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MEASURED NOISE REDUCTIONS RESULTING FROM MODIFIED APPROACH PROCEDURES FOR BUSINESS JET AIRCRAFT

Frank W. Burcham, Jr., Terrill W. Putnam,
Paul L. Lasagna, and O. Owen Parish

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16. Abstract

Five business jet airplanes were flown to determine the noise reductions that result from the use of modified approach procedures. The airplanes tested were a Gulfstream II, JetStar, Hawker Siddeley 125-400, Sabreliner-60 and LearJet-24. Noise measurements were made 3, 5, and 7 nautical miles from the touchdown point. In addition to a standard 3° glide slope approach, a 4° glide slope approach, a 3° glide slope approach in a low-drag configuration, and a two-segment approach were flown. It was found that the 4° approach was about 4 EPNdB quieter than the standard 3° approach. Noise reductions for the low-drag 3° approach varied widely among the airplanes tested, with an average of 8.5 EPNdB on a fleet-weighted basis. The two-segment approach resulted in noise reductions of 7 to 8 EPNdB at 3 and 5 nautical miles from touchdown, but only 3 EPNdB at 7 nautical miles from touchdown when the airplanes were still in level flight prior to glide slope intercept. Pilot ratings showed progressively increasing workload for the 4°, low-drag 3°, and two-segment approaches.

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INTRODUCTION

The application of recent technological advances in aeroacoustics to new aircraft has resulted in significant reductions in noise at the source. The reduction of aircraft noise at the source, usually the aircraft engines, is economically justifiable only when considered in the initial aircraft design, however. Consequently, operational techniques for reducing the noise of existing aircraft are being sought.

Most of the more than 1600 business jet aircraft currently in use in North America are powered by turbojet or low bypass ratio turbofan engines not specifically designed for low noise. Test data are required to formulate operational procedures for use by the operators of these aircraft to minimize community noise, particularly for landing approach, since noise reductions are potentially large.

The Flight Research Center recently completed a series of tests using several business jet aircraft to evaluate the noise reduction achievable by using different landing approach techniques. The tests were conducted by the National Aeronautics and Space Administration (NASA) with the cooperation of the Federal Aviation Administration (FAA) and the National Business Aircraft Association (NBAA).

Flight safety considerations usually require aircraft to be stabilized in the landing configuration and at final approach speed prior to reaching a point at least 2 nautical miles from touchdown. Consequently, changes to operational techniques offer little hope for noise reductions at the FAR Part 36 measuring station 1 nautical mile from the threshold. For this study, three types of approaches were selected that appeared to have potential for reducing the noise at distances from 3 to 8 nautical miles from touchdown and, based on discussions with various pilots and representatives of NASA, the FAA, and the NBAA, are probably operationally feasible. Noise measurements were made at distances of 3, 5, and 7 nautical miles from touchdown. At least six approaches of each type were made. In addition, several standard 3° glide slope approaches were flown.

The test aircraft included a Grumman Gulfstream II, a Lockheed JetStar, a Hawker-Siddeley (HS) 125-400, a Rockwell Sabreliner-60, and two consecutively used Gates LearJet-24's. These five airplanes represent over 60 percent of the business jet transports operating in North America. The JetStar was provided by the NASA Flight Research Center. The other airplanes and flight crews were provided through the efforts of the NBAA; United States Steel provided the Gulfstream II, Beech-Hawker the HS 125-400, Rockwell the Sabreliner-60, and Gates and Lacey Aviation the two LearJet-24's.

This report presents the noise measurements for the four types of approaches in terms of effective perceived noise level. Only data from the microphones located on the approach centerline are presented. Pilot ratings of the degree of difficulty of flying the various approaches are also given.

SYMBOLS

D	distance from touchdown point, n. mi.
$EPNL$	effective perceived noise level, EPNdB
h	altitude above the ground, m (ft)

APPROACH DESCRIPTION

The four types of approaches flown are shown in figure 1. The standard 3° glide slope approach (fig. 1(a)), which is flown at normal approach speed, is used as the baseline approach. The glide slope was intercepted 822 meters (2700 feet) above the ground, about 8.5 nautical miles from touchdown.

The landing gear and landing flaps were extended at the glide slope intercept. In normal operations, the landing gear may not be extended until the outer marker is reached (about 5 nautical miles from touchdown). In some cases, pilots may also delay the use of full landing flaps until closer to touchdown. However, the use of full landing configuration at glide slope intercept provides a "worst case" baseline with which to evaluate the other approaches.

The second type of approach (fig. 1(b)) was flown on a 4° glide slope at normal approach speed in the landing configuration. The 4° approach was selected because it could be implemented without any additional guidance information by simply raising the glide slope angle. The 4° approach was expected to reduce the noise because of the higher altitudes and the slightly lower power settings required. The landing gear and flaps were extended at glide slope intercept 914 meters (3000 feet) above the ground, about 7 nautical miles from touchdown.

The third type of approach flown (fig. 1(c)) was a two-segment approach at normal approach speed with a 6° glide slope upper segment and a 3° glide slope

lower segment. The transition point was at an altitude of 230 meters (750 feet), about 2.3 nautical miles from the touchdown point. The noise levels on the upper segment would be expected to be considerably reduced compared with the standard 3° approach because of the higher altitude and reduced power setting required. No change in noise would be expected on the inner 3° segment. Gear and landing flaps were extended when the 6° glide slope was intercepted. Glide slope intercept occurred 914 meters (3000 feet) above the ground 6 nautical miles from touchdown. Considerable experience with this type of approach has been accumulated for commercial jet transports (ref. 1), but few data are available for the business jet class of airplanes.

The fourth type of approach flown (fig. 1(d)) was a 3° glide slope approach flown in a low-drag configuration at a reference speed plus approximately 20 knots. The glide slope was intercepted 822 meters (2700 feet) above the ground 8.5 nautical miles away from touchdown. An approach flap setting was used with the landing gear retracted until a point 2.5 nautical miles from touchdown was reached. At this point, the landing gear was extended, flaps were extended to the landing setting, and power was added to maintain speed. This type of approach, called the low-drag approach, would be expected to reduce approach noise because of the considerably lower power setting required in the low-drag configuration.

The three approaches selected for comparison with the standard approaches are undoubtedly not the only types of approaches that would be useful in studying approach noise reductions. However, they are believed to cover a suitable range of the variables. No attempt was made to optimize any of the approaches for the airplane flown. The optimum approach for one airplane might not be optimum for another airplane.

One other type of approach, a decelerating approach, was considered in this study. Reference 2 showed that substantial noise reductions were possible with this approach, and it was briefly evaluated using the JetStar airplane. The approach was flown on a 3° glide slope, with an airspeed from 200 to 220 knots at glide slope intercept. Engine power was reduced to idle, the flaps were progressively lowered as speed was bled off, the gear was extended, and engine power was increased as the reference speed was reached. It was evident to the pilots that this approach would be difficult to use, however, because of the effects of winds along the glide slope and the need to continually change speed and configuration during the approach.

It may be possible to develop an automatic system to handle a decelerating approach. However, without such a system a decelerating approach does not appear to be operationally feasible for business jets, and this type of approach was not considered further for this study.

TEST AIRPLANES

The five airplanes flown in the approach noise study are shown in figure 2. The characteristics of the airplanes are presented in table 1 (from ref. 3). Each of

these airplanes has a low wing, a cruise Mach number of about 0.8, and engines mounted on the aft fuselage.

The Gulfstream II (fig. 2(a)) is the largest airplane, with a maximum weight of 275,800 newtons (62,000 pounds). It is powered by two Rolls-Royce Spey low bypass ratio turbofan engines and can carry up to 19 passengers.

The JetStar (fig. 2(b)) has a maximum weight of 186,800 newtons (42,000 pounds). It is powered by four Pratt & Whitney JT12A-8 turbojet engines and accommodates up to 13 passengers.

The HS 125-400 (fig. 2(c)) has a maximum weight of 103,638 newtons (23,300 pounds). It is powered by two Rolls-Royce Viper 522 turbojet engines and can carry up to 12 passengers.

The Sabreliner-60 (fig. 2(d)) has a maximum weight of 88,900 newtons (20,000 pounds). It is powered by two Pratt & Whitney JT12A-8 turbojet engines and can carry up to ten passengers.

The smallest aircraft tested is the LearJet-24 (fig. 2(e)). It has a maximum weight of 57,800 newtons (13,000 pounds) and is powered by two General Electric CJ610-4 turbojet engines. The LearJet-24 can seat up to six passengers.

All these airplanes are operated with a crew of two.

INSTRUMENTATION

Data for the flight tests were acquired from four sources: acoustic instrumentation, weather instrumentation, radar tracking, and instrumentation on board each airplane.

Acoustic Instrumentation

The placement of the microphone stations along the approach ground track is shown in figure 3. Microphones were placed on the runway centerline, on the hard packed clay lakebed surface 3 and 5 nautical miles from the touchdown point. Microphones were also placed 7 nautical miles from the touchdown point on sandy soil about 10 meters (33 feet) above the lakebed elevation. Additional microphones were placed at lateral positions 762 meters (2500 feet) and 1524 meters (5000 feet) off the ground track, as shown in figure 3. The microphones were mounted approximately 1.2 meters (48 inches) above the ground, which was free of vegetation. For redundancy in case of the failure of a microphone system and to aid in checking the validity of the data, two identical microphone stations were placed at each extended centerline position.

Condenser microphones with a diameter of 2.54 centimeters (1 inch) with cathode followers, power supplies, and line drive amplifiers were used at each

station. The line drive amplifiers incorporated a preemphasis filter circuit which provided additional amplification between 1000 hertz and 20,000 hertz to improve the signal-to-noise ratio at the higher frequencies. The signal from the line drive amplifier was routed through shielded two-conductor cable to a mobile acoustic van, where the data were recorded on a 14-track wideband fm recorder. Voice comments describing each test and a broadcast time code were also recorded. There were three mobile acoustic data vans, one near each extended centerline position.

Before and after each day's test, an acoustic calibration was applied to each microphone. The resulting signal was recorded for use in the data reduction process. In addition, a pink noise calibration was recorded for each microphone system so the effects of the preemphasis filtering could be removed during data processing.

Weather Instrumentation

A portable instrumentation tower with a height of 10 meters (30 feet) was erected at the mobile acoustic data van, which was near the 5-nautical-mile microphone station. Wind speed and direction were monitored to insure that the wind speed did not exceed the limits set for the tests. Ambient temperature and dew point temperature were recorded for each data run. These data were used for correcting the data to standard day conditions in accordance with FAR Part 36 (ref. 4).

Radar Tracking

A ground-based fixed-pedestal precision tracking radar (FPS-16) was used to provide glide slope information to the pilots and to correlate the aircraft position with the noise measurements. To aid in tracking, a portable radar transponder beacon was carried on each airplane tested. The same beacon was used to locate the microphone stations and the visual approach slope indicator (VASI) light at the touchdown point. Time of day and the radar data were recorded on magnetic tape for later processing. The radar data were also displayed on a plot board for glide slope and ground track information, and were used as inputs for a digital computer which calculated and displayed the deviation from the desired glide slope to the ground controller.

Aircraft Onboard Instrumentation

Data descriptive of the aircraft operating conditions during each approach were read from cockpit instruments. These included airspeed, rate of descent, engine rpm, engine pressure ratio and fuel flow, fuel quantity (used for gross weight determination), and flap and landing gear positions.

TEST CONDITIONS

The flights were conducted when the wind, temperature, and humidity were within the allowable limits as stated in FAR Part 36 (ref. 4) for noise measurements.

Surface temperatures were generally 4° C to 15° C (40° F to 60° F), winds less than 7 knots, and humidity between 30 and 60 percent. Winds aloft were sometimes higher than the surface winds, and in a few instances significant wind shears about 300 meters (1000 feet) above the ground were reported by the pilots. Ambient noise levels were generally low when data were being acquired. A few approaches had to be repeated, because other aircraft interfered with the noise measurements on the sideline microphone locations.

TEST PROCEDURE

The test aircraft were flown by a NASA research pilot. A company crew member for each airplane acted as copilot except for the JetStar, which was flown by two NASA pilots. Prior to flight, the operational characteristics of each airplane were reviewed and the operator's experience in his aircraft was used to establish the procedure to be followed. Each aircraft was flown on at least 2 days in the approach noise study. Twelve approaches were scheduled on each day: three two-segment approaches were flown first, then three low-drag 3° approaches, three 4° approaches, and finally three standard 3° approaches.

The approaches were flown over lakebed runway 23 on Rogers Dry Lake (elevation 693 m (2275 ft)) to a simulated touchdown point at the far end of the runway. For all approaches, an approach flap setting was selected about 10 nautical miles from touchdown, prior to glide slope intercept. The approach profiles shown in figure 1 were flown down to a point 1 to 1.5 nautical miles from touchdown. A go-around was then initiated.

Each aircraft normally started the first approach at approximately maximum landing weight. The weight change was significant during the tests, particularly for the smaller airplanes, but no corrections were made to the data for weight effects.

The normal approach speed was selected by the crew of each airplane, and was generally 5 to 10 knots over the manufacturer's handbook reference speed for the existing weight and airplane configuration. For the standard 3° approach, the 4° approach, and the two-segment approach, landing gear and landing flaps were selected at glide slope intercept and speed was held essentially constant through the approach. For the low-drag 3° approach, the approach flap setting was maintained at glide slope intercept, and a speed of about 20 knots above the approach flap reference speed was maintained to approximately 5 nautical miles from touchdown. At this point, the speed was reduced if necessary to permit the landing gear and landing flaps to be extended at 2.5 nautical miles from touchdown. Because of the differing speed restrictions and flap settings for each airplane, there were considerable variations in speed for the low-drag approaches. Typical airspeeds read at the 5-nautical-mile location are shown in table 2 for the various airplanes and the four types of approaches.

For each approach, the crew recorded the airplane weight, speed, engine power settings, and airplane configuration at the 5-nautical-mile point. Deviations from the established procedures at other times were also noted.

The pilots used a combination of a VASI light and ground-controlled approach (GCA) callouts to maintain the desired glide slope on all except the two-segment approaches. For the two-segment approaches, the VASI was moved to the point where the 6° upper segment intersected the ground, and the transition and 3° glide slope were flown on GCA callouts only. Glide slope was usually maintained within 15 meters (50 feet), except during wind shear or turbulence, which caused deviations of up to 46 meters (150 feet). A typical series of glide slopes is shown in figure 4. The deviations are believed to be representative of those occurring during normal approach conditions. The pilots maintained the desired ground track visually using the runway painted on the dry lakebed. Only small deviations from the track occurred.

At the end of each flight, the pilot recorded a pilot rating for the degree of difficulty of each type of approach using the Cooper-Harper rating scale (ref. 5), a subjective rating on a scale from 1 to 10 (fig. 5). Ratings greater than 3.5 are not desirable for operational procedures.

DATA REDUCTION AND ANALYSIS

The radar tracking data were smoothed and then processed to relate the aircraft position with respect to time to each microphone location. The distance between the airplane and the microphone was later used to make atmospheric absorption corrections to the noise measurements.

The acoustic data were processed with a computer-controlled real time analyzer that met the FAR Part 36 specification (ref. 4) for equipment used to analyze aircraft noise data. The data were scaled and frequency corrections were made. Test day values of overall sound pressure level, perceived noise level, and tone-corrected perceived noise level were then calculated.

The noise levels measured at large distances from an aircraft are often limited by background or system noise levels. The application of atmospheric absorption corrections to background or system noise levels to obtain standard day spectra results in erroneous answers. Therefore, the following technique was used in applying atmospheric absorption corrections. The first spectrum in the recording of a particular run was taken to be the background or system noise spectrum. When the difference between the spectrum at the maximum tone-corrected perceived noise level and the background, at frequencies greater than 400 hertz, was equal to or less than 3 decibels, the atmospheric absorption correction consisted of the value used for the last band with a signal-to-noise ratio greater than 3 decibels. The corrected spectrum was then used in the calculation of the effective perceived noise level.

In most cases, six approaches of each type were flown, with two centerline microphones available for each approach at each location. The time histories were examined for adequate signal-to-noise ratio and possible spurious noise inputs. The results from the adjacent microphones were compared. All valid measurements were averaged, and the standard deviations were computed.

RESULTS AND DISCUSSION

Noise Measurements

The noise measurement data are summarized in table 3. The number of valid measurements for each approach at each location varied from 4 to 20, with an average of 12. The standard deviations varied considerably. Most of the variations occurred when the winds along the glide slope varied significantly from one day to another. The different noise levels always correlated with the different engine power settings required.

The effective perceived noise level (EPNL) as a function of distance from touchdown for the five airplanes flying the four types of approaches are shown in figure 6. As expected, the standard 3° approach was the noisiest at all three measuring stations for all airplanes. The noise reductions from the standard 3° approach varied considerably from one airplane to another.

For all five airplanes, the two-segment approach noise reduction was larger at the 3-nautical-mile and 5-nautical-mile locations, where the airplane was on the 6° segment, than at the 7-nautical-mile point, where the airplane was in level flight (fig. 1(c)). The 6° glide slope was intercepted at about 6 nautical miles from touchdown, and the decrease in noise was faired into the two-segment data at this point.

The low-drag and 4° glide slope approaches resulted in reduced noise at all three measurement locations. The amount of reduction varied with the particular airplane. For example, the low-drag approach on the HS 125-400 showed very large noise reductions (fig. 6(c)), but the Sabreliner-60 showed only small reductions (fig. 6(d)).

A better understanding of the relative noise levels measured for the various approaches can be gained by examining the difference in noise level between the standard 3° approach and each of the other approaches. These differences or noise reductions from the standard 3° approach are summarized in figure 7.

For the 4° glide slope (fig. 7(a)), a fairly consistent noise reduction of 4 to 5 EPNdB was shown at the three measuring locations. The noise reduction resulted because the airplanes were at a higher altitude over each measurement location and because the aircraft engines were at lower power settings, since less power was required to fly down the 4° glide slope than the 3° glide slope. The consistency of the reductions was probably due to the fact that the airplane configuration and speed were similar to the standard 3° approach.

The low-drag 3° approach noise reductions varied from between 13 and 14 EPNdB for the HS 125-400 to only 4 EPNdB for the Sabreliner-60. The noise reduction occurred for this type of approach because the aircraft flaps were only partially deflected and because the landing gear was retracted until each aircraft was about 2.5 nautical miles from touchdown. This low-drag configuration required less thrust, which consequently reduced the engine noise. The noise reduction for a given airplane is approximately the same at the three measuring locations. Two

factors are believed to be responsible for the large variation in noise reduction on the low-drag 3° approaches. The first is that the flap setting selected for the low-drag approach (table 1) varied for each airplane, according to the preference of the flight crew and the flap settings available. Thus, the drag increment, and hence the noise increment, between the standard and the low-drag approach was different for each airplane. Note the large difference between approach flap and landing flap settings for the HS 125-400. The normal approach flap setting is 25°, but it cannot be used unless the landing gear is down. The second factor concerns the absolute noise level of the standard 3° approach for each airplane (fig. 8). The HS 125-400 and JetStar are significantly noisier than the other three airplanes at all three measurement locations, possibly because of the 50° landing flap setting used. Since these airplanes were the noisiest on the standard approach, they had the largest potential for noise reduction. The Gulfstream II, the largest airplane tested, was relatively quiet on the standard 3° approach. This is because it has large engines which were operating at low thrust. Furthermore, the engines are turbofans, so the jet velocities are lower. The Sabreliner-60, which uses only 25° of landing flaps, is the quietest airplane on the standard 3° approach (fig. 8) and shows only small noise reductions in the low-drag approach (fig. 7(b)).

The absolute noise levels on the low-drag 3° approach are shown for each airplane in figure 9. The JetStar is noisiest and the LearJet-24 is the quietest. It appears that the low-drag 3° approach can give large noise reductions only if an airplane has a large drag increment between the landing configuration and a usable low-drag approach flap configuration.

The two-segment approach noise reductions are shown in figure 7(c). At the 3- and 5-nautical-mile measurement locations, substantial noise reductions occurred because of the increased altitude and reduced thrust required on the 6° segment. The reductions are generally larger at 5 nautical miles than at 3 nautical miles because at the 5-nautical-mile station the airplanes were well above the 3° glide slope, while at 3 nautical miles the 6° segment was only about 65 meters (200 feet) above the 3° glide slope. At the 7-nautical-mile location, the reductions were smaller because the airplanes were still flying level prior to glide slope intercept, with the engines at the thrust level required to maintain level flight. If the 6° glide slope intercept altitude were raised, the noise reductions at 7 nautical miles would probably exceed those shown at 5 nautical miles.

A comparison of absolute noise levels for the airplanes flying the two-segment approach is shown in figure 10. The JetStar, Gulfstream II, and LearJet-24 tended to group together, with the HS 125-400 noisier and the Sabreliner-60 quieter, particularly at the 3- and 5-nautical-mile locations. On the 6° glide slope, some of the airplanes were at or near idle thrust, particularly if a tail wind existed along the glide slope. This might not be operationally acceptable for airplanes that require engine bleed air for anti-icing. It also makes speed control on the 6° segment more difficult.

To summarize the results in figure 7, it is evident that noise reductions are fairly consistent for the 4° approach, but that results for the low-drag and two-segment approaches are strongly dependent on the airplane characteristics.

To determine the overall effect of the business jet noise reduction approaches, a fleet-weighted average, based on the airplane distribution shown in table 4, was found (fig. 11). It shows about a 4.2-EPNdB reduction for the 4° approach (fig. 11(a)); an 8.5- to 9-EPNdB reduction for the low-drag approach (fig. 11(b)); and a 3- to 8.5-EPNdB reduction for the two-segment approach (fig. 11(c)).

An additional factor to consider is the noise reduction that would be expected inside the 3-nautical-mile point, where the low-drag and the two-segment approaches would not be expected to be significantly different from the standard 3° approach. However, the 4° approach noise reductions would be expected to continue down to touchdown.

PILOT RATINGS

Pilot ratings for all of the approaches were taken. The approach procedures were not optimized for each airplane, and the GCA and VASI guidance used for glide slope information was less desirable than a cockpit glide slope display, and added to the workload. However, the fact that the approaches were flown in VFR conditions may have compensated for some workload. Since these approaches were not conventional instrument approaches, the values of the pilot ratings shown in figure 12 may not be as significant as the differences in the ratings for the four types of approaches. Ratings for the standard 3° approach are between 1 and 2.

The 4° approaches were rated 1.5 to 2.5, indicating only a slight increase in pilot workload. One pilot commented that the 4° approach seemed like a 3° approach with a 10-knot tailwind.

Pilot ratings for the low-drag approach varied between 2 and 4. The trim changes during the configuration change 2.5 nautical miles from touchdown caused some increase in pilot workload, as did the power changes that were required.

The two-segment approach received pilot ratings between 3 and 5. Glide slope and speed control on the 6° segment were more difficult, although the lack of an onboard glide slope display was undoubtedly a contributing factor. Wind shear on the 6° segment were more of a problem than on the lower glide slope approaches. The power change during the transition to the 3° segment was also a factor.

CONCLUDING REMARKS

The Flight Research Center flew a series of approaches with five business jet aircraft to determine the noise reductions that resulted from modified approach procedures. It was found that an approach with a 4° glide slope was about 4 EPNdB quieter than an approach with a standard 3° glide slope. Noise reductions for a low-drag 3° approach varied widely among the airplanes tested, with an average reduction of 8.5 EPNdB on a fleet-weighted average. A two-segment approach resulted in noise reductions of 7 to 8 EPNdB at 3 and 5 nautical miles from the

touchdown point, but only 3 EPNdB for a point 7 nautical miles from touchdown when the airplanes were still in level flight prior to glide slope intercept. Pilot ratings showed progressively increasing pilot workload for the 4°, low-drag 3°, and two-segment approaches.

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TABLE 1.–AIRPLANE DIMENSIONS AND WEIGHTS

	Gulfstream II	JetStar	HS 125-400	Sabreliner-60	LearJet-24
Wingspan, m (ft)	20.98 (68.8)	16.60 (54.5)	14.33 (47.0)	13.54 (44.4)	10.84 (35.7)
Overall length, m (ft)	24.36 (79.9)	18.4 (60.4)	14.45 (47.5)	14.73 (48.3)	13.18 (43.2)
Height, m (ft)	7.47 (24.5)	6.23 (20.4)	5.03 (16.5)	4.88 (16.0)	3.84 (12.6)
Weight –					
Maximum takeoff, N (lb)	275,776 (62,000)	186,816 (42,000)	103,638 (23,300)	88,900 (20,000)	57,824 (13,000)
Maximum landing, N (lb)	260,208 (58,500)	155,680 (35,000)	88,960 (20,000)	77,840 (17,500)	52,842 (11,880)
Empty, N (lb)	153,011 (34,400)	98,185 (22,074)	54,532 (12,260)	50,707 (11,400)	30,024 (6,750)
Engine type	2 RR/Spey/MK511-8 turbofan	4 P&W JT12A-8 turbojet	2 RR Viper 522 turbojet	2 P&W JT12A-8 turbojet	2 GE CJ610-4 turbojet
Maximum thrust per engine, N (lb)	50,707 (11,400)	14,678 (3,300)	14,945 (3,360)	14,678 (3,300)	12,677 (2,850)
Wing area, m^2 (ft^2)	73.7 (793.5)	50.4 (542.5)	32.8 (353)	31.78 (342.0)	21.53 (231.8)
One-quarter-chord wing sweep, deg	25	30	20	28.5	13
Flap type –					
Leading edge	- - - - - - - - - - -	Hinged	- - - - - - - - -	Aerodynamically actuated slat	- - - - - - - - -
Trailing edge	Fowler	Double slotted	Double slotted	Single slotted	Single slotted
Approach flap setting, deg	20	20	15	15	20
Landing flap setting, deg	39	50	50	25	40

TABLE 2.–AVERAGE AIRSPEED OVER 5-NAUTICAL-MILE POSITION

Type of approach	Airplane				
	Gulfstream II	JetStar	HS 125-400	Sabreliner-60	LearJet-24
	Average airspeed over 5-nautical-mile position, knots				
Standard 3°	135	130	118	114	110
4°	135	130	124	115	115
Two-segment	150	140	140	130	125
Low-drag 3°	160	150	145	127	160

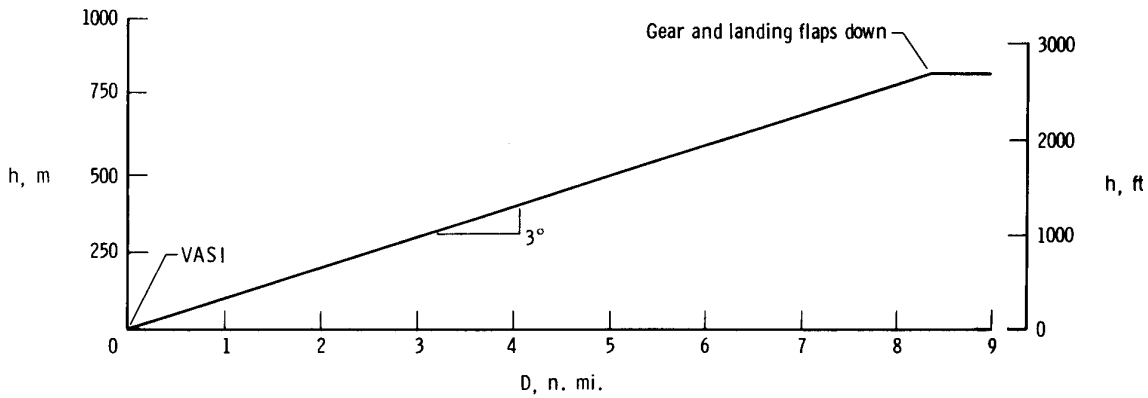
TABLE 3.–MEASURED NOISE DATA

Airplane	Type of approach	Distance from touchdown, n. mi.								
		3			5			7		
		Number of measurements	Average EPNL	Standard deviation	Number of measurements	Average EPNL	Standard deviation	Number of measurements	Average EPNL	Standard deviation
Gulfstream II	Standard 3°	12	90.6	0.7	14	86.0	1.4	8	83.9	1.6
	4°	11	86.8	0.5	14	82.8	0.8	8	79.6	0.9
	Low-drag 3°	12	85.1	0.7	14	81.1	0.9	7	79.1	1.2
	Two-segment	14	86.3	0.8	14	79.2	1.9	4	80.2	1.7
JetStar	Standard 3°	8	95.5	0.5	8	90.4	0.5	8	87.7	0.3
	4°	6	89.9	0.6	12	85.5	1.3	12	85.5	1.3
	Low-drag 3°	12	86.9	1.5	12	82.3	1.3	12	80.3	1.0
	Two-segment	10	87.7	1.7	10	80.1	1.4	12	84.6	0.9
HS 125-400	Standard 3°	12	97.3	0.6	12	91.9	1.2	10	89.3	2.4
	4°	12	92.6	1.2	12	87.2	1.6	12	85.2	2.2
	Low-drag 3°	12	82.9	1.0	11	79.5	1.4	12	76.3	1.5
	Two-segment	12	91.0	0.8	12	84.3	1.2	10	86.0	1.6
Sabreliner-60	Standard 3°	13	90.3	1.8	18	84.9	2.9	15	82.0	2.6
	4°	16	86.3	2.2	18	79.6	2.9	15	77.9	2.5
	Low-drag 3°	15	86.2	1.5	18	81.3	2.4	12	78.0	2.9
	Two-segment	16	80.0	0.75	20	74.8	1.3	14	81.4	2.2
LearJet-24	Standard 3°	8	91.5	1.0	12	86.7	1.5	12	84.5	1.4
	4°	8	87.6	1.9	10	83.2	2.6	12	78.9	1.5
	Low-drag 3°	8	80.9	0.3	14	75.9	1.6	14	74.2	0.5
	Two-segment	12	85.8	2.2	12	79.1	2.3	9	80.6	2.0

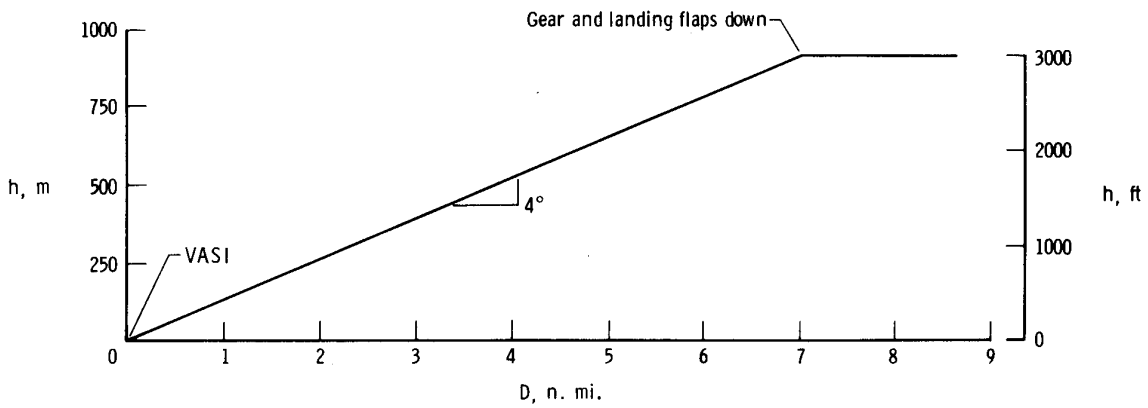
TABLE 4.–NUMBER OF BUSINESS JET AIRCRAFT REPRESENTED BY AIRCRAFT TESTED IN THIS STUDY

(From ref. 6; number of business jets in North America as of Jan. 1975, 1615)

Airplane	Number operating in North America
Gulfstream II	136
JetStar	128
HS 125	174
LearJet	357
Sabreliner	193
	Total: 988

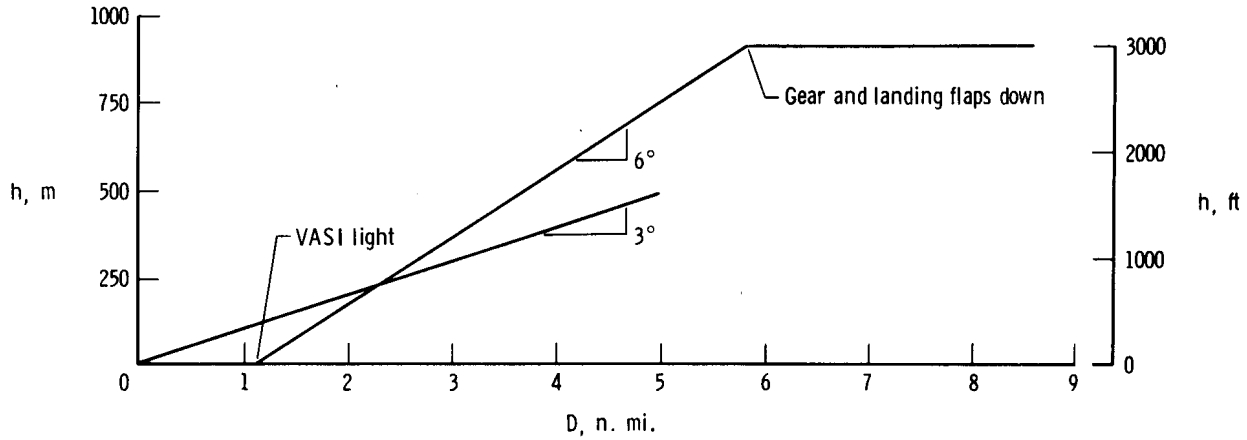


(a) Standard 3° approach.

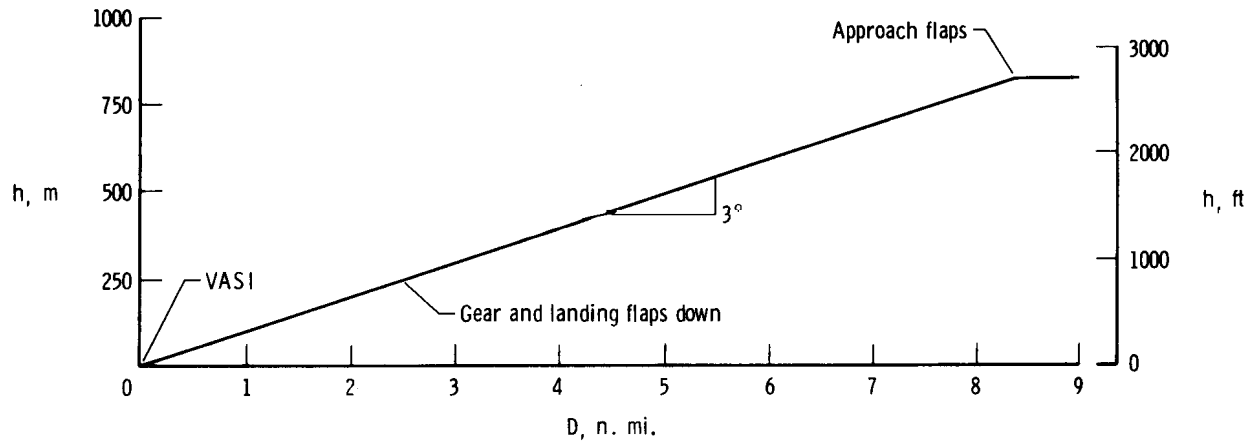


(b) 4° approach.

Figure 1. Approaches flown.

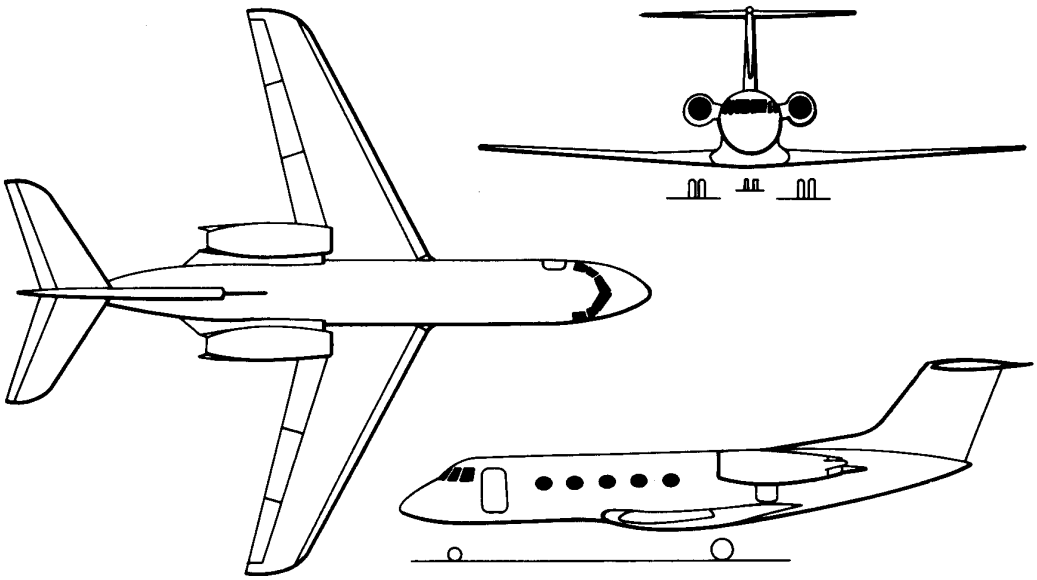


(c) Two-segment approach.

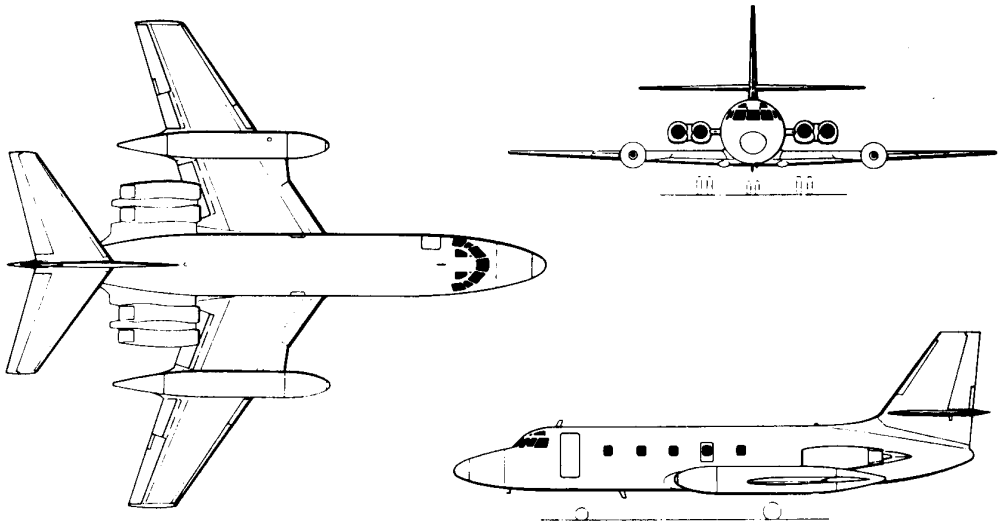


(d) Low-drag 3° approach.

Figure 1. Concluded.

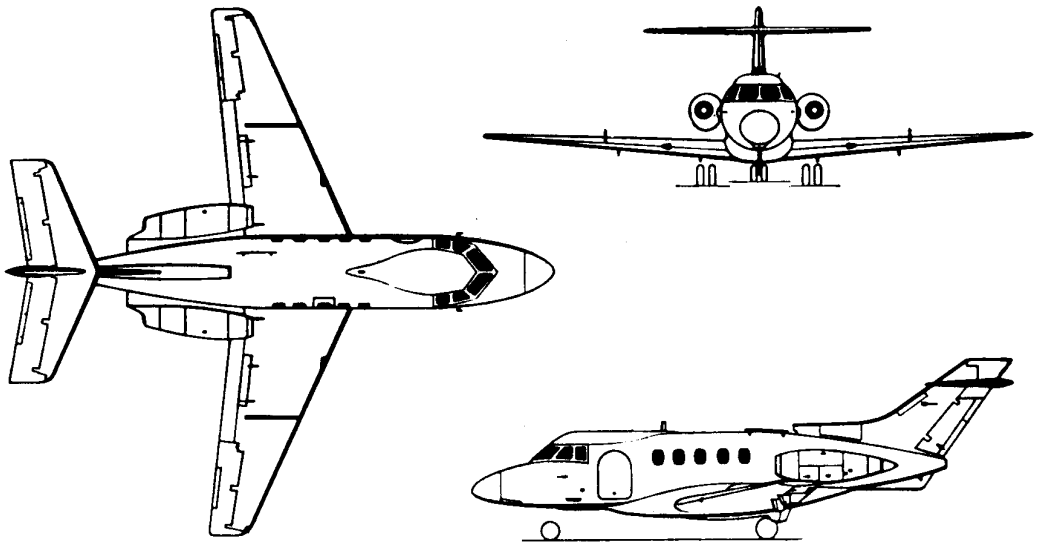


(a) Gulfstream II.

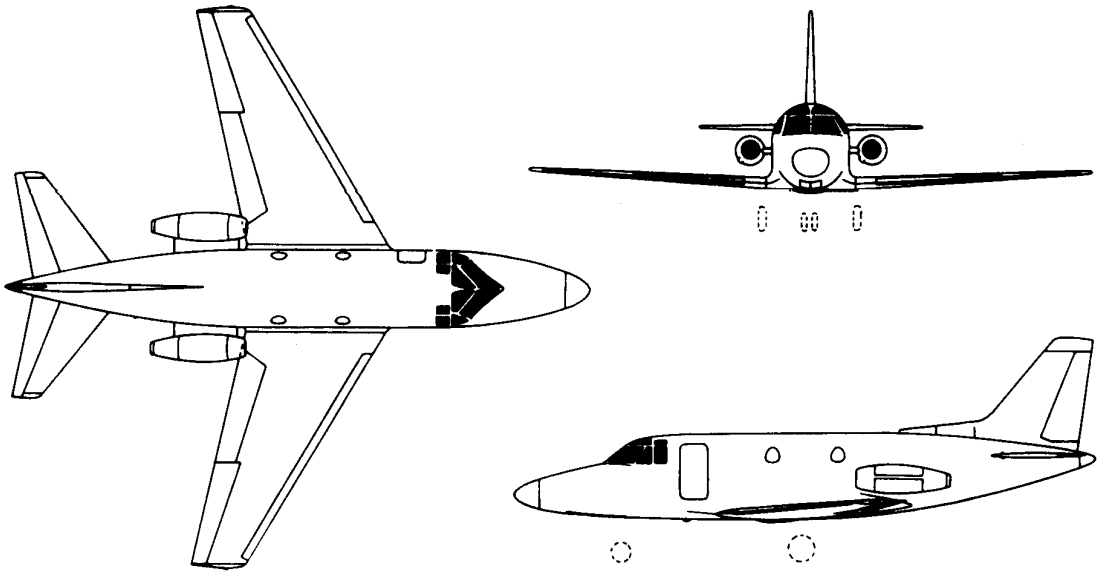


(b) JetStar.

Figure 2. Three-view drawings of the airplanes tested.

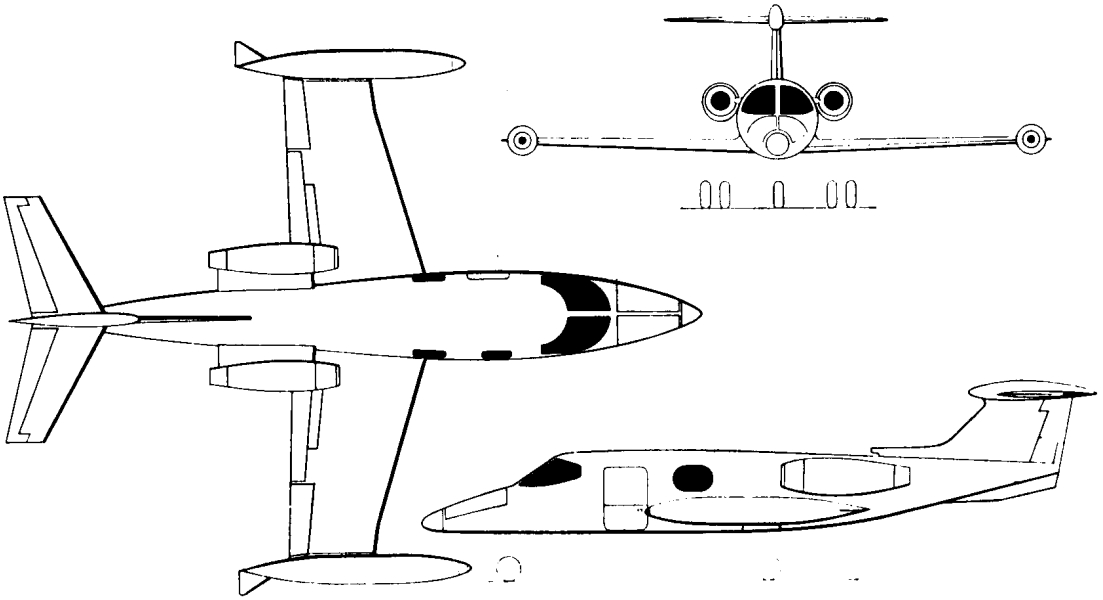


(c) HS 125-400.



(d) Sabreliner-60 (ref. 3).

Figure 2. Continued.



(e) Learjet-24 (ref. 3).

Figure 2. Concluded.

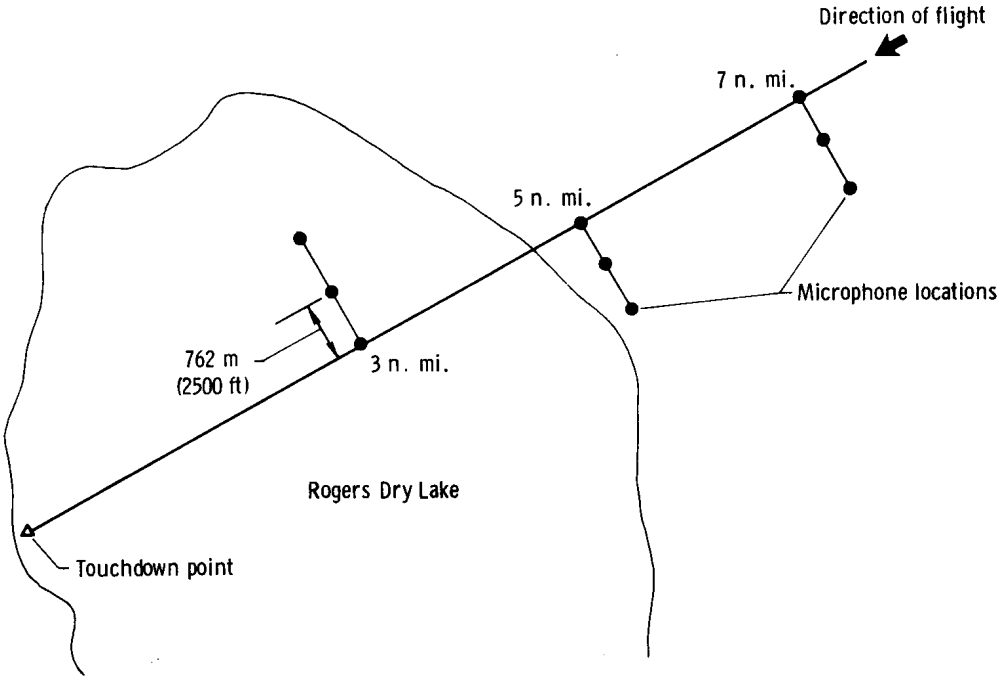
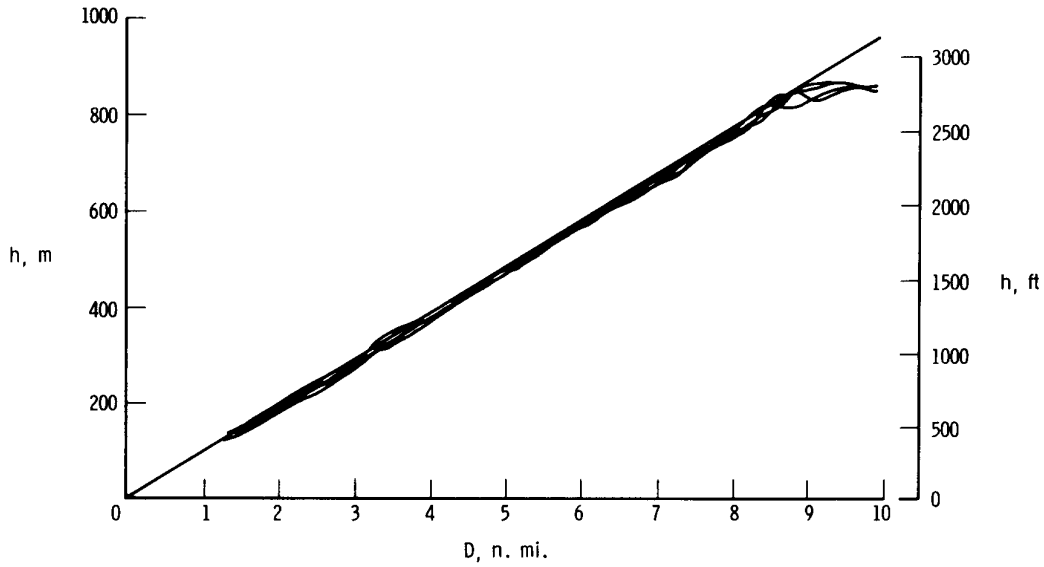
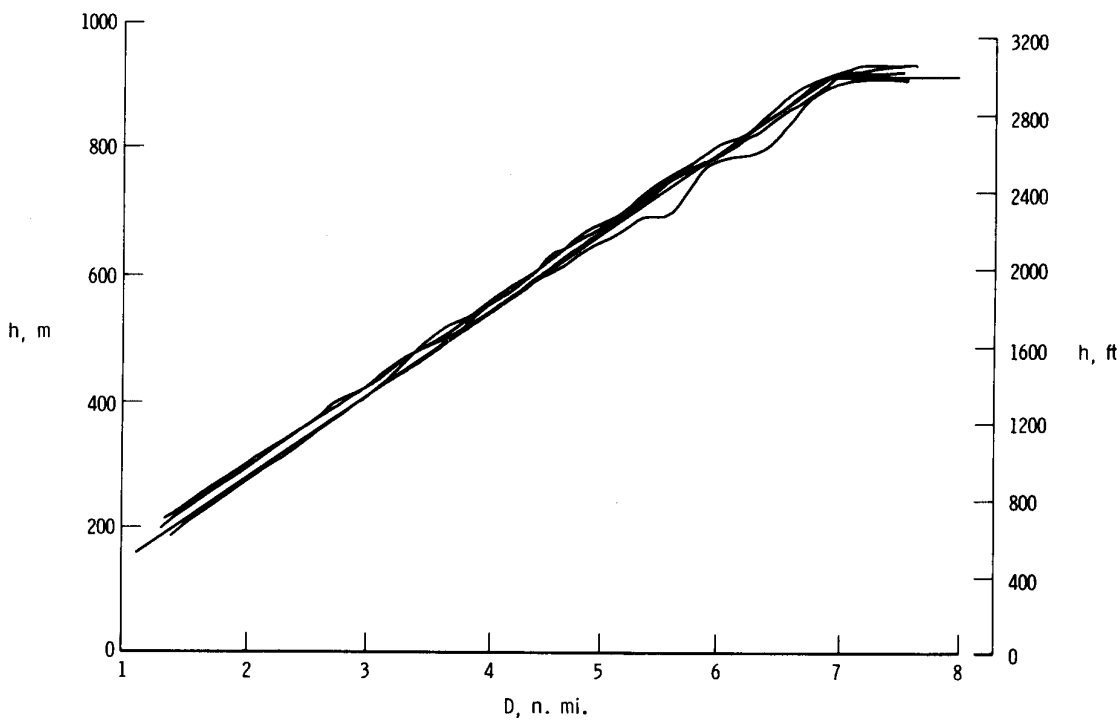


Figure 3. Microphone placement on approach path.

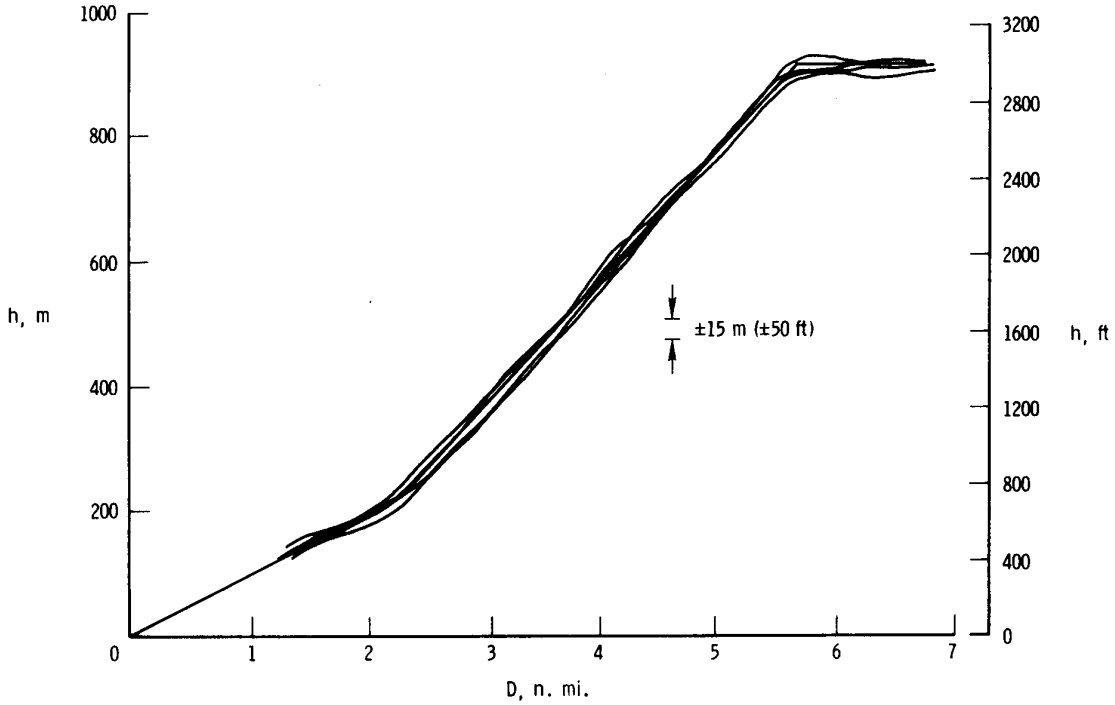


(a) Standard 3° approach.

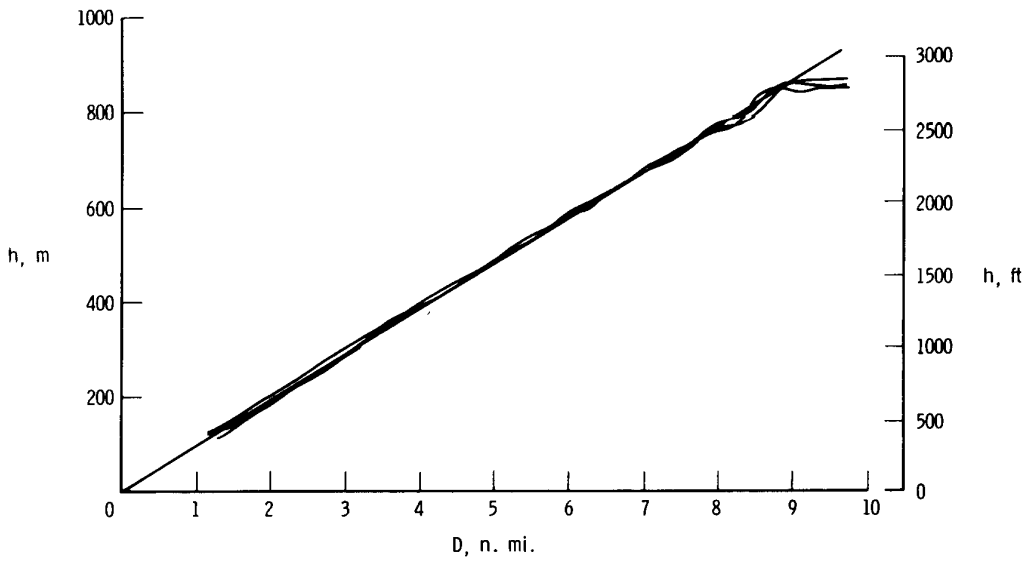


(b) 4° approach.

Figure 4. Typical glide slope radar plots.



(c) Two-segment approach.



(d) Low-drag 3° approach.

Figure 4. Concluded.

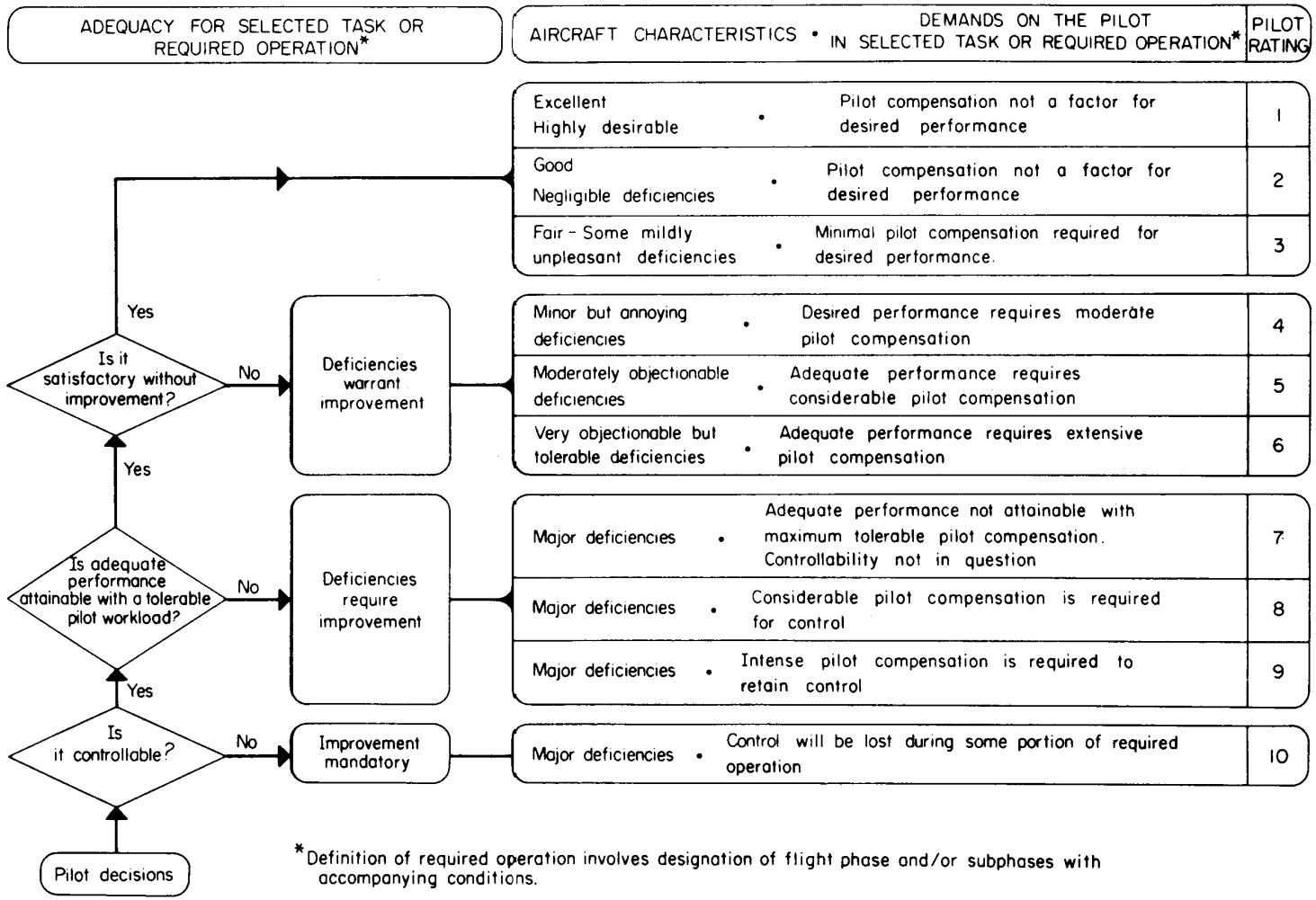
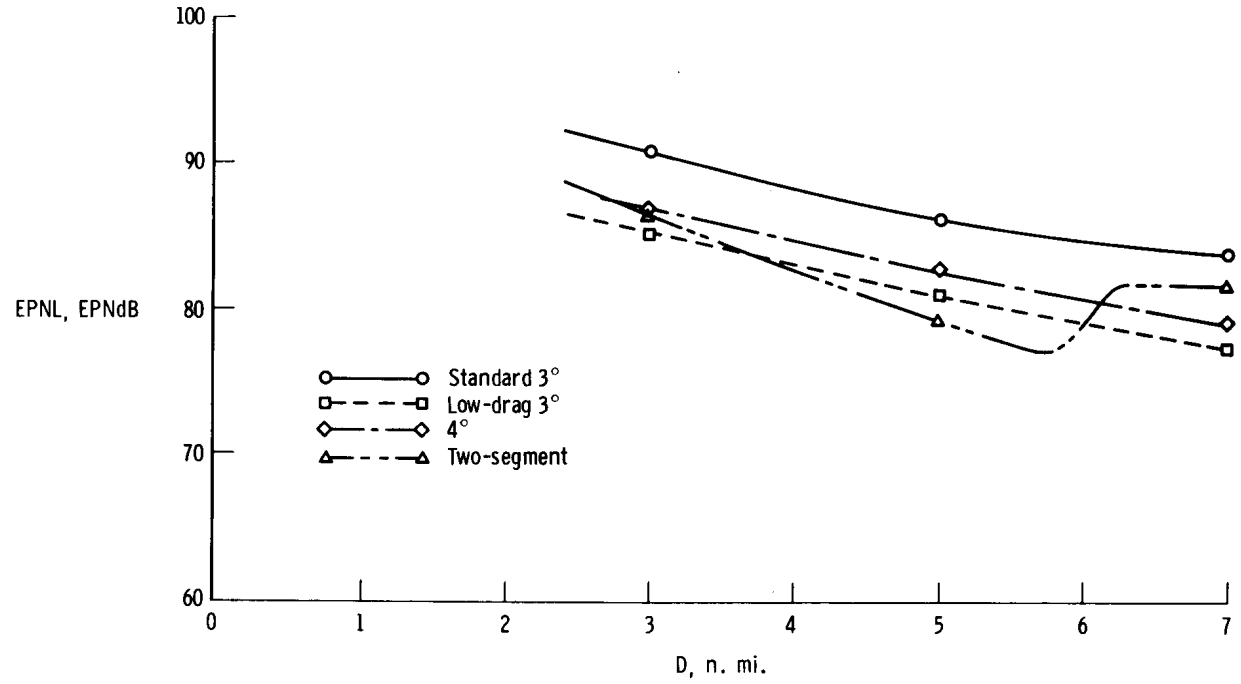
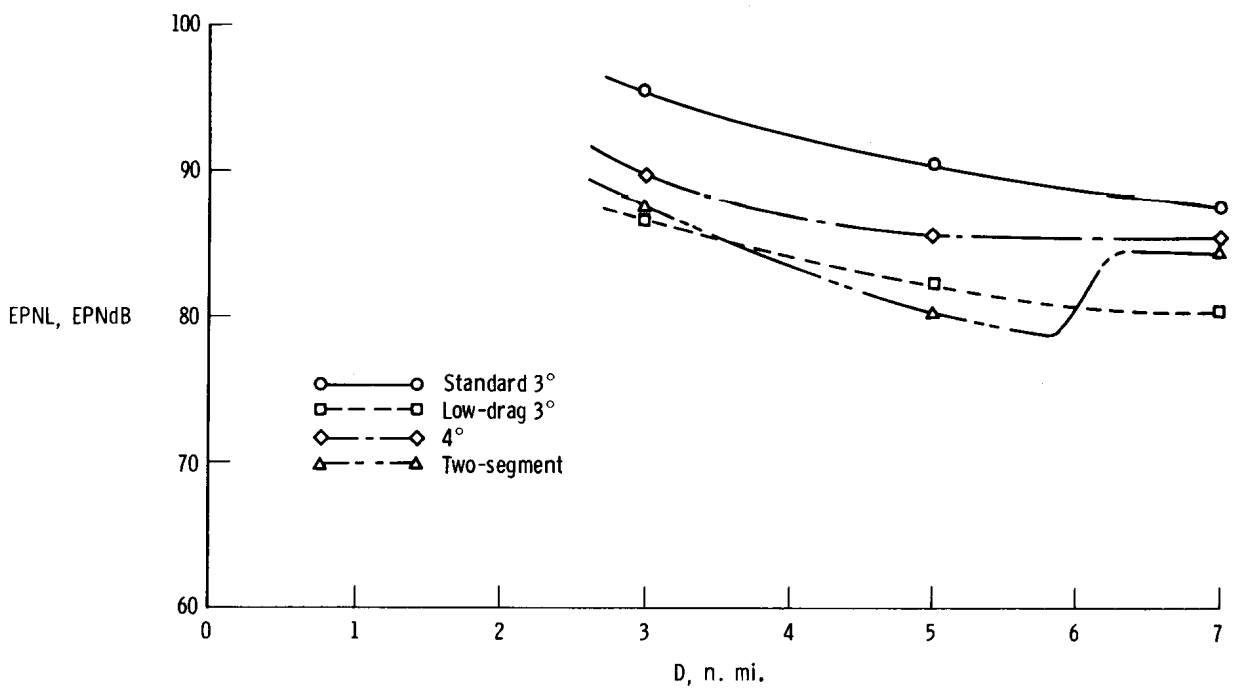


Figure 5. Cooper-Harper rating scale for aircraft handling qualities (ref. 5).

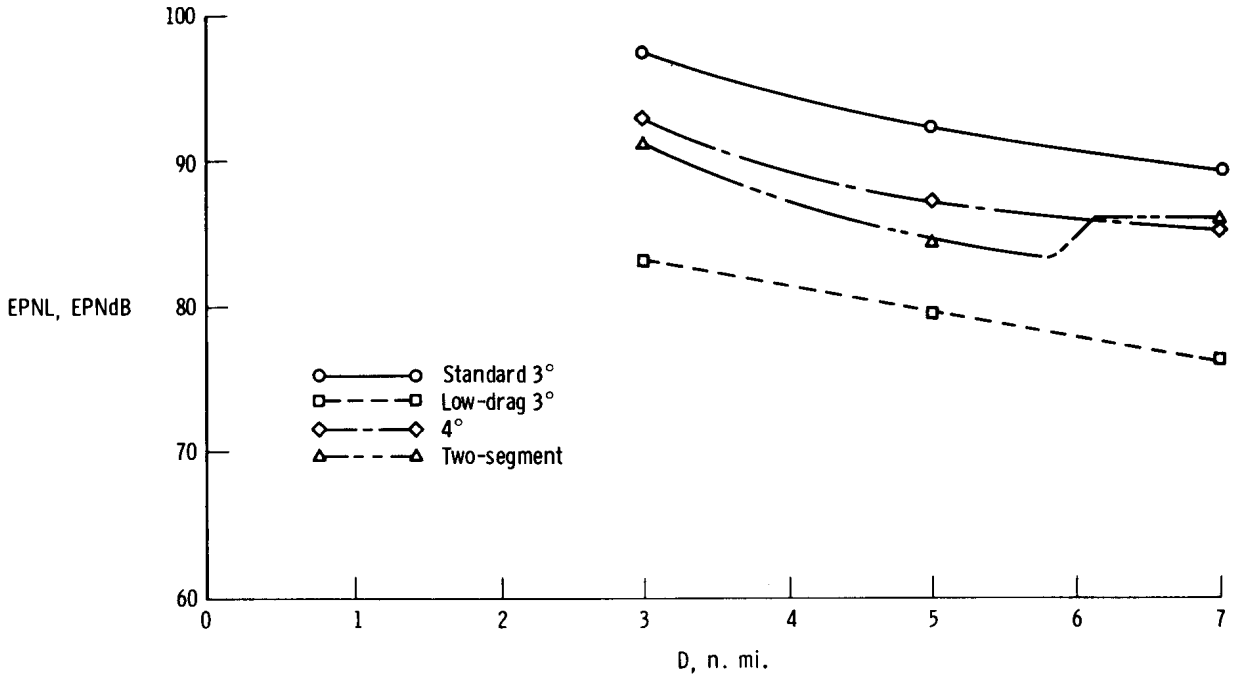


(a) Gulfstream II.

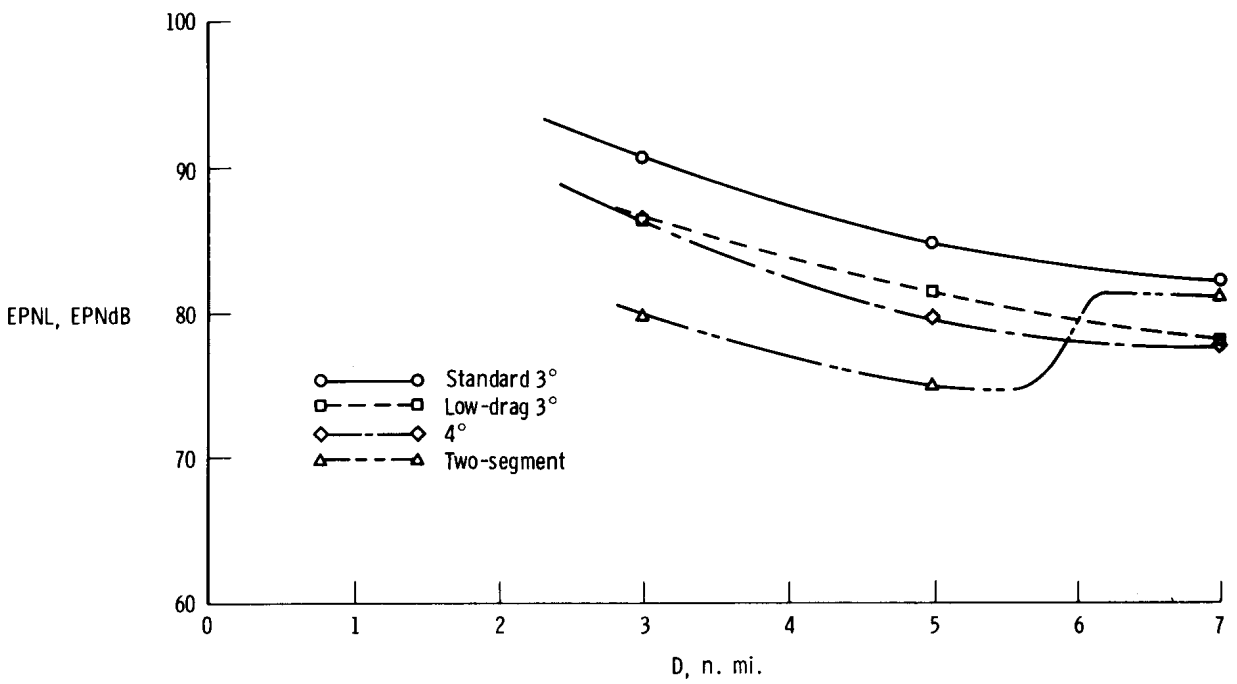


(b) JetStar.

Figure 6. Variation of noise level with distance from touchdown for the four approaches flown.

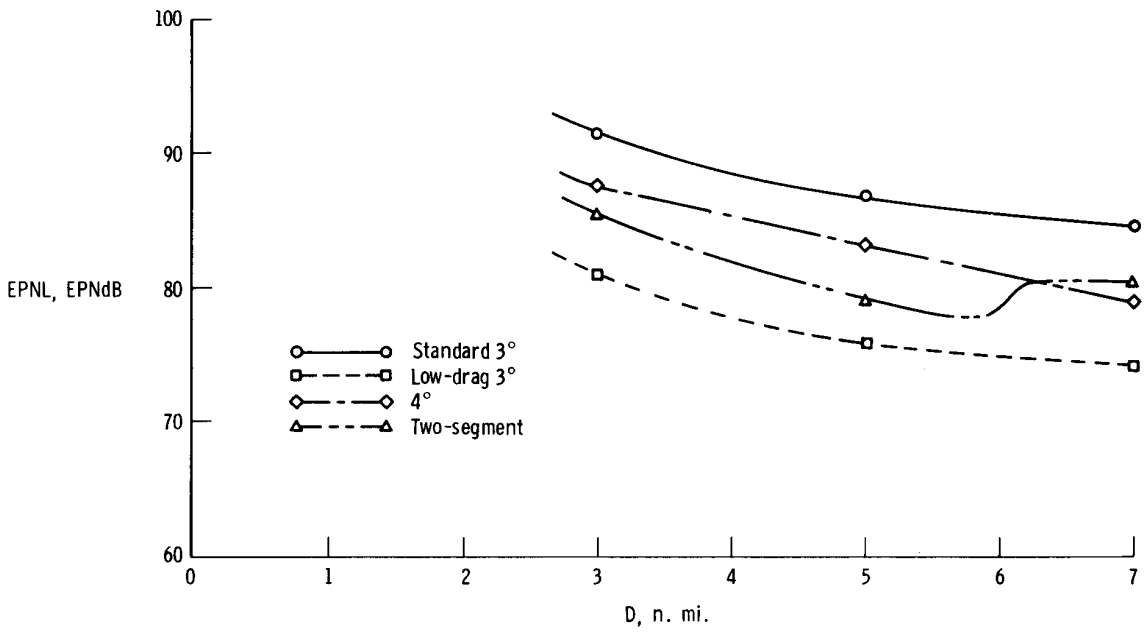


(c) HS 125-400.



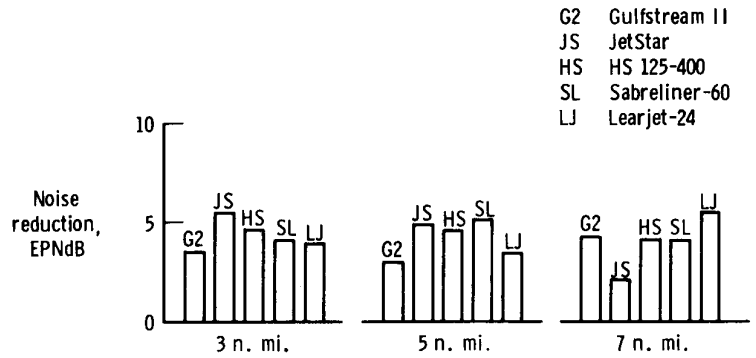
(d) Sabreliner-60.

Figure 6. Continued.

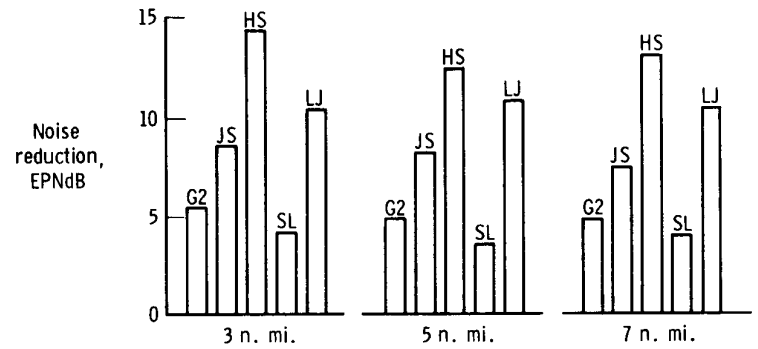


(e) Learjet-24.

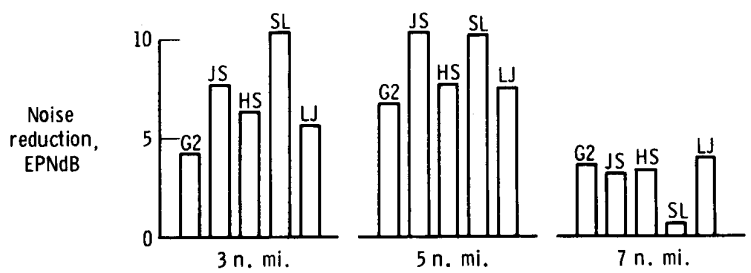
Figure 6. Concluded.



(a) 4° approach.



(b) Low-drag 3° approach.



(c) Two-segment approach.

Figure 7. Approach noise reduction from standard 3° approach.

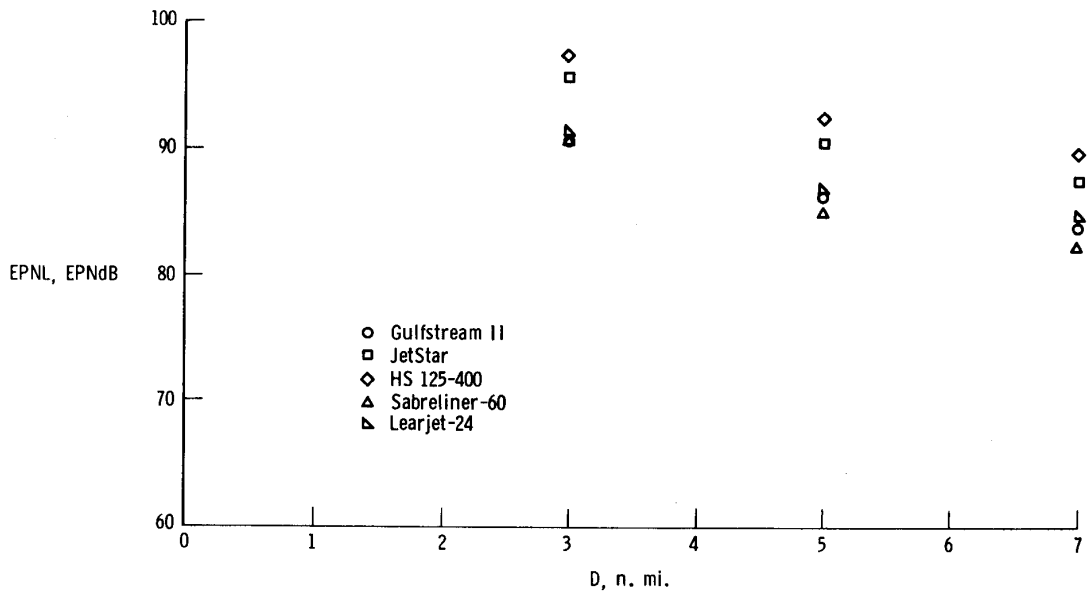


Figure 8. Variation of noise level with distance for the standard 3° approach.

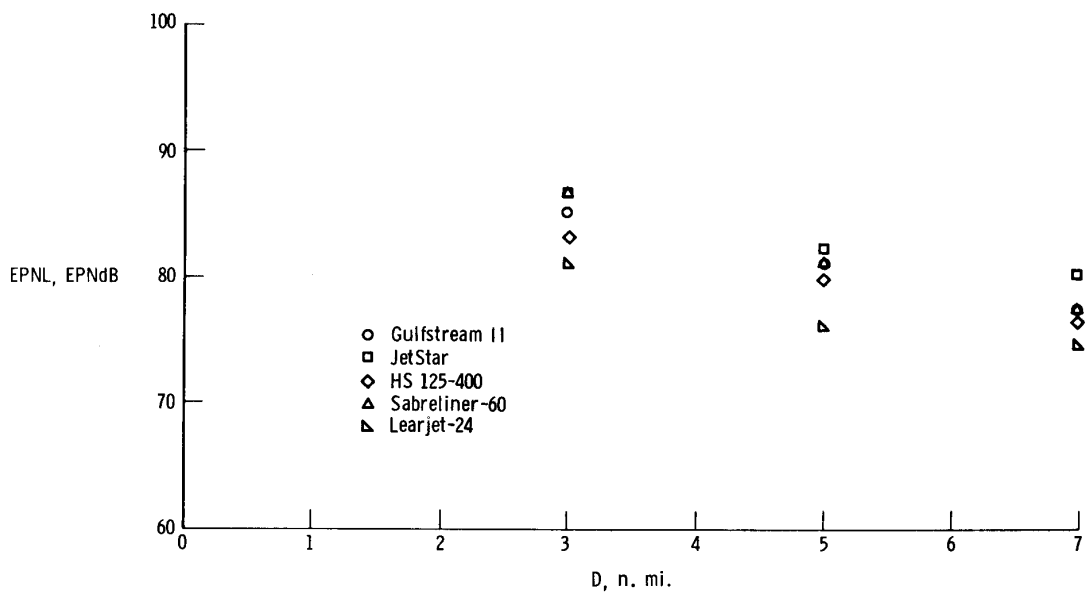


Figure 9. Variation of noise level with distance for the low-drag 3° approach.

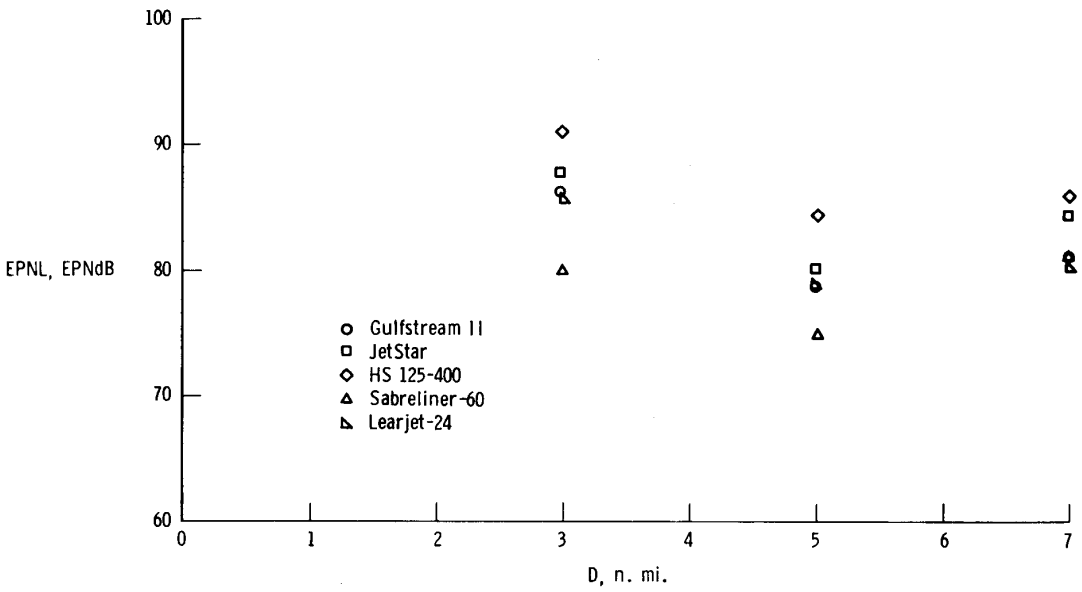
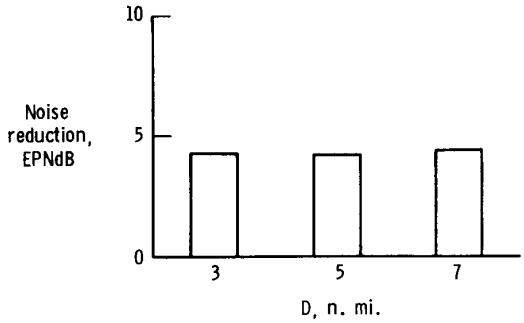
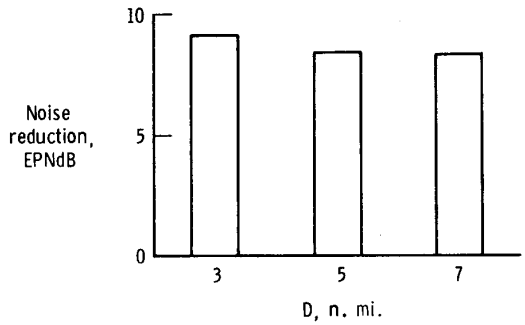


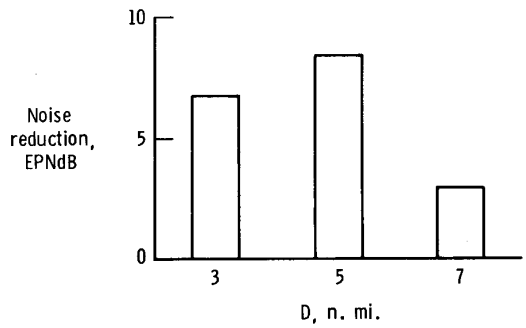
Figure 10. Variation of noise level with distance for the two-segment approach.



(a) 4° approach.



(b) Low-drag 3° approach.



(c) Two-segment approach.

Figure 11. Business jet fleet-weighted average noise reduction from standard 3° approach.

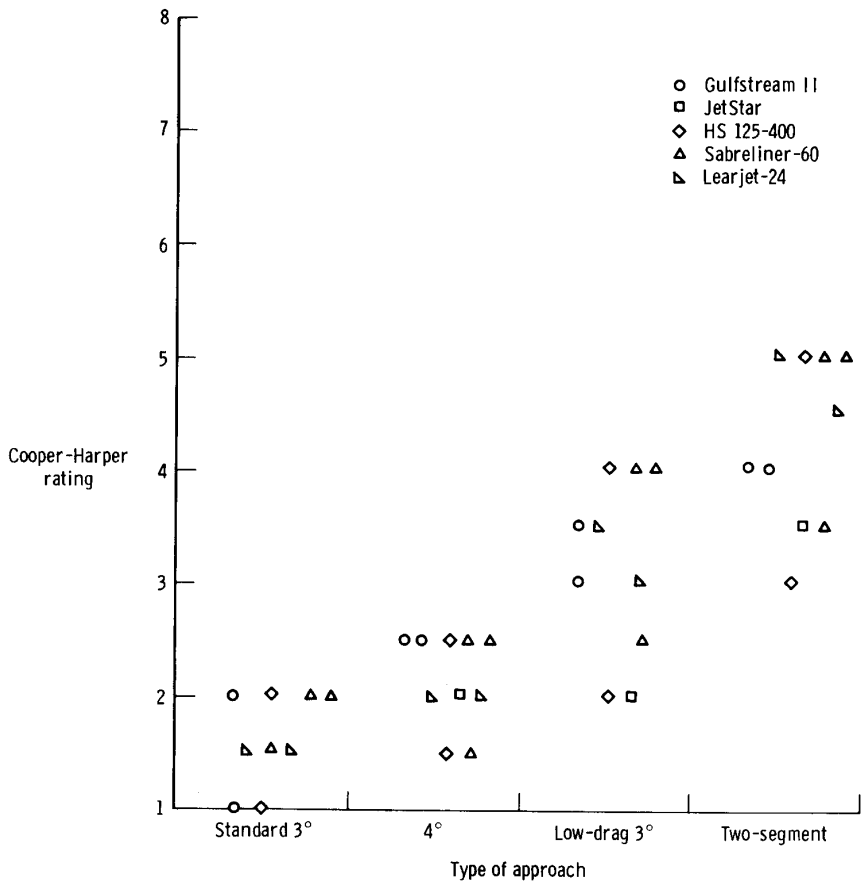


Figure 12. Pilot ratings for the four types of approaches using GCA and VASI guidance.