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VARIATION IN ENGINE NOISE FOR TWO LANDING-APPROACH CONFIGURATIONS OF A JET TRANSPORT AIRCRAFT

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Flight Research Center
Edwards, Calif.

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16. Abstract

A limited flight investigation was conducted to determine the effect of reduced flap deflections on power required and the resulting engine noise for a subsonic jet transport aircraft. Noise levels were measured during level flight at an altitude of 400 feet (122 meters) at approach speeds. Data were obtained during flybys with flap deflections of 50° and 36°.

The maximum overall sound pressure level (OASPL) from flybys with 36° of flap deflection averaged 3 decibels (ref. 0.00002 newtons/meter^2) lower than for flybys with 50° of flap deflection. Buffet intensity was reduced by the use of lower-flap deflections.

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INTRODUCTION

With the advent of jet transport aircraft in commercial airline service, noise in the vicinity of airports has been a matter of great concern to the general public, aircraft manufacturers, airline operators, and governmental regulatory agencies. When jet aircraft were first introduced, the noise produced during takeoff and landing was due primarily to the jet exhaust. More recently, with the introduction of larger, more powerful turbofan-powered aircraft, it has become apparent that compressor and fan discharge noise contribute significantly to the overall engine noise.

Many studies have been conducted to obtain a better understanding of jet-engine noise generation and propagation, and some studies have served to identify ways of reducing the noise caused by jet aircraft (for example, refs. 1 to 9). Some recent studies have dealt with reducing noise generation at the source, whereas others have proposed methods for operating jet transport aircraft to reduce the noise.

Methods for reducing generated noise necessitate extensive and costly modifications to engines or aircraft, or both. By following this approach, maximum results can be achieved only through lengthy design and development efforts to produce quiet engines. Such an approach will not alleviate the present jet-noise problem for several years, and the cost of retrofitting present aircraft may not be economically feasible.

Reference 3 and paper 26 in reference 9 describe several landing-approach profiles which can be flown to reduce noise by as much as 10 to 12 PNdB (perceived noise level) compared with the noise propagated during normal landing-approach profiles. In these profiles the noise reduction was a result of reduced engine power and increased altitude.

The present study was directed at providing some abatement of landing-approach noise, similar to that provided by the current practice of power reduction after takeoff. If successful, the proposed method could produce immediate results without significantly affecting the economies of airline operations. Therefore, a limited flight program was conducted to determine if the noise of an aircraft, approaching to land, could be reduced by flying in a lower drag configuration (less flap deflection) than that normally used; such a configuration would require less power to maintain a safe airspeed. The results of this program are presented and discussed in this report.

TEST AIRPLANE

The test airplane was a four-engine turbojet, all-metal, low-wing transport of medium-range, high-altitude capabilities. Constructed primarily of high-strength aluminum alloy, the airplane has an external appearance characterized by a 35° (measured at the quarter chord) swept-back wing of full cantilever construction with four antishock bodies, a single vertical tail, a conventional horizontal tail, and a tricycle landing gear. A photograph is shown in figure 1, and table I lists the pertinent dimensions of the airplane.

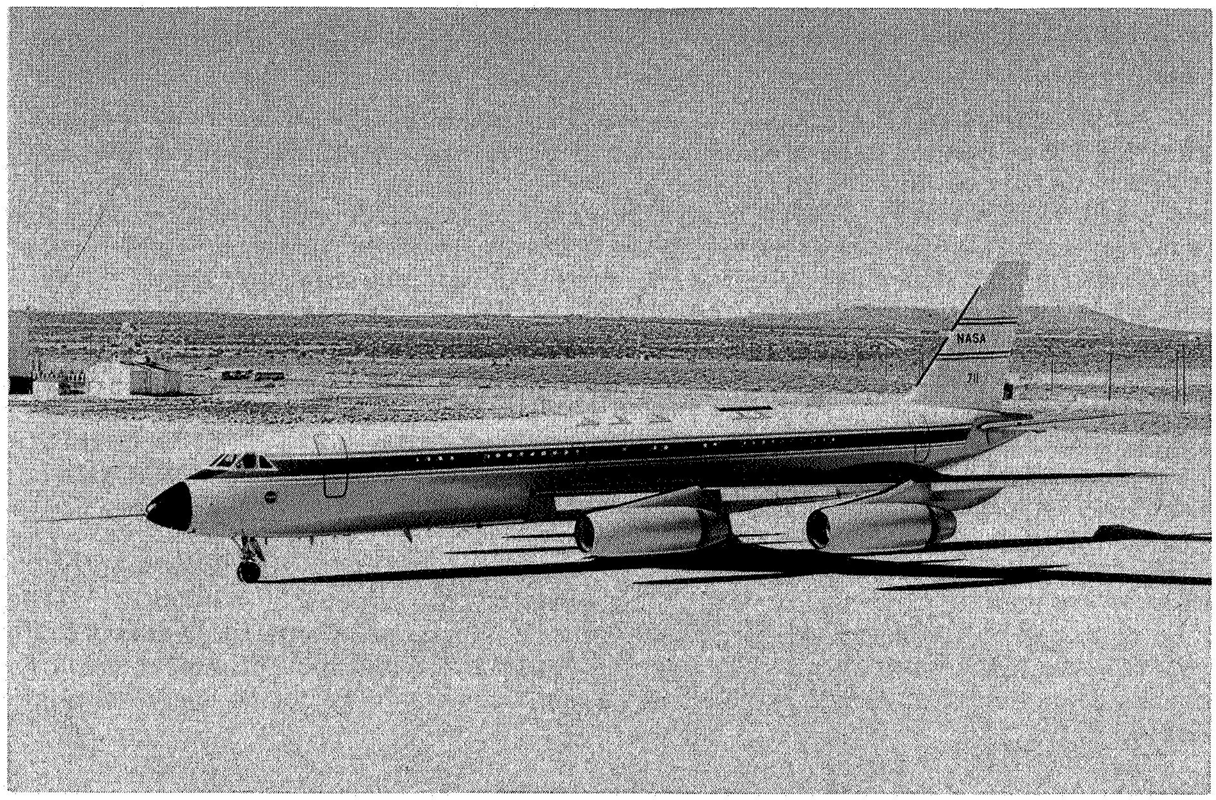

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Figure 1.– Subsonic jet transport test airplane.

The powerplants used were turbojet, axial-flow, aft-fan engines with a takeoff rating in the 16,000-pound- (711,680-newton-) thrust class. The engine incorporates a 17-stage axial-flow compressor which is driven by a three-stage reaction turbine, a cannular combustion section, a free-floating single-stage aft fan, a fixed-area concentric-exhaust section with a thrust reverser, and a hydromechanical fuel control.

A cutaway schematic drawing of the engine is shown in figure 2. Pertinent engine specifications are given in table II and performance values in table III.

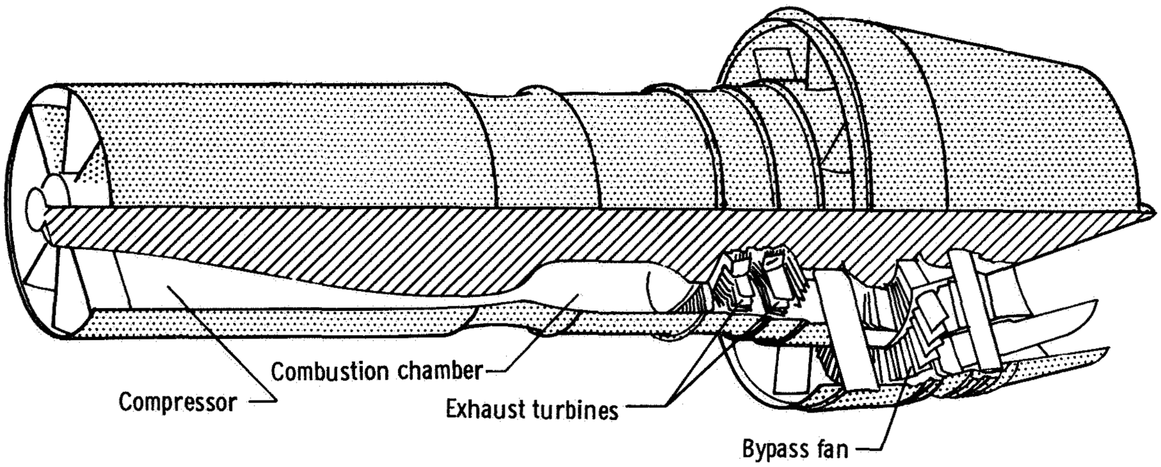
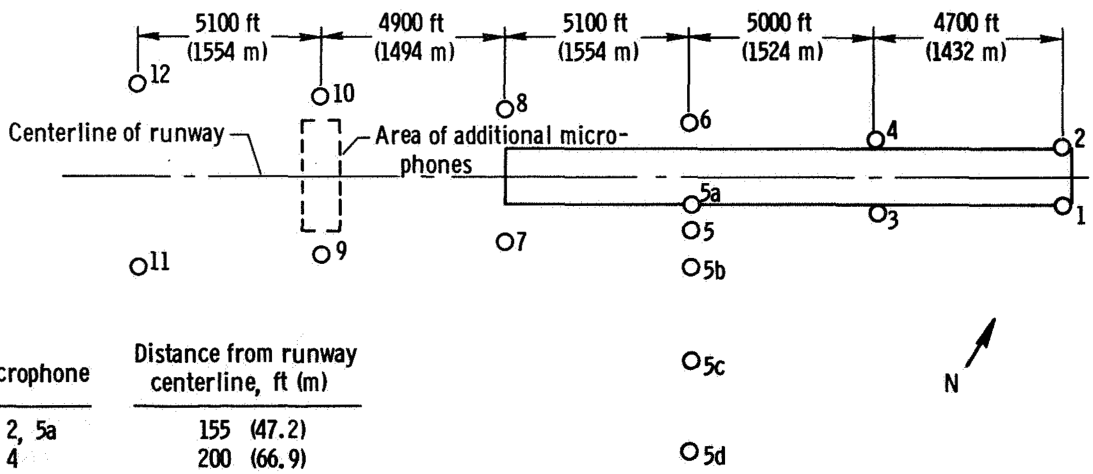


Figure 2.– Sketch of the aft turbofan engine.

NOISE-MEASUREMENT RANGE

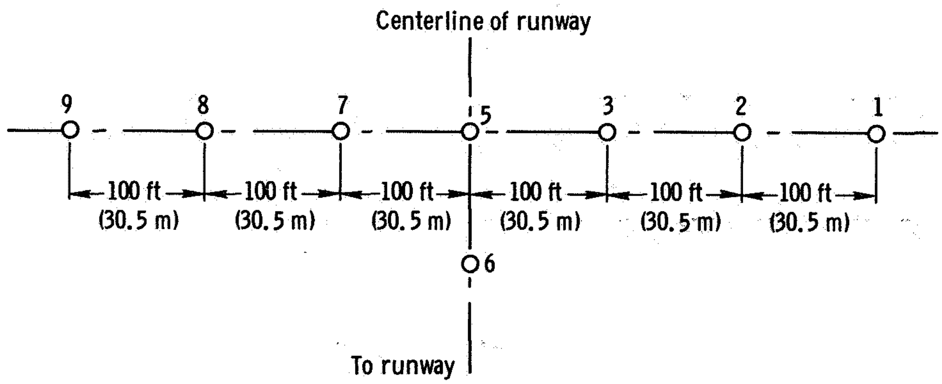
The NASA Flight Research Center at Edwards, Calif., developed and is operating a noise-measurement range. The range is along and beyond the 300-foot- (91.4-meter-) wide, 15,000-foot- (4572-meter-) long main runway at Edwards Air Force Base, as shown in figure 3(a). Sixteen separate, self-contained microphone stations and a signal-conditioning and recording system comprise the noise-measurement range. Also shown in figure 3(a) is an area in which additional microphones were installed. Figure 3(b) shows the arrangement of the additional microphones.



Microphone	Distance from runway centerline, ft (m)
1, 2, 5a	155 (47.2)
3, 4	200 (66.9)
5, 6	290 (88.4)
7, 8	360 (109.7)
9, 10	430 (131.1)
11, 12, 5b	500 (152.4)
5c	1000 (304.8)
5d	1500 (457.2)

(a) Normal runway noise-range microphone positions.

Figure 3.– Microphone locations along the main runway at Edwards Air Force Base.



(b) Microphone locations in the area of additional microphones in figure 3(a).

Figure 3.– Concluded.

A schematic diagram of a range microphone station and the signal-conditioning and recording system is shown in figure 4. The station consisted of a microphone and a microphone power supply with an amplifier to drive the data signal through buried cable to an instrument van. Power was supplied by batteries through an inverter. The cable from each microphone station was terminated at the van with a line isolation transformer; then the signal was routed to an amplifier and recorded on an instrumentation type of magnetic-tape recorder. A time-code receiver was used to decode the master time signal broadcast by Edwards Air Force Base to obtain time of day, which was also recorded on the tape.

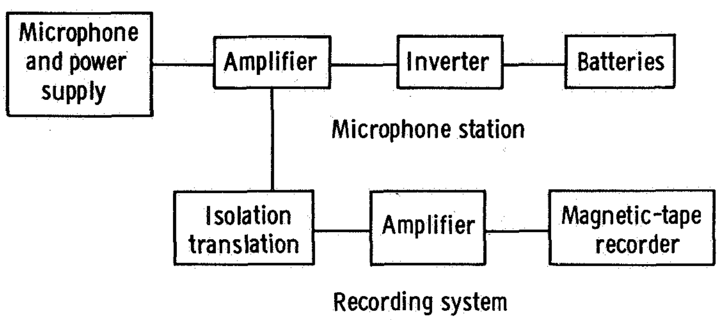


Figure 4.– Schematic diagram of microphone station and recording system for normal runway microphones shown in figure 3(a).

A schematic diagram of one of the additional microphone stations and signal-conditioning and recording system is presented in figure 5. The system consisted of a microphone and an inductance to form a tuned radio-frequency circuit, connected to an oscillator at the recording station by a low-impedance coaxial cable. A diode detector circuit was used to recover the microphone signal, which was then amplified and recorded on an instrumentation type of magnetic-tape recorder. Time of day was also recorded from a portable time generator synchronized with the Base broadcast time.

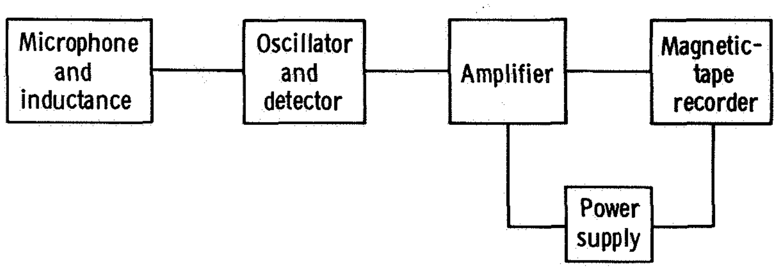


Figure 5.– Schematic diagram of microphone station and recording station for additional microphones shown in figure 3(b).

The entire instrument range was calibrated electrically and acoustically. The electrical calibration consisted of introducing a 1-volt root-mean-square signal at various frequencies from 20 hertz to 20,000 hertz and determining any variation in recorded signal level. The microphone and electrical-system calibrations were combined to obtain the total recording-system calibration.

Periodic system recalibrations are performed as necessary to insure that the system response does not vary more than ±0.2 decibel. Pre-test and post-test acoustic calibrations are made. Instrumentation accuracy is ±1.5 decibels for the measured overall noise levels presented.

DATA-REDUCTION SYSTEM

A schematic diagram of the noise-analysis system is shown in figure 6. An instrumentation type of magnetic-tape playback unit was used to recover the data signal, which was routed to a noise analyzer to obtain an average overall sound pressure level (OASPL). The OASPL signal was then routed through a log converter to a strip-chart recorder.

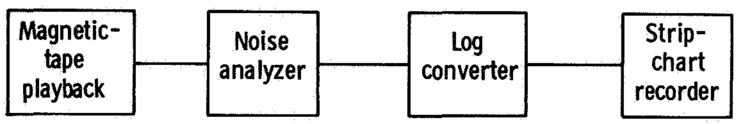


Figure 6.– Schematic diagram of data-reduction system.

TEST PROCEDURES AND CONDITIONS

Procedures

Constant-altitude flybys for obtaining noise data were planned to be flown at a speed that would provide the same stall-speed margin regardless of the configuration. The configuration variables were the flap position and the airplane gross weight. The stall-speed margin was arbitrarily set at $0.3\ V_S + 10$ knots (5.1 m/sec), where V_S was the handbook stall speed for each selected flap deflection and the existing airplane gross weight. Thus, the desired approach speed for these tests was $1.3\ V_S + 10$ knots (5.1 m/sec). This speed is commonly utilized in the test airplane during normal, full-flap approaches by many of the commercial users.

The radar altimeter was used as the reference to maintain a constant altitude of 400 feet (122 meters) above the ground for all flybys. The flap position was preset for each flyby prior to entering the noise range. At the same time the engine power was preset at levels estimated by the pilot to yield the desired approach speed. Once set, the engine power remained constant, and the airspeed was allowed to stabilize as the airplane approached the noise measuring range. When the airplane entered the range, the instrument-panel readings of airspeed and fuel quantity were recorded. Gross weight and the desired approach speed were then calculated and recorded. These data are presented in the following table:

TEST AIRPLANE COCKPIT-INSTRUMENT READINGS FOR NOISE-MEASUREMENT FLYBYS

Airplane flyby	Time (PST)	Flap deflection, deg	Indicated airspeed,		Radar altitude,		Gross weight,		Desired approach speed,		Engine pressure ratio	Fuel flow,	
			knots	m/sec	ft	m	lb	kg	knots	m/sec		lb/min	kg/min
1	0835	50	150	77.2	400	122	185,200	84,006	150	77.2	1.50	4800	2177
2	0843	50	156	80.2	400	122	182,600	82,827	149	76.6	1.52	4900	2223
3	0850	36	162	83.3	400	122	180,700	81,965	149	76.6	1.44	4300	1950
4	0904	36	161	82.8	400	122	177,800	80,650	148	76.1	1.44	4300	1950

The desired flight track was along the range centerline, as shown in figure 3(a). The flyby direction was west to east for all data passes. The flight track was flown by using visual reference only. Airplane space-position data were not obtained; however, pilots and observers reported that the airplane was within 50 feet (15 meters) of the centerline for all flybys.

Weather

All flybys were flown within a half-hour period at Edwards Air Force Base, Calif. Some local meteorological data for this period are presented in the following tabulation:

EDWARDS AIR FORCE BASE SURFACE WEATHER

[Elevation 2302 feet (701.6 meters)]

Time (PST)	Station pressure,		Altimeter setting,		Temperature,		Dew point,		Wind direction, deg	Wind velocity,	
	in. Hg	N/m^2	in. Hg	N/m^2	°F	°C	°F	°C		knots	m/sec
0800	27.855	94,317	30.29	102,562	24	-4	8	-22	300	2	1.03
0900	27.865	94,351	30.30	102,596	30	-1	9	-23	Calm	Calm	

The effects of changes in atmospheric conditions on the airplane noise propagated to the surface were expected to be minimized by obtaining data for all flybys within a one-half-hour period. There was an inversion layer at 350 feet (107 meters) above the surface during the test period. The temperature at the 400-foot (122-meter) flight level was about 50° F (10° C) for all flybys.

RESULTS AND DISCUSSION

Effects of Flaps on Power Required for Level Flight

As previously stated, the power settings required to maintain the desired approach speed in level flight for the two flap settings were estimated by the pilot, set up, and thereafter remained constant for the flybys. The airspeed was then allowed to stabilize at the expected approach speed. A comparison of the indicated airspeed and desired approach speed (which varied over a range of only 2 knots (1.1 m/sec) for the variations in gross weight and flap settings) given in the tabulation at the top of this page shows that the power used was high, particularly for the flybys at the 36° flap deflection where the indicated airspeed was 13 knots (6.7 m/sec) too fast. A linear extrapolation of the data shown in the table indicates that the power setting required to maintain level flight at the desired approach speed should have been at an engine pressure ratio (EPR) of 1.40 instead of the 1.44 value used. This decrease in power setting would tend to reduce the noise generated by the four jet engines.

Pilots and passengers reported that there was a noticeable amount of buffet associated with full-flap deflection on the test airplane. With flap deflection reduced to 36°, the amount of buffet was reduced.

Effect of Flap Setting on Noise

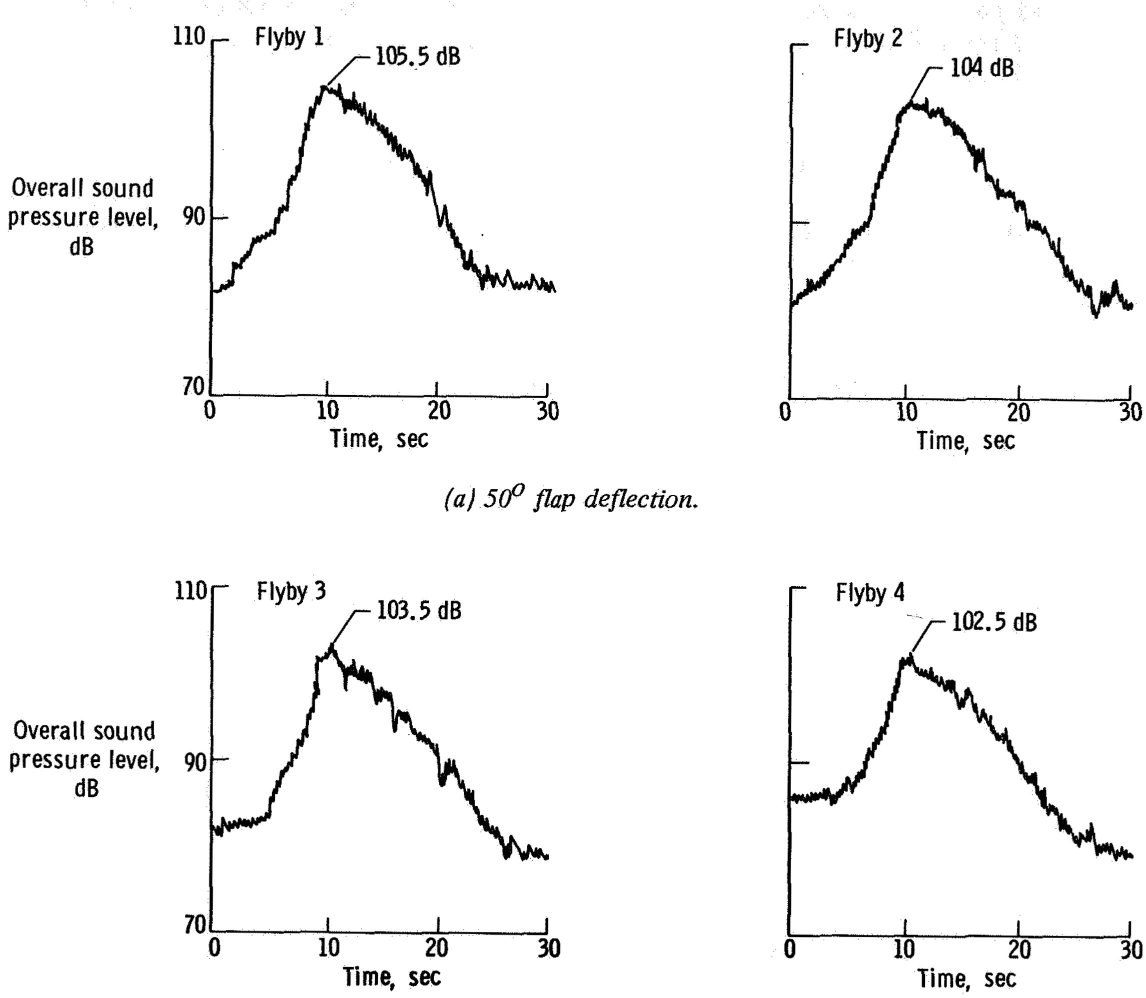
The overall sound pressure levels were measured during four flyby passes using all microphones of the noise-measurement range (figs. 3(a) and 3(b)). However, only the data from 19 representative microphones are presented and discussed. The tabulation below presents the peak average overall sound pressure level and the microphone distance from the range centerline for each of the four flyby passes of the test airplane. Microphone numbers prefixed with "P" are the microphone positions shown in figure 3(b), and microphone numbers prefixed with "B" are the microphone positions shown in figure 3(a). The airplane flap deflection and engine power setting are also given.

PEAK OVERALL SOUND PRESSURE LEVEL FOR JET TRANSPORT FLYBYS

Microphone			OASPL, dB (ref. 0.00002 newtons/meter^2)			
Number	Distance from range centerline,		Aircraft flyby			
	ft	m	1	2	3	4
P-1	300 L*	91.4	104	103	101.5	100
P-2	200 L	61.0	105	104.5	102	101
P-3	100 L	30.5	105	104.5	102	101
P-5	0	0	105.5	104	103.5	102.5
P-6	0	0	104.5	104	102	102
P-7	100 R**	30.5	105	104	102	101
P-8	200 R	61.0	103.5	103	101	100.5
P-9	300 R	91.4	103.5	102.5	100.5	99.5
B-10	430 L	131.1	102	102	98	98
B-9	430 R	131.1	102	102	99	99
B-5a	155 R	47.2	105	105	101	101
B-5	290 R	88.4	103	103	100	100
B-5b	500 R	152.4	102	102	98	99
B-5c	1000 R	304.8	94	95	91	92
B-5d	1500 R	457.2	93	93	90	90
B-6	290 L	88.4	103	104	100	99
B-7	360 R	109.7	102	101	97	98
B-11	500 R	152.4	103	103	99	100
B-12	500 L	152.4	102	101	98	98
Flap deflection, deg			50	50	36	36
Engine pressure ratio			1.50	1.52	1.44	1.44

*L indicates microphones to the left of the flight track.
**R indicates microphones to the right of the flight track.

Typical time-history profiles of overall sound pressure levels recorded during each flyby are shown in figures 7(a) and 7(b). Microphone P-5 was selected as representative of all microphones. The data in figure 7 show a reduction in maximum average overall sound pressure level from 0.5 decibel to 3 decibels for the flybys at the reduced flap deflection of 36°.

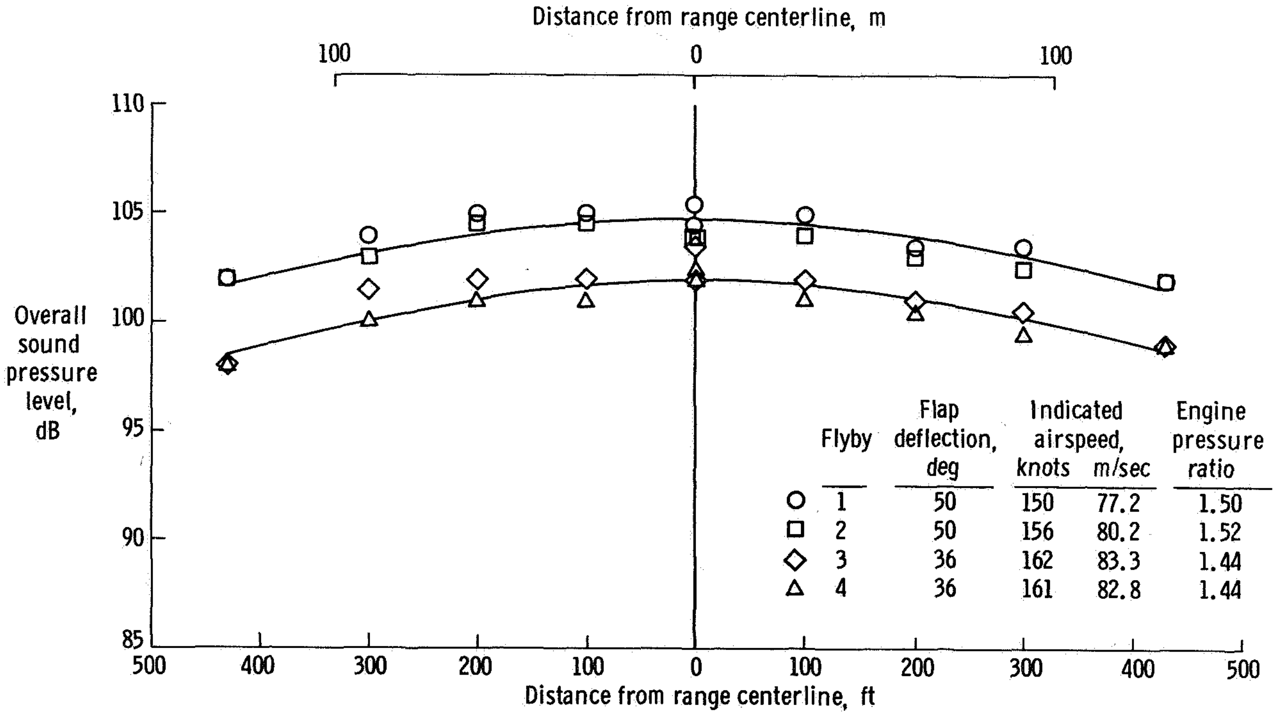


(a) 50° flap deflection.

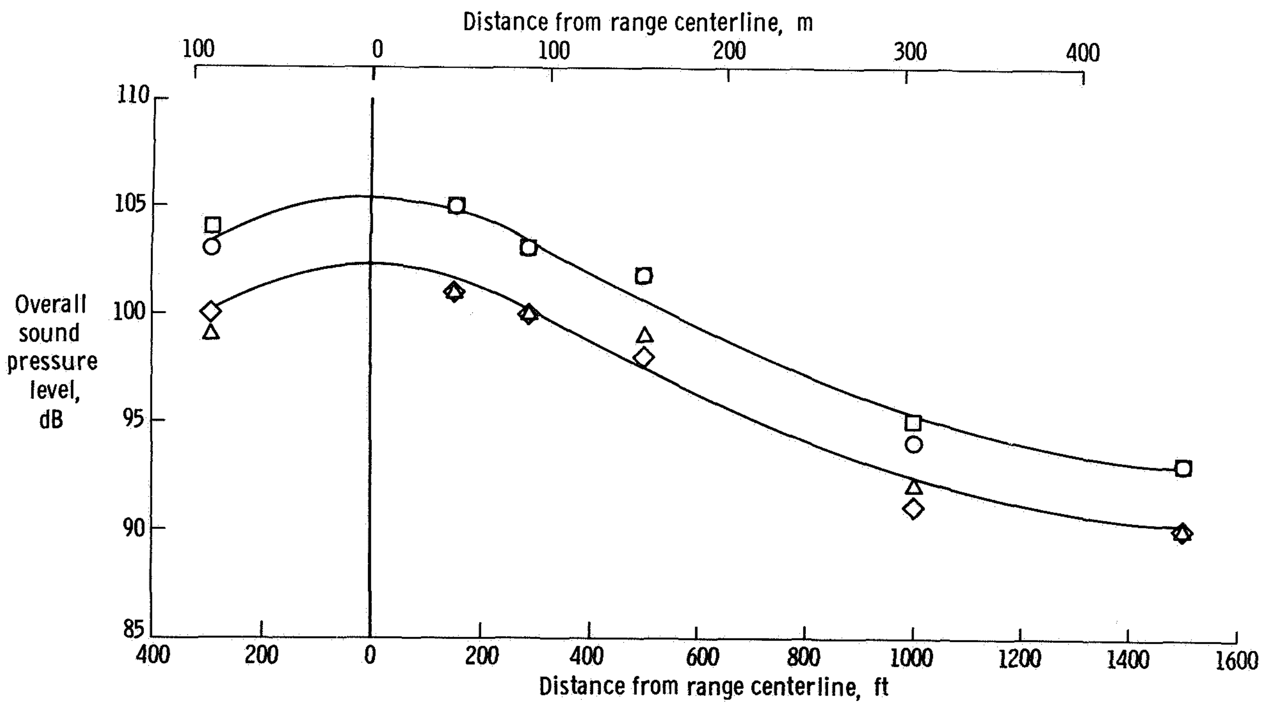
(b) 36° flap deflection.

Figure 7.– Typical time histories of overall sound pressure level for the four flybys (microphone P-5). Note: Data-reduction system was calibrated for relative 30-dB linearity.

The maximum average overall sound pressure levels recorded during all flybys for selected microphone positions are summarized in figures 8(a) and 8(b). The data are shown as a function of the distance from the noise-range centerline. These data show that an average reduction in maximum overall sound pressure level of 3 decibels was achieved by operating the airplane at a flap deflection of 36° instead of the full flap deflection of 50°.



(a) 4900 ft (1494 m) west of west end of runway.



(b) 5100 ft (1554 m) east of west end of runway.

Figure 8.– Peak average overall sound pressure levels on the ground created by the test airplane at an altitude of 400 ft (122 m) in a landing configuration.

CONCLUDING REMARKS

A limited flight program was conducted with a subsonic, four-engine jet transport to determine the effect of reduced flap deflections on power required and the resulting engine noise. The maximum average overall sound pressure level from two flybys with 36° of flap deflection was 3 decibels lower than for two flybys with 50° of flap deflection. The reduced flap deflection had no significant effect on the desired approach speed for the test airplane at the gross weights existing for the tests.

Actual speeds at which tests were performed with the flaps deflected 36° were higher than necessary. Therefore, it is believed that additional noise reduction would be achieved by maintaining the recommended approach speeds with their associated reduced engine power settings.

Pilots and passengers reported a reduction in buffet intensity with reduced flap deflection.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., August 12, 1969.

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TABLE I. – TEST AIRPLANE DIMENSIONS AND AREAS

Overall dimensions –	
Span, ft (m)	120 (36.6)
Length (nose to trailing edge of elevator panels), ft (m)	139.20 (42.43)
Height (over vertical stabilizer), ft (m)	39.36 (12.00)
Fuselage –	
Maximum width (outside), ft (m)	11.50 (3.50)
Cabin interior width, ft (m)	10.67 (3.25)
Maximum height (not including antenna housing), ft (m)	12.42 (3.79)
Length, ft (m)	134.75 (41.72)
Wing –	
Airfoil section:	
Root (extended chord)	NACA 0011-64 (Mod)
31.5 percent semispan (break)	NACA 0009-64 (Mod)
Tip	NACA 0008-64 (Mod)
Incidence (root), deg	4
Span (aerodynamic), ft (m)	117.99 (35.96)
Area (total), ft^2 (m^2)	2250 (209.0)
Root chord, ft (m)	29.15 (8.88)
Tip chord, ft (m)	8.83 (2.69)
Mean aerodynamic chord (leading edge at fuselage station 821.1), ft (m)	20.83 (6.35)
Dihedral (at manufacturing chord plane), deg	7
Aspect ratio, $\frac{\text{Span}^2}{\text{Area}}$	6.2
Sweep (leading edge), deg	39
Flaps	Double slotted
Leading-edge devices (Krueger flaps)	Extensible
Engine pod clearance:	
Inboard, ft (m)	3.29 (1.00)
Outboard, ft (m)	4.23 (1.29)
Horizontal tail –	
Airfoil section designation:	
Root	NACA 009-64 (Mod)
Tip	NACA 008-64 (Mod)
Area, ft^2 (m^2)	426.5 (39.6)
Dihedral, deg	7.5
Sweep (leading edge), deg	41
Span, ft (m)	38.74 (11.81)
Vertical stabilizer –	
Airfoil section designation:	
Root	NACA 0010-64 (Mod)
Tip	NACA 0008-64 (Mod)
Area, ft^2 (m^2)	295 (27.4)
Sweep (30-percent chord), deg	35

TABLE II. – ENGINE SPECIFICATIONS

Engine type	Aft-fan turbojet
Airflow:	
Gas generator, lb/sec (kg/sec)	168 (76.2)
Aft fan, lb/sec (kg/sec)	237 (107.5)
Pressure ratio:	
Gas generator	12.5 to 1
Fan	1.54 to 1
Engine length, in. (m)	148 (3.76)
Engine diameter:	
Compressor inlet, in. (m)	31.6 (0.80)
Fan inlet, in. (m)	53.0 (1.35)
Gas-generator exit-nozzle and area, ft^2 (m^2)	3.1 (0.29)
Fan exit-nozzle and area, ft^2 (m^2)	3.9 (0.36)

TABLE III. – ENGINE SEA-LEVEL STATIC PERFORMANCE*

Condition	Net thrust,		Net specific fuel consumption,	
	lb	N	$\left(\frac{\text{lb/hr}}{\text{lb thrust}}\right)$	$\left(\frac{\text{kg/hr}}{\text{N}}\right)$
Takeoff	16,100	716,130	0.560	0.057
Maximum continuous	14,400	640,510	.545	.056
Maximum cruise	13,350	593,810	.540	.055

*Based on standard day of 59° F (15° C) temperature and 80-percent relative humidity; use of specified turbine fuel having an average lower heating value of 18,600 Btu/lb and oil conforming to Specification MIL-L-7808C; no load on accessory drives; no inlet screens; no compressor air bleed; a concentric jet nozzle; and 100-percent ram recovery.

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