NASA TECHNICAL NOTE

NASA TN D-4044

c.1

NASA TN D-4044

NASA RESEARCH ON NOISE-ABATEMENT APPROACH PROFILES FOR MULTIENGINE JET TRANSPORT AIRCRAFT

by John A. Zalovcik and William T. Schaefer, Jr.

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1967

NASA TN D-4044

NASA RESEARCH ON NOISE-ABATEMENT APPROACH PROFILES FOR MULTIENGINE JET TRANSPORT AIRCRAFT

By John A. Zalovcik and William T. Schaefer, Jr.

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

NASA RESEARCH ON NOISE-ABATEMENT APPROACH PROFILES FOR MULTIENGINE JET TRANSPORT AIRCRAFT*

By John A. Zalovcik and William T. Schaefer, Jr.
Langley Research Center

SUMMARY

The NASA, as part of the national effort to reduce the noise of modern aircraft, is conducting a study of the operating problems associated with a steepened approach path. To date, approach-profile geometry, airplane type, navigational aids, and pilot augmentation have been explored.

Considerable progress has been made in resolving the elements of a safe steep approach profile. Tests and analysis have indicated that an approach profile of about 6° should be feasible and that:

1. The prime source of noise reduction is the power cutback to fly the steepened glide path which, combined with the effect of increased height, amounts to about 13 dB in sound pressure level.

2. Pilot activity for glide-path control can make a spread in noise level of 8 dB (sound pressure level) for a nominal 6° approach.

3. Improved flight-path control is required if steep approaches are to be made to low minimums of ceiling and visibility and to achieve reduced scatter about the lower noise level.

4. Improved engine response time would be a significant factor in assuring a safe steep approach.

5. Improved displays to guide the pilot through transition and flare will be needed.

INTRODUCTION

Studies of steep approach paths were initiated in 1963 in the interest of potential reductions in airspace and noise. The primary efforts have been aimed at the problems

---

*The contents of this report were submitted to the United Kingdom International Conference on the Reduction of Noise and Disturbances Caused by Civil Aircraft, held in London, England, November 22-30, 1966.

of accomplishing steep approach paths safely within the constraints imposed by the airplane, noise limitations, and navigational equipment. The increased emphasis on noise abatement in the terminal area has intensified NASA's efforts in regard to approach-path operations and, at the present time, the current criterion is whether the steepened approach path will reduce approach noise.

The current studies are closely coordinated with the efforts of the Federal Aviation Agency and much of the present work could not be accomplished without their material assistance in the form of test aircraft and crews. The approach has been that NASA efforts are in the area of defining problems and potential solutions with the advice of FAA and industry and that the FAA will develop and qualify the equipment, techniques, and training procedures indicated by the research. If the many ramifications involved in changing operating procedures are considered, it is obvious that the final solution must involve the best ideas and views of many interested groups.

At this time, many facets of steep-approach operations are under study but this report is concerned primarily with the flight-test results obtained to date. Current experience and views as to approach-path geometry, aircraft capabilities, navigational aids, and piloting techniques are touched on. Since this is a progress report on continuing effort, potential study areas and ideas are indicated.

Symbols and abbreviations used herein are defined in the appendix.

GENERAL CONSIDERATIONS

The experimental data of figure 1 show that for a representative jet transport the sound pressure level is reduced almost linearly as the approach path is steepened from 3° to 6°. A reduction of about 13 dB is obtained for constant-speed approaches, which involve reduced power as the approach angle is steepened. Figure 2 shows, however, that for constant-thrust approaches at 3° and 6° the sound pressure level is reduced by about 4 to 6 dB, depending on distance from touchdown. The simple and obvious conclusion is that for the approach angles shown, the noise reduction is obtained through both reduced power and increased height, the reduced power providing a larger portion of the noise reduction.

On the basis of the preceding remarks, the problem evolves into developing safe paths and flight procedures for approaches at reduced power settings. The reduced power becomes the major constraint on the use of the steepened approach path and, together with other constraints, defines the limits of freedom in accomplishing the task. The second major constraint will be safe day-to-day operations by a pilot of average skill – a criterion difficult to define or evaluate.

Constraints

The following is a list of the constraints imposed on the task of flying steep approaches and the elements that can be varied to accomplish the task:

Constraints	Variables
Reduced power	Navigational aids
Aircraft compatibility	Configuration changes for flight-path control
Approach speed	Autothrottle
Common approach path	Autopilot – autoland
Pilot skill	Ceiling and visibility
Stability and control	

There are other potential constraints, such as engine-out flight and wave-off, but these have not been considered in the exploratory work. The key element, as previously mentioned, is that of commonality and compatibility with current aircraft and pilot skills. The elements that can be worked on are, of course, improvements to the aircraft and electronic and mechanical aids to the pilot. The variable "ceiling and visibility" is based, with considerable justification, on the premise that increased ceiling and visibility can be traded for the potentially more difficult task of flying the steepened approach path.

Research Variables

The basic elements that appear amenable to research are:

(a) The geometry of the approach path

(b) The type and form of information provided the pilot

(c) The airplane and its associated automatic flight systems

The approach-path configuration is significant in that changes in attitude or flight path must be within the capabilities of the airplane to maneuver and the ability of the average pilot to respond to the path commanded. The airplane capabilities are generally the outer physical limits that make success possible or impossible. Pilot response time and the amount of lead information available will tend to shrink these limits.

The information provided to the pilot can take many forms, and old and new aids must be evaluated in the environment of the steep approach. It has been established many times by many investigators that the type of display and motion or noise cues can be the difference between a routine and an impossible task.

The airplane and the various augmentation systems represent many methods of varying the speed and flight-path angle that can ease the pilot's task. Net drag can be varied by use of thrust and by reversers, spoilers, flaps, and elevator, to name a few. The use of autothrottles, coupled autopilots, and similar systems can simplify the control task when precision is required if such devices are on the particular aircraft. The aim is to explore these and other tools at our command to satisfy the constraints of the steepened approach path.

Research

With the many variables involved, NASA has chosen a phased approach. The major phases are:

(a) Preliminary flight and simulator studies such as those reported in references 1 and 2, to become familiar with the task and the associated problems

(b) Exploratory tests to establish likely approach paths, suitable research tasks, and the capabilities of current aircraft and of pilot navigational aids such as radio control, cross pointers, and attitude displays (this phase is currently in progress and forms the basis of the present report)

(c) Analytical, aerodynamic, and simulator studies of better methods of controlling speed, glide path, and displays (these studies are currently being implemented)

(d) Flight evaluations or special tests of any improvements that may arise from either NASA or industry research

As might be expected, these are parallel efforts. It should also be apparent that efforts to reduce noise by engine treatment are closely correlated with these studies.

APPROACH AND METHOD

In consultation with FAA personnel, two approach paths were chosen for study, a two-segment and a single-segment profile, as shown in figure 3. The two profiles have their individual attractions. The two-segment approach has the apparent advantage that the final approach is along the standard 3° glide path so that the final approach and landing maneuver is unchanged. Unless new equipment is developed, the two-segment approach will possibly require two ILS beams. The single-segment approach is simpler to mechanize but will require a longer flare or perhaps a greater rotation of the aircraft. In the case of a rejected landing, the establishment of a positive rate of climb from a high rate of sink could require higher decision altitudes and increased concern for engine response. An added factor is that for a given approach speed, the higher sink rate of the steep approach will influence the effect of wind shear on the airplane. Current thinking is for the word "steep" to mean about 6°.

The NASA flight procedure being used varies somewhat, but the basic elements are:

(a) Precision IFR task including glide-slope intercept with breakout at 200 feet (61 m)

(b) Task evaluation with flight director and ILS needles as available in the cockpit

(c) Task evaluation with automatic augmentation systems – installed or simulated

(d) Variation of $6^{\circ}/3^{\circ}$ intercept from threshold to establish distance required for stabilization on 3° segment

(e) Effect of airplane configuration on task

In general, preliminary tests are made at altitude to establish power levels and general characteristics that the pilots feel are acceptable. All approaches are then made in VFR weather to permit the safety pilot to take over if required. On occasion, simulators have been utilized to check on procedures and airplane capability prior to flight tests.

SCOPE

The general characteristics and operating conditions of the airplanes used in the investigation are given in table I and table II. All aircraft except airplane B were turbine-powered; airplane B was a piston-engine propeller aircraft of World War II vintage. Airplanes A and C were military fighter types that were available for preliminary studies. Airplane C was the more modern airplane with drag brakes and high power, including afterburning available to the pilot.

Airplanes A to D were utilized in preliminary studies to establish the task, equipment, and problems that might be encountered. Airplanes E to G were thoroughly instrumented with control-position recorders, glide-path indicators, and standard motion recorders. The three aircraft were commercial four-engine jet transports and were flown in standard configuration.

Flarescan equipment was utilized for preliminary path guidance with airplanes A to C (refs. 3 and 4). In tests with all aircraft starting with D, an AN/GSN-5 radar was used for approach guidance and position measurement (ref. 5). Most of the tests have been made at the Chincoteague facility attached to the NASA Wallops Station. This location was chosen because of the difficulty in performing such tests at an active field such as Langley Air Force Base, and some 30 or 35 approaches a day have been performed at Chincoteague where an AN/GSN-5 radar is located.

In most of the tests, research test pilots have been used as the basic subjects with pilots from airlines and the FAA being brought in as a cross check on the results. In the case of airplane D, a four-engine jet transport, restrictions required that the pilots be those of the contracting airline. It might be noted that a project pilot flies most of the approaches to obtain technical data on a consistent basis, but other pilots are utilized to provide the practical viewpoints of operating personnel as to the findings.

Tables III and IV present a summary of the tests accomplished to date. Many of the variables, such as mode of airplane control, are indicated, but others, such as the variation in flight-path configuration, are not covered. Numerous short tests have been made to examine flare-path geometry, transition geometry for two-segment profiles, and segment length. In a progress report such as this, it is not practical to include all the detailed studies.

FLIGHT-PATH GEOMETRY

Table IV indicates that for the conditions of the tests (weight, speed, configuration, etc.) all aircraft except airplane G negotiated the 6° single segment. Because of limited availability of airplane G, test runs at 6° could not be made, but it is highly probable that no difficulty would be experienced with such runs. Flights of airplanes A to D represent preliminary tests to establish methods and problems, without particular regard to noise. In the case of airplane C, a military fighter, steeper glide slopes (9°) could be accomplished by means of the drag brake. Military power was available for missed approaches; however, use of military power is not conducive to noise reduction. On the basis of the work to date, a single-segment 6° glide slope appears to be the highest common path that can be considered.

The sample time histories of figure 4 show that for the 3° and 6° approaches the pilot activity on the controls was about the same, and was less than for the two-segment approach. The elevator and throttle movements for the two-segment approach show increasing activity, starting at the transition from the 6° slope to the 3° slope. It would appear that the pilot's efforts to maintain speed and to stabilize on course for the new slope required almost constant adjustment of the elevator. It should be noted that all runs were below the nominal approach path.

Figures 5 to 11 represent vertical and lateral displacements and angular deviations from the nominal glide slope and from the nominal course. Although the samples are small, the figures indicate that glide-slope and course angular deviations were within 5° of the nominal for both the start of flare from the 6° single-segment and the end of transition for the two-segment approaches. Angular deviations were as much as 14° at 5000 feet (1524 m) beyond glide-slope capture.

Inspection of many tracks such as those shown in figure 4 indicates that the path is generally oscillatory in character with wavelengths of 5000 feet (1524 m) and 15 000 feet (4572 m), so that the motion may be a characteristic of the airplane-pilot combination rather than an indication of action taken for course correction. In some cases plots made of aircraft deviation and velocity showed that the airplane was headed away from target position rather than toward it. The short-wavelength oscillation in both pitch and yaw appears to vary between pilots and could be pilot induced.

The study of rates of transition either from 6^{o} to flare or from 6^{o} to 3^{o} indicates a desired rate of change of about 7 seconds per degree. While a rate of 3.5 seconds per degree can be negotiated, the pilots found that it was very difficult to track. For slower rates, say 14 seconds per degree, the transition period was considered too long for a transitory flight condition without good reference. (Some pilots referred to the transition as "open loop" since the command indicators are flown but there is no way to cross check as to performance during the maneuver.)

For the two-segment transitions, it was found that the crews required at least 2.2 miles following transition to stabilize on the 3^{o} glide slope. It is probable that a reasonable distance for stabilization would be at least 3 miles from touchdown, and in this region, of course, no noise reduction would be accomplished. Since quantitative criteria have not been established, and the amount of data is not sufficient for statistical confidence, firm conclusions must await further work.

The vertical and lateral deviations for the "standard" 3^{o} slope had about the same scatter as shown in figures 5 to 9. Figures 10 and 11 indicate that a possible exception is in the angular deviations from nominal glide slope, where the maximum scatter is about $\pm 2^{o}$ at both the initiation of flare and glide-slope acquisition. It would appear, therefore, that to date there is no significant difference in the flight-path control for the 3^{o} and 6^{o} single-segment approaches. Less vertical angular deviation might be expected because the pilots are performing a familiar task.

Study of the (a) parts of figures 5 to 9 indicates that in most cases the aircraft was below the glide path. With two of the three jet transports, operations were characteristically below the nominal profile. The deviations plotted in figures 5 to 9 correspond to a line-of-sight deviation of about $\pm 0.2^{o}$ for the three transition regions – glide slope acquisition, 6^{o} to 3^{o} transition, and flare. Laterally, the corresponding angular deviation was $\pm 2^{o}$. (These deviations should not be confused with the angles shown in figures 6 through 10 which represent the local flight-path angles.)

AIRPLANE CHARACTERISTICS

Except for airplane B, the limitation on glide slope was set by available power settings, and in a general sense the crews selected power settings such that glide paths at least 2^{o} steeper than nominal could be attained by setting the power at flight idle. Airplane B, a propeller-driven airplane, was the only aircraft that caused adverse comments as to stability and control. Of the airplanes tested, airplane C, the fighter, elicited the best opinions because of the ability to use high power and drag, since these tests were made before the noise constraint was well defined. A strong impression is created that if engine response time could be reduced, the pilot task would be eased and his confidence increased in performing the steep approach.

A few flights were attempted with airplane F, using the spoilers for flight-path control, but were not very successful. In these tests the spoilers were partially raised for the nominal flight path, and lift corrections were attempted by raising or lowering them. It appears from these few tests and general considerations that flight-path control by direct action on wing lift rather than through use of the elevator and throttle will require further study. Systems such as the Navy Direct Lift Control (ref. 6) fall into this category when considered for use on large aircraft. Wind-tunnel, simulator, and flight studies of the application of direct-lift principles to the steepened approach path are under consideration.

No consideration was given to the use of drag devices or thrust reversers for approach-path control because both methods violate the constraint of reduced power for noise reduction. From tests and studies to date, methods of flight-path modification appear to be limited to basic power settings and changes in lift to accomplish the task.

NAVIGATIONAL AIDS AND DISPLAYS

The three difficult regions are the glide-slope acquisition, transition from 6° to 3°, and the flare. Comments of pilots indicated that during these periods lead information is needed for glide-slope intercept, for the end of transition, and for the start of flare. In many instances there was a marked overall improvement in performance with a flight director, as compared with cross-pointer information. During these transitory periods, when nothing remains constant and the pilot must follow the command blindly, the feeling of insecurity deepens the longer the time period.

Studies and discussions indicate three approaches – a better display, special fan markers to signal the crew at critical points, and the possibility of spreading the beam at high altitudes to provide some lead on glide-slope intercept. At this time little effort is being expended on this problem but a limited laboratory study of possible profile track displays is being developed. The many factors that affect the operation cannot be attacked simultaneously because of limitations of manpower, money, and equipment.

For the straight segments of the approach, some of the pilots utilized the vertical-speed indicator to assist in stabilization. Two pilots who initially had difficulty achieving stabilized flight from attitude and glide-slope information were able to make excellent approaches by using the vertical-speed indicator. How valid the vertical-speed indicator will be in the general case has not been established, but the characteristics of these indicators for both steady and maneuvering flight will require study to insure that they will contribute to a safe approach under all conditions.

AIRCRAFT SYSTEM AIDS

The preliminary studies indicate that the use of autothrottles and autopilot control of the lateral axis could result in significant improvements in pilot performance, but fully coupled autopilots of current vintage are not adequate for controlling glide slope. Figure 12 shows sample approaches, fully manual and with assistance from coupled modes. The curves indicate a significant improvement in track for "split axes," that is, with the autopilot controlling the lateral-directional axes only, and, if anything, a degradation in performance for fully coupled approaches. Discussions with aircraft personnel have indicated that the significant lack is in autopilot authority to negotiate the transition in glide slope. The study of autothrottles has been simulated by using the second pilot, since the aircraft thus far incorporated into the NASA effort have not had autothrottles installed. In the comparison shown in figure 13, some improvement in the elevator trace, due to an easing of the pilot task, resulted when the simulated autothrottle was used.

EFFECT OF PILOTING TECHNIQUE ON NOISE LEVEL

Control of an aircraft along the approach flight path involved control of deviations of airspeed from the target airspeed and of deviations of position, both vertical and lateral, from the flight path. The technique used in controlling these deviations with the use of the throttle, therefore, determines the variation in noise level produced along the ground track. For example, if frequent throttle adjustments are made to control the deviations to within small limits, the variation in noise level will be small. On the other hand, if the deviations are allowed to grow to large magnitudes before a correction is made, the variation in noise level can be large. For aircraft G, for example, an increase in thrust of 10 000 pounds (44 482 N) can result in an 8 dB increase in the sound pressure level. Such an increase in thrust could essentially nullify the noise reduction obtainable through the use of noise abatement procedures at ground locations above which the large increases in thrust are made. Another example is illustrated in figure 14, where time histories of throttle position, lateral and vertical deviations from the flight path, and indicated airspeed are shown for two approaches with airplane E under manual control. At the 4.4-mile noise-measuring station the thrust level for one of the approaches was sufficiently high to result in a 5 dB higher sound pressure level. At the 2.6-mile station, the thrust and resulting noise level were practically the same.

In order to keep speed and position deviations to a minimum and hence avoid large variations in the sound pressure level, it appears desirable to make use of autothrottle and coupled approaches. For the noise-abatement procedures, however, modifications are indicated in the autothrottle to allow operation over a wider range of thrust levels and in the autopilot to permit operation over a wider altitude range without recycling and, perhaps, greater force authority to allow negotiation of the transition for two-segment approaches. For manual control, improved guidance displays would be a necessity for the pilot.

GENERAL OBSERVATIONS

If steepened approach paths could be mechanized immediately, the work done to date indicates that minimum ceiling and visibility requirements would have to be increased. For routine operations, three improvements are indicated: better engine response, improved methods of flight-path control, and improved displays of information to the pilot. While these observations represent an extrapolation of current work, consideration of the day-to-day environment, pilot training and experience, and airplane capability lend credence to the observation.

Experience indicates that the introduction of the steepened approach geometry into the terminal area would be an evolutionary process. The steps in implementation might be as follows:

1. Steepened approach-path configuration usable with increased ceiling and visibility. If a two-segment approach were selected, the ceiling would be above transition maneuver from one glide slope to the other
2. Improved displays and piloting techniques, permitting lower minimums for two-segment approaches
3. Single-segment to touchdown, constant approach speed, and increased minimums
4. Improved glide path and speed control permitting lower minimums
5. Further refinement in approach techniques such as use of simultaneous altitude and airspeed bleed. This procedure may be found economically desirable to decrease approach time but will require considerable study before being classed as of a routine nature.

CONCLUDING REMARKS

The studies to date indicate that the 6° approach path at reduced power can reduce the approach noise of current jet transports by 13 dB (sound pressure level). Particular features that have come to light are:

1. Unless the steepened glide path is accompanied by reduced power, the noise reduction will be considerably less than the maximum obtainable.
2. The use of the throttle for glide-path control should be a backup for a more direct method of controlling flight path.

3. Until better displays ("how goes it" information) are provided the pilot, operations involving transition from 6° to other slopes (including 0°) should be performed with adequate visibility and ceiling. The approach would be an instrument task but visual contact would provide the pilot with situation information when needed.

4. Improved engine response would be of considerable assistance and may be required if lower ceilings are contemplated.

5. The single-segment approach appears to require less pilot effort than the two-segment path.

6. Unless piloting techniques can be consistently improved by training and/or improved controls and displays, the power and flight-path variations can negate the noise reduction over a given station, in many instances.

In conclusion, this progress report indicates that steepened approach paths are a feasible method of noise reduction but considerably more study and qualification of the task will be needed before it could be considered operational. As viewed at this time, the major obstacles are in the information provided the pilot, the method of flight-path control, and the problem of providing paths equivalent to those provided by the research radar equipment used in the tests.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 3, 1967,
126-16-05-01-23.

APPENDIX

NOTATION

Symbols

N	number of data runs
V_{IAS}	indicated airspeed
x	horizontal distance from touchdown point
y	lateral distance from reference course
Δy	course deviation; lateral displacement of aircraft from reference course
z	vertical distance from touchdown point
Δz	glide-slope deviation; vertical displacement of aircraft from reference glide slope
γ	nominal glide-slope angle, deg
γ_o	reference glide-slope angle at any point along flight path, deg
γ_1	actual glide-slope angle of aircraft, deg
δ_c	control-column displacement
δ_t	throttle displacement
δ_w	control-wheel displacement
ψ	actual angular deviation from reference course, deg

Abbreviations

dots	indices of localizer and glide-slope displacement display; full scale or five dots is equal to 150 microamperes
GS	glide slope

APPENDIX

IFR	Instrument Flight Rules
ILS	instrument landing system
LOC	localizer
SPL	sound pressure level, decibels
VFR	Visual Flight Rules

REFERENCES

1. Hall, Albert W.; and McGinley, Donald J., Jr.: Flight Investigation of Steep Instrument Approach Capabilities of a C-47 Airplane Under Manual Control. NASA TN D-2559, 1965.
2. Hall, Albert W.; and McGinley, Donald J., Jr.: Flight Investigation of Steep Instrument Approach Capabilities of a T-33 Airplane Under Manual Control. NASA TN D-2775, 1965.
3. Geraci, Phil: AIL's "Flarescan" Offers ILS Guidance to Touchdown. Airlift, vol. 25, no. 7, Dec. 1961, pp. 43-44.
4. Litchford, G. B.; Tatz, A.; and Battle, F. H., Jr.: A Look at the Future of Automatic Landing Systems. IRE, Trans. Aeron. Navigational Electron., vol. ANE-6, no. 2, June 1959, pp. 118-128.
5. Powell, F. D.: The AN/GSN-5 Automatic Landing System. Navigation, vol. 7, no. 1, Spring 1960, pp. 48-56.
6. Smith, L. R.; Prilliman, F. W.; and Slingerland, R. D.: Direct Lift Control as a Landing Approach Aid. AIAA Paper No. 66-14, Jan. 1966.

TABLE I.- GENERAL CHARACTERISTICS OF AIRPLANES USED IN TESTS

Airplane	Propulsion		Powerplant		Maximum gross weight, lb (mass, kg)	Wing area, ft^2 (m^2)	Wing span, ft (m)	Guidance display	
	Type	No. of engines	Max. thrust/eng., lb (N)	Max. power/eng., hp (kW)				ILS	Flight director
A	Turbojet	1	5200 (23 129)	------	11 965 (5420)	237 (22.0)	39 (11.9)	GS/LOC	-------
B	Piston	2	-------	1200 (895.2)	31 000 (14 043)	987 (91.7)	95 (28.9)	GS/LOC	-------
C	Turbojet	1	10 900 (48 483)	------	27 000 (12 231)	662 (61.5)	38 (11.6)	GS/LOC	-------
D	Turbofan	4	18 000 (80 064)	------	315 000 (142 695)	2868 (266.4)	142 (43.3)	GS/LOC	LOC
E	Turbojet	4	11 650 (51 819)	------	193 000 (87 429)	2000 (185.8)	120 (36.6)	GS/LOC	LOC
F	Turbofan	4	16 100 (71 612)	------	244 000 (110 532)	2250 (209.0)	120 (36.6)	GS/LOC	LOC
G	Turbojet	4	12 000 (53 376)	------	203 000 (91 959)	2433 (226.0)	131 (39.9)	GS/LOC	GS/LOC

TABLE II.- OPERATING CONDITIONS

Airplane	Flaps, deg	Weight, lb (mass, kg)	Stall speed, knots	Approach speed, knots	Glide slope, deg	
					Limit	Operational
A	45	11 000 to 13 000 (4983 to 5889)	90 to 97.5	115 to 120	[a]9	6
B	45	24 700 to 31 000 (11 189 to 14 043)	56.5 to 62.9	75 to 85	10	6
C	No flaps	23 000 to 24 000 (10 419 to 10 872)	[b]115 to 135	160 to 180	Above 9	Above 7
D	50	164 000 to 203 500 (74 292 to 92 185)	91 to 101.5	130 to 150	Not determined	6
E	44	112 000 to 158 000 (50 736 to 71 574)	92.3 to 110	130 to 153	7	6
F	50	149 400 to 195 200 (67 678 to 88 426)	101 to 117	143 to 164	8	6
G	50	121 500 to 181 000 (55 039 to 81 993)	82.1 to 99	117 to 137	9	6

[a] At 150 knots.

[b] Minimum speed at which altitude may be maintained: military power, 115 knots; maximum power, 135 knots.

TABLE III.- SUMMARY OF PRELIMINARY EXPLORATORY TESTS

Profile description	Glide slope, deg	VFR	Simulated IFR	Number of runs	Total runs
Airplane A					
Single-segment	9		x	6	107
	8		x	6	
	7		x	6	
	6		x	49	
	2.5		x	40	
Airplane B					
Single-segment	10	x		1	85
	9		x	3	
	8		x	3	
	7		x	3	
	6		x	54	
	2.5	x		1	
	2.5		x	20	
Airplane C					
Single-segment	9	x		1	29
	9		x	4	
	7	x		2	
	7		x	5	
	5	x		2	
	5		x	11	
	3		x	4	
Airplane D					
Single-segment	6	x		7	47
	6		x	23	
	5	x		1	
	5		x	4	
	4	x		1	
	4		x	3	
	3	x		3	
	3		x	5	

TABLE IV.- SUMMARY OF CURRENT EXPLORATORY TESTS

Airplane E

Profile description	Glide slope, deg	VFR	Simulated IFR	Control mode		Throttle control			Flare rate, sec/deg	No. of runs
				Manual	Coupled	Manual, constant speed	Simulated auto, constant speed	Manual, constant thrust		
Single-segment	3	x		x		x			3.5	2
	3		x	x		x			3.5	14
	3		x		Complete	x			3.5	4
	4		x	x		x			3.5	4
	5	x		x		x			3.5	1
	5		x	x		x			3.5	7
	6	x		x		x			3.5	2
	6		x	x		x			3.5	8
	7	x		x		x			3.5	1
	7		x	x		x			3.5	2
Two-segment, 1.5 n. mi. intercept	6-3		x	x		x			3.5	11
	6-3		x		Simulated split axes	x			3.5	2
	6-3		x	x				x	3.5	5
	6-3		x	x			x		3.5	8
	6-3		x		Complete	x			3.5	8
	6-3		x		Complete			x	3.5	3
Two-segment, 2.2 n. mi. intercept	6-3		x	x		x			3.5	9
	6-3		x	x			x		3.5	11
Two-segment, 3.0 n. mi. intercept	6-3		x	x		x			3.5	10
	6-3		x	x			x		3.5	14
	6-3		x		Complete		x		3.5	10
									Total	136

TABLE IV.- SUMMARY OF CURRENT EXPLORATORY TESTS – Continued

Airplane F

Profile description	Glide slope, deg	VFR	Simulated IFR	Control mode		Throttle control			Flare rate, sec/deg	No. of runs
				Manual	Coupled	Manual, constant speed	Simulated auto, constant speed	Manual, constant thrust		
Single-segment	3		x	x		x			3.5	12
	3		x	x			x		3.5	1
	4	x		x		x			3.5	1
	4		x	x		x			3.5	4
	5		x	x		x			3.5	4
	6	x		x		x			3.5	2
	6		x	x		x			3.5	11
Two-segment, 1.5 n. mi. intercept	5-3	x		x		x			7.0	3
	5-3		x	x		x			7.0	35
	5-3		x	x			x		7.0	2
	6-3	x		x		x			7.0	2
	6-3		x	x		x			7.0	29
	6-3		x	x			x		7.0	9
	6-3		x	x		x			5.5	4
	7-3	x		x		x			7.0	1
	8-3	x		x		x			7.0	2
Two segment, 2.2 n. mi. intercept	6-3	x		x		x			7.0	5
	6-3		x	x		x			7.0	30
	6-3		x	x			x		7.0	11
	6-3		x		Complete	x			7.0	1
									Total	169

TABLE IV.- SUMMARY OF CURRENT EXPLORATORY TESTS – Concluded

Airplane G

Profile description	Glide slope, deg	VFR	Simulated IFR	Control mode		Throttle control			Flare rate, sec/deg	No. of runs
				Manual	Coupled	Manual, constant speed	Simulated auto, constant speed	Manual, constant thrust		
Single-segment	3	x		x		x			3.5	12
	3		x	x		x			3.5	12
Two-segment, 1.5 n. mi. intercept	5-3	x		x		x			7.0	2
	5-3		x	x		x			7.0	8
	5-3		x	x			x		7.0	4
	7-3	x		x		x			7.0	3
	8-3	x		x		x			7.0	3
	9-3	x		x		x			7.0	1
Two-segment, 2.2 n. mi. intercept	5-2.5	x		x		x			7.0	2
	5-2.5		x	x		x			7.0	9
	5-2.5		x	x			x		7.0	6
	6-3	x		x		x			7.0	4
	6-3		x	x		x			7.0	12
	6-3		x	x			x		7.0	8
	6-3		x	x		x			5.5	6
	6-3		x	x		x			3.5	6
	6-3		x		Complete	x			7.0	1
									Total	99

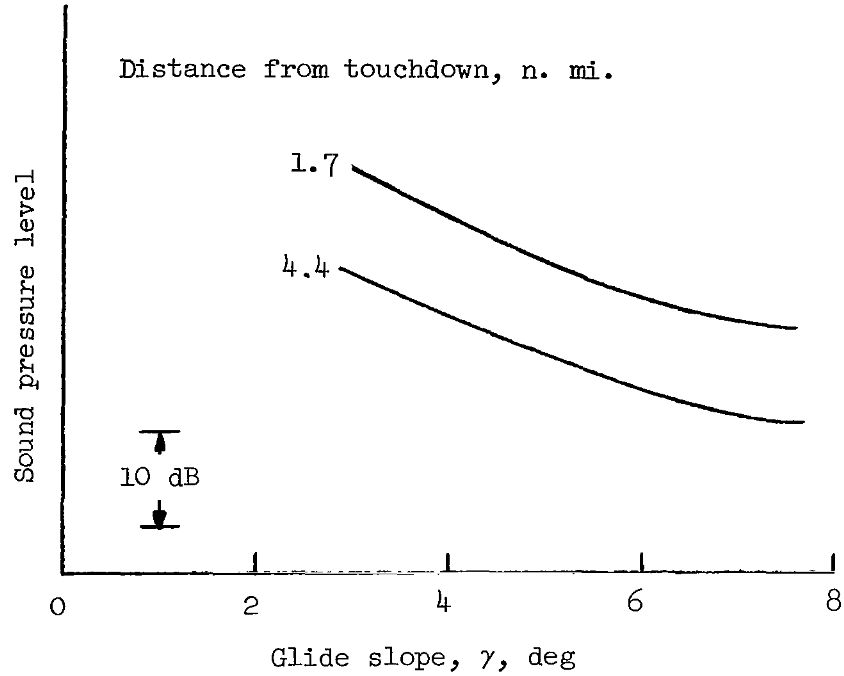


Figure 1.- Variation of sound pressure level with glide slope at ground stations 1.7 and 4.4 nautical miles from touchdown. Single-segment, constant-speed approaches.

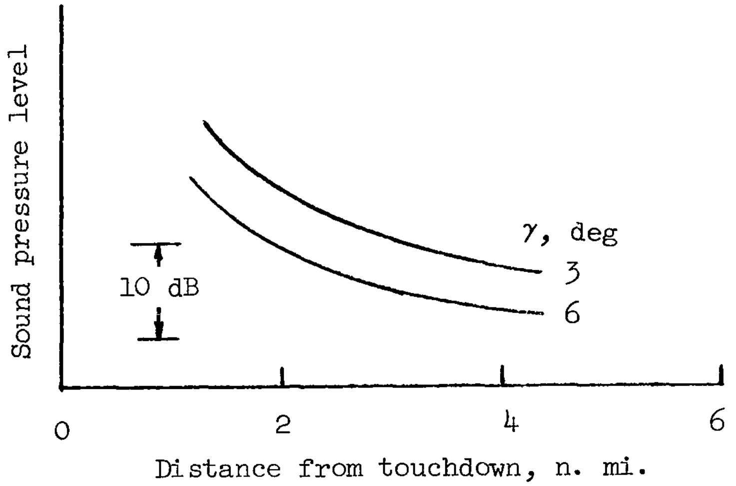
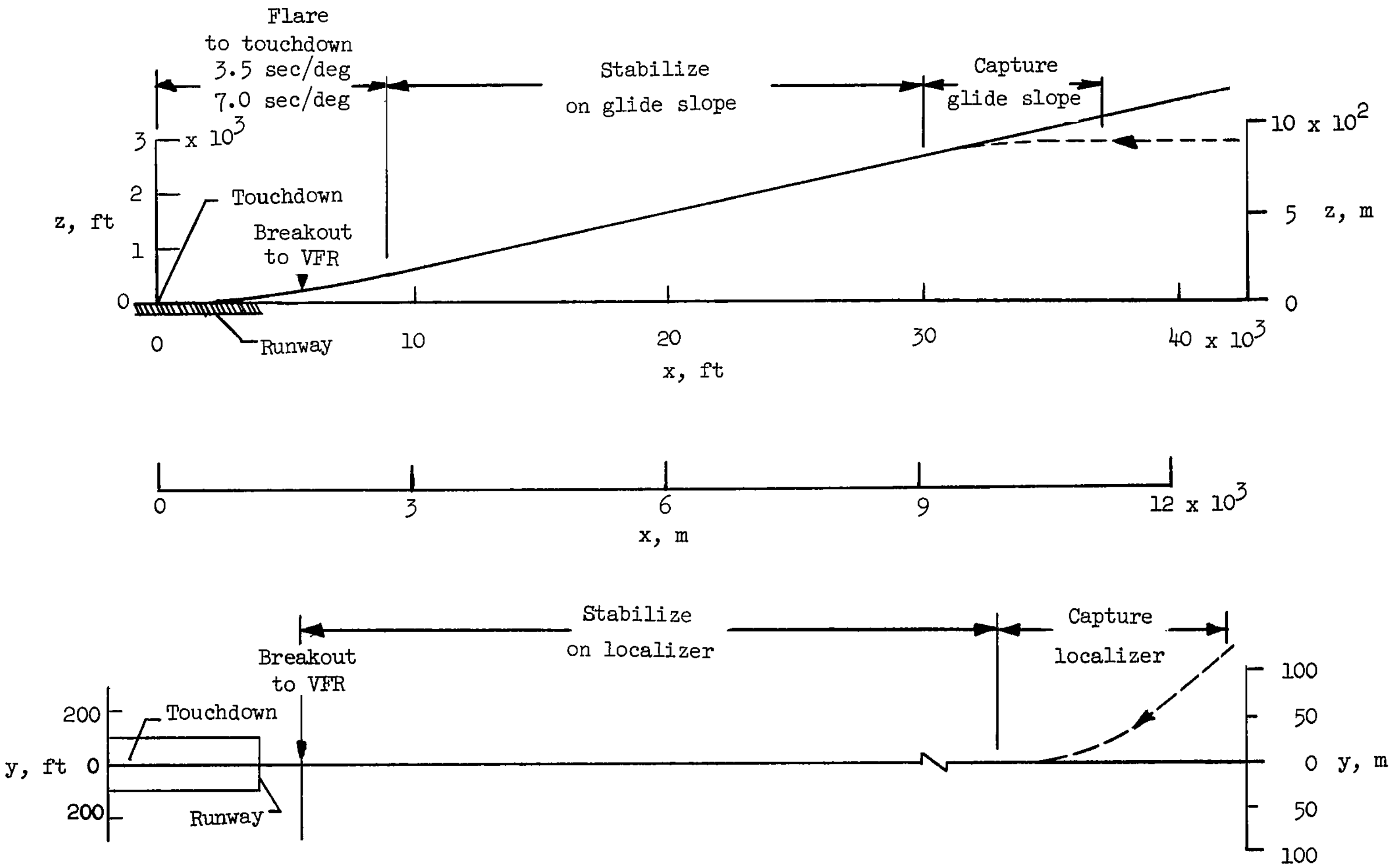
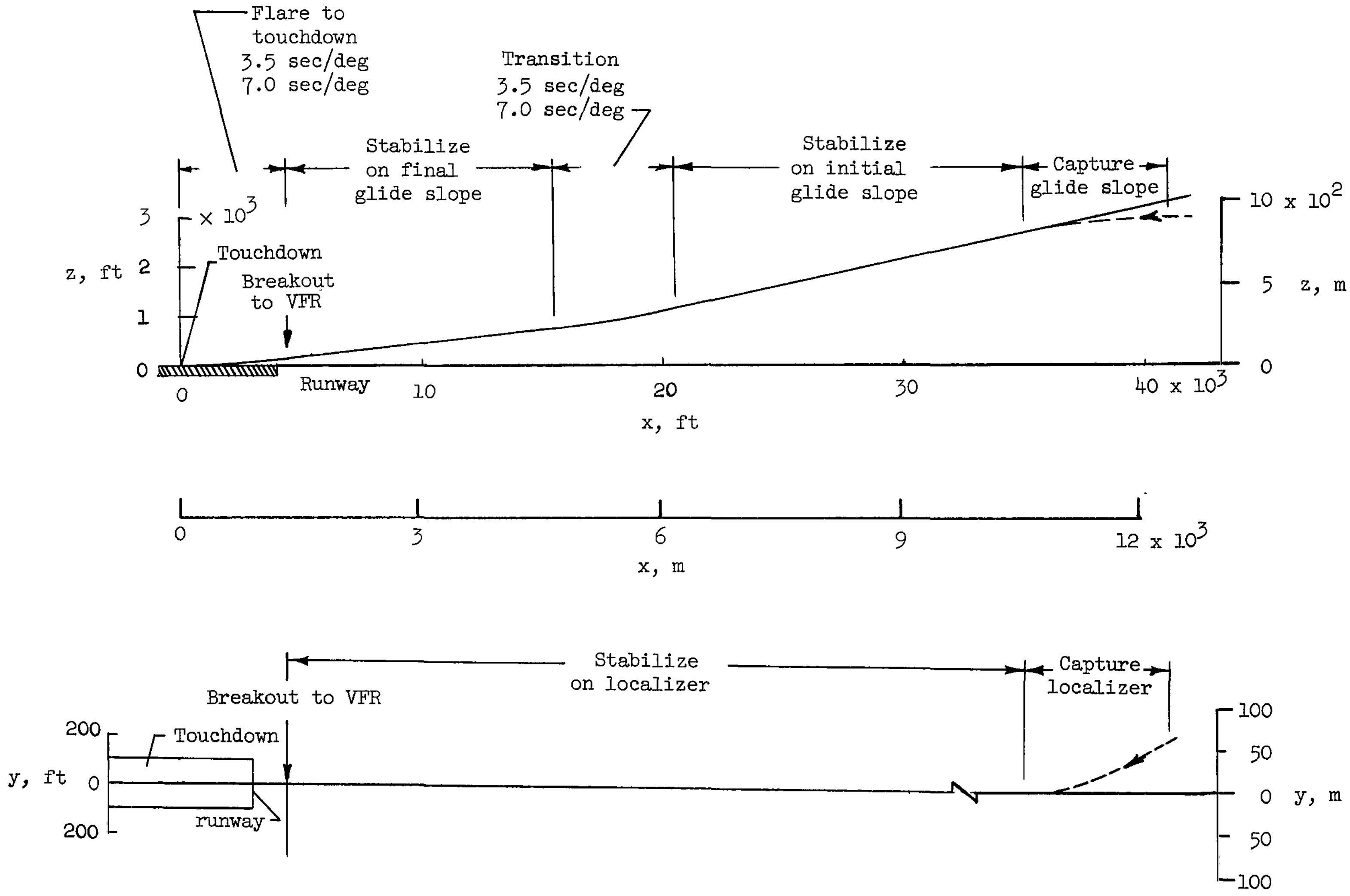


Figure 2.- Variation of sound pressure level with distance from touchdown for single-segment approaches with same thrust on 6^0 as on 3^0 glide slope.



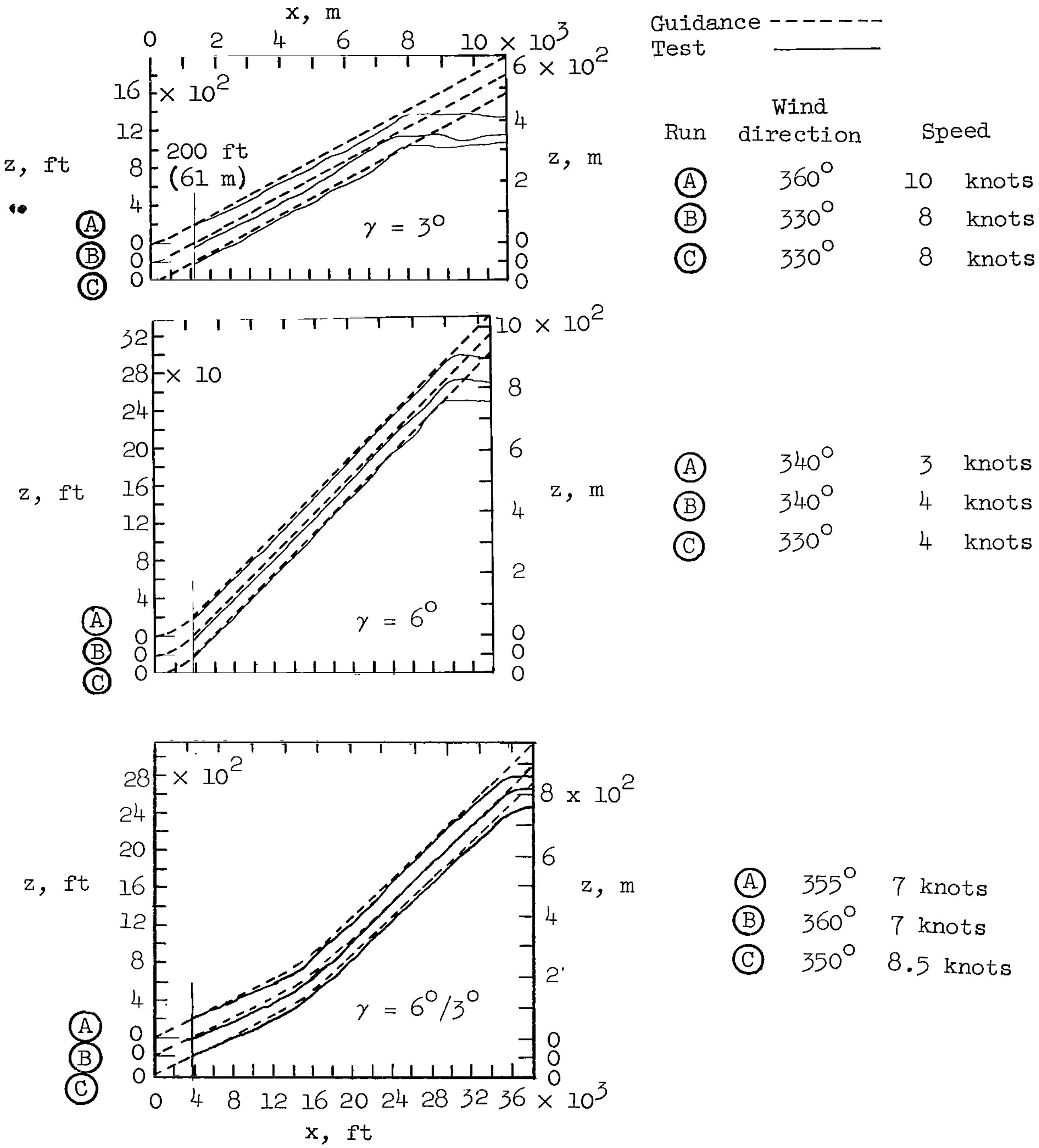
(a) Single-segment profile.

Figure 3.- Noise-abatement profiles.



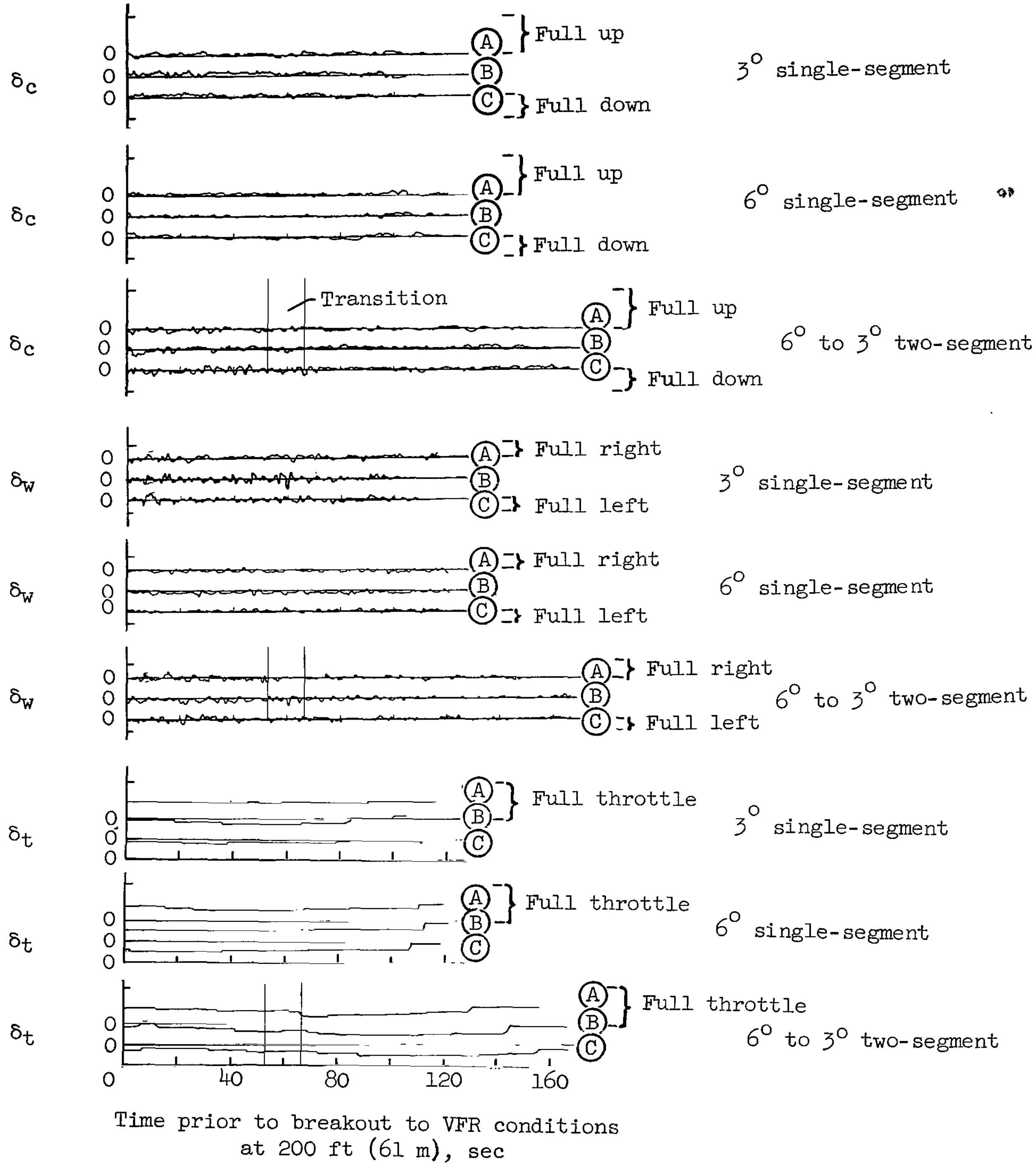
(b) Two-segment profile.

Figure 3.- Concluded.



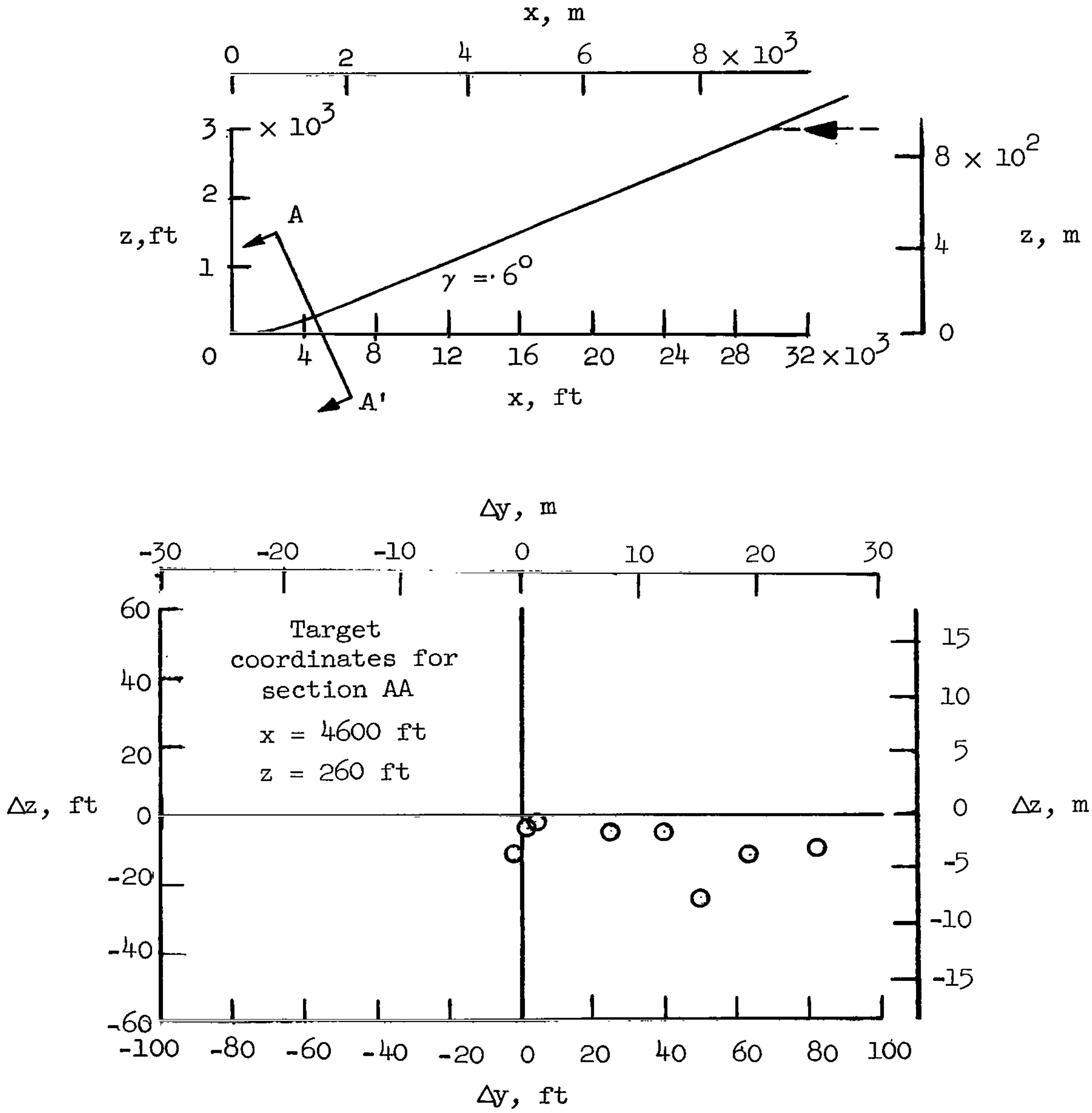
(a) Elevation profiles; approaches to runway 10. Breakout to VFR conditions at 200 feet (61 m). Constant speed; manual operation of flight controls and throttles.

Figure 4.- Performance and pilot control inputs on typical noise-abatement profiles and on conventional 3° profile.



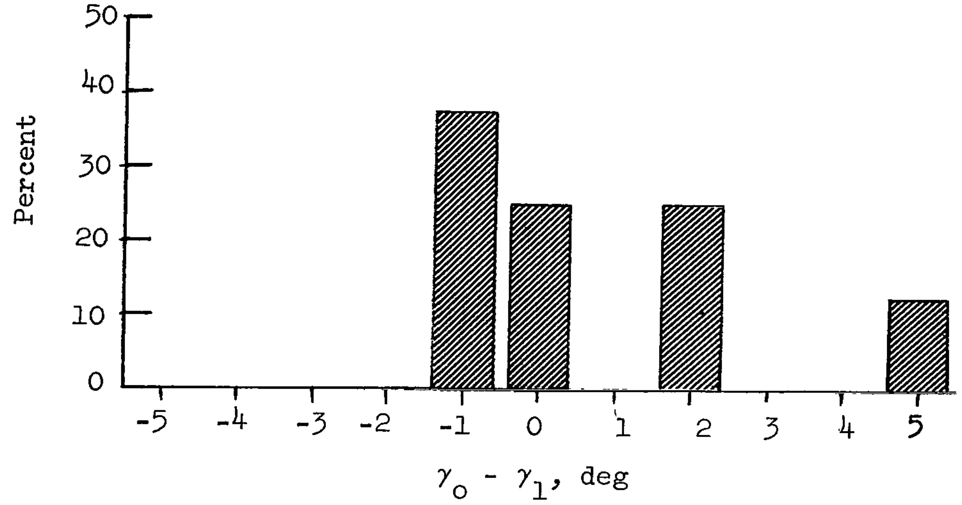
(b) Time histories of pilot control inputs.

Figure 4.- Concluded.

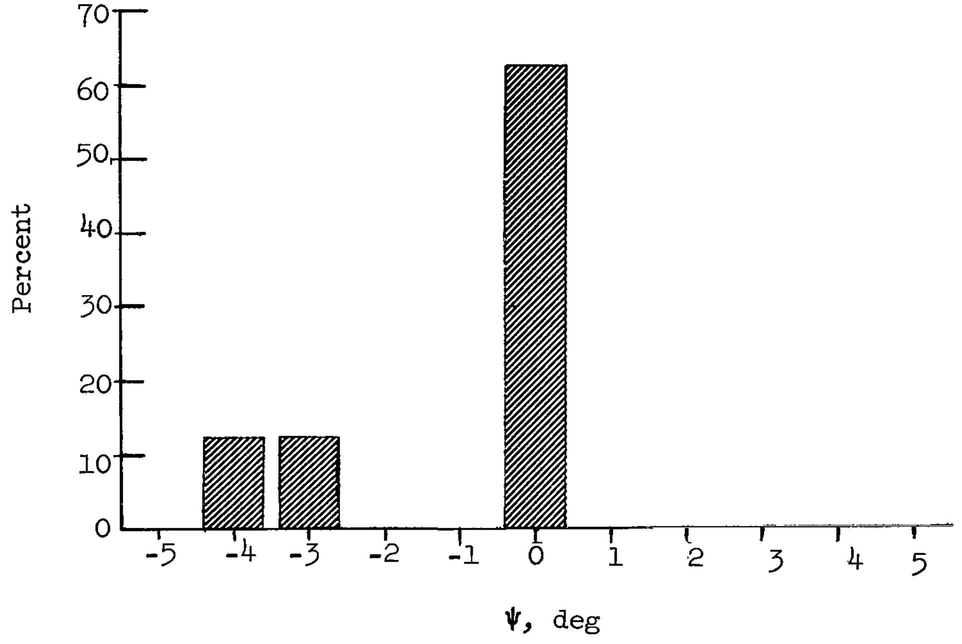


(a) Vertical and lateral displacements.

Figure 5.- Flight-path deviations for airplane E at start of 3.5 sec/deg flare to touchdown from 6^0 single-segment profile. Section AA'; N = 8.

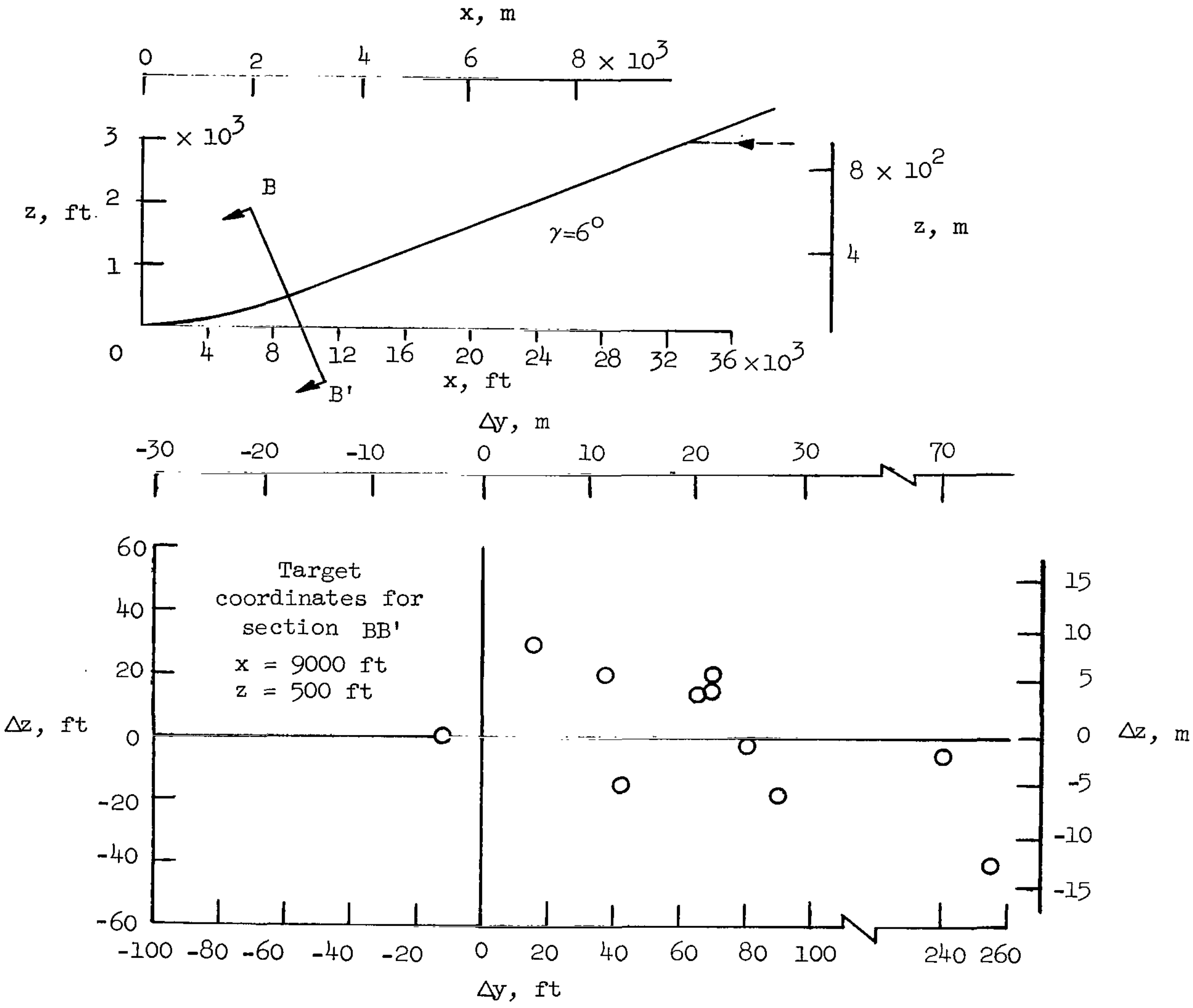


(b) Angular deviation from nominal glide slope.



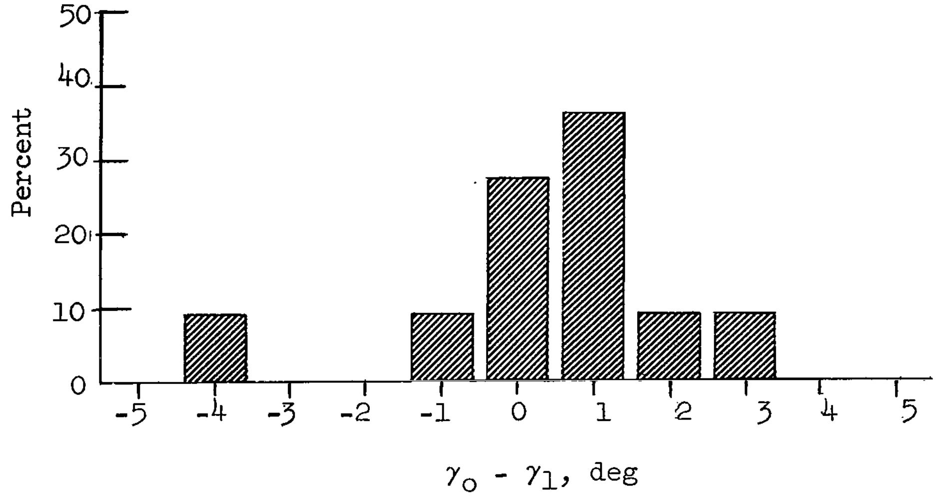
(c) Angular deviation from nominal course.

Figure 5.- Concluded.

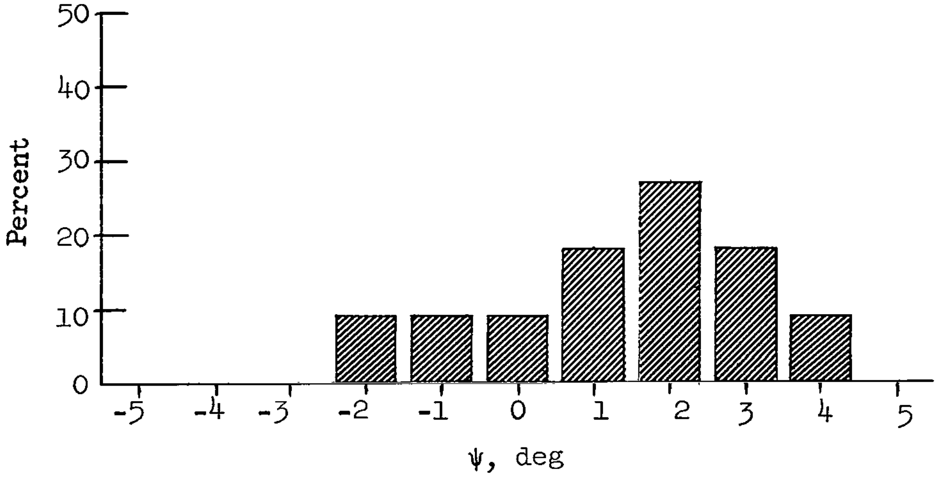


(a) Vertical and lateral displacements.

Figure 6.- Flight-path deviations for airplane F at start of 7.0 sec/deg flare to touchdown from 6° single-segment profile. Section BB'; N = 11.

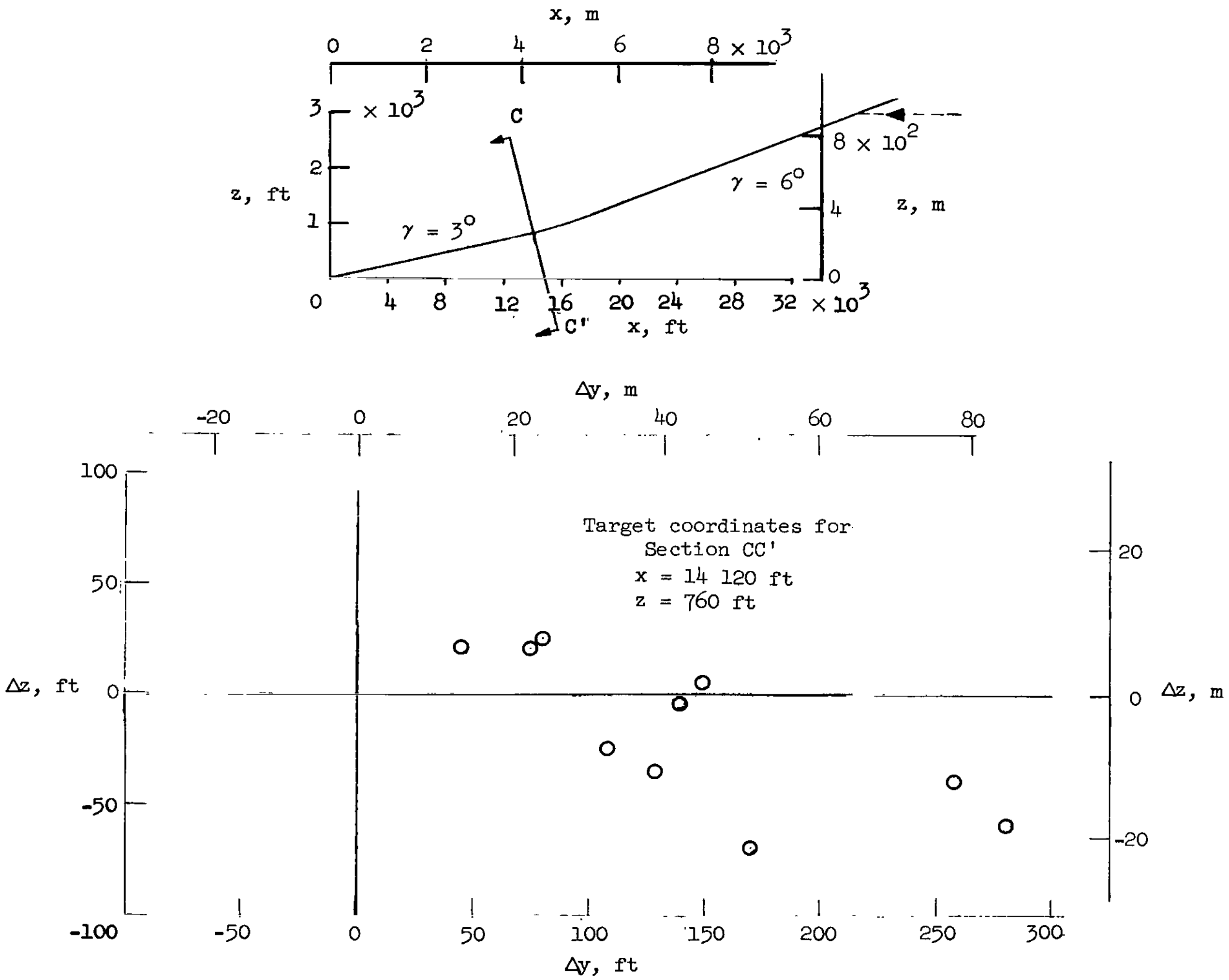


(b) Angular deviation from nominal glide slope.



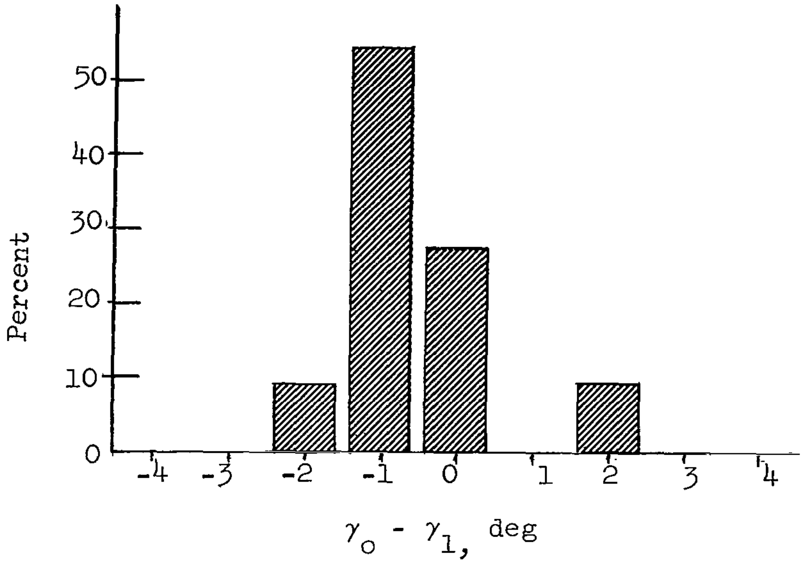
(c) Angular deviation from nominal course.

Figure 6.- Concluded.

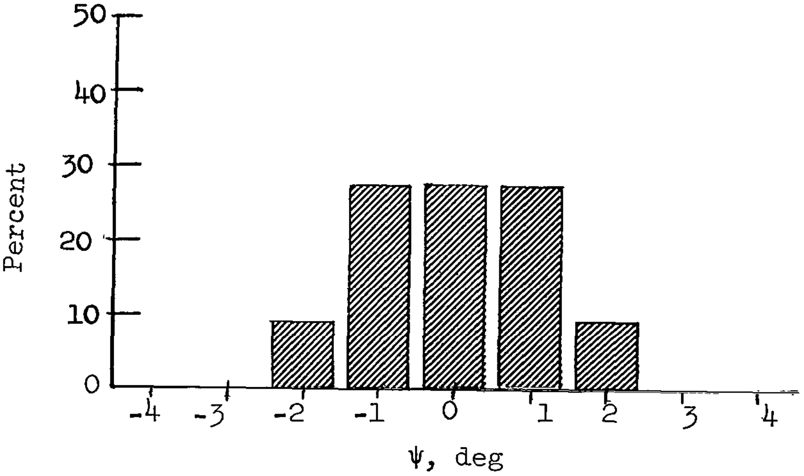


(a) Vertical and lateral displacements.

Figure 7.- Flight-path deviations for airplanes E and G at completion of 3.5 sec/deg transition on two-segment profile. Section CC'; N = 11.

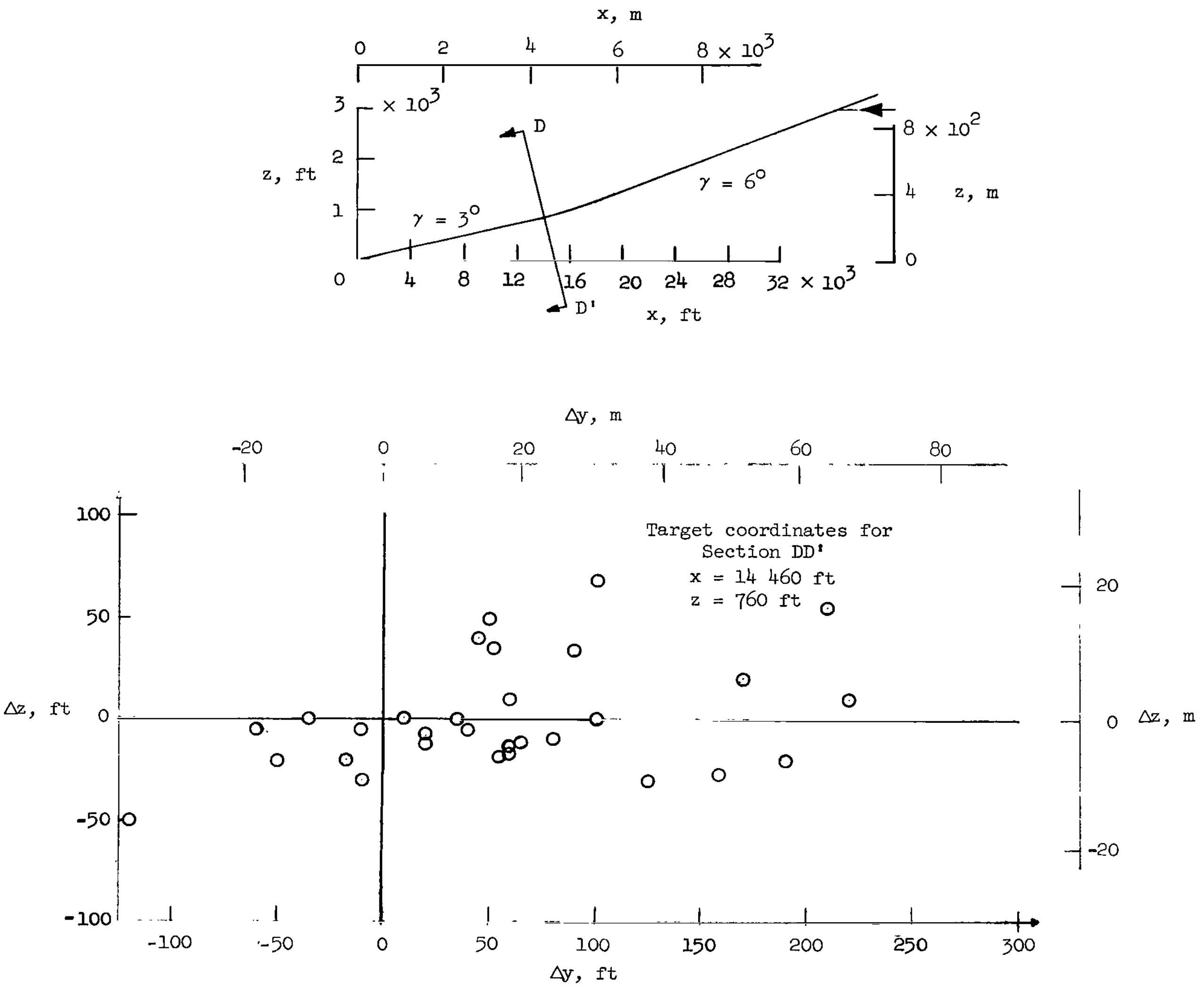


(b) Angular deviation from nominal glide slope.



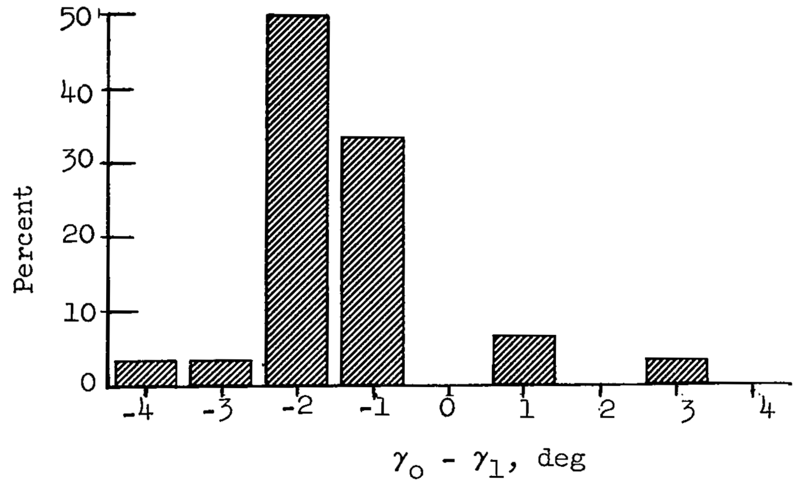
(c) Angular deviation from nominal course.

Figure 7.- Concluded.

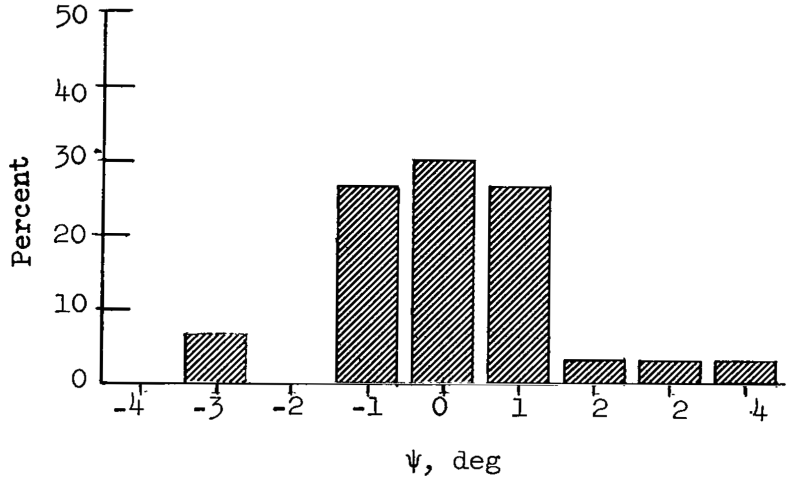


(a) Vertical and lateral displacements.

Figure 8.- Flight-path deviations for airplanes F ang G at completion of 7.0 sec/deg transition on two-segment profile. Section DD'; N = 30.

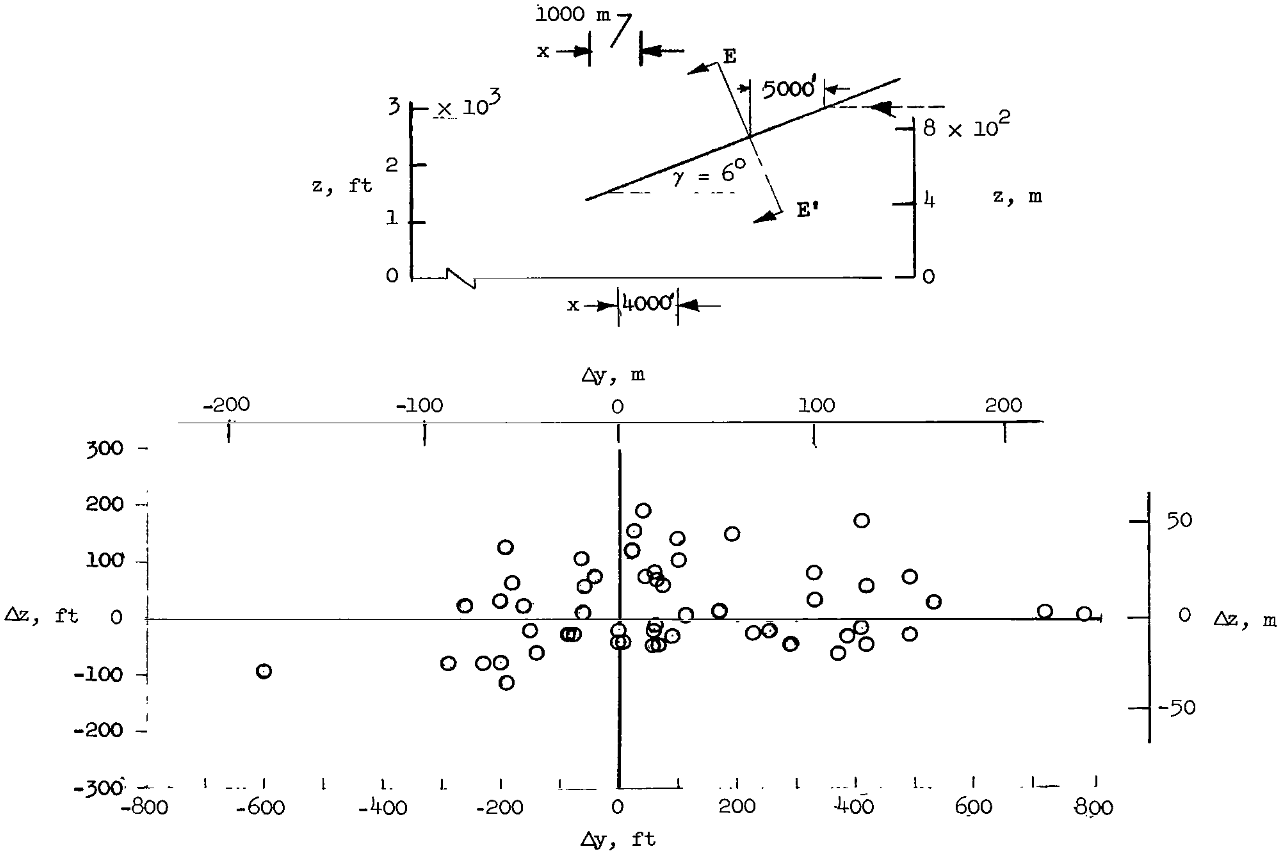


(b) Angular deviation from nominal glide slope.



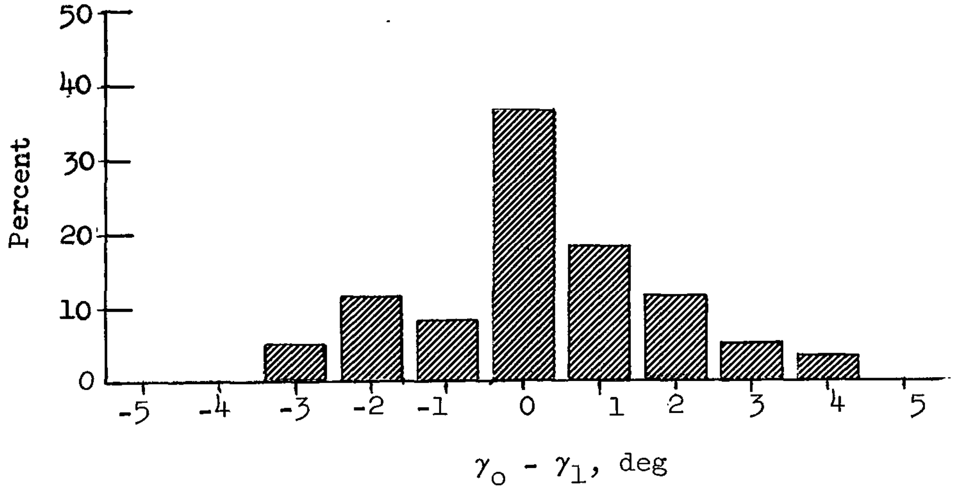
(c) Angular deviation from nominal course.

Figure 8.- Concluded.

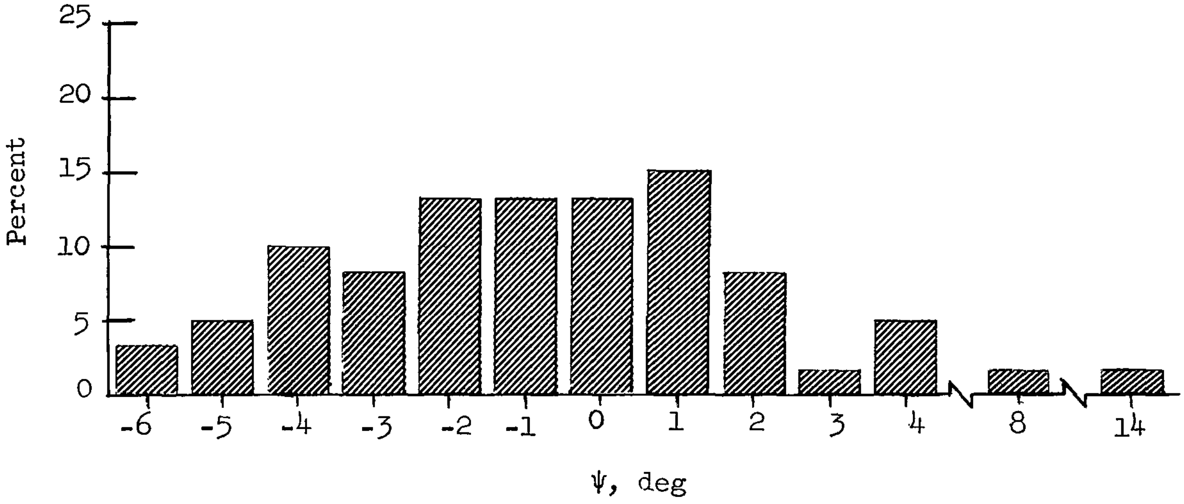


(a) Vertical and lateral displacements.

Figure 9.- Flight-path deviations for airplanes E, F, and G, 5000 feet (1524 m) after 6^0 glide-slope capture. Section EE'; N = 60.

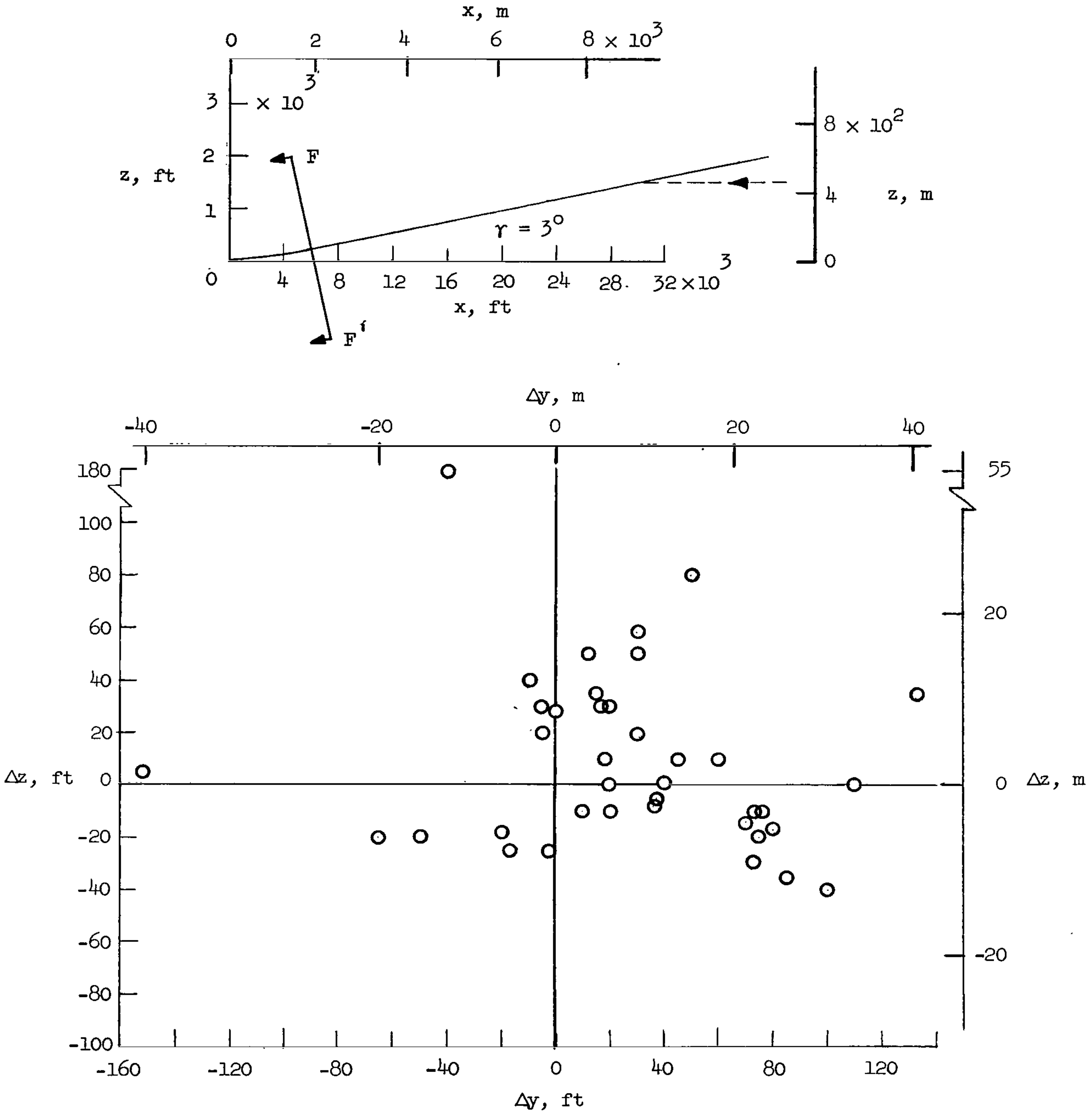


(b) Angular deviation from nominal glide slope.



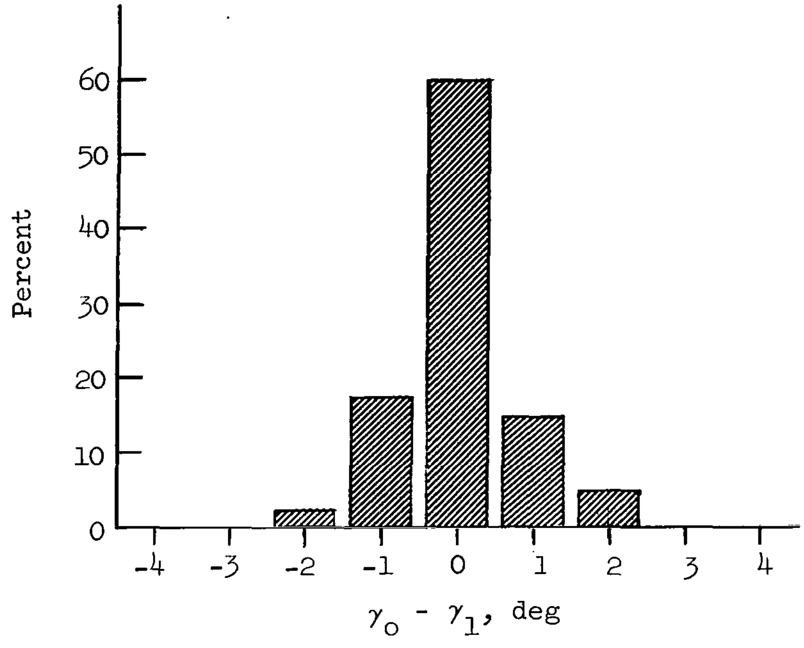
(c) Angular deviation from nominal course.

Figure 9.- Concluded.

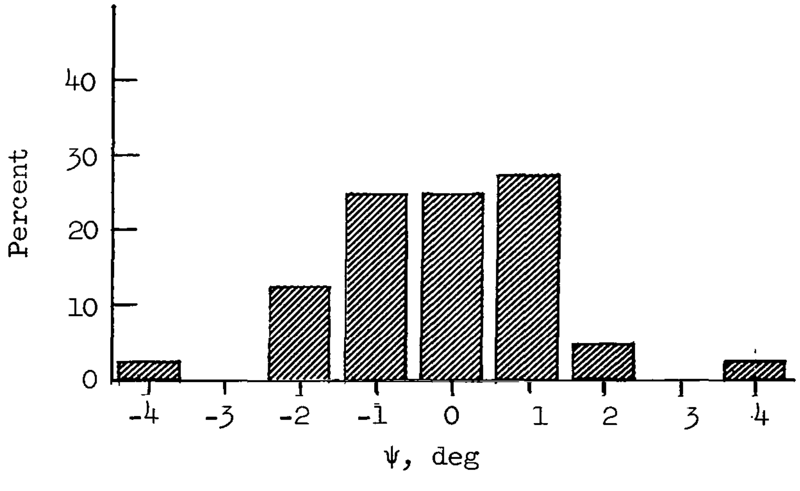


(a) Vertical and lateral displacements.

Figure 10.- Flight-path deviations for airplanes E, F, and G on 3^{0} single-segment profile. Section FF'; N = 40.

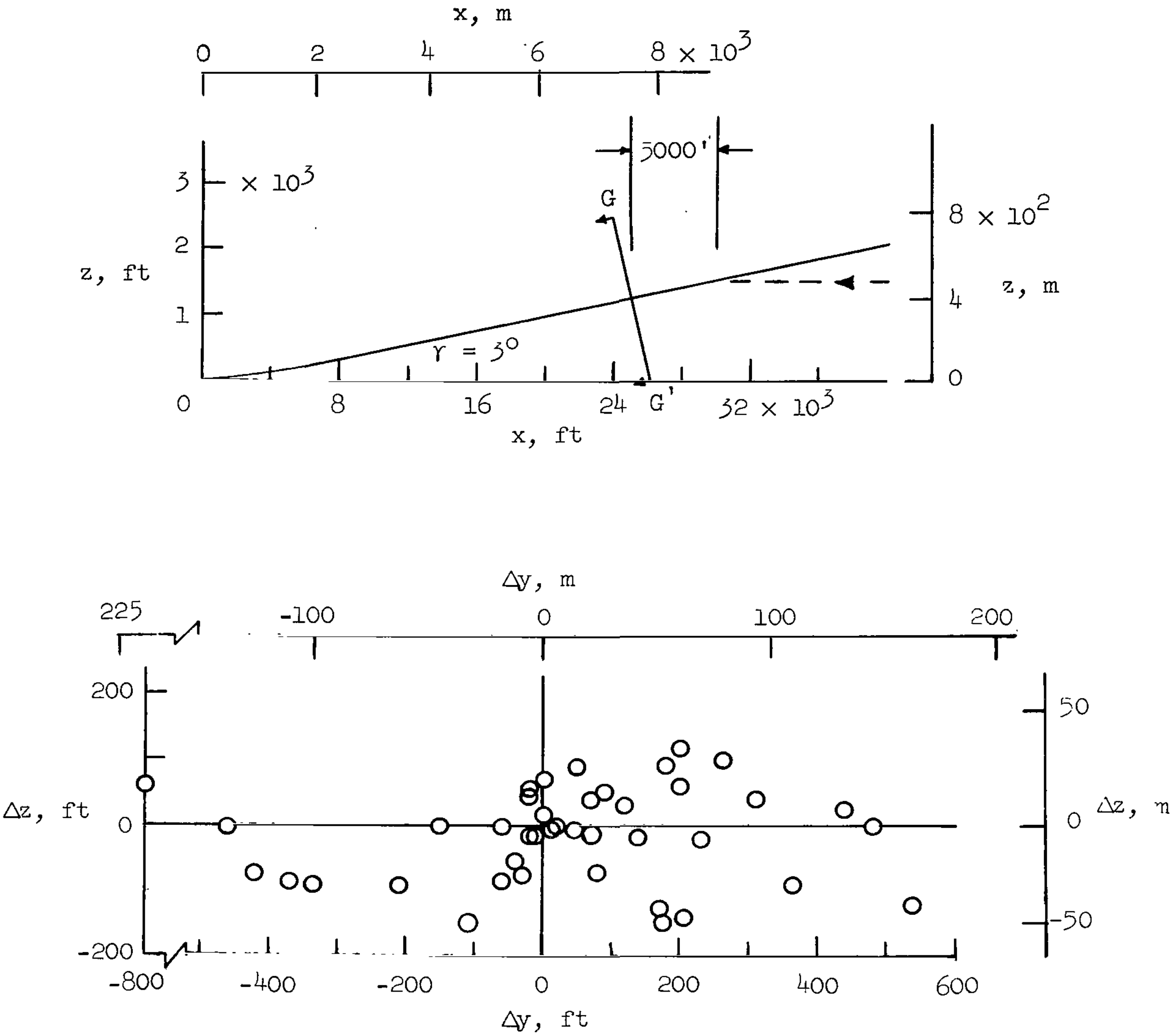


(b) Angular deviation from nominal glide slope.



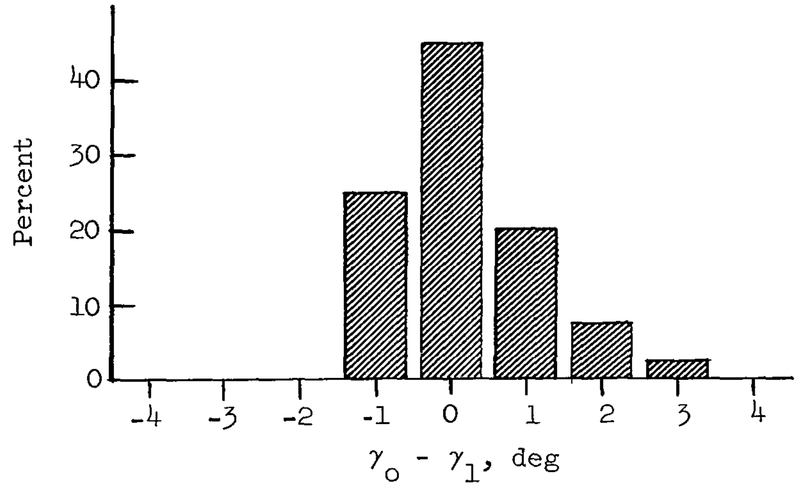
(c) Angular deviation from nominal course.

Figure 10.- Concluded.

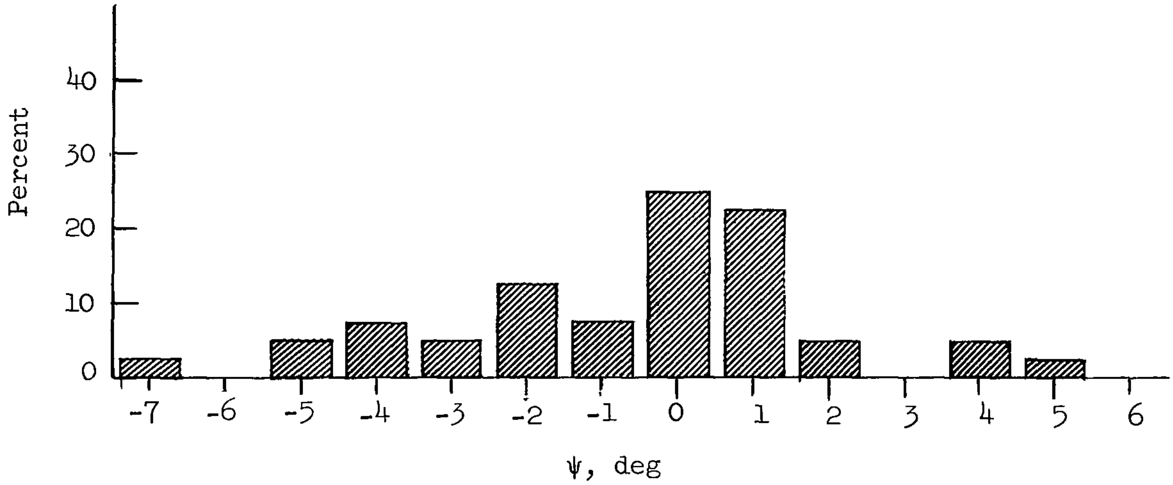


(a) Vertical and lateral displacements.

Figure 11.- Flight-path deviations for airplanes E, F, and G, 5000 feet (1524 m) after 3° glide-slope capture. Section GG'; N = 40.



(b) Angular deviation from nominal glide slope.



(c) Angular deviation from nominal course.

Figure 11.- Concluded.

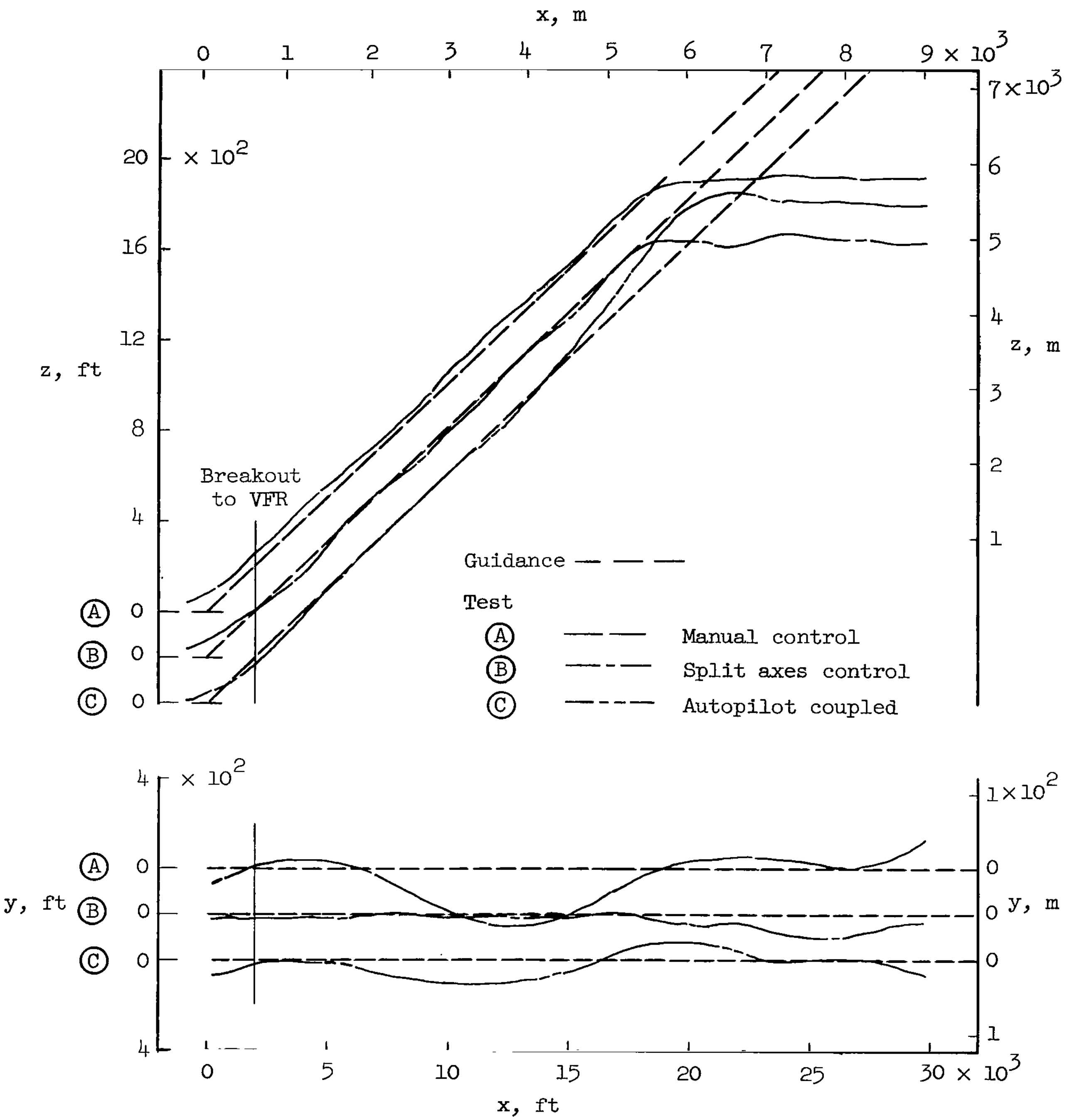


Figure 12.- Typical elevation profiles and ground tracks for airplane D for various control modes. $\gamma = 6^0$.

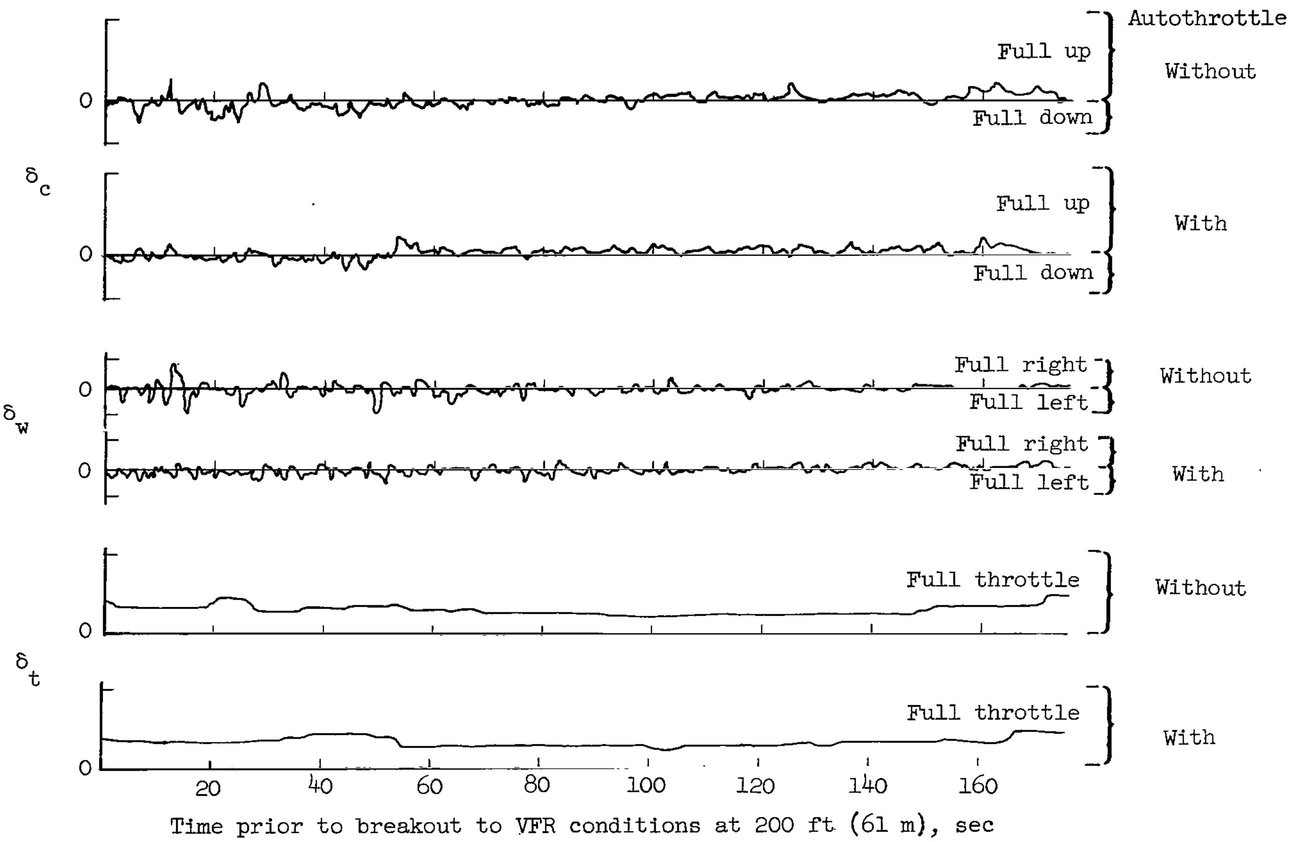


Figure 13.- The effect of simulated autothrottle on pilot control inputs. γ = $6^0/3^0$; 2.2-mile intercept.

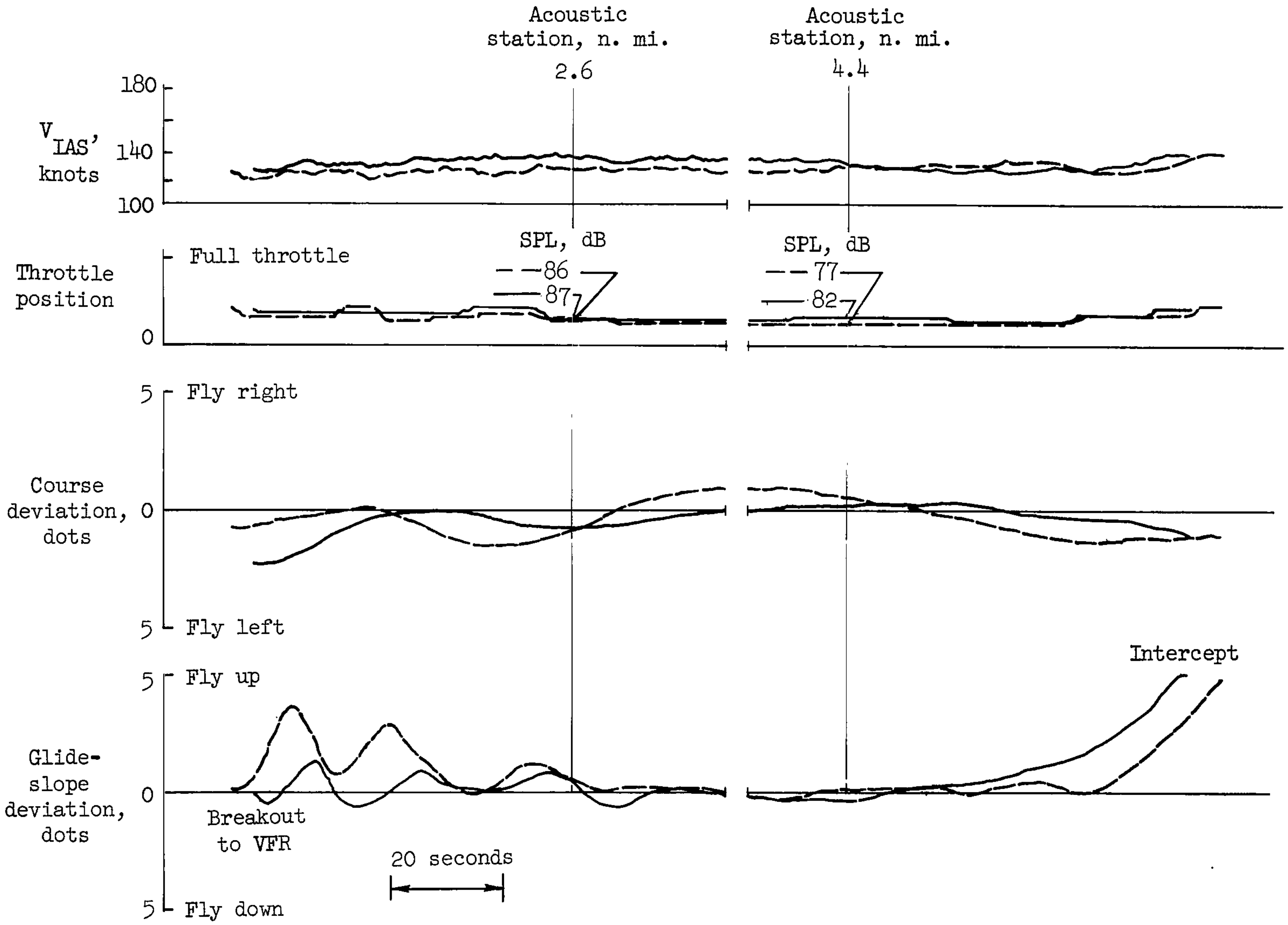


Figure 14.- Time histories of airspeed, throttle position, and course and glide-slope deviations. Effect of throttle on sound pressure level is indicated at 2.6 and 4.4 n. mi. stations.

NASA-Langley, 1967 — 2 L-5264

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*
>
> —National Aeronautics and Space Act of 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546