General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

V/STOL TERMINAL AREA INSTRUMENT FLIGHT RESEARCH

By John P. Reeder

NASA Langley Research Center
Langley Station, Hampton, Va.

Presented at the Air Transport Session of the 11th Annual Meeting
of the Society of Experimental Test Pilots

GPO PRICE $

CFSTI PRICE(S) $

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

Beverly Hills, California
September 28-30, 1967

FACILITY FORM 602

N68-27445 (ACCESSION NUMBER) (THRU)

37 (PAGES) 1 (CODE)

TMX-60456 (NASA CR OR TMX OR AD NUMBER) 02 (CATEGORY)

V/STOL TERMINAL AREA INSTRUMENT FLIGHT RESEARCH

By John P. Reeder
Aero-Space Technologist/Research Pilot
NASA Langley Research Center

INTRODUCTION

V/STOL aircraft would seem to have the ultimate potential for safe Category III landings, even onto rooftop landing pads. However, problems have been experienced during instrument flight studies at low speeds on an approach guidance system. Also, there are added piloting tasks required in the operation of some V/STOL aircraft types in transition flight. These factors indicate an urgent need for research in the critical terminal area instrument flight environment.

The research program at NASA-Langley is designed to investigate the handling and operating problems of V/STOL aircraft during instrument flight throughout the sequential operations from cruise flight to landing on a pad. The take-off to cruise flight operation will also be studied. Design information, solutions to operating problems and more suitable operating procedures than presently possible are desired results.

This paper will first summarize the state-of-the-art in V/STOL instrument flight to illustrate the problems and will then discuss the three facets of the Langley research program which are intended to generate solutions to the problems.

These facets are:

a. Basic handling qualities

b. Pilot information requirements and flight displays

c. Terminal area operations with actual V/STOL aircraft

STATE-OF-THE-ART

The best V/STOL aircraft we have today, the helicopter, has been a production article since 1943 but has attained only limited IFR certification and use to date. V/STOL aircraft other than helicopters have been available in only crude form to date. Langley Research Center has had limited flight experience with 11 of these. Only one aircraft, the XC-142, is suitable for realistic instrument flight studies. However, only limited instrument flight has been accomplished to date even with this aircraft.

When Langley began instrument flight studies with helicopters in 1950 it became apparent that the nature and magnitude of some major problems had not been anticipated. It was found that instrument flight without following a guidance system could be accomplished reasonably well, even with unstable aircraft, and it is felt that this is true for many of the V/STOL aircraft flying today. This type of instrument flight is illustrated in figure 1. Examples in practice are ASW "dips" where exact spatial position is not required, and GCA approaches to large airports at cruise speeds.

The problem becomes an order of magnitude more difficult, however, when it is desired to hit a small, specific spot in very low visibility (refs. 1, 2, 3, and 4). An example of this requirement might be landing on the Pan American building roof in New York when it is in the clouds. This type of operation is illustrated in figure 2, and with present technology, requires a specific path to the specific point. It is assumed there will be many desired landing sites similar to this in both commercial and military V/STOL operations. In fact, V/STOL aircraft may not be economically justified in feeder operations unless they can operate routinely in lower weather minima than airplanes do today.

Thus far it has not been found possible on an operational basis for a pilot to slow to a hover and land on a specific spot by instruments despite the fact that stabilization systems have been extensively developed for helicopter use. For the time being, therefore, the final slowdown and vertical landing from an instrument approach must be accomplished visually.

The state-of-the-art in guidance systems provides a localizer course for directional alinement as well as the glide path for guidance in the vertical plane. Over many years the precision instrument approach technique in using this system which has been found necessary for the airplane, a simpler vehicle than V/STOL aircraft, is that shown in figure 3. Note that the only intended variable during the final approach is altitude. All other parameters have a fixed reference about which only necessary small corrections are made. The need for adhering to this technique is greater today than ever as weather minima are reduced. In other words the number of variables for the pilot to manage must be kept to a minimum for concentration on the primary task of following the guidance system. The flare and landing are then performed visually after breakout.

In contrast, desirable V/STOL approaches are shown in figure 4. These approaches approximate minimum time and also maximum utilization of airspace in the case of the curved path. Note that nearly everything is variable, so with current technology the human pilot would have a virtually impossible task to perform during an instrument approach.

Since the pilot cannot cope with all the variables of the desirable V/STOL aircraft approaches shown in figure 4, the approach must be flown at a constant airspeed and glide-path angle until visual contact is established with the landing area. To see and land at zero speed with a reasonable maneuver in 1/8-mile visibility, such as the Pan American roof might probably have when ceilings at New York airports are approaching airplane minima, the approach closure speed should not exceed that shown in figure 5 (ref. 5) or about 35 knots.

The objective with present technology, then, is to get into position for landing visually at the proper speed. A non-helicopter V/STOL aircraft instrument approach for best performance (straight in) using current technology might appear as in figure 6 in vertical cross section. Following descent the flight path is leveled so the pilot can concentrate on starting auxiliary lift systems if required. During this operation he must readjust for large drag changes and probably large pitching moment changes. The aircraft must still remain wingborne during this stage. This operation will require at least a minute if everything is planned and executed perfectly. It is to be noted that if this operation cannot be performed in the clouds the aircraft must adhere to circling weather minima or higher, since there would not be sufficient time after breakout under lower ceilings.

The next operation is to reduce speed below that for wing-borne flight to a lower, maneuvering value by thrust vectoring and adjustments of lift and cruise thrust systems. In the pure vectored-thrust type (including the tilt-wing aircraft) this vectoring to obtain speeds below purely wing-borne flight will be the first step in setting up the approach, as there are no auxiliary systems to start. Reduction to speeds below fully wingborne is thought necessary for all V/STOL types prior to the final stages of the approach because large lift, drag and pitching moment changes of initial conversion and required adjustments should be made before the precision guidance phase begins.

Following this partial conversion, the pilot is ready to establish his precision alinement and readjust his speed and height for intercept of the glide path. The alinement procedure will require at least one minute based on flight experience. The glide path is then acquired and final speed established. Both speed and glide path angle are then essentially constant until breakout to visual conditions for landing. Flight experience has indicated that this phase of the approach requires about 90 seconds or 1-1/2 minutes to allow for acquisition of steeper glide slopes than the usual 3° and the effects of wind gradients with height. When visual contact is established, the aircraft is slowed to a vertical landing visually. Note that at least 5 minutes of slow flight are required for this pattern. For a jet type, this slow flight represents a very high fuel consumption and could amount to about one-third the range of the aircraft. Missed approaches are prohibitive in cost in this case. Propeller or fan type aircraft will not suffer such a large penalty in range.

In all probability the best performance approach illustrated cannot be accomplished because of traffic conditions, wind and landing direction, and approach aids available. Although omni-directional approach systems have been suggested for VTOL facilities (ref. 6) they are intended to provide for approaches into the wind under all conditions, and <u>not</u> for approaches from any direction regardless of wind. Operation of VTOL at low speed will be seriously hampered by large cross-wind and tail-wind components. Consequently, the pattern flown might be more nearly as shown in figure 7, where maneuvering is required between steps to get into position. Time for the approach will, of course, increase. Pattern size is directly proportional to speed as the comparison with that for the airplane in the figure indicates. The reason is that time required for alinement on the precision courses is very nearly the same for both types of aircraft.

For practical reasons such as the avoidance of adverse airflow conditions in the lee of buildings, for obstacle clearance, or for expediting descent from cruise altitudes a glide path angle of at least 6° is suggested. Although 6° does not seem steep to the uninitiated, instrument flight trials of references 1, 2, 3, and 4 have indicated limitations to the use of appreciably steeper angles. As stated earlier, vertical approaches on instruments have not yet been found possible or even desirable in most cases. In fact, flight at low airspeeds and steep angles on a guidance system have proved difficult. Also, rate of descent should not exceed 700 feet per minute to allow time to arrest descent when visual contact is made. Since wind effects and flight path control difficulties decrease as speed is increased the 6° slope rather than steeper angles allows a selection of higher flight path speeds if acceptable without exceeding 700 feet per minute rate of descent.

Control of the glide path for a V/STOL aircraft at low speed differs from airplane flight and is indicated in figure 8. Note that adjustment of the thrust vector angle determines the approach speed and the thrust or power level is adjusted for unaccelerated flight at the selected speed. To control the glide path, then, the thrust vector angle is modulated primarily if the angle of attack must be held within narrow limits to avoid stall, pitchup, excessive dihedral, or large drag buildup. If the angle of attack can safely vary as for the tilt-wing or helicopter types, the thrust or power level can be modulated for glide path control with essentially constant attitude.

PROBLEMS OF LOW SPEED FLIGHT

As indicated earlier, an instrument approach to a vertical landing at a selected spot in 1/8-mile visibility with present technology requires that a maximum steady speed of about 35 knots be maintained for about 1-1/2 minutes. The problems encountered at low speeds such as this on a guidance system are listed in figure 9. It is noteworthy that very few organizations have tried this type of flight to learn of the problems, even with helicopters, although those which have tried have reached similar conclusions (refs. 1, 2, 3, 4, 7, and 8). As a result, no large scale effort toward solutions has been undertaken. The factors that cause problems are:

a. High angular rates of deviation from flight path occur due to small upsets in attitude. These rates are, simply, inversely proportional to speed and do not depend on aircraft type. However, in some V/STOL aircraft types large sideslip angles may result instead of a turn should the aircraft deviate from laterally level flight.

b. The high angular rates of deviation occur with vanishing acceleration clues for detection by the pilot.

c. Wind-shear effects require rapid and large glide path and heading corrections below 200 feet even in light winds, and below 700 feet, or so, in strong winds regardless of whether the aircraft has stabilization systems. Lateral flight path control is always performed by banking and turning to accomplish heading corrections. In the first place it is considered highly undesirable to hold heading and vary sideslip to stay on track because of the continually changing lateral and directional trim requirements with no fixed reference. Secondly, dihedral effect has proved to be high for most V/STOL types, so there is every possibility of using all of the lateral, or even the directional control for trim, allowing none for maneuvers, disturbances or emergencies. Also, as glide path angles are steepened the wind-shear effects geometrically alter the glide path angle in space, if airspeed is maintained. Flying the glide path thus becomes more difficult and corrections become markedly larger, particularly on slopes higher than 6^{o}.

d. For the speeds being discussed flight is most probably on the "backside" of the thrust or power required curve which leads to difficulties in glide path control if angle of attack or attitude inadvertently vary or if attitude alone is used in flying the glide path guidance system.

e. Although V/STOL aircraft may be statically stable in an engineering sense at low speeds the magnitude of restoring moments is decreased to low levels about one or more axes because of low dynamic pressures.

f. The aerodynamic damping forces and moments about the linear and angular axes of the aircraft, respectively, also tend to be low due to low dynamic pressure, resulting in further deterioration of handling qualities. The jet supported aircraft have been troubled with low linear damping along the vertical axis which has led to "accelerated settling" during night or simulated instrument approaches where visual references have deteriorated and constant attention to this axis cannot be maintained.

The end result of these low speed characteristics is to force the pilot's rate of instrument scanning to an excessively high level. Eye fixations have been measured at two per second. This is true even with present stabilization systems since many flight path corrections are required. A brief distraction or requirement for a large correction may easily allow the aircraft to get ahead of the pilot and the approach may have to be abandoned.

It cannot be denied that automation of portions or all of the approach and landing will be accomplished eventually. We prefer to think that the characteristics of the aircraft and the methods of operation within the aircraft operational envelope must be explored before intelligent automation can be employed. Automation will probably then be applied progressively to critical portions of the overall task as feasibility is demonstrated. It is not reasonable to expect complete automation of a VTOL approach and landing without an extensive development period as the overall operation is more complex than an airplane landing today, particularly if it involves a decelerating descent. It is of interest to note that the airplane, even today, has achieved automatic landings in only experimental operations, or in a few trial cases with passengers aboard when visibility was adequate for the pilot to take over control at any time.

ATTACKING THE PROBLEMS

In order to examine and solve the problems of the "high performance" instrument approach for V/STOL aircraft and to simplify the techniques and shorten the procedures for approach and landing Langley has been proceeding on a three-facet research program which is outlined in figure 10. The program includes handling qualities studies with a helicopter used as an airborne V/STOL simulator, pilot information requirements and display studies in another helicopter, and terminal area instrument flight operations studies with several V/STOL aircraft other than helicopters. An experimental GSN-5 radar is used to provide a wide range of guided flight paths for the studies.

The three facets of the program are discussed in turn:

Airborne Simulator.- For the past 3-1/2 years Langley has been operating a CH-46C (Vertol 107) tandem helicopter as a variable-stability-and-control airborne simulator which uses the model-following technique with analog computers. Its mission is to explore and develop better aircraft characteristics for the critical tasks of V/STOL operation. The aircraft has been used for study of many of the individual handling qualities parameters involved in piloted visual and instrument flight. Flight control systems and automation about the various aircraft axes for automated approaches and landings will be investigated.

Two recent studies of particular interest to V/STOL operation will be discussed to illustrate the use of this aircraft. The first study is of an "on-off" control system similar to that used in spacecraft (ref. 9), the characteristics of which are shown in figure 11. As illustrated on the right of the figure full control is either on or off as control is displaced beyond a ±1/4-inch deadband at neutral. This system was flown in the CH-46C through all normal maneuvering and precision hovering tasks near the ground for comparison with proportional control. Results are compared with th proportional system in figure 12 as control power and damping for a satisfactory pilot rating (Cooper 3-1/2). Note that satisfactory ratings were achieved with the on-off control with control powers found unacceptable for the normal proportional control, and they were about one-quarter those for satisfactory proportional control. This result is significant in that some V/STOL aircraft derive control power from bleed flow from the lifting system, thus influencing the size and weight of the lift-propulsive systems and therefore, the aircraft. The on-off control may thus influence the configuration and minimize the size of the aircraft. The satisfactory control shown is for maneuvering only, and additional control moments must be provided for trim. Additional trim requirements can be accommodated more readily with a proportional system.

The second study referred to is of the thrust-to-weight ratio (T/W) required to arrest the vertical velocity of V/STOL aircraft for landings from steep descents at 500 to 1000 feet per minute performed visually (ref. 10). Results are shown in figure 13 as pilot rating for combinations of vertical damping and T/W ratio where power required is constant with speed. This power required characteristic is typical of a jet aircraft near hover. Surprisingly, for typical V/STOL aircraft damping a T/W ratio of only 1.05 was found satisfactory (Cooper 3-1/2), although the pilots would like more for unlimited maneuvering. It will be of great interest to see what T/W ratios are required for actual V/STOL aircraft for glide path corrections during instrument approaches at low speed. In the study from which the figure was drawn the pilots actually demanded higher T/W ratios for horizontal acceleration and climb capability than they did for the landing maneuver.

Pilot displays.- Until automation is fully developed, our research viewpoint is that the pilot should remain in the control loop as an active participant. The reason for this thinking is that failures do and will continue to occur. Since it is likely that V/STOL aircraft will have more systems involving more components than present airplanes the component failure rate may well increase. Guidance system malfunctions must also be considered. In order for the pilot to take over as quickly as possible in any situation he must be directly geared to the operation.

We have hopes that, with vastly improved displays and improved guidance systems, approaches which we now fly visually and which are close to the minimum-time type may possibly be flown with these displays all the way to touchdown at the desired point. No displays to date have permitted such VTOL operation, at least on an operational basis. Our goal is to reduce the approach time required from 5 to 6 minutes by present procedures to 1-1/2 to 2 minutes. We are, therefore, actively working on improved displays with a helicopter, trying at the same time to keep them simple in mechanization; i.e., mechanical and/or electrical.

For evaluation of the displays a GSN-5 radar (prototype of the SPN-10) is used to provide any shape or width of approach path and, by means of radio data link, it provides the aircraft with cockpit-displayed guidance signals. The radar also plots the vertical and horizontal tracks of the aircraft for measurement of task performance. The approach paths selected by trial have been wider than normal ILS courses and of constant linear width from 1500 feet range to the pad to reduce the sensitivity at a critical point in the approach. The glide path angle has been 6°.

Our display program started out with initially three phases:

1. Flight director with auxiliary information on vertical tapes
2. Horizontal situation display with auxiliary information on vertical tapes
3. Contact analog with auxiliary information for landing on a specific spot

The program has expanded somewhat as new ideas have been generated by experience.

We have thoroughly explored "needles at their best" (ref. 11) with the flight director shown in figure 14 which is augmented by vertical tape displays of ground speed, geometric height, range, airspeed and vertical speed. We are now convinced that needles do not and cannot give the pilot sufficient knowledge of his situation to do the job. It has become evident that the pilot needs quantitative position information in the landing area and his velocity vector, both speed and track over the ground, in addition to attitude and relative heading, if a worthwhile reduction in workload and improvement in accuracy at breakout is to be accomplished. This has been confirmed with the graphic horizontal situation display (ref. 12) shown in figure 15 which is augmented by vertical tape display of coarse and fine geometric height, airspeed and vertical speed. Labels on the figure explain the information provided by elements of the display. The pilot gains a more complete appreciation for his horizontal situation and what to do about it than needles can possibly give him. The indications are that large attitude instrument above the display gives the pilot reference attitude information without specific eye fixations on it.

The next version of the display having vertical situation added will use a 6-inch horizon (5-inch at present) without command needles. A measure of effectiveness of this display in reducing workload is shown in figure 16 as breakout position at a 50-foot height from the 6°-glide slope flown at 30 knots airspeed. The longitudinal dispersion, evidence of glide path control difficulties caused by wind gradient effects below about 200 feet, is cut to less than half because the pilot can spend more time on glide path control using the improved horizontal situation display. Pilot comments attest to an even greater reduction in workload than the dispersion data indicate.

The display work is only partially complete and is being pursued along several promising lines. After a preliminary study using a television picture of the real world (ref. 13), we are beginning work with a contact analog in which auxiliary picture information is provided for judging height and range to the pad and for execution of vertical touchdowns.

It is worth noting that the same inputs to the displays that the pilot needs to assess his situation are those needed for automation of the approach. The velocity inputs are not available from present operational guidance systems, although airborne doppler or inertial systems might be used in combination with them.

We feel that improved displays are a logical and necessary step toward easier and shorter instrument approaches not only for piloted control but also for full automation. In the latter case improved displays may be able to present the total situation of the aircraft clearly enough that the pilot can be a passive monitor and still take quick corrective action should anything go wrong (2 secs. instead of 6 secs. for action). This capability would go a long way toward speeding up pilot acceptance of full automation.

Terminal area operations.- The third phase of Langley's V/STOL flight program is to get experience in "high performance" instrument flight with actual VTOL aircraft. So far, this type of flight has simply not been explored with VTOL aircraft other than helicopters. Langley's terminal area operations studies are a "systems approach" to solving the high performance instrument approach and landing problems. The operations will include entrance into the landing area patterns of figures 6 and 7 from cruise flight and performing all the necessary operations to a vertical landing in simulated instrument flight. The takeoff and transition into cruise flight will also be investigated. Thus the various phases of the operation are integrated in proper sequence into a realistic operational task.

The objectives of the terminal area operations program are the determination of the flight controls requirements for critical flight tasks; the piloting problems of managing and operating the propulsion and conversion systems while performing the required flight tasks, and determination of operating procedures that minimize pilot workload, time and airspace. The overall program is intended to explore several types of lift-propulsion systems, the autostabilization or augmentation systems required, and significantly improved pilot displays. These objectives are shown in figure 17. As stated earlier, a long-range objective is the reduction of time from cruise to landing from 5 to 6 minutes with present technology to 1-1/2 to 2 minutes. The reduction in time probably means reduction of airspace required as well as fuel. If these factors are reduced it will have been because the piloting tasks have been simplified toward that of visual flight and the risk of missed approaches will be greatly reduced.

The aircraft Langley plans to use for these studies are:

1. Hawker P.1127
2. Jet V/STOL research aircraft
3. XC-142

We have recently begun terminal area operations studies with a Hawker P.1127 which was made available to us by the Department of Defense following the U.S. National Trials. With this aircraft we hope to get design information and initial experience with which to firm up the program for a planned jet V/STOL operations research aircraft. As shown in figure 18, the P.1127 is limited in its research capability for low speed instrument flight because it has a single engine, carries a single pilot, has no stability augmentation, carries little payload, has a low excess T/W ratio available, and has little hovering time available. However, important favorable characteristics of the P.1127 are its simple, quick and flexible vectoring system which permits it to fly at any speed in the transition speed range, to accelerate and decelerate from hover to airplane flight, and vice versa, at a rapid rate and to descend at moderately steep angles at low speed while holding desired attitude of angle of attack. These characteristics and capabilities provide reference points at one end of a spectrum of V/STOL aircraft characteristics and capabilities by which to gauge more complex systems in terms of times required, flight path angle and path control capabilities, and the pilot workload.

Although it has been proposed by Langley for some time to acquire a jet V/STOL operations research aircraft and an XC-142 for terminal area operations studies, approval of the jet V/STOL program and funding for an XC-142 operation have not yet been obtained. Firm plans, therefore, cannot be formulated.

The jet V/STOL operations research aircraft is intended to develop technology for military fighters of the 1975-1980 time period. General requirements would be as shown in figure 18. As indicated this aircraft would have multiple lift and propulsive units and the aerodynamic configuration to simulate the low speed characteristics of advanced designs. The latest technology would be applied in all areas. The payload, two-man crew, endurance, engine-out safety, an excess of control power and vectoring over most present systems and variable stability and control provisions would provide capability for advanced research. Langley contracted with two companies for engineering studies of the feasibility, and for the best design and current cost of such an aircraft for both new and modified airframes. These studies have recently been completed and indicate that suitable aircraft can be built to the stated requirements within the state-of-the-art with a few acceptable compromises. This technology is available in published form and are listed as references 14 and 15. Immediate implementation of a portion of the planned research for this vehicle may be forthcoming through a cooperative program with the Air Force in which one of the two XV-4B aircraft would be modified as feasible to meet the special requirements of NASA's program and would be operated by NASA. Acquisition of this aircraft as an airworthy research aircraft would require about two years after go ahead.

NASA has long had a strong desire to acquire an advanced propeller-driven V/STOL such as the XC-142 for a terminal area operations research program. Acquisition of one of the XC-142 aircraft from the Air Force now seems promising. The general program and objectives will be similar for the propeller and jet types of aircraft.

CONCLUDING REMARKS

It should be emphasized that the research described in this paper is oriented toward solving problems of Category III VTOL instrument flight. It is considered that at least some V/STOL aircraft types are already suitable for operation in Category I weather minima today.

REFERENCES

1. Reeder, John P.; and Whitten, James B.: Notes on Steep Instrument Approaches in a Helicopter. Proc. Twelfth Ann. Natl. Forum of the Am. Helicopter Soc., Inc., May 1956, pp. 80-86
2. Trant, James P., Jr.; and Algranti, Joseph S.: Investigation of VTOL Approach Methods by Use of Ground-Controlled-Approach Procedures. NASA TN D-1489, 1962
3. Kelly, Francis X., Jr.: A New Technique for Steep Angle Approach Guidance. Proc. Twentieth Ann. Natl. Forum, Am. Helicopter Soc., Inc., May 1964, pp. 117-126
4. Fance, D. F.; and Johnson, H. B.: All-Weather Approach and Landing for Helicopters. AGARD Conference Proceedings No. 7. Helicopter Developments, January 1966, pp. 441-451

5. Reeder, John P.: The Impact of V/STOL Aircraft on Instrument Weather Operations. NASA TN D-2702, 1965

6. Staff of Langley Research Center: A Preliminary Study of V/STOL Transport Aircraft and Bibliography of NASA Research in the VTOL-STOL Field. NASA TN D-624, 1961

7. Kestrel Evaluation Trials, Task V - Instrument Flying. Report Supplement "F," KES/C4/AIR, February 1966

8. Kestrel Evaluation Trials, Task VI - Night Flying. Report Supplement "G," KES/C4/AIR, February 1966

9. Garren, John F., Jr.; DiCarlo, Daniel J.; and Driscoll, Norman R.: Flight Investigation of an On-Off Control For V/STOL Aircraft Under Visual Conditions. NASA TN D-3436, 1966

10. Kelly, James R.; Garren, John F., Jr.; and Deal, Perry L.: Flight Investigation of V/STOL Height-Control Requirements for Hovering and Low-Speed Flight Under Visual Conditions. NASA TN D-3977, 1967

11. Gracey, William; Sommer, Robert W.; and Tibbs, Don F.: Evaluation of Cross-Pointer-Type Instrument Display in Landing Approaches with a Helicopter. NASA TN D-3677, 1966

12. Gracey, William; Sommer, Robert W.; and Tibbs, Don F.: Evaluation of a Moving-Map Instrument Display in Landing Approaches with a Helicopter. NASA TN D-3986, 1967

13. Gracey, William; Sommer, Robert W.; and Tibbs, Don F.: Evaluation of a Closed-Circuit Television Display in Landing Operations with a Helicopter. NASA Proposed Technical Note, 1967

14. "Conceptual Design Study Report." Prepared by Northrop Corporation, Norair Division (NOR 67-6R), under NASA Contract NAS1-6777, Revised July 1967

15. "Airplane Specification for Northrop N-309 NASA V/STOL Jet Operations Research Airplane." Prepared by Northrop Corporation, Norair Division (NOR 67-8), under NASA Contract NAS1-6777. NASA CR-66417, July 1967, Vol. I

16. "Airplane Specification for Northrop Modified T-39A NASA V/STOL Jet Operations Research Airplane." Prepared by Northrop Corporation, Norair Division (NOR 67-8), under NASA Contract NAS1-6777. NASA CR-66418, July 1967, Vol. II

17. "Substantiating Technical Data." Prepared by Northrop Corporation, Norair Division (NOR 67-8), under NASA Contract NAS1-6777. NASA CR-66419, July 1967, Vol. III

18. "Aircraft Development Plan Report." Prepared by Northrop Corporation, Norair Division (NOR 67-8), under NASA Contract NAS1-6777, July 1967, Vol. IV

19. "Part I - Aircraft Preliminary Design Report V/STOL Jet Operations Research Airplane Design Study - Sections I to V," by G. Rosenthal, J. Chung, E. Schiller, J. Wright, and E. Vogel, Fairchild Hiller Corporation, Republic Aviation Division, under NASA Contract NAS1-6778. NASA CR-66421, 1967

20. "Part II - Aircraft Preliminary Design Report V/STOL Jet Operations Research Airplane Design Study - Sections VI to XI," by G. Rosenthal, J. Chung, E. Schiller, J. Wright, and E. Vogel, Fairchild Hiller Corporation, Republic Aviation Division, under NASA Contract NAS1-6778. NASA CR-66422, 1967

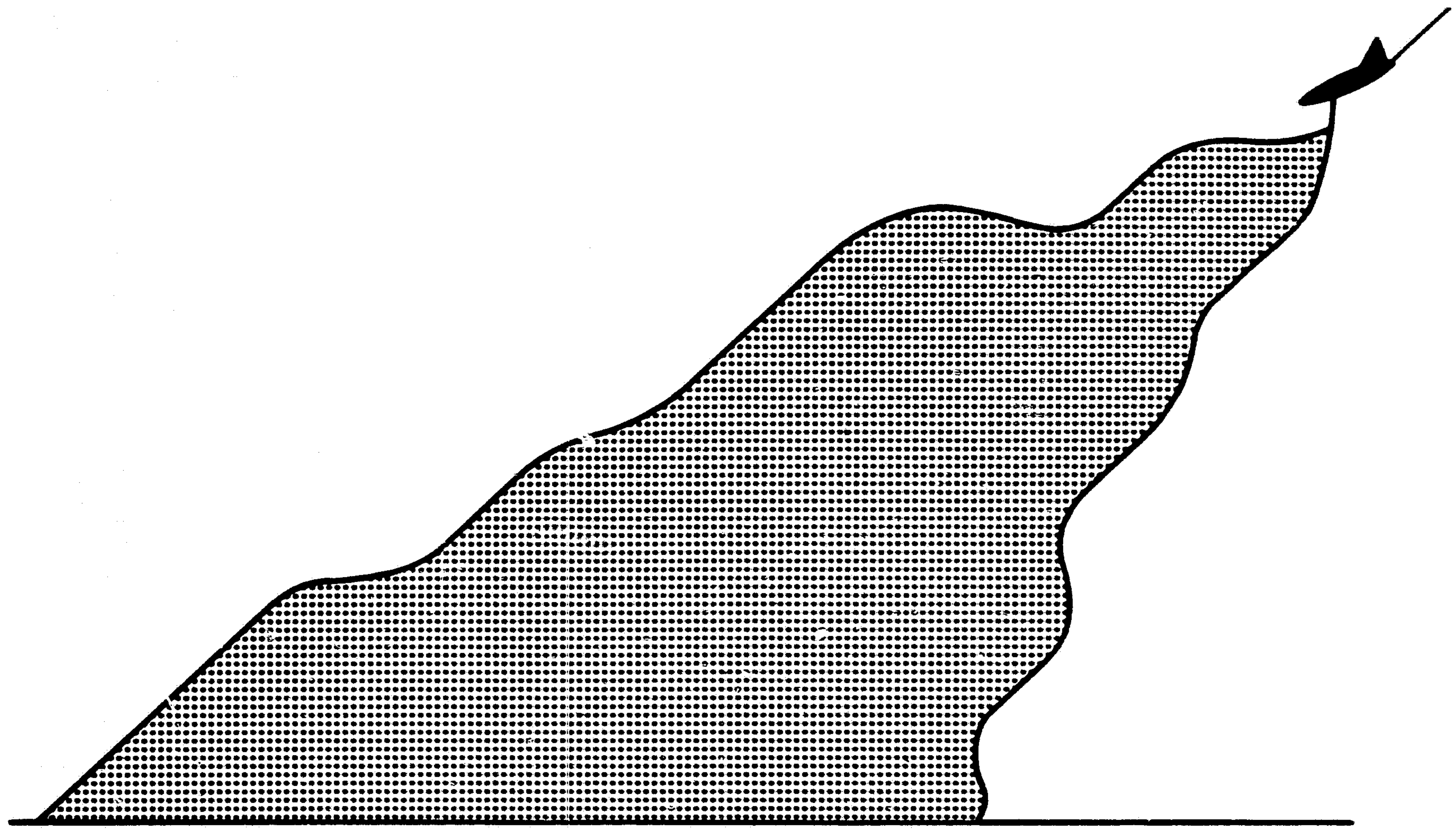


Figure 1.- Instrument flight without path constraint not difficult.

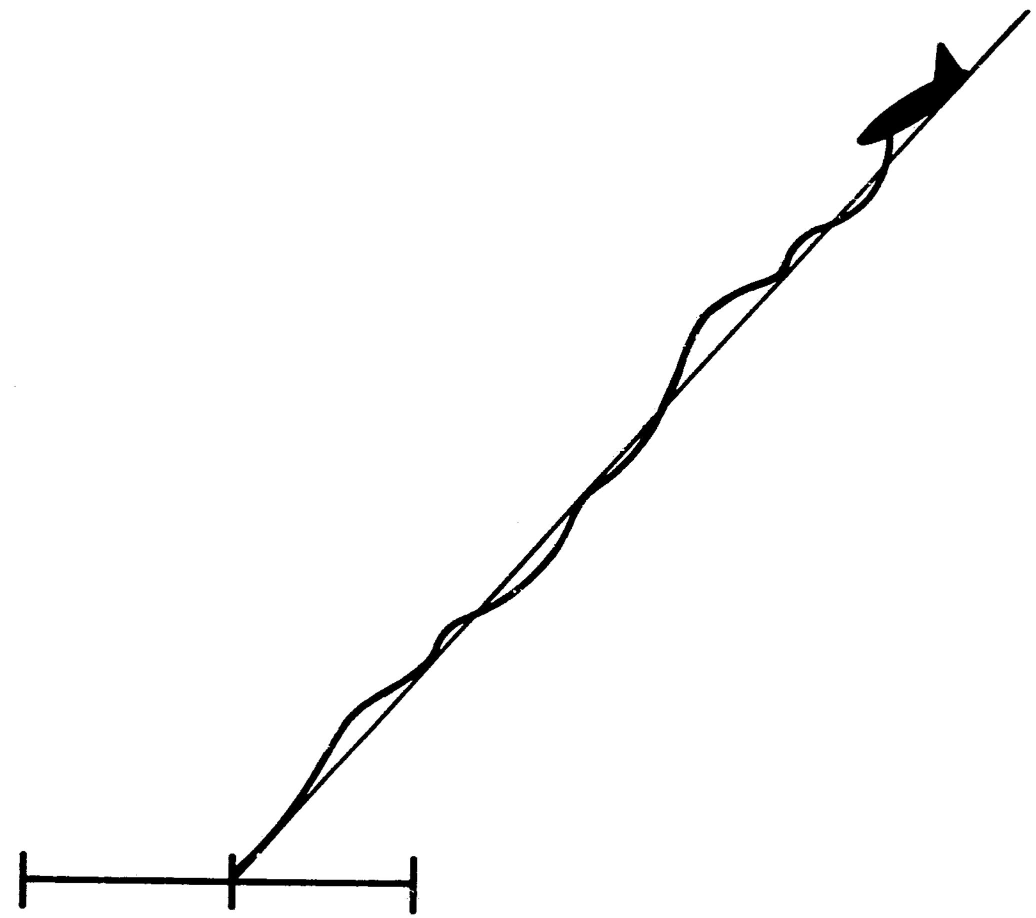
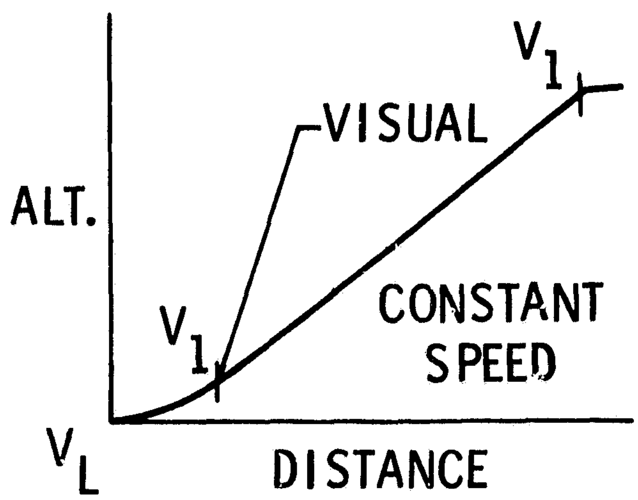


Figure 2.- Instrument flight on specific path to specific spot much more difficult.

CONSTANT:

CONFIGURATION
AIRSPEED
RATE OF DESCENT
ANGLE OF DESCENT
ATTITUDE
GROUND TRACK
TRIM
POWER



VARIABLE:

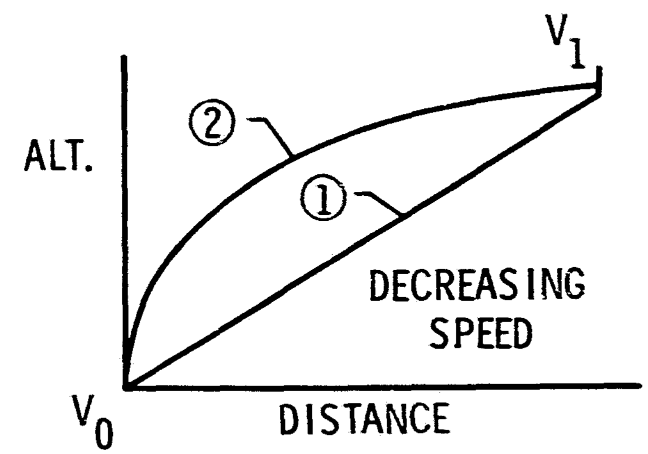
ALTITUDE

Figure 3.- Instrument final approach as performed by airplanes.

CONSTANT:

GROUND TRACK

ANGLE OF DESCENT ①



VARIABLE:

ALTITUDE
CONFIGURATION (CRUISE THRUST DIVERSION, AS EXAMPLE)
AIRSPEED
RATE OF DESCENT
ANGLE OF DESCENT ②
ATTITUDE
ANGLE OF ATTACK
(BOTH FOR ①, OR EITHER FOR ②, MAY BE CONSTANT IF VECTORING PROVIDED)
TRIM
THRUST LEVEL
THRUST VECTOR ANGLE (UNLESS ATTITUDE USED IN LIEU OF VECTORING)

Figure 4.- Instrument final approach desirable for VTOL aircraft.

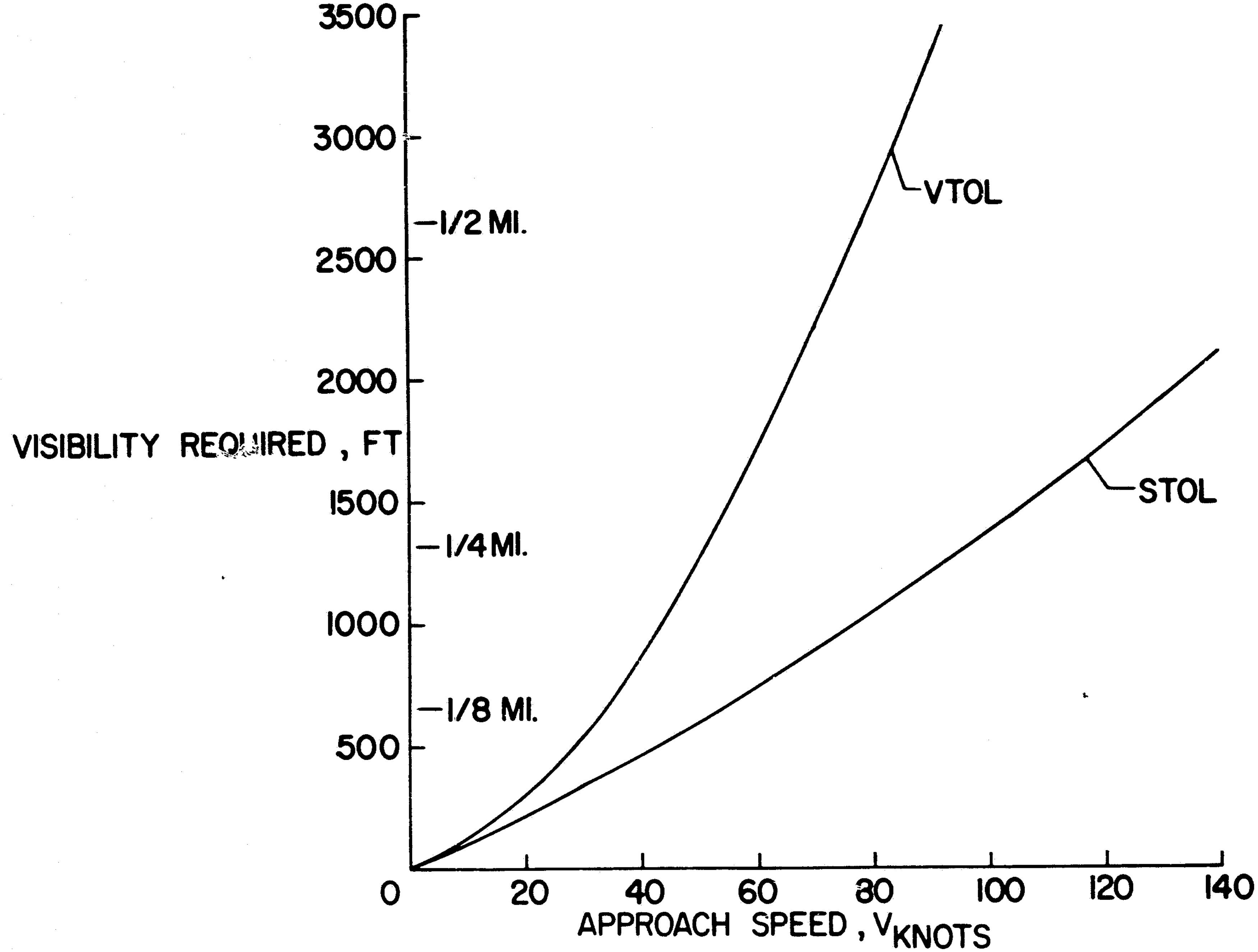


Figure 5.- Visibility required for visual landing for VTOL and STOL aircraft.

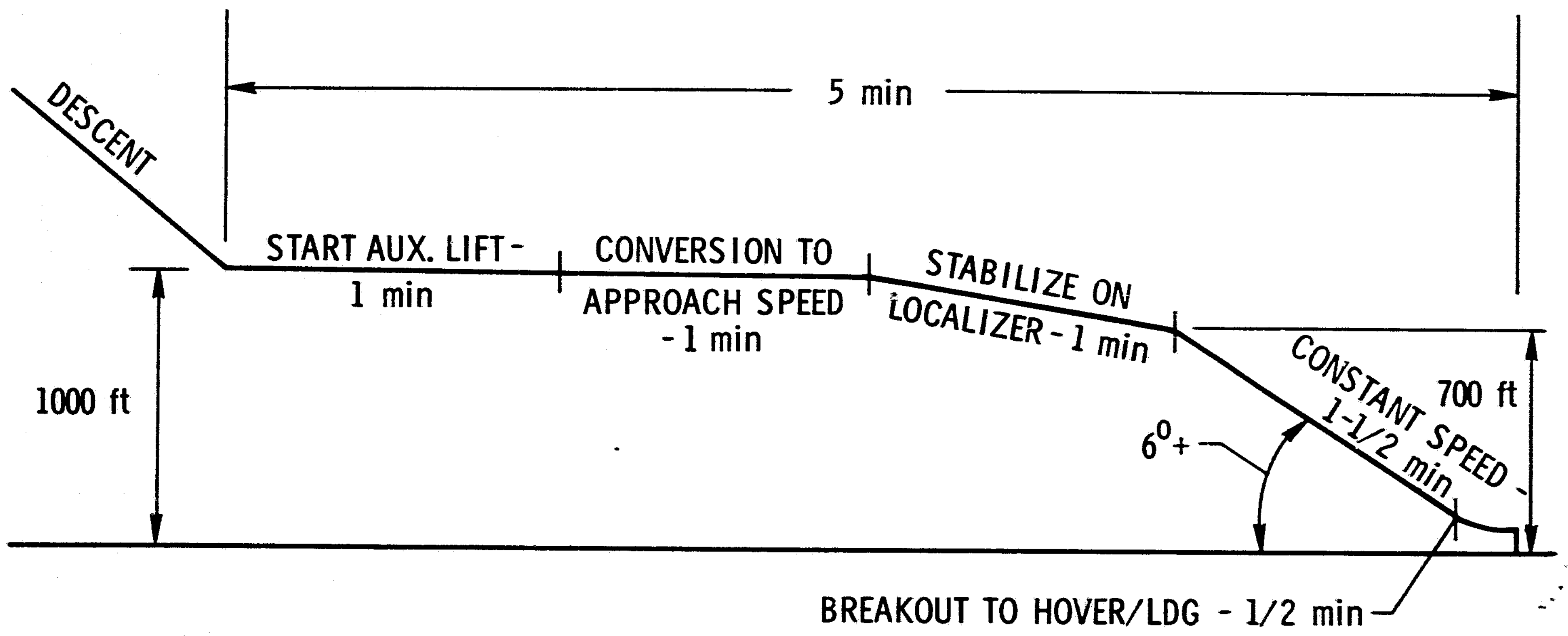


Figure 6.- Best performance VTOL instrument approach with current technology.

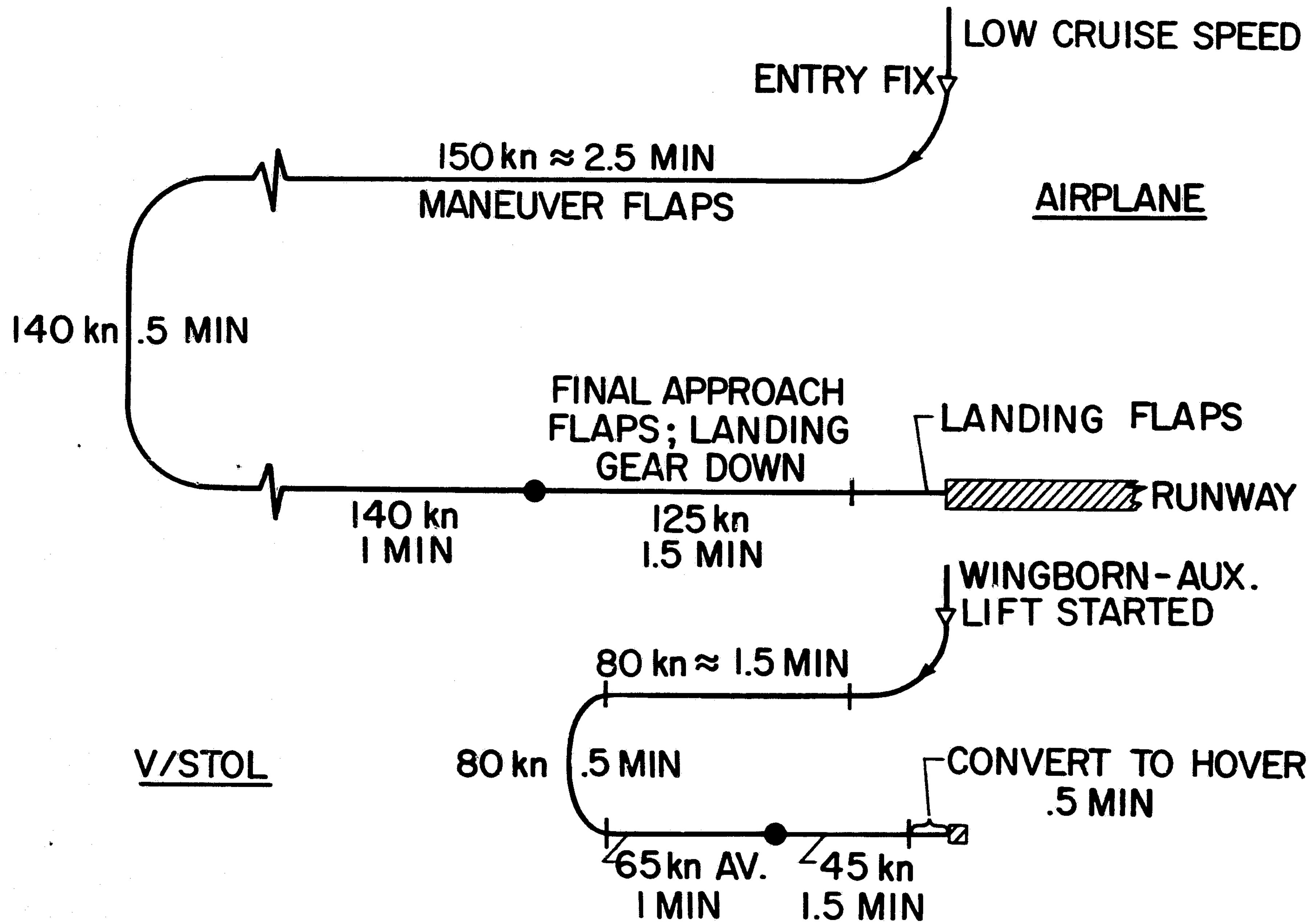


Figure 7.- Least advantageous instrument approach patterns necessitated by direction of wind, direction of arrival, or by traffic.

I.

(a) THRUST VECTOR ANGLE SELECTS SPEED

(b) THRUST LEVEL ADJUSTED FOR UNACCELERATED FLIGHT AT SELECTED SPEED

II.

(a) VECTOR ANGLE MODULATED FOR GLIDE PATH CONTROL IF ANGLE OF ATTACK MUST BE LIMITED (STALL, PITCHUP, DRAG, EXCESSIVE DIHEDRAL, ETC.)

(b) THRUST LEVEL MODULATED FOR GLIDE PATH CONTROL IF ANGLE OF ATTACK CAN SAFELY VARY (ATTITUDE NEARLY CONSTANT)

Figure 8.- Basic methods of glide-path control for VTOL aircraft.

1. NOT ENOUGH PEOPLE HAVE TRIED IT TO LEARN THE PROBLEMS

2. FOR HIGH PERFORMANCE (SPECIFIC PATH TO SPECIFIC SPOT AT LOW SPEED AND STEEP ANGLES) THESE FACTORS CAUSE PROBLEMS:

   (a) HIGH ANGULAR RATES OF DEVIATION FROM PATH DUE TO LOW SPEED

   $$\left(\frac{DEG}{SEC} \propto \frac{1}{V}\right)$$

   (b) VANISHING ACCELERATION CLUES FOR PILOT

   (c) PRONOUNCED WIND GRADIENT AND SHEAR EFFECTS ON GLIDE PATH (IF STEEP) AND TRACK

   (d) BACKSIDE OF POWER OR THRUST CURVE

   (e) SMALL INHERENT STABILIZING MOMENTS ABOUT ONE OR MORE AXES

   (f) LOW ANGULAR AND LINEAR DAMPING WITH RESPECT TO ALL AXES (ACCELERATED SETTLING, FOR EXAMPLE)

3. PILOT'S INSTRUMENT SCAN FORCED TO EXCESSIVELY HIGH RATE.

Figure 9.- Problems inherent in low-speed instrument flight.

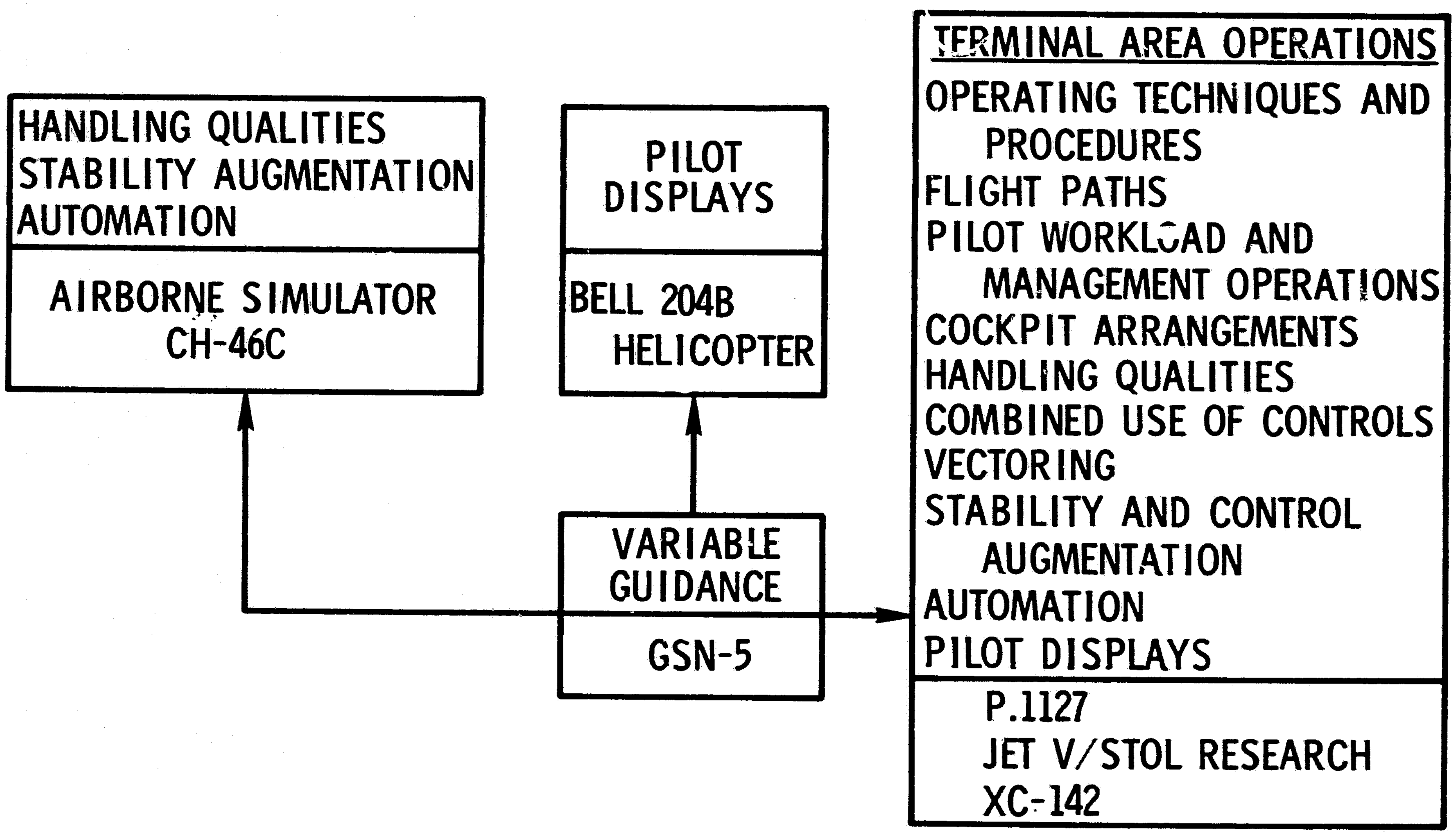


Figure 10.- Current and planned V/STOL flight-research programs.

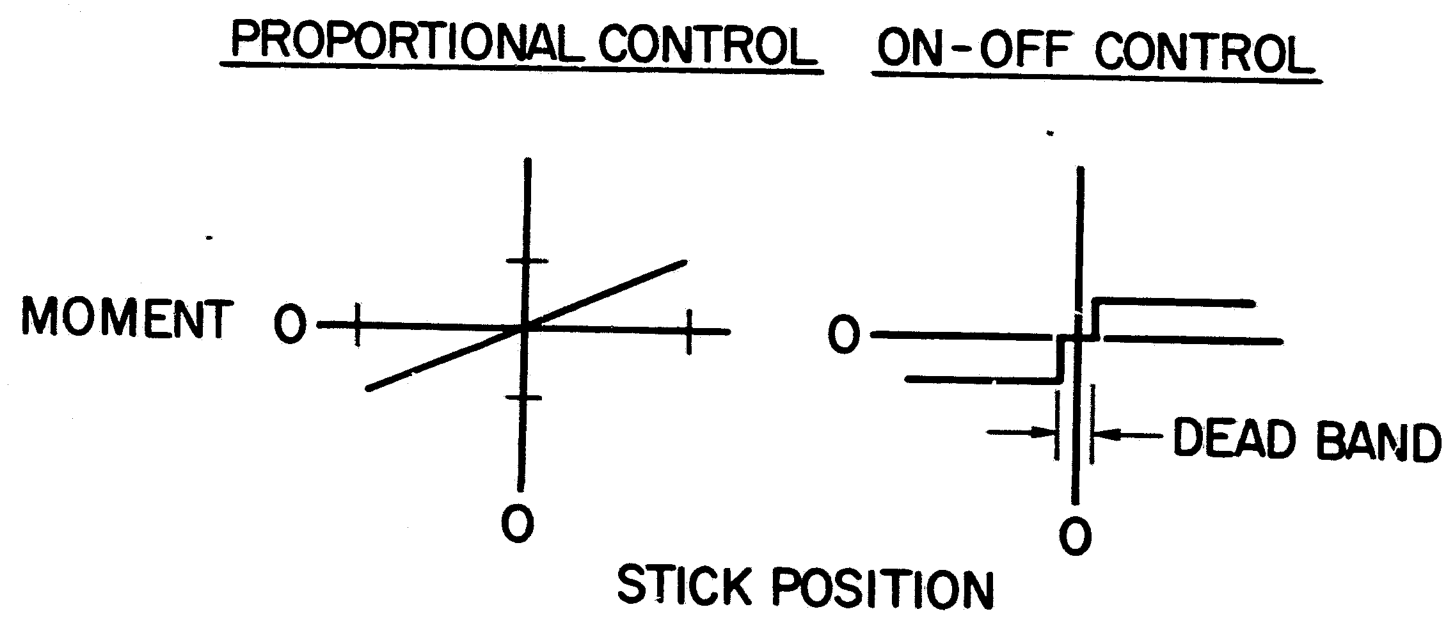


Figure 11.- Basic characteristics of on-off and proportional controls evaluated.

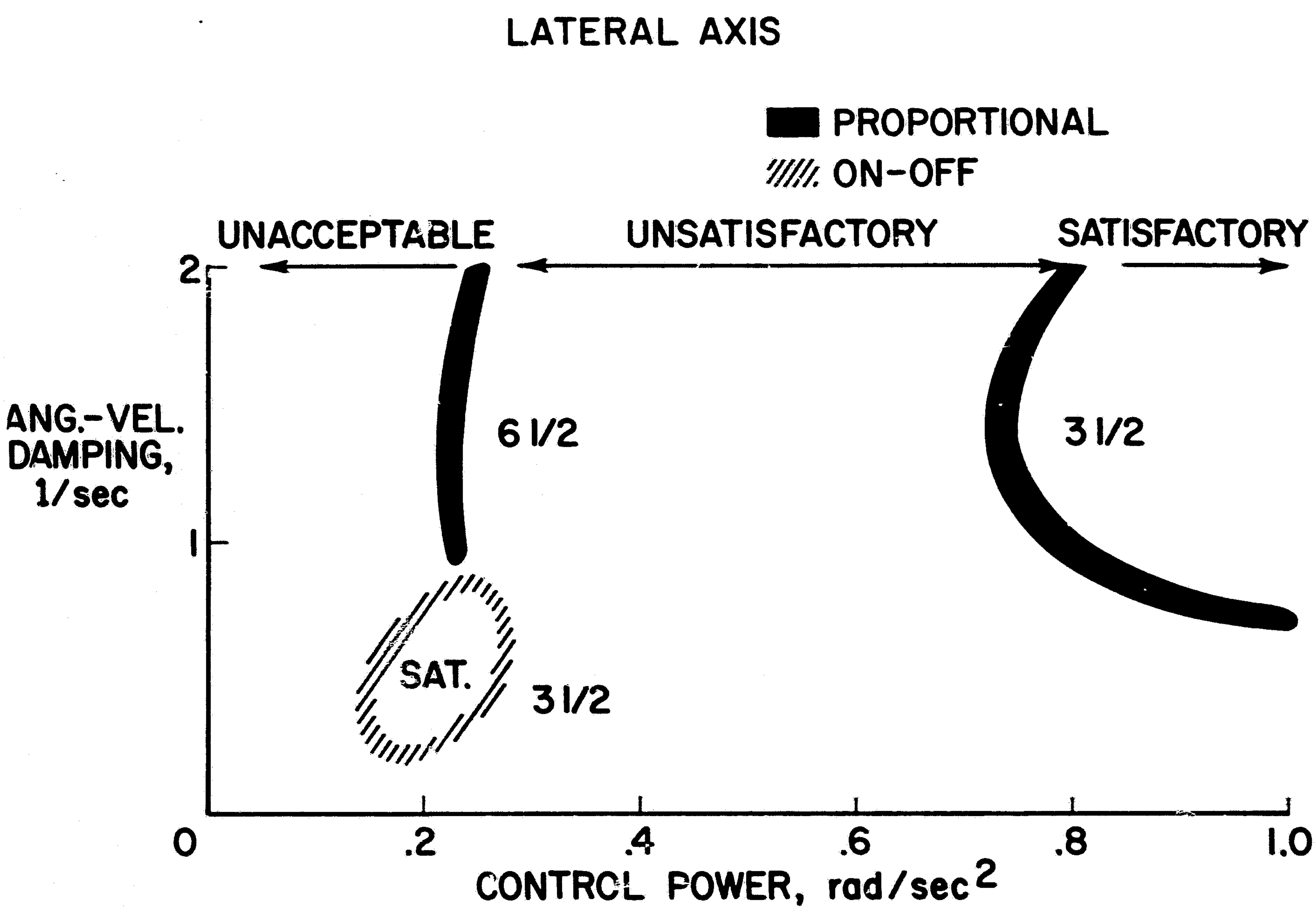


Figure 12.- Control power found satisfactory for on-off and proportional controls.

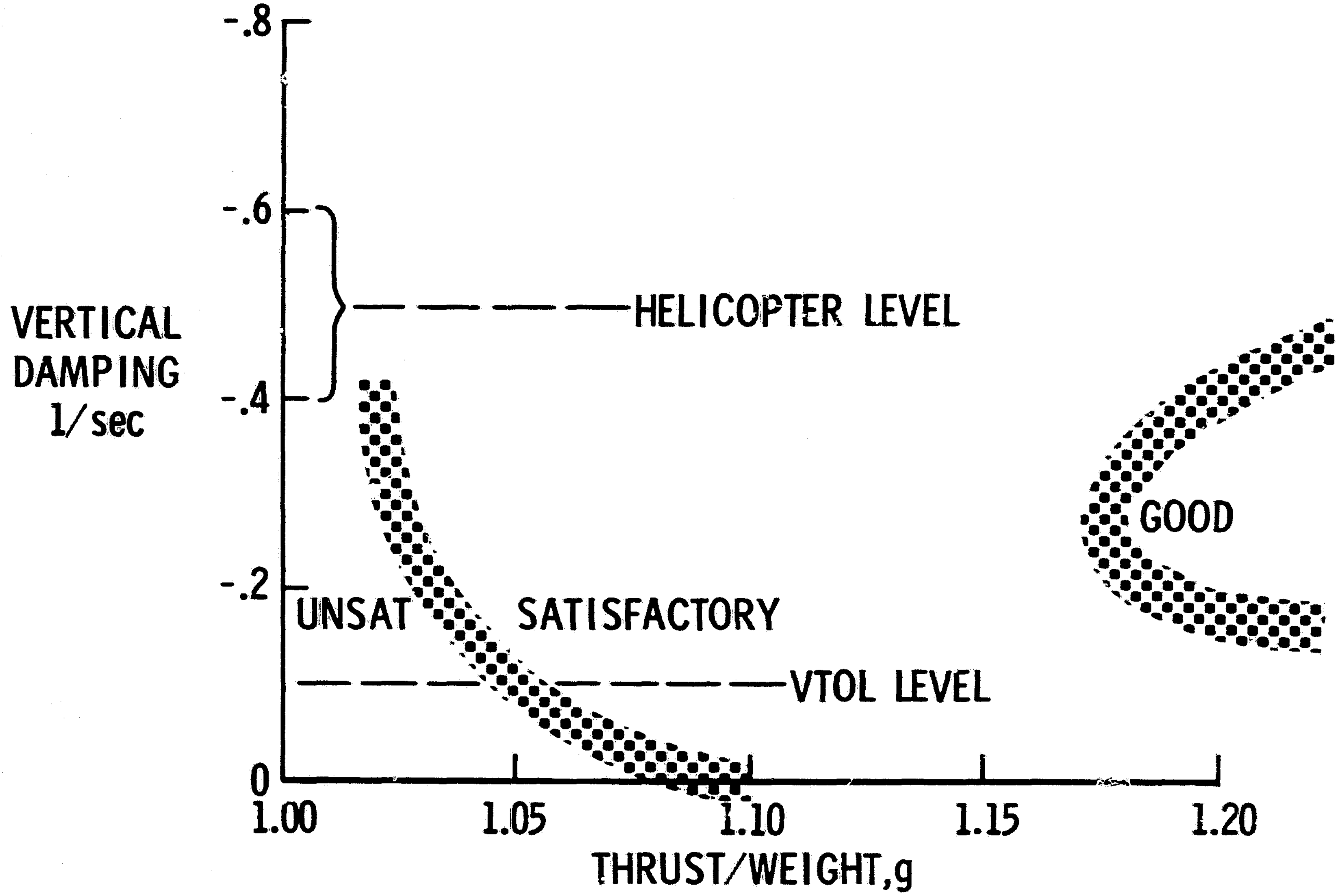


Figure 13.- Thrust-to-weight ratio required to arrest descent of 500 to 1000 fpm for visual landing, power required constant with speed.

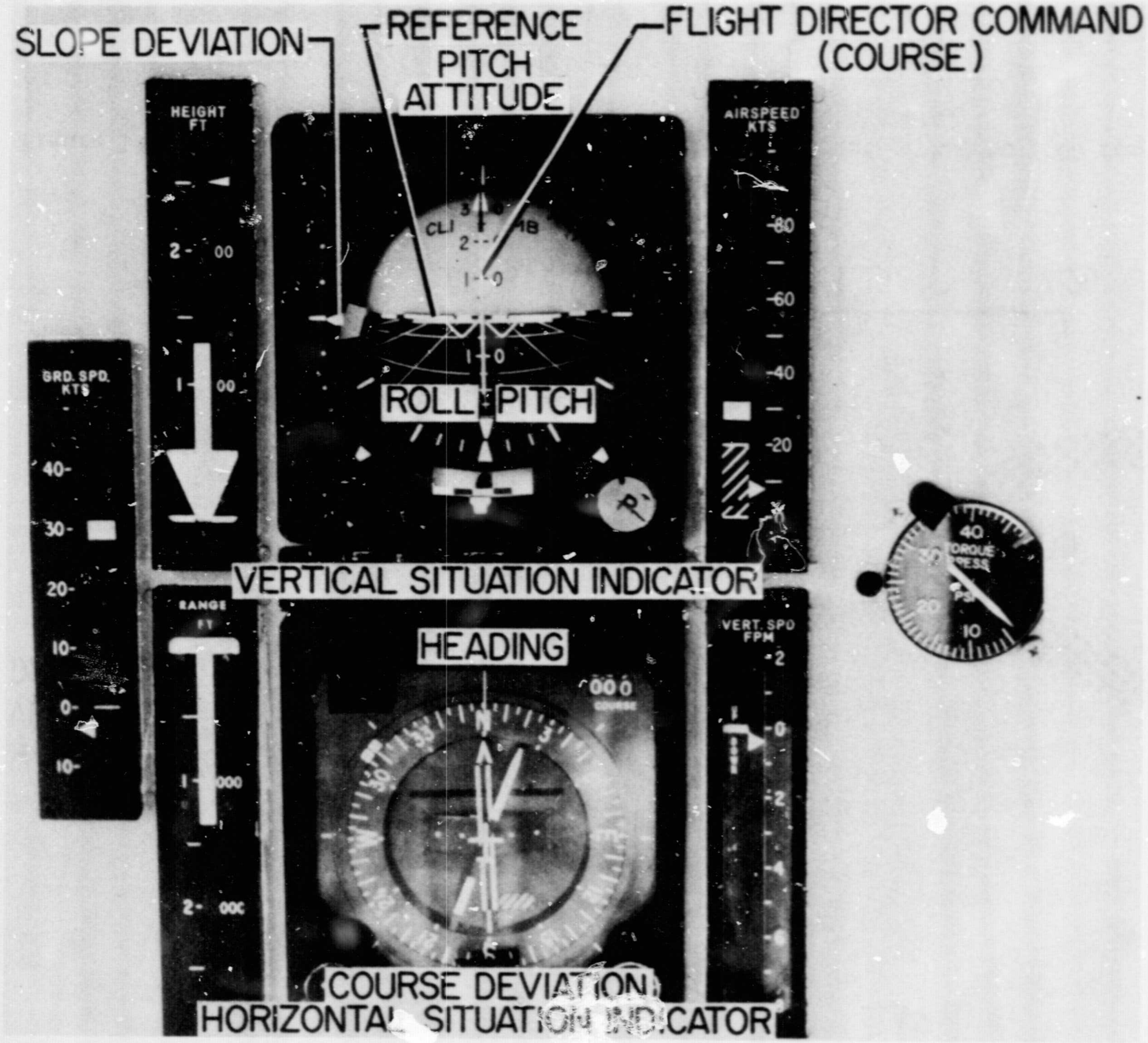


Figure 14.- Flight director and vertical-tape display evaluated.

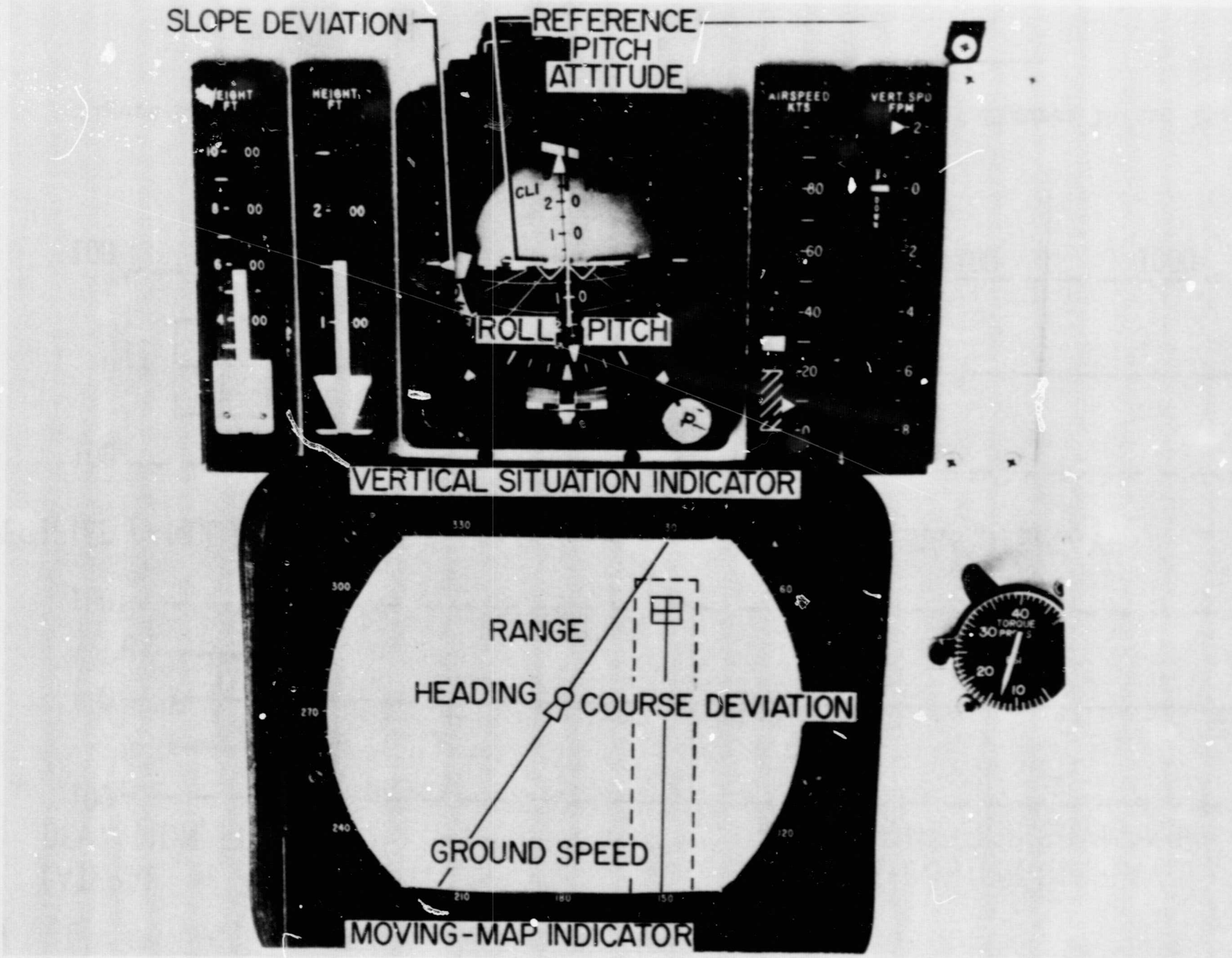


Figure 15.- Moving-map and vertical-tape display evaluated.

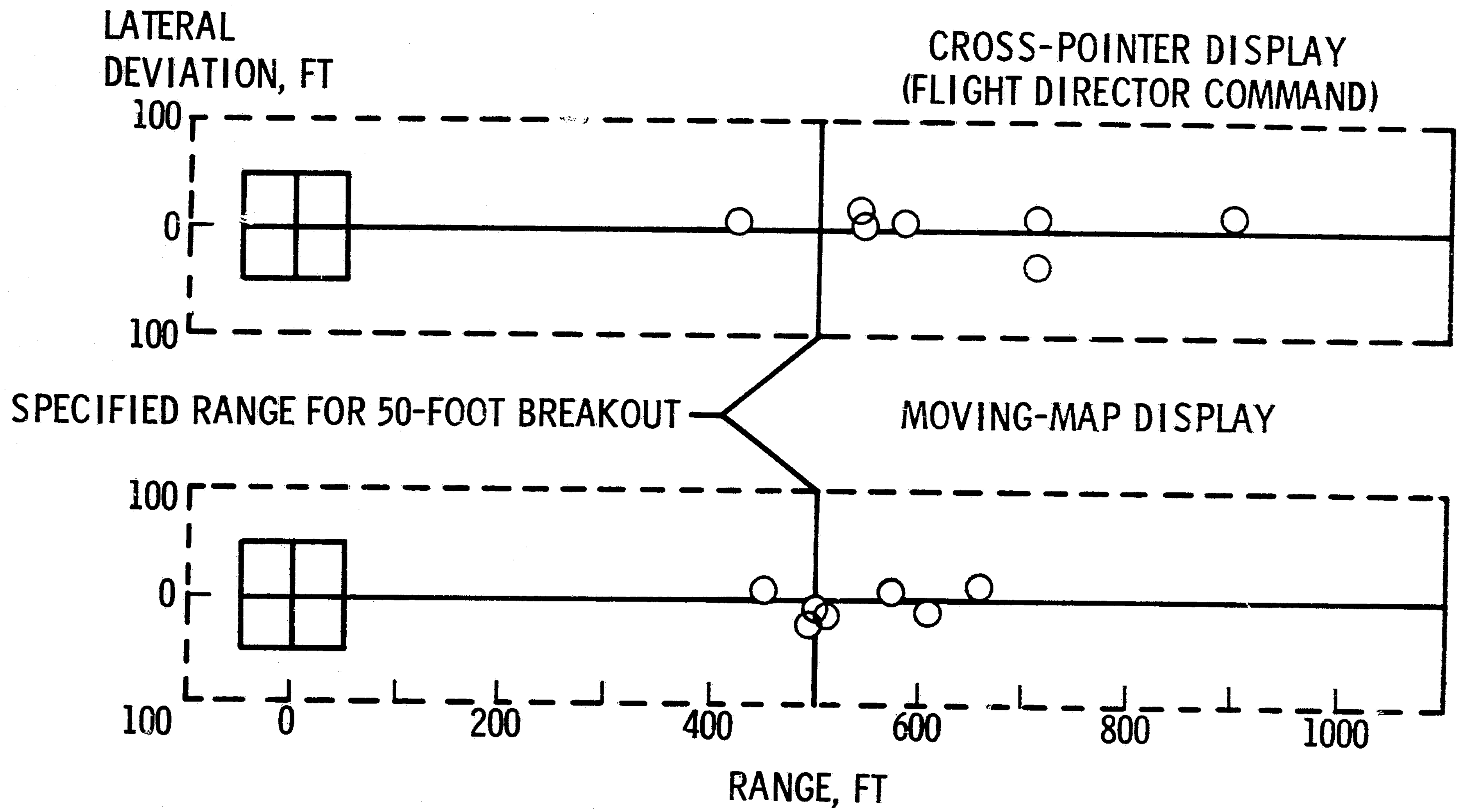


Figure 16.- Measured positions at 50-foot height for displays of figures 14 and 15.

DETERMINATION OF

1. FLIGHT CONTROLS REQUIREMENTS
2. PILOTING PROBLEMS
3. BEST OPERATIONAL PROCEDURES

TASK

V/STOL TAKE-OFF, LANDING APPROACH, AND LANDING IN INSTRUMENT WEATHER

VARIABLES

1. TYPE OF PROPULSION SYSTEM
2. TYPE OF AUTOSTABILIZATION
3. TYPE OF PILOT DISPLAY

Figure 17.- Objectives of terminal area instrument flight operations studies.

I P-1127

SINGLE-ENGINE VECTORED THRUST
TRANSITION SIMPLE, QUICK
RESEARCH CAPABILITY LIMITED
-AVAILABLE NOW
START 2-YR PROGRAM APRIL 1967

II RESEARCH AIRCRAFT DESIRED

SUPERSONIC TYPE CONFIGURATION (SUBSONIC CAPABILITY ONLY)
LIFT PLUS LIFT-CRUISE ENGINE COMBINATION
CREW OF TWO
15-MINUTE HOVER TIME
800-POUND PAYLOAD
LIFT-WEIGHT RATIO OF 1.15 (80^{0} F, SEA LEVEL, 50% CONTROL APPLIED)
MAINTAIN ATTITUDE AND ALTITUDE WITH ANY ENGINE FAILED
CONTINUOUS, RAPID VECTORING 15^{0} FORWARD TO 45^{0} AFT
INTEGRATED COCKPIT
SUBSTANTIALLY MORE THAN AGARD CONTROL POWER
SAS AND VSS SYSTEMS

Figure 18.- Planned jet V/STOL terminal area studies.

NASA-Langley, 1967