THE ENERGY COSTS OF SOME NOISE ABATEMENT PROCEDURES

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1. INTRODUCTION

The growth of commercial jet transport since 1957 has been accompanied by a growing concern with the increased noise levels in communities adjacent to airports. To alleviate this impact, noise abatement procedures for aircraft operations were implemented. Amongst these procedures are: the use of preferential runway systems to avoid overflying densely populated areas, power reduction after takeoff, reduced thrust takeoff, steeper glide slopes during approach and delayed flap landing. However, the recent "energy crisis" and subsequent sharp rise in aviation fuel prices have created a need to determine how much these noise abatement procedures are costing us. In an attempt to obtain some energy costs of these procedures, a theoretical study was conducted. For this paper, fuel consumption and noise reduction benefits of some noise abatement departures are presented.

2. NOISE ABATEMENT DEPARTURES

The departure noise problem occurs as the aircraft passes over or near noise sensitive areas after departing the immediate vicinity of the runway. This problem is dominated by the engine noise and the climb performance of the airplane. A reduction of engine power at some point of the departure is recognized as a means of reducing noise at the ground level. TABLE I lists the two types of noise abatement departures that utilize thrust reduction. Departure Type A (ATA Procedure) in use by several airlines, establishes the 1,000 ft. height as the point for flap retraction. Upon clean-up, thrust is reduced and the airplane then climbs at zero flap speed to 3,000 ft. Unlike the ATA Procedure, Type B departure tends to keep the airplane high before flap retraction or thrust reduction or both is applied. It usually establishes thrust reduction when the airplane is still in a "dirty" configuration.

Figure 1 illustrates the ATA Departure (Type A) profile of a B747. It requires the airplane to climb out using takeoff thrust to 1,000 ft. at V2 + 10 knots. At this point, the airplane continues climbing and at the same time retracts flaps at the appropriate minimum speeds. After clean-up, it reduces thrust and climbs at zero flap speed, VZF (in this case V2 + 80 kts.) to 3,000 ft. At this altitude or higher, the aircraft accelerates expeditiously from VZF to 250 kts., maintaining an approximate rate of climb of 500 - 1,000 ft/min. Type B, shown in Figure 2, requires the aircraft to climb using takeoff thrust to 1,500 ft. at a constant V2 + 10 kts. and takeoff flap. Climb thrust is then set and straight climb out is performed with flaps retracted at the scheduled speeds. The aircraft then accelerates to 250 kts. and climbs to 10,000 ft. In order to determine the energy costs of these noise abatement departures, a takeoff procedure that does not contain noise abatement is used as a reference. The departure profile is shown on Figure 3. It requires the aircraft to climb straight ahead at V2 + 10 kts. to the height selected for flap retraction. In this study, the FAA minimum height requirement of 400 ft. is used. The aircraft then accelerates and retracts flaps at the appropriate minimum speeds. Upon clean-up climb thrust is set and the aircraft then accelerates to 250 kts.

3. FUEL CONSUMPTION ANALYSIS

The fuel consumption analysis of a departure is done in steps related to specific segments defined by changes in airplane configuration, engine thrust or speed. Figure 4 shows the segments used in the fuel consumption analysis of the B747 ATA (Type A) departure. The first segment begins where the airplane has attained a height of 35 feet to the flap retraction height of 1,000 ft. AGL. The second segment starts at this altitude and ends at the point where the next flap retraction speed is reached (here V2 + 20 kts.). The third segment begins from here and ends at the height where V2 + 40 kts. is reached and so on until clean-up. The next segment, then, is the climb at VZF to 3,000 ft. AGL and the last segment is the acceleration from clean-up speed to 250 kts.

The outline of the procedure used in calculating the fuel consumed in each segment is given in Figure 5. The data required for each segment are: aircraft takeoff weight, aircraft speeds at the start and end of segment, flap setting, thrust setting, airport temperature, initial and final or estimated final aircraft altitudes and rate of climb (if available). From here, drag, delta, mach number, sonic speed, dT/dH and TAT are computed. With these aerodynamics quantities, the thrust per engine is then calculated. If the aircraft speed is maintained constant throughout the segment, then the acceleration, rate of climb, climb gradient, traversed time and distance are calculated. If the aircraft is accelerating as well as climbing, then its traversed time and distance, its acceleration and final altitude are computed. Finally, the fuel consumed is computed from the fuel flow rate for the thrust setting and the traversed time.

4. DISCUSSION OF RESULTS

Figure 6 shows the effect of the three types of departure on the noise level under the flight path. The aircraft is a B747-100 at a takeoff weight of 513,000 lbs. and powered by four JT8D-3A engines. As can be seen, the two thrust reduction departures are about 2 - 5 EPNdB quieter then the non-noise abatement (reference) procedure for most distances under the flight path. The ATA procedure (Type A), however, has an additional 1-2EPNdB reduction. This is due to two factors:
(1) the reduction in thrust upon clean-up, and (2) the higher altitude attained due to the higher speeds associated with a clean configuration. Table II gives the results of the computation. It is evident that the two noise abatement departures consumed more fuel; about 993.1 lbs. more fuel for the Type B and 201.9 lbs. more for the ATA procedure. Based on the fuel price of 8¢ per lb., their respective extra costs are $79.45 and $16.16. It would appear that for the B747-100, the Type A (ATA procedure) departure offers the best compromise between noise and fuel consumed.

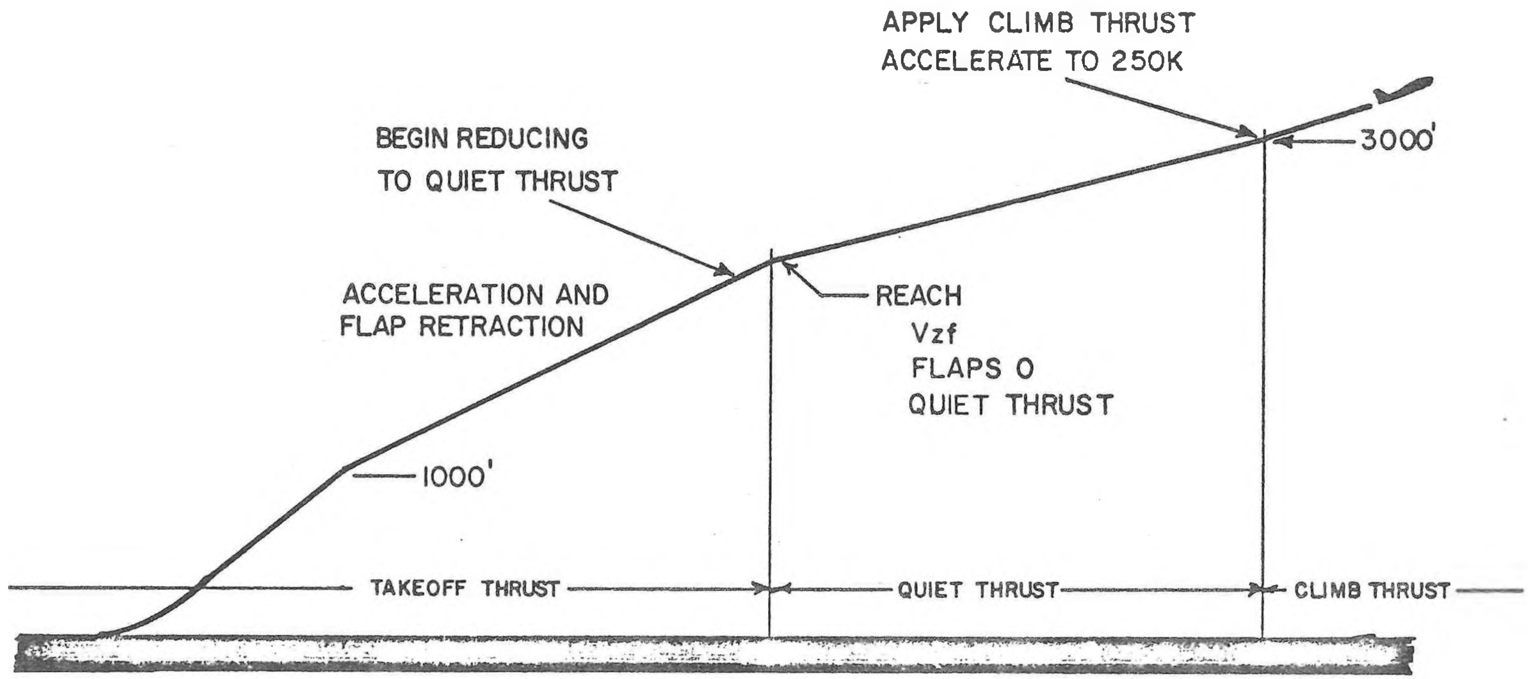
Figure 7 shows the noise levels under the flight path of the three departures. The aircraft is a L-1011 at a takeoff weight of 425,000 lbs. and powered by three RB.211-22B engines. Again it can be seen that the two noise abatement departures are substantially quieter (2 - 5 EPNdB) than the reference procedure. The ATA procedure also shows a slight noise advantage over the normal takeoff procedure (Type B). The energy costs of these departures are shown in Table III.

Figure 8 shows the noise levels under the flight path of a B727-200. The aircraft is at a takeoff weight of 191,000 lbs. and powered by three JT8D engines. At the takeoff phase of the departure, the noise due to the Type A (ATA) procedure is 1 - 2EPNdB higher than that of the Type B. This is mainly due to the lower altitude of the aircraft during flap retraction. However, after clean-up the aircraft maintains a much higher altitude; subsequently, its noise level under the flight path is much lower than that due to the other two departures. Figure 9 shows similar noise benefits from the two noise abatement departures for the DC-9-30 airplane. The ATA (Type A) departure, however, is not significantly quieter than the normal (or Type B) departure.

The energy costs of using noise abatement departures for both the B727-200 and the DC-9-30 are given in TABLE IV. It would appear that there is little extra fuel consumed by the DC-9-30 airplane even when noise abatement techniques are carried out during departure. For the case of the B727-200 the cost penalties are slightly higher. The short flap retraction schedules and light takeoff weights may be the reasons behind the smaller cost penalties associated with noise abatement departures.

The effect of takeoff weight on fuel consumption for the two noise abatement departures is illustrated from the results in Table V. For the Type A (ATA) departure, as the takeoff weight gets larger, the fuel penalty decreases. This may be due to the similarities in the flight characteristics of the two departures at large takeoff weight. The Type B departure, on the other hand, has the reverse trend. This may be due to the extra power required by the airplane to maintain the necessary heights and climb gradients of the profile.

Note: The above paper reflects the views of the author and should not be thought to reflect those of Transport Canada.



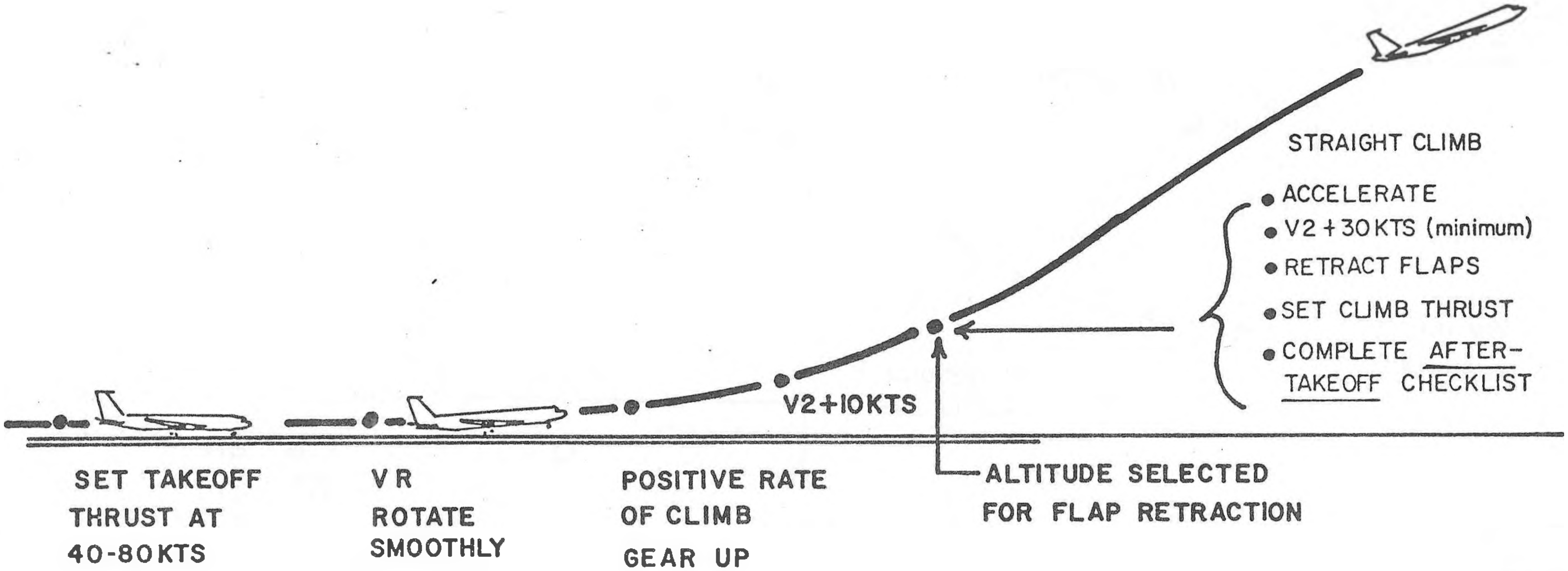
THRUST CUTBACK PROCEDURE

FIG. I

STANDARD TAKEOFF AND CLIMB

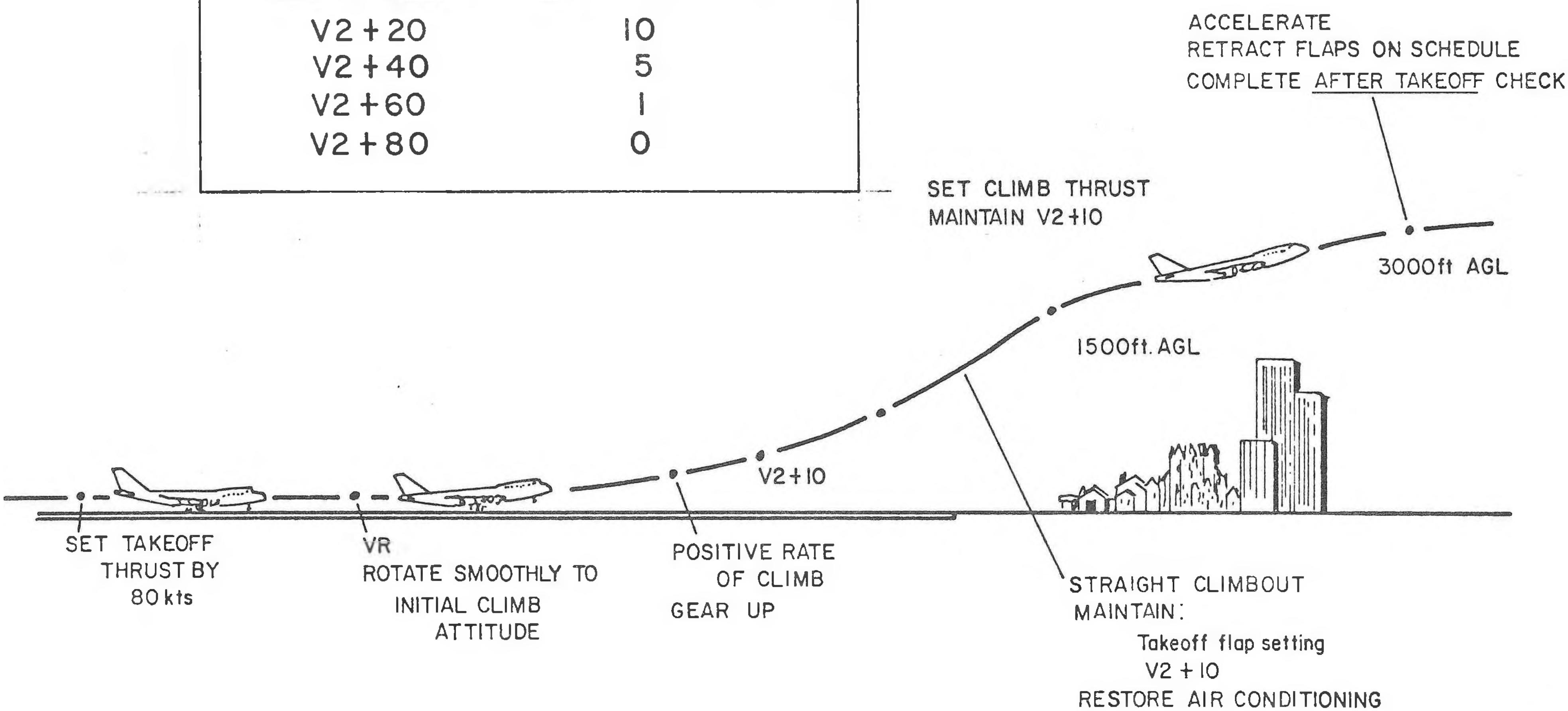
(NON-NOISE ABATEMENT)

FIG. 3



TAKEOFF FLAP RETRACTION SCHEDULE

AT SPEED	SELECT FLAPS
V2 + 20	10
V2 + 40	5
V2 + 60	1
V2 + 80	0



STANDARD TAKEOFF AND CLIMB

FIG. 2

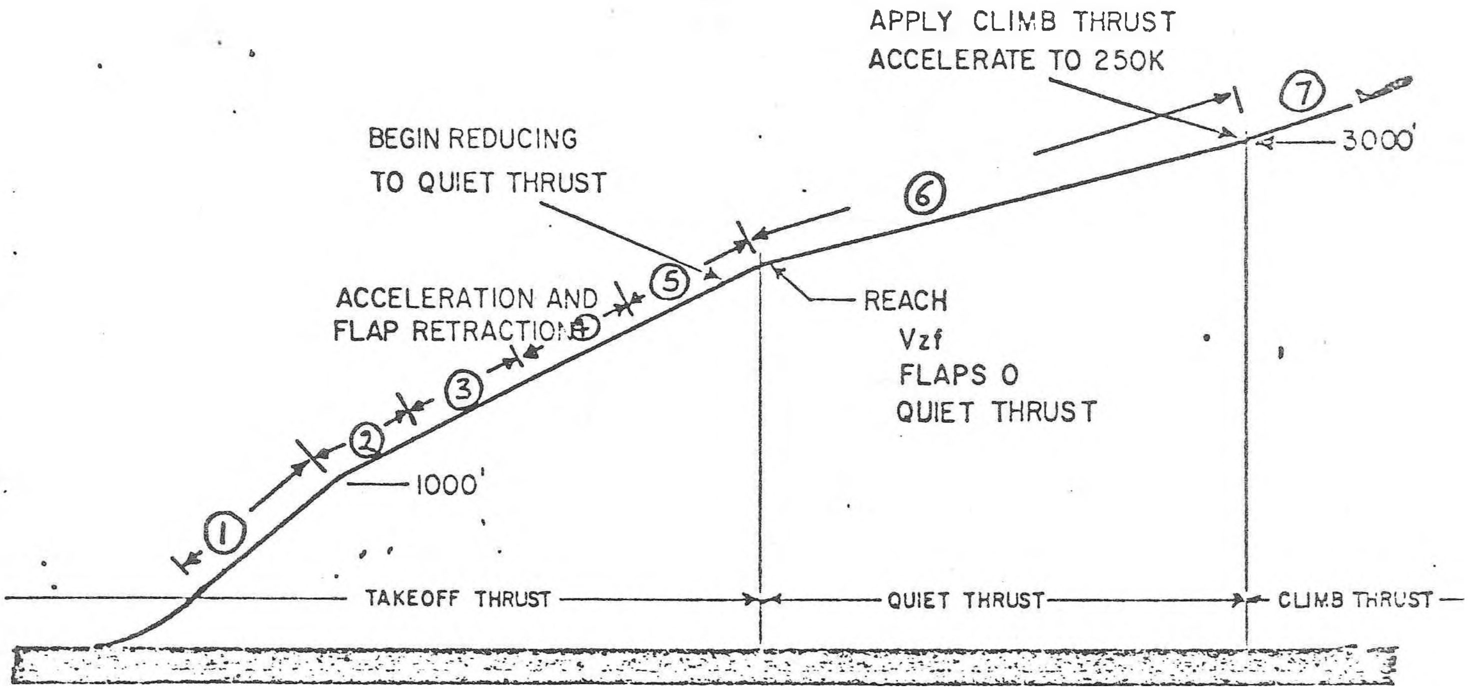


FIGURE 4: PROFILE TYPE A (ATA) DEPARTURE

SEGMENT	1	2	3	4	5	6	7	8
ALTITUDE	35' TO 1,000'	1,000' TO FLAP 10°	FLAP 10° TO FLAP 5°	FLAP 5° TO FLAP 1°	FLAP 1° TO FLAP 0°	FLAP 0° TO 3,000'	3,000' TO 10,000'	
VELOCITY (KTS.)	V2+10	V2+10 TO V2+20	V2+20 TO V2+40	V2+40 TO V2+60	V2+60 TO V2+80	V2+80	V2+80 TO 250 KTS.	
THRUST	T.O	T.O	T.O	T.O	T.O	REDUCED THRUST	CLIMB THRUST	

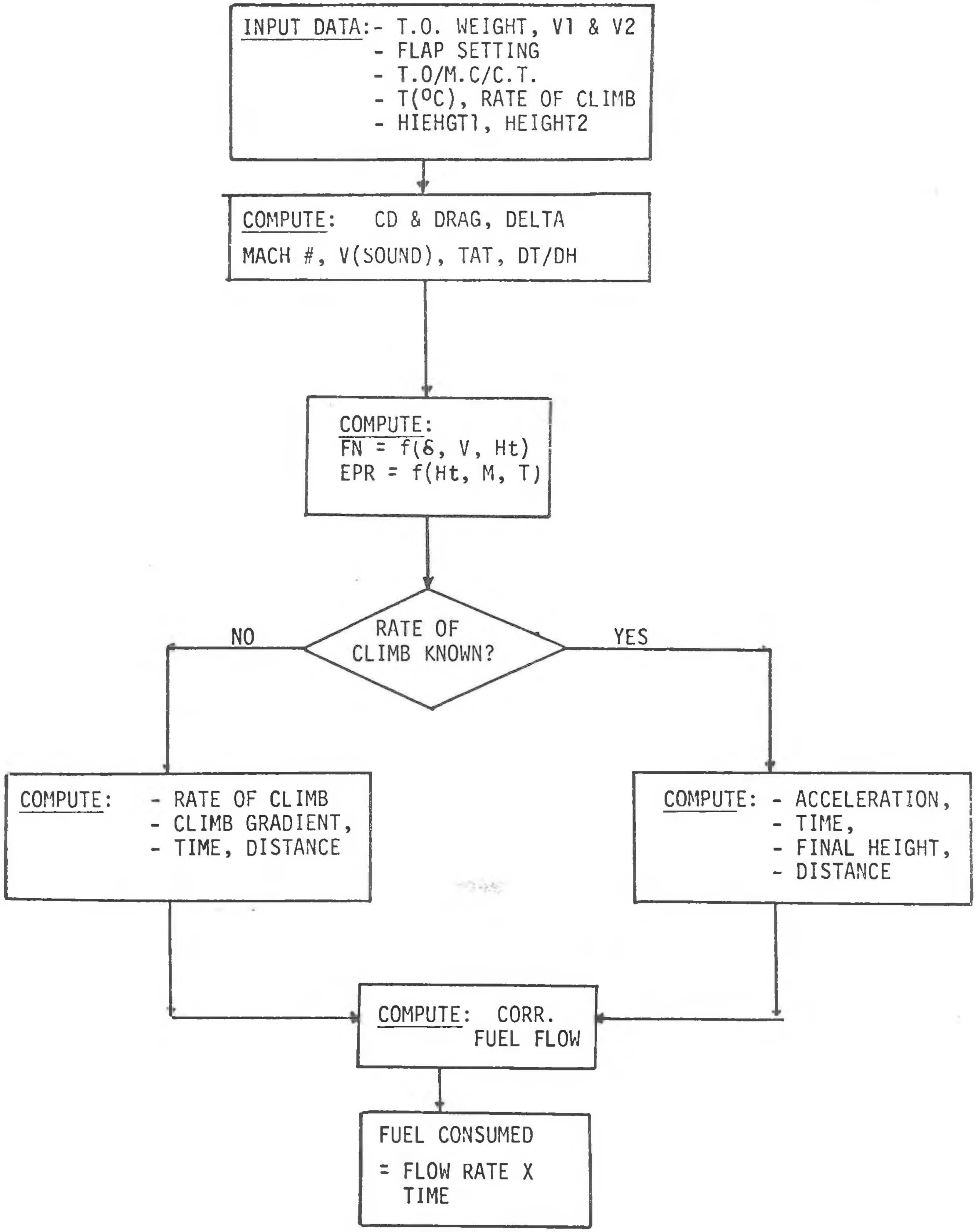

INPUT DATA:- T.O. WEIGHT, V1 & V2
- FLAP SETTING
- T.O/M.C/C.T.
- T(°C), RATE OF CLIMB
- HIEHGT1, HEIGHT2
COMPUTE: CD & DRAG, DELTA
MACH #, V(SOUND), TAT, DT/DH
COMPUTE:
FN = f(δ, V, Ht)
EPR = f(Ht, M, T)
RATE OF CLIMB KNOWN?
NO
YES
COMPUTE: - RATE OF CLIMB
- CLIMB GRADIENT,
- TIME, DISTANCE
COMPUTE: - ACCELERATION,
- TIME,
- FINAL HEIGHT,
- DISTANCE
COMPUTE: CORR.
FUEL FLOW
FUEL CONSUMED
= FLOW RATE X
TIME

FIGURE 5

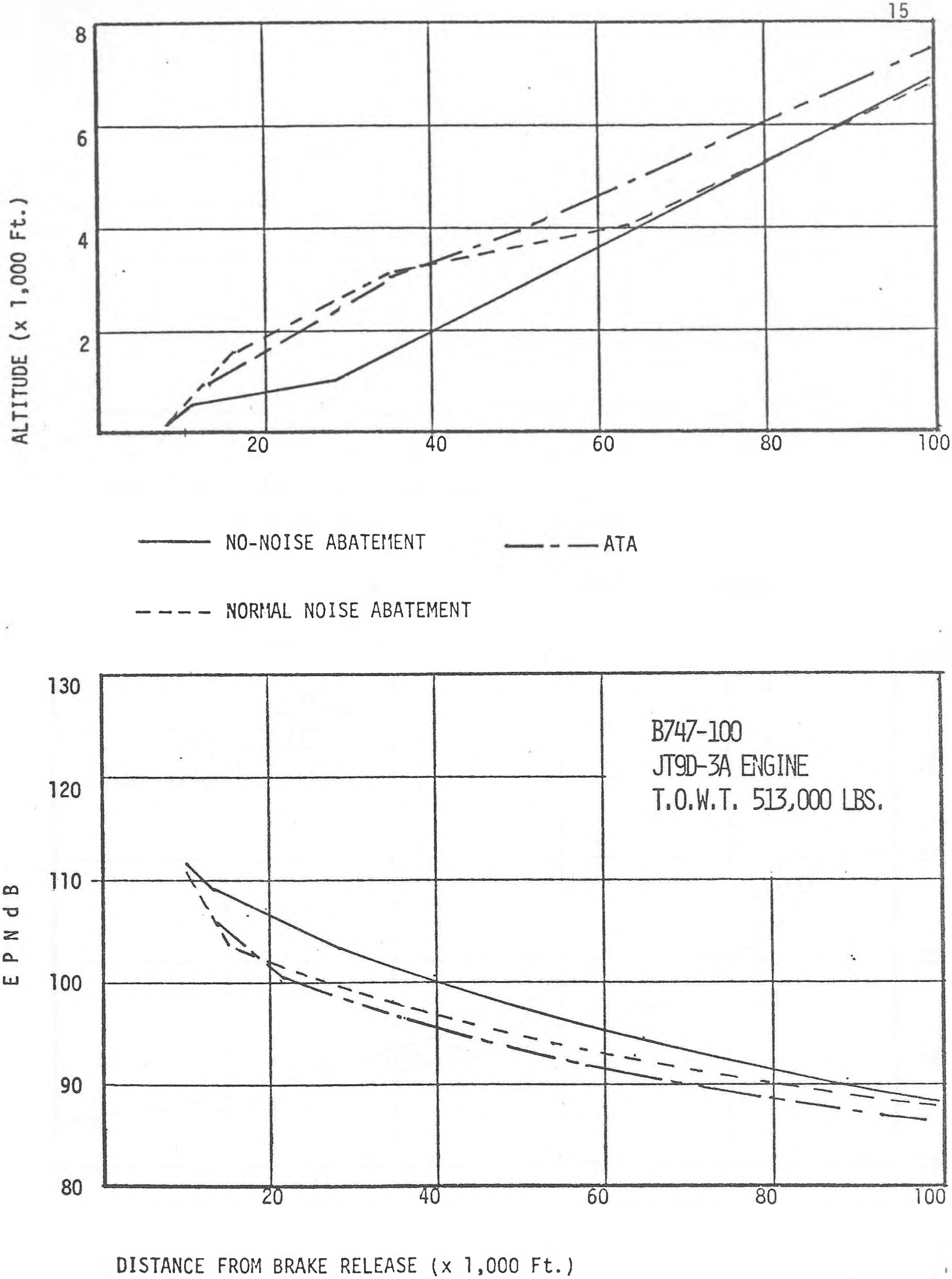

ALTITUDE (x 1,000 Ft.)
8
6
4
2
20
40
60
80
100
NO-NOISE ABATEMENT
ATA
NORMAL NOISE ABATEMENT
EPNdB
130
120
110
100
90
80
B747-100
JT9D-3A ENGINE
T.O.W.T. 513,000 LBS.
20
40
60
80
100
DISTANCE FROM BRAKE RELEASE (x 1,000 Ft.)

FIGURE 6

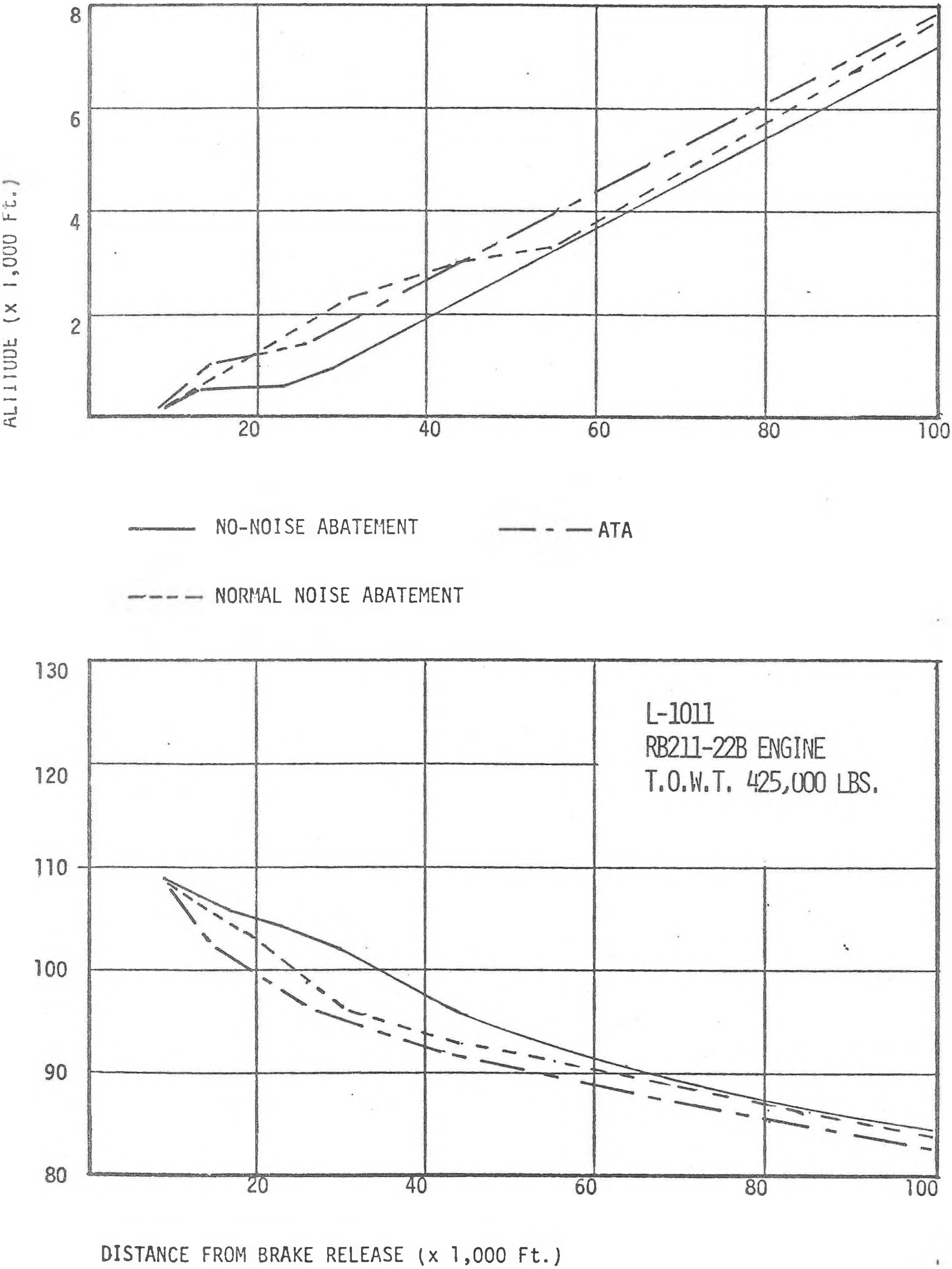

ALTITUDE (x 1,000 Ft.)
8
6
4
2
20
40
60
80
100
NO-NOISE ABATEMENT
ATA
NORMAL NOISE ABATEMENT
130
120
110
100
90
80
L-1011
RB211-22B ENGINE
T.O.W.T. 425,000 LBS.
20
40
60
80
100
DISTANCE FROM BRAKE RELEASE (x 1,000 Ft.)

FIGURE 7

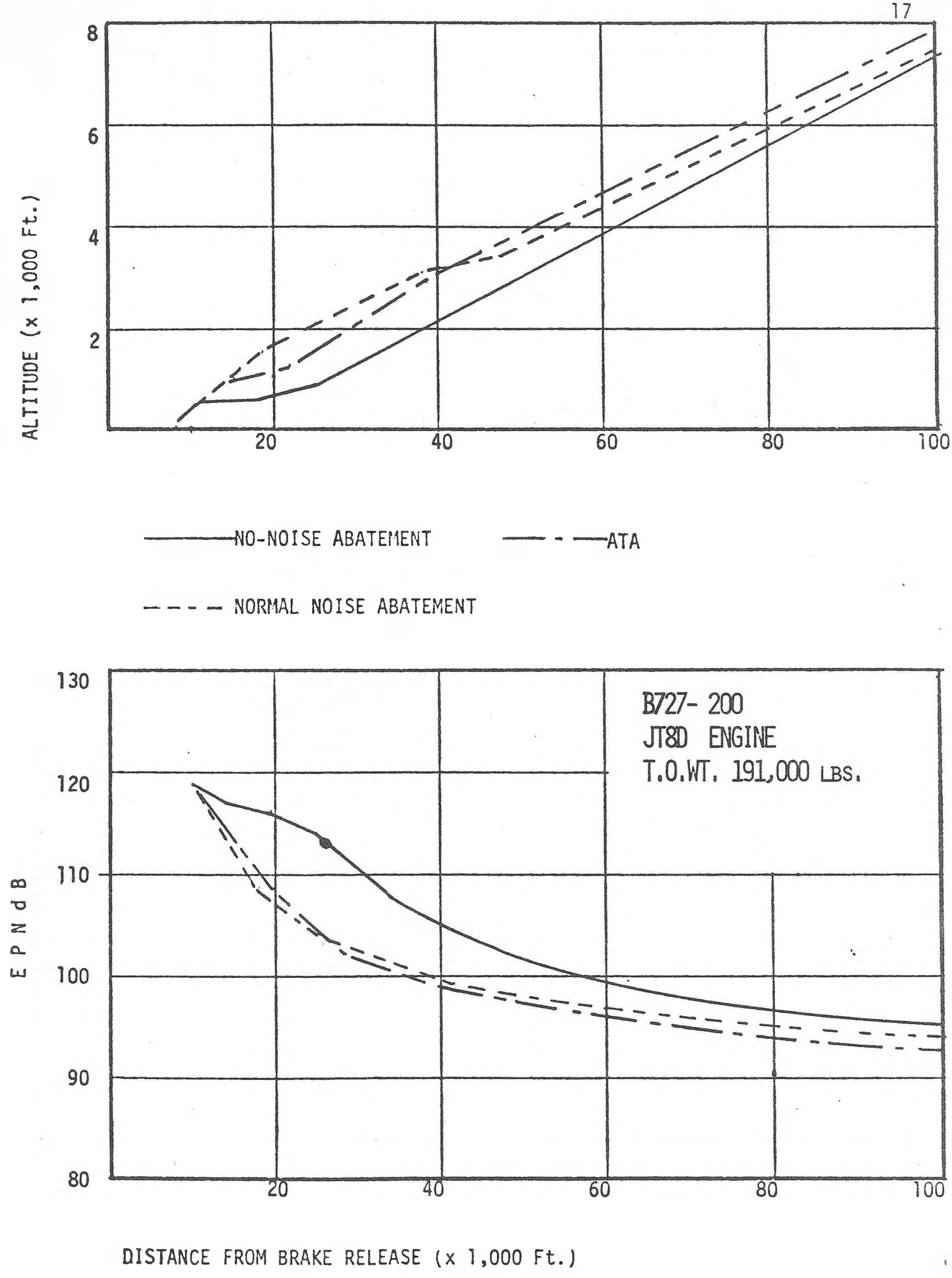

8
6
4
2
ALTITUDE (x 1,000 Ft.)
20
40
60
80
100
NO-NOISE ABATEMENT
ATA
NORMAL NOISE ABATEMENT
130
120
110
100
90
80
E P N d B
B727- 200
JT8D ENGINE
T.O.WT. 191,000 LBS.
20
40
60
80
100
DISTANCE FROM BRAKE RELEASE (x 1,000 Ft.)

FIGURE 8

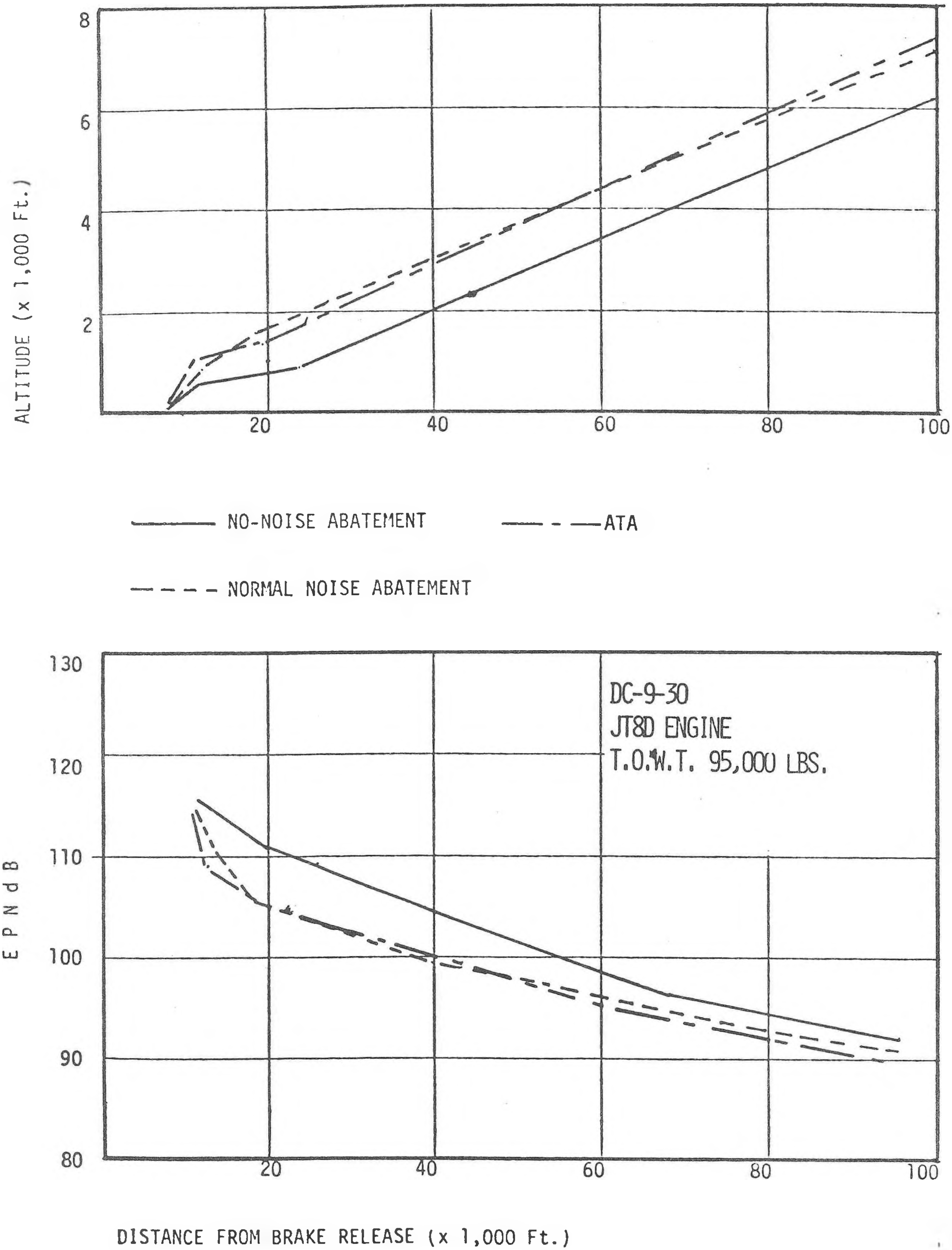

ALTITUDE (x 1,000 Ft.)
8
6
4
2
20
40
60
80
100
NO-NOISE ABATEMENT
ATA
NORMAL NOISE ABATEMENT
130
120
110
100
90
80
E P N d B
DC-9-30
JT8D ENGINE
T.O.W.T. 95,000 LBS.
20
40
60
80
100
DISTANCE FROM BRAKE RELEASE (x 1,000 Ft.)

FIGURE 9

TABLE 1

DEPARTURE TYPE	FEATURES
TYPE A (ATA PROCEDURE)	- TAKE-OFF THRUST - AT 1,000 FEET, RETRACT FLAPS - REDUCE THRUST, CLIMB AT VZF TO 3,000 FEET - ACCELERATE FROM VZF TO 250 KNOTS AND MAINTAIN APPROPRIATE RATE OF CLIMB
TYPE B (NORMAL NOISE ABATEMENT PROCEDURE)	- TAKE-OFF THRUST TO 1,500 FEET ALTITUDE - REDUCE THRUST TO CLIMB SETTING AND RETRACT FLAPS - ACCELERATE FROM VZF TO 250 KNOTS AND MAINTAIN APPROPRIATE RATE OF CLIMB

TABLE II

DEPARTURE TYPE	FUEL CONSUMED LBS.	COSTS $0.08/LB.
REFERENCE	3747.8	$299.82
TYPE A (ATA PROCEDURE)	3949.7	$315.98 (+ $16.16)
TYPE B (NORMAL NOISE ABATEMENT)	4740.9	$379.27 (+ $79.45)

TABLE III

DEPARTURE TYPE	FUEL CONSUMED Lbs.	COSTS $0.08/Lb.
Reference	3110.6	$248.85
Type A (ATA Procedure)	3382.1	$270.57 (+ $21.72)
Type B (Normal Noise Abatement)	3601.7	$288.14 (+ $39.29)

TABLE IV

Aircraft	Departure	Fuel Penalty (Lbs.)	Cost Penalty $0.08/Lb.
B727-200	Type A (ATA Procedure)	+ 188.2	+ $15.06
	Type B (Normal Noise Abatement)	+ 389.9	+ $31.19
DC-9-30	Type A (ATA Procedure)	+ 86.9	+ $ 6.95
	Type B (Normal Noise Abatement)	+ 112.7	+ $ 9.02

TABLE V

B747 Takeoff Weight (lb.)	Type A (ATA) Departure		Type B Departure	
	Fuel Penalty (lbs.)	Cost Penalty ($0.08/lb.)	Fuel Penalty (lbs.)	Cost Penalty ($0.08/lb.)
513,000	+ 201.9	$ 16.15	+ 993.1	$ 79.45
650,000	+ 181.3	$ 14.50	+ 1690.5	$ 135.24
700,000	+ 134.7	$ 10.78	+ 2501.3	$ 200.10