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FACTORS AFFECTING HANDLING QUALITIES OF A LIFT-FAN AIRCRAFT DURING STEEP TERMINAL AREA APPROACHES

Ronald M. Gerdes
and
Charles S. Hynes

Ames Research Center–NASA
Moffett Field, Calif. 94035

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16. Abstract

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FACTORS AFFECTING HANDLING QUALITIES OF A LIFT—FAN AIRCRAFT DURING STEEP TERMINAL AREA APPROACHES

Ronald M. Gerdes
Aerospace Engineer & Pilot
Charles S. Hynes
Aerospace Engineer
Ames Research Center—NASA, Moffett Field, California 94035

SUMMARY

The XV-5B lift-fan aircraft was one of four NASA V/STOL research vehicles recently used to explore the factors affecting handling qualities in the terminal area. The objectives of the program were to define the limitations of powered-lift VTOL aircraft that prevent full exploitation of their low-speed capabilities, and to develop operationally feasible techniques for performing simulated precision instrument landing approaches. A 10° ILS approach task was selected as representing a typical steep-angle approach with which to explore these problems. Three major phases of the approach were considered: (1) interception of the glide slope at 457.2 m (1,500 ft), (2) glide-slope tracking, (3) deceleration along the glide slope to a spot hover. Variations in airplane deck angle, deceleration schedule, and powered-lift management were studied to assess their effects on handling qualities. The overall descent performance envelope was identified on the basis of such operational limitations as fan stall, maximum comfortable descent rate, and controllability restrictions. The "collective-lift" stick provided precise glide-slope tracking capability (to within ±6.1 m (20 ft) through direct control of fan lift, but the pilot tended to "chase" glide slope if engine power (throttle) was modulated. The pilot preferred a deck-parallel (to glide slope) attitude, for which he used powered lift (collective) to control glide slope and pitch attitude (stick) to keep the angle of attack near zero, which minimized his workload. This technique also provided a greater angle-of-attack margin from fan stall. Workload was reduced when the deceleration schedule was delayed until the aircraft was well established on the glide slope, since thrust vector changes induced flight path disturbances.

INTRODUCTION

After about 15 years of being relegated to proof-of-concept testbed duties, it now appears that VTOL aircraft may very well be placed into service to solve some of our most pressing military and commercial air

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transportation problems. The introduction of limited numbers of Hawker-Siddeley AV-8A Harriers into U.S. Marine Corps service, and the high priority assigned by the DOT and NASA to development of a VTOL transport for service in the 1980's support this viewpoint. Such vehicles must have characteristics that assure the acceptance of both pilots and passengers throughout the entire operational spectrum from high speed cruise to hover touchdown. Satisfactory handling qualities are a prerequisite for safe and profitable operations. Past experience with VTOL research vehicles has indicated that handling qualities were optimized for the cruise and hover regimes, and it was left up to the pilot to struggle through the transition from one to the other. Instrument flight in this "in between" region was found to be very difficult, if not altogether impossible. The terminal area instrument approach, therefore, has been identified as one of the most demanding problems the VTOL transport pilot and the designer both face.

Present V/STOL handling quality criteria and specifications, such as references 1 and 2, contain only "guideline" information relative to operations in the terminal area. Further and more complete definition will depend on operational experience as well as a clearer understanding of the factors peculiar to powered-lift aircraft which affect the handling qualities of these vehicles.

This paper describes some of the preliminary results of the terminal area study conducted at the Ames Research Center with the XV-5B lift-fan research airplane. Its purpose is to identify some of the operational factors that the pilot considered to be of major significance from a handling qualities point of view. The factors described, especially the management of powered lift and thrust vector control have caused handling difficulties on several other powered-lift vectored-thrust aircraft — difficulties so severe as to limit their practical usefulness. The details of the pilot's criticism of handling qualities depend, of course, on the peculiarities of each aircraft (especially control mechanization), as in the case of the XV-5B. However, these differences are seen in more general perspective when it is realized that no vectored-thrust powered-lift vehicle yet flown by the NASA has solved these handling problems well enough to take full advantage of vectored-thrust performance during terminal area operations.

In the XV-5B program, an ILS approach along a 10° glide slope was selected as the terminal area mission. Three major piloting tasks were considered: (1) glide-slope interception, (2) glide-slope tracking, (3) deceleration along the glide slope to a spot hover. Variations in airplane deck angle, deceleration schedule, and powered-lift management were studied in terms of handling qualities and associated pilot workload. The overall descent performance envelope was explored to identify operational limitations. The scope of this paper is restricted to longitudinal axis maneuvering about the glide slope in the fan mode of flight only, and does not treat the jet (or conventional) mode of flight or the conversion from jet mode to fan mode operations prior to the approach.

DESCRIPTION OF THE AIRCRAFT

Pertinent details of the XV-5B, shown in hovering flight in Fig. 1, are described in limited detail to provide a basic understanding of the systems used to perform the fan-mode approach. Only controls that affect the longitudinal axis are described. A more detailed description of the XV-5B is contained in reference 3. The XV-5B is the XV-5A aircraft modified to incorporate outboard fixed landing gear.

The major elements of the propulsion system can be seen in figure 2. For flight from 100 knots down to hover, the thrust-to-weight ratio is increased from 0.5 to 1.25 by diverting the J-85 hot gas efflux to drive the tip turbines of the two 1.5 m (5-ft) diameter lift fans. A similar 0.91 m (3-ft) fan, located in the nose, provides pitch control through two thrust reversing doors located below the nose fan. Movable vanes ("exit louvers") located in the exit plane of each wing fan vector the thrust from 7° forward to 45° aft of the vertical, and can spoil as much as 25% of fan thrust by pinching action to provide lift control.

The pilot is provided with conventional helicopter controls (stick, pedals, and collective) and conventional quadrant-mounted throttles. The conventional aerodynamic control surfaces move with the cockpit controls at all times. A mechanical mixer links the cockpit stick and pedals to the fan exit-louver and thrust-reverser-door actuators. Pitch attitude is controlled by longitudinal stick which actuates the reverser doors. The collective stick provides height control during hover by spoiling thrust by actuating the wing fan exit louvers. Turbojet RPM is controlled independently by the throttles, which are locked together and mechanically connected to a twist grip on the collective. Wing fan RPM is neither governed (like the gas turbine-powered helicopter) nor independently controlled, but rather is determined by the combination of gas power input to the fan from the gas generators and the loading due to fan flow, which is sensitive to flow conditions at the fan inlets. The pilot thus uses J-85 RPM as a direct reading reference for power settings.

Thrust vector angle is controlled electrically by "beep" switches located on the right throttle handle and on the collective grip. Because of the drag characteristics of the airplane in forward flight, airspeed closely follows vector angle changes. Transition to control by the conventional aerodynamic surfaces at the higher fan-mode speeds is effected by mechanical washout within the mixer of louver response to cockpit controls at vector angles exceeding 20°, which corresponds to speeds above 50 knots in fuselage-level flight. At vector angles exceeding 30° (70 knots in level flight), louver response to collective stick inputs is entirely washed out, and the pilot can control fan thrust only indirectly by setting turbojet RPM with the throttles.

A stability augmentation system provides limited-authority pitch, roll and yaw rate damping through the fan-mode control servos.

FACTORS CONTRIBUTING TO PILOT WORKLOAD

Powered-Lift Management

The high workloads required to manage the powered-lift system are responsible for the major difficulties affecting handling qualities of this aircraft. Designed as a proof of concept research vehicle, the XV-5B was intended to be transitioned through the fan-mode regime as rapidly as possible in level flight in VFR conditions. Controllability was optimized for hover and jet-mode flight. In contrast, the terminal area approach requires precision instrument flying during transition through a region of "aerodynamic overlap" where the pilot must adapt to a complex set of controls. Factors contributing to pilot workload during terminal area maneuvering are discussed below. Although this paper discusses XV-5B characteristics, experience has shown that very similar factors have influenced the handling qualities of other vectored-thrust aircraft, such as the DO-31, P.1127 and XC-142A.

Lift Magnitude Control — Lift magnitude, or fan thrust, can be controlled by two independent methods: louver (and reverser door) modulation with collective stick and changes in fan RPM by modulation of J-85 power with the throttles. Fan thrust response to collective input is immediate since only louver and reverser door movement is required. When engine throttles are used for height control, the pilot must cope with a combination of engine-plus-fan thrust lag of the order of 1.5 seconds. A deceleration schedule which commences with vector angles above 30° requires that the pilot not only switch from one method of glide slope control to the other but also compensate for the change in response characteristics with airspeed.

One problem was identified with using collective stick for glide slope control. Angle-of-attack increases as collective stick is lowered to increase descent rate. The resultant build-up in aerodynamic lift reduces collective downward control power to the point where the collective often ends up on the bottom stop with the pilot complaining about "running out of collective." The only alternative is to reduce power and/or drop the nose.

Lift Vector Control — Lift vector angle provides a very effective means of controlling velocity along the glide slope, but the resulting lift and thrust component transients cause flight path disturbances which require pilot compensation to maintain glide slope tracking. Lift component disturbances must be countered with collective stick, throttle, or longitudinal stick. Thrust (or velocity) transients are less of a problem and require retrimming to the new airspeed. Changing vector angle by "beeping" the control instead of constant rate steps allows the pilot to compensate for the resultant flight path disturbances more easily.

Fan Stall — Avoiding fan stall is the major angle-of-attack restriction considered because it limits the maximum deck-level (zero pitch attitude) glide-slope angle capability of the airplane. Full-scale wind-tunnel tests indicate that fan stall occurs at about 15° angle of attack and is characterized by a gradual downward pitching moment, a loss in fan thrust, and an increase in fan speed. An approach to the fan stall was encountered during several deck-level approaches when the pilot was correcting for a "fly down" glide slope error. A 10° approach angle was therefore felt to be the limit, allowing a 5° maneuver margin from the stall in the deck-level approach.

Longitudinal Stability and Control

Serious deficiencies in the longitudinal control system were found to be responsible for a general degradation in the overall terminal area maneuverability. The primary longitudinal control task was to maintain a prescribed attitude (either deck-level or deck-parallel to the glide slope) as the aircraft was decelerated along the glide slope from about 70 knots to hover. Two characteristics affecting longitudinal control, which together made controlling pitch attitude a continuously demanding task were: (1) large changes in static longitudinal stability ranging from negative (at airspeeds between about 75 and 55 knots) to positive (at speeds between about 55 and 25 knots) and (2) inadequate nose-down pitch trim authority in the 30 to 75 knot speed range. Static longitudinal stability is presented in figure 3. Since maintaining deck attitude is the primary longitudinal control task, it is evident that much of the pilot's attention may be required to contend with these adverse characteristics. Providing artificial attitude stability has worked well with other VTOL aircraft. The pilot cannot manage a powered-lift system effectively if controlling aircraft attitude demands excessive attention.

SELECTION OF APPROACH PROCEDURES FOR INVESTIGATION

Operational Criteria

The approach procedures for this investigation were based on the following operational criteria: (1) The approach should make use of a high rate of descent and rapid deceleration to hover to conserve fuel and reduce traffic congestion; (2) The approach should be along a steep glide slope and make maximum use of wing lift to reduce propulsion system noise and fuel consumption; (3) One should be able to conduct safe operations in IFR conditions without increasing the pilot's workload and with reasonable passenger comfort.

Selection of Deck Angle

Two deck angles (pitch attitudes) were evaluated as limiting cases from an operational point of view: (1) deck-parallel and, (2) deck-level. In the deck-parallel case, the fuselage is alined parallel to the glide slope, resulting in a near-zero angle-of-attack approach, a technique now used with some STOL aircraft. The deck-level approach, of course, provides more wing lift. In addition, it was hoped that for this technique the attitude-control workload would be reduced since a constant level attitude is maintained throughout the approach (see figs. 4(a) and 4(b)). A deck-level attitude would also be preferable for passenger comfort.

Selection of Deceleration Schedule

The VTOL terminal area approach, when compared to conventional procedures, is unique in that the aircraft must be decelerated along the glide slope to a hover before the touchdown. This requirement presents a very demanding piloting task, and it was found that pilot workload could be significantly reduced by proper selection of a deceleration scheme. Initially, two such schemes, or devector schedules, were devised by programming thrust vector angle as a function of indicated pressure altitude: (1) gradual deceleration and (2) terminal deceleration. The vector angle (and thus the resultant airspeed) was decreased gradually with altitude in the gradual deceleration case, and was decreased rapidly as the hover spot was approached in the terminal deceleration case. The pilot's task was thus simply to "track" the devector schedule printed around the periphery of the altimeter using the 100-foot needle as a pointer-reference. Figure 5 is an example of a typical devector schedule, showing its placement on the altimeter.

Descent Performance

The fan mode descent capability of the XV-5B was determined for flight path angles as steep as 20° during the initial phases of the investigation. A summary of the descent performance for both the deck-parallel (zero angle of attack) and deck-level approaches is presented in figs. 6(a) and 6(b) and shows the relationship between airspeed and descent rate along a given flight path angle at various vector angles. These relationships were found useful in establishing various approach procedures and in determining operational limitations.

Figure 6(a) shows the variations of rate of descent and flight path angle (solid radial lines) with airspeed that result when pitch attitude is held fixed at zero (the deck-level procedure) and thrust vector angle is fixed at one of the five values illustrated by the broken contours. The nearly vertical slope of these contours shows that in fuselage-level flight the airspeed depends only on thrust vector angle and is independent of descent angle; thus the descent angle can be controlled without change of airspeed by regulating thrust magnitude while keeping the fuselage level and the thrust vector angle fixed. The cross-hatched boundary shows the limitation of descent angles to 15° due to the onset of fan stall at angles of attack near 15°; with the fuselage level, angle of attack and flight path angle are, of course, numerically equal.

Figure 6(b) illustrates the resulting variations in descent angle and airspeed when pitch attitude is varied to keep angle of attack fixed at zero (the deck-parallel procedure); thus pitch (or deck) attitude coincides with flight path angle. The slope of the broken contours of thrust vector angle downward and to the right shows that when descent is steepened by lowering the nose, a compensating reduction in vector angle is required to avoid an increase in speed; furthermore, the magnitude of the vector angle reduction is very nearly equal to the change in flight path angle. For example, when a 10° descent is initiated from level flight at 70 knots (point A) by lowering the nose 10°, the thrust vector angle must be reduced about 10° (from 30° to 20°) to maintain a speed of 70 knots in the 10° descent (point B). Since rotating the aircraft in pitch rotates the thrust vector as well when the exit louvers remain fixed, compensating changes in thrust vector angle (exit louver position) simply cause the inclination of the thrust vector to remain fixed with respect to the earth. Exact equality of these angular increments in thrust vector angle and flight path angle would be expected at constant speed when angle of attack is fixed at zero, since aerodynamic lift then remains constant. The near-equality of such increments as may be read from the chart of figure 6(b) shows that these simple ideas predict the flight results with surprising accuracy.

Selection of Approach Angle and Initial Speed

For the present study an approach angle of 10° was selected as a reasonably steep approach which enabled comparison of the deck-parallel and deck-level techniques. Deck-parallel approaches could be flown without uncomfortably steep nosedown attitudes, and deck-level approaches could be flown with safe (5°) angle-of-attack margins. An initial approach speed of 70 knots was chosen as providing a good combination of descent rate and collective effectiveness. The vector angle was 20° at 70 knots during the deck-parallel approach and 30° at 70 knots during the deck-level approach (see figs. 6(a) and 6(b)). Two operational considerations dictated that a common airspeed (70 knots) rather than a common thrust vector angle be chosen for the initial conditions of the two approaches. If the deck-level approach had been initiated with a 20° vector angle, so as to provide collective stick authority, both the velocity and descent rate would have been reduced considerably, yielding a "dragged out" approach requiring slightly increased fuel reserves. A 30° vector angle and 90-knot approach speed could have been used for the deck-parallel approach, but complete phase-out of collective control and an excessive descent rate would have been too detrimental to pilot tracking performance. With the approach angle fixed at 10° and the initial speed fixed at 70 knots, detailed flight procedures were developed for the approach evaluations.

Terminal Area Approach Procedures

Two operationally promising approach procedures (see fig. 4) were chosen for this investigation, although flexibility of control would have made possible the selection of many other combinations of parameters. A 10° ILS approach with a 457.2 m (1,500 ft) intercept altitude and termination to a spot hover was specified as the basic guidance task. All approaches were conducted in VFR conditions with an initial airspeed of about 70 knots. An attempt was made to extrapolate observations to IFR conditions. Deck-parallel and deck-level approaches were evaluated interchangeably for direct comparison. The deck-parallel approach required a 10° nose-down pitch change upon glide-slope intercept, followed by a return to a near level attitude just prior to coming to a hover. Pitch attitude remained nearly constant throughout the deck-level approach. In each case, the vector angle was systematically reduced according to a selected deceleration schedule in order to slow the aircraft to a hover at about 6.1 to 7.6 m (20 - 25 ft) altitude. Both gradual and terminal deceleration schedules were evaluated.

The piloting task can thus be summarized as follows: The glide slope was intercepted at 457.2 m (1,500 ft) and an airspeed of about 70 knots and was either deck-parallel or deck-level. The pilot tracked the glide slope as closely as possible while decelerating the aircraft to an eventual hover over the touchdown spot.

HANDLING QUALITIES CRITERIA

Handling qualities described in this investigation were judged to be poor when an approach task required pilot compensation for vehicle deficiencies which significantly increased pilot workload. Pilot assessment of handling qualities in terms of compensation and workload are clearly described in reference 4. Definition of some of the major terms pertaining to handling qualities contained in this reference are reproduced in figure 7 to help clarify the reader's understanding of the handling qualities factors described below.

RESULTS OF FLIGHT EVALUATION

Deck-Parallel Approach Handling Qualities

The initial approach speed of 70 knots required a vector angle of 30° in level flight before the glide path was intercepted (see fig. 6(b)—point A). Early attempts to intercept the glide slope at constant vector angle (of 20°) by merely "dropping the nose" 10° was found to be undesirable because there was a tendency to "balloon" through the glide slope. In addition, initial glide slope tracking was hindered somewhat by the requirement to retrim to the new airspeed (from 50 to 70 knots). A technique which was found to work well, was to approach the glide slope at a 30° vector angle and perform a constant airspeed pitch-over by reducing vector angle 10° (to 20°) simultaneously with pitch attitude (from point A vertically downward to point B on fig. 6(b)).

Collective stick was found to be extremely effective for tracking the glide slope. Response to this "direct lift control" was precise and quick. During on-course tracking, J-85 power was set through experience to place the collective somewhere in its midrange. The piloting task was simply to track glide slope with collective and keep the angle of attack somewhere near zero with pitch attitude (stick). Once glide slope was established at constant speed, this task was found to be pleasant and easy. If very large "fly-down" glide-slope errors were encountered, J-85 power had to be adjusted to avoid "running out of collective."

Both terminal and gradual deceleration schemes were evaluated. The terminal deceleration technique was judged unacceptable because of the intolerable workload in coping with the ensuing attitude and flight path disturbances close to the ground. This "quick stop" maneuver was felt to be completely unsuitable as an instrument approach procedure.

A gradual deceleration scheme, consisting of a series of 5° vector changes every 76.2 m (250 ft) down the glide slope, was found to be unsatisfactory. Starting the devector schedule immediately upon intercepting the glide slope resulted in a dual piloting task of getting established on glide slope while following the schedule. Workload was intensified and glide slope tracking performance deteriorated (see fig. 8(a)). The devector increments of 5° were also considered to be too small in that there was insufficient time to compensate completely for the flight path disturbances produced by one vector change before it was time to devector once more to the next one. The resulting flight profile was oscillatory.

A revised or delayed devector schedule intended to improve on the deficiencies of the first two was found to work very well. Initiation of the vector schedule, consisting of two nominal 10° vector changes, was delayed until the aircraft was well established on the glide slope at about 152.4 m (500 ft). The vector changes were actually made in a series of smaller increments or "beeps" (instead of 5° steps) to reduce the severity of the resulting disturbances and give the pilot an opportunity to compensate with collective stick inputs. The resulting oscillatory behavior was greatly reduced (see fig. 8(b)). The use of 10° increments allowed for increased tracking time and reduced the required vector schedule scan rate, thus reducing pilot workload. With the vector angle already set (below 61 m (200-ft) altitude) at the hover position of -3°, transition to hover was executed at about 21.3 m (70 ft) by a gradual rotation to a level attitude and a check of final sink rate with collective stick.

Deck-Level Approach Handling Qualities

The deck-level approach was initiated with a vector angle of 30° (70 knots) to evaluate the use of J-85 thrust modulation for glide-slope tracking and as a basis for direct comparison with the deck-parallel method. Because of the complete phase-out of collective authority at the vector angle of 30°, a power reduction was required to initiate glide slope capture. J-85 RPM was reduced as the glide slope was approached, and after some experience, the pilot was able to achieve a relatively smooth constant-speed capture. When the pilot overshot the glide slope, however, he was forced to reduce pitch attitude during the "fly down" to avoid the fan stall boundary. It should be emphasized that throughout the entire approach, fan stall proximity was a major concern to the pilot whenever a large "fly down" situation presented itself.

Glide-slope tracking technique before the vector angle was reduced below 30° for the deceleration consisted of modulating J-85 RPM to correct to and hold "on course." As expected, the pilot tended to chase the glide-slope needle with the throttles, inducing as oscillatory flight path as shown in figure 9. Engine-plus-fan time constant of the order of 1.5 sec was felt to be the primary cause of this high workload, and this behavior was in sharp contrast to the relative ease of controlling glide slope with collective during the deck-parallel approach.

In general, increased pilot workload and a deterioration in task performance were evident as compared to the deck-parallel case. Some of the reasons for this are not fully understood. Although power, noise and fuel consumption were reduced, indications were that the addition of aerodynamic lift hindered the pilot's tracking performance by reducing the aircraft's vertical displacement response to powered lift controls. This effect has not yet been clearly defined but precise flight path control at high angles of attack was significantly reduced whether the pilot used the collective or the throttles. The pilot stated that "the approaches were wormy and felt generally uncomfortable." (Some lateral-directional disturbances also influenced pilot opinion.) One specific complaint based on deck-parallel experience was that larger than expected powered-lift reductions were required when responding to "fly down" commands. Even at vector angles below 20°, the pilot was sometimes forced to reduce J-85 power because of "running out of down-collective." From a pilot workload point of view, this meant that any advantage of using collective stick for glide-slope control was lost when the pilot was forced to make additional engine power adjustments. This problem points to the necessity of having a single integrated powered-lift control.

Delaying the initiation of the deceleration schedule in order to give the pilot time to complete the glide slope capture and get well established reduced cockpit workload as in the deck-parallel case. Terminal deceleration was again found to be completely unacceptable. Termination to hover was executed at about 21.3 m (70 ft) by increasing power by the amount it had been reduced to capture the glide slope.

PILOT PREFERENCE AND RECOMMENDATIONS

Preferred Approach Profile

A deck-parallel approach, employing a delayed deceleration schedule with 10° vector increments, was judged to be the most preferable from a handling qualities point of view. Major considerations were safety, tracking performance, workload, and comfort (ride quality). The following terminal area approach technique was preferred for a 10° ILS task:

1. Line up on the localizer in level flight at a vector angle of 30° with J-85 power set for a mid-collective position (in the approach).
2. Upon approaching the glide slope, simultaneously reduce vector angle to 20° and pitch 10° nose down.
3. Track the glide slope with collective stick and keep angle of attack near zero with pitch attitude.
4. Select a delayed devector schedule which allows sufficient glide-slope tracking time prior to start of deceleration.
5. Use 10° devector increments employing a "beeping" technique and collective adjustment to correct for resultant flight path disturbances.
6. Make final deceleration to hover by simply pitching up to a hover attitude and adjusting final sink rate with collective.

Recommended Vehicle Improvements

It is felt that some of the major handling qualities characteristics which caused unacceptable levels of pilot workload during the terminal area approach in the XV-5B can be improved by the following modifications to the powered-lift and control systems. These are listed for consideration in future designs.

1. Integrated Power Management - This system would integrate and automatically schedule engine power and fan-lift controls in such a way as to give the pilot a single powered-lift control as in the present day turbine-powered helicopter. It should also reduce the changes in effectiveness of the longitudinal controls during terminal area approach maneuvering.
2. Automatic Devector Control - This system would eliminate the piloting tasks of following a devector schedule. For example, vector angle could be automatically programmed as a function of height above the touchdown spot.
3. Attitude Stability Augmentation - This system would relieve the pilot of the task of coping with attitude disturbances. It is generally agreed that any operational VTOL aircraft will require attitude stability for IFR missions.

CONCLUSIONS

An evaluation of steep terminal area approaches along a 10° ILS approach path was performed in the XV-5B lift-fan aircraft in VFR conditions to ascertain the major operating factors that affect its handling qualities. The following conclusions were drawn as a result of this investigation:

1. The XV-5B exhibited a broad descent capability which was generally suited for steep terminal area approach profiles. The major source of handling problems was found to be in the management of the powered-lift systems.

2. For glide-slope tracking, control of powered lift with the collective stick was preferred over engine power modulation. When engine power was used, lags in propulsion system response caused the pilot to chase the glide slope with throttle movement.
3. Changing thrust vector angle was a very effective means of controlling velocity along the glide slope, but tracking performance deteriorated if the deceleration (or devector) schedule was initiated immediately upon glide-slope intercept. Pilot workload was significantly reduced when the devector schedule was delayed until the airplane was well established on the glide slope.
4. Changing thrust vector angle induced flight path disturbances during deceleration, but the pilot was able to cope with them if vector changes were "beeped" in 10° increments.
5. The deck-parallel (to glide slope) approach was preferred over the deck-level approach because it allowed a greater fan stall maneuver margin and minimized aerodynamic lift effects. In the deck-level case, aerodynamic lift supplemented powered lift, but aerodynamic lift effects hindered glide-slope tracking performance.
6. Control of pitch attitude was found to cause a high workload because of disturbances induced by maneuvering, adverse longitudinal static stability, and inadequate pitch trim authority.
7. Terminal area approach handling qualities could have been improved if the XV-5B had been modified to include integrated power management, automatic devector control, and attitude stabilization augmentation.

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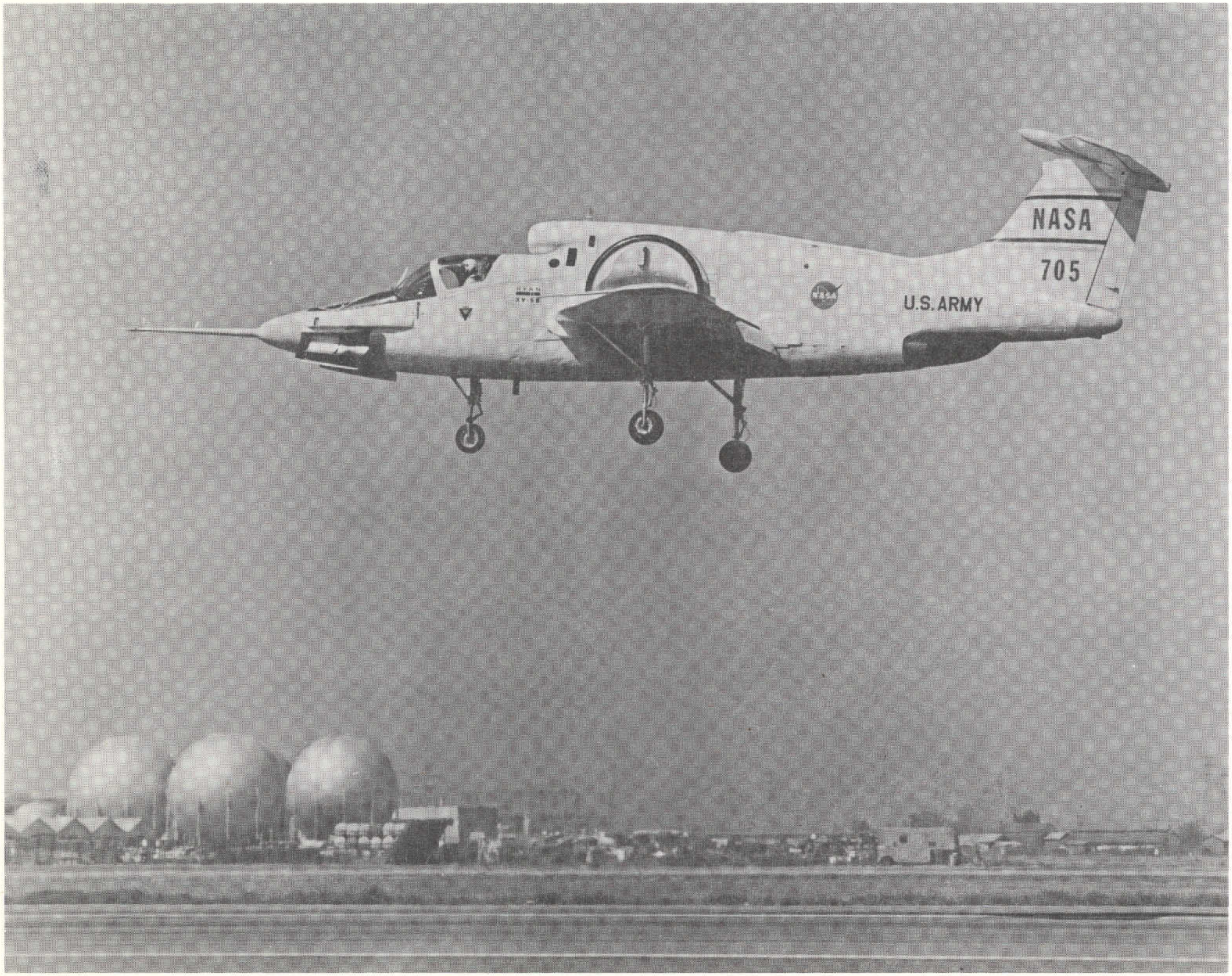


Figure 1.- Airplane in hover flight.

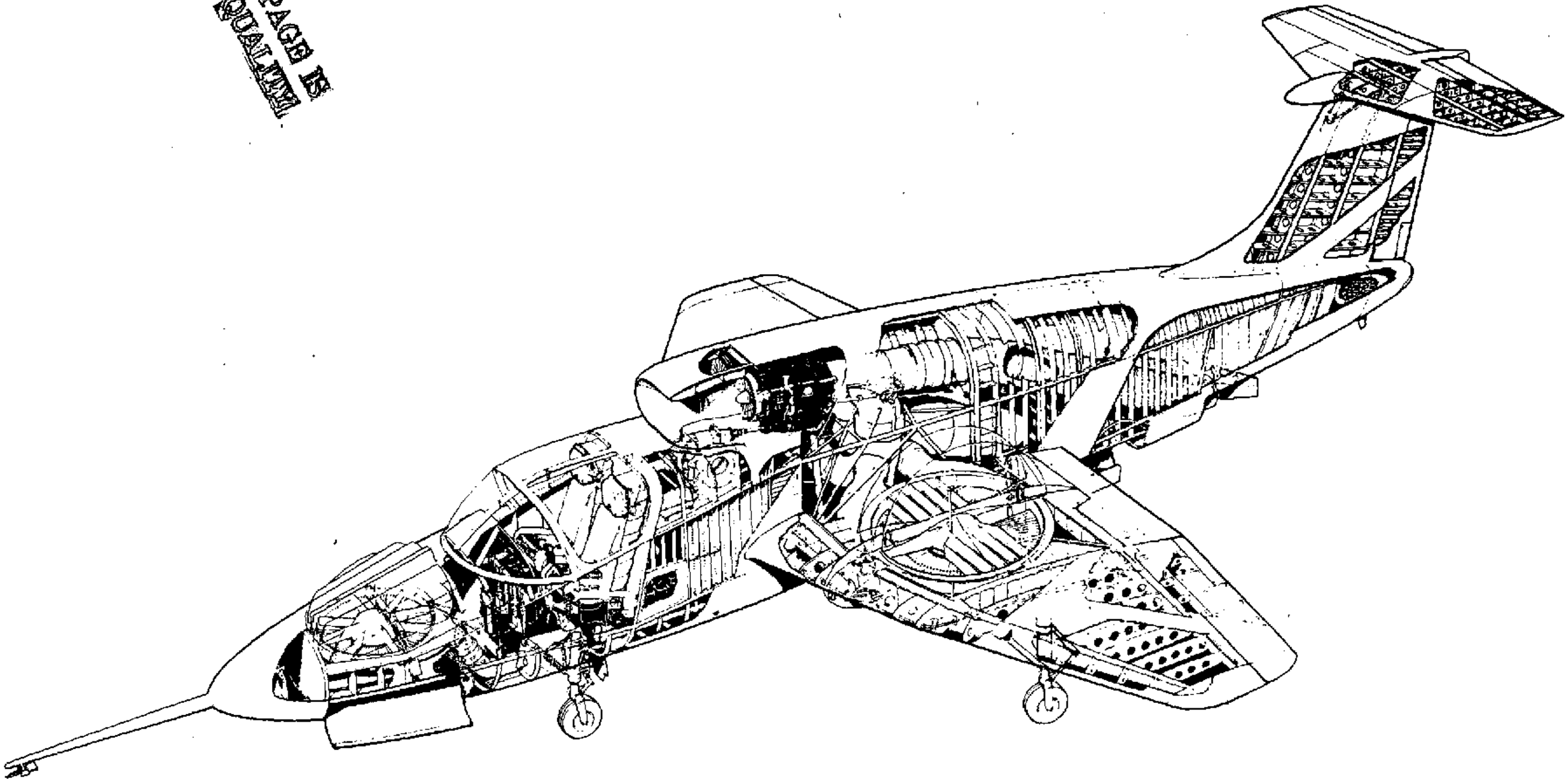


Figure 2.- Cutaway of the airplane.

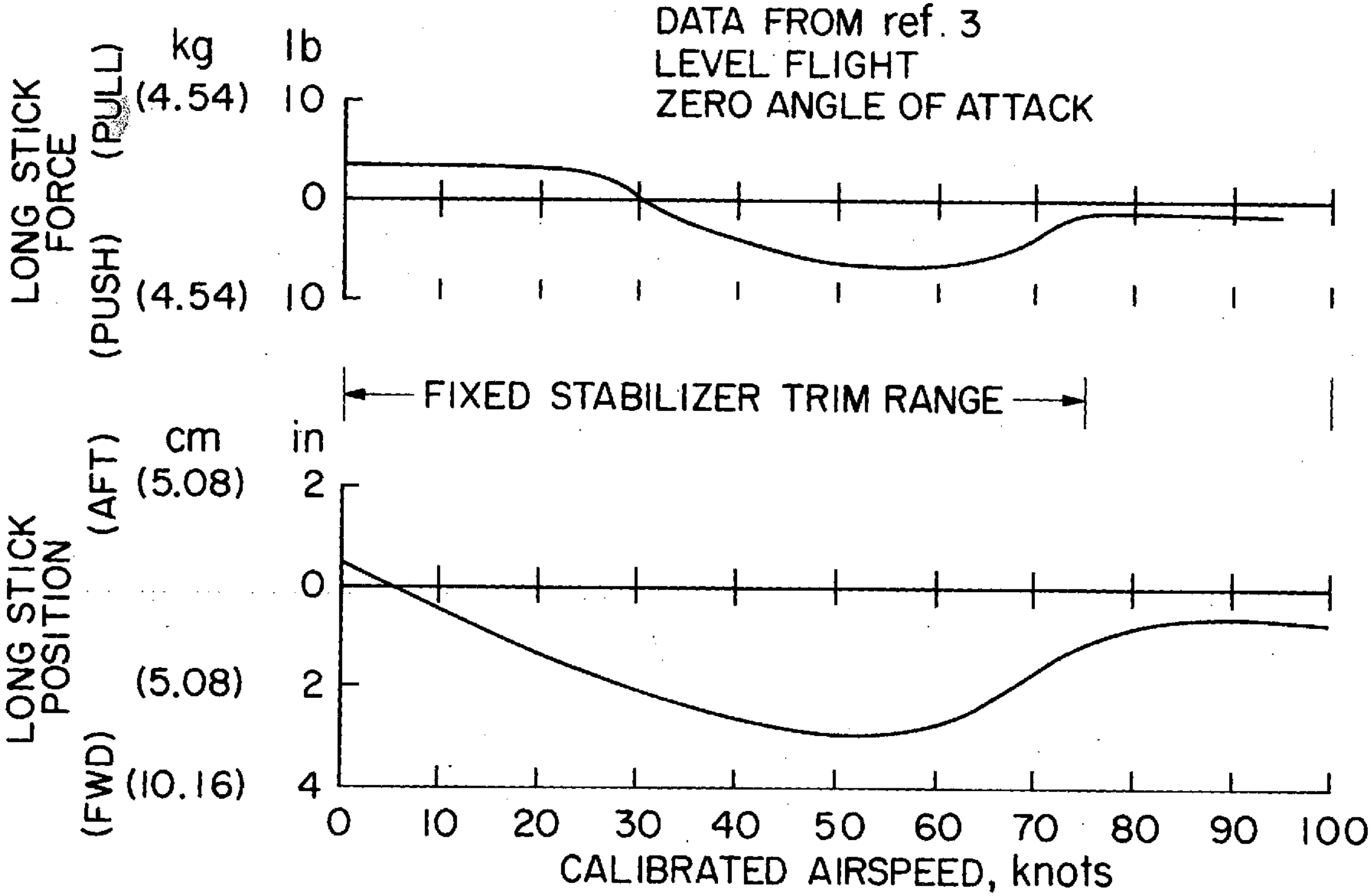


Figure 3.- XV-5B static longitudinal stability.

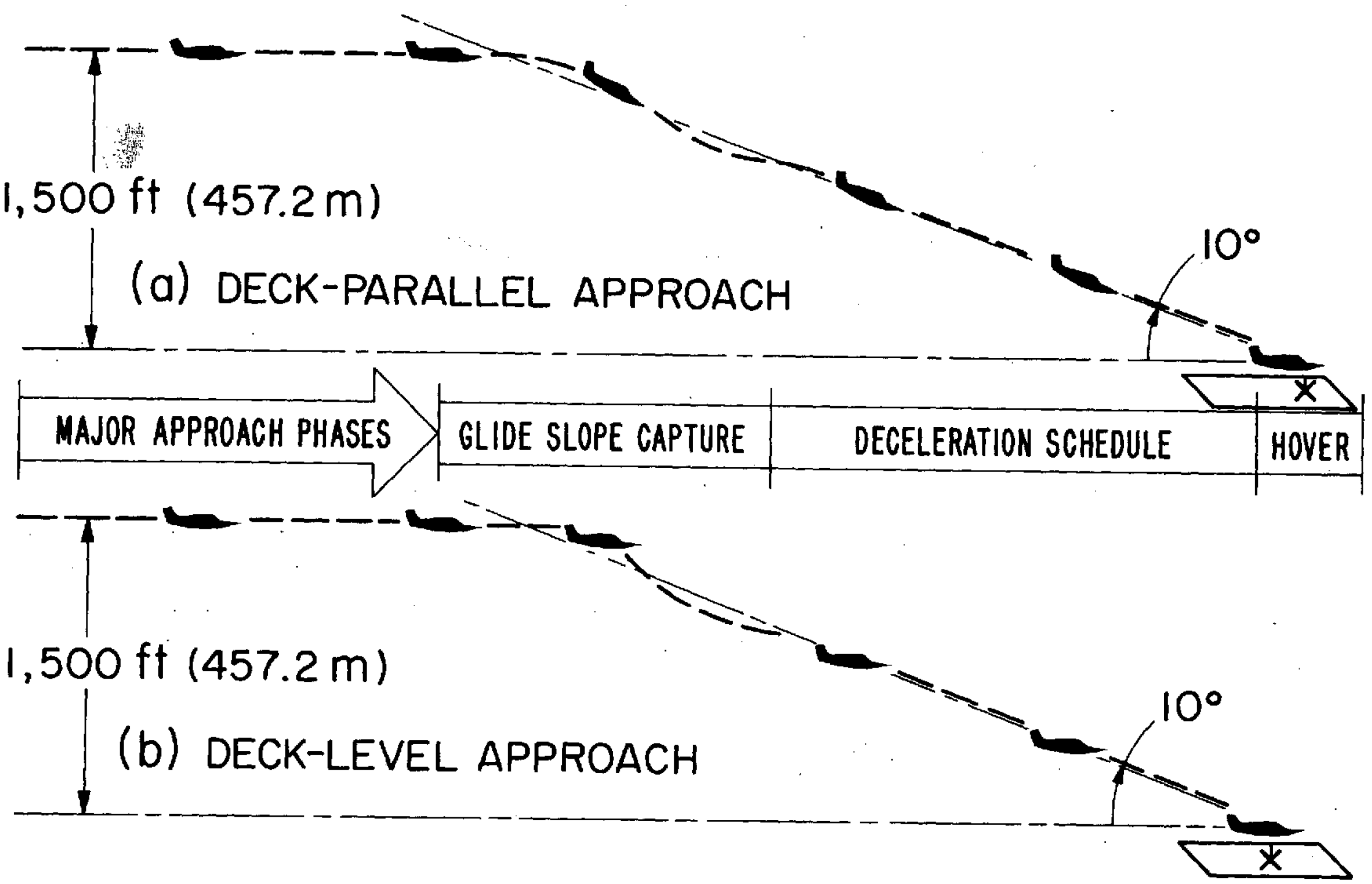
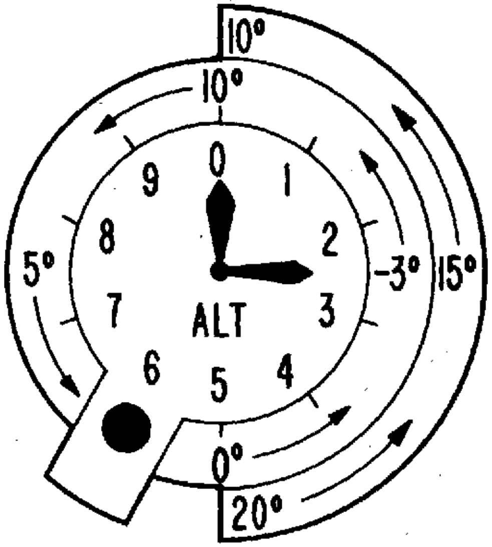


Figure 4.-Terminal area procedures.

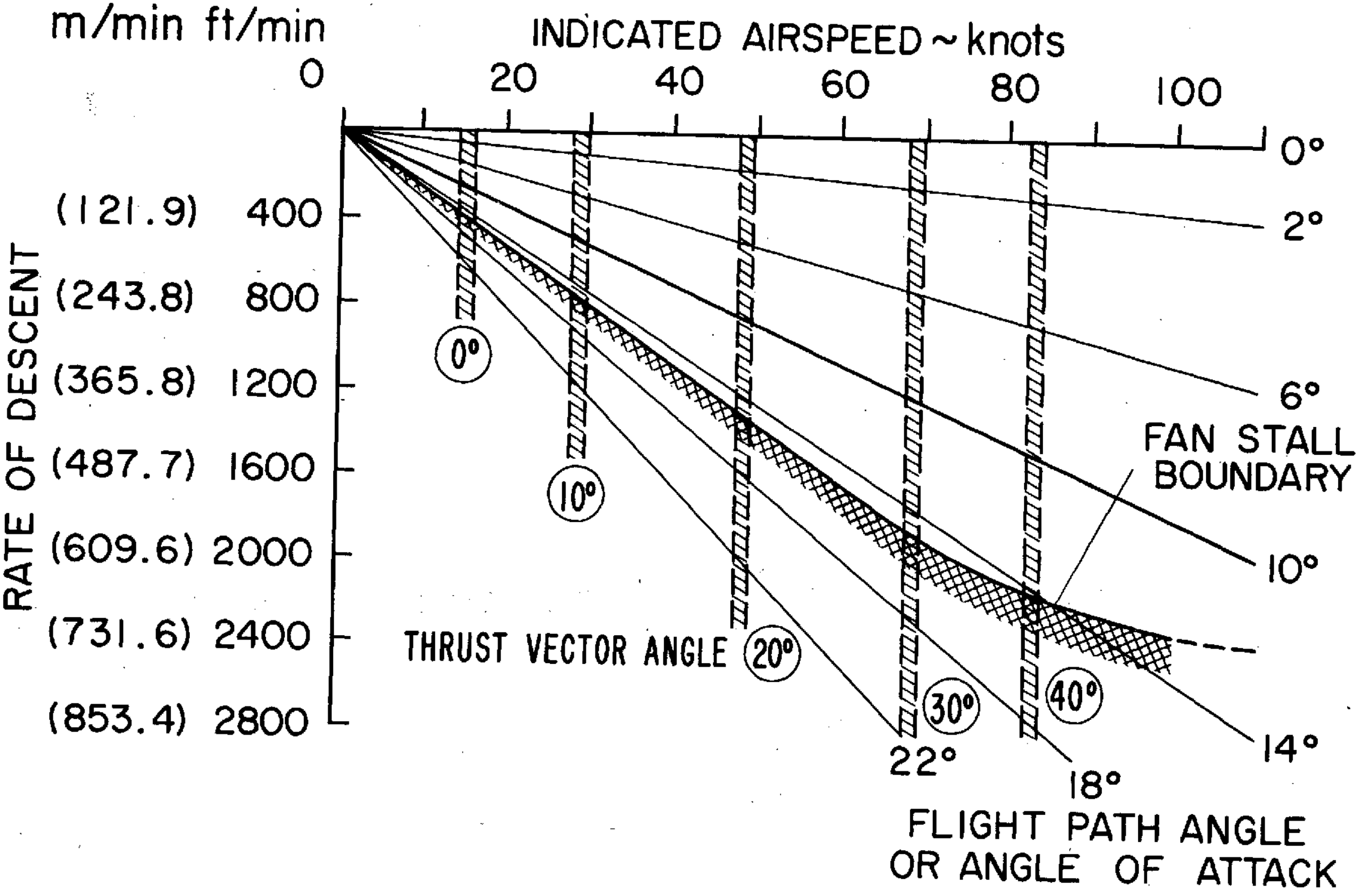
DECK-PARALLEL DEVECTOR SCHEDULE-10° ILS

INDICATED ALTITUDE, m	ft	VECTOR ANGLE, deg	DESIRED AIRSPEED, knots
(457.2)	1500	20	70
(381.0)	1250	15	62
(304.8)	1000	10	51
(228.6)	750	5	42
(152.4)	500	0	32
(76.2)	250	-3	25 → 0



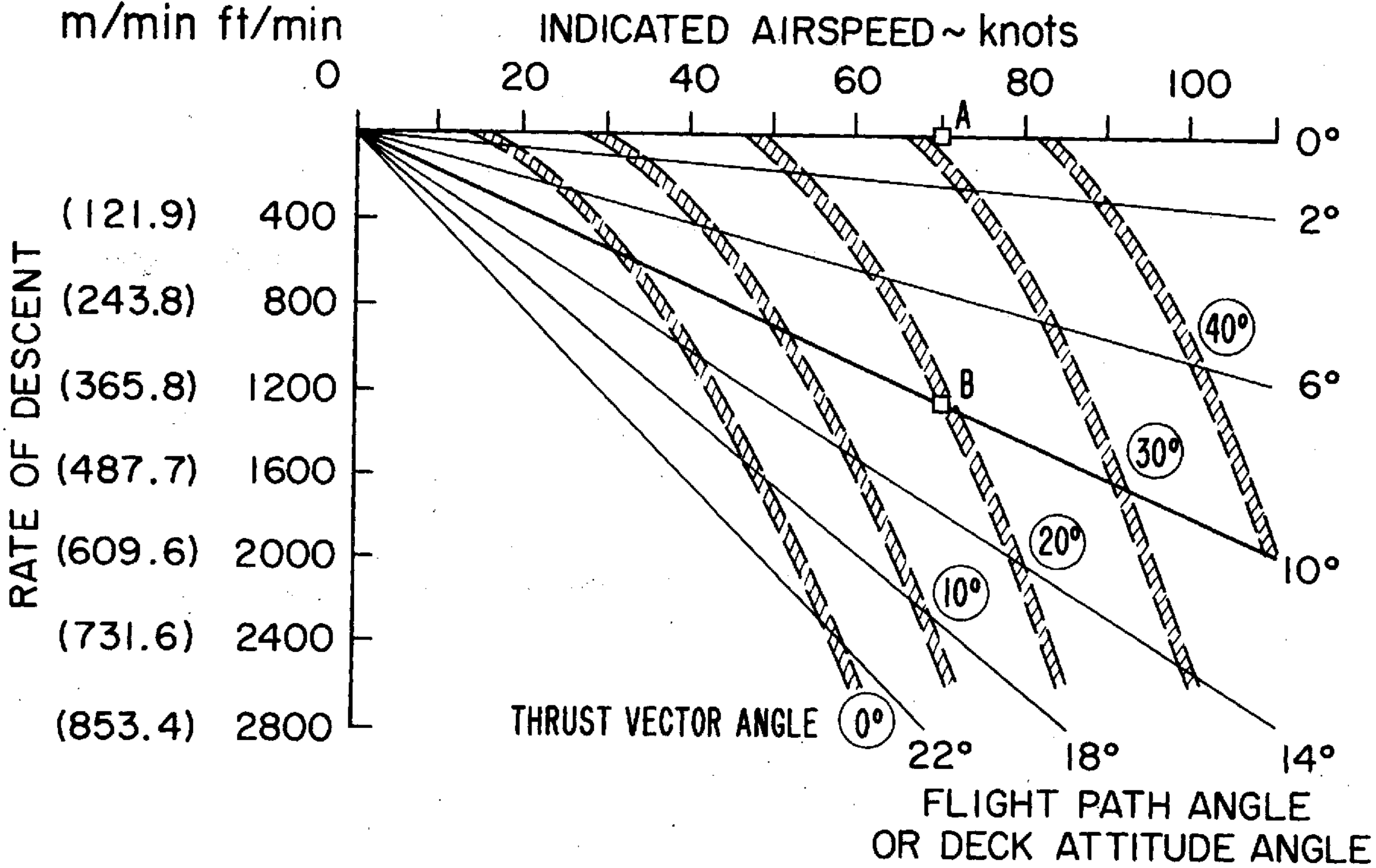
PILOT'S INDICATOR ON ALTIMETER

Figure 5.- Typical deceleration devector schedule – deck-parallel approach.



(a) Deck level.

Figure 6.- Descent performance.



(b) Deck parallel.

Figure 6. — concluded.

DEFINITIONS FROM TN-D-5153

COMPENSATION

The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

HANDLING QUALITIES

Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role.

MISSION

The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase.

PERFORMANCE

The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task.)

ROLE

The function or purpose that defines the primary use of an aircraft.

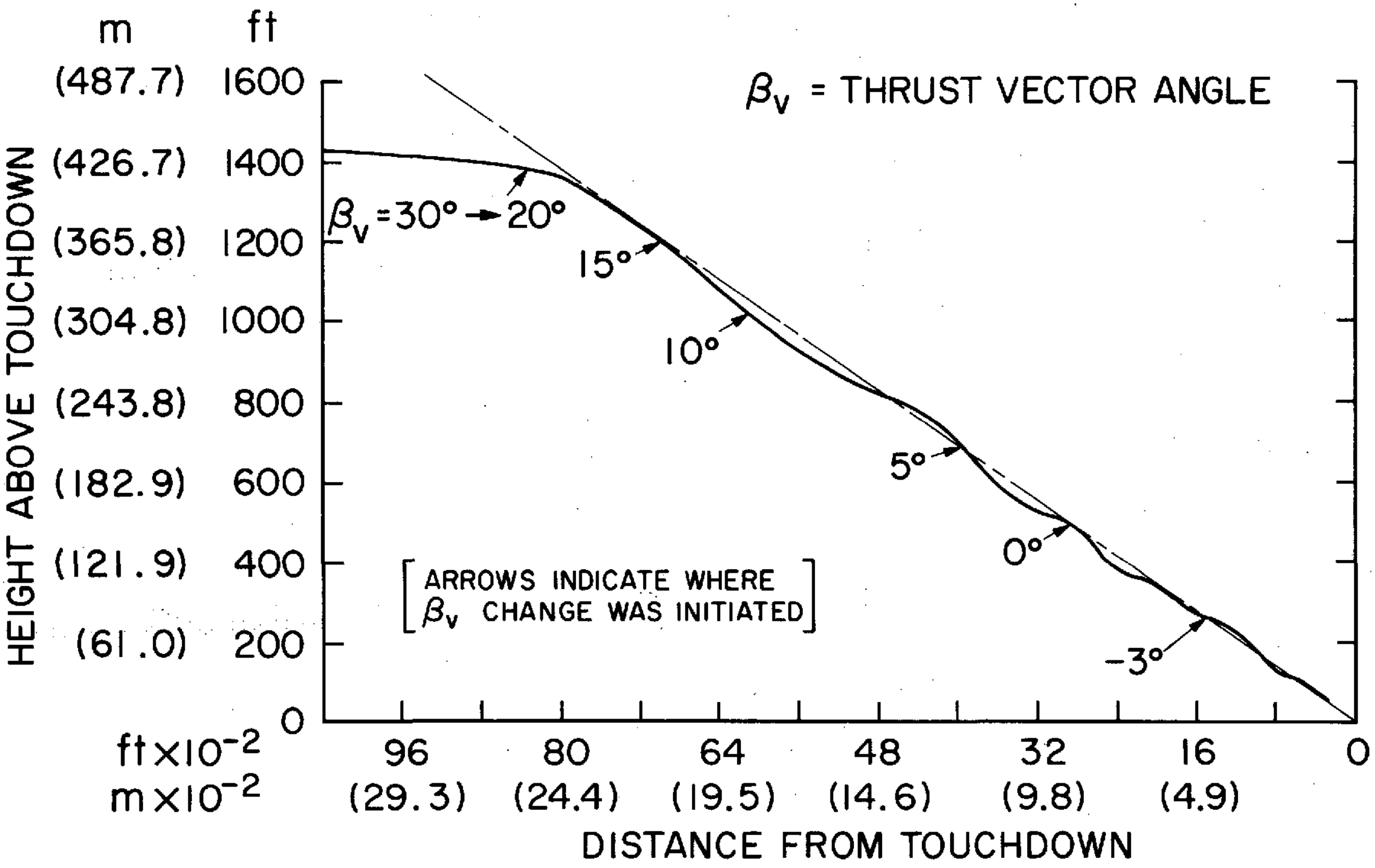
TASK

The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

WORKLOAD

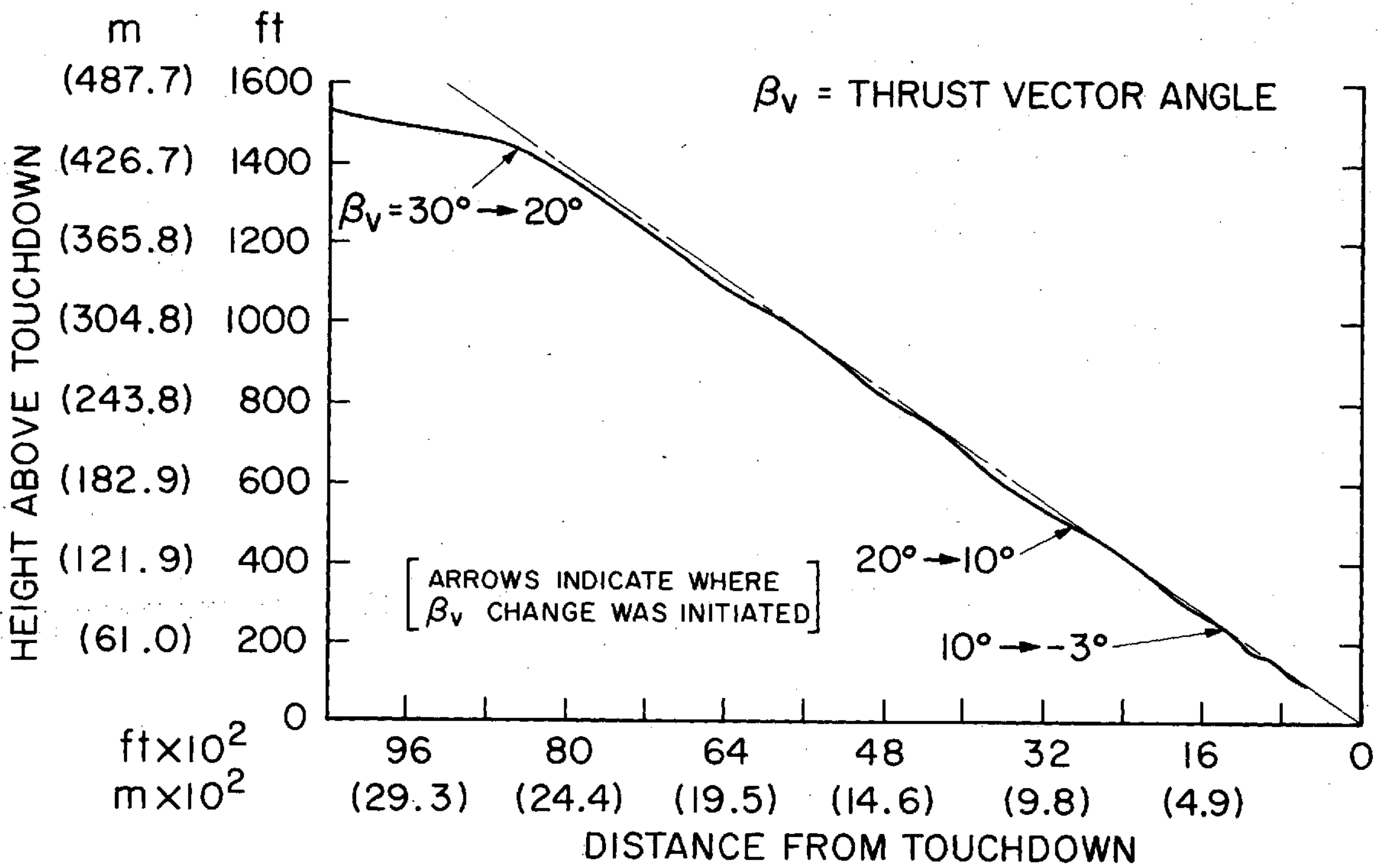
The integrated physical and mental effort required to perform a specified piloting task.

Figure 7.- Handling qualities evaluation terms from reference 4.



(a) Gradual deceleration schedule.

Figure 8.- Radar profile of a deck-parallel approach.



(b) Delayed deceleration schedule.

Figure 8. — concluded.

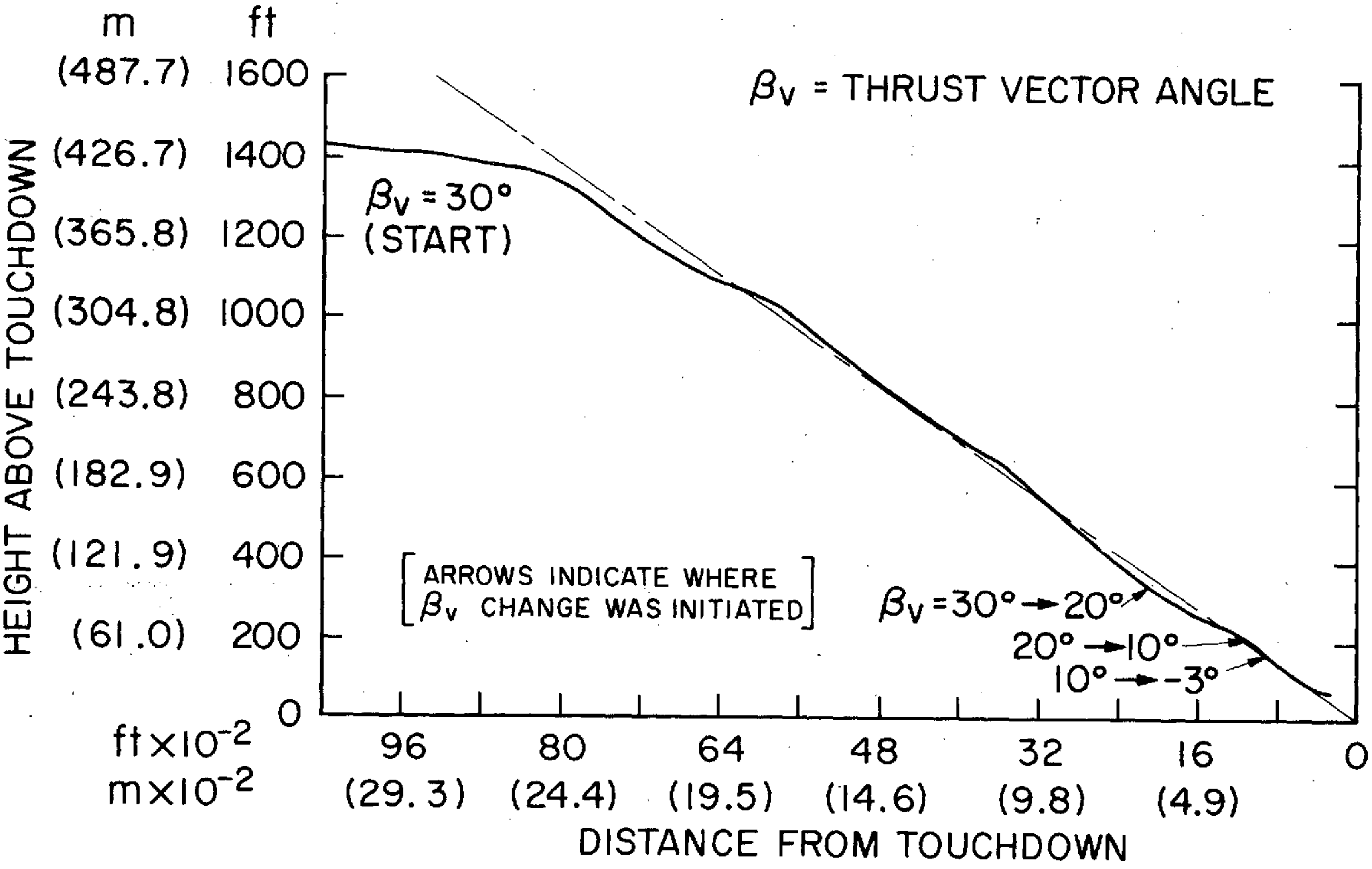


Figure 9.- Radar profile of a deck-level approach — delayed deceleration schedule.