System may result in minor modification to these procedures.

CHAPTER 9

MANAGEMENT OF FOG DISPERSAL SYSTEMS

Today, there are no operational ground-based warm fog dispersal systems in the United States. There has been no decision as to the responsibility for, operation of, or funding for fog dispersal systems. These matters are under discussion within the FAA in an effort to reach a resolution.

For the Los Angeles International Airport it is proposed that the airport manager be responsible for the operation and maintenance of the ground-based fog dispersal system. He must, however, coordinate his actions with the FAA. Currently (1975) there is no published procedure for certification of air crews or aircraft to land in zones cleared by fog dispersal systems.

CHAPTER 10

CONCLUSIONS

This study has considered various techniques for warm fog dispersal and developed cost estimates for the installation and operation of thermal fog dispersal systems at a selected airport. It is concluded that:

(1) The application of heat to evaporate fog is presently the only mechanism demonstrated effective for warm fog dispersal.

(2) It is feasible to install and operate a thermal fog dispersal system at Los Angeles International Airport. Potential benefits from fog dispersal at LAX are the highest when compared to other U.S. Airports.

(3) The thermokinetic and the modified passive thermal fog dispersal systems, both of which can use natural gas for fuel, are cost-effective for Los Angeles International Airport. For the thermokinetic, the benefit-to-cost ratio is 8.7 to 1 while for the modified passive the ratio is 4.8 to 1 based on a ten year system life and two year installation period. These potential benefits include benefits to passengers and airlines.

(4) Both fog dispersal systems can improve visibility from CAT III minimums to CAT II minimums so that CAT II certificated aircraft and aircrews can land on a CAT II ILS runway when otherwise they would be precluded from doing so because of fog. If it is desired to clear to the CAT II minimums, the thermokinetic system would be preferred over the modified passive system by virtue of its higher benefit to cost ratio. However, if it is desired that the system clear to CAT I minimums, the modified passive system would be the preferred technique, since data are not available to conclude that a thermokinetic system could clear to such minimums nor to determine installation configuration and associated costs that would be necessary for it to clear to CAT I minimums.

(5) Integration and coordination of fog dispersal operations with existing procedures is feasible.

(6) Compatability with ILS glide slope and localizer can be accomplished in the detailed design of the systems.

(7) Similar analyses at 38 airports in the United States reveal that a thermokinetic fog dispersal system should produce benefit to cost ratios greater than one at 15 airports (see Appendix C).

APPENDIX A

METEOROLOGICAL DATA FOR LOS ANGELES INTERNATIONAL AIRPORT (Reference 4)

LAX

WIND SPEED VS. FREQUENCY

	CALM	1	2	3	4	5	6	7	8	9	10	11	12	13	>13
FREQUENCY	760	4	230	534	762	575	370	174	107	33	23	4	6	0	5

STATISTICAL RESULTS

MEAN	3.62 KNOTS
MODE	4.00 KNOTS
MEDIAN	4.00 KNOTS
STD. DEV.	2.43 KNOTS
SKEW	-0.16

WIND SPEED VS. CUMULATIVE WIND FREQUENCY

CUMULATIVE FREQUENCY	CALM	<2	<4	<6	<8	<10	<12	<14	TOTAL
	760	764	1528	2865	3409	3549	3576	3582	3587

WIND DIRECTION VS. FREQUENCY

	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
FREQUENCY	760	55	50	109	275	485	395	235	112	99	33	67	191	402	160	96	57

TRUE WIND DIRECTION

WIND DIRECTION VS. WIND SPEED

	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
>12	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0
10-12	0	0	0	0	0	5	1	2	0	0	0	2	6	15	2	0	0
WIND 7-9	0	0	2	6	15	57	49	19	7	4	0	5	37	93	18	1	1
SPEED 4-6	0	26	27	66	188	408	257	153	61	54	25	34	106	226	96	50	30
KNOTS 1-3	0	29	21	37	72	16	88	61	44	41	13	26	40	65	44	45	26
CALM	760	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TRUE WIND DIRECTION

LAX

LAX

VISIBILITY VS. FREQUENCY
NOTE: 7/16 MILE IS NOT A REPORTABLE VALUE

FREQUENCY	440	576	600	348	599	118	387	0	419
POSITION	0	1	2	3	4	5	6	7	8
	0	1 - 16	1 - 8	3 - 16	1 - 4	5 - 16	3 - 8	7 - 16	1 - 2

VISIBILITY (MILES)

STATISTICAL RESULTS

MEAN	3.31/16
MODE	4.00/16
MEDIAN	3.00/16
STD. DEV.	2.46/16
SKEW	-0.23

TEMPERATURE VS. FREQUENCY

TEMPERATURE (F)	FREQ.
15	0
15 TO 16	0
17 TO 18	0
19 TO 20	0
21 TO 22	0
23 TO 24	0
25 TO 26	0
27 TO 28	0
29 TO 30	0
31 TO 32	0
33 TO 34	0
35 TO 36	0
37 TO 38	0
39 TO 40	0
41 TO 42	11
43 TO 44	62
45 TO 46	100
47 TO 48	188
49 TO 50	337
51 TO 52	508
53 TO 54	643
55 TO 56	515
57 TO 58	319
59 TO 60	406
61 TO 62	269
63 TO 64	154
65 TO 66	72
67 TO 68	3
69 TO 70	0
71 TO 72	0
>72	0

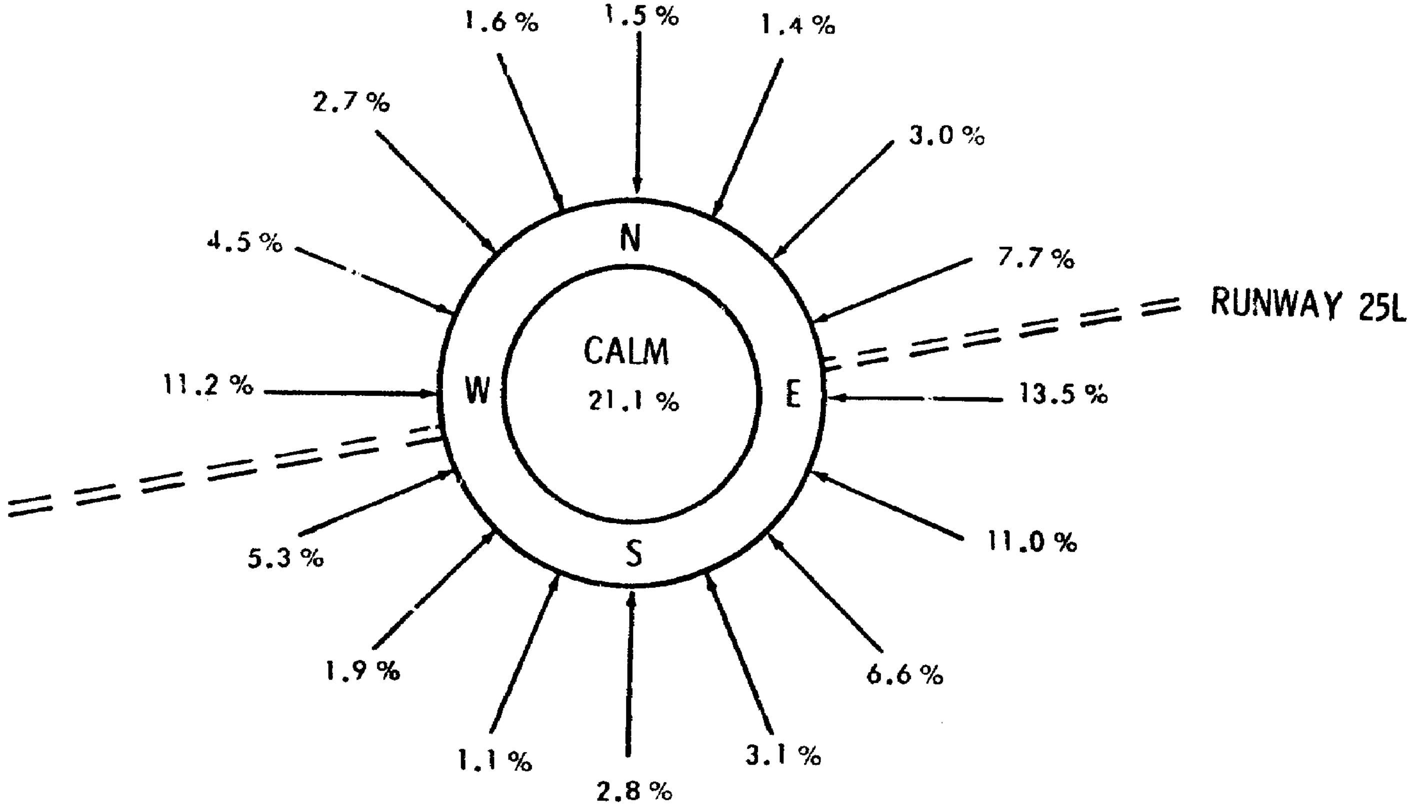
STATISTICAL RESULTS

MEAN	54.70 °F.
MODE	53.30 °F.
MEDIAN	53.50 °F.
STD. DEV.	4.97 °F.
SKEW	0.24

HOURLY OBSERVATIONS 1477 SPECIAL OBS. 2110 TOTAL OBSERVATIONS 7293 FOG WITH SMOKE AND/OR HAZE 1479

WIND DIRECTION AT LAX

DURING FOG

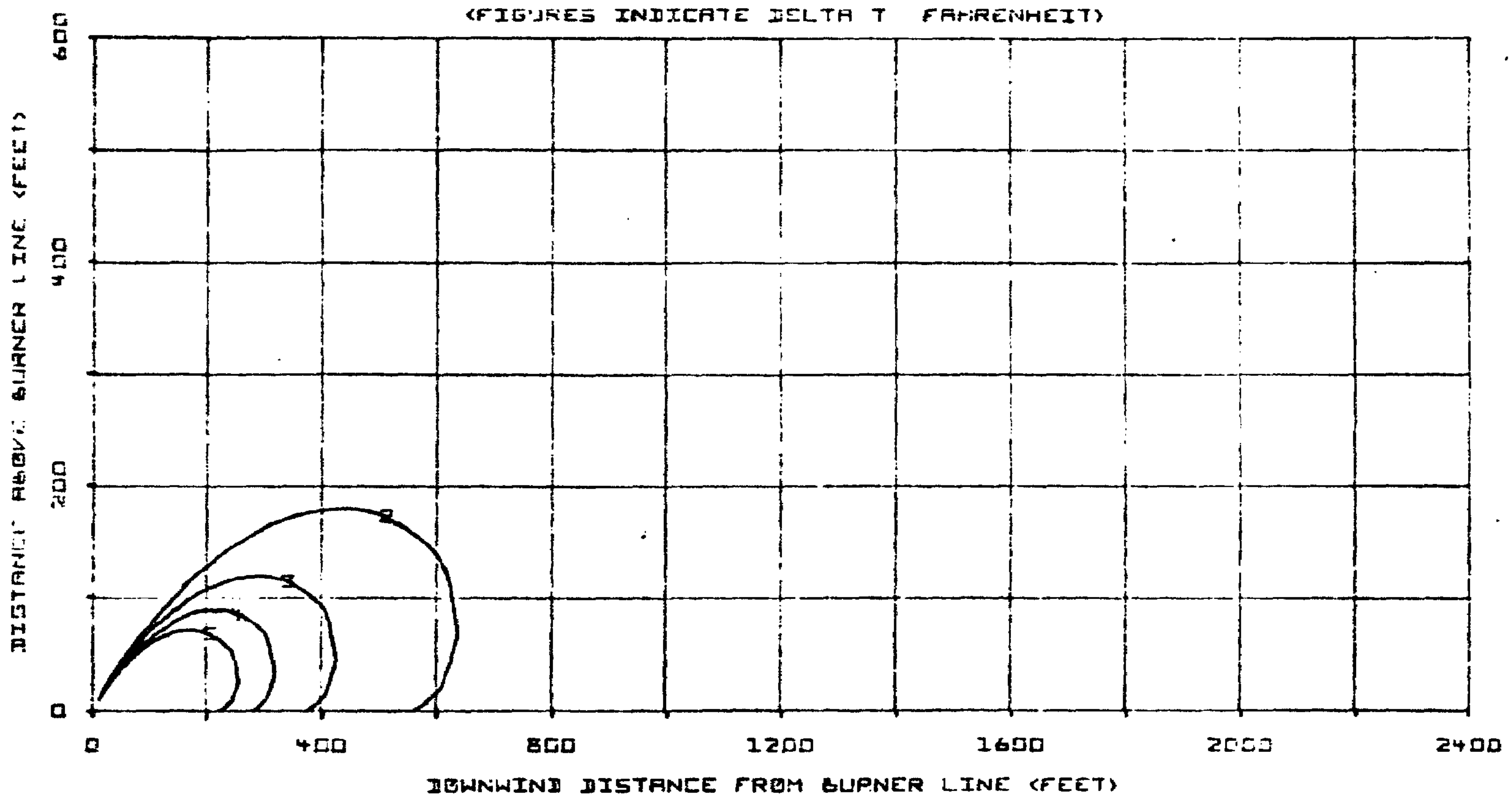


APPENDIX B

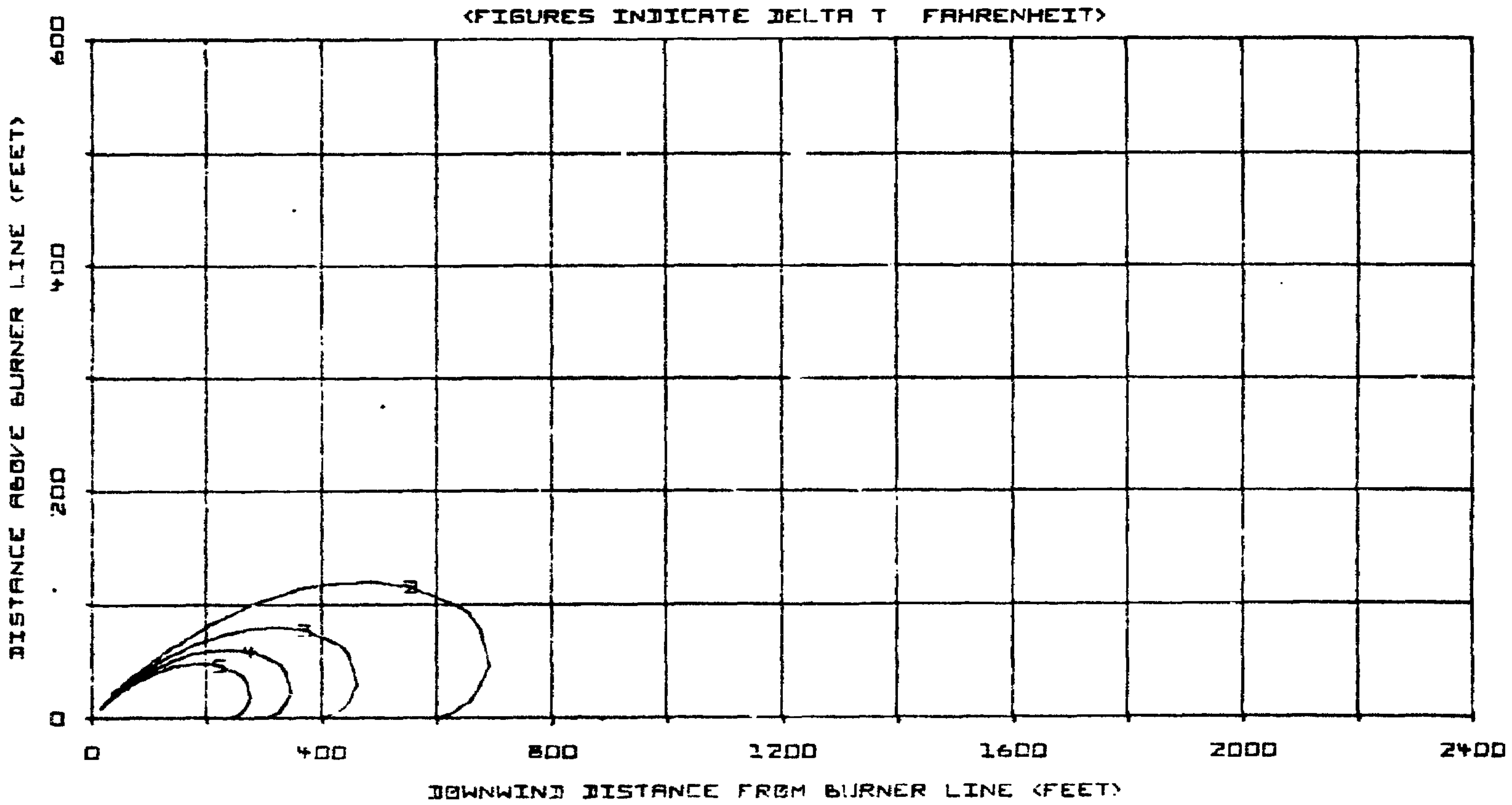
CROSSWIND THERMAL PATTERNS AND CALCULATIONS

Computer algorithms were developed to calculate various heat outputs of a modified passive thermal system under various crosswind speeds in order to determine the horizontal and vertical extent of the heat plumes under these conditions (Reference 3). The following graphs were used to position the burner lines and to calculate the amount of heat energy (in therms per linear yard hour) needed in various segments of the burner lines to bring about clearing of the fog as related to ambient wind conditions. Additionally, the width of the clearance zone over the approach and runway specified volume was calculated. Although only a 2° F. temperature increase is needed over the ambient temperature to dissipate fog (Reference 3), a 3° F. temperature increase has been used as a standard in this study.

WIND SPEED 2.0 KNOTS
5 THERMS/YD-HR

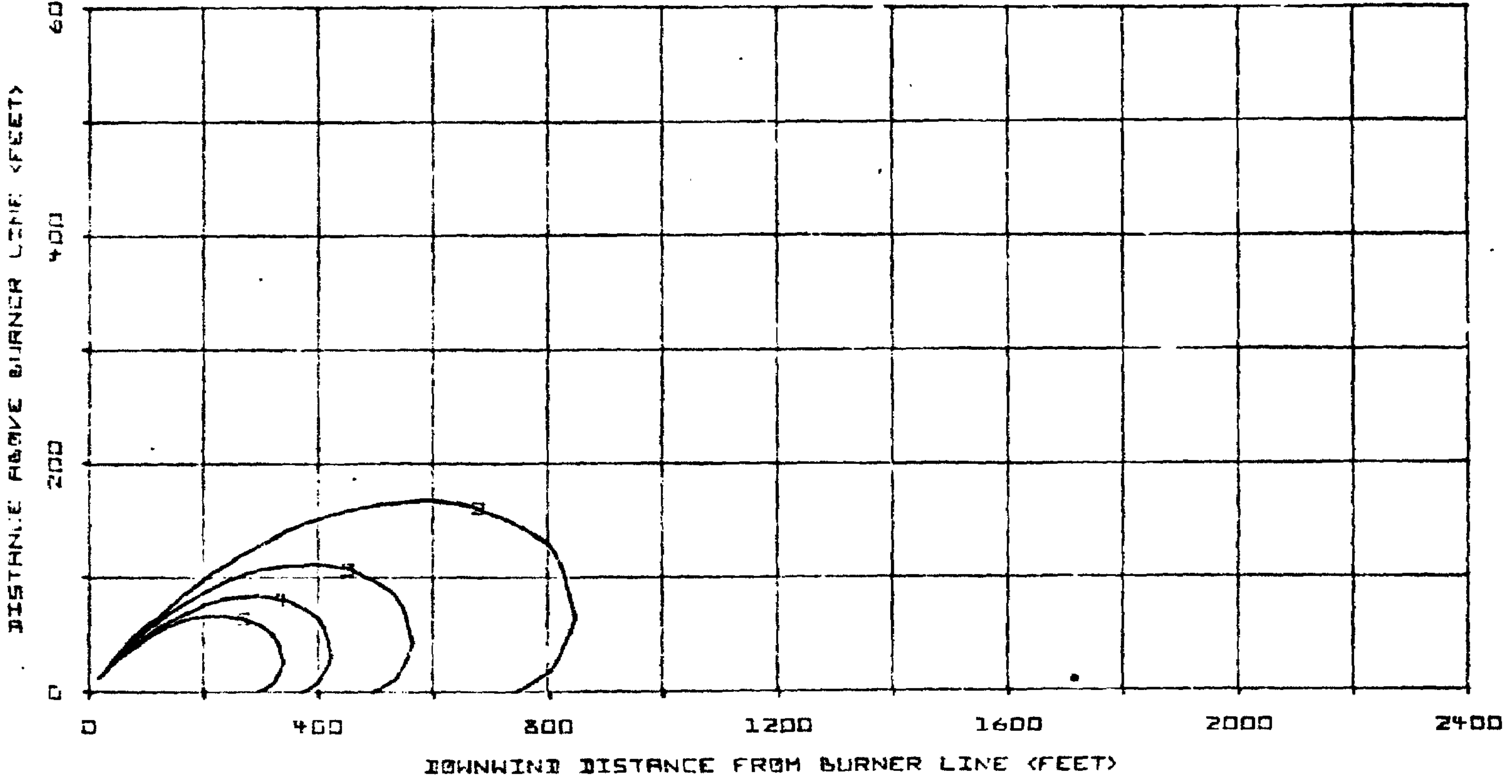


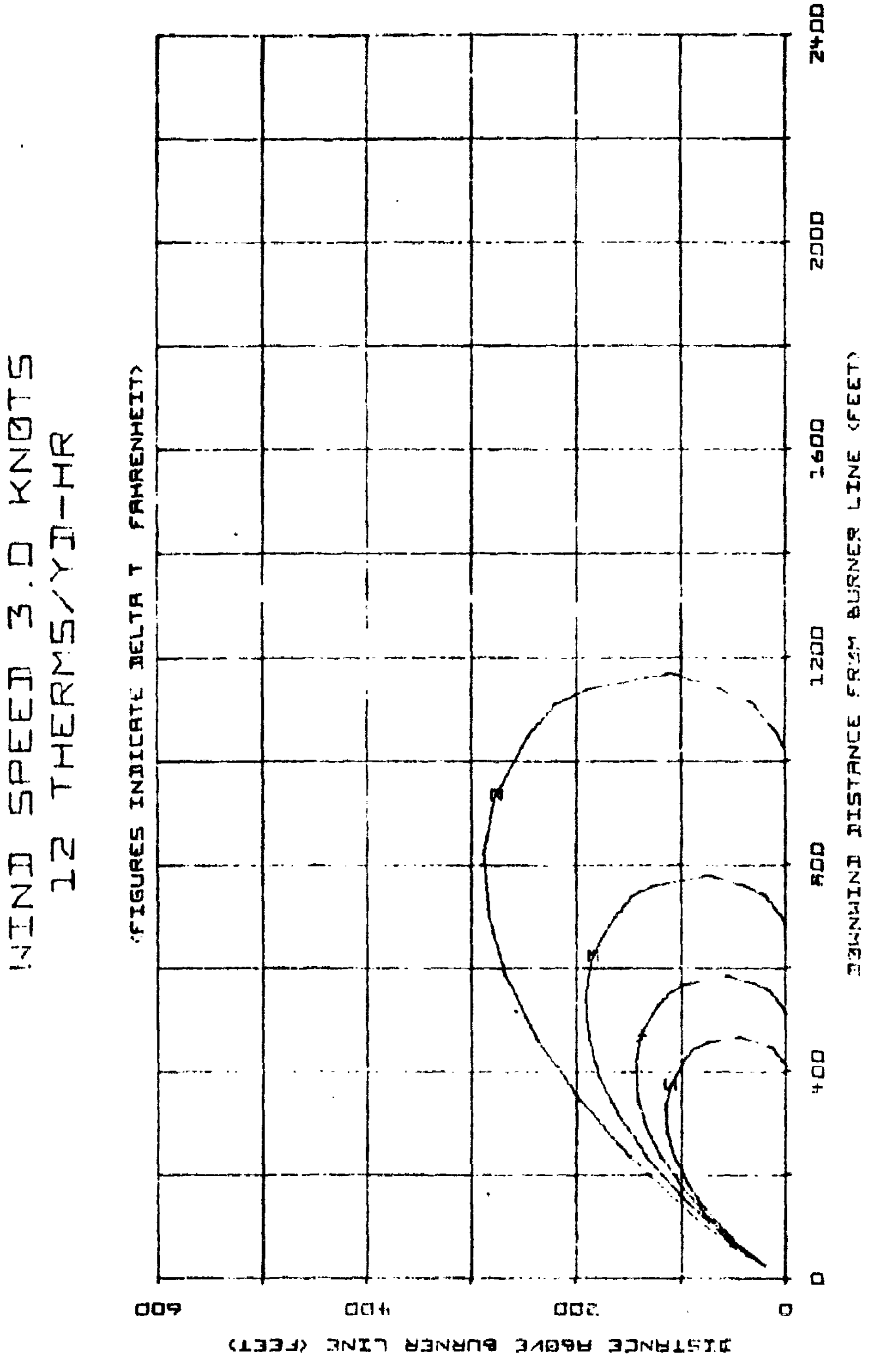
WIND SPEED 3.0 KNOTS
5 THERMS/YD-HR

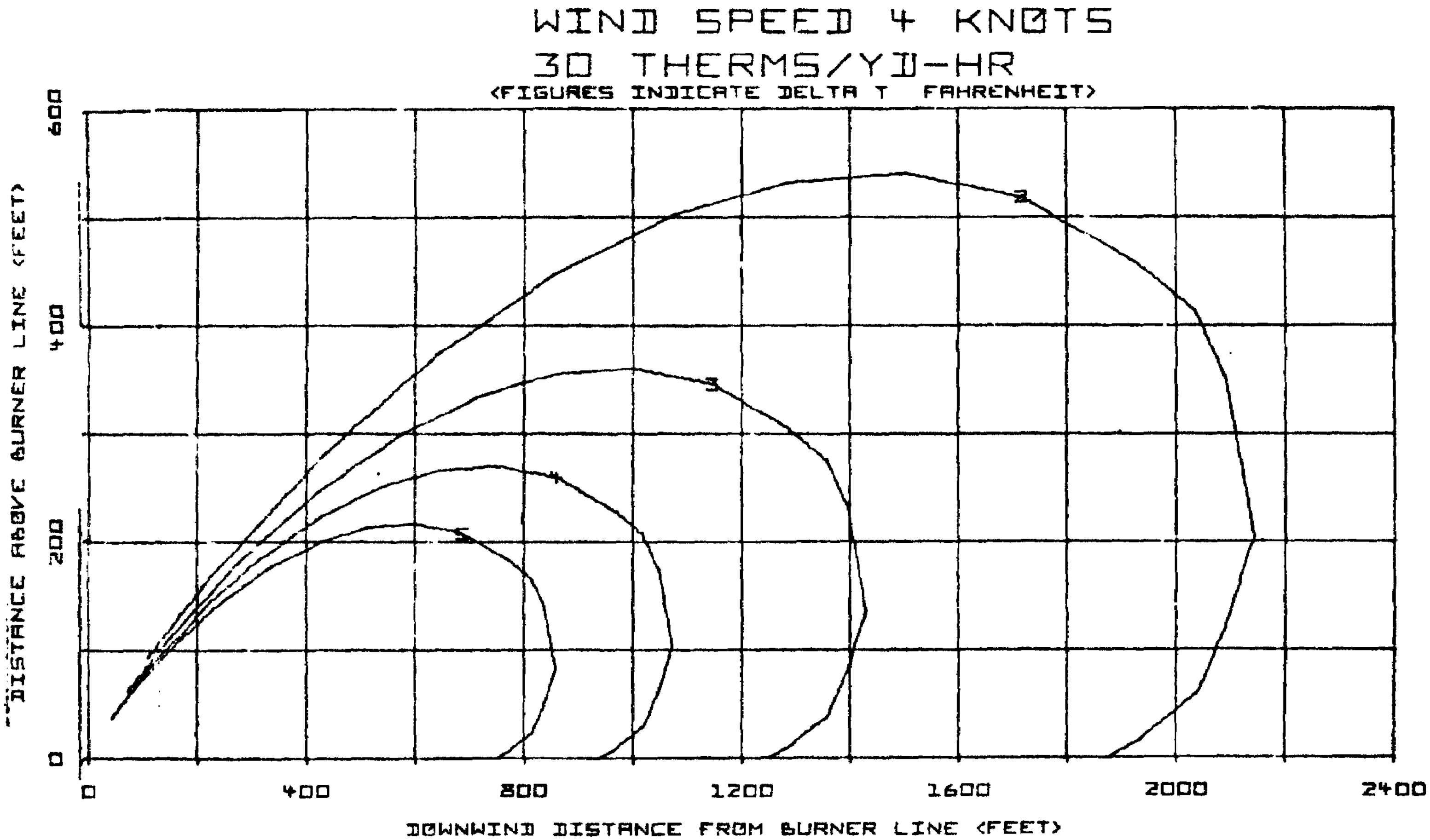


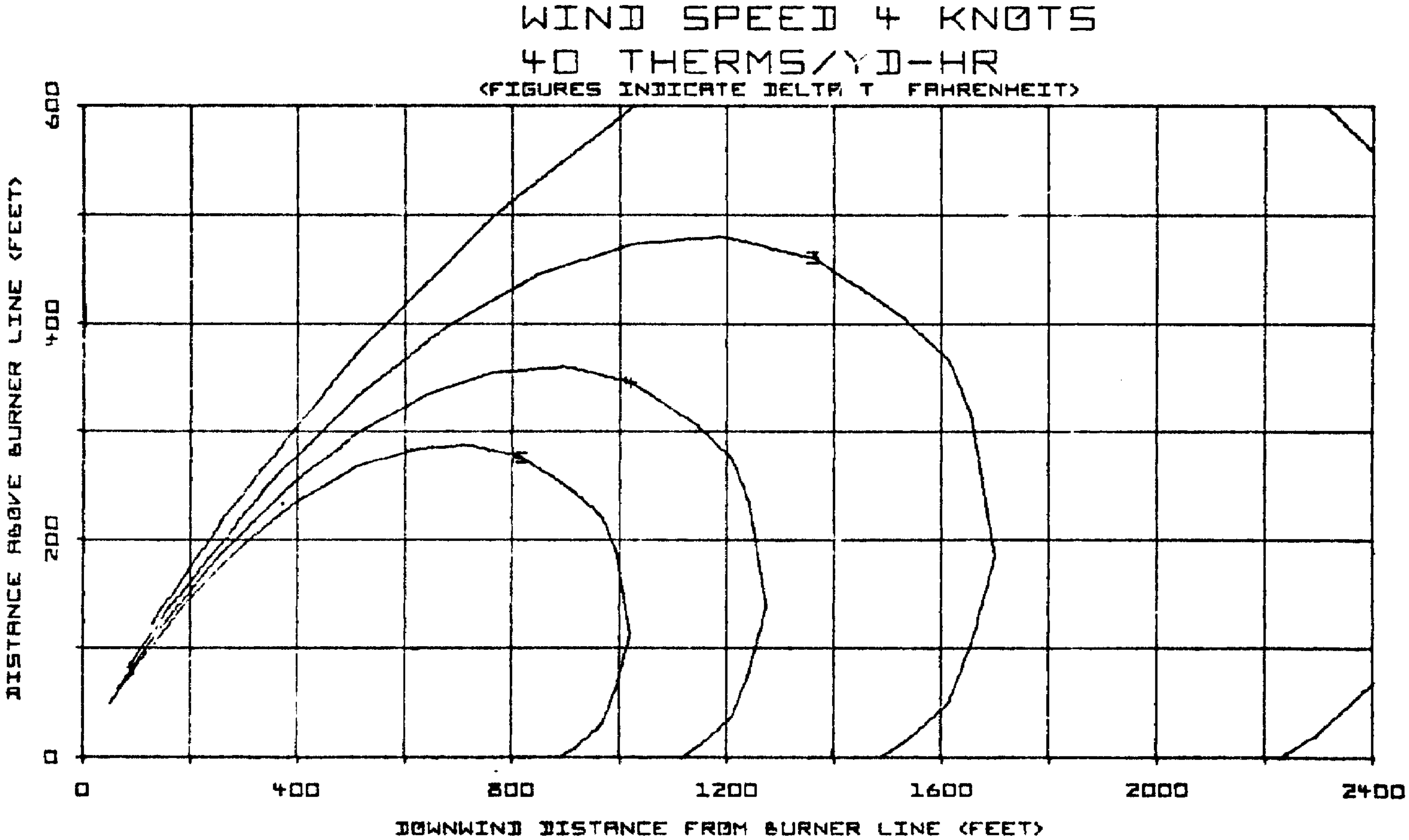
WIND SPEED 3.0 KNOTS
7 THERMS/YD-HR

(FIGURES INDICATE DELTA T FAHRENHEIT)

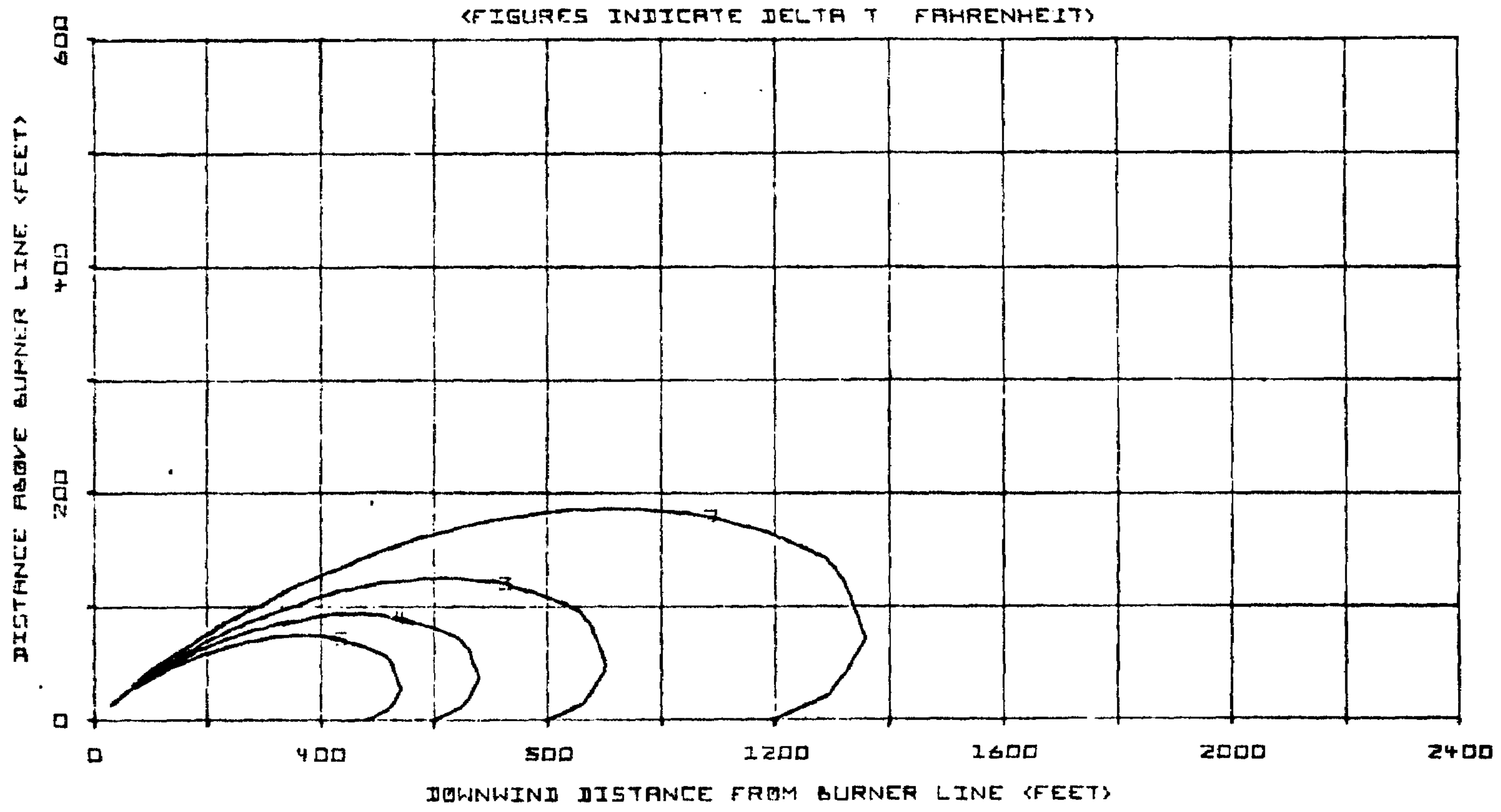



WIND SPEED 3.0 KNOTS
12 THERMS/YD-HR
(FIGURES INDICATE DELTA T FAHRENHEIT)
DOWNWIND DISTANCE FROM BURNER LINE (FEET)
DISTANCE ABOVE BURNER LINE (FEET)
0
400
800
1200
1600
2000
2400
0
200
400
600
2
3
4
5

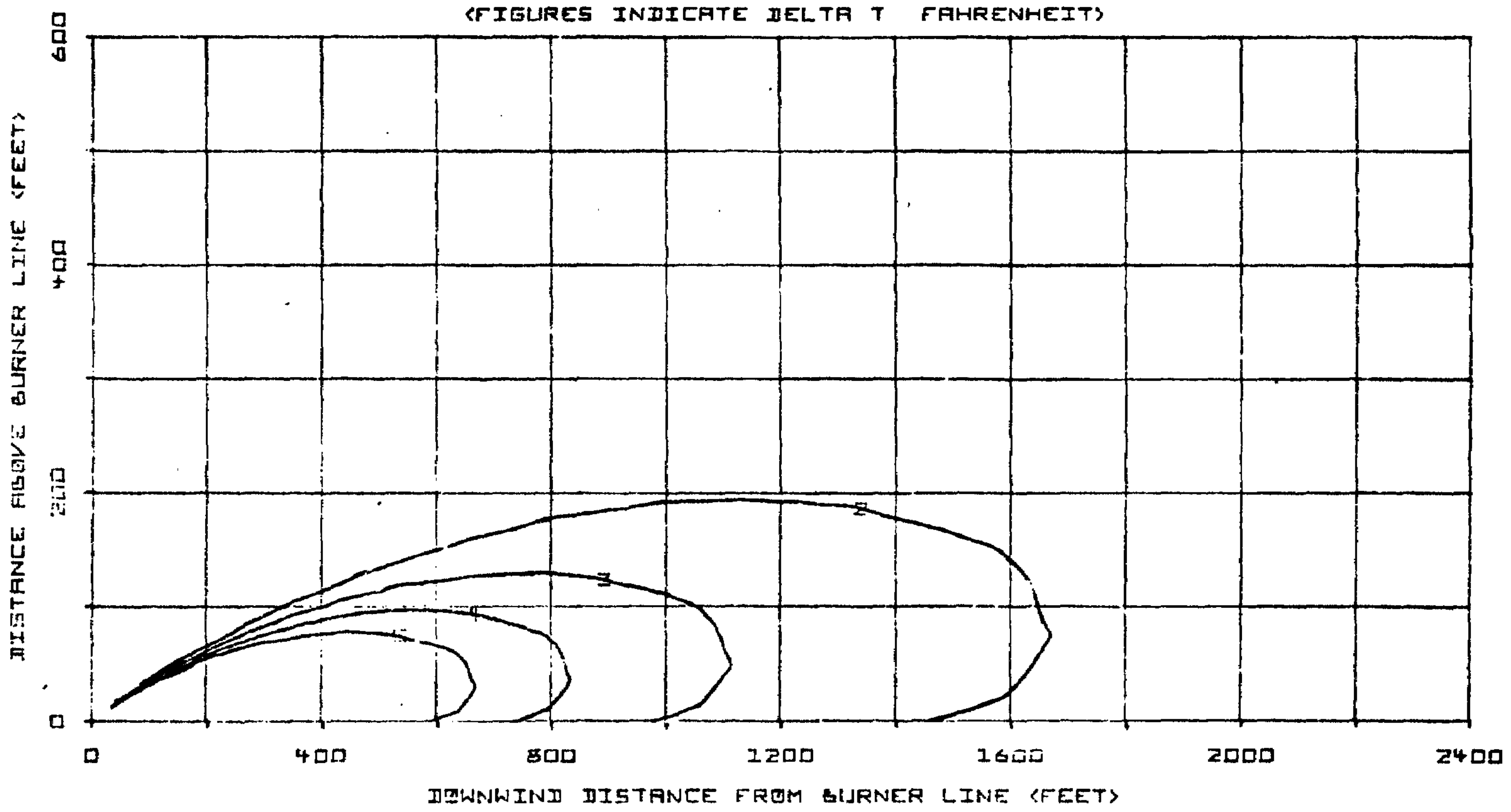

WIND SPEED 4 KNOTS
30 THERMS/YD-HR
(FIGURES INDICATE DELTA T FAHRENHEIT)
2
3
4
5
0
200
400
600
DISTANCE ABOVE BURNER LINE (FEET)
0
400
800
1200
1600
2000
2400
DOWNWIND DISTANCE FROM BURNER LINE (FEET)


WIND SPEED 4 KNOTS
40 THERMS/YD-HR
(FIGURES INDICATE DELTA T FAHRENHEIT)
DISTANCE ABOVE BURNER LINE (FEET)
0
200
400
600
DOWNWIND DISTANCE FROM BURNER LINE (FEET)
0
400
800
1200
1600
2000
2400
3
4
5

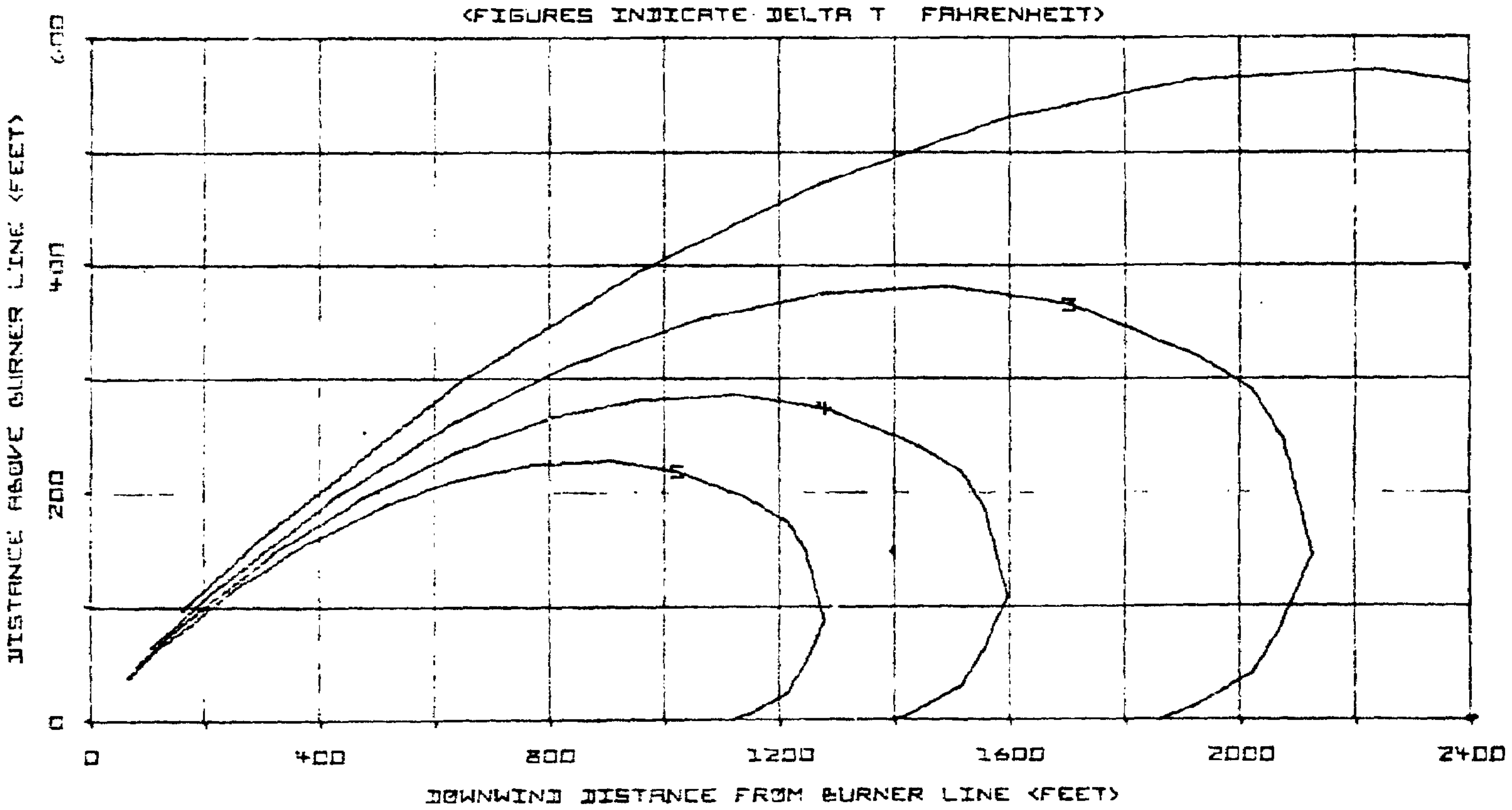
WIND SPEED 5.0 KNOTS
13 THERMS/YD-HR



WIND SPEED 6.3 KNOTS
17 THERMS/YD-HR



WIND SPEED 6.3 KNOTS
50 THERMS/YD-HR



APPENDIX C

BENEFIT/COST CALCULATIONS FOR 38 SELECTED AIRPORTS

Derivation of Benefit to Cost Ratios

Conservative calculations of benefit to cost ratios are based on an installation period of approximately 2 years, expected fog dispersal system life of 10 years, and an annual interest rate of 10%. The installation and procurement cost is assumed to be equally divided during the 2 year installation period, one half the total cost for the first year, one half for the second year. System benefits are based on the projected 1981 level of traffic throughout the conservative 10 year life expectancy of the fog dispersal system (Tables 4.1 and 4.2). It should be noted that the benefit/cost figures become larger as the life of the system exceeds the 10 year figure.

The installation and procurement costs used for all airports are the same as those quoted for LAX. Additionally, the operating costs and benefits are for a system capable of effecting clearings in approximately 90% of all occurrences of fog. Because of the possible differences in procurement and installation costs arising from diversity in runway configurations at different airports and the possible changes in operational costs and benefits due to variations in percentage of winds less than eight knots at different airports, the actual B/C ratios may reflect slightly different benefits and costs than the conservative figures indicated here. These variations are estimated in most cases to cause an increase in benefits over costs.

The format for these calculations is presented in Chapters 5 and 6 and is done in accordance with the Office of Management and Budget Circular No. A-94. All calculations are based on 1975 dollars.

Note: Both Dallas and Houston have had recent changes in airport location. Consequently, there is no long term climatology of the type used for the other airports to determine the occurrence of fog at these locations. Therefore, Dallas and Houston have not been included in the analyses.

DISCUSSION AND FINDINGS

1. If the imputed value of passenger delay is excluded, the following airports show a favorable benefit-to-cost ratio for 1981 with respect to a thermokinetic fog dispersal system as stipulated in the assumptions:

AIRPORT	B/C JET-A	 NAT. GAS
(1) Los Angeles International	1.5	1.8
(2) Seattle-Tacoma International	1.1	1.5
(3) O'Hare International, Chicago	1.0	1.0
(4) JFK, New York	1.0	1.0

BENEFIT-TO-COST RATIO ASSOCIATED WITH DISRUPTIONS OF SCHEDULED ARRIVALS OF AIRCRAFT OF FIRST AND SECOND LEVEL U.S. CERTIFICATED ROUTE AIR CARRIERS IN DOMESTIC AND INTERNATIONAL PASSENGER SERVICE DUE TO CAT III A&B WEATHER (FOG)

AIRPORT	A. EXCLUDING VALUE OF PASSENGER DELAY		B. INCLUDING VALUE OF PASSENGER DELAY	
	JET-A	NAT. GAS	JET-A	NAT. GAS
1. Anchorage	.07	.07	.2	.2
2. Atlanta	.7	.8	3.0	3.1
3. Baltimore-Washington	.5	.6	2.2	2.4
4. Birmingham	.03	.03	.1	.1
5. Boston (Logan)	.4	.4	1.5	1.6
6. Buffalo	.1	.1	.5	.5
7. Chicago (O'Hare)	1.0	1.0	4.3	4.5
8. Covington, KY (Grtr. Cinn.)	.2	.2	.7	.7
9. Cleveland	.2	.2	.6	.6
10. Columbus, OH	.1	.1	.4	.4
11. Dayton, OH	.1	.1	.3	.3
12. Denver (Stapleton)	.1	.1	.2	.2
13. Detroit	.5	.5	2.1	2.3
14. Windsor Locks, CT	.1	.1	.4	.5
15. Indianapolis	.1	.1	.5	.6
16. Kansas City (Int'l) MO	.2	.2	.9	1.0
17. Los Angeles	1.5	1.8	7.2	8.7
18. Louisville, KY	.1	.1	.2	.2
19. Miami	.2	.2	.7	.7
20. Milwaukee	.2	.2	.9	1.0
21. Minneapolis	.1	.1	.5	.5
22. Nashville	.1	.1	.2	.2
23. Newark	.3	.3	1.0	1.0
24. New Orleans	.4	.4	1.4	1.6
25. New York (JFK)	1.0	1.0	4.1	4.4
26. New York (LGA)	.2	.3	1.0	1.0
27. Oakland	.1	.1	.3	.3
28. Philadelphia	.4	.4	1.6	1.8
29. Pittsburgh	.2	.2	.6	.6
30. Portland, OR	.5	.6	2.0	2.5
31. Rochester	.1	.1	.2	.2
32. St. Louis, MO	.1	.1	.5	.5
33. Salt Lake City	.2	.2	8	.9
34. San Francisco	.6	.6	2.3	2.5
35. Seattle-Tacoma	1.1	1.5	5.2	7.1
36. Syracuse	.02	.02	.1	.1
37. Dulles	.6	.7	2.4	2.7
38. Washington-National	.1	.1	.5	.5

2. If the imputed value of passenger delay is included, the following airports show a favorable benefit-to-cost ratio for 1981 with respect to a thermokinetic fog dispersal system as stipulated in the assumptions:

	AIRPORT	B/C JET-A	NAT. GAS
(1)	Los Angeles	7.2	8.7
(2)	Seattle-Tacoma	5.2	7.1
(3)	Chicago (O'Hare)	4.3	4.5
(4)	New York (JFK)	4.1	4.4
(5)	Atlanta	3.0	3.1
(6)	Dulles	2.4	2.7
(7)	San Francisco	2.3	2.5
(8)	Baltimore	2.2	2.4
(9)	Detroit	2.1	2.3
(10)	Portland	2.0	2.5
(11)	Philadelphia	1.6	1.8
(12)	Boston	1.5	1.6
(13)	New Orleans	1.4	1.6
(14)	Newark	1.0	1.0
(15)	New York (LGA)	1.0	1.0

Los Angeles appears to be the airport which will derive the highest benefit from the installation and operation of a thermokinetic fog dispersal system as stipulated.

3. Not considered are potential benefits accruing to:
   - foreign flag carriers
   - general aviation aircraft
   - military aircraft
   - cargo service aircraft
   - aircraft departures

These benefits are estimated to range from 15% for the airports considered and would have the net effect of increasing the benefit-to-cost ratios.

The most reliable costs developed in reference (2) are the airline costs which are composed of the following elements:

(1) Flight Delays
    a. Interrupted Trip Expense
    b. In-Flight Aircraft Delay

(2) Flight Diversions (including overflights)
    a. Interrupted Trip Expense
    b. In-Flight Aircraft Delay
    c. Ferrying Expense to Reposition Aircraft
    d. Cost of Subsequent Cancellation

(3) Flight Cancellations
    a. Interrupted Trip Expense
    b. Ferrying Expense to Reposition Aircraft
    c. Passenger Revenue Loss
    d. Duplicate Handling of Passengers
    e. Savings in Aircraft Operating Cost

The values assigned to passenger delay in the above three categories of flight delays, diversions and cancellations depend primarily on family income of commercial air travelers.

APPENDIX D

AIRCRAFT OPERATIONS WITH TURBOCLAIR SYSTEM DURING FOG FROM SEPTEMBER 23 TO DECEMBER 6, 1975 AT ORLY AND ROISSY-CHARLES DE GAULLE AIRPORTS

Date of Flight	Aircraft Type	Flight No.	Company	Meteorological Data					Appendix D	
				Temp. (in °F)	RVR on Runway (Feet)	Surface Wind		Visibility Outside Turboclair Area (Feet)		
						Direction (Degrees)	Speed (Kts.)		Aircraft Operation	Airport
1975										
Sept. 23	B-727	4200	Lufthansa	50	650	300-340	1-4	<100	Landing	Orly
"	B-727	126	"	52	1300	180	5	"	"	"
"	Airbus		Air France	50	650	300-310	2-3	"	Take-Off	"
Oct. 22	DC-9	720	Swiss Air	39	650	100	6-9	"	Landing	"
"	DC-9	740	"	39	800	90-100	4-7	"	"	"
"	DC-9	700	"	39	1000	80-110	4-9	"	"	"
"	B-737	126	Lufthansa	41	800	90-110	7-9	"	"	"
"	B-737	130	"	41	1150	80	4	"	"	"
"	Mercure	7420	Air Inter	39	1150	90-110	8-10	"	"	"
"	Fokker F-27	654	"	39	1150	90-100	6-7	"	"	"
"	SE-210	771	Air France	37	800	90-100	8-10	"	"	C.D.G
"	SE-210	661	"	37	800	90-100	8-10	"	"	"
"	B-727	911	"	37	800	90-100	8-10	"	"	"
"	B-707	890	TWA	39	800	90-100	8-10	"	"	"
"	B-747	760	"	39	800	90-100	8-10	"	"	"
Oct. 24	DC-9	700	Swiss Air	43	650	160-180	2-4	"	"	Orly
"	DC-9	728	"	50	1000	90-100	0-2	"	"	"
"	DC-9	708	"	50	650		Calm	"	"	"
"	DC-9	747	"	48	650	80	1	"	"	"
"	DC-9	748	"	50	650	60-80	1-3	"	"	"
"	DC-9	730	"	50	650	60	3	"	"	"
"	B-737	126	Lufthansa	46	1300	260-280	0-2	"	"	"
"	B-727	138	"	50	1000		Calm	"	"	"
"	B-727	122	"	48	650	80	0-1	"	"	"

AIRCRAFT OPERATIONS WITH TURBOCLAIR SYSTEM (CONTINUED)

Date	Aircraft	Flt. No.	Company	Temp.	RVR	Wind		Visibility	Operation	Airport
Oct. 24	B-737	116	Lufthansa	50	650	60	3	<100	Landing	Orly
"	B-727	725	Air France	50	1000		Calm	"	"	"
"	Air Bus	847	"	50	650		Calm	"	"	"
"	SE-210	687	"	50	650		Calm	"	"	C.D.G
"	B-727	514	"	50	650		Calm	"	"	"
Oct. 28	DC-9	709	Swiss Air	41	1150	180-190	5-6	"	"	Orly
"	DC-9	819	"	39	1300	170	1-3	"	"	"
"	DC-9	807	"	39	1150	160-200	2-4	"	"	"
"	DC-9	729	"	39	1000	200	3-4	"	"	"
"	B-727	116	Lufthansa	39	1000	210	1-2	"	"	"
"	B-727	657	Air France	39	1150	180-190	5	"	"	"
"	B-727	747	"	41	1300	150-170	3-4	"	"	"
Oct. 29	DC-10		Air Zaire	37	800	140-160	2-5	"	"	"
"	DC-10		"	37	1000	140-160	2-5	"	"	"
"	B-707	1332	Air France	36	650	140	3-5	"	"	"
"	B-707	181	"	36	650	160	2	"	"	"
"	SE-210	771	"	37	800	140-160	2-5	"	"	"
"	Air Bus	5317	"	37	1000	160	5	"	"	"
"	Air Bus	402	"	37	1500	200-210	2-6	"	"	"
Nov. 3	DC-9	720	Swiss Air	36	800	180	4-5	"	"	"
"	DC-9	740	"	36	650	180-200	2-3	"	"	"
"	DC-9	700	"	36	650	200	3	"	"	"
"	B-727	130	Lufthansa	39	1500	190	7-8	100	"	"
"	B-707	3384	Air France	36	1150	220	1	<100	"	"
Nov.4	B-747	460	"	48	1800		Calm	100	"	"
"	B-707	179	"	48	1650	350-10	1-3	200	"	C.D.G
Nov. 12	DC-9	700	Swiss Air	34	650	80-90	7-9	<100	"	Orly
"	B-737	126	Lufthansa	34	650	100-110	6-7	"	"	"
"	B-707	1291	Air France	32	1300	80	6-7	100	"	C.D.G
"	B-727	663	"	32	1300	60-80	5-7	"	"	"
"	B-727	911	"	32	1300	60-80	5-7	"	"	"
"	B-707	810	TWA	32	1300	80	6-7	"	"	"

AIRCRAFT OPERATIONS WITH TURBOCLAIR SYSTEM (CONTINUED)

Date	Aircraft	Flt. No.	Company	Temp.	RVR	Wind		Visibility	Operation	Airport
Nov. 14	DC-9	700	Swiss Air	45	800	200	2-3	<100	Landing	Orly
"	DC-9	708	"	48	1650		Calm	"	"	"
"	DC-9	730	"	48	1300		Calm	"	"	"
"	DC-9	748	"	48	1150	100	3	"	"	"
"	B-737	122	Lufthansa	48	1150		Calm	"	"	"
"	B-727	116	"	48	1150	90	5-6	"	"	"
"	B-727	725	Air France	48	1150		Calm	"	"	"
"	B-727	2512	"	48	1150		Calm	"	"	"
"	B-727	2044	"	48	1000		Calm	"	"	"
"	Air Bus	2322	"	48	1000		Calm	"	"	"
"	B-727	2702	"	48	1000		Calm	"	"	"
Dec. 1	DC-9	720	Swiss Air	32	650	190-200	7-8	"	"	"
"	DC-9	222	"	32	650	180-190	8-9	"	"	"
"	B-727	126	Lufthansa	32	800	200-210	7-8	"	"	"
"	B-727	233	Air France	32	800	190	5-6	"	Take-Off	"
"	B-707		TWA	34	800	210-220	7-8	"	Landing	"
Dec. 4	B-727		Air France	34	800	170	4	"	"	C.D.G
"	B-727		"	34	1500	140-240	2-4	"	"	"
"	B-747		"	36	800	210	5-6	"	"	"
"	B-707		"	36	1650	200-210	5-7	100	"	"
"	B-707		TWA	34	1000	100-140	3-5	"	"	"
"	B-707		"	34	800	140-170	4-5	<100	"	"
"	B-707		"	34	1150	140-170	3-5	100	"	"
"	B-747		"	34	1150	140-170	3-5	"	"	"
"	B-707		"	36	1150	210	5-6	<100	"	"
Dec. 6	B-747	070	Air France	41	1000	200	4-5	"	"	"
"	B-707		"	41	650	190-200	3-4	"	"	"
"	B-747	1305	"	41	800	180-220	2-4	"	"	"
"	Air Bus	015	"	43	800	220	3-4	"	"	"
"	B-747	030	"	43	800	220	3-4	"	"	"
"	SE-210	911	"	43	1150	220	3-5	"	"	"
"	B-707	609	TWA	41	800	200	3-5	"	"	"
"	B-747	8087	"	41	800	200	4-5	"	"	"
"	B-747	800	"	41	1000	200	4-5	"	"	"
"	B-707	810	"	43	800	220	3-4	"	"	"

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