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NASA TECHNICAL MEMORANDUM

NASA TM X- 71953

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NASA TM X- 71953

EFFECT OF ADVANCED AIRCRAFT NOISE REDUCTION TECHNOLOGY ON THE 1990 PROJECTED NOISE ENVIRONMENT AROUND PATRICK HENRY AIRPORT

By Jimmy M. Cawthorn and Christine G. Brown

(NASA-TM-X-71953) EFFECT OF ADVANCED AIRCRAFT NOISE REDUCTION TECHNOLOGY ON THE 1990 PROJECTED NOISE ENVIRONMENT AROUND PATRICK HENRY AIRPORT (NASA) 38 p HC $5.00 CSCL 01C

N74-20660

Unclas
G3/02 35562

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No. TM X-71953

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Effect of Advanced Aircraft Noise Reduction Technology on the 1990 Projected Noise Environment Around Patrick Henry Airport

5. Report Date

6. Performing Organization Code 26.100

7. Author(s)
Cawthorn, Jimmy M.; and Brown, Christine G.

8. Performing Organization Report No. TM X-71953

9. Performing Organization Name and Address
NASA-Langley Research Center
Hampton, VA 23665

10. Work Unit No. 501-24-01-06

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
Material was presented orally to the Patrick Henry Airport Commission on February 19, 1974.

16. Abstract

A study has been conducted of the future noise environment of Patrick Henry Airport and its neighboring communities projected for the year 1990. An assessment was made of the impact of advanced noise reduction technologies which are currently being considered. These advanced technologies include a two-segment landing approach procedure and aircraft hardware modifications or retrofits which would add sound absorbent material in the nacelles of the engines or which would replace the present two- and three-stage fans with a single-stage fan of larger diameter.

Noise Exposure Forecast (NEF) contours were computed for the baseline (non-retrofitted) aircraft for the projected traffic volume and fleet mix for the year 1990. These NEF contours are presented along with contours for a variety of retrofit options. Comparisons of the baseline with the noise reduction options are given in terms of total land area exposed to 30 and 40 NEF levels. Results are also presented of the effects on noise exposure area of the total number of daily operations.

17. Key Words (Suggested by Author(s)) (STAR category underlined)
Noise, Airport community noise exposure, Aircraft noise

18. Distribution Statement
Unclassified
Unlimited

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of Pages 36 38

22. Price*

*Available from { The National Technical Information Service, Springfield, Virginia 22151
STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

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INTRODUCTION

In 1970 the Peninsula Airport Commission contracted with Arnold Thompson Associates, Inc., White Plains, N.Y., for a study of the future development of aviation facilities for the Virginia Peninsula. The results of this study were released in December 1971 (ref. 1). Included in this report were forecasted noise level contours around Patrick Henry Airport for the year 1990 which were based on an estimate of the air traffic volume and fleet mix projected for that time period. The noise estimates were calculated using noise levels of present day aircraft with no consideration given to noise reductions which could result from current studies which are considering retrofitting today's narrow-body fleet with quieter engines. As was pointed out on page 57 of reference 1, this approach was taken intentionally.

> "The Federal Government, the aircraft industry, and the airlines have pursued many research programs to reduce aircraft noise by advanced engine technology, operational changes, and other promising programs. There has been much progress in the development of quieter aircraft engines and recent aircraft models are quieter than the existing fleet. An engine retrofit of today's fleet would reduce the future impact of aircraft noise at Patrick Henry, but it would be poor planning to assume that this will occur soon. It is, therefore, recommended that the area around the Airport be planned in accordance with the estimated 1990

noise impact, Exhibit 18, and the Land Use Plan, Exhibit 15."

As indicated in the quotation from the 1971 report, research to reduce aircraft noise has made progress in the development of quieter aircraft engines and operating procedures. Since the above report release, there have been impressive applications of this new technology in aircraft design and operations. In some routine airline services there are aircraft with special acoustically treated engine nacelles (DC-10, Lockheed 1011 etc.) and procedures are in operation to reduce community noise during landing approach. Therefore, in the time period since the Arnold Thompson Study was completed, the use of noise reduction technology has gained application practicality and the prognosis for it to have significant impact on Patrick Henry Airport noise by 1990 has been enhanced.

Accordingly, in the fall of 1973, the Peninsula Airport Commission requested NASA Langley Research Center to assess the impact of the application of the advanced noise reduction technology now coming from these research programs on the noise levels forecast for Patrick Henry Airport. The present study results from that request in accordance with the Center's stated policy of providing assistance to the local community in its areas of technical expertise.

In the present study the noise predictions of the Arnold Thompson study are essentially extended to include aircraft using noise reduction technology advances. These predictions are in the form of Noise Exposure Forecasts (NEF) and use Arnold Thompson's 1990 projection for number of operations, runway mix, and mix of aircraft type. Before the new noise predictions were developed the originally forecasted aircraft noise contours from reference 1 were verified. However, for this study, a new base of comparison was calculated using currently accepted methods for calculating NEF contours.

The new technology advances considered included a modified landing approach procedure, the two-segment approach in which the aircraft would begin the landing approach at a 6° glide slope angle with a transition to 3° rather than making the entire approach at 3°. The other advances consisted of modifications to the hardware including the addition of sound absorbent material in the nacelles of the engines and the replacement of the present two- and three-stage fans with a single-stage fan of larger diameter.

The report is divided into four sections: a description of the study procedure used to compute the noise contours, a description of the noise reduction technologies considered, a discussion of the results, and concluding remarks.

STUDY PROCEDURE

NEF Concept

The method for assessing the airport noise environment which was used in this study is based on the computation of Noise Exposure Forecast (NEF) contours. The NEF concept is illustrated in figure 1. The NEF level is proportional to a factor of the aircraft noise plus a factor of the number of aircraft operations over a 24-hour period. A series of NEF levels can be computed around an airport and can be used to determine contours of equal

NEF values as illustrated in the figure. The NEF levels which are normally considered to be of importance are NEF 30 and NEF 40. The land uses normally associated with these NEF levels are as follows: area exposed to less than 30 NEF are normally acceptable for any type of construction, areas between 30 and 40 NEF are normally unacceptable for single-unit residential construction but would be acceptable for multi-unit construction with sound-proofing; areas greater than 40 NEF are clearly unacceptable for practically all types of residential construction and this area should be restricted to agricultural, outdoor recreational, or industrial uses.

Duplication of Arnold Thompson Associates Predictions

The initial step of the study was to duplicate the noise predictions given in reference 1. The aircraft fleet mix and number of daily operations used by Arnold Thompson Associates were obtained through the Peninsula Airport Commission and these data were used as inputs for the baseline case, to which all other cases are compared. In duplicating the predictions of reference 1 it was learned that the original study was done according to an early definition of NEF as given in reference 2. Under this procedure separate computations were made for daytime and nighttime operations, NEF contours were drawn for each, and the worst (largest area) contour was selected for the airport. The currently acceptable definition of NEF (refs. 3 and 4) is given as "Noise Exposure Forecast (NEF) is the total summation (on an energy basis) over a 24-hour period (weighted for the time of day) of Effective Noise Level (EPNL) minus the constant 88 dB" (ref. 4). That is a single computation is made including both the daytime and nighttime operations and this computation would naturally result in larger contours than daytime and nighttime events considered separately.

By computing the baseline case per the previous NEF definition the resulting contours adequately duplicated those in the Arnold Thompson report. This satisfied the requirement that the noise predictions of reference 1 were reproducible; therefore, the remainder of the study was undertaken. All computations were performed using the present definition of NEF. A new baseline set of contours was established and all modified fleet mixes, operations, and source noise characteristics are compared to that new baseline.

Operational Assumptions

The number of flights, fleet mix, and runway utilization used in the test cases for this exercise were consistent with those used by Arnold Thompson for the originally forecasted 1990 C. E.* contours. The number of operations was forecasted to be 152 (76 take-offs and 76 landings) per day of which approximately fifty-percent would be two- and three-engined turbofan airplanes and the other fifty-percent would be four-engined turbofan airplanes. Ten percent of the operations were considered to be nighttime operations. Percentages were also established for the number of operations of each runway. With this as a basic premise, the type and number of aircraft and runway utilization for daytime and nighttime operations was established. These data are presented in Table 1 and Table 2 (A through F). Six cases are computed using a variety of mixes of the retrofit options which are described in the following section. The cases ranged from the baseline to a fleet of completely retrofitted narrow-bodied aircraft. Also included

*Common Era

were wide-bodied aircraft and hypothetical new-technology aircraft equipped with two high-by-pass ratio engines. These cases all assumed a single segment landing approach of three-degrees and are designated as Case 1A-6A. The same six cases were repeated with a two-segment landing approach of six degrees with a transition to three degrees at an altitude of 750 feet. These cases are designated as Case 1B-6B.

Computer Program Description

The FORTRAN language program used for this study was originally developed by Serendipity, Inc. for the DOT/NASA Joint Office of Noise Abatement, as described in reference 5. It was altered for use on Langley Research Center's CDC 6000 computer under the Scope 3.2 operating system, and the capability of producing computer generated plots was added.

The program uses a data base composed of a set of noise vs distance tables for a variety of aircraft types. The data base is given in Tables 3A and 3B, where Table 3A is for takeoff conditions and Table 3B is for landing approach conditions. The aircraft types included in the data base are the current domestic fleet of wide-body and narrow-body aircraft, called the baseline aircraft in this study, plus a hypothetical, new technology airplane. Noise vs distance estimates are also included for two methods of acoustically modifying the narrow-body fleet to reduce their noise levels as is described in the following section. The information contained in the tables was supplied by the aircraft manufacturers.

The basic noise unit computed by the program is the Noise Exposure Forecast (refs. 3 & 4). With inputs of types of aircraft and flight path information the program computes noise levels by interpolating the noise vs distance functions contained in the program. An iterative search procedure generates ground coordinates at which the noise contributions of each flight during a 24-hour period are calculated and summed on an energy basis. The coordinates having equal noise levels define the Noise Exposure Forecast contours.

NOISE REDUCTION TECHNOLOGY

Aircraft Operations

One advanced technology concept which is being considered as a potential aircraft noise reduction technique is the two-segment landing approach. This concept is illustrated in figure 2. Presently the normal landing procedure used by the majority of aircraft is a single-segment approach with a glide slope of 3°. Utilizing the two-segment approach the aircraft would initiate the landing approach at a glide slope of 6° and make a transition to a 3° glide slope at an altitude between 1000 feet and 500 feet. (For this study the transition to the 3° glide slope was assumed to be 750 feet.) The noise benefits derived from this technique are dependent on two factors: during the 6° portion of the approach the aircraft is at a higher altitude than for a single-segment 3° approach and therefore the noise source is at a greater distance from an observer on the ground; also, an aircraft requires less power to fly a two-segmented ($6^{\circ}/3^{\circ}$) approach than is required to fly a single-segment (3°) approach and therefore less noise is generated at the source.

The two-segmented approach concept has been the subject of a considerable amount of research conducted by the NASA (see reference 6) and the technique has been demonstrated in test flights. Also, the technique is currently in routine service use by some short-haul commuter airlines on the west coast.

The incorporation of this type of landing approach technique could be achieved without modifying the aircraft; however some avionic or navigation aid equipment would have to be installed both in the aircraft and on the ground at the airport.

Hardware Modifications

The second advanced technology concept for noise reduction which was considered in this study was concerned with two engine-retrofit-techniques. The first of these would add Sound Absorbent Material (SAM) to the inside surfaces of the engine nacelles to reduce the fan/compressor inlet noise and the fan exhaust noise. This retrofit technique is referred to as SAM. As is seen from the data presented in table 3 the SAM retrofit technique will modestly reduce the engine noise levels.

The technology concept of the SAM retrofit technique has been shown to be feasible and aircraft with acoustically treated nacelles have been flight demonstrated. References 7 and 8 report on some of the research efforts which have investigated the nacelle acoustical treatment technology.

The second engine-retrofit-technique utilized in this study is the refan (RFN) in which the two-or three-stage fan in the present engines would be replaced with a single-stage fan of a larger diameter. The benefits derived from this technique are two-fold. The RFN provides significant noise reductions while the thrust of the engine is increased. The disadvantage of this type of retrofit is its high cost. The RFN technology is currently under development in NASA research studies.

The SAM and RFN concepts are further described in reference 9.

New Technology Aircraft

The third factor associated with noise reduction technology included in this study is the introduction of an advanced technology aircraft. It is a conceptual design of an aircraft with two High-By-Pass-Ratio engines (HBPR) and would incorporate the technology advances resulting from studies of the two above-mentioned retrofit techniques. Design studies for this type of aircraft are underway by some aircraft manufacturers.

RESULTS AND DISCUSSION

The results of investigating the effects of a variety of fleet mixes, retrofit options, new technology aircraft, and landing approach glide slopes which are detailed in the previous section are presented in figures 3A - 8B and are summarized in Table 3 and figure 9. Figure 3A is the baseline (case 1A) to which all other options are compared. Note that all figures are drawn to the same scale. In these figures are shown the critical 30 and 40 NEF contours around the airport for each of the test cases considered. The two runways are depicted along with the airport controlled land which includes the combined areas of the airport and the Harwood's Mill reservoir watershed.

This controlled land is not included in the computation of the area enclosed by the contours. That is, only the areas contained in the contours outside the controlled areas are computed.

It is believed that the most meaningful method of showing the benefits of the new technology which can be derived from the contour sets is a ratio of the area of each retrofit/operation option to the area of the baseline case. This ratio is shown in Table 4 and figure 9, which summarize the results shown in figures 3A to 8B. For convenience in discussing the results the discussion will be limited to the area within the 30 NEF contour. It is seen that area reductions are achieved with each retrofit option and that there is a wide range of area reductions possible. A fleet of all SAM treated aircraft (case 2A) would reduce the area within 30 NEF to 64% of the baseline (case 1A) while an all RFN fleet with a new technology aircraft (case 4A) would drastically reduce the area to 4.0% of the baseline. The credibility of the results are dependent primarily on the accuracy of the source noise data base and the validity of the projected airport operations (fleet mix and number). Both the noise data base and the projected operations are subject to updating in response to improved noise measurements and changing economic growth patterns. The NEF contours are adequate for analyzing trends for comparing noise abatement alternatives, and for indicating the general areas in which noise problems may exist. The exact locations of the contours, transferred to a map of the locality should be used in a general way rather than as a precise boundary of the noise problem area.

One item of interest is the result obtained from the two-segment approach considerations. Operating the untreated fleet with a $6^{o}/3^{o}$ landing approach (case 1B) reduces the 30 NEF area to 74% of the baseline. But, it is seen that operating the quieter aircraft (any treated case) on the two-segment approach results in very little additional benefit. There are two reasons for this. First, when the source noise levels are significantly reduced the transition from the 6^{o} to the 3^{o} occurs at distances greater than the 30 NEF contour extends; therefore the noise computations are not impacted by the steeper approach. Secondly, the retrofit packages are designed such that their primary benefit occurs during landing in which case the take-off noise would dominate the NEF contours; therefore, changes in landing operation procedures would have little impact on the contours.

As is pointed out in reference 9, there are constraints associated with both the SAM and RFN retrofit options. For example, the SAM option does not reduce the noise levels as much as is desired. Although the refan option would reduce the noise levels significantly it is much more costly and would require a longer time to implement. Furthermore, it is believed that the expense of refanning the fleet may make the refan option economically unfeasible. Because of these constraints it appears that of the options considered for this study the most reasonable one for the 1990 time period might be a mix of SAM and HBPR (case 6A or 6B). These cases represent a mix of 25% two-engine SAM treated aircraft, 25% three-engine SAM treated aircraft, and 50% two-engine, high-by-pass-ratio new technology aircraft (rather than the larger four-engine aircraft). It is seen from Table 4 and figure 9 that this option reduced the 30 NEF area to about 40% of the baseline (case 1A). The area contained within the 40 NEF contour is reduced to about 10% of the baseline.

Consideration was given to one further parameter which is very important to the resulting computations - the number of operations per day. A total of 152 operations per day was used in the original Arnold Thompson study which projected a growth of almost 400% in airport operations. Assuming this 400% growth might not be realized additional computations were made to determine the effect of fewer operations.

The results of these computations are shown in figure 10. Plotted on the abscissa is the number of operations and on the ordinate is the percentage of the area where 100% area corresponds to 152 operations.

This factor is relatively independent of retrofit options, fleet mixes, or operating procedures within reasonable accuracies. That is, it demonstrates the relative area reductions which would result from fewer flights of any given option case. It is also relatively independent of the NEF contour, that is, it is equally valid for the area inside the 30 NEF contour, inside the 40 NEF contour, or for the area between the two. From the figure it is seen that for 114 total daily operations the noise exposed area would be reduced to about 85% of the 152 daily operations case. For 76 and 38 operations the noise exposed areas would be reduced to about 60% and 40%, respectively.

It should be pointed out that these results are based on the projection that 10% of the operations would occur at night. Since the NEF computation procedure weighs nighttime flights much more heavily than daytime, reductions or elimination of the number of nighttime operations would have a more marked effect on reducing the noise exposed areas.

CONCLUDING REMARKS

The primary purpose of this study was to determine the future noise environment of Patrick Henry Airport and its neighboring communities for the 1990 C.E. time period if advantage were taken of advanced technologies for reducing the aircraft source noise. The study was based on predicted NEF (Noise Exposure Forecast) contours and the non-airport-controlled areas within these contours. The forecasts are adequate for analyzing trends, for comparing noise abatement alternatives, and for indicating the general areas in which noise problems may exist. The exact location of the contours, transferred to a map of the locality should be used in a general way rather than as a precise boundary of the noise problem area.

The results of the study support the additional concluding remarks:

1. Beneficial reductions in the noise exposed area can be obtained through the use of a two-segment landing approach (initial 6^o with transition to 3^o) as opposed to a single segment (3^o) approach. The benefits of the two-segment approach are greater for the noiser aircraft (untreated) and additional benefits are small or non-existent for the quieter aircraft employing advanced noise reduction technology.

2. Significant reductions in area contained within the 30 NEF contours (outside the airport boundaries) can be achieved with either of the two retrofit options considered: addition of sound absorbent material in the aircraft engines reduces the exposed area to about 65% of the untreated case while retrofitting the entire fleet with the refan option would reduce the exposed area to about 4% of the untreated case and represents a likely lower bound on achievable noise reduction.

3. A practical retrofit option in combination with a two-segment approach would reduce the exposed area within the 30 NEF contour to about 45% of the area impacted by the untreated fleet operating on a single-segment landing approach.

4. Should the 1990 daily operations fall short of the projected 152 there would be substantial reductions in the predicted noise impacted areas. For 114, 76, and 38 operations the noise impacted areas would respectively be 85, 60, and 40 percent of the area impacted by the projected 152 operations.

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TABLE 1. - FLEET MIX TEST CASES USED FOR
PATRICK HENRY AIRPORT 1990 NOISE FORECAST STUDY

CASE 1 A & B

25%	737
25%	727
50%	707

Case 4 A & B

12%	737 RFN
13%	727 RFN
50%	707 RFN
25%	2-ENG. HBPR

CASE 2 A & B

25%	737 SAM
25%	727 SAM
50%	707 SAM

CASE 5 A & B

12%	737 RFN
13%	727 RFN
50%	DC-10/L-1011
25%	2-ENG HBPR

CASE 3 A & B

12%	737 SAM
13%	727 RFN
50%	707 SAM
25%	2-ENG. HBPR

CASE 6 A & B

25%	737 SAM
25%	727 SAM
50%	2-ENG. HBPR

A - SINGLE-SEGMENT APPROACH

B - TWO-SEGMENT APPROACH

TABLE 2A. - UNTREATED BASELINE AIRCRAFT - CASE 1A SINGLE SEGMENT (3^{o}) APPROACH AND CASE 1B TWO SEGMENT ($6^{o}/3^{o}$) APPROACH

	RUNWAY	737-200		727-200		707-320B	
		NO. DAY OPERATIONS	NIGHT	DAY	NIGHT	DAY	NIGHT
TAKE-OFF	6	7	1	8	1	13	1
	2	6	1	6	1	12	1
	24	2	1	2		4	
	20	2	1	2		4	
	Total	17	4	18	2	33	2
LANDING	6	12	2	12	2	24	2
	24	4		4	1	8	1
	2	3		1			
	Total	19	2	17	3	32	3

TABLE 2B. - ALL AIRCRAFT TREATED WITH SAM RETROFIT OPTION

CASE 2A SINGLE-SEGMENT (3^0) APPROACH

CASE 2B TWO-SEGMENT ($6^0/3^0$) APPROACH

	RUNWAY	737-200 SAM		727-200 SAM		707-320B SAM	
		NO. DAY OPERATIONS	NIGHT	DAY	NIGHT	DAY	NIGHT
TAKE-OFF	6	7	1	8	1	13	1
	2	6	1	6	1	12	1
	24	2	1	2		4	
	20	2	1	2		4	
	Total	17	4	18	2	33	2
LANDING	6	12	2	12	2	24	2
	24	4		4	1	8	1
	2	3		1			
	Total	19	2	17	3	32	3

TABLE 2C. - MIX OF SAM AND RFN RETROFIT AIRCRAFT PLUS NEW TECHNOLOGY AIRCRAFT
CASE 3A SINGLE-SEGMENT (3^{o}) APPROACH AND
CASE 3B TWO-SEGMENT ($6^{o}/3^{o}$) APPROACH

	RUNWAY	737-200 SAM		727-200 RFN		707-320B SAM		2-ENG. HBPR	
		NO. DAY OPERATIONS	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
TAKE-OFF	6	3	1	4	1	13	1	8	
	2	3	1	3	1	12	1	6	
	24	1	1	1		4		2	
	20	1	1	1		4		2	
	Total	8	4	9	2	33	2	18	0
LANDING	6	6	1	6	1	24	2	12	2
	24	2		2	1	8	1	4	
	2	1		1				2	
	Total	9	1	9	2	32	3	18	2

TABLE 2D. - ALL AIRCRAFT TREATED WITH RFN RETROFIT OPTION PLUS NEW TECHNOLOGY AIRCRAFT

CASE 4A SINGLE-SEGMENT (3^o) APPROACH AND

CASE 4B TWO-SEGMENT ($6^o/3^o$) APPROACH

	RUNWAY	737-200 RFN		727-200 RFN		707-320B RFN		2-ENG. HBPR	
		NO. DAY OPERATIONS	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
TAKE-OFF	6	3	1	4	1	13	1	8	
	2	3	1	3	1	12	1	6	
	24	1	1	1		4		2	
	20	1	1	1		4		2	
	Total	8	4	9	2	33	2	18	0
LANDING	6	6	1	6	1	24	2	12	2
	24	2		2	1	8	1	4	
	2	1		1				2	
	Total	9	1	9	2	32	3	18	2

TABLE 2E. - MIX OF RFN, WIDE-BODY, AND NEW TECHNOLOGY AIRCRAFT

CASE 5A SINGLE-SEGMENT (3^{o}) APPROACH AND

CASE 5B TWO-SEGMENT ($6^{o}/3^{o}$) APPROACH

	RUNWAY	737-200 RFN		727-200 RFN		DC-10/L-1011		2-ENG. HBPR	
		NO. DAY OPERATIONS	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
TAKE-OFF	6	3	1	4	1	13	1	8	
	2	3	1	3	1	12	1	6	
	24	1	1	1		4		2	
	20	1	1	1		4		2	
	Total	8	4	9	2	33	2	18	0
LANDING	6	6	1	6	1	24	2	12	2
	24	2		2	1	8	1	4	
	2	1		1				2	
	Total	9	1	9	2	32	3	18	2

TABLE 2F. - MIX OF TWO- AND THREE-ENGINED SAM AIRCRAFT PLUS NEW TECHNOLOGY AIRCRAFT
CASE 6A SINGLE-SEGMENT (3°) APPROACH AND
CASE 6B TWO-SEGMENT ($6^{\circ}/3^{\circ}$) APPROACH

	RUNWAY	737-200 SAM		727-200 SAM		2ENG HBPR	
		NO. DAY OPERATIONS	NIGHT	DAY	NIGHT	DAY	NIGHT
TAKE-OFF	6	7	1	8	1	13	1
	2	6	1	6	1	12	1
	24	2	1	2		4	
	20	2	1	2		4	
	Total	17	4	18	2	33	2
LANDING	6	12	2	12	2	24	2
	24	4		4	1	8	1
	2	3		1			
	Total	19	2	17	3	32	3

TABLE 3A. - NOISE DATA BASE IN EPNdB - TAKEOFF CONDITIONS

AIRCRAFT TYPE	Distance from Aircraft, ft, (m)						
	400 (121.9)	600 (182.9)	1000 (304.8)	2000 (609.6)	4000 (1219.2)	8000 (2438.4)	10000 (3048.0)
DC10/L1011	115.0	111.7	107.6	100.6	90.5	76.5	71.2
707-320B	122.5	119.2	114.5	106.5	98.0	89.0	86.5
727-200	119.5	116.6	113.0	107.2	100.7	93.8	91.5
737-200	117.5	114.5	111.0	105.0	96.0	87.0	84.0
707 SAM	118.0	115.0	110.6	106.2	101.8	95.0	92.5
727 SAM	118.3	115.7	112.0	106.5	100.6	94.7	92.6
737 SAM	115.5	112.7	108.5	103.0	96.2	89.0	86.5
707 RFN	109.1	106.0	102.1	95.4	88.0	80.1	77.5
727 RFN	108.0	105.3	101.9	96.9	91.9	87.3	85.8
737 RFN	108.0	104.5	100.5	95.0	87.8	80.5	78.0
2 Eng. HBPR	113.0	109.7	105.6	98.6	88.5	74.5	69.2

TABLE 3B. - NOISE DATA BASE IN EPNdB - LANDING CONDITIONS

AIRCRAFT TYPE	Distance from Aircraft, ft, (m)						
	400 (121.9)	600 (182.9)	1000 (304.8)	2000 (609.6)	4000 (1219.2)	8000 (2438.4)	10000 (3048.0)
DC10/L1011	101.6	98.1	93.6	86.8	78.0	67.7	64.0
707-320B	119.0	115.6	110.5	101.0	91.0	82.5	79.0
727-200	109.1	106.0	101.6	94.8	87.2	79.7	76.9
737-200	110.5	106.0	100.0	92.5	83.5	73.6	70.5
707 SAM	105.0	102.0	98.0	93.3	88.5	81.6	79.0
727 SAM	102.4	99.4	95.9	90.0	84.0	78.0	76.0
737 SAM	105.5	101.8	96.5	89.0	81.0	73.2	70.5
707 RFN	100.5	97.0	92.4	85.5	78.0	70.0	67.3
727 RFN	96.0	93.0	89.2	84.4	79.5	74.4	72.9
737 RFN	98.5	94.9	89.5	83.5	76.0	67.0	63.5
2 Eng. HBPR	99.6	96.1	91.6	84.8	76.0	65.7	62.0

TABLE 4. - SUMMARY OF NOISE EXPOSED AREAS WITHIN NEF CONTOURS

NOISE REDUCTION	CASE NO.(1)	WITHIN 30 NEF CONTOURS(2) AREA			WITHIN 40 NEF CONTOURS(2) AREA		
		Sq. Mi.	Sq. Km	%	Sq. Mi.	Sq. Km.	%
Baseline	1 - A	16.58	42.9	100	2.38	6.2	100
	1 - B	12.21	31.6	74	2.04	5.3	86
SAM	2 - A	10.55	27.3	64	0.37	1.0	16
	2 - B	9.95	25.8	60	0.37	1.0	16
SAM + RFN	3 - A	7.28	18.9	44	0.21	0.5	9
+ HBPR	3 - B	7.14	18.5	43	0.20	0.5	8
RFN + HBPR	4 - A	0.62	1.6	4	0.03	0.1	1
	4 - B	0.61	1.6	4	0.03	0.1	1
RFN + HBPR	5 - A	1.57	4.1	9	0.06	0.2	3
+ Wide body	5 - B	1.57	4.1	9	0.06	0.2	3
SAM + HBPR	6 - A	6.30	16.3	38	0.25	0.6	10
	6 - B	6.18	16.0	37	0.25	0.6	10

(1) A: Single-segment approach
B: Two-segment approach

(2) Exclusive of airport controlled area

$$NEF = EPNL + 10\ \log[N_{day} + 16.67\ N_{night}] - 88$$

NEF CONTOURS

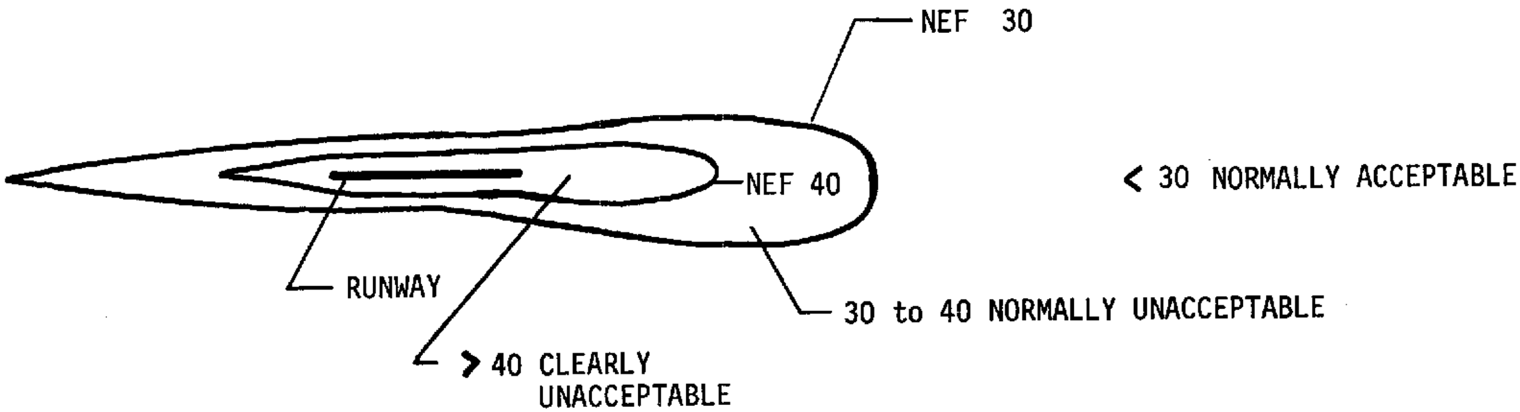


FIGURE 1. - Illustration of Noise Exposure Forecast (NEF) concept for assessment of airport noise environment.

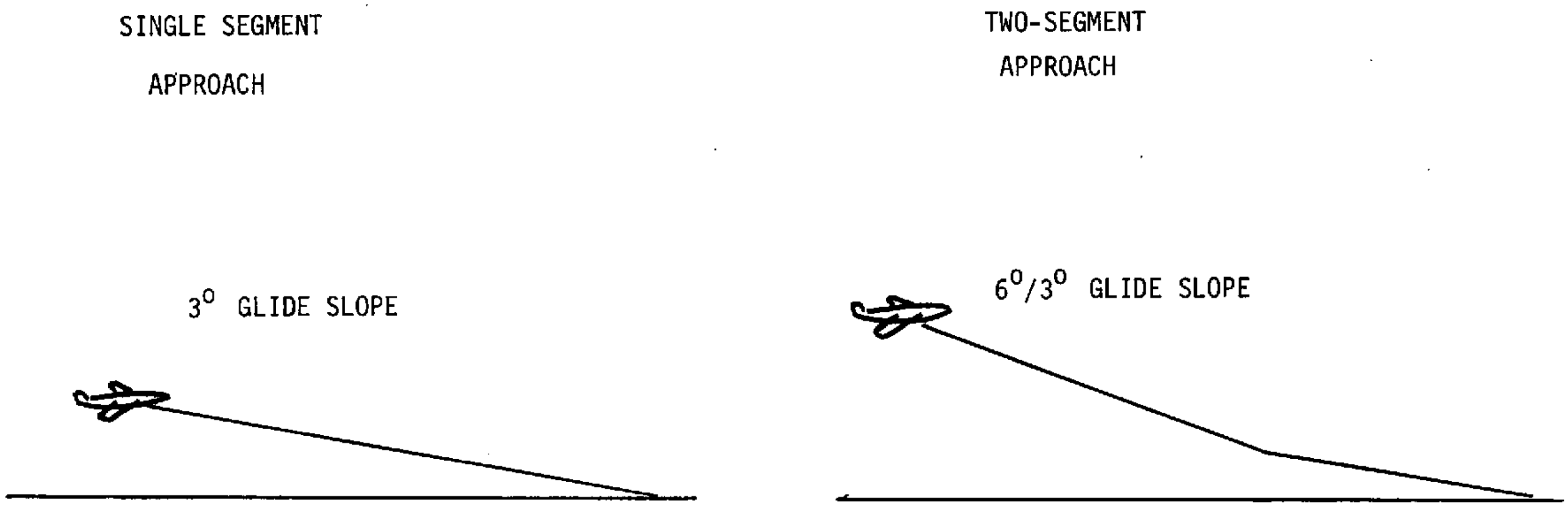
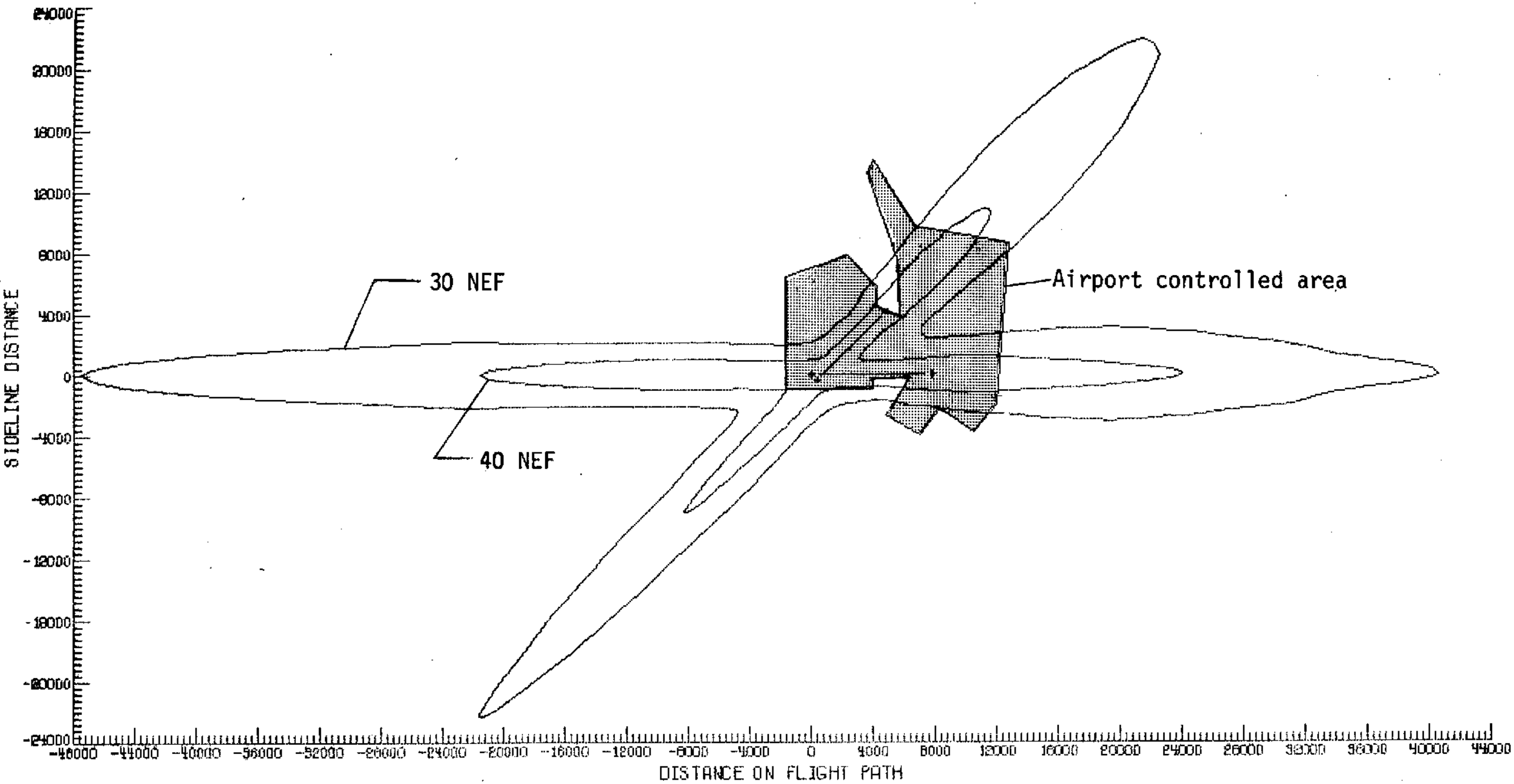
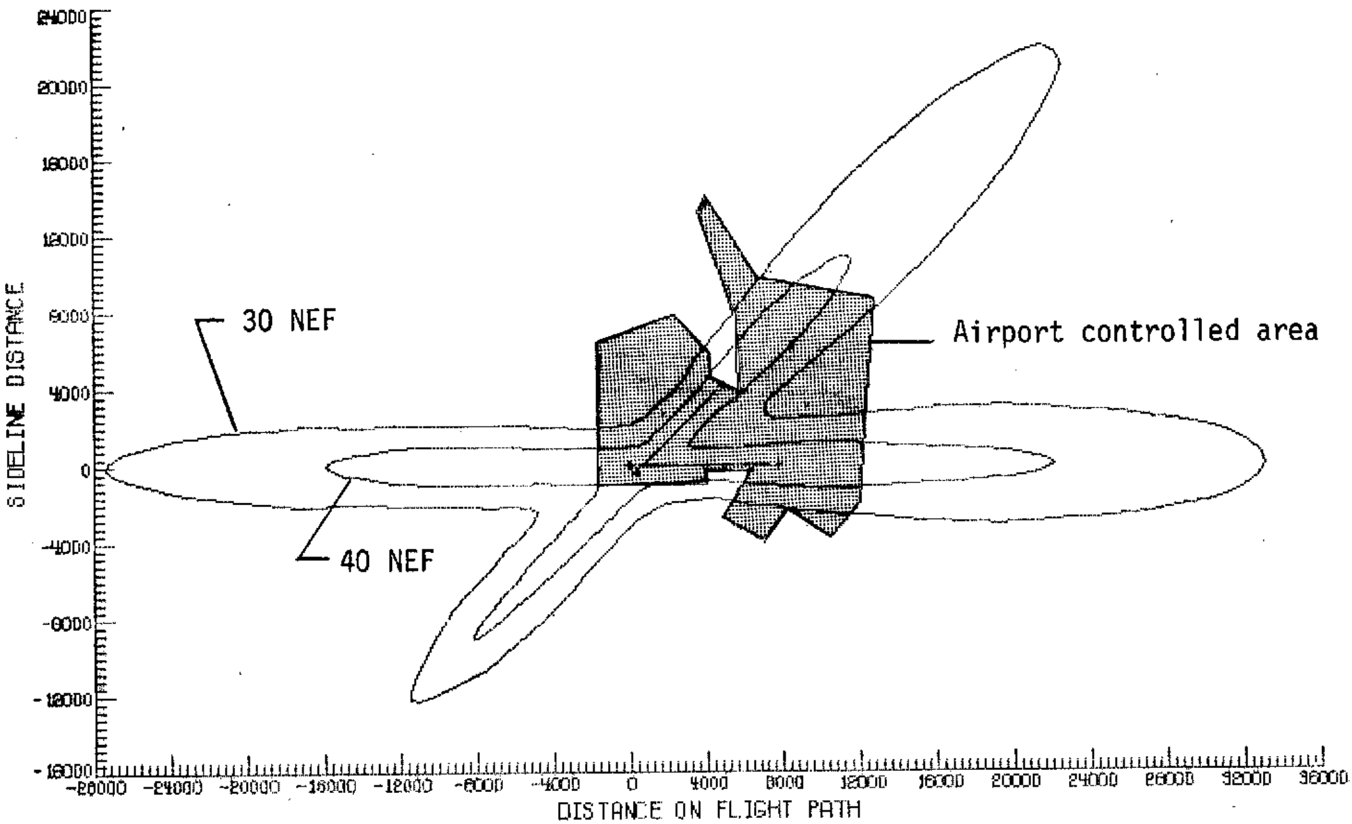


Figure 2. - Aircraft operation noise reduction technique; two-segment landing approach.



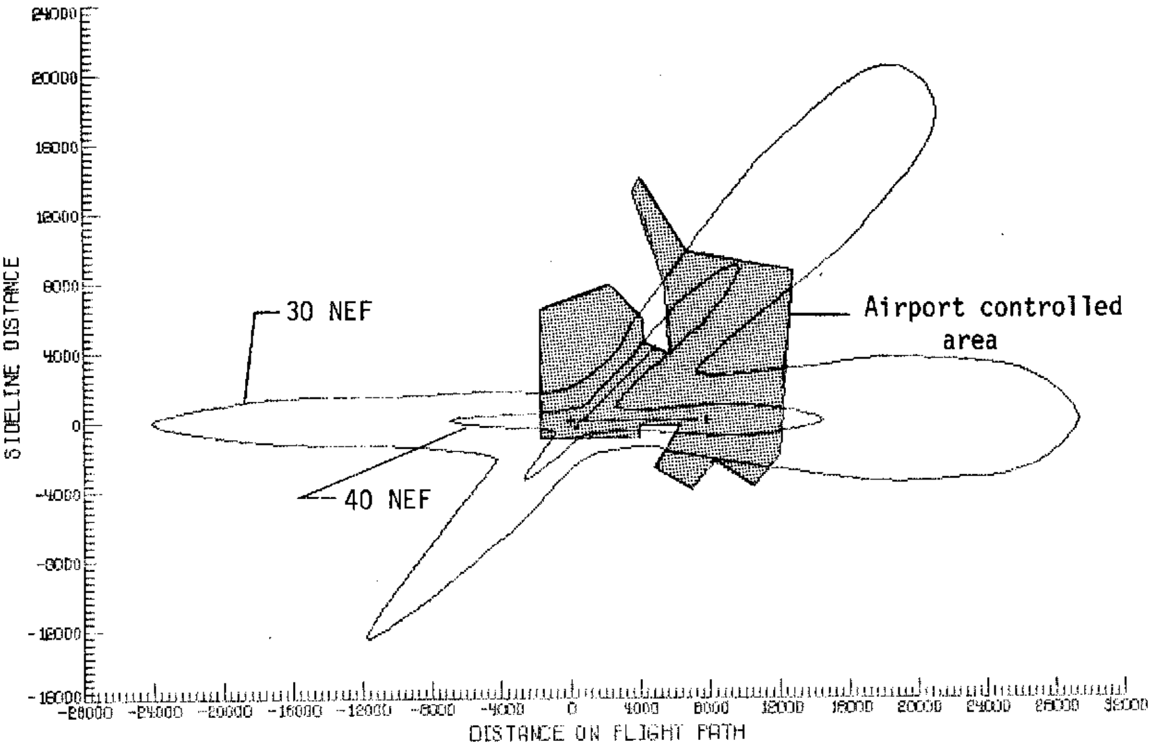
(a) Case 1A - 3^{o} single-segment landing approach

Figure 3. - Patrick Henry Airport Noise Exposure Forecast Contours for year 1990.
Baseline: 25% 737, 25% 727, 50% 707. Distances plotted in feet (0.3048 m).

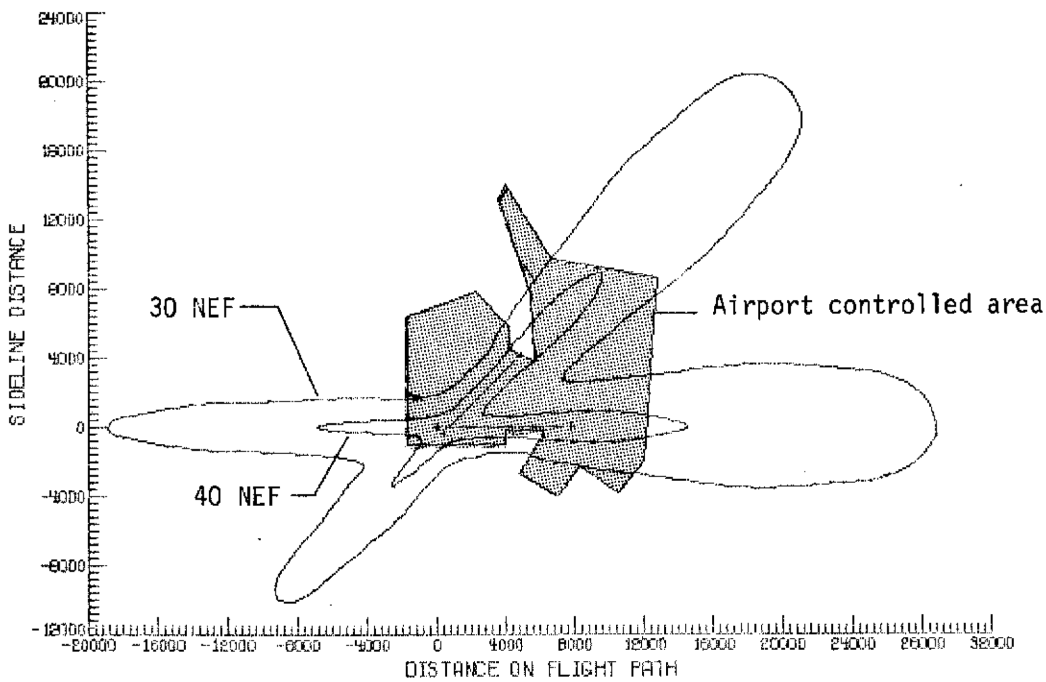


(b) Case 1-B ; $6^{0}/3^{0}$ two-segment landing approach

Figure 3. - Concluded

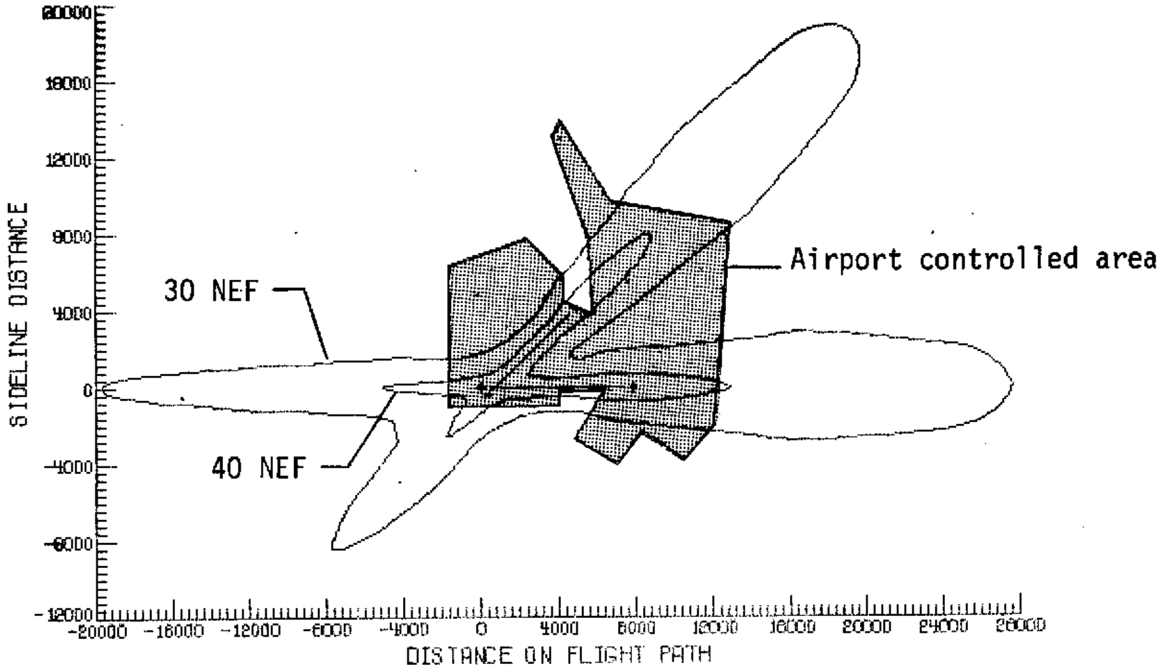


(a). - Case 2-A; single-segment landing approach

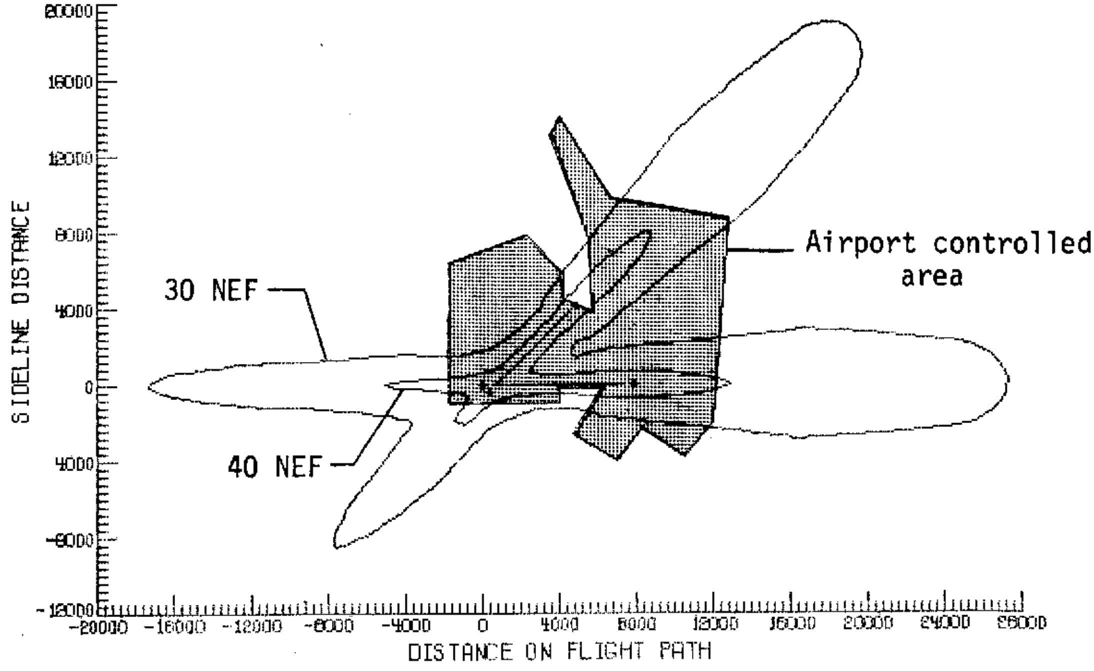


(b) Case 2-B; $6^{\circ}/3^{\circ}$ two-segment landing approach

Figure 4. - Patrick Henry Airport Noise Exposure Forecast contours for year 1990. 25% 737 SAM; 25% 727 SAM; 50% 707 SAM. Distances plotted in feet (0.3048 m)

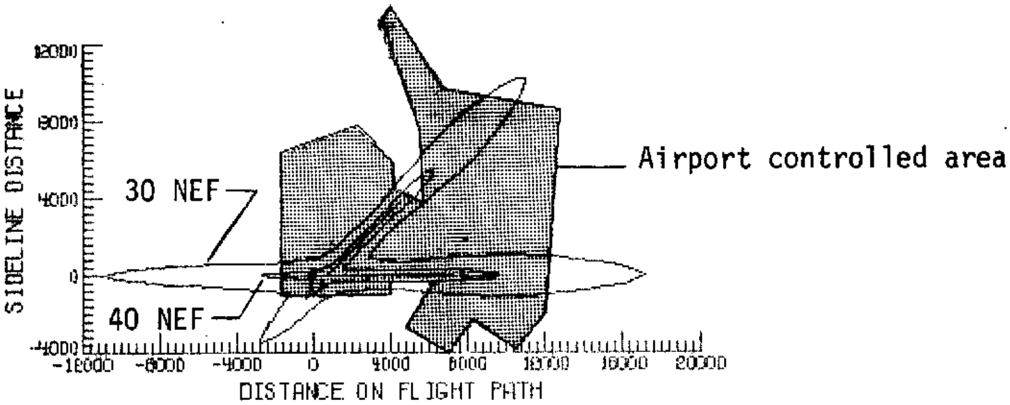


(a). Case 3-A; 3° single-segment landing approach

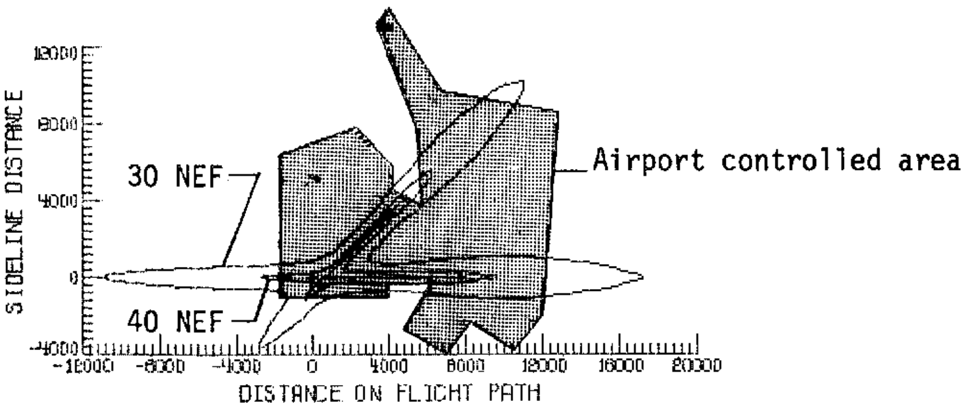


(b) Case 3-B; 6°/3° two-segment landing approach

Figure 5. - Patrick Henry Airport Noise Exposure Forecast contours for year 1990. 12% 737 SAM; 13% 727 RFN; 50% 707 SAM; 25% 2-Engine High-Bypass-Ratio. Distances plotted in feet (0.3048m).

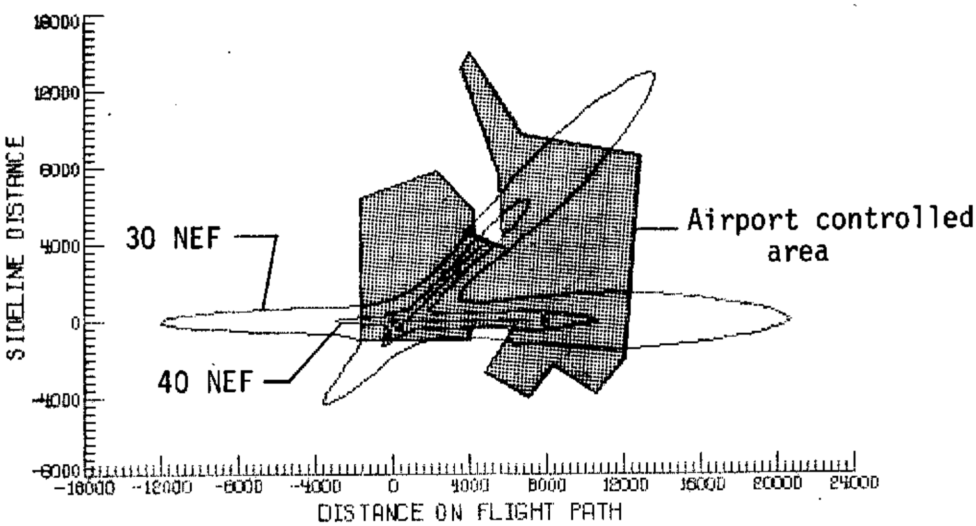


(a) Case 4-A; 3^{o} single-segment landing approach

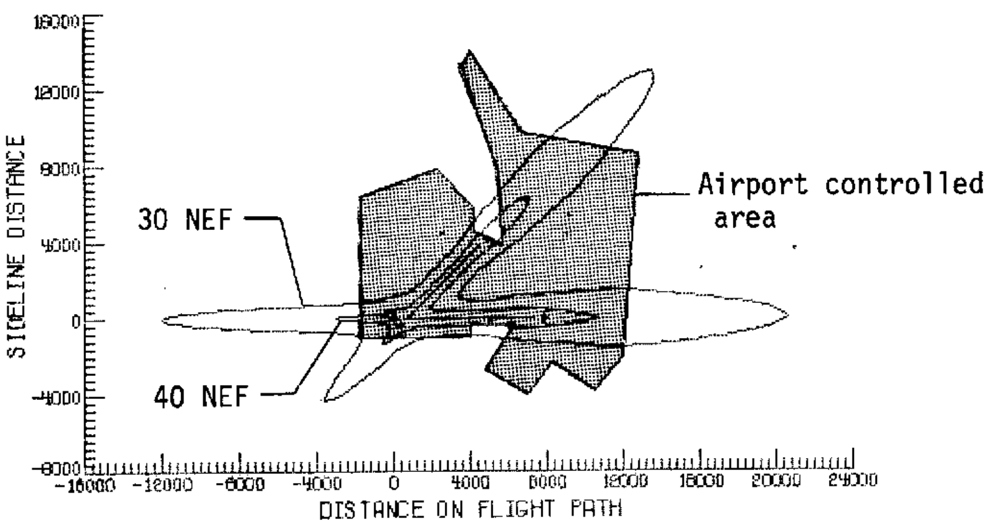


(b) Case 4-B; $6^{o}/3^{o}$ two-segment landing approach

Figure 6. - Patrick Henry Airport Noise Exposure Forcast contours for year 1990. 12% 737 RFN; 13% 727 RFN; 50% RFN; 25% 2-Engine High-Bypass-Ratio Distances measured in feet (0.3048 m).

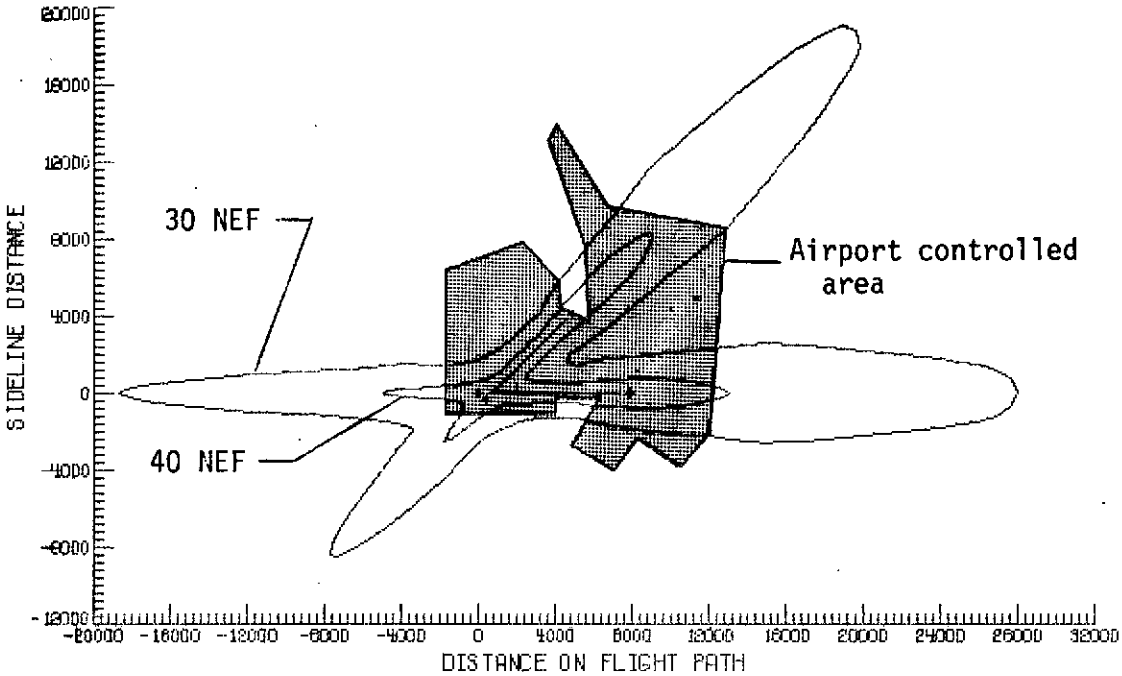


(a) Case 5-A; 3^{o} single-segment landing approach

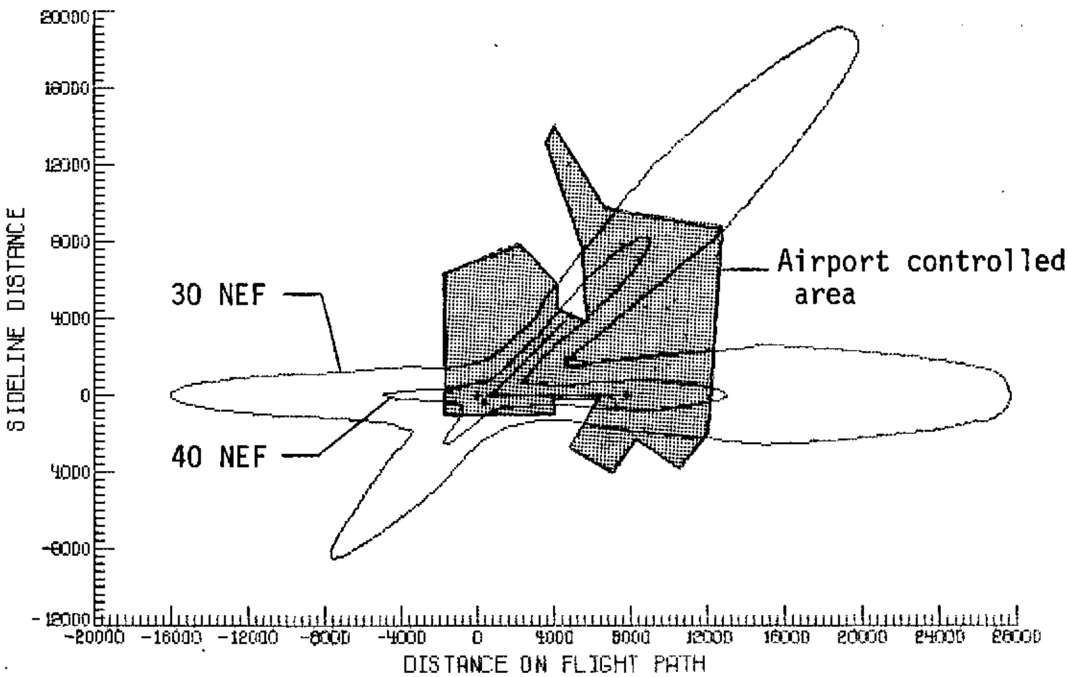


(b) Case 5-B; $6^{o}/3^{o}$ two-segment landing approach

Figure 7. - Patrick Henry Airport Noise Exposure Forecast contours for year 1990. 12% 737 RFN; 13% 727 RFN; 50% DC10/L1011; 25% 2-Engine High-bypass-ratio. Distances plotted in feet (0.3048 m).



(a) Case 6-A ; 3^{o} single-segment landing approach



(b) Case 6-B; $6^{o}/3^{o}$ two-segment landing approach

Figure 8. - Patrick Henry Airport Noise Exposure Forecast contours for year 1990. 25% 737 SAM; 25% 727 SAM; 50% 2-Engine High-Bypass-Ratio. Distances plotted in feet (0.3048 m).

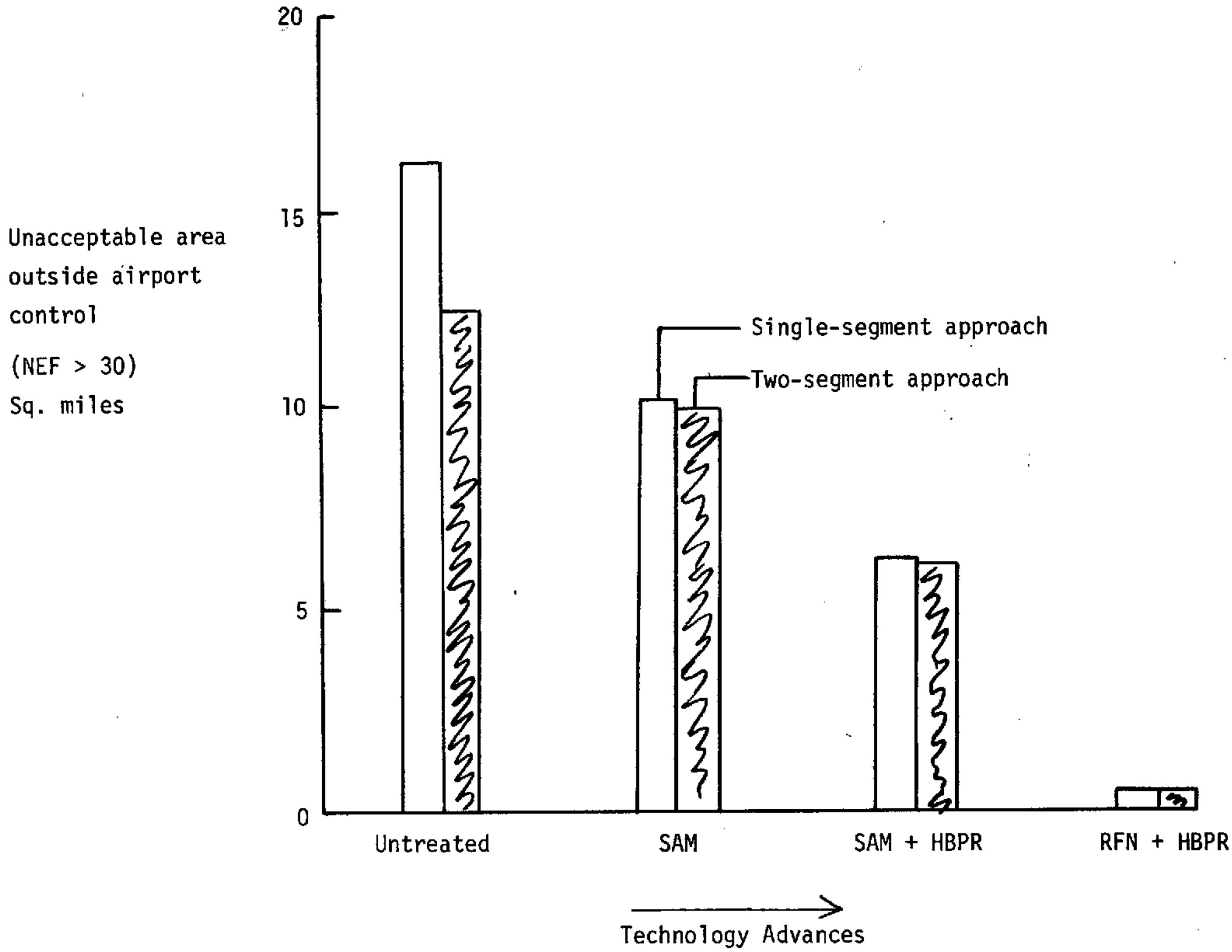


Figure 9. - Effects of aircraft noise reduction technology on residential use of land near Partick Henry Airport. (1 sq. mi. = 2.59 sq. km.)

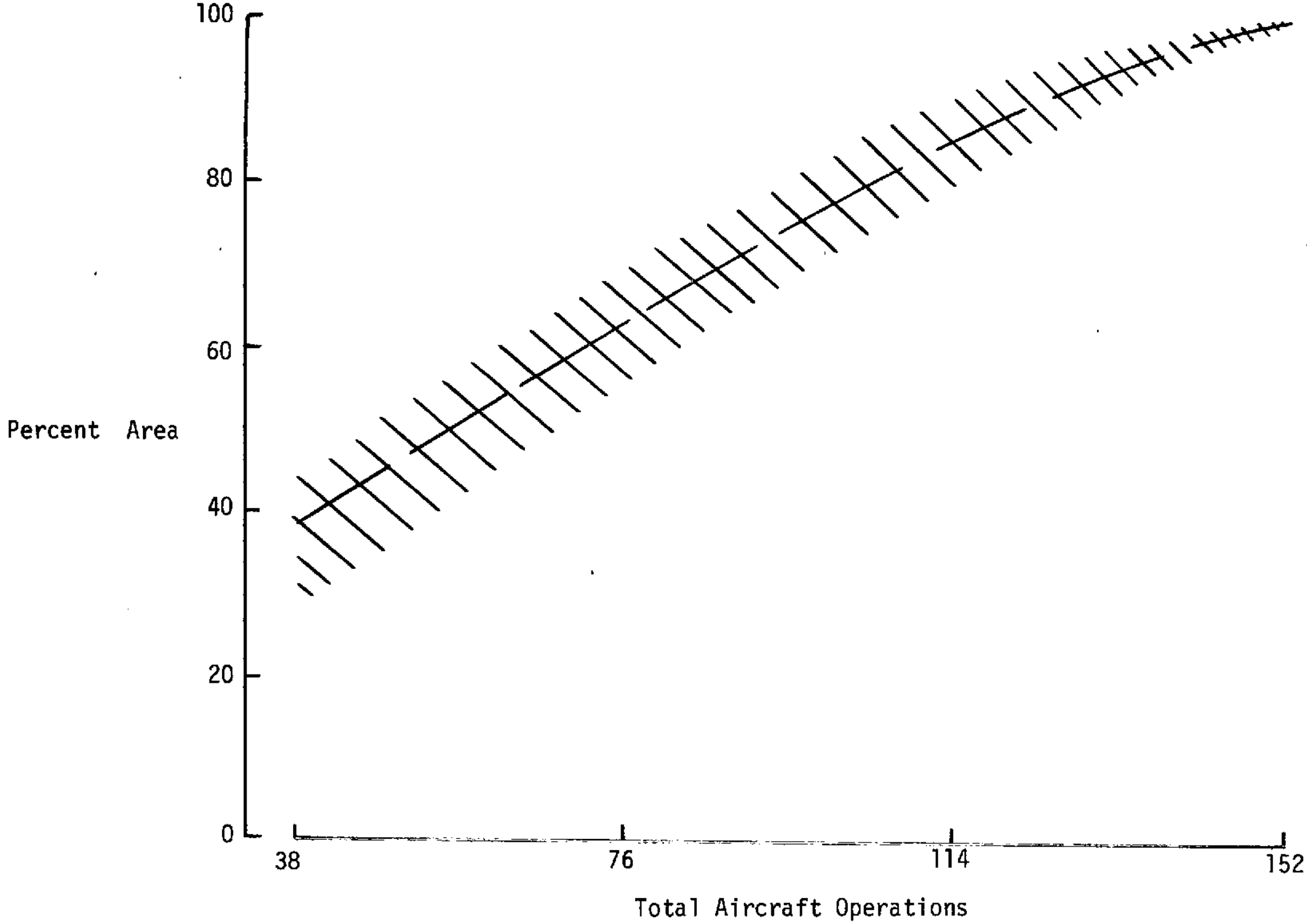


Figure 10. - Effect of reducing number of aircraft operations on noise exposed area. (Nighttime operations = 10%)