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**STUDY OF HELICOPTER PERFORMANCE
AND
TERMINAL INSTRUMENT PROCEDURES**

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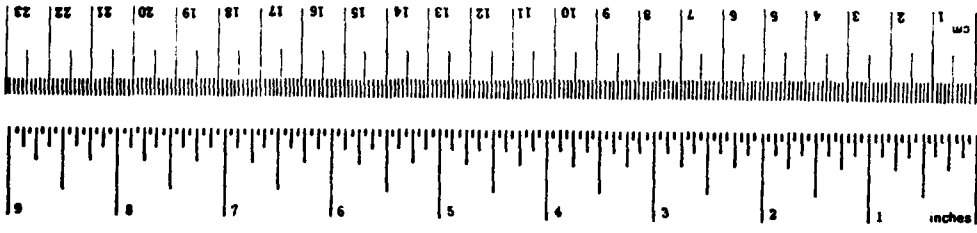
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
LENGTH							
in	inches	2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	0.6	miles
AREA							
sq in	square inches	6.5	square centimeters	sq cm	square centimeters	0.16	square inches
sq ft	square feet	0.09	square meters	sq m	square meters	1.2	square yards
sq yd	square yards	0.8	square meters	sq km	square kilometers	0.4	square miles
sq mi	square miles	2.6	square kilometers	ha	hectares (10,000 m ²)	2.5	acres
MASS (weight)							
oz	ounces	28	grams	g	grams	0.035	ounces
lb	pounds	0.45	kilograms	kg	kilograms	2.2	pounds
	short tons (2000 lb)	0.9	tonnes	t	tonnes (1000 kg)	1.1	short tons
VOLUME							
teaspoon	teaspoons	5	milliliters	ml	milliliters	0.03	fluid ounces
fl oz	fluid ounces	15	milliliters	l	liters	2.1	pints
c	cups	30	milliliters		liters	1.06	quarts
pt	pints	0.24 *	liters		liters	0.26	gallons
qt	quarts	0.47	liters		cubic meters	35	cubic feet
gal	gallons	0.95	liters		cubic meters	1.3	cubic yards
cu ft	cubic feet	3.8	cubic meters	m ³	cubic meters		
cu yd	cubic yards	0.03	cubic meters				
		0.76	cubic meters				
TEMPERATURE (exact)							
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$1.25, SO Catalog No. C13.117286.

PREFACE

The study described in this report was sponsored by the Helicopter Systems Branch of the Systems Research and Development Service, Federal Aviation Administration, U.S. Department of Transportation, under Contract No. DOT-FA-79WAI-019. Mr Glen D. Adams (ARD-330) served as technical monitor and engineer for SRDS. The authors wish to express their appreciation to the branches and sections of the FAA; namely, the Office of Flight Operations (AFO-203), and the Flight Standards National Field Office (AFO-560 and AFO-507) at Oklahoma City, for their cooperation in this research effort.

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LIST OF ABBREVIATIONS

AC	Advisory Circular
ASW	Antisubmarine Warfare
DH	Decision Height
DME	Distance Measuring Equipment
DOD	Department of Defense
FAA	Federal Aviation Administration
HIGE	Hover In Ground Effect
HOGE	Hover Out of Ground Effect
H-V	Height-Speed (Height-Velocity)
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MLS	Microwave Landing System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ROC	Rate of Climb
ROD	Rate of Descent
RVR	Runway Visual Range
SRDS	Systems Research and Development Service
TERPS	Terminal Instrument Procedures
TCA	Terminal Control Area
TN	Technical Note

LIST OF ABBREVIATIONS

USCG United States Coast Guard

VMC Visual Meteorological Conditions

V/STOL Vertical/Short Takeoff and Landing

LIST OF SYMBOLS

V Velocity.

V_{ne} Velocity never exceed.

V_v Velocity, vertical, knots or feet/minute

V_{TOSS} Takeoff safety speed

γ Flight path angle, degrees

g Acceleration due to gravity (32.2 ft/sec^2)

SECTION 1

INTRODUCTION

The objective of this effort is to conduct a study and analysis which will provide data to support development of new criteria and procedures for operation of helicopters in the terminal environment, and update existing terminal instrument procedures (TERPS).

The U.S. Standard for Terminal Instrument Procedures (TERPS Handbook) contains the criteria used to formulate, review, approve and publish procedures for instrument approach and departure of aircraft to and from both civil and military airports; and it provides standardized methods for use in designing instrument flight procedures. These criteria apply at any location where the U.S. exercises jurisdiction over terminal area flight procedures and are officially adopted by the Federal Aviation Administration (FAA) and the Army, Navy, Air Force and Coast Guard (USCG). The scope of the TERPS Handbook (Reference 1-1) is extensive, including criteria for take-off and landing minimums, missed approach procedures, obstacle clearance requirements for approaches and departures, criteria for using the various forms of approach aids, criteria for determining visibility and ceiling minimums, and enroute requirements such as feeder routes and sector altitudes. Chapter 11 (Helicopter Procedures) of the TERPS Handbook applies to "helicopter only" procedures, i.e., those "...designed to meet low-altitude, straight-in requirements only." The criteria contained elsewhere in the Handbook otherwise apply, and were developed originally with fixed wing aircraft in mind.

The criteria contained in Chapter 11 were developed jointly by the FAA, Department of Defense (DOD) and USCG to give credit to the unique capabilities of helicopters. This was based on the premise that helicopters are approach Category A aircraft with special maneuvering characteristics. The intent of Chapter 11 is, and has been, to provide relief for helicopters from those portions of other chapters of the TERPS Handbook which are more restrictive than necessary for the management of helicopter traffic in unique procedures.

When Chapter 11 was first issued in 1970, numerous military helicopters were operating under instrument meteorological conditions, but only two civil helicopter models were certified for flight under Instrument Flight Rules (IFR). Because the vast majority of IFR-capable helicopters were in the military, much of the data used in developing Chapter 11 were derived from flight tests with military equipment. At present, more than 11 civil helicopter models are IFR-certified, others are undergoing the certification process, and most future helicopters are expected to be offered by manufacturers IFR-certified "off-the-shelf". This has been the result of operator demand and some industry estimates suggest that the number of IFR capable helicopters operating in the United States may number well into the thousands in the 1980s.

As the state-of-the-art of the helicopter industry improves, the FAA continues to revise TERPS to permit greater latitude in helicopter IFR operations. Industry requests for additional freedom have been based upon assertions of unique capabilities of helicopters. Such requests typically include: reduced landing and takeoff minimums, less restrictive alternate minimums, steeper approach angles, revised obstruction clearance gradients, relaxed weather reporting criteria, and more.

When addressing the operation of helicopters under instrument meteorological conditions (IMC) within the national airspace system (NAS), there is one particular segment of that airspace system that is readily identified as being critical, with significant impact on operational profiles: the terminal environment. That terminal environment typically is a highly structured airspace that ranges from high-density Terminal Control Areas (TCAs) to light and medium-density airport traffic areas. As the helicopter becomes more and more integrated into the IFR operational environment, terminal operations foreseeably may include a number of remote traffic areas suitable only for helicopter use.

In an effort to provide the data needed to examine the feasibility of new procedures and criteria for helicopter terminal instrument procedures, this study effort addresses helicopter IFR operations in two parts. First, it documents, in a collective sense, the IMC and visual meteorological conditions (VMC) performance capabilities of currently IFR-certified helicopters. Second, it addresses helicopter instrument procedures in the long-term sense (future TERPS) and offers recommendations for post - 1985 operations.

SECTION 2
HELICOPTER PERFORMANCE

INTRODUCTION

This section addresses capabilities of helicopters as they bear upon the problems of managing IFR operations in approach, missed approach and departure at sites uniquely suited for helicopters or other forms of Vertical/Short Takeoff and Landing (V/STOL) aircraft. The discussion centers on limiting aspects of helicopter performance capabilities to ensure that criteria for IFR terminal procedures intended for "Copter Only" utilization may be considered within the envelope of physical capability rather than scoped entirely by experience evolved from operations with fixed wing aircraft.

The discussion of helicopter capabilities addresses performance of helicopters as defined by current certification standards, the most significant aspect of which is the definition of a minimum IFR airspeed for each certificated helicopter. Consequently, the discussion focuses on Category I and II approaches in which the airspeed is stable upon reaching decision height and minimal changes are necessary to effect a missed approach. Corollary issues concern the IMC procedural interfaces with the visual decelerating segment to the landing spot and the visual acceleration segment during departure.

As an introduction to the discussion, characteristics of currently active IFR capable helicopters have been reviewed. Data, principally obtained from their respective flight manuals, have been summarized for each of eleven different helicopters, mostly civil, with certification for IMC operations in the U.S. plus a few military helicopters to complete the spectrum of size and configuration. Individual summaries are presented in Appendix A.

GENERALIZATIONS ON CHARACTERISTICS OF IFR CAPABLE HELICOPTERS

Data Sources

The summaries of performance data contained in Appendix A are limited in scope to those data of nearly universal availability in FAA approved (or analogous military) flight manuals. Generally speaking, these manuals reveal information concerning limitations on capability specified in the Type Certificate or IFR Supplementary Type Certificate and a modest scope of performance characteristics in climb, hover, and cruising flight. Some information concerning autorotation characteristics is provided, but several manufacturers had to be directly consulted to obtain rates-of-descent associated with their recommended airspeeds. Military manuals were much more comprehensive, but neither military nor civil manuals provided direct data or discussion of handling characteristics. It may only be inferred from these manuals that handling qualities are acceptable within the limitations imposed; but there is no assurance that handling qualities meet current criteria beyond those limitations. In particular, it may be assumed that the minimum IFR airspeed of a civil helicopter represents a boundary below which criteria regarding control force or position stability characteristics cannot be satisfied. Military aircraft do not universally impose a minimum IFR airspeed; however, most military flight manuals reviewed did suggest that airspeeds below 40-50 knots be avoided during IMC operations due to the unreliability of pitot-static instrumentation in that flight regime. Civil regulations do not establish performance requirements for airspeed measuring systems which completely cover the low airspeed spectrum of the helicopter performance envelope.

Overview of Certification Limits

Figure 2-1 provides an overview of the boundaries imposed by certification limits. Minimum IFR airspeeds for level or descending flight range between 40 and 60. The range of maximum V_{ne} runs from 130-175 knots for the aircraft summarized in Appendix A. However, V_{ne} is decreased below this maximum limit for all of these aircraft when altitude is increased and

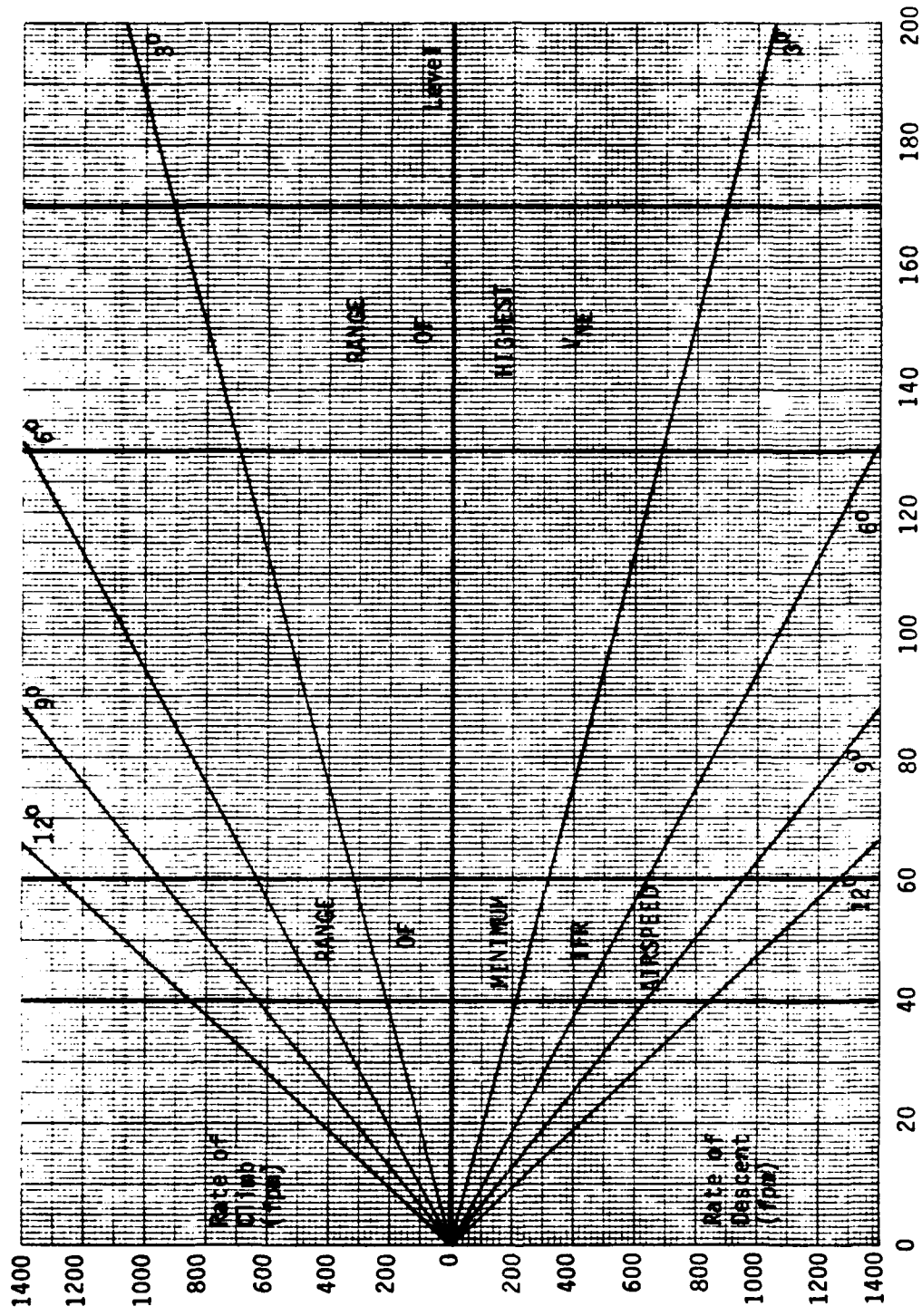


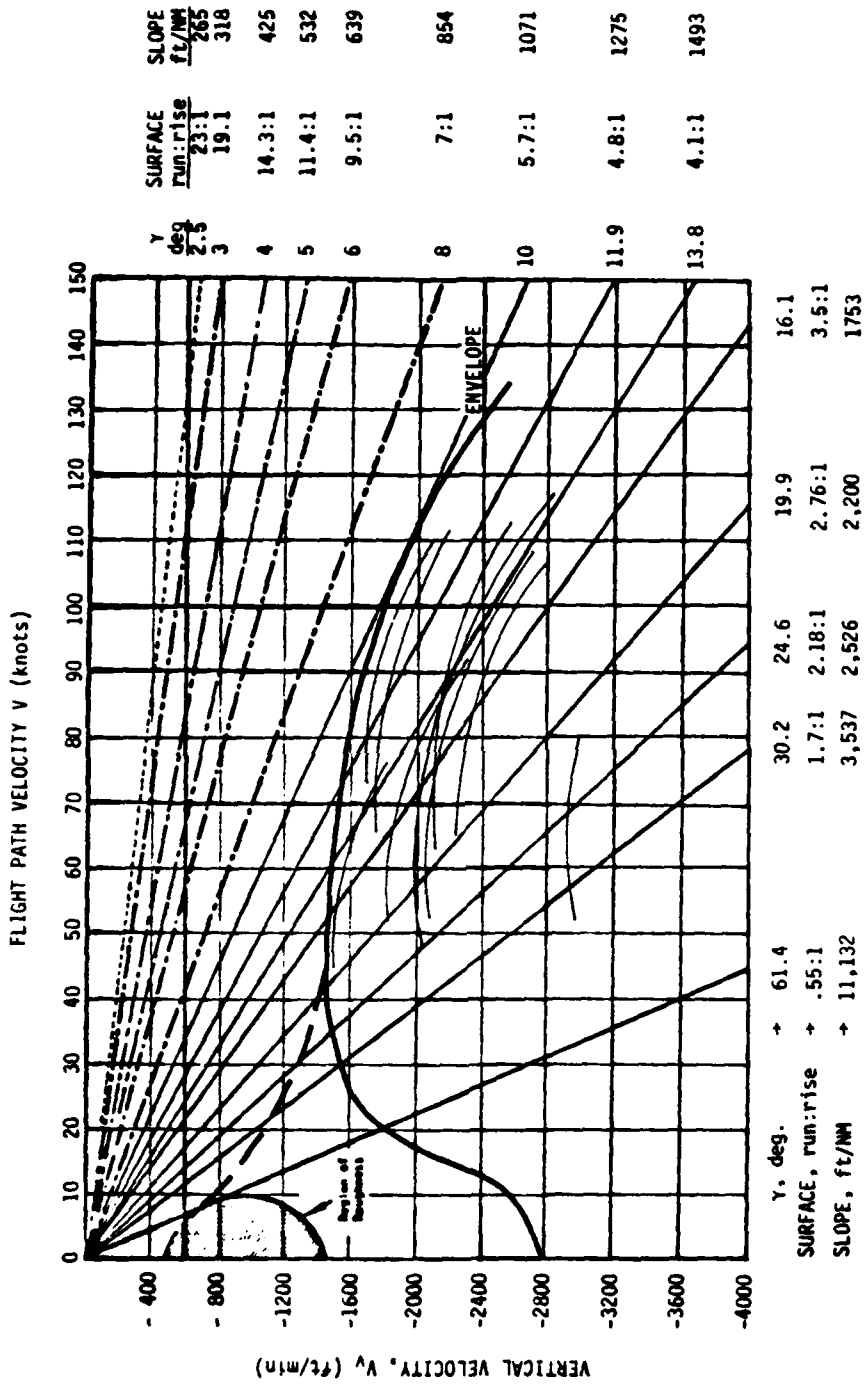
Figure 2-1
 Overview of Bounds on Helicopter IFR Flight Envelope
 (Type Certificate/Supplementary Type Certificate Limitations Summarized)

and for many when gross weight is increased. This variation can reduce V_{ne} to the point that some models of helicopter barely satisfy minimum IFR airspeed requirements while operating at the reduced V_{ne} at maximum authorized altitudes and/or weights. Additional limitations have been imposed on aircraft individually regarding maximum rates of climb or descent, steepest approach angle, or maximum altitude for landing and takeoff. These additional limitations have resulted, in some cases, from the extent to which capabilities have been demonstrated and, in others, from inherent bounds on capability vis-a-vis certification requirements. Flight manuals do not identify the rationale for such limitations, only the performance boundaries.

Aspects of Performance Considered

Three aspects of performance are documented in the data packages of Appendix A for each IFR capable helicopter. These are autorotation performance, climb performance and hover performance. Autorotation performance is discussed in this report to define physical limitations on rate of descent. Climb performance is documented for best rate-of-climb airspeed or recommended IFR climb airspeed, when different, using maximum continuous power. Hover performance significantly influences considerations for possible employment of decelerating or other innovative approaches to be discussed in Section 3 and may be employed to advantage in reviewing missed approach procedures for "Copter Only" within current certification requirements as well.

Autorotation performance capabilities are summarized in Figure 2-2. Where data were available, airspeed and rate-of-descent have been plotted for each helicopter at the speed for minimum rate-of-descent in autorotation and also at the speed for shallowest glide angle. Collectively, the individual performance curves have been bounded by an envelope curve in Figure 2-2. This shows that helicopters, in general, are physically limited to rates of descent of as little as 1400 fpm at airspeeds between 50-70 knots and may not be capable of descent angles (under no wind conditions) steeper than 10° at airspeeds above 100 knots.



Individual Helicopter Capability

Note: Helicopters cannot physically descend in controlled flight at a higher rate of descent than achieved in autorotation. This envelope curve, therefore, defines the regime of descending flight achievable by the family of IFR certificated helicopters evaluated in this report.

Figure 2-2

Envelope of Autorotation Characteristics
(IFR Certificated Helicopters, Sea Level, Standard Day)

The carpet plots of climb performance shown in Appendix A do not provide such a useful opportunity for generalization regarding capabilities as the autorotation data do. It can be seen from examining the climb performance data for any of the helicopters that, for some combinations of gross weight, temperature and altitude, each helicopter is absolutely unable to climb at maximum continuous power. Inasmuch as climb performance of helicopters is not readily generalized, it is more useful to look at a generalization of the current terminal procedure requirements. Presently, "Copter Only" approaches require a 20:1 missed approach surface, and conventional airplane approaches a 40:1 missed approach surface. Figures 2-3 and 2-4 plot ground speed versus rate of climb necessary to attain these gradients. Reference to these figures permits comparison with the discrete capabilities for the specific case of interest.

Hover performance is included on the carpet plots of climb performance contained in the individual aircraft performance summaries of Appendix A. Traces marked 'HOGE Boundary' and 'HIGE Boundary' (for hover out of ground effect and hover in ground effect respectively) cross the carpet plots at appropriate combinations of helicopter gross weight and altitude to permit comparison of climb performance with hovering capability. At combinations of gross weight and altitude higher than those indicated by the boundary, hover (for conditions relative to ground effect as specified) will not be possible. On the boundary, hover becomes marginally possible; and, when either gross weight or altitude is further reduced, hover becomes clearly possible. These boundaries will prove useful in the discussions which follow. Figure 2-5 provides an example carpet plot with HOGE and HIGE boundaries indicated.

DISCUSSION OF HELICOPTER CAPABILITIES IN RELATION TO CURRENT CERTIFICATION REQUIREMENTS

In this section, helicopter performance capabilities as constrained by current certification requirements are discussed as they apply to instrument flight. Enroute operations are only briefly mentioned with emphasis reserved for the arrival and departure phases.

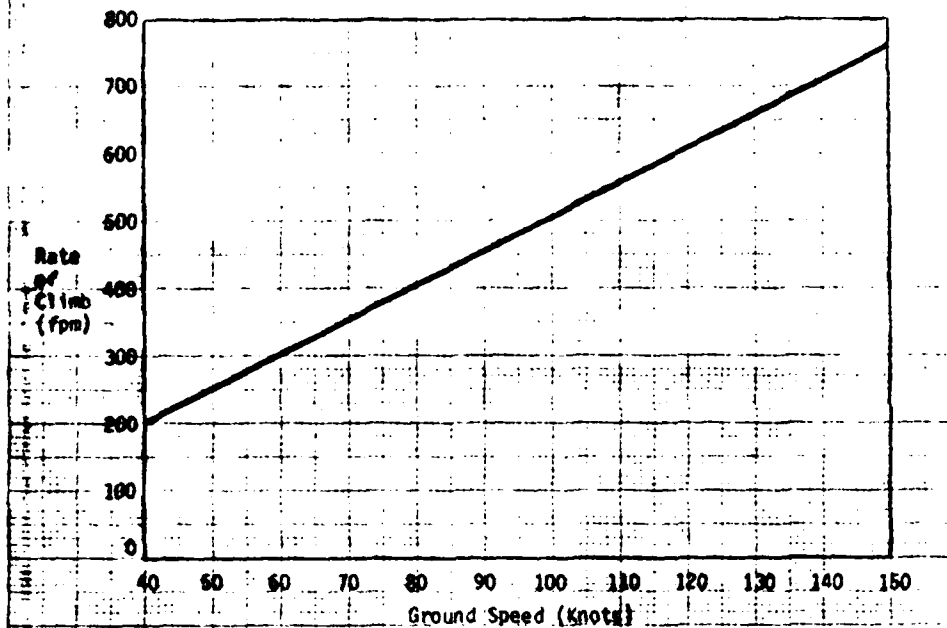


Figure 2-3
 Variation of Rate of Climb with Groundspeed Necessary
 to Maintain a 1:20 Climb Gradient

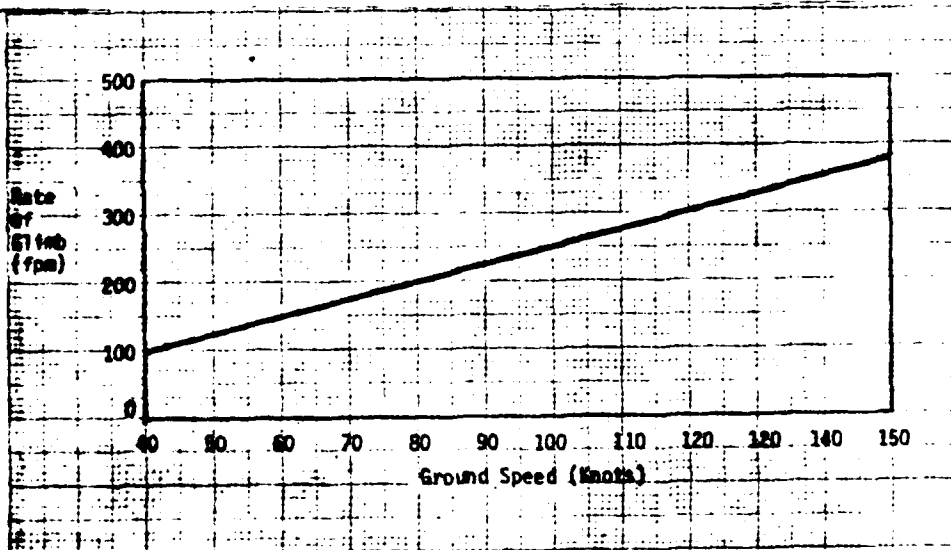


Figure 2-4
 Variation of Rate of Climb with Groundspeed Necessary
 to Maintain a 1:40 Climb Gradient

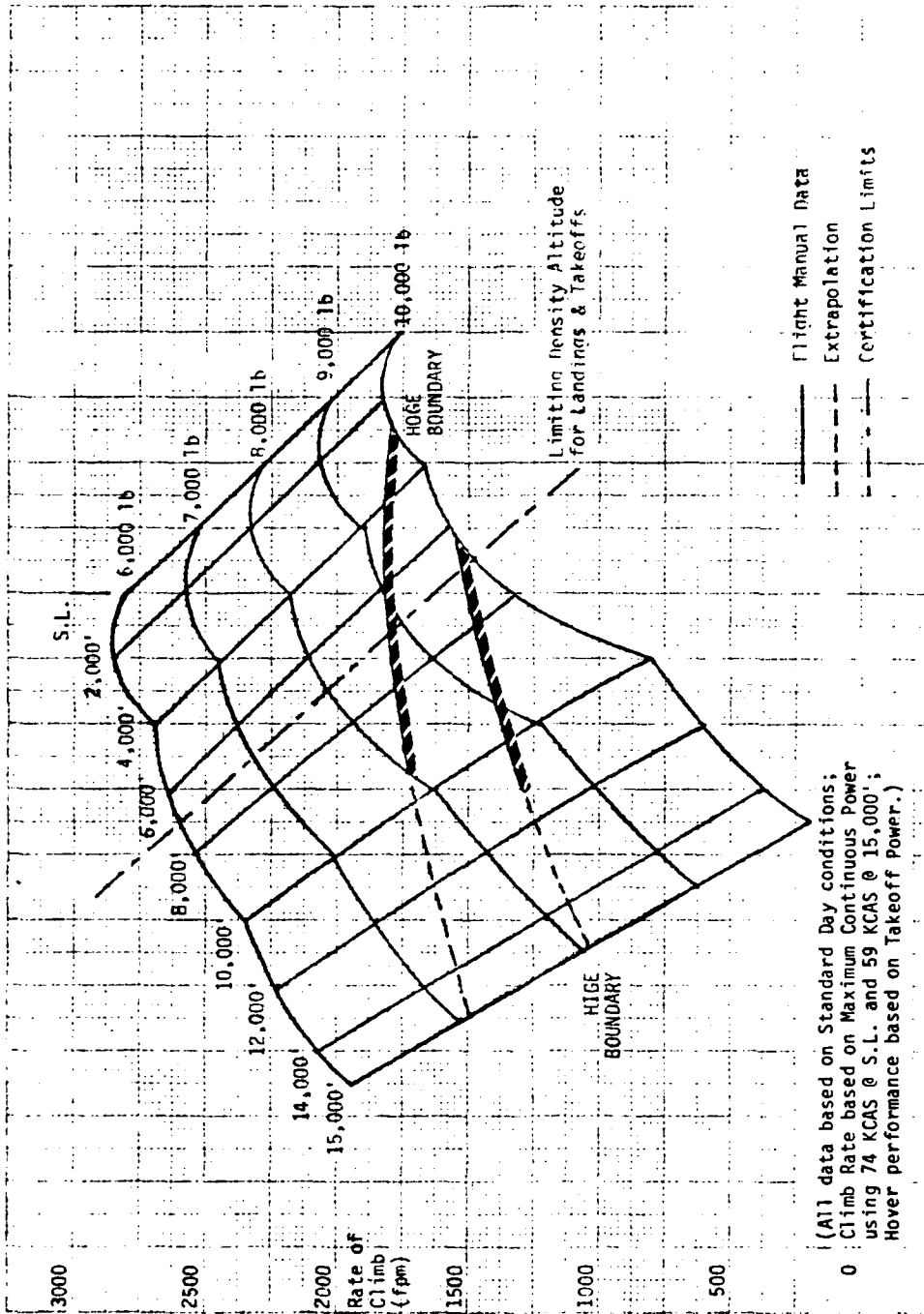


Figure 2-5
Example Carpet Plot of Climb Performance Capability
for a Representative Modern Helicopter

Certification requirements regularly result in definition of three limitations which impact enroute performance of helicopters operating IMC. These are the definition of minimum IFR airspeed--typically ranging from 40-60 knots in level or descending flight; maximum altitude--variously defined as pressure or density altitude and typically of the order of 15,000-20,000 feet; and V_{ne} --the maximum values of which range between 130 and 175 knots. These data are summarized in Figure 2-1. Helicopters may also be limited by handling qualities to maximum rates of descent or climb in IMC; and, in some cases, higher minimum IFR speeds apply during climb--ranging up to 70 knots.

Limits shown in Figure 2-1 represent the range of maximum V_{ne} for the aircraft considered. Published V_{ne} always decreases from the maximum as a function of increasing altitude and/or temperature. Many helicopters also inhibit V_{ne} for increasing gross weight. Each civil aircraft must display a placard of V_{ne} variations. At the greatest extremes of density altitude (and sometimes gross weight) V_{ne} is reduced to airspeeds of the order of 70 to 100 knots. (In one case the minimum V_{ne} is actually less than the corresponding minimum IFR airspeed). Helicopter V_{ne} is usually defined by structural or control considerations, such as the approach of retreating blade stall (determined by blade loading, true airspeed and air density). The published limits are determined through the certification process, but they are linked to performance limitations which reflect both excessive vibration and the onset of controllability problems. V_{ne} , when expressed as calibrated airspeed, is typically constant with increasing altitude until a critical density altitude is reached at which blade stall effects require a further limitation in airspeed. Density altitudes at which this transition occurs are a function of gross weight and reflect the arbitrary design choices resulting from tradeoffs. Density altitudes of 3000-5000 feet are typically the regime in which blade stall effects begin to limit V_{ne} , but individual designs or extremes in gross weight may result in significant deviations. Once blade stall effects are encountered, V_{ne} must be reduced by approximately 3-8 knots per 1000' of additional altitude. The rate of reduction again results from design choices peculiar

to the individual helicopter. In the immediate future, application of noise standards may also impact the design choices which influence V_{ne} inasmuch as rotor impulsive noise is associated with the high local Mach numbers near the tip of the advancing blades at the same time that stall considerations apply to the aerodynamic performance of the retreating blades. The several phenomena which now, or shortly will, influence V_{ne} all contribute to a very pragmatic preference among helicopter pilots for the lowest feasible enroute altitudes.

Arrival Phase

The arrival phase of instrument operations is not, generally, impacted by additional certification constraints. (An exception; one helicopter is precluded from precision approaches involving glide paths steeper than 3.5° .) However, practical limits on rate of descent must be considered in evaluating helicopter approach capabilities.

Practical Limits On Rate Of Descent

With the prospective advent of Microwave Landing Systems (MLS) which will provide precision elevation guidance signals up to 20° , much interest has been shown by the helicopter community in flying steeper precision approaches than are supportable with present Instrument Landing Systems (ILS) (slightly more than 3°). Figure 2-2 shows curves of limiting rate of descent in autorotation for IFR capable helicopters. An envelope curve has been inferred and drawn which bounds the autorotation curves of each of the individual helicopters. Autorotation is a physical limitation on rate of descent of helicopters, so a buffer descent rate of approximately 400-500 fpm is necessary to define a mean sustainable rate of descent or descent angle. The buffer is needed because autorotation is a state of operations in which the rotor system is driven by the descent of the helicopter rather than power from the engine(s). Rotor speed is no longer governed by the engine power management system, and controllability may become marginal. If attempting to track a prescribed glidepath, pilots

should not be expected to correct from a high, fast error position by operating near the autorotation boundary. Consequently, 1,000 fpm would appear to be the reasonable maximum rate of descent which can be practically achieved in the airspeed regime of 40-70 knots. This figure gradually increases to 1,500 fpm by 110 knots. These recommendations correspond to descent angles which range from 14° at the low end of the airspeed spectrum to 8° at 110 knots. Above 110 knots, at all airspeeds, descent angles of up to 8° should be sustainable throughout the allowable airspeed range unless handling qualities should deteriorate at very high speeds and high rates of descent.

Two factors should be considered in attempting to evaluate the implications of these limits on descent rate or descent angle. First, steep descent angles can only be achieved at the low end of the airspeed spectrum near the minimum IFR airspeed. The influence of wind on flight path is most severe at the lower speeds since any given amount of wind represents a higher proportion of the approach speed; and, at minimum IFR airspeed, the aspects of handling qualities have already been shown to be marginal. The second factor relates to non-precision approaches. According to helicopter TERPS, the steepest permissible gradient for such approaches is 800 feet per nautical mile, which corresponds to 7.5° (with no wind). This already presses the limiting capability of helicopters at the higher airspeeds which many flight manuals recommend for such approaches, so there is little opportunity to increase the non-precision approach gradient. Consequently, instrument approaches steeper than now authorized may only become practical for MLS supported precision approaches. Figure 2-6 shows the relationship of rate of descent (ROD) to either descent angle or slope and airspeed over the total range of IFR airspeeds.

Visual Approach Segment Profiles

The steeper approaches, which can be made possible through use of MLS, require consideration of not only helicopter performance during the approach to decision height, but also the visual continuation segment from

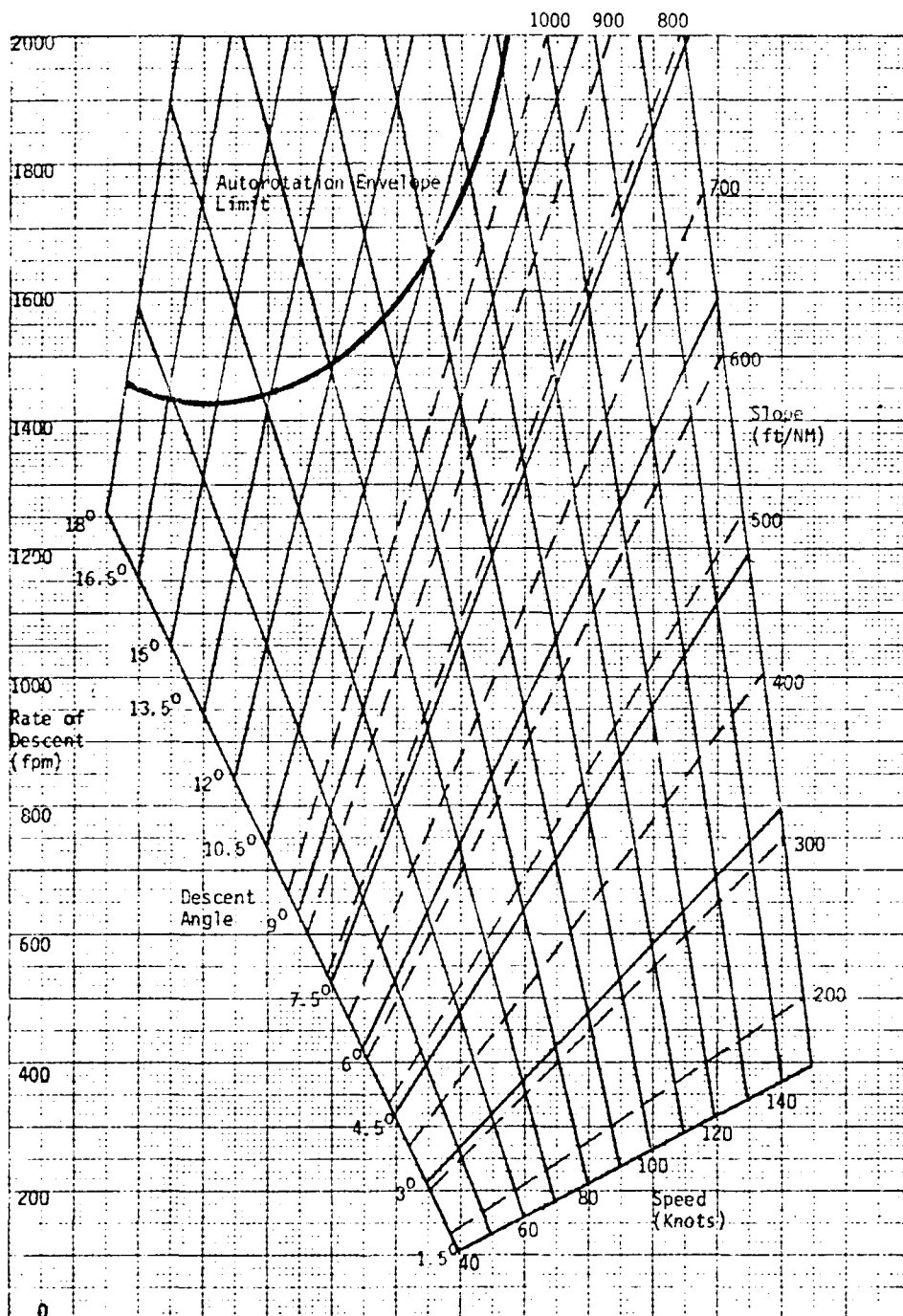
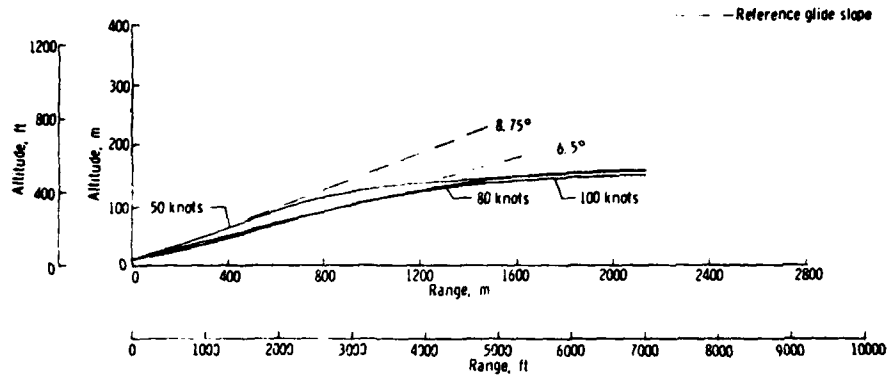


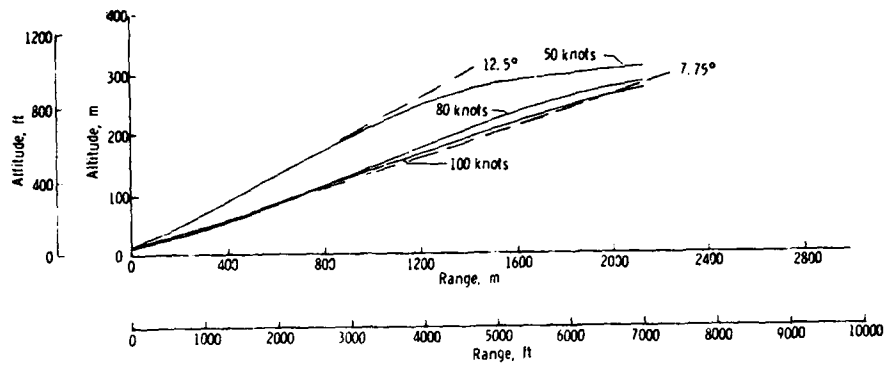
Figure 2-6

Variation of Rate of Descent with Aircraft Speed and Descent Angle or Slope

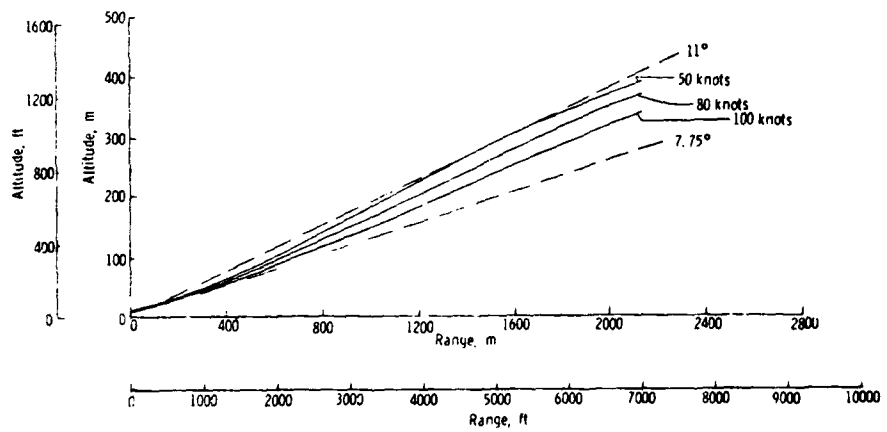
decision height decelerating to hover. National Aeronautics and Space Administration Technical Note (NASA TN) D-8275, "A Parametric Analysis of Visual Approaches for Helicopters" provides excellent insight into the characteristics of normal, visual helicopter approaches. Utilizing four very different helicopters, representative of all but the very heaviest members of the helicopter community, "normal" approaches were flown from three different initial airspeeds--50, 80, 100 knots--and three different initial altitudes--500, 1,000, 1,500 feet. A variety of pilots were used and all were proficient in the helicopters flown. Pilots were instructed to maintain initial altitude and airspeed until they desired to initiate deceleration and/or descent toward the point of intended landing. All were instructed to fly as though there were commercial passengers embarked and, thus, to avoid abrupt maneuvers. The intent of the study was to accurately define parameters of comfortable, desirable approach profiles freely chosen by the subject pilots in order to establish a useful data base for improvement of helicopter instrument approaches. The resulting approach profiles proved to be essentially independent of pilot or aircraft type. Consequently, it is possible to generalize the characteristics of desirable approach profiles. Descent angles ranged from approximately 6° - 12° . The steepest approaches were associated with slowest entry speeds and the two highest entry altitudes. Descent angles became progressively more shallow as entry speed increased. It may be inferred from these data that the optimum descent angles range between 6° and 9° but that angles up to 12° were acceptable. No approaches involved angles significantly steeper nor more shallow than this range. Figures 2-7, 2-8 and 2-9 have been extracted directly from the NASA TN to illustrate the points discussed herein. Figure 2-7 shows altitude profiles averaged for each of the entry conditions evaluated. Figure 2-8 shows the average groundspeed profiles, and Figure 2-9 shows deceleration profiles. Each of these figures plots its parameter of interest versus range for the final 2,800 feet of ground track in the approach.



(a) Initial altitude, 150 m (500 ft).

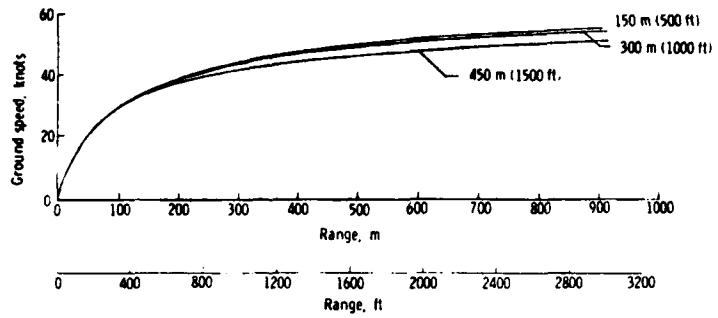


(b) Initial altitude, 300 m (1000 ft).

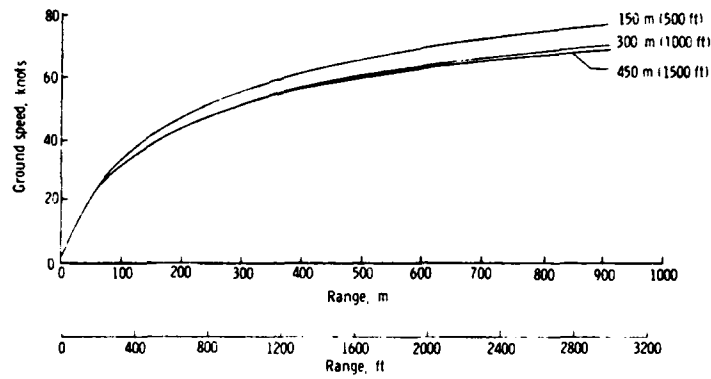


(c) Initial altitude, 450 m (1500 ft).

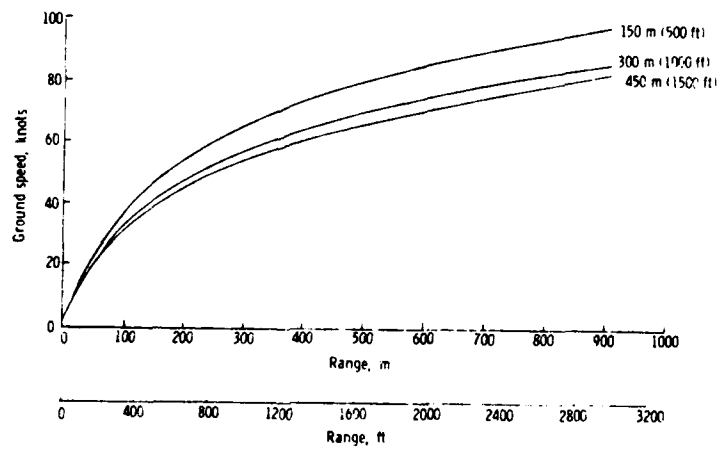
Figure 2-7
Average VFR Altitude Profiles
(Extracted from NASA TN D-8275)



(a) Initial approach airspeed, 50 knots.

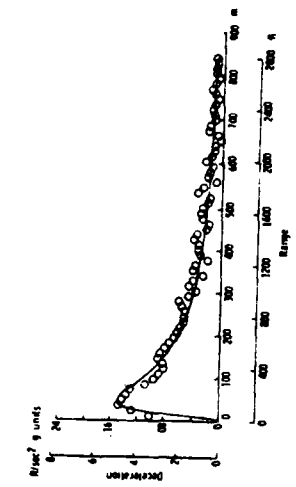


(b) Initial approach airspeed, 80 knots.

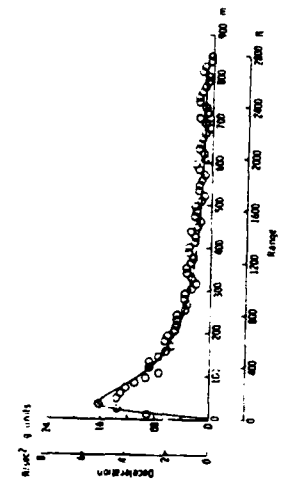


(c) Initial approach airspeed, 100 knots.

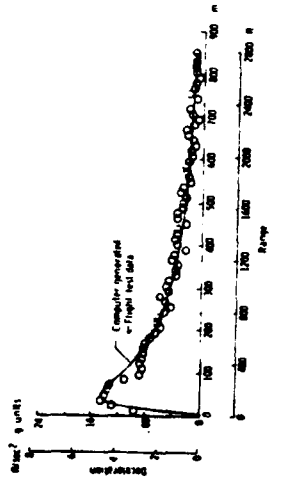
Figure 2-8
Average Ground-Speed Profiles
(Extracted from NASA TN D-8275)



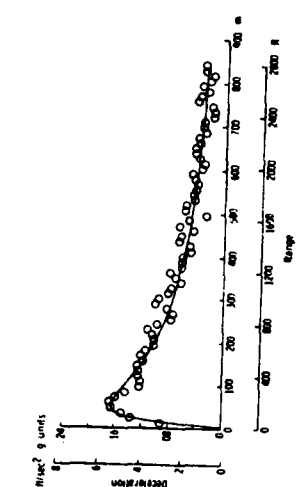
(a) 50 knots, 150 m (500 ft).



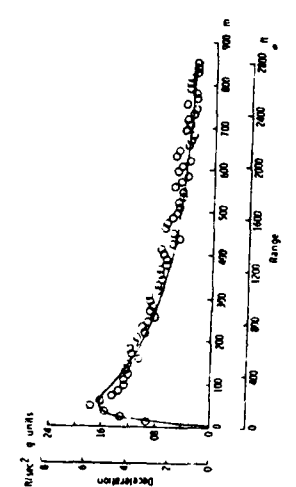
(b) 50 knots, 300 m (1000 ft).



(c) 50 knots, 450 m (1500 ft).



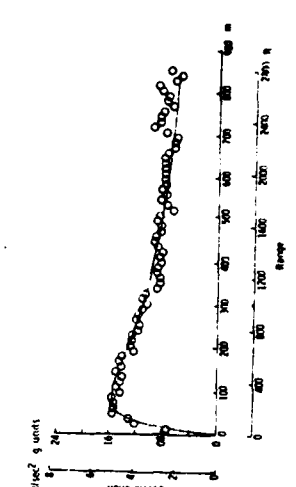
(d) 80 knots, 150 m (500 ft).



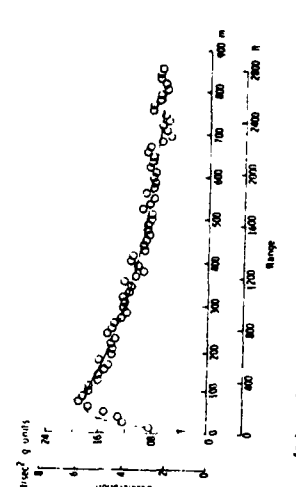
(e) 80 knots, 300 m (1000 ft).



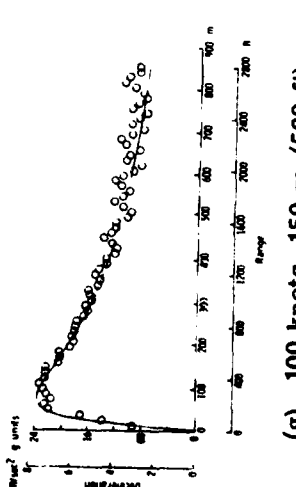
(f) 80 knots, 450 m (1500 ft).



(g) 100 knots, 150 m (500 ft).



(h) 100 knots, 300 m (1000 ft).



(i) 100 knots, 450 m (1500 ft).

Figure 2-9
Computer-Generated Deceleration Profiles for Different Airspeed and Altitude Conditions
(Extracted from NASA TN D-8275)

Advantages Of Steeper Precision Approaches

Two advantages would result from steeper approaches in the 6° - 12° range of descent angles. First, the perspective of the landing site gained at decision height would be normal and comfortable requiring no abrupt transition maneuvers to complete the visual segment of the approach. Second, consider the nature of an isolated heliport. As an example, assume a 200 foot decision height (DH) approach; Figure 2-10 illustrates the corresponding runway visual range (RVR) necessary to see the point of intended landing (hover) upon reaching DH. With an RVR requirement of 1,200 feet, these data imply that descent angles slightly greater than 9° will be required to ensure sighting of the landing point upon reaching DH. With more shallow approach gradients, the landing point may be beyond visual range; and some form of guidance will be needed along the approach path to aid the helicopter pilot during the visual segment of his approach. Positioning of heliports often precludes installation of visual aids along the approach path (e.g. rooftop heliports or offshore platforms). Therefore, approach gradient can be tailored to permit the final approach to deliver the helicopter at DH in a natural position to complete the approach from within the prescribed RVR minimum. Approaches steeper than 12° can be considered, but further investigation is essential to ensure that the visual segment will comfortably connect with the instrument segment of the approach. Of significant concern in approaches steeper than 12° will be cockpit cutoff interference with visual perspective at DH. Approaches more shallow than 6° have a long history of success using ILS. It should be remembered, though, that the ILS approaches have generally provided visual segments with approach lights and runways to lead the helicopter pilot onward to his landing site. Precision approaches slightly steeper than the norm for ILS are now accommodated by helicopter TERPS, which prescribes minimum decision heights of 100' for descent angles (glide slopes) of 3.8° or less, 150' for descent angles between 3.81° and 5.7° and 200' for descent angles greater than 5.7° . A limiting airspeed of 90 knots (maximum) is also imposed. It is the intent of these constraints to permit adequate time upon reaching decision height to initiate deceleration, check the rate of descent and arrive comfortably over the intended point of landing. Before addressing these points further, several parametric relationships concerning approach to hover will be introduced.

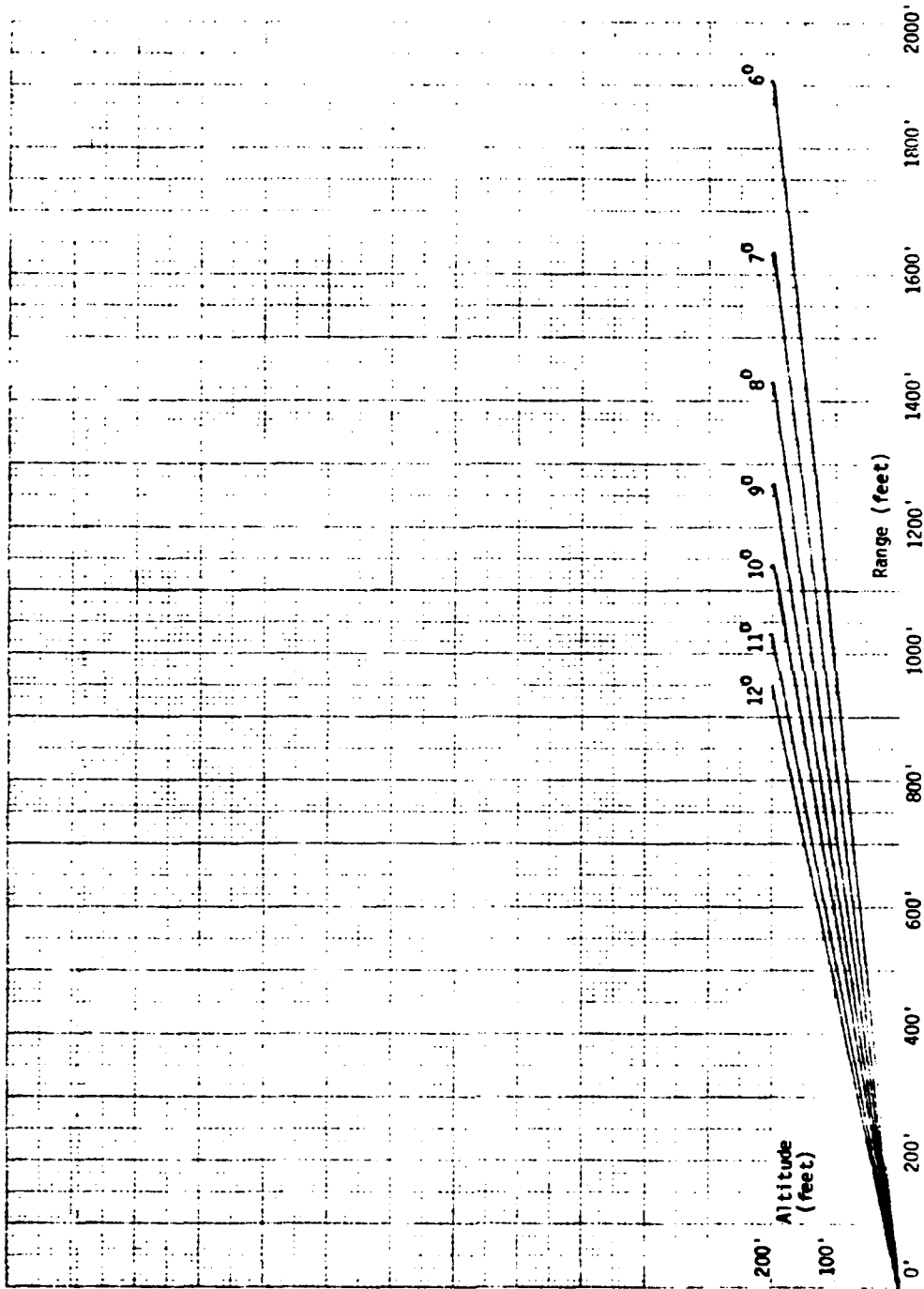


Figure 2-10
Correspondence of Altitude with Range for Various Descent Angles

Parametric Analysis Of Helicopter Approach Performance

Figures 2-11 through 2-15 introduce a series of parametric analyses into aspects of helicopter performance. Input parameters used in these figures are predominantly descent angle and approach speed to define the corresponding values of associated ROD in Figure 2-11, approach time or time to ground impact in Figure 2-12, distance covered in Figure 2-13 and mean deceleration rate in Figure 2-14. Figure 2-15 uses descent angle and peak deceleration rate to define power requirements. These figures are based on very simple computations solely to define the nature of the relationships shown and the order of magnitude which should be expected. The characteristics of no particular helicopter have been used as a basis for these data. Normalized equations were used and appropriate parameters chosen to eliminate the need for displaying such parameters as weight. Figure 2-11 results from simple trigonometric relationships in which approach speed is the speed along the flight path. Figure 2-12 is based on an assumption of a constant deceleration rate which may be more conveniently considered to be the mean deceleration rate. Two output time variables are shown. The left margin depicts approach time between the assumed 200 foot DH and the hover based on the mean deceleration rate necessary to sustain the descent angle. The right hand margin depicts the time between a 200 foot DH and ground impact if DH goes unnoticed and flight is continued without modification of approach speed or descent angle. Figure 2-13 depicts the ground distance between DH and hover for various descent angles which are maintained throughout the visual approach segment. Figure 2-14 identifies the mean deceleration rate necessary to reach a hover along a constant descent angle from 200 foot employing a specific approach speed to DH. Figure 2-15 provides an estimate of the peak power necessary to decelerate to a hover associated with descent angle and the expected deceleration rate. In employing Figure 2-15 an expected deceleration rate 1.5 time greater than the mean determined from Figure 2-14 should be used. This thumb rule is justified by inspection of Figure 2-9, which shows that the maximum deceleration rate occurs just before reading hover and is typically about 1.5 times the mean. Figure 2-15 also required an estimate of

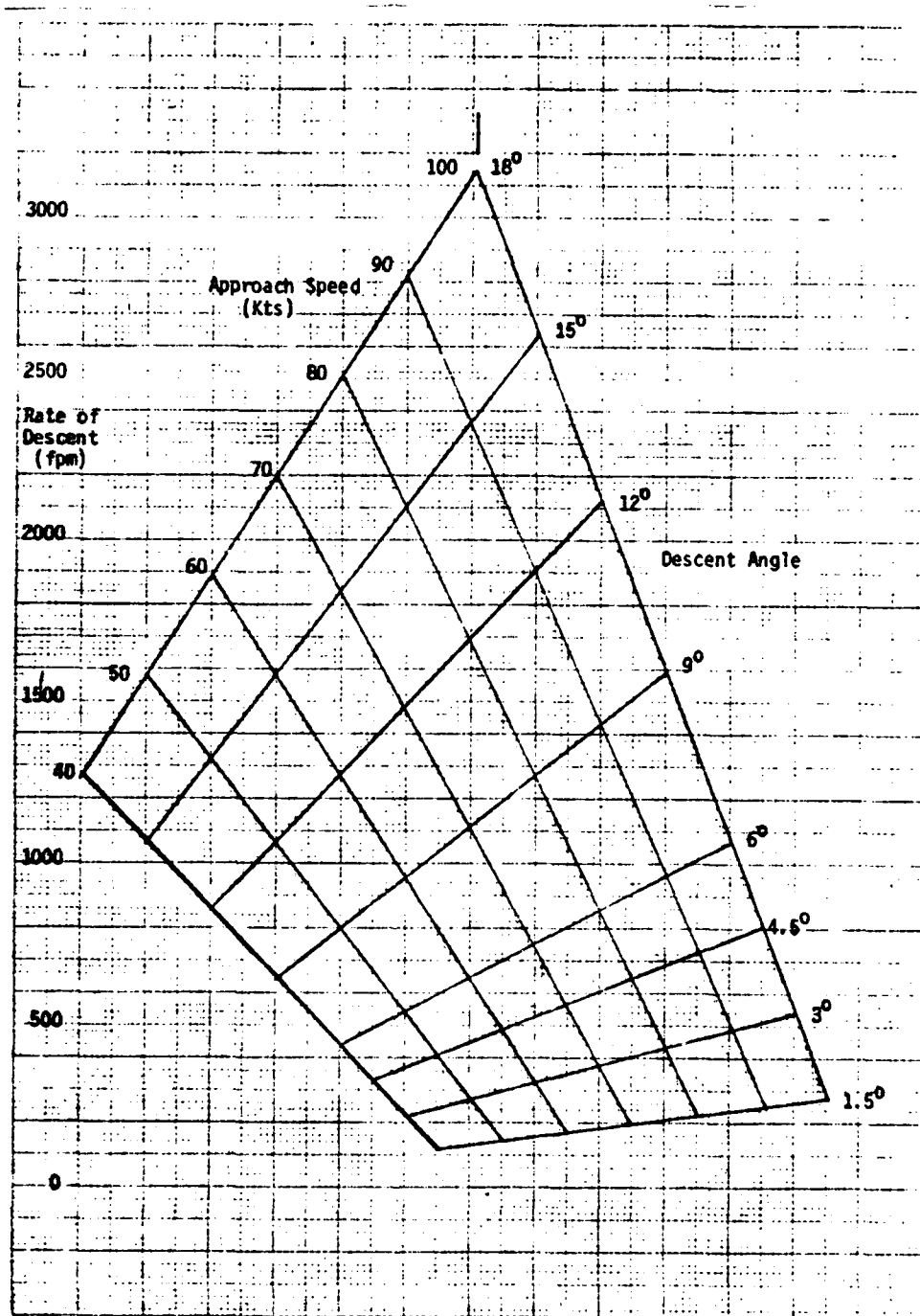
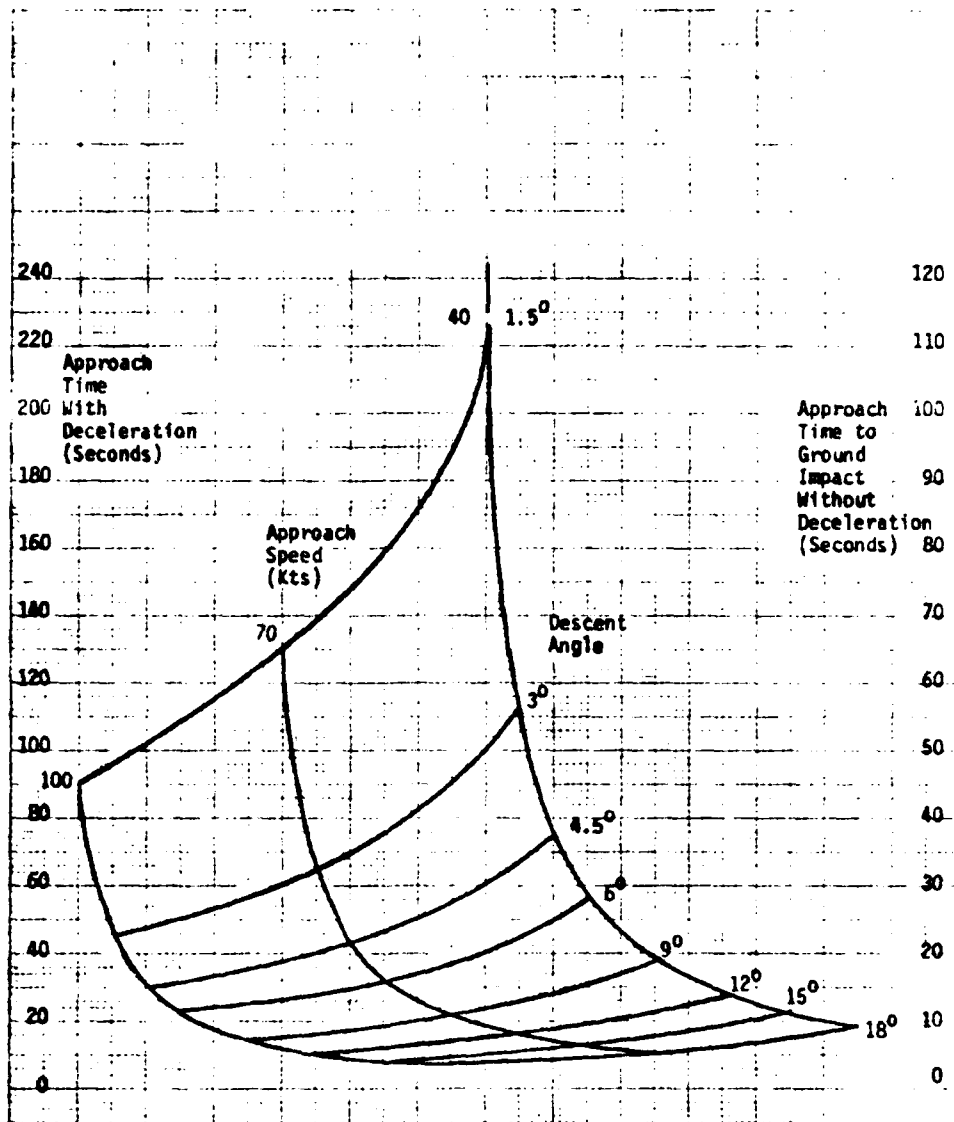


Figure 2-11
 Variation of Rate of Descent with Various
 Approach Speeds and Descent Angles



NOTE: Times are based on a 200' decision height. Approach time (left hand scale) assumes a constant deceleration from the plotted approach speed to a hover, decelerating along the defined descent angle. Time to ground impact assumes that the decision height is unnoticed and descent continues unabated from 200' until ground impact along the defined descent angle.

Figure 2-12

Variation of Approach Time or Impact Time with Descent Angle for Various Approach Speeds or Impact Time

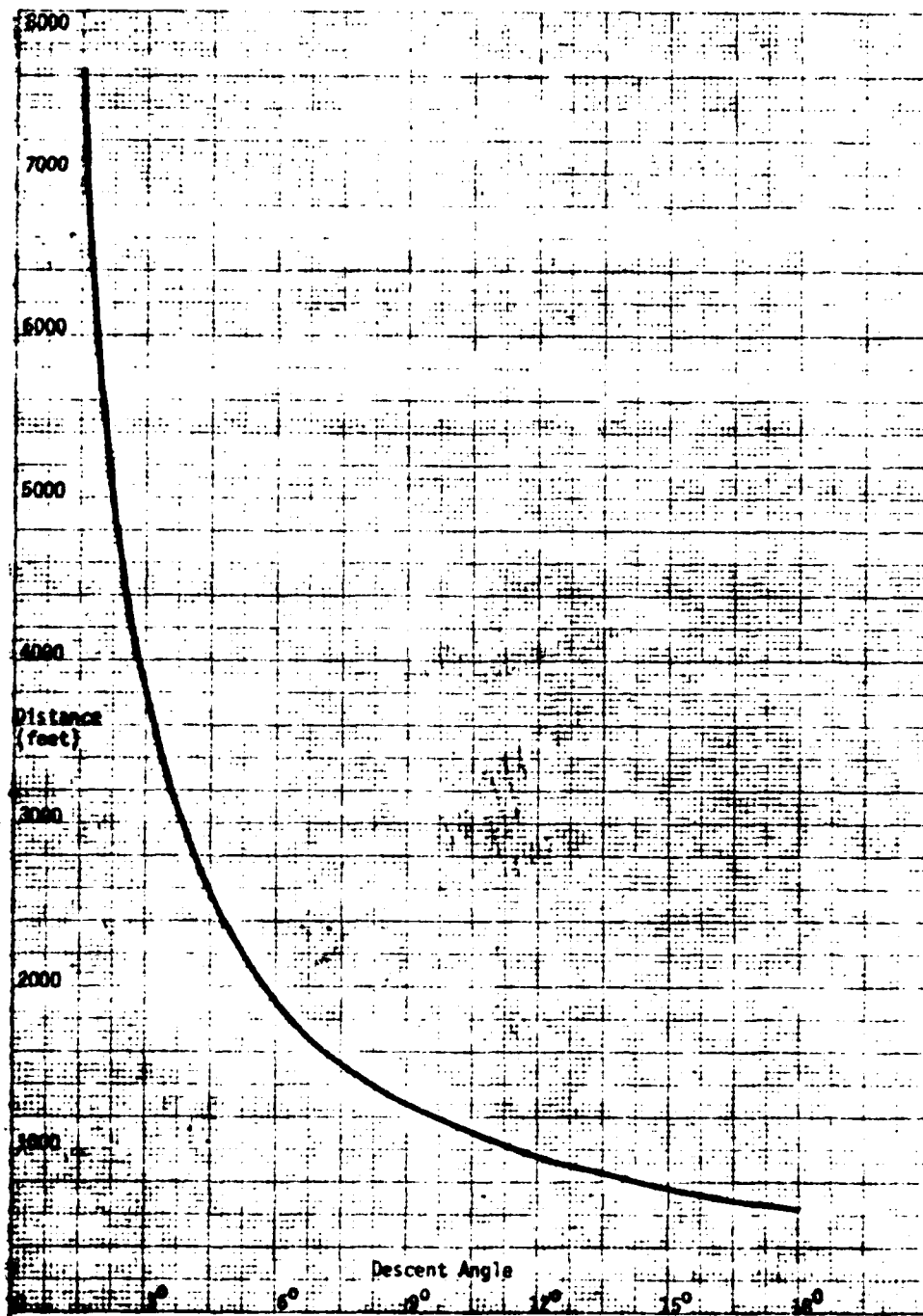


Figure 2-13

Distance Covered in Constant Deceleration Rate Approach
 from 200' at the Prescribed Descent Angle
 (independent of approach speed)

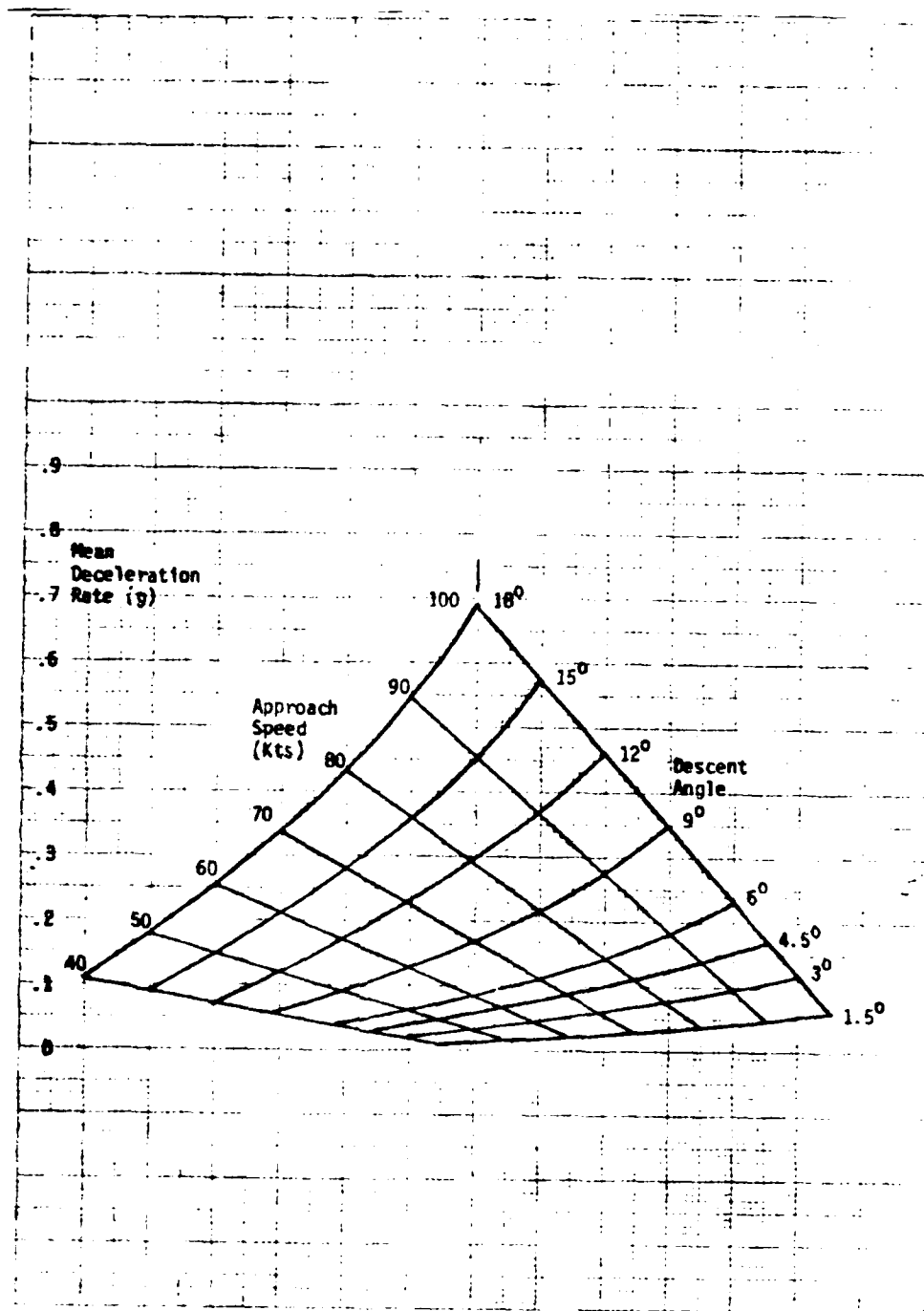


Figure 2-14
 Variation of Required Mean Deceleration Rate with Approach Speed
 and Descent Angle (Employing Constant Deceleration from 200' to Hover)

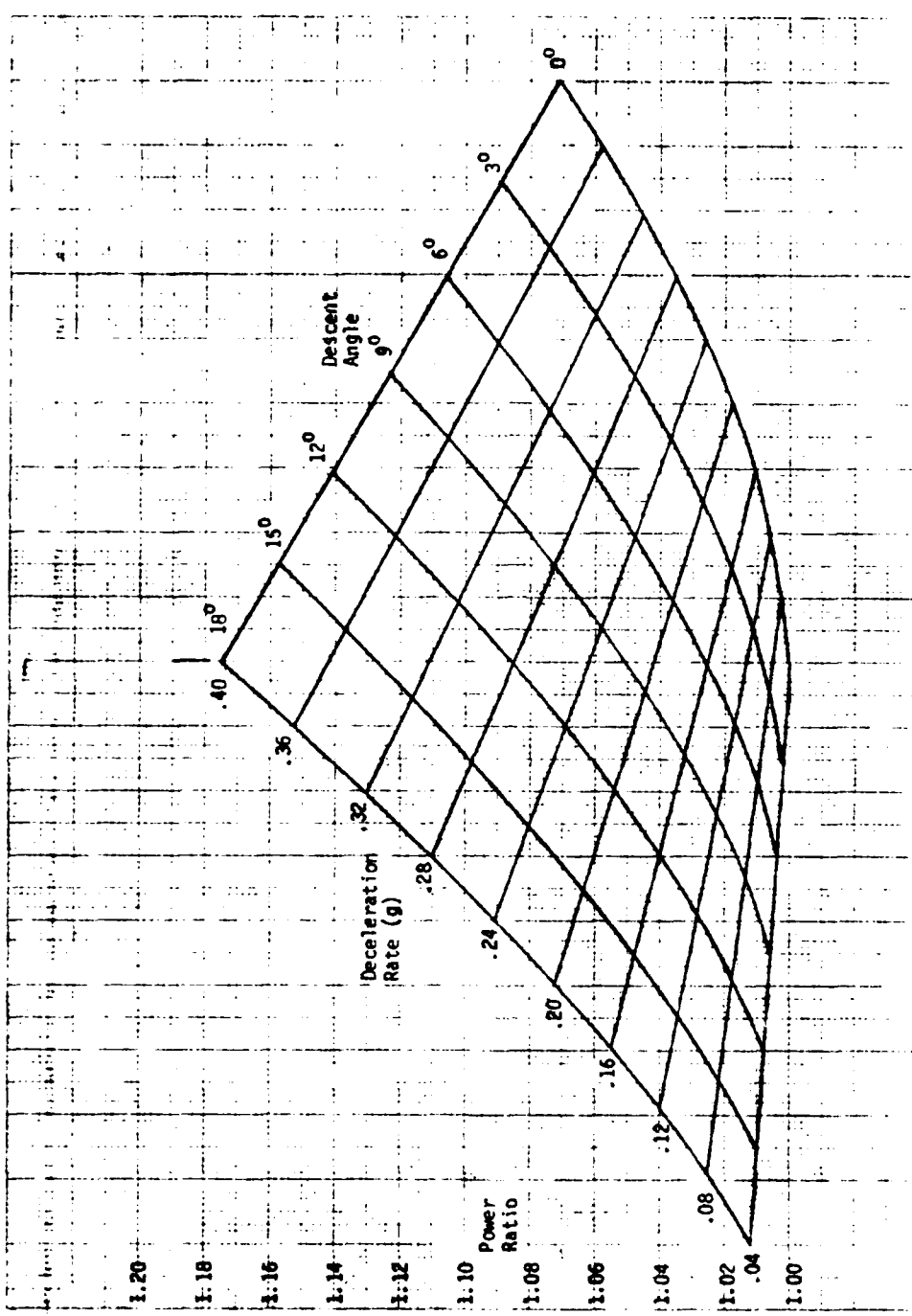


Figure 2-15
 Ratio of Power Required for Deceleration/Power Required to Hover
 for Various Deceleration Rates and Descent Angles

hover performance in its construction. For these purposes a hover-figure-of-merit of .6 has been arbitrarily assumed to ensure that the added power for deceleration is presented in appropriate proportion to the total power needed to hover. Hover-figure-of-merit is the ratio of the theoretical power required to hover to actual power required which considers such factors as friction and accessory losses and tail rotor power. The .6 value is typical of modern helicopters operating near gross weight. A better or higher figure of merit would increase the ratio of needed power for deceleration to hover power and a lesser or worse figure-of-merit would reduce that ratio. The Figures 2-11 through 2-14 assumed constant deceleration or defined a necessary mean deceleration. Figure 2-15 should be entered with a maximum deceleration based on 1.5 times the mean defined by Figure 2-14.

As an example in using these charts, assume that we wish to evaluate a 90° approach angle maintaining 70 knots to DH. Figure 2-11 shows that the associated rate of descent is 1100 feet per minute. Figure 2-12 shows that the visual segment at constant deceleration would take 22 seconds for a 200' decision height. That figure also shows that a failure to react at decision height would result in ground contact 11 seconds after passing through 200'. Figure 2-13 shows that 1280' would be the distance made good over the ground while continuing on the 90° glide slope. Figure 2-14 shows that the mean deceleration rate required would be .17g. To estimate the peak acceleration the mean rate of .17g is multiplied by 1.5 yielding .26g. Figure 2-15 shows that a 90° glide slope with .26g maximum deceleration results in a peak power during the approach 6 1/2% greater than that required to hover.

Recommended Extension To Helicopter TERPS Approach Criteria

Returning to the helicopter TERPS criteria previously introduced, descent angles of 3.8°, 5.7° and 7.6° flown at the 90 knot maximum allowable airspeed for "Copter Only" approaches results in rates of descent of 605, 906 and 1207 fpm respectively. These descent rates and the corres-

ponding decision heights of 100, 150 and 200 feet each define an interval of ten seconds between DH and ground impact if descent should continue unabated. A ten second time interval should be adequate for missed approach initiation even if a two second delay in execution is assumed at DH. Referring again to NASA TN D-8275, analysis of the data presented in Figure 2-7 reveals that all approach profiles flown converged on a flight path which brought the helicopter through a gate about 50-60 feet above the intended point of landing with 35-40 knots of ground speed and a 500 fpm ROD. Each approach profile based on the present TERPS criteria can readily achieve the deceleration required to converge on the visual profiles defined by the NASA tests. It must, of course, be assumed that the modest power margins required are, in fact, available.

For approaches to be flown at descent angles greater than 7.6° , it is recommended that TERPS criteria require a reduction in the maximum approach airspeed to permit use of a 200 foot DH while retaining the ten second time margin inherent in the current criteria for more shallow approaches. As an example of such a steep approach, a 12° glideslope would require 55-60 knots airspeed (Figure 2-12) and not more than .2g (Figure 2-14) mean deceleration. If peak deceleration 1.5 times the mean is assumed, this example would use a maximum of about 9% more power to decelerate (Figure 2-15) than would be needed once hover is achieved. The approach would be completed 20 seconds after reaching DH (Figure 2-12) and would advance 970 feet over the ground from DH to the hover point (Figure 2-13).

Departure/Missed Approach Phase

Departure and missed approach share many of the same considerations. IFR departure, however, first involves acceleration to obtain minimum IFR airspeed; missed approach rarely involves an acceleration requirement. Figure 2-16 displays the time required for level acceleration, and Figure 2-17 displays the corresponding distance required. Power margins required

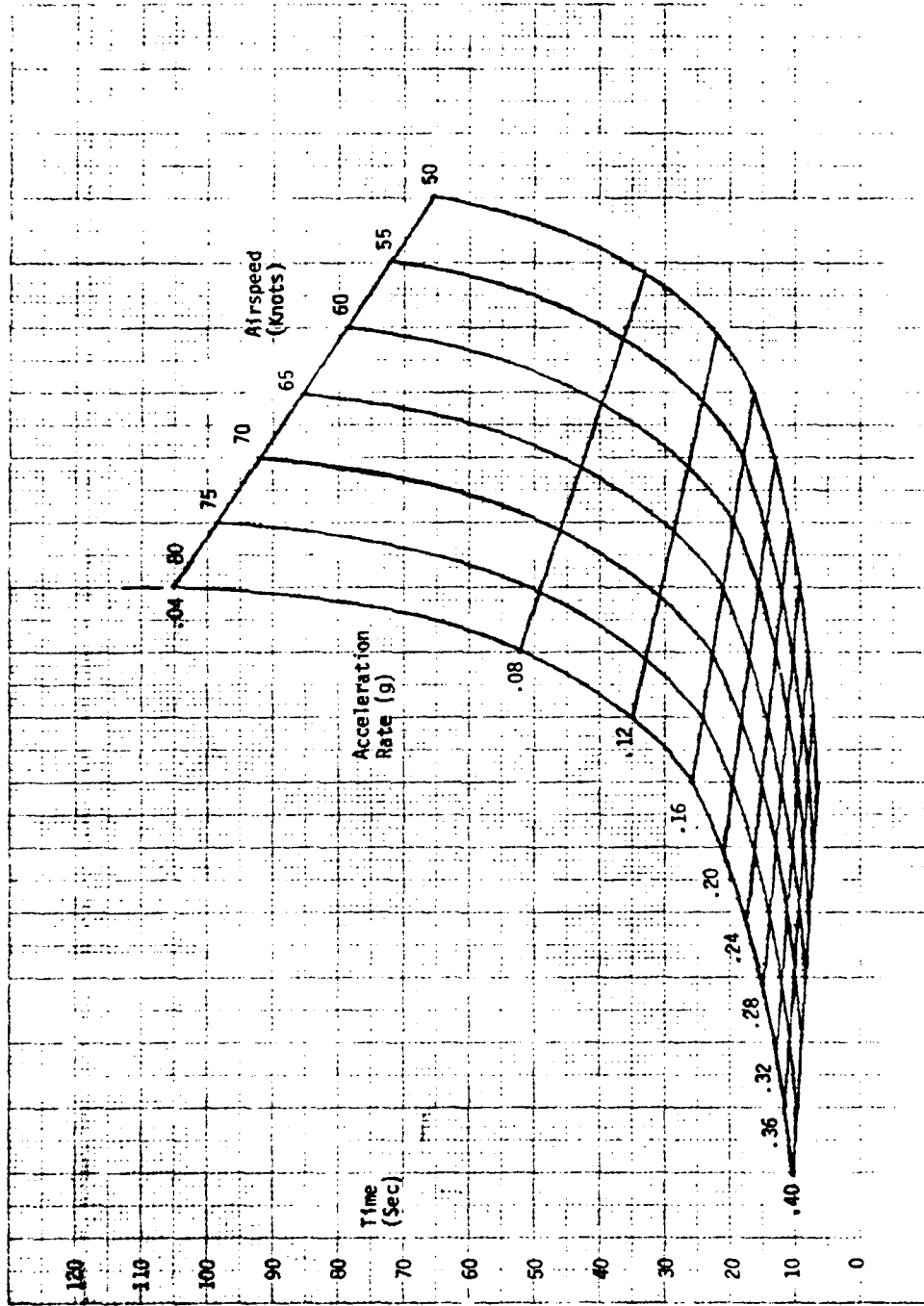


Figure 2-16
 Time Required for Level Acceleration From Zero
 Airspeed to Various Airspeeds at Various Acceleration Rates

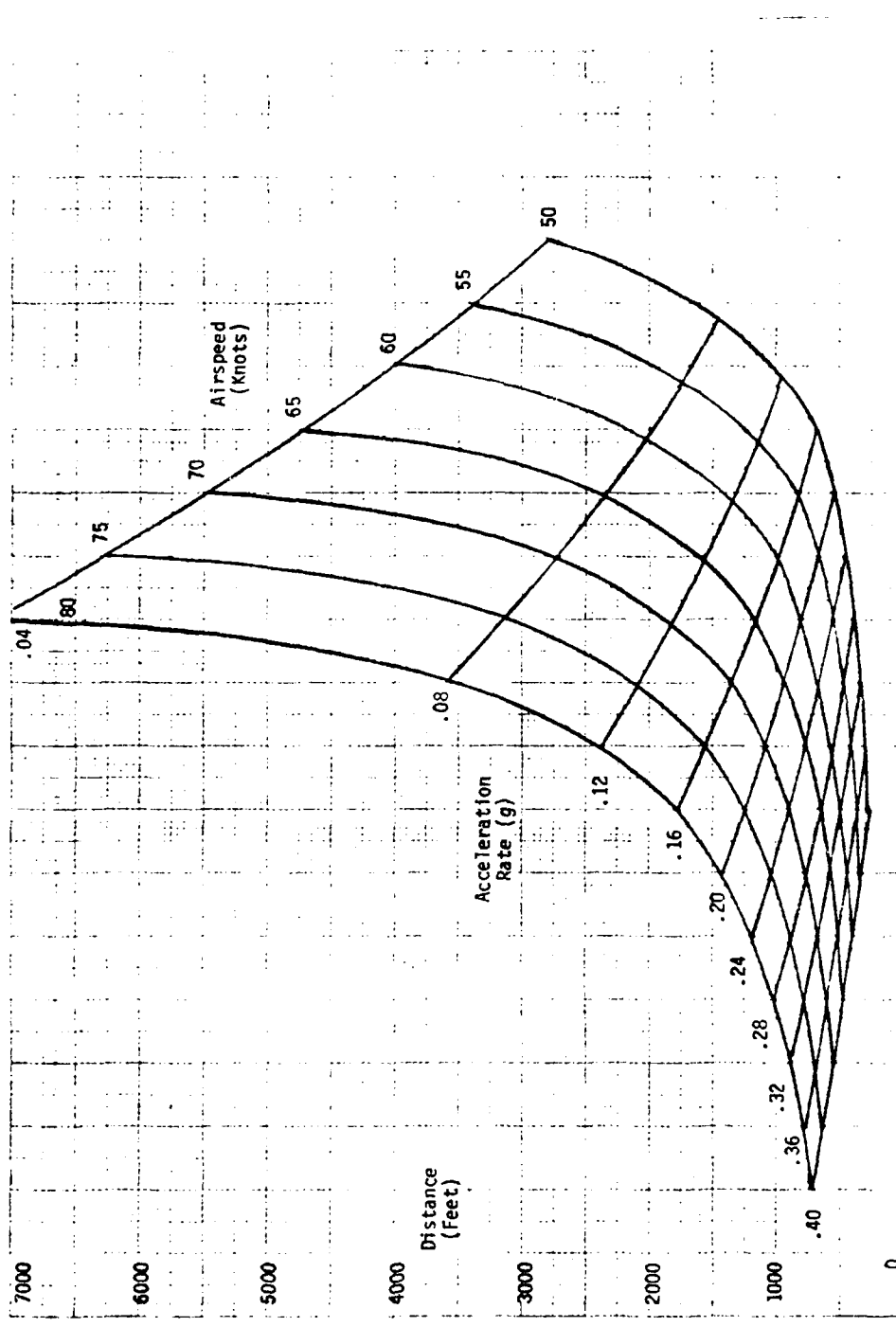


Figure 2-17
 Distance Required for Level Acceleration From Zero Airspeed
 to Various Airspeeds at Various Acceleration Rates

may again be determined from Figure 2-15 using the 0° descent angle since power required to accelerate and decelerate is equivalent. Acceleration from hover may be readily approximated by a simple step increase to a constant acceleration rate; thus, for example .4g acceleration in level flight from hover needs about 7% more power than needed while stationary. Constant acceleration is readily sustainable since power required diminishes as airspeed increases (assuming a no wind hover initially). A .4g acceleration in purely level flight would result in an uncomfortable nose down rotation of approximately 20° . Most flight manuals recommend a more modest rotation of 10° and an accelerating shallow climb until reaching takeoff safety speed (V_{TOSS}) or airspeed for best rate of climb. The level acceleration profile and step acceleration rate input are used to approximate the more sophisticated normal procedure.

Climb for departure differs from climb for missed approach in only one aspect. No discrete considerations are included in helicopter TERPS for climbout on departure. Consequently, helicopters are governed by normal airplane requirements even though leaving a heliport, and a 40:1 criterion applies in defining the climb surface. Rates of climb corresponding to this requirement are shown with corresponding ground speeds in Figure 2-4. On the other hand, a "Copter Only" missed approach may use a climb surface with a 20:1 gradient. Rates of climb corresponding to this requirement are shown with corresponding ground speeds in Figure 2-3. Data contained in Appendix A show that the maximum rate of climb for helicopters is obtained at airspeeds ranging from 50 to 80 knots (calibrated airspeed). Rates of climb are shown in Appendix A for each of the IFR helicopters summarized therein with the corresponding recommended climb airspeed. Climb performance data are shown for maximum continuous power; therefore, more power would be available to initiate a missed approach or to accelerate after takeoff. Inasmuch as climb performance is very sensitive to changes in altitude, gross weight and temperature, carpet plots of these variations are also provided in Appendix A based on maximum continuous power and best rate of climb airspeed. These plots clearly show that some combinations of performance parameters preclude sufficient rates-of-climb to sustain the

missed approach or departure gradients. Generalizations based on climb performance alone do not define a useful performance envelope analogous to the limitations in rate-of-descent definable by autorotation characteristics. There is, however, a consistent relationship between hover performance and climbing performance. To illustrate this relationship, hover performance boundaries have been plotted across the carpet plots contained in the summaries of Appendix A. These boundaries are plotted for both HOGE and HIGE conditions (where data are published for both) and define hover performance limits based on combinations of the same three parameters which impact climb performance. Consequently, superposition of the hover boundaries on the carpet plots of climb performance permits instant comparison of climb capability with hover capability. It can be seen through evaluation of the performance summaries that HOGE capability ensures sufficient power to climb compatibly with a 20:1 gradient for those aircraft capable of IFR operation at the airspeed for best rate of climb. HIGE capability does not provide the same assurance, but does demonstrate compatibility with a 40:1 gradient with the same restriction. These comments, of course, assume no wind conditions as the worst case. Too much tail wind can, in all cases, degrade climbout gradient unacceptably. These characteristics imply that flight planning which ensures HOGE capability at all enroute stops will concurrently ensure adequate climb capability to execute IFR missed approach at each stop. However, this insurance may not apply if airspeeds significantly higher than speed for best rate of climb are utilized. Figure 2-3 shows that rate of climb requirements to maintain the 20:1 gradient increase rapidly with increasing airspeed. The required increase is 5 feet per minute per knot of groundspeed. Since the surplus of power which may be applied to climbing flight is reduced when airspeed is increased, as well, it becomes doubly important for helicopter pilots to maintain an appropriate climb speed during "Copter Only" missed approach procedures. Flight planning to ensure HIGE will also ensure sufficient climb capability to satisfy 40:1 departure climb gradients, but acceleration to minimum IFR airspeed or best rate of climb airspeed will require a reasonable horizontal distance if takeoff is conducted near the hovering performance limit.

A better angle of climb may be attained by climbing at an airspeed lower than that required for best rate of climb. Unfortunately, no simple rule of thumb defines the airspeed for best angle of climb or the angle which would result therefrom. Simplistically, whenever there is more power than needed for HOGE, vertical climb is possible. But, climb at the minimum airspeed useable for IFR climb does not assure the best IFR climb angle. It does assure, however, a better climb angle than attainable at best rate of climb airspeed. On the other hand, when HOGE cannot be attained, climb at the minimum airspeed useable for IFR climb may result in a lesser climb angle than obtainable from use of the best rate of climb airspeed. Consequently, climb angle performance is not predictable even in a qualitative sense, except when using airspeeds for which data is published in the applicable flight manuals.

To illustrate the preceding discussion, Figure 2-18 provides examples of three different levels of power for the same helicopter. The rate of climb curve is typical in shape, a reflection of power required. In Figure 2-18(a) the positive rate of climb at zero airspeed indicates more power available than needed to hover out of ground effect. The point "A" represents the rate of climb at best rate of climb airspeed, and the point C represents the rate of climb at minimum IFR speed. The angles AOD and COD are proportional to (not exactly) the respective climb angles. In this example, the best angle of climb for approved airspeeds is attainable at the minimum IFR speed. In Figures 2-18(b) and (c) the rate of descent shown at zero airspeed indicates that HOGE is not attainable. The points "A" and "C" retain their previous connotations and the points "B" represent the rate of climb and airspeed for best angle of climb. In both figures, angle BOD is greater than either AOD or COD. Note that in Figure 2-18(b), angle COD is greater than AOD indicating that the minimum IFR speed provides a greater angle of climb than the best rate of climb speed. However, in Figure 2-18(c), the situation is reversed. The resultant differences in performance capability are not identifiable by simple rule-of-thumb. Published flight data are needed to reliably predict climb performance.

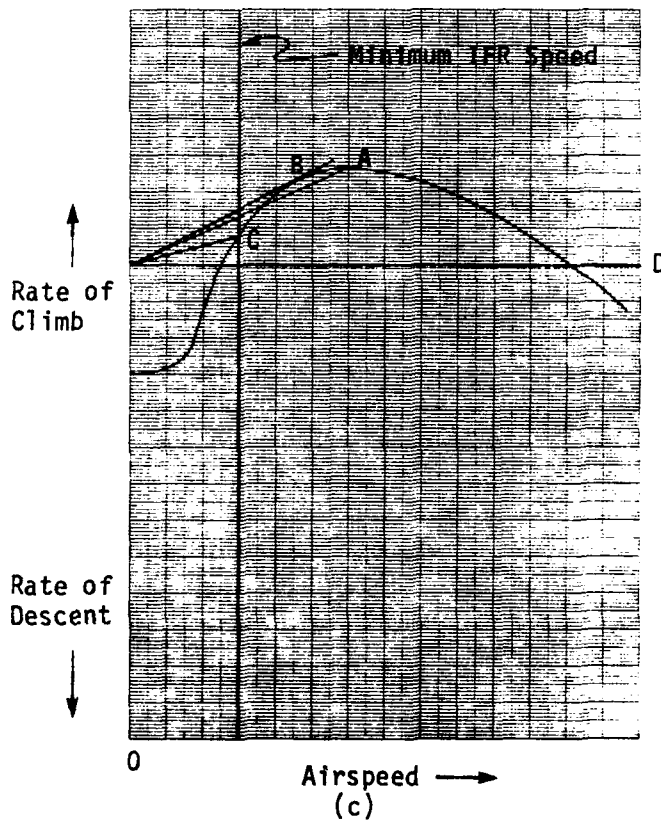
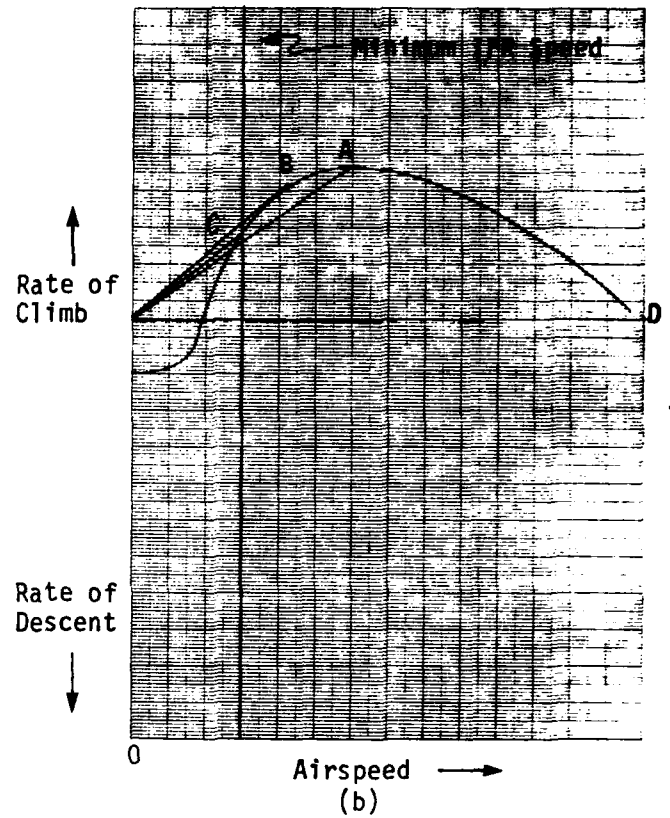
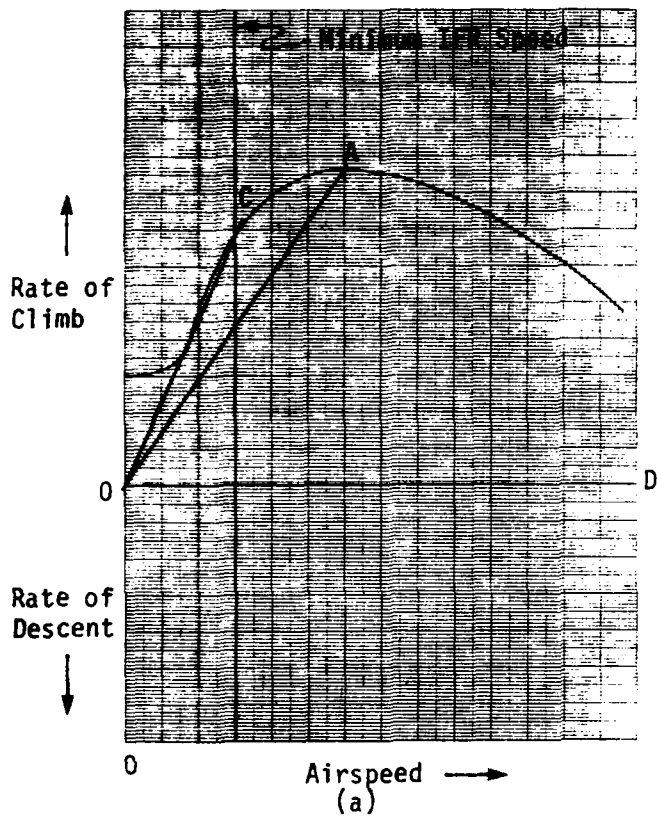


Figure 2-18. Variation of Rate of Climb with Airspeed
(Undimensioned typical curves)

SUMMARY OF HELICOPTER PERFORMANCE

Data extracted from the flight manuals of a broad spectrum of IFR helicopters are contained in Appendix A. These data reveal the general character of the performance of IFR capable helicopters showing that all are limited by current certification requirements to minimum IFR airspeeds (40-60 knots) only slightly below the minimum power speeds which are associated with the best rate of climb (ROC) and minimum ROD during autorotation. From a practical point of view, autorotation may be found to limit the descent capability of modern, IFR helicopters, as a class, to ROD approximately 1000 fpm near the minimum IFR airspeeds and to ROD generating descent angles of 8° or less as V_{ne} is approached. ROC varies so significantly with altitude, gross weight, and air temperature that all helicopters studied fail to be able to sustain positive ROC for some combinations of these parameters. However, combinations of these three parameters which assure HOGE capability were found also to ensure a sufficient ROC to satisfy TERPS missed approach climb gradient requirements (20:1) for "Copter Only" approach procedures provided the airspeed for best ROC is employed.

Within the scope of current certification requirements it was found that there are advantages to "Copter Only" approaches employing descent angles up to 12° in terms of improved compatibility with the approach profiles normally employed under VMC. Such steep approaches also move the intercept of DH and the approach path to a point which can be within RVR minimums. This last characteristic will benefit heliports so located that approach lighting placement would be impractical. It was found that airspeed should be reduced below the current "Copter Only" maximum of 90 knots when the glideslope becomes steeper than 7.6° .

SECTION 3

FUTURE DEVELOPMENTS

INTRODUCTION

This section attempts to forecast future development in helicopter procedures for TERPS. In attempting to define the nature of future changes, the concerns of a wide spectrum of the helicopter operating industry have been reviewed. It was found that industry appears to focus its interest on three basic changes: that block time be minimized, that terminal minimums be reduced to the lowest possible values, and that navigation and approach aids should ideally be as self contained as possible. (This latter issue is beyond the scope of the present discussion.) Of the first two issues, the greatest interest was shown in reduced minimums, reflecting a desire for increased mission dependability. Interest was shown in reduction of both ceiling minimums and visibility minimums. Consequently, two aspects of performance attain especial significance, steeper approaches to more readily ensure obstacle clearance and lower airspeed to sustain or reduce ceiling and visibility requirements in conjunction with steeper approach paths.

The potential changes of interest center on exploitation of the low speed flight regime of helicopters in which instrument flight is pursued on the "back side of the power curve", i.e., speeds below the speed for minimum power and mostly below the current "minimum IFR airspeed". For purposes of discussion in this section, this flight regime will be referred to as "slow flight".

This slow flight regime, which includes the ability to hover downwind or crosswind, is the aspect of flight which distinguishes helicopters from airplanes. To be sure, airplanes do fly on the back side of their power curves but, under normal circumstances, only briefly during acceleration on takeoff or the final stages of landing. Helicopters have

operated VMC in this flight regime to great advantage enabling landing and departure at confined sites, utilization as an airborne crane, or very slow patrolling operations. An almost infinite variety of similar tasks can be predicated on the demonstrated ability of helicopters to land and takeoff vertically, hover for prolonged periods at a point in space, or fly in precisely controlled but very low speed motion. Most such operations seem inconsistent with instrument meteorological conditions except for takeoff and landing. The whole objective of the NAS is to foster safe movement of aircraft in IMC. It seems only logical, then, to pursue every reasonable opportunity to extend that capability to exploit rather than inhibit these unique characteristics of helicopters by opening the slow flight regime more fully to terminal operations in the NAS, thus fostering the helicopter operators quest for greater mission dependability.

HANDLING QUALITIES IN SLOW FLIGHT

Each civil helicopter, for which performance is summarized in Appendix A, has imposed upon it a minimum IFR airspeed. Below these speeds the aircraft are not certificated for instrument flight, yet they must routinely operate under VMC in that slower flight regime and do so quite successfully. Several factors influence these certification limits, most of which are not made manifest in either the type certificate or the flight manual. Handling qualities in slow flight are judged to be unsatisfactory. Why? They are judged to be unsatisfactory in relationship to the cues available for instrument flight. This permits postulation of two attacks on the problem--improve the handling qualities or improve the cues. Probably a combination of these two approaches is most reasonable.

Instrumentation and Cues

The most significant cues lost in IFR flight at slow speed are those which relate a sense of motion to the pilot. In VMC, visual cues are provided by various aspects of the scene including peripheral vision. The typically expansive window areas of helicopters permit instant perception

of changes in velocity laterally, vertically and longitudinally. These cues are developed by movement relative to objects; thus they are ground-speed related. In IMC they can be generated by doppler radar systems or by synthesis from precision positioning information such as MLS with distance measuring equipment (DME). Mere readout of rate is helpful, but does not synthesize the tertiary aspect of the background relative motion sensed through peripheral vision. Slow speed three axis rate information has been displayed to military pilots in ASW missions for many years, but manual control with this limited degree of cue augmentation has proven to be very difficult. A form of display analogous to the peripheral visual scene would enhance utilization of rate cues and reduce workload.

Slow Flight Performance

Helicopter performance characteristics are determined by airspeed, not groundspeed. A fundamental problem in helicopter slow flight is airspeed measurement. Certification standards for both transport and utility helicopters are carefully worded to permit use of conventional pitot-static systems by helicopters for measurement of airspeed. This was a pragmatic choice, when the standards were established, inasmuch as no alternative airspeed indicating systems were available. Nevertheless, the consequence has been, and remains so with such systems, that helicopters do not have a reliable indication of airspeed in slow flight. This is true when the helicopter is moving directly into the wind with the pitot tube aligned with the relative motion; the problem becomes more pronounced when lateral components of relative motion are introduced. There is no provision for measuring the direction of relative motion with conventional pitot-static tube airspeed indicating systems, only the magnitude of the velocity and that imperfectly at low speeds or with sideslip. Current requirements specify measurement of airspeeds ranging upward from about 30 knots (for Part 29 multi-engine helicopters) or 80% of climbout speed (for Part 27 and single engine Part 29 helicopters). Consequently, helicopter pilots have never enjoyed a truly valid basis for assessing aircraft performance in slow flight, since they have used mostly groundspeed rather than air-speed cues.

These airspeed instrumentation considerations affect the significance of handling characteristics. For example, trim may vary through the slow flight regime in such a manner that the same combinations of attitude and cyclic stick position apply to trimmed flight at more than one airspeed. Such characteristics are clearly unsatisfactory when no airspeed measurement is available to provide a basis for correlating expected aircraft response to control inputs. However, if airspeed were reliably (i.e., promptly and repeatably) displayed in vector form (either direction and magnitude or orthogonal components), these adverse trim characteristics would become far less significant. With such instrumentation, it would become more important to consider any discontinuities in control position or force gradients than merely their sense and magnitude. Flight demonstration with adequate airspeed measurement is needed to establish handling quality criteria appropriate to IMC operation more fully into the slow flight regime.

Control Augmentation

Handling qualities may be directly improved for slow flight although this is not a simple task. The significant trim changes which occur in the slow flight regime result from the transition of rotor wash from a vertical flow to a nearly horizontal flow and the related development of two vortices along the wake in translational flight. The significant changes in flow move across the aircraft body and interact with various parts of it to produce pitching and yawing moments which build and fade throughout the transition. Thus, trim characteristics are innately variable in the slow flight regime. Augmented flight control systems could be devised to isolate the pilot from these variations and produce trim force and position gradients acceptable under the present standards. Alternatively (or additionally) approaches could be directly coupled to remove the pilot from the control input loop during the slow flight phase of approach. However, programming a control system to perform either of these functions on a repeatable basis requires a performance measurement system that accurately senses the total nature of the flight condition, namely a low airspeed direction and velocity measurement system as just discussed.

Army Experience

The U.S. Army at Fort Monmouth has conducted tests of decelerating instrument approaches using a four cue flight director system. Success has been claimed for the system in both manual and coupled precision decelerating approaches to hovering flight for glideslopes ranging between 3° and 12° . The approach aid is a military MLS system with precision DME which provides localizer, glideslope, range and range rate to the aircraft for processing by the flight director computer. Test results were summarized before the American Helicopter Society (AHS) at the 35th Annual National Forum in May 1979 in a paper entitled, "Advances in Decelerating Steep Approach and Landing for Helicopter Instrument Approaches". All approaches reported upon were based on use of a constant initial approach speed of 60 knots (range rate along glide-path) and deceleration rate of 0.05g. Consequently, the slant range for the deceleration phase of each approach was 3125 feet and the elapsed time 62.5 seconds for all glideslope angles. The resulting height above touchdown for initiation of the deceleration phase varies as the sine of the glide slope from 164 feet for 3° to 650 feet for 12° . Initial airspeed was unreported, but necessarily varied as a function of wind velocity to establish the 60 knot initial range rate.

The aircraft utilized was an unspecified single engine version of the UH-1 series which would closely approximate the flying characteristics of the Bell Model 212 reported on in Appendix A. This implies that the reporting agency, the U.S. Army Avionics R&D Activity (AURADA) was satisfied with the man/machine performance that resulted from use of the pilot cues presented by the four cue flight director in the slow flight regime below the 40 knot minimum IFR airspeed which applies to the Bell 212. The cues utilized provided commands in pitch, roll and collective throughout the approach profile and yaw below 45 knots airspeed.

APPROACH PROFILES IN SLOW FLIGHT

If the issues involving certification criteria for slow flight are resolved, decelerating approaches in IMC to much lower minimums than now utilized will become practical considerations. Two questions remain, the first of which is not germane to this discussion. First, the quality of the supporting navigation system must permit positioning of the aircraft in three dimensions to the accuracy required for safe operations at each site. (Heliports may be as small as 1.5 rotor diameters for the largest helicopter to be operated.) Second, approach profiles must be defined which are within the safe performance capabilities of the aircraft.

Height-Speed Envelope Considerations

Performance capabilities germane to questions of slow flight are summed up for each helicopter in its limiting height-speed (H-V) envelope. A set of composite height-speed envelopes for the helicopters summarized in Appendix A is shown as Figures 3-1 for single engine helicopters and 3-2 for multi-engine helicopters. It can be seen from these figures that the present performance of multi-engine helicopters permits slightly higher safe hover height and significantly reduced airspeed. The low altitude, high speed portions of the two composite H-V envelopes are essentially equivalent. Limiting H-V performance is the source of some consternation for slow speed IMC operations. Prudence would seem to require that an IMC approach to a hover should require a somewhat greater hover height than a normal, VMC approach. For example, the U.S. Navy uses a hover height of 40 feet (over water) for its IMC operations in the antisubmarine warfare (ASW) mission. Yet, the H-V diagrams imply that a limit of 10-15 feet would predominate among current helicopters. Furthermore, the decelerating approach path would encroach, at least marginally, on the "avoid" regimes in reaching a hover at such heights. Wind considerations have not been central to any of the earlier discussion; they now become especially significant. Notice that Figures 3-1 and 3-2 are based on calibrated airspeed. A headwind, in effect, blows the leading edge of the "avoid" area away. Conversely, a tail wind would have the undesirable opposite

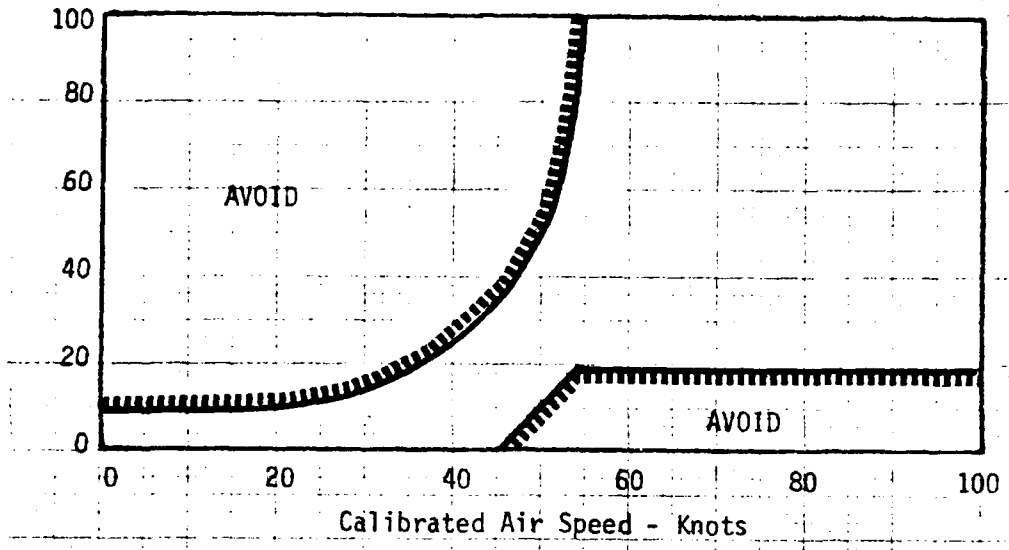


Figure 3-1
 Composite Height-Speed Diagram
 for Single Engine IFR Certificated Helicopters
 (Permits Safe Autorotational Landing)

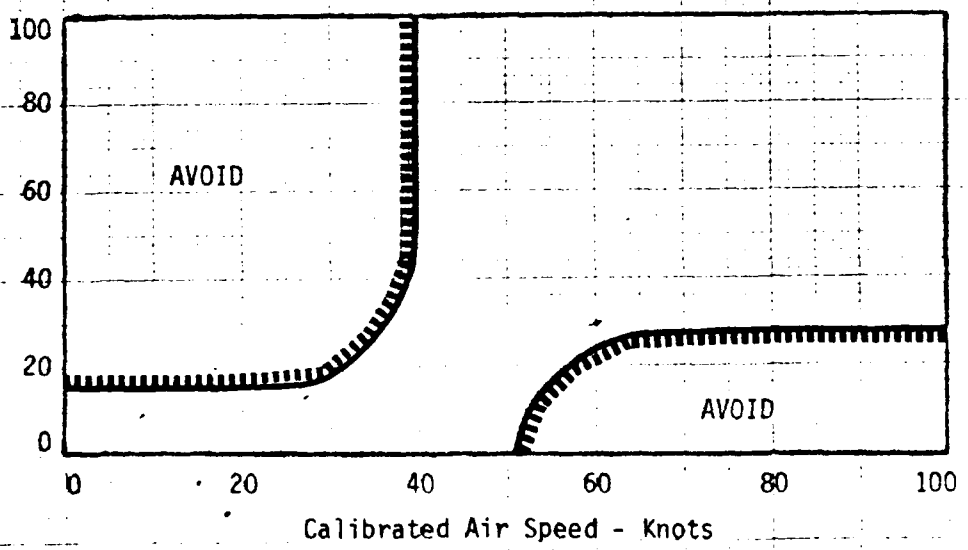


Figure 3-2
 Composite Height-Speed Diagram
 for Multi Engine IFR Certificated Helicopters
 (Permits Safe Landing After Failure of One Engine)

effect. It is, then very important that decelerating approaches be made into the wind to avoid the potentially hazardous flight regime. ("Potentially" is used advisely inasmuch as the H-V diagrams identify areas hazardous only if the one engine of single engine helicopters or the most critical engine of multi-engine helicopters should fail.)

Approach Corridor Considerations

Evaluation of both height-speed figures would indicate an altitude of 40' at 60 knots to be nearly optimum as a gate to decelerate through the safe corridor. Assuming the terminal hover to be at 10', the maximum deceleration to be .4g (therefore mean of about .25g), a straight line approach uses about 12 seconds, 600' of horizontal distance and results in a descent angle of 3°. Such an approach is considerably more shallow than the "normal" approaches defined by the NASA TN and involves, in this example, much higher deceleration. Employing a peak deceleration of .24g (mean .16g) typical of the highest speed, lowest altitude entry and resulting in the highest deceleration profile recorded in the NASA tests, extends the deceleration time to 20 seconds, distance to 1000' and reduces the descent angle to 1.7°. It is easy to infer from these analyses that the NASA pilots routinely flew through the lower right hand corner of the H-V diagram low speed avoid areas in making normal approaches unless one assumes sufficient wind. Wind velocity was not recorded in the NASA data; but, judging by the groundspeed profiles, probably did not exceed 10 knots. Ten knots of wind would increase the descent angles of the two example approach terminal phases to 4° and 2.5° respectively. (Data presented in the NASA TN do show some reduction in descent angle in the terminal phases of approach, but the published data are not presented with sufficient precision to precisely identify the relationship of flight profile to H-V limitations. See Figure 2-7.) The very much slower decelerating approaches (simulated IMC) employed in the Ft. Monmouth tests also must have involved flight within the low speed avoid region of the H-S envelope when employing glide slope above 3°. It appears from these reported

tests and from analysis of the necessary performance characteristics that it is neither practical nor desirable to consider the H-V envelope as an aircraft limitation during landing approach.

Very Steep, Constant Speed Approaches

The future portends a requirement to support not only helicopters, but also advanced V/STOL aircraft which will have their own particular performance limitations. It has been characteristic of high disc loading V/STOL aircraft to date that vertical landing is usually initiated from a high hover, out of ground effect and typically of the order of 100 feet above the point of landing. Takeoff usually involves a rapid, primarily vertical ascent to a similar altitude before initiating transition into forward flight. Two factors have generated the need for those profiles, neither of which has any obvious solution that may permit future V/STOL aircraft to emulate current helicopters in landing and takeoff maneuvers. These characteristics are an adverse or negative ground effect sometimes referred to as "suck down" and a propensity to recirculate the hot exhaust gases into the engine intakes during flight in ground effect. The hot gas recirculation can have an adverse effect on power available in a power critical flight regime. Safety considerations are stimulating military requirements to ensure sufficient power redundancy to permit safe landing following engine failure within this high, slow flight regime.

Helicopters could equally well use similar arrival and departure profiles, and to some advantage. Of course, similar considerations for safety in the event of helicopter power failure would also be required. Some multi-engine helicopters can now effectively demonstrate such redundancy under certain loads. The distinct advantages of a high hover with steep approach cone arrival and departure profiles results from the opportunity to always orient the slow speed flight directly into the wind. This minimizes power required in the hover phase, ensuring a greater margin of

safety. Direction and magnitude of the airspeed vector are wanted cockpit information for proper management of the flight profile. Helicopter pilots will want it for determination of power margin. Pilots in jet V/STOL aircraft will want it to avoid a hazardous limitation resulting from slip-roll coupling.

We will briefly examine helicopter implications of such procedures. Needed are H-V characteristics which essentially eliminate the high altitude, low airspeed avoid areas shown in Figure 3-2. Inasmuch as orientation can be maintained into the wind throughout the deceleration into a high hover, and orientation on the steep approach cone can be varied to ensure heading into the wind, a small avoid area of ten knots or less may be practical. Figure 3-3 illustrates the impact of steep descent angles and selected ROD upon the closing groundspeed. This procedure, at the higher rates of descent depicted, approaches a flight regime known as the "area of roughness" (approximated in Figure 2-2) associated with a flight phenomenon called "vortex ring state". A related phenomenon known as "settling with power" may also be involved. Therefore, the utility of the highest rates of descent is suspect and warrants thorough test on a case by case basis. Nevertheless, lower rates of descent of the order of 10 feet per second and less are of especial interest because the potentially hazardous flight regime is avoided and descent may be maintained within the design sink rate of the helicopter landing gear. IMC departures from a site of limited size may be made by using controlled climb rates to ensure emergency capability following engine failure during a similarly steep landing approach. Consequently, no portion of the flight regime, during departure, will need to expose the aircraft and occupants to hazards that may now be experienced as helicopters gain takeoff safety speed (V_{TOSS}) by translational acceleration away from the point of takeoff.

Instrumentation, cues and handling qualities would, in all respects, need the capabilities already discussed in this section. New design criteria would need to be developed for helicopter TERPS to define appropriate

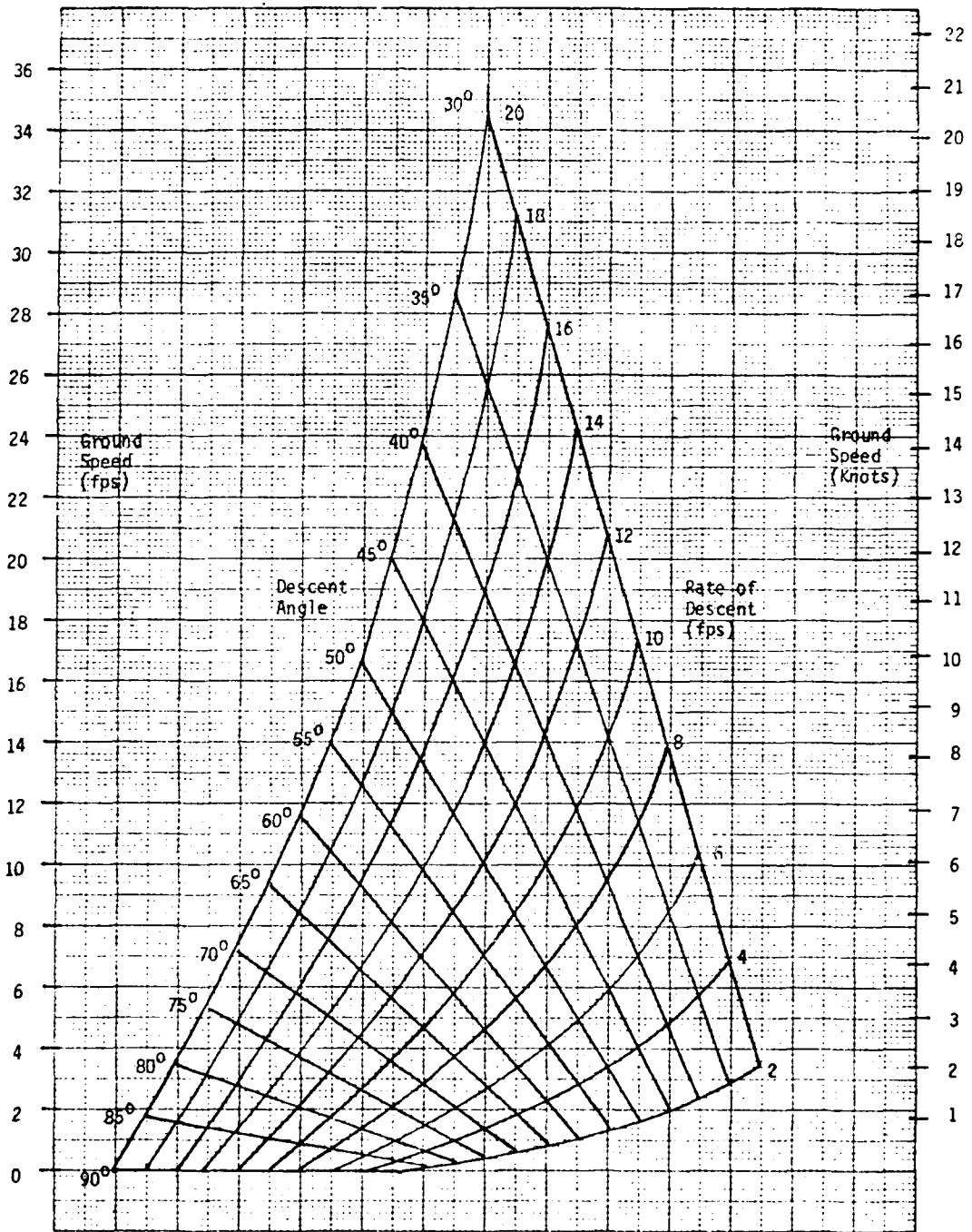


Figure 3-3

Variation of Ground Speed with Rate of Descent and Descent Angle for Steep Descents

approach and departure paths and stipulate requirements for assurance of supporting aircraft performance. Horizontal deceleration to hover followed by gradual steep descent would reduce pilot workload significantly in comparison to a simultaneously descending, decelerating approach along a precision glide path; and steep descent would permit a constant, creeping approach speed with ROD that is entirely compatible to the design characteristics of the landing gear.

APPENDIX A

INDIVIDUAL HELICOPTER PERFORMANCE SUMMARIES

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APPENDIX A

INDIVIDUAL HELICOPTER PERFORMANCE SUMMARIES

INTRODUCTION

This appendix compiles performance summaries extracted from the flight manuals of a group of IFR certificated civil helicopters plus a few IFR capable military helicopters.

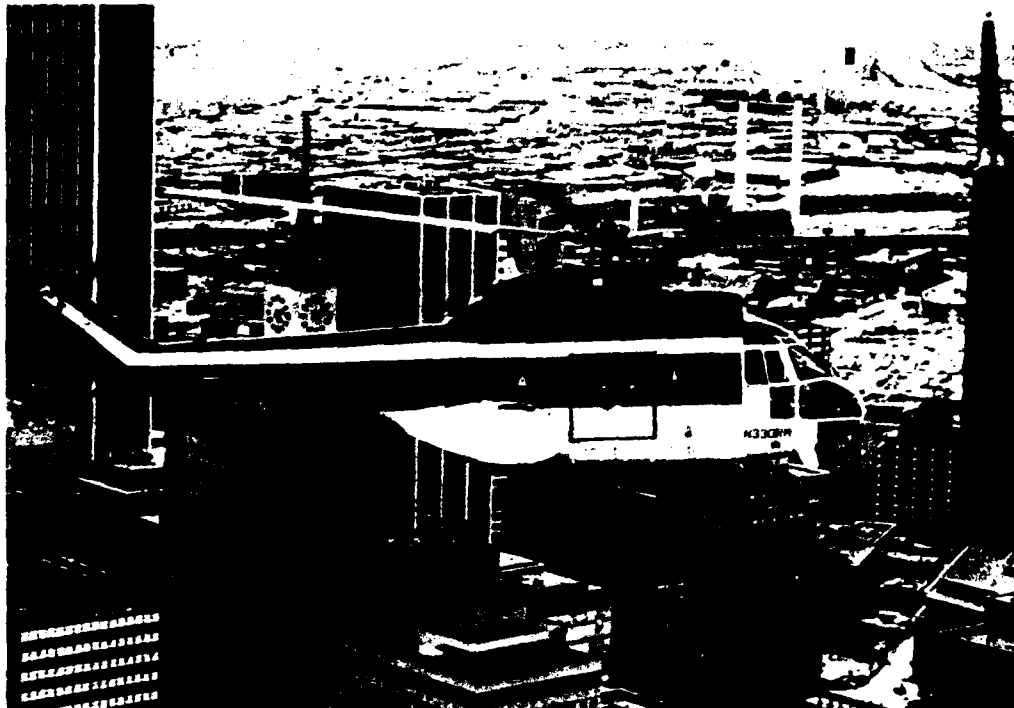
Each summary starts with an overview sheet which provides a picture plus a listing of the most cogent descriptive characteristics. This is followed by a narrative introduction which presents a more elaborate general description.

Following the introductory narrative is a sheet of data on which are listed the flight limitations which impact instrument flight rule (IFR) performance. These data are extracted from many locations in the basic flight manual and the IFR supplement, if applicable. Most such data are published in the limitations sections of these sources. To complete orientation to the aircraft, three view drawings with dimensions are provided.

The remainder of each summary consists of data which varies with one or more parameters. Charts, graphs, or nomograms of the never exceed speed (V_{NE}) and the height-speed (H-V) diagram are provided to show physical limitations on safely usable maximum and minimum airspeeds. PACER interpretations of flight manual data present figures of the variation of rate-of-descent (ROD) with airspeed in autorotation for that range of airspeeds which includes minimum ROD and shallowest glide angle (therefore maximum gliding distance). The remaining charts deal with climb performance. The first chart shows rate-of-climb (ROC) and associated calibrated airspeed (CAS) at maximum gross weight and a nearly empty gross weight. These data represent sea level, standard day conditions as do the autorotation data.

The last charts present the variability of ROC with altitude and gross weight for two different temperature conditions - standard day and standard day plus 20 C. These data are presented for maximum continuous power with all engines operating and airspeed held at the prescribed best rate of climb (BROC) airspeed. Carpet plots are employed to reflect the interrelationships of the two parameters in defining ROC. Superimposed upon the carpet plots are boundary traces which represent the limiting combinations of gross weight and altitude that permit hover out of ground effect (HOGE) and hover in ground effect (HIGE). Hover data are based on takeoff power. The traces of these boundaries demonstrate the ROC which may be expected at BROC airspeed for the combinations of altitude and gross weight which reflect marginal hover capability. Any region above a boundary ensures hover for the conditions specified by the boundary (in ground effect or out of ground effect).

THE AEROSPATIALE SA-330J PUMA HELICOPTER



MEDIUM WEIGHT SINGLE MAIN ROTOR HELICOPTER POWERED BY TWO TURBINE ENGINES,
DESIGNED FOR PERSONNEL TRANSPORT.

MANUFACTURER: AEROSPATIALE (distributed by Aerospatiale Helicopter Corporation).

POWER PLANT: Two Turbomeca TURMO IVC free power turbine engines rated at 1,495 SHP for takeoff (5 min) and 1,260 SHP maximum continuous.

AIRCRAFT UTILITY: FAA certified for dual pilot IFR flight, dual pilot FAR 29 Category A, or single pilot FAR 29 Category B.

SEATING CAPACITY: Variable cabin arrangements permit seating up to 19 passengers plus crew (2 or 3).

INTRODUCTION

The SA-330J Puma is a 19 passenger medium helicopter manufactured by Societe Nationale Industrielle Aerospatiale of Marignane, France and marketed in the U.S. by Aerospatiale Helicopter Corporation of Grand Prairie, Texas. The helicopter was originally designed for troop carrying and battlefield supply missions. It is used by the military of several European nations. (It is jointly produced with Westland Helicopters Limited, UK).

The SA-330J is certificated under Type Certificate H4EU (Rev. 2) for Transport Category A and B operations and two pilot IFR operations. It is a compact single main rotor design with a four bladed main and five bladed anti-torque rotors. Retractable tricycle wheeled landing gear are used.

The aircraft is powered by two free power turbine Turbomeca TURMO IVC engines. Each engine is rated at 1,495 SHP (5 min limit) for normal dual engine takeoff operations and 1,260 SHP maximum continuous operations. Emergency ratings for operation of a single remaining engine permit 1,555 SHP (2 1/2 min) or 1,380 SHP (30 min). The main gearbox is rated at 2,427 SHP for dual engine takeoff and 1,742 SHP continuous rating (either single or dual engine operations).

Performance data presented herein are extracted from the SA-330J Puma Flight Manual (approval date April 29, 1976).

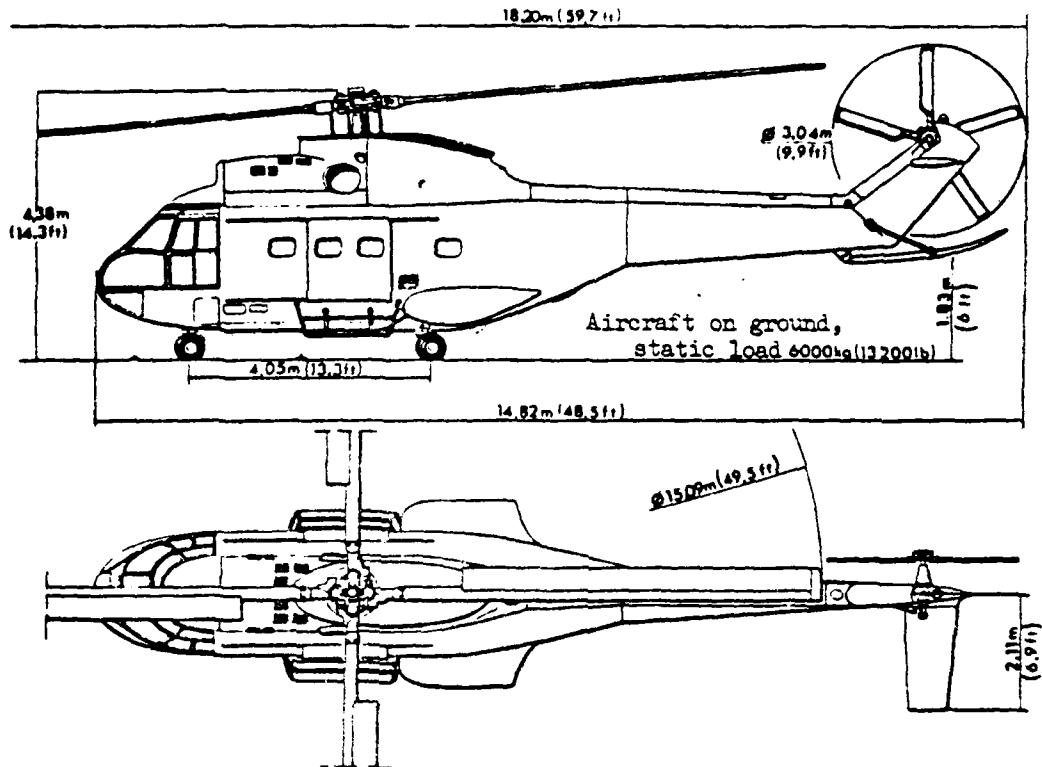
GENERAL IFR PERFORMANCE DATA

Maximum VNE	167 KIAS
Maximum Operating Altitude	16,500 ft.
Optimum Climb Speed (best rate of climb)	70 KIAS
Optimum approach speed	100 KIAS

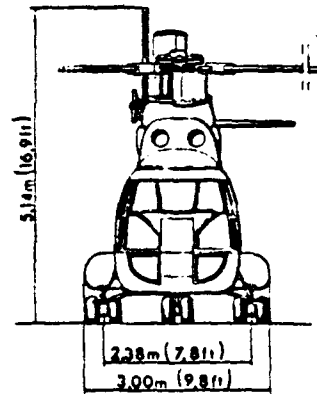
Recommended IFR flight parameters:

	With Autopilot No Turbulence	Autopilot Failed or with turbulence
Minimum Speed		
Level or descending	55 KIAS	65 KIAS
Climb	65 KIAS	65 KIAS
Maximum collective pitch in level flight	15°	13°
Vertical Rate-of-descent	1,650 ft/min	1,650 ft/min
Maximum Bank Angle		
14,800 lb. or less	40°	20°
over 14,800 lbs.	30°	20°

1 - MAJOR DIMENSIONS OF AIRCRAFT

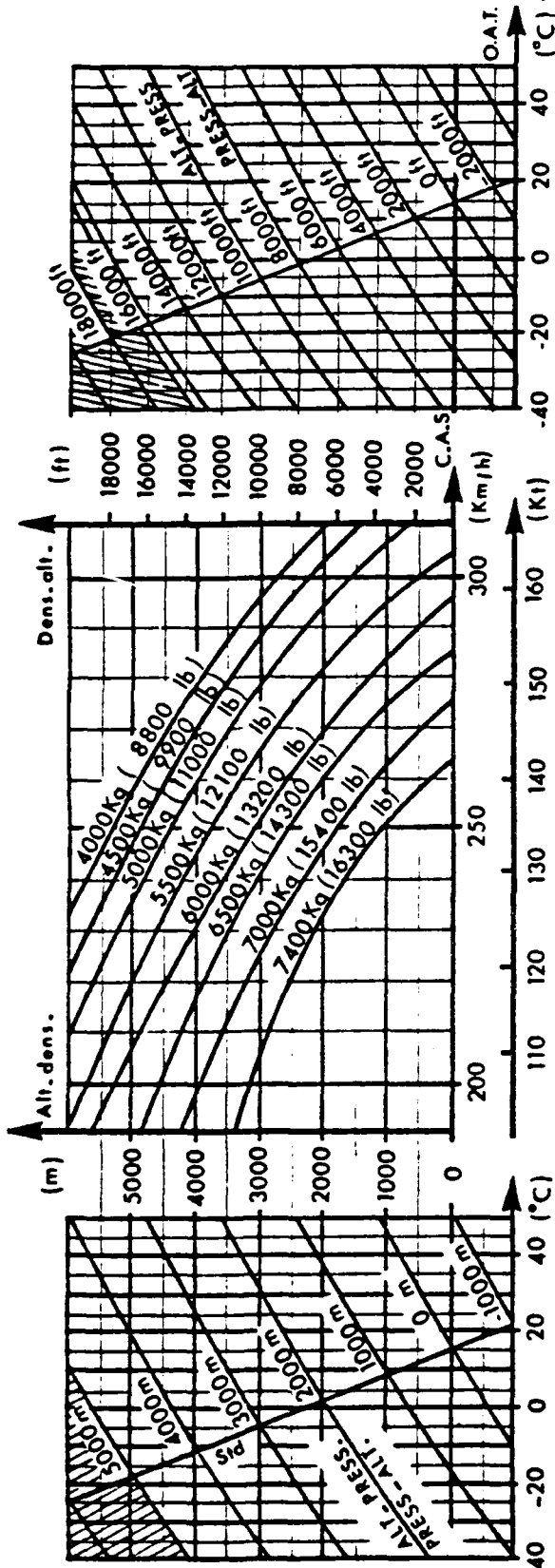


Three-view drawing



SA-330J Puma

(Extracted from Flight Manual)

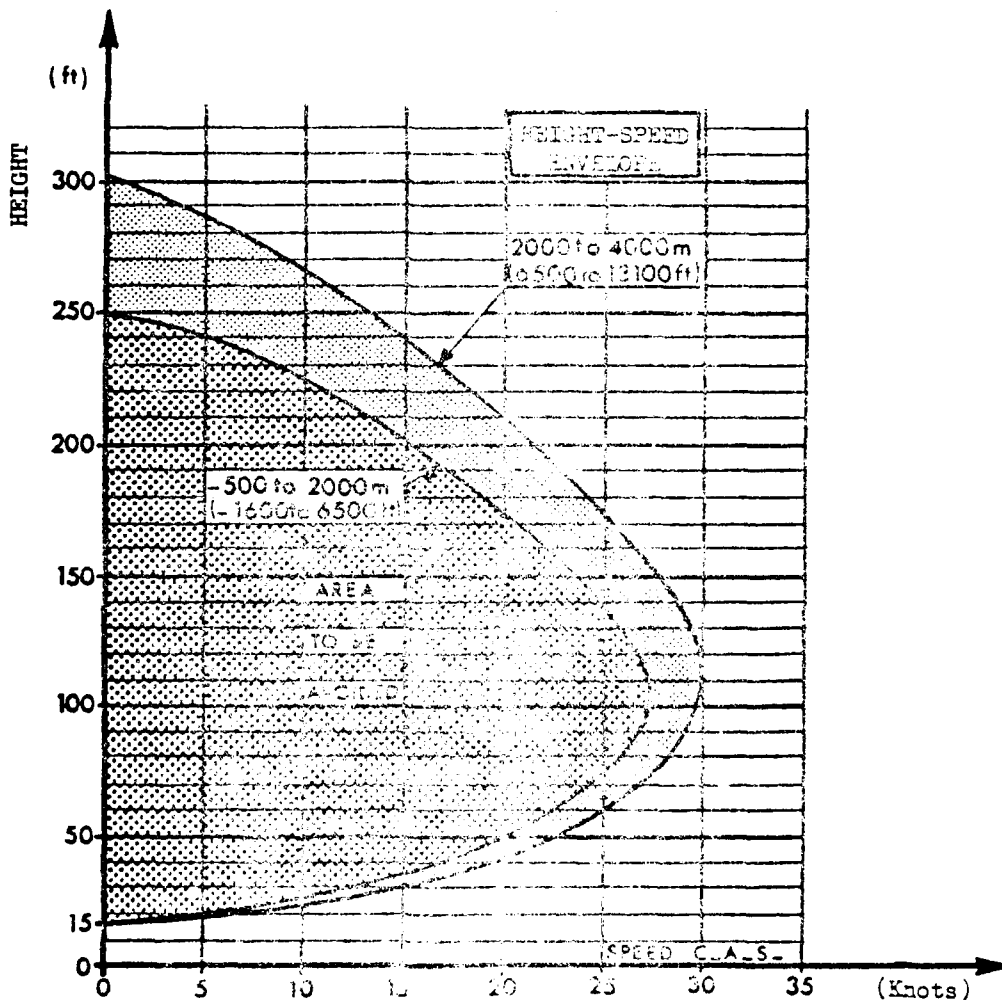


METRIC UNITS		VNE										ENGLISH UNITS					
DENSITY ALTITUDE (m)	WEIGHT (kg)	0	1000	2000	3000	4000	5000	DENSITY ALTITUDE (ft)	WEIGHT (lb)	0	2000	4000	6000	8000	10000	12000	16500
4000	310	310	310	310	297	279	259	10000	167	167	167	167	164	160	155	149	132
4500	310	310	310	303	288	270	249	11000	167	167	167	165	162	157	152	145	127
5000	310	308	294	279	260	235		12000	165	163	160	160	156	151	145	138	120
5500	303	295	282	266	245	220		13000	159	157	154	154	150	144	137	130	112
6000	294	284	270	252	231			14000	156	153	149	149	144	138	131	124	100
6500	284	274	261	241	218			15000	151	147	143	143	137	131	123	115	VNE
7000	274	262	246	225			VNE	16000	144	142	137	132	124	115			(Ki)
7400	263	252	234				(Km/h)	16300	142	138	134	128	120	111			

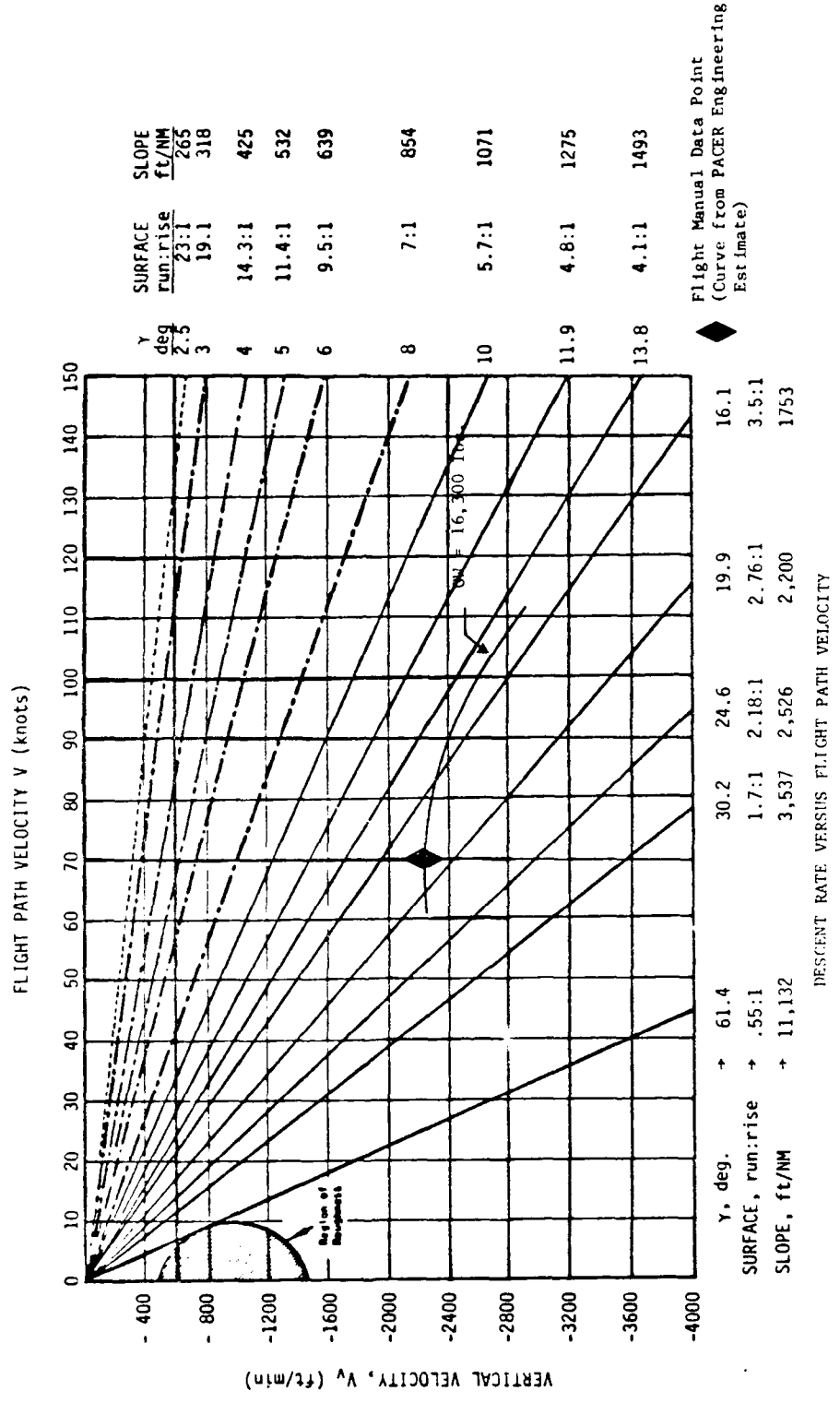
Example : OAT = - 5 °C
 Pressure altitude = 1000 m
 Weight = 6000 kg
 The corresponding density altitude is 500 m.
 The never-exceed-speed is :
 CAS = 290 km/h.

NEVER EXCEED SPEED (V.N.E.)

SA-7001 PUNA



AEROSPATIALE SA-330J
AUTOROTATION (Power off)



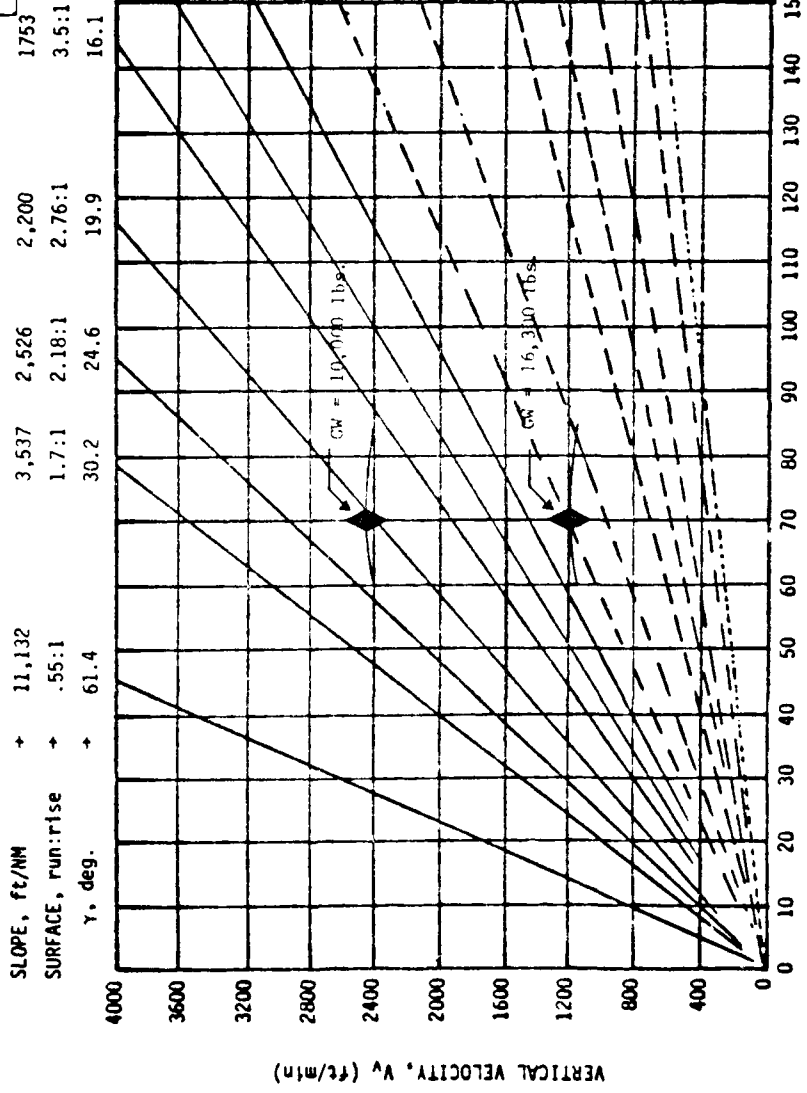
DESCENT RATE VERSUS FLIGHT PATH VELOCITY

Y, deg. + 61.4

SURFACE, run:rise + .55:1

SLOPE, ft/NM + 11,132

AEROSPATIALE SA-330J
STANDARD DAY, SEA LEVEL
MAXIMUM CONTINUOUS POWER



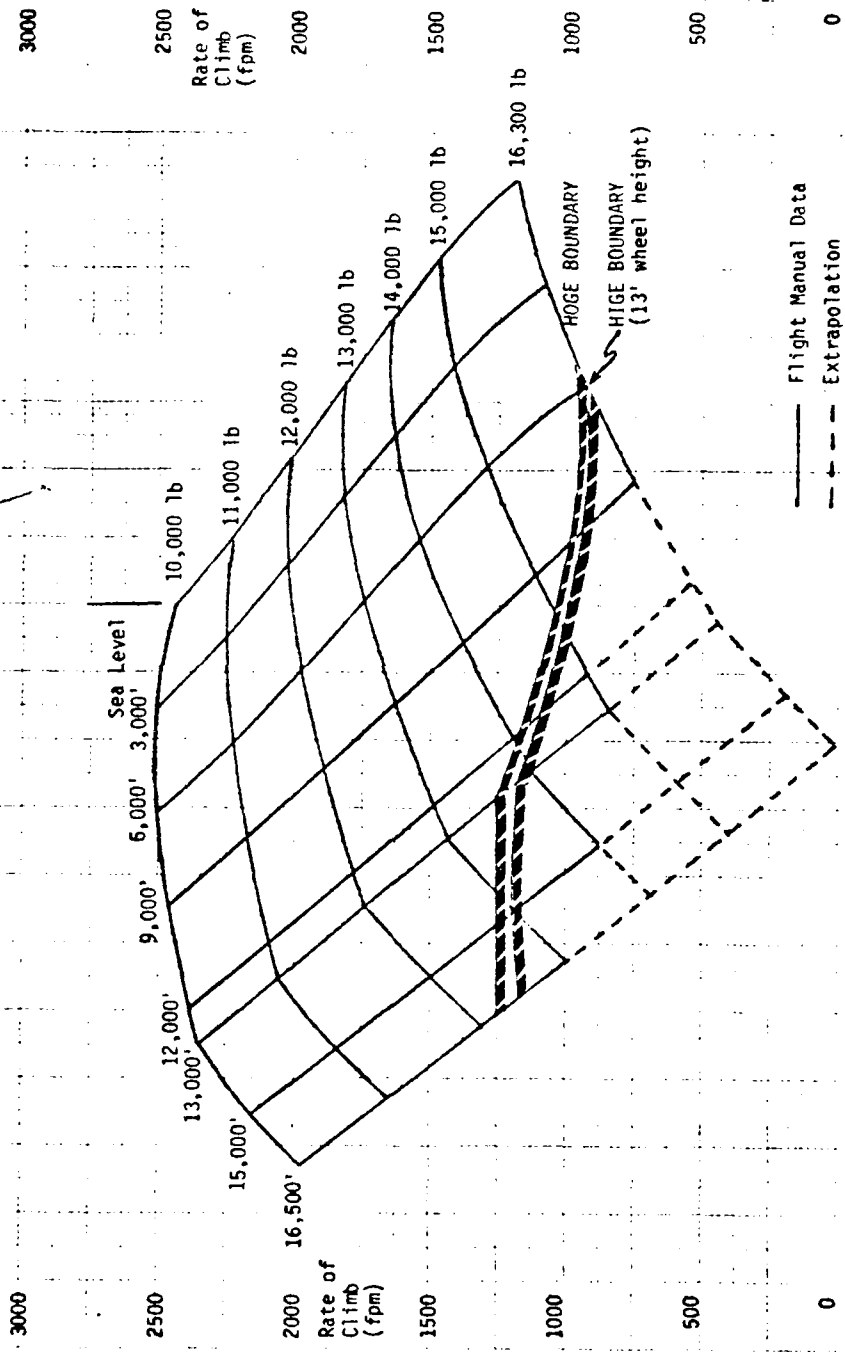
FLIGHT PATH VELOCITY V (knots)
CLIMB RATE VERSUS FLIGHT PATH VELOCITY

Flight Manual
Data Points

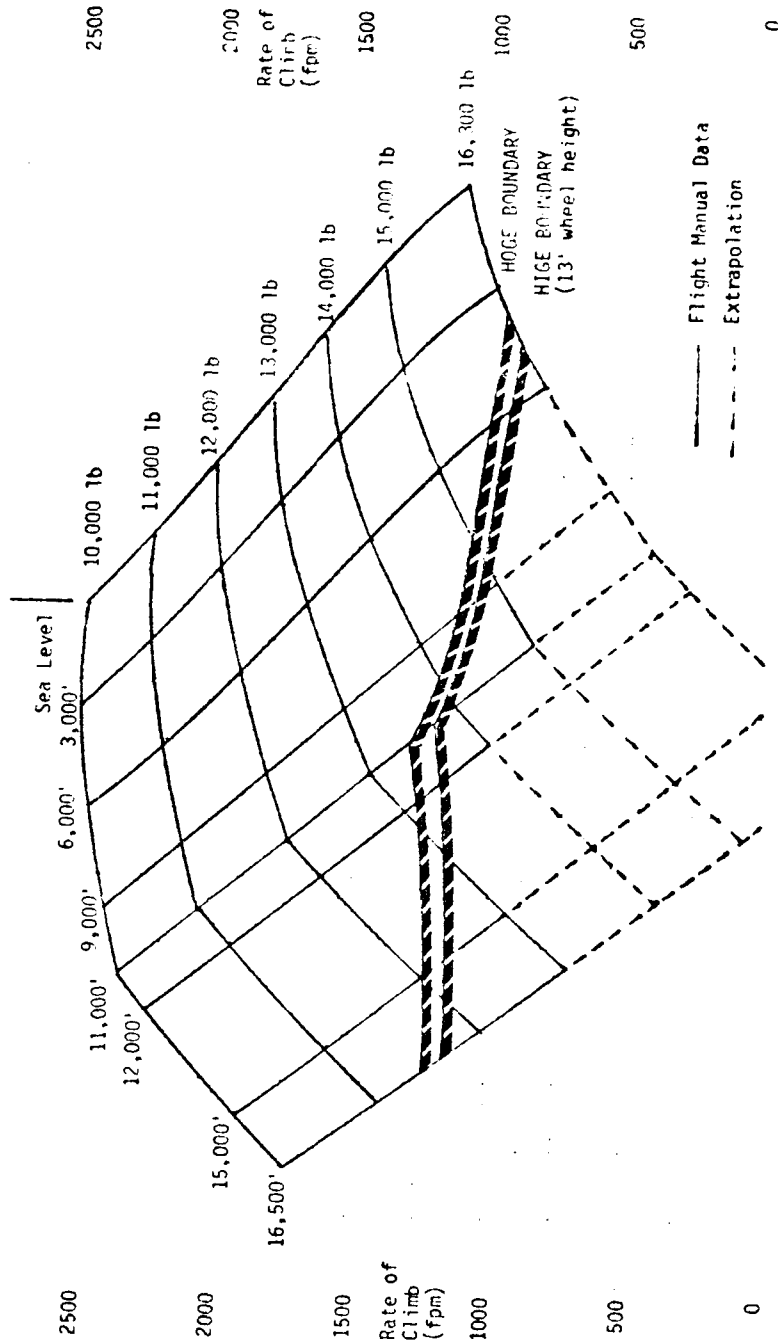
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)

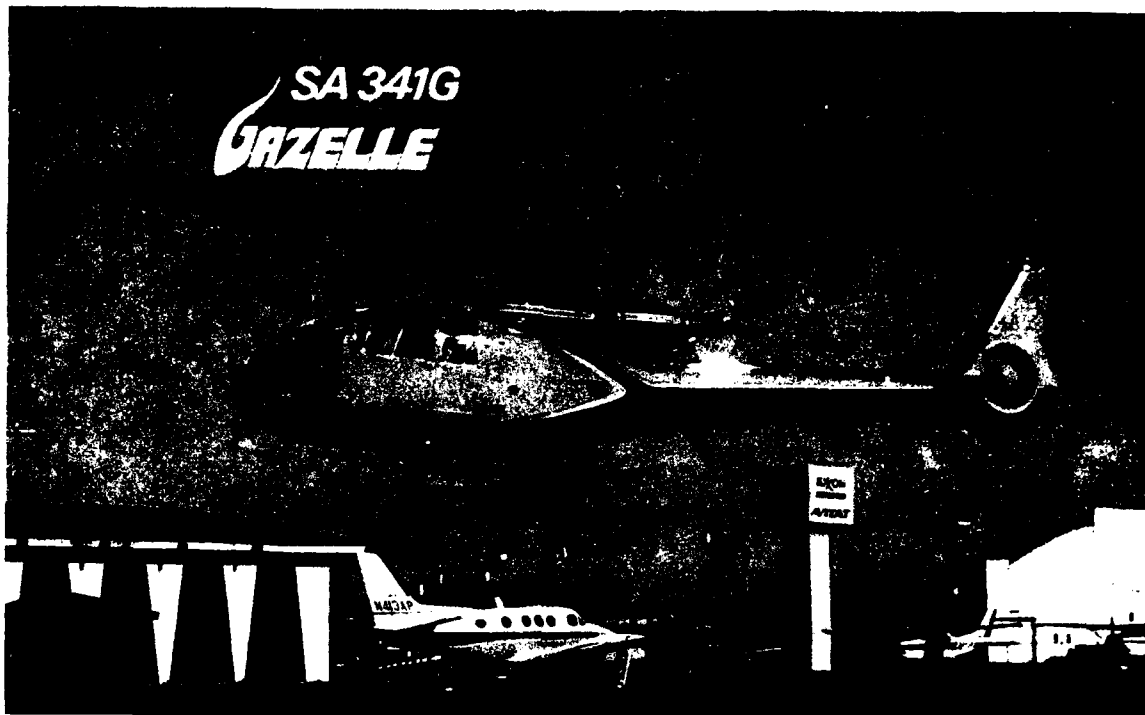


SA 330 J Puma Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



SA 330 J Puma Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

THE AEROSPATIALE MODEL SA-341G GAZELLE HELICOPTER



LIGHTWEIGHT SINGLE MAIN ROTOR HELICOPTER POWERED BY A SINGLE
TURBINE ENGINE, DESIGNED FOR GENERAL PURPOSE OPERATIONS.

MANUFACTURER: AEROSPATIALE (distributed by Aerospatiale
Helicopter Corporation)

POWER PLANT: One Turbomeca Astazou III A turboshaft engine
rated at 592 SHP for takeoff or continuous
operation. (Transmission limited to 494 SHP)

AIRCRAFT UTILITY: FAA certificated for single pilot Category II
operations in IFR Flight

SEATING CAPACITY: Five including crew

INTRODUCTION

The SA-341G Gazelle is a five place (pilot plus four) light utility helicopter originally designed for use by the French and British armed forces. It is manufactured by the Helicopter Division of Societe Nationale Industrielle Aerospatiale of Marignane, France and marketed in the U.S by Aerospatiale Helicopter Corporation of Grand Prairie, Texas.

The SA-341G is certificated under Type Certificate H6EU (Rev 3). With appropriate supplemental type certificate(s), it can be certified for single pilot IFR Category I (and Category II). It employs a single, fully articulated, three-bladed main rotor and a multibladed fan-in-fin, or fenestron, type of anti-torque tail rotor. Skid type landing gear is employed.

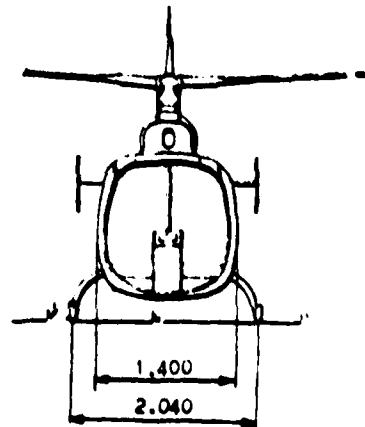
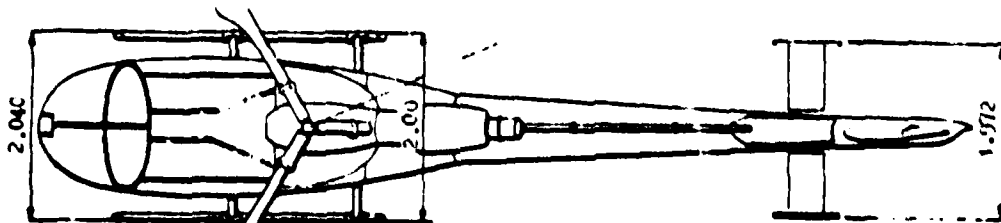
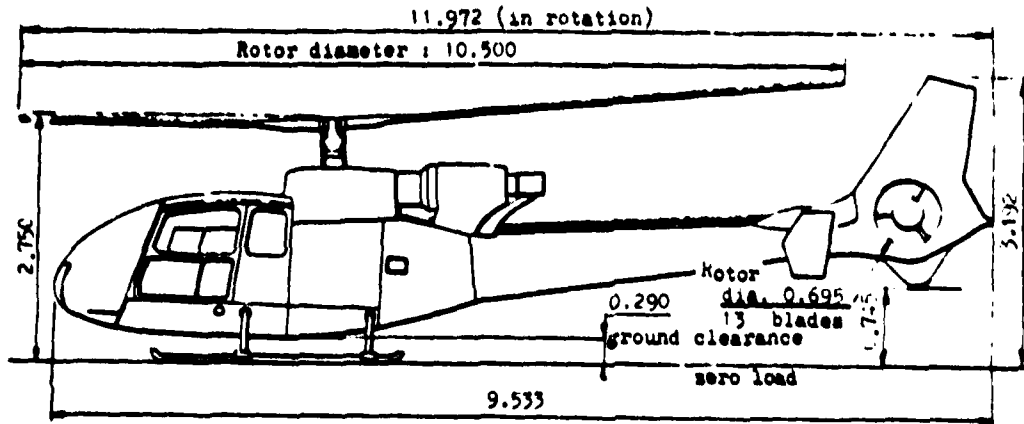
The aircraft is powered by one, single spool Turbomeca Astazou IIIA engine rated at 592 SHP. The same rating applies for both takeoff and maximum continuous power. The transmission is limited to 494 SHP. Again takeoff and maximum continuous ratings are the same.

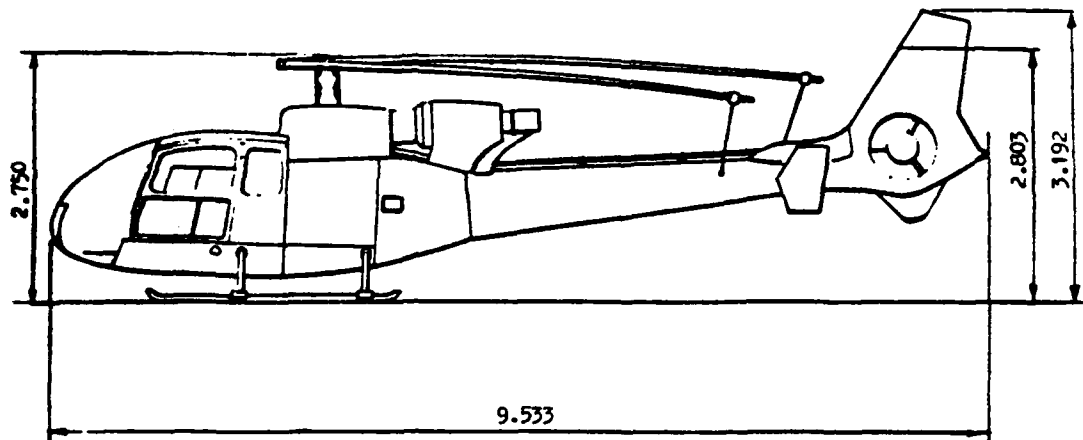
Performance data presented herein have been extracted from the SA-341G Gazelle Flight Manual (approval date December 1974), IFR Supplement (dated October 28, 1975) and Category II IFR Supplement (dated February 2, 1977).

GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	40 KIAS
Minimum ILS Approach Speed (2 cue)	60 KIAS
Recommended Approach Speed	80-130 KIAS
Minimum Category II Approach Speed	70 KIAS
Maximum Category II Approach Speed	130 KIAS
V _{ne} (diminishes with increasing altitude)	168 KIAS
Maximum altitude	20,000 feet
Optimum Climb Speed (Surface to 10,000 feet)	65 KIAS
Optimum Climb Speed (Above 10,000 feet)	55 KIAS

1. OVERALL DIMENSIONS OF THE HELICOPTER (Metric Dimensions)





1.1. Overall dimensions with blades spread

Rotor diameter	10.500 m	(34.449 ft)
Overall length	11.972 m	(39.278 ft)
Overall height	3.192 m	(10.474 ft)

1.2. Overall dimensions with blades folded

Length	9.533 m	(31.272 ft)
Width	2.040 m	(6.693 ft)
Overall height	3.192 m	(10.474 ft)

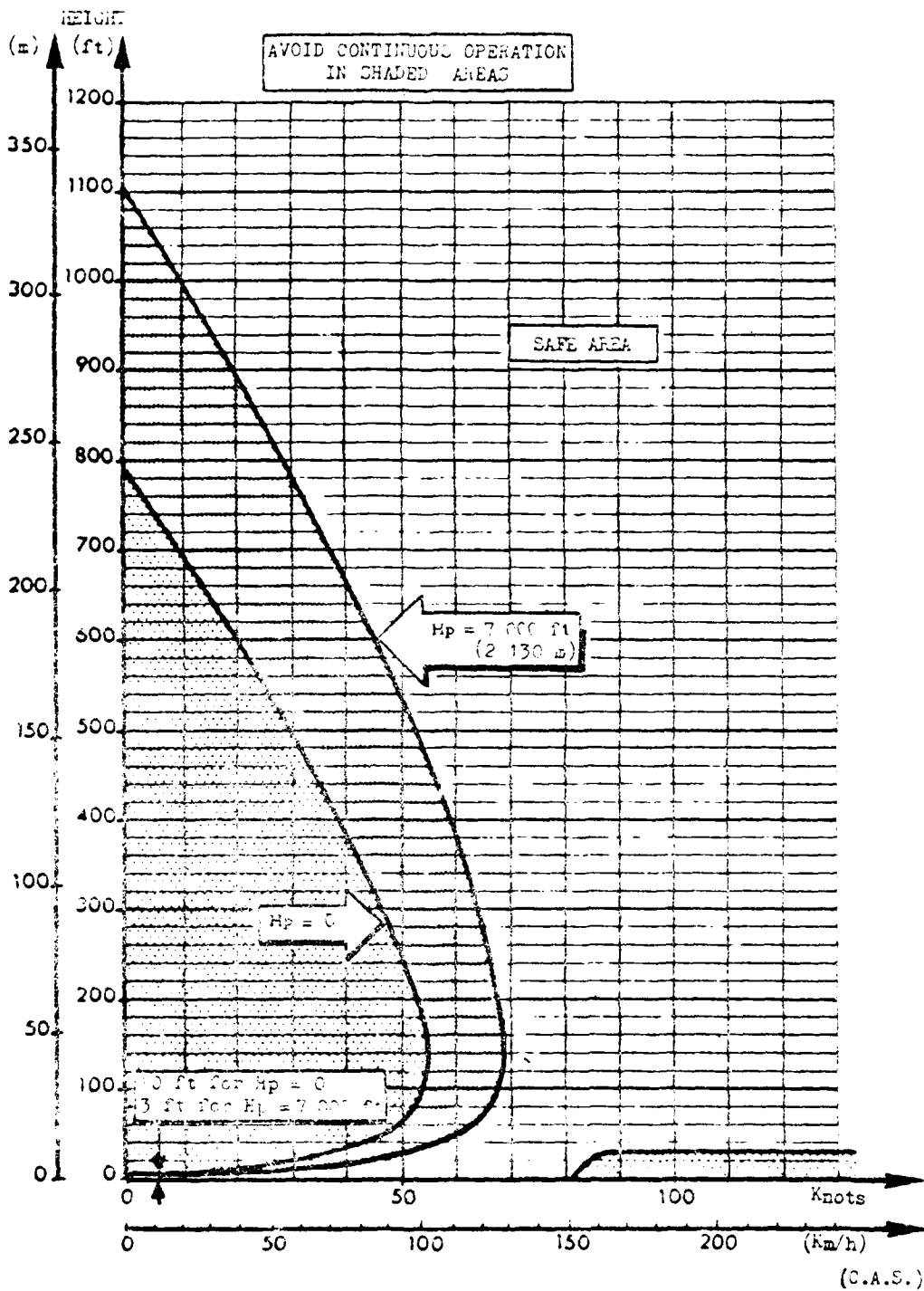
1.3. Overall dimensions for transport

Length	9.533 m	(31.272 ft)
Width	2.040 m	(6.693 ft)
Overall height	3.192 m	(10.474 ft)
Overall height less tail fin cap	2.803 m	(9.196 ft)

1.4. Ground clearance (zero load less antenna, less equipment)

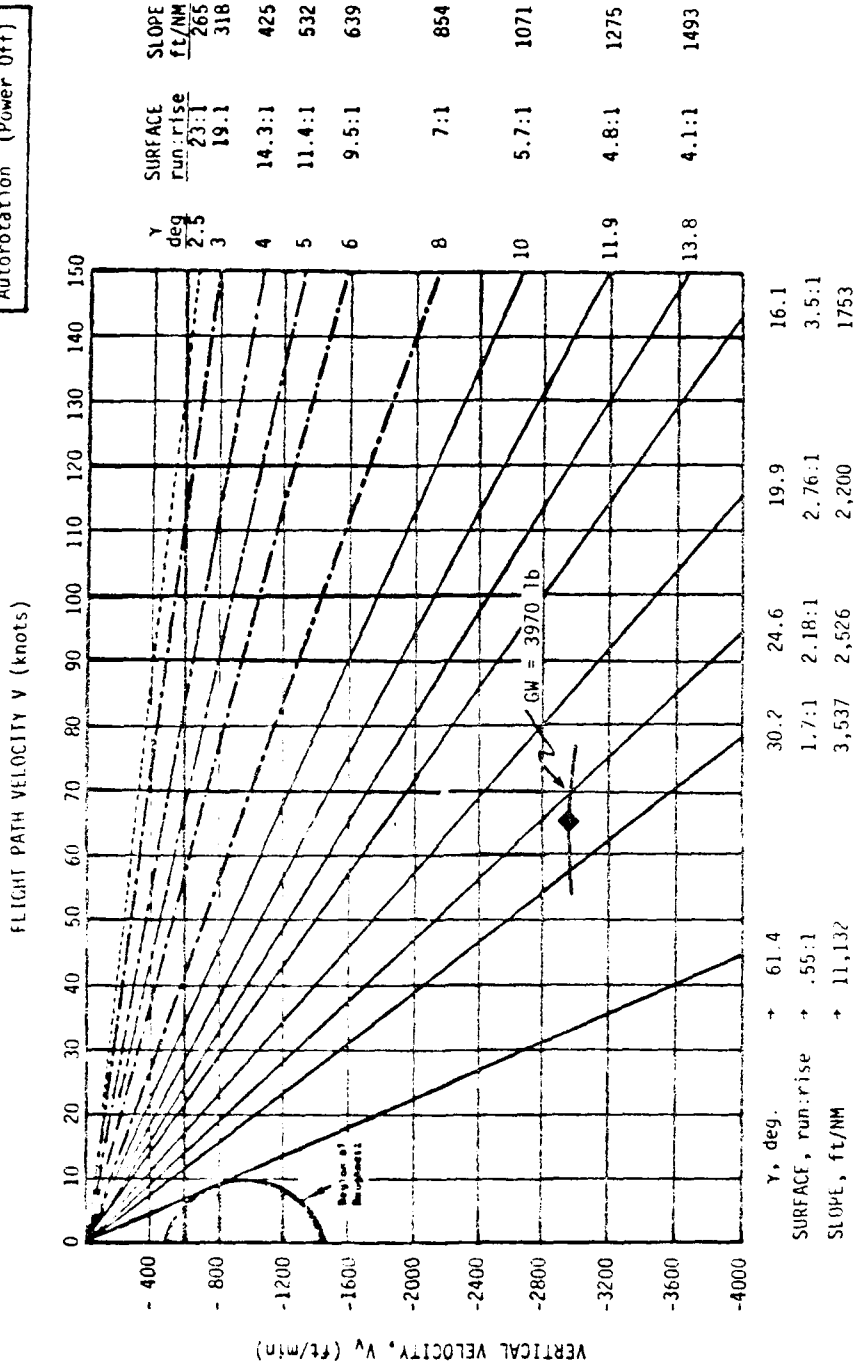
Under fuselage	0.290 m	(0.951 ft)
Under tail	0.745 m	(2.444 ft)

VNE in English units (indicated airspeed)											
PRESSURE ALTITUDE (ft)	-1500 to 0	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
VNE (knots)	168	160	152	144	136	128	120	112	104	96	88



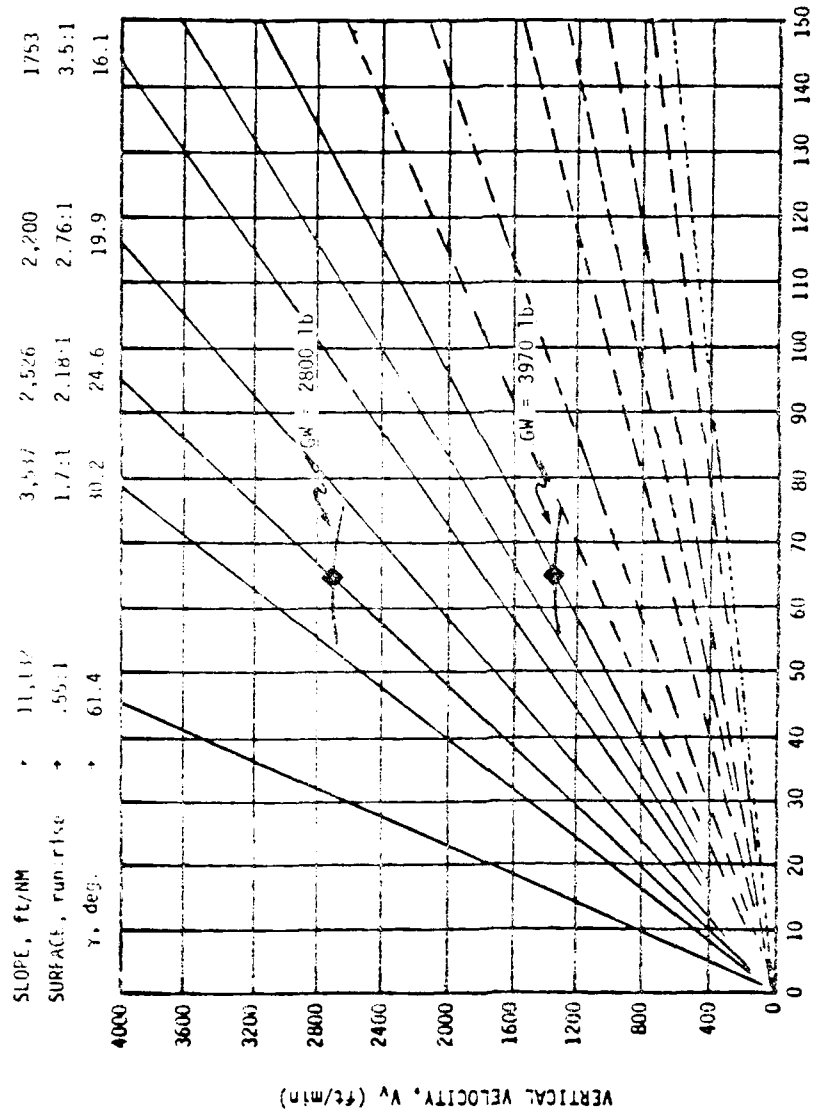
Height-velocity diagram at maximum weight
Standard atmosphere

SA341G Gazelle
Standard Day, Sea Level
Autorotation (Power Off)



Descent Rate versus Flight Path Velocity

SA341G Gazelle
Standard Day, Sea Level
Maximum Continuous Power



SLOPE, ft/NM	11.1:1	3.5:1	2.5:1	2,200	1753
SURFACE run:rise	1.7:1	2.18:1	2.76:1	19.9	3.5:1
γ, deg.	30.2	24.6	16.1		

13.8	4.1:1	1493
11.9	4.8:1	1275
10	5.7:1	1071
8	7:1	854
6	9.5:1	639
5	11.4:1	532
4	14.3:1	425
3	19.1	318
2.5	23:1	265
γ deg	SURFACE run:rise	SLOPE ft/NM

FLIGHT PATH VELOCITY V (knots)

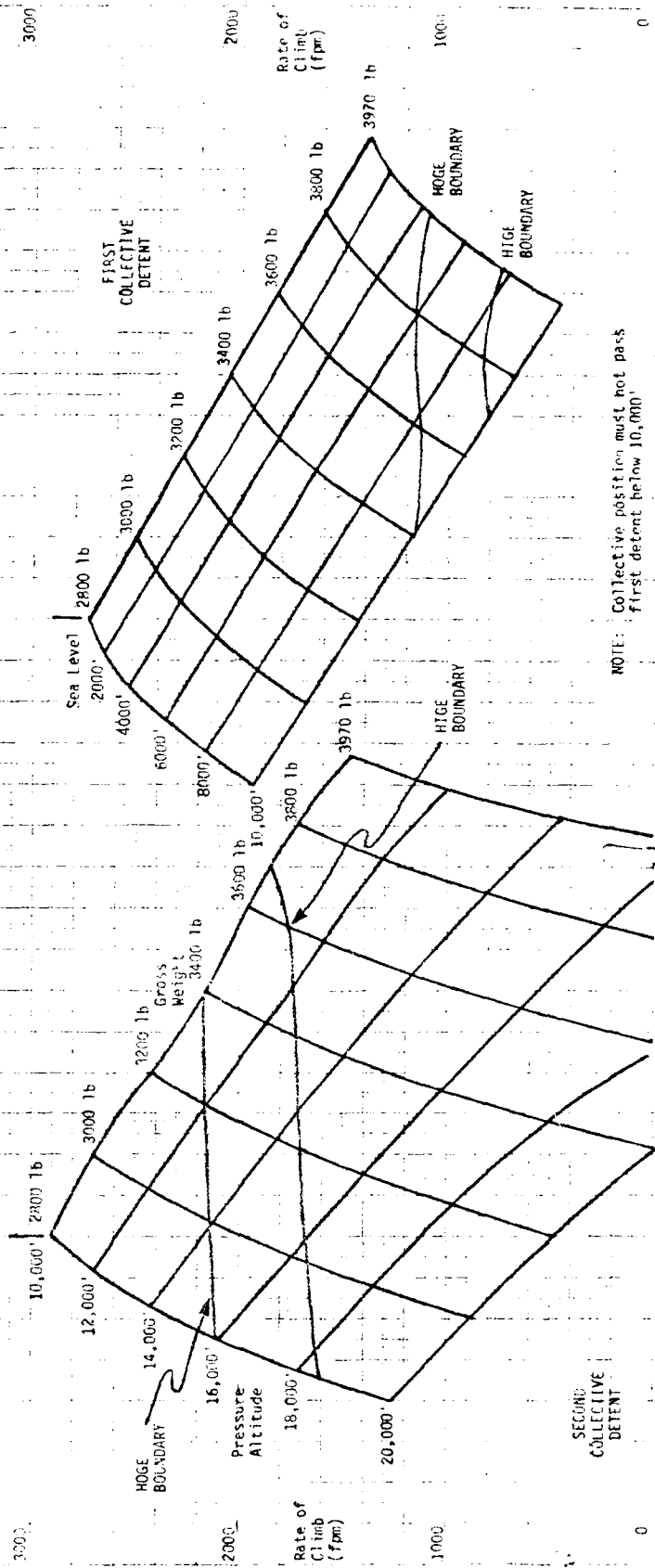
◆ Flight Manual Data Points

Climb Rate versus Flight Path Velocity

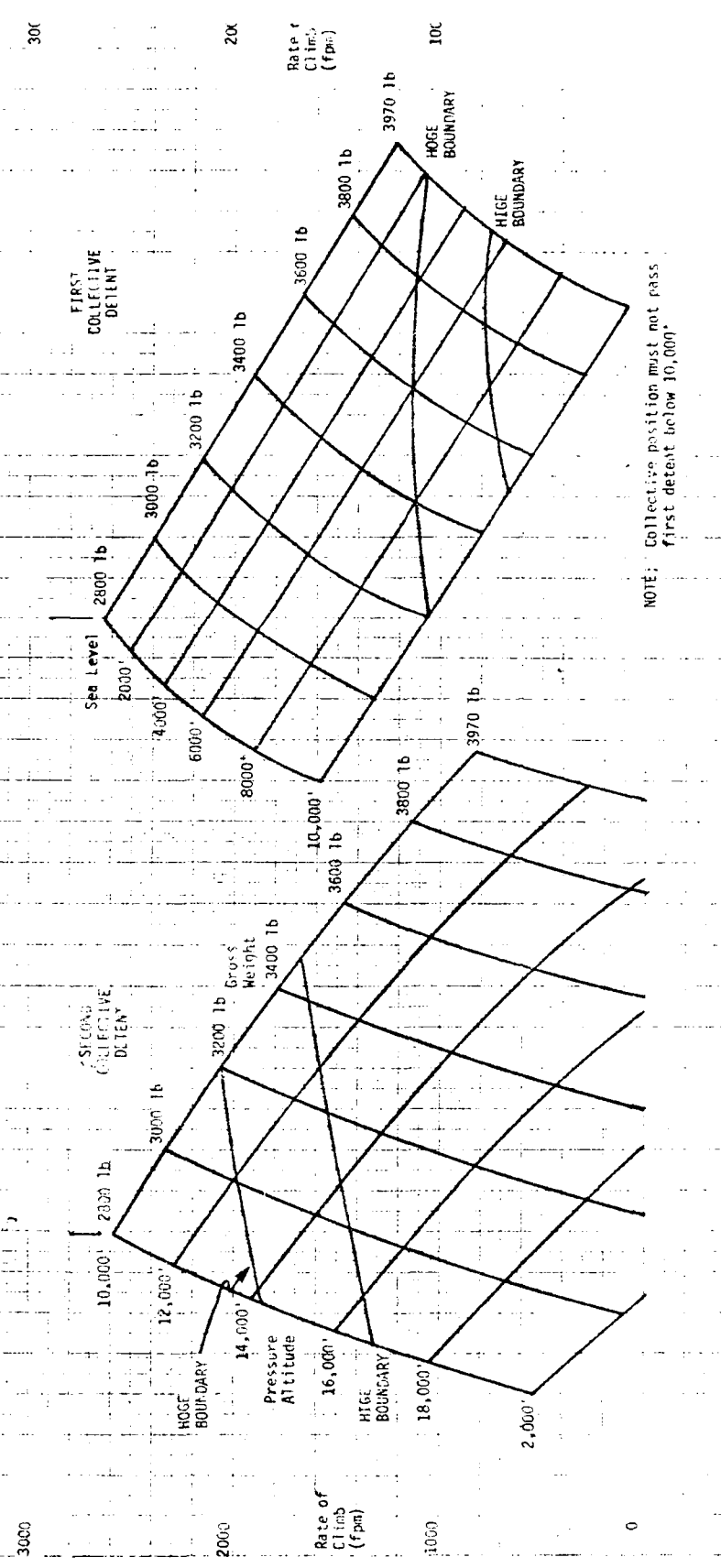
Climb Rates

The following two figures present carpet plots of best rate of climb attainable at optimum speed and minimum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents standard day performance and the other hot day performance based on temperatures uniformly 20°C warmer than standard day for all altitudes.

Each figure employs two carpets. The right hand carpet covers pressure altitudes from sea level to 10,000 feet; the left hand, from 10,000 to 20,000 feet. The double presentation results from a power limit imposed on the SA-341G below 10,000 feet. Two collective pitch control detents are utilized in the flight control system. Collective pitch is not to be increased beyond the first detent below 10,000 feet. Collective pitch up to the second detent is permitted to 20,000 feet. In all cases transmission torque limits are to be observed.



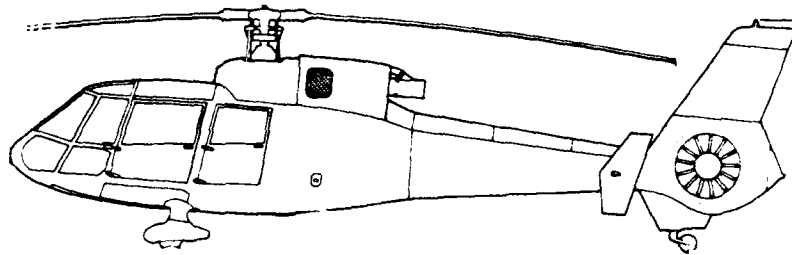
SA341G Gazelle
 Best Rate of Climb
 vs
 Gross Weight & Altitude
 (Standard Day Temperatures)



NOTE: Collective position must not pass first detent below 10,000'

SA341G Gazelle
 vs
 Best Rate of Climb
 Gross Weight & Altitude
 (Standard Day Temperatures +20°C)

THE AEROSPATIALE SA-360C DAUPHIN I HELICOPTER



LIGHT WEIGHT SINGLE MAIN ROTOR HELICOPTER POWERED WITH A SINGLE TURBINE ENGINE, DESIGNED FOR GENERAL PURPOSE OPERATIONS.

- MANUFACTURER: AEROSPATIALE (distributed by Aerospatiale Helicopter Corporation)
- POWER PLANT: One Turbomeca ASTAZOU XVIIIIA fixed turbine derated to 871 SHP for takeoff (5 min) and 804 SHP for continuous operations. (Transmission limits match engine limits.)
- AIRCRAFT UTILITY: FAA certified for single or dual pilot IFR flight.
- SEATING CAPACITY: Variable cabin arrangement permits seating configurations for up to 14 persons (crew included).

INTRODUCTION

The SA-360C Dauphin is a 14-place lightweight helicopter manufactured by Societe Nationale Industrielle Aerospatiale of Marignane, France, and marketed in the U.S. by Aerospatiale Helicopter Corporation of Grand Prairie, Texas. The helicopter is designed for general purpose uses in the civil sector. (The U.S. Coast Guard has recently ordered a twin-engine variant for their use; otherwise it is not used in any U.S. Military forces.) It has been FAA certificated for single pilot IFR when equipped with an attitude hold SAS and for dual pilot IFR without SAS when dual controls and instruments are installed.

Standard configuration includes fixed wheel conventional landing gear, four bladed main rotor and fan-in-fin or fenestron enclosed tail rotor.

The SA-360C is powered by one Turbomeca ASTAZOU XVIIIA single spool turboshaft engine. The engine has an integral reduction gear and automatic speed governor. The engine is flat rated at 871 SHP for takeoff (5 min) and 804 SHP continuous. (Takeoff power is derated from 991 SHP).

Performance data presented herein are extracted from the Dauphin Flight Manual (approval date December 21, 1976) unless otherwise noted.

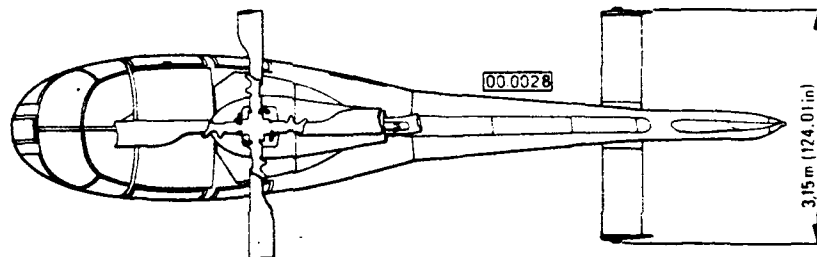
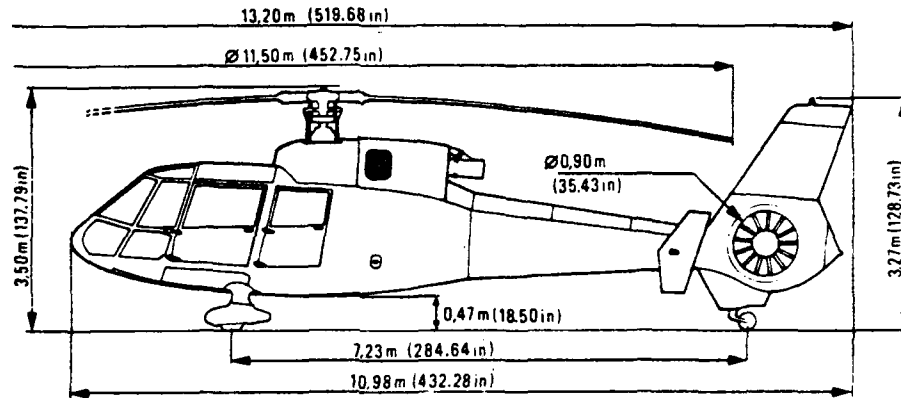
GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	50 KIAS *
Minimum Approved Airspeed for Coupled ILS Approach	60 KIAS *
Recommended Climb Speed	70 KIAS
Minimum Airspeed for Engagement of Flight Director/ Stability Augmentation Combination (FD/SAS)	50 KIAS *
Maximum Roll Angle for FD/SAS Engagement	5 degrees *
Recommended Approach Airspeed	70 KIAS
Maximum Altitude	15,000 ft.

*Data from FAA approved IFR Supplement (January 24, 1978) to Dauphin Flight Manual (December 21, 1976)

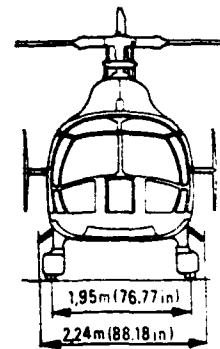
1 - PRINCIPAL DIMENSIONS OF THE HELICOPTER.

Printed in France



A. DIMENSIONS, ROTOR TURNING

Rotor disc diameter 11,50 m (452.75 in)
 Overall length 13,20 m (519.68 in)
 Overall height 3,50 m (137.79 in)



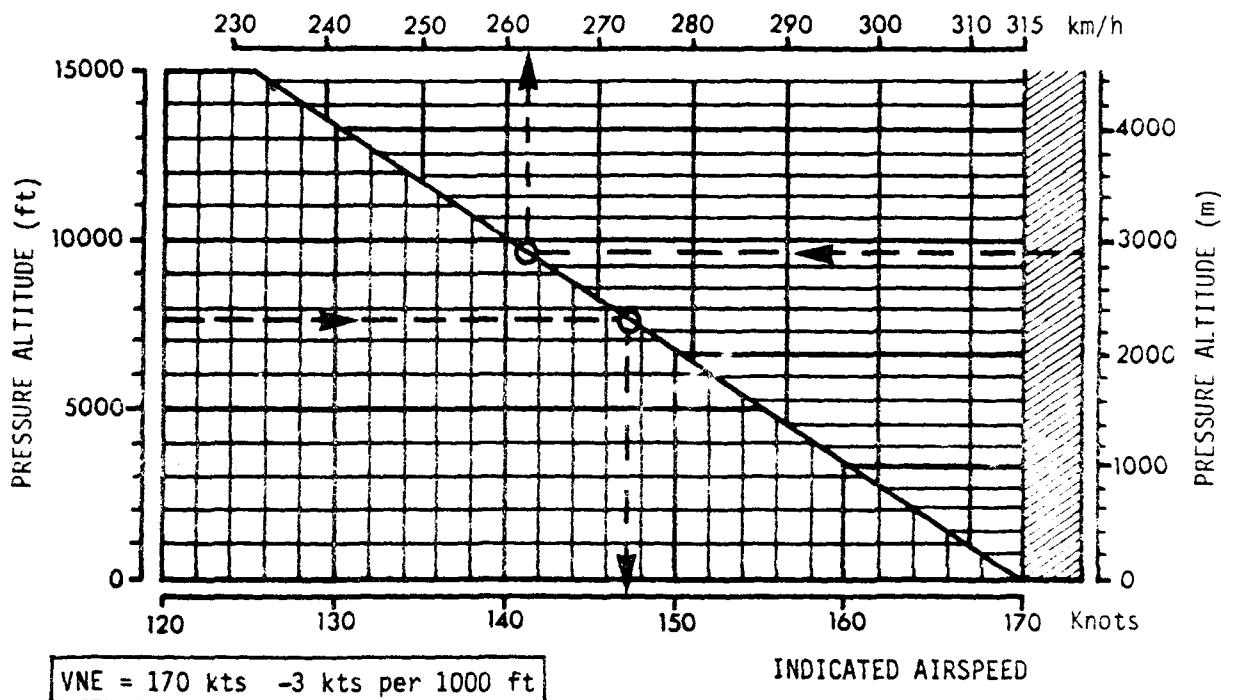
SA-360C Dauphin

(Extracted from Flight Manual) A-27

7. NEVER EXCEED SPEED (VNE)

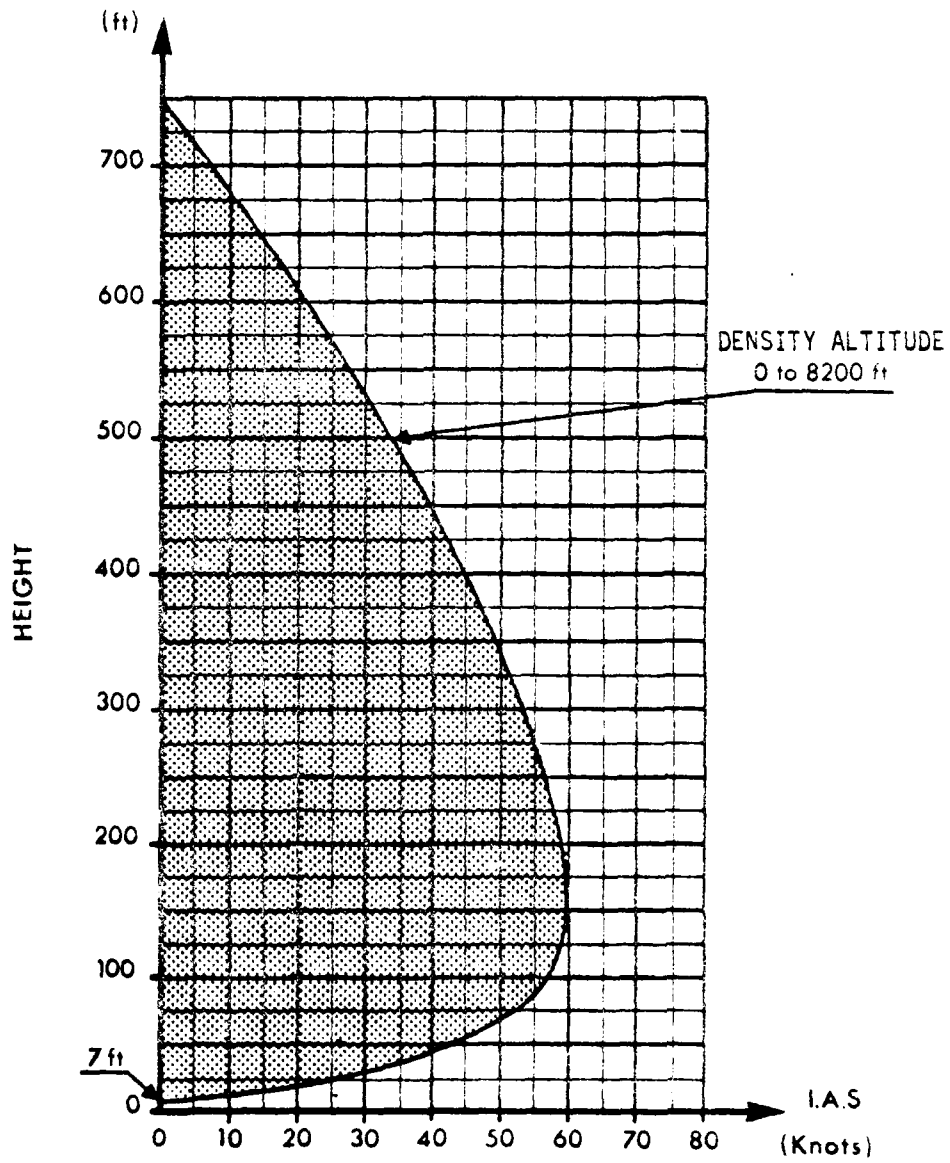
Never exceed speed is shown in the following chart for all approved conditions of weight and temperature.

Absolute VNE is : 170 Knots (315 Km/h).

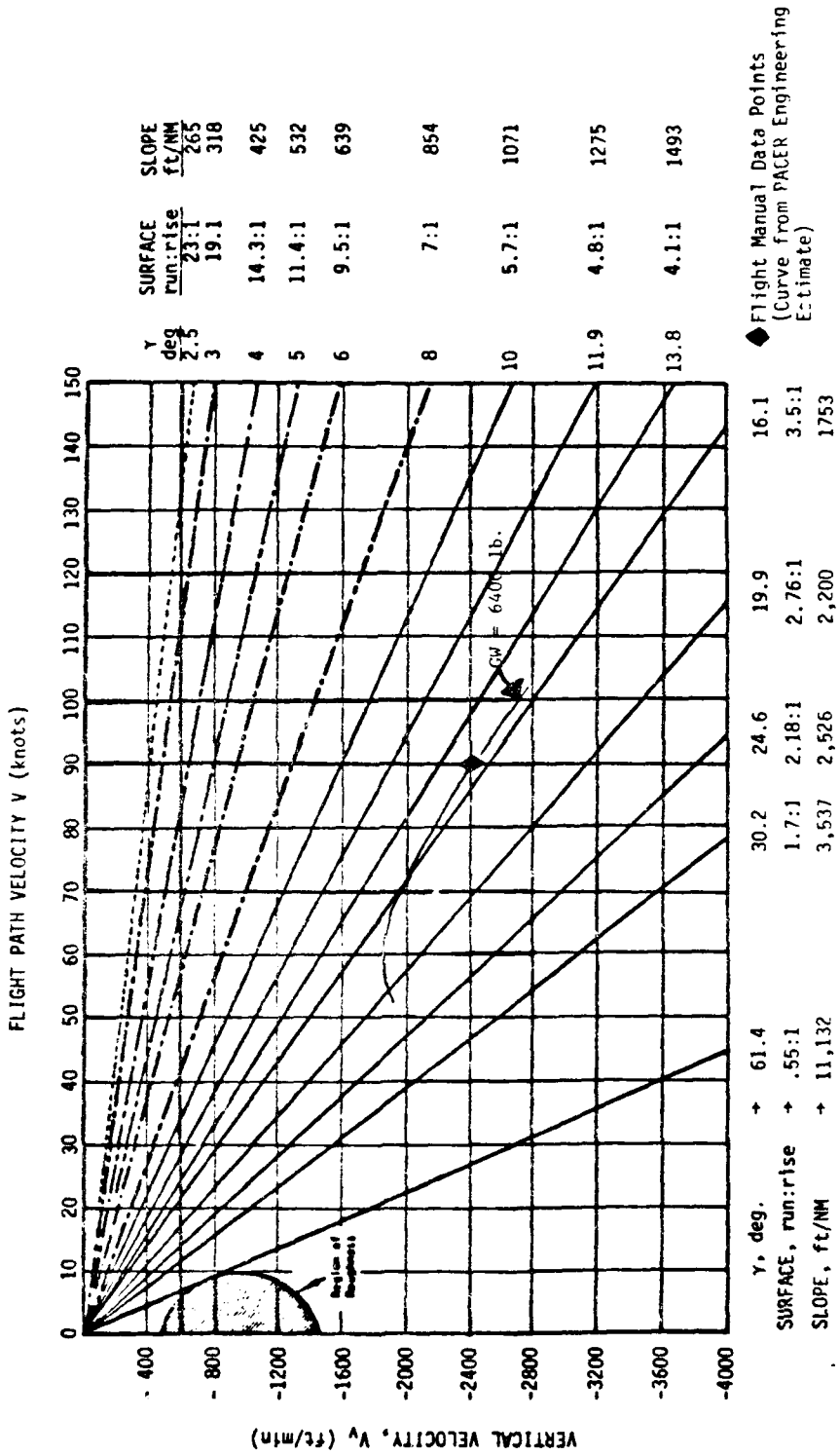


17. HEIGHT - SPEED ENVELOPE

Vertical Clearance



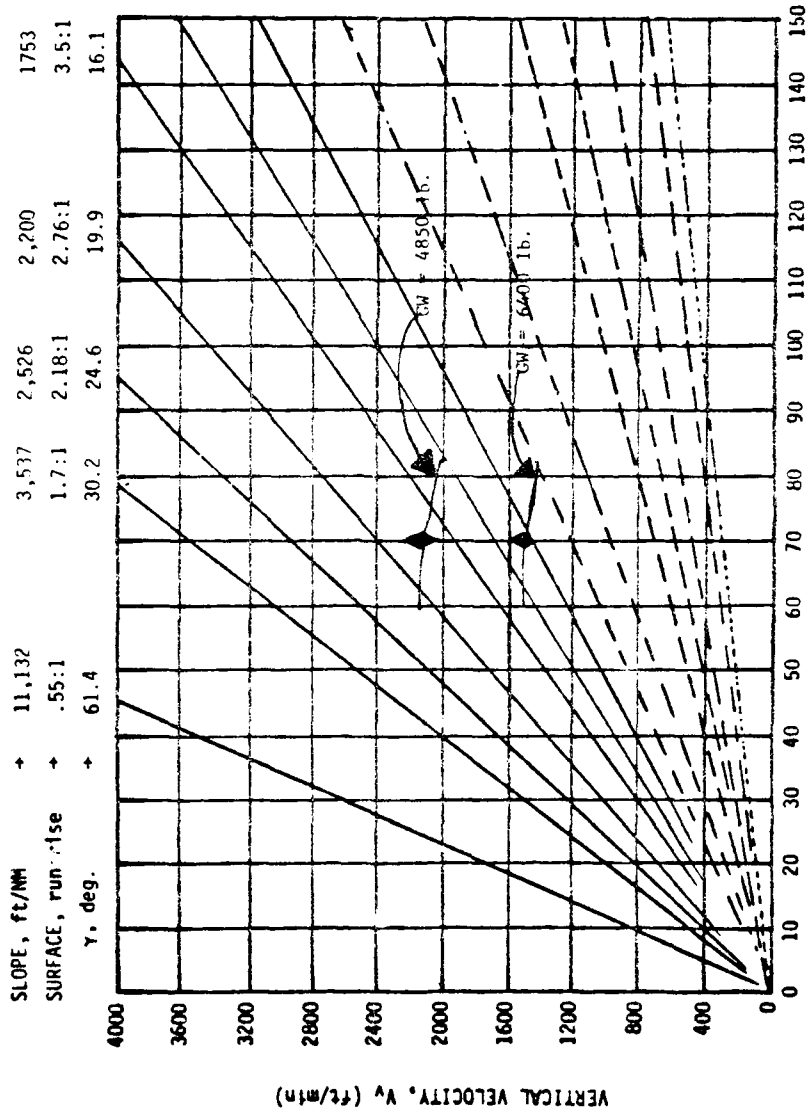
AEROSPATIALE SA-360C
AUTOROTATION (power off)



DESCENT RATE VERSUS FLIGHT PATH VELOCITY

AEROSPATIALE SA-360C
STANDARD DAY, SEA LEVEL
MAXIMUM CONTINUOUS POWER

13.8	4.1:1	1493
11.9	4.8:1	1275
10	5.7:1	1071
8	7:1	854
6	9.5:1	639
5	11.4:1	532
4	14.3:1	425
3	19.1	318
2.5	23:1	265
Y deg	SURFACE run:rise	SLOPE ft/NH



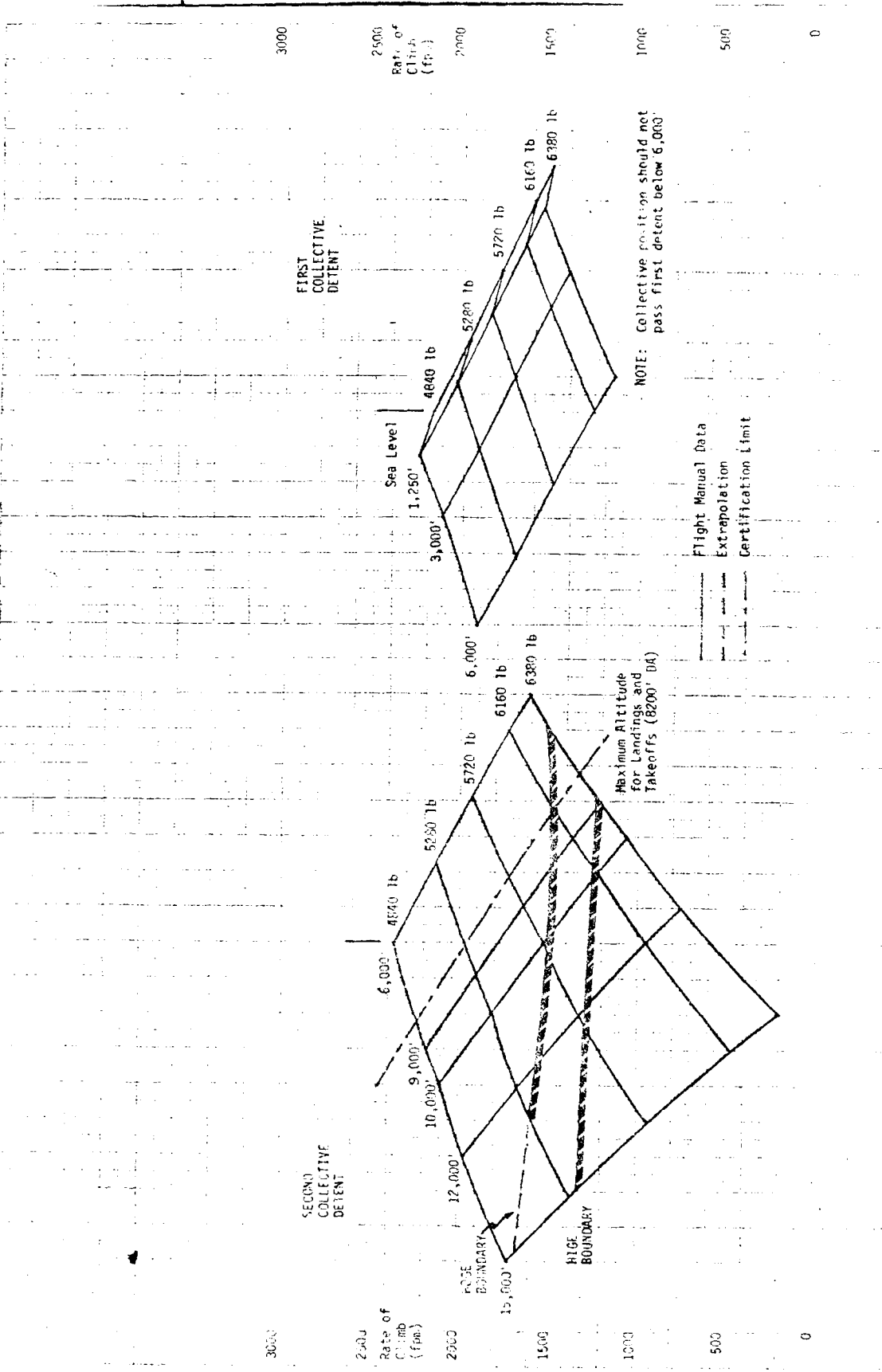
◆ Flight Manual Data Points

CLIMB RATE VERSUS FLIGHT PATH VELOCITY

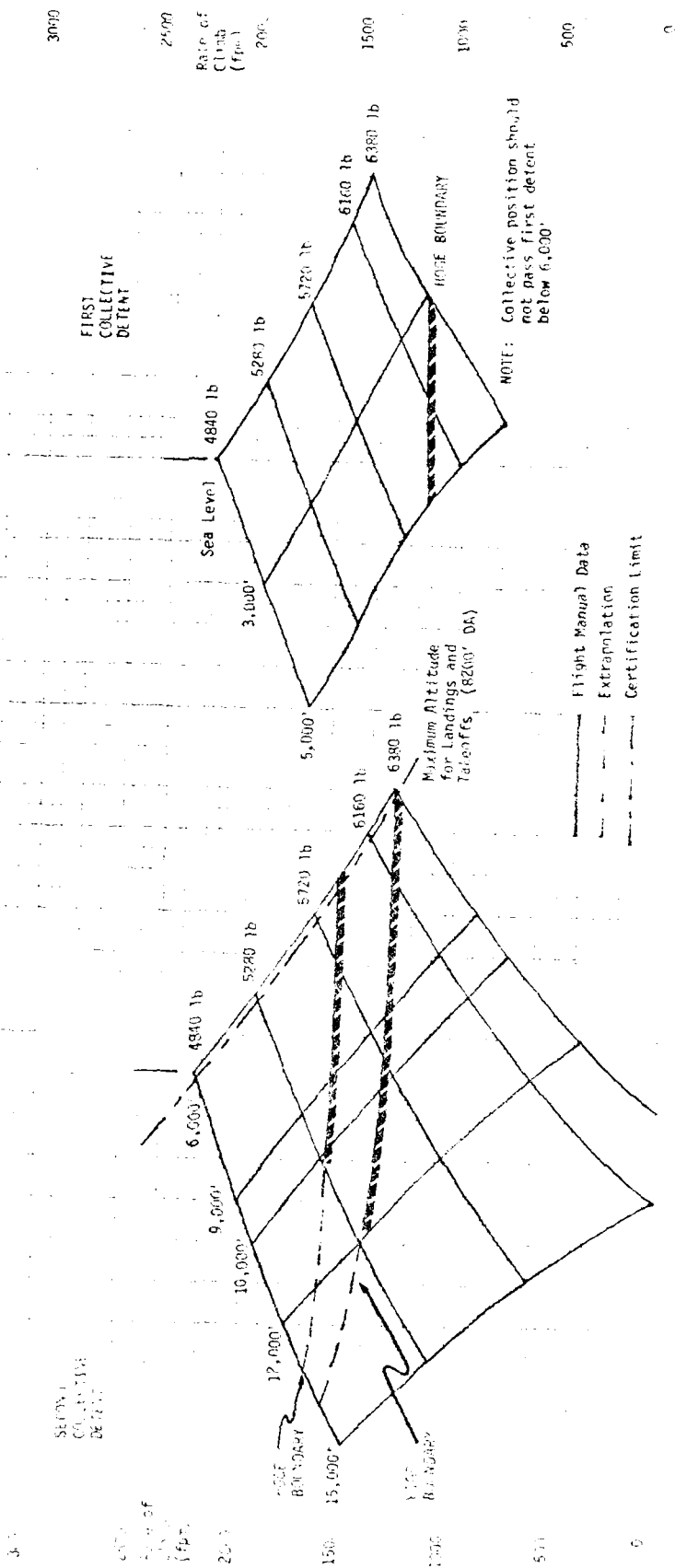
Climb Rates

The following two figures present carpet plots of best rate of climb attainable at optimum speed and minimum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents standard day performance and the other hot day performance based on temperatures uniformly 20°C warmer than standard day for all altitudes.

Each figure employs two carpets. The right hand carpet covers pressure altitudes from sea level to 6,000 feet; the left hand, from 6,000 to 15,000 feet. The double presentation results from a power limit imposed on the SA-360C below 6,000 feet. Two collective pitch control detents are utilized in the flight control system. Collective pitch is not to be increased beyond the first detent below 6,000 feet. Collective pitch up to the second detent is permitted to 15,000 feet. In all cases transmission torque limits are to be observed.

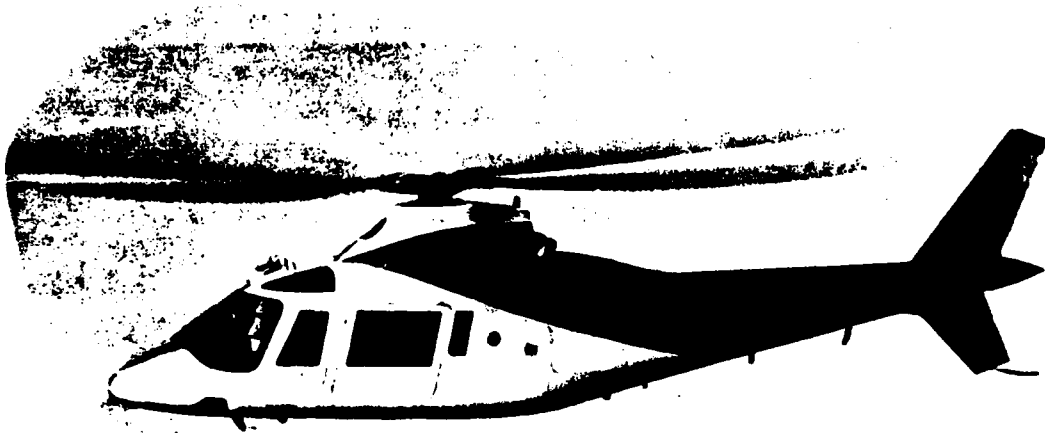


SA 360 C Dauphin Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



SA 360 C Dauphin Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures +20°C)

THE AGUSTA A109A HELICOPTER



LIGHTWEIGHT SINGLE MAIN ROTOR HELICOPTER POWERED BY TWO TURBOSHAFT ENGINES.
DESIGNED FOR EXECUTIVE AND UTILITY TRANSPORT.

MANUFACTURER: COSTRUZIONI AERONAUTICHE GIOVANNI AGUSTA OF MILAN,
ITALY

POWER PLANT: Two Detroit Diesel Allison Model 250-C20B free power turbine engines rated at 420 SHP each for takeoff and 400 SHP each for maximum continuous operations. The transmission is torque limited to permit a total of 692 SHP for either takeoff or continuous operations with two engines.

AIRCRAFT UTILITY: FAA certificated under Type Certificate H7EU Revision 4 of November 14, 1978, for FAR Part 27. STC No. SH 2699SW provides single or dual pilot IFR capability.

SEATING CAPACITY: Variable cabin arrangements permit seating for up to 8 persons (crew included).

INTRODUCTION

The A109A is an 8-place lightweight helicopter manufactured by Costruzioni Aeronautiche Giovanni Agusta of Milan, Italy. The helicopter was designed for civil use in executive and utility transport roles.

Standard configuration includes a four-bladed, single, main rotor with anti-torque tail rotor. Landing gear is retractable in tricycle configuration.

The A109A is powered by two Detroit Diesel Allison Model 250-C20B turbo-shaft engines. Each engine can produce 420 SHP at takeoff (5 minute) rating or 400 SHP continuously. The transmission is torque limited to 692 SHP with both engines operating without time limit. Following failure of one engine the transmission may accept 400 SHP from the remaining engine for 5 minutes or 385 SHP continuously.

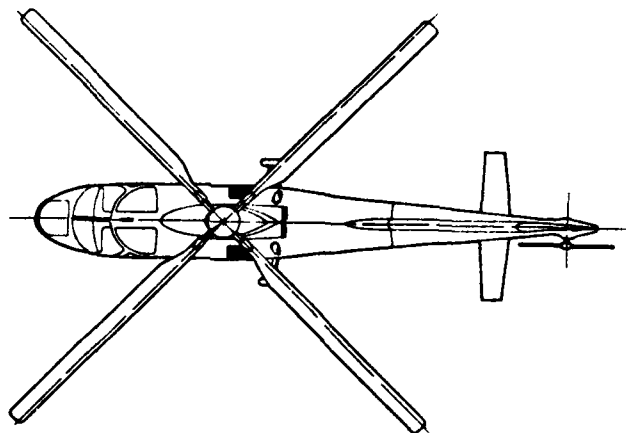
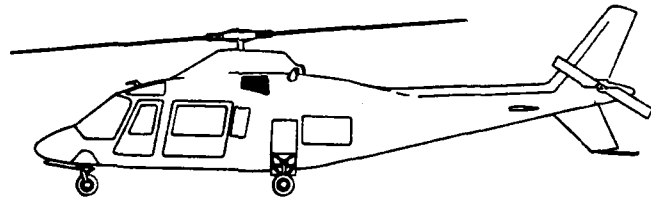
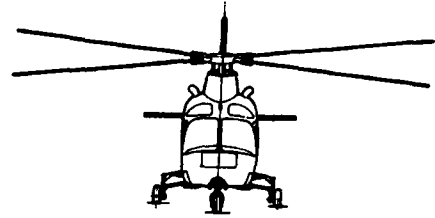
Performance data presented herein have been extracted from the Agusta A109A Flight Manual (approval date March 4, 1976) unless otherwise noted. (Autorotation rate of descent data were obtained directly from the manufacturer since they are not published in the manual.)

GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	40 KIAS
Minimum IFR Approach Speed	50 KIAS
Maximum Rate of Climb with One Helipilot Failed	500 FPM
Maximum Operating Altitude (Pressure)	15,000 ft.
V _{ne} (diminishes with increasing altitude and gross weight)	168 KIAS

DIMENSIONAL DATA

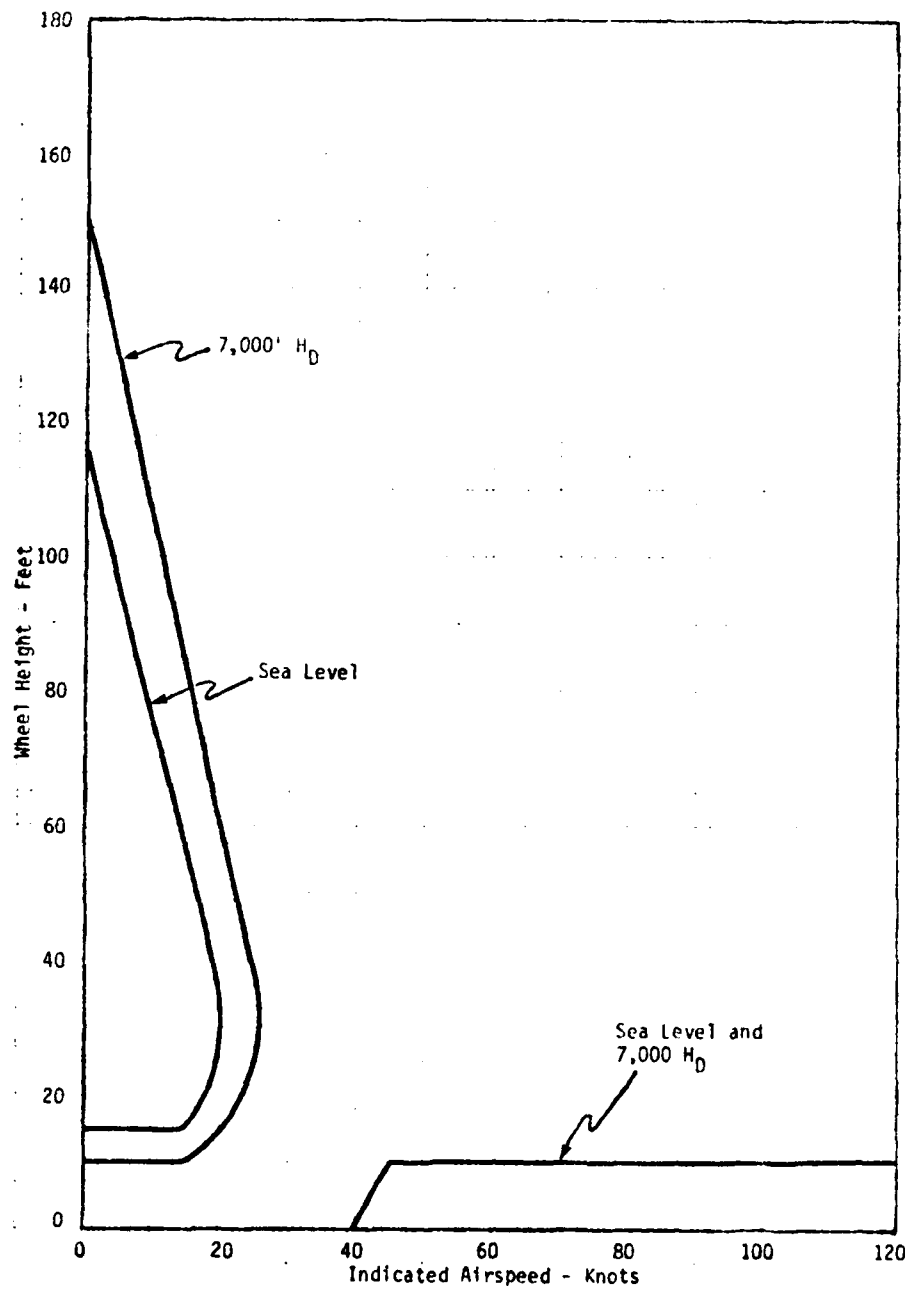
	Feet	Meters
Length	36'8"	11.14
Width	9'2"	2.88
Height	10'9"	3.30
MAIN ROTOR		
Diameter	36'1"	11.00
Chord	1'1"	0.33
Disc Area	1023 ft ²	95 m ²
TAIL ROTOR		
Diameter	6'7"	2.00
Chord	0'7"	0.20
Disc Area	34 ft ²	3.14 m ²



Agusta A109A - 3 View

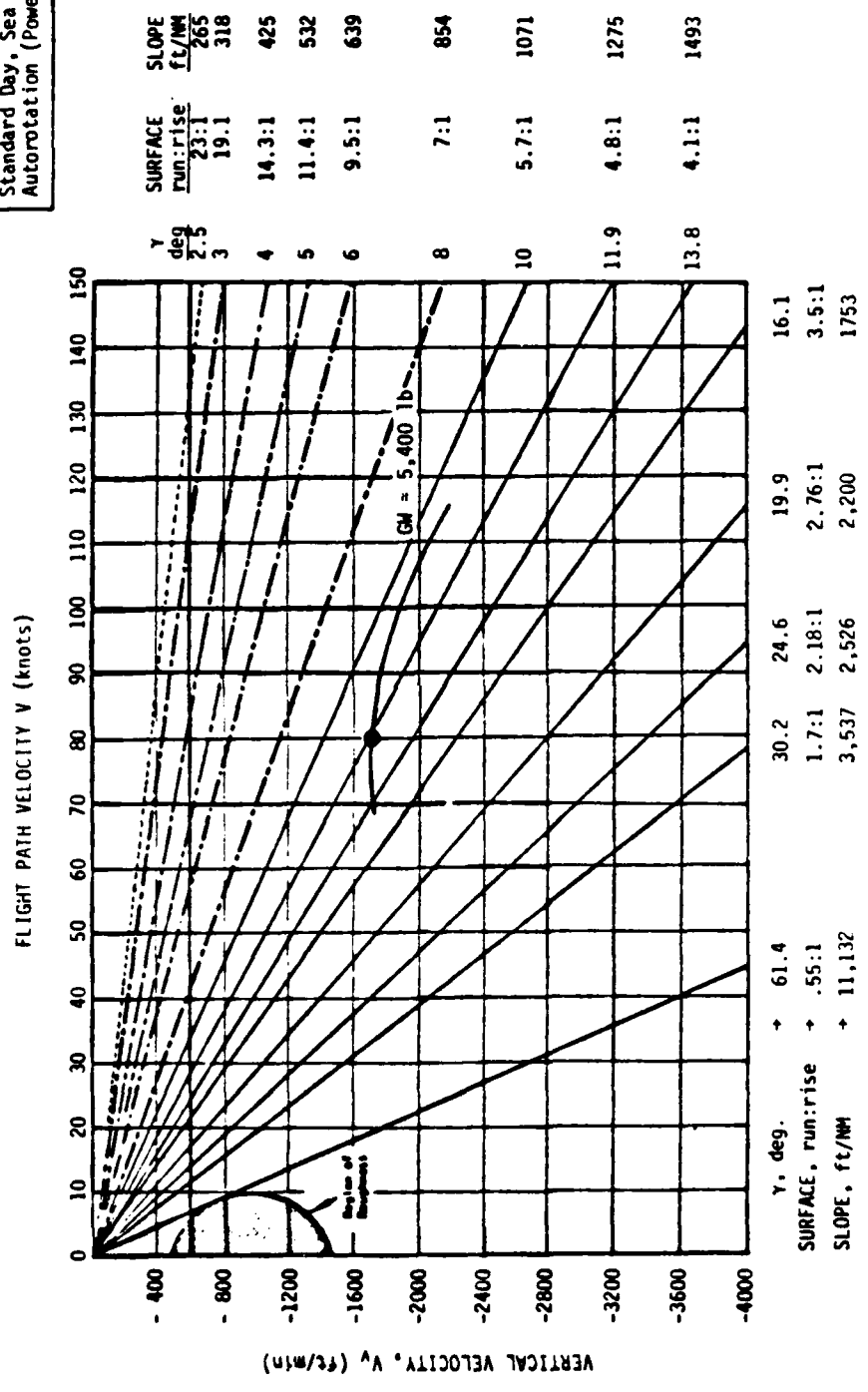
V _{NE} Kts IAS						
OAT °C \ Hp ft	S.L.	3000	6000	9000	12000	15000
35	168	167	158	149	141	132
25	168	168	161	152	144	135
15	168	168	164	155	147	138
5	168	168	167	158	149	141
-5	168	168	168	160	152	144
-15	168	168	168	163	155	147
-25	168	168	168	165	158	149
-35	168	168	168	168	160	152

Agusta A109A Airspeed Limitations



Agusta A109A Height Velocity Diagram
(One Engine Inoperative)

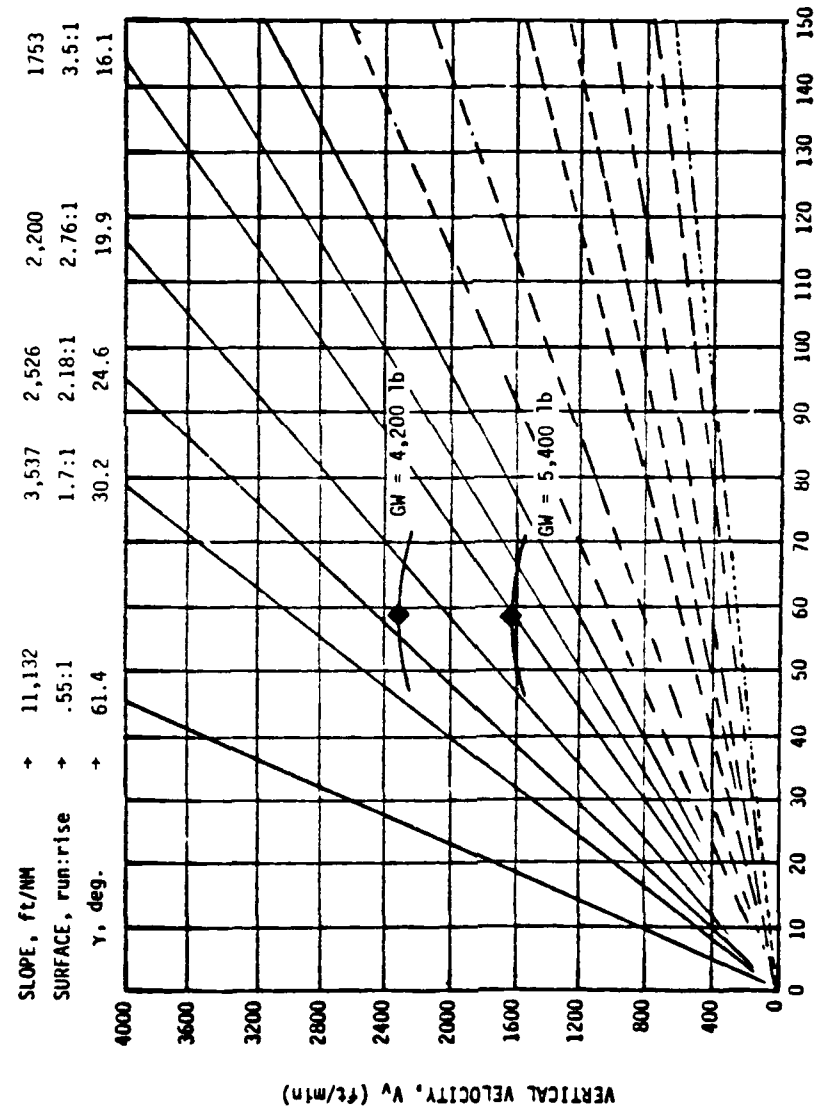
Agusta A109A
Standard Day, Sea Level
Autorotation (Power Off)



● Data Provided by Agusta, Curve Based on PACER Engineering Estimate

Descent Rate Versus Flight Path Velocity

Agusta A109A
Standard Day, Sea Level
Maximum Continuous Power



Y, deg	SURFACE run:rise	SLOPE ft/NM
13.8	4.1:1	1493
11.9	4.8:1	1275
10	5.7:1	1071
8	7:1	854
6	9.5:1	639
5	11.4:1	532
4	14.3:1	425
3	19.1	318
2.5	23:1	265

FLIGHT PATH VELOCITY V (knots)

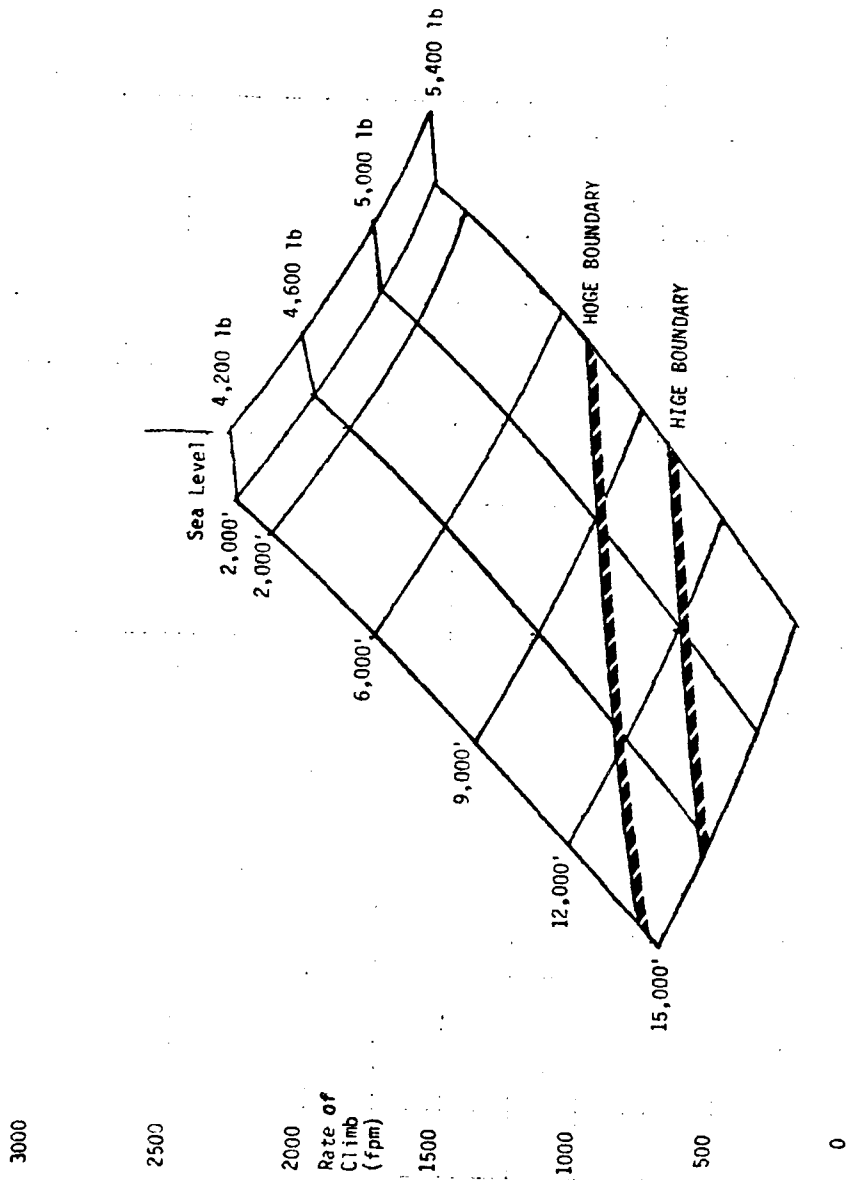
◆ Flight Manual Data Points

Climb Rate Versus Flight Path Velocity

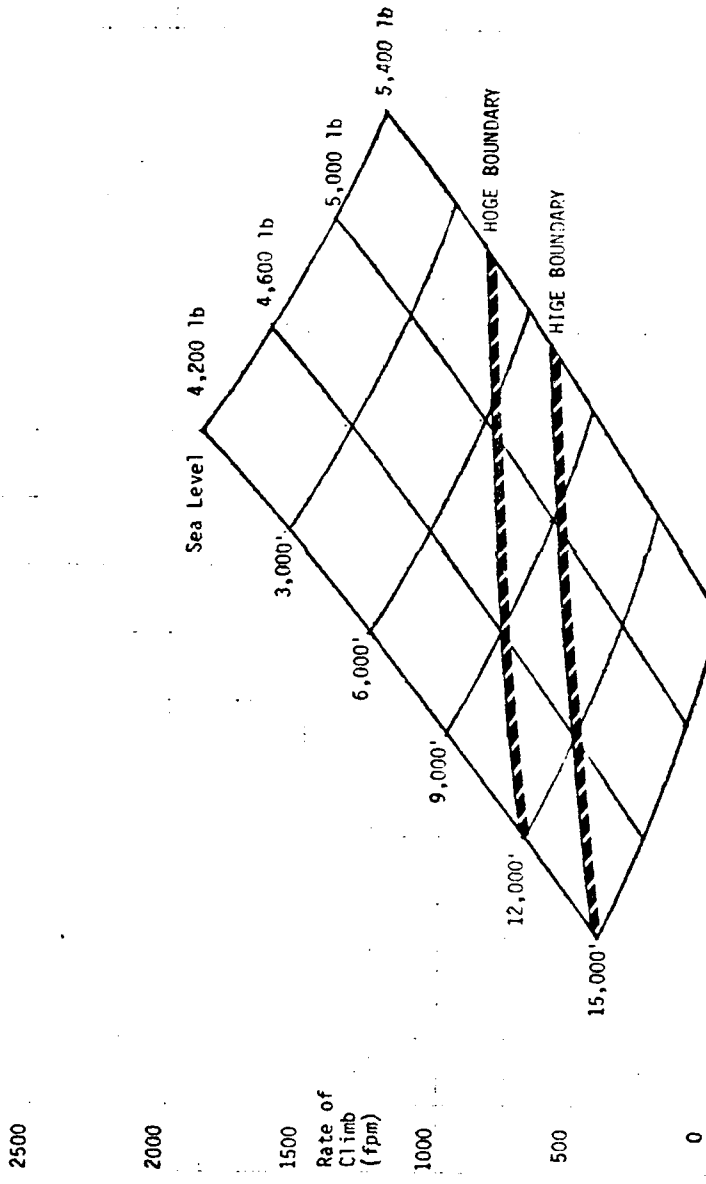
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)



Agusta A-109 Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



Agusta A-109 Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

THE BELL MODEL 206L-1 LONGRANGER II HELICOPTER



LIGHTWEIGHT SINGLE MAIN ROTOR HELICOPTER POWERED BY A SINGLE TURBINE ENGINE, DESIGNED FOR GENERAL PURPOSE OPERATIONS.

MANUFACTURER: BELL HELICOPTER TEXTRON

POWER PLANT: One Allison Model 250-C28B turboshaft engine with free power turbine rated at 435 SHP for takeoff, 370 SHP for continuous operations.

AIRCRAFT UTILITY: FAA certified for single pilot IFR flight.

SEATING CAPACITY: Variable cabin arrangement permits seating configurations for up to 7 persons (crew included).

INTRODUCTION

The Model 206L-1 LongRanger II is a 7-place lightweight helicopter manufactured by Bell Helicopter Textron of Fort Worth, Texas. The helicopter is designed for general purpose uses in the civil sector. It is a stretched version of the Model 206 JetRanger series which includes the military light observation helicopter OH-58A Kiowa and the naval training helicopter TH-57A SeaRanger. The LongRanger II has been FAA certificated for single pilot IFR when equipped with functioning autopilot, force trim and normally required instruments, navigation and communication equipment. Flight into IMC is prohibited upon installation of certain auxiliary equipment packages such as the cargo hook, several landing gear and flotation options and other externally carried equipment not approved for IFR flight.

Standard configuration includes fixed skid landing gear, teetering two-bladed main rotor and conventional two-bladed tail rotor. Weighted main rotor blades ensure high rotational inertia for good auto rotational landing capabilities and minimized gust sensitivity.

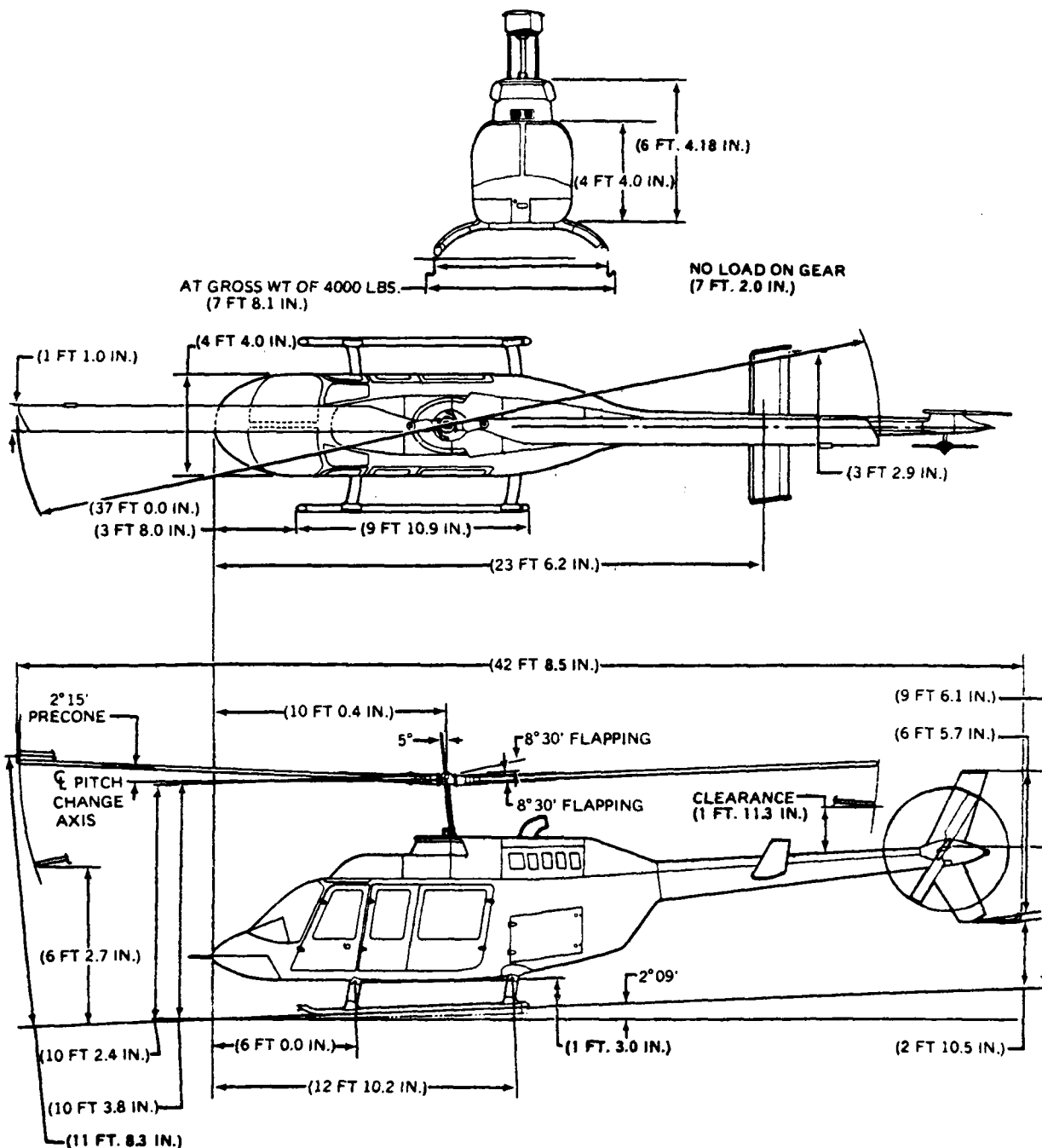
The Model 206L-1 is powered by one Detroit Diesel Allison Model 250-C28B turboshaft engine of the free power turbine type. The power turbine section is two stage. Integral reduction gearing reduces output shaft rpm to 6000. Maximum horsepower is 435 SHP. Continuous rating is for 370 SHP.

GENERAL IFR PERFORMANCE DATA*

Minimum IFR Airspeed (Cruise, descent & approach)	60 KIAS
Minimum IFR Climb Speed	70 KIAS
Recommended IFR Climb Speed	80 KIAS
Recommended IFR Approach Speed	100 KIAS
Maximum IFR Vertical Velocity (Climb or Descent)	1000 ft/min
Maximum Precision Approach Glide Slope	3.5°
IFR Altitude Limit	15,000 ft.
Minimum Speed to Disengage Autopilot (except Attitude Retention)	60 KIAS

* Data from FAA approved IFR Supplement for 206-705-001 IFR Configuration certified December 20, 1978 (with Revision 1 thereto).

Bell Helicopter **TEXTRON**



206L-1 Three View Drawing

(Extracted from Bell literature)

IFR CONFIGURATION

PLACARDS

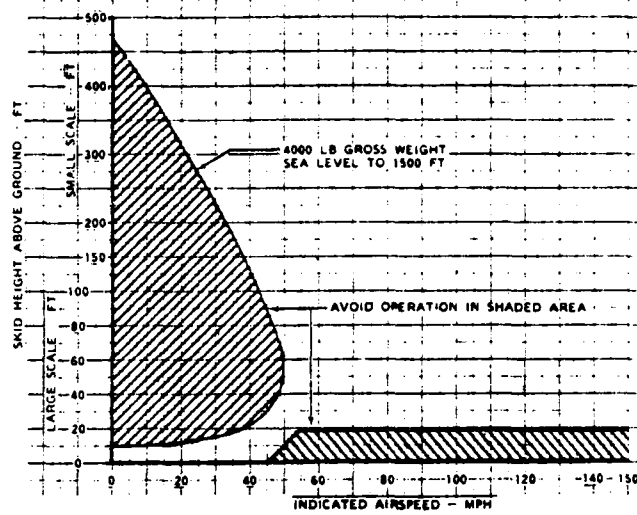
AIRSPEED LIMITATIONS												
Hp	FT	0	2	4	6	8	10	12	14	16	18	20
	1000	VNE - IAS - KTS										
36	130	—	—	—	—	—	—	—	—	—	—	—
40	130	127	—	—	—	—	—	—	—	—	—	—
20	130	130	126	120	114	107	101	—	—	—	—	—
0	130	130	130	126	120	113	107	100	94	88	81	—
20	130	130	130	130	126	119	113	107	100	94	87	—
40	128	123	120	115	111	107	103	99	96	91	88	—
50	117	113	109	105	102	97	94	90	87	83	80	—

AUTOPILOT ENGAGED											
Hp	FT	0	2	4	6	8	10	12	14	15	
	1000										
20	130	130	129	124	120	114	109	106	103	—	
40	119	114	110	106	101	97	94	89	87	—	
50	108	104	99	95	92	87	84	81	80	—	

L206099-3

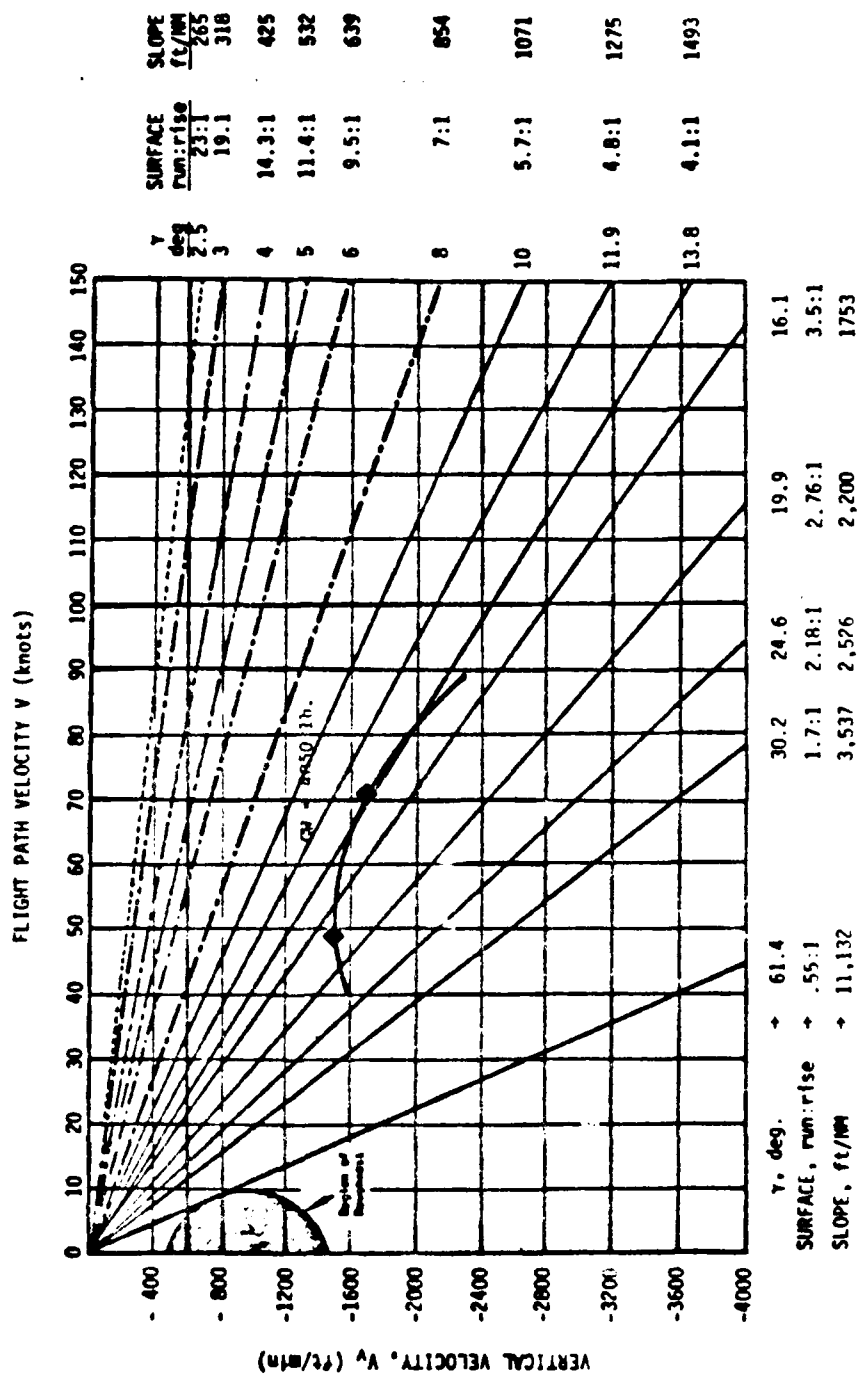
(Extracted from Flight Manual)

HEIGHT VELOCITY DIAGRAM



(Extracted from Flight Manual)

BELL 206 L-1
STANDARD DAY SEA LEVEL
AUTOROTATION (Power off)



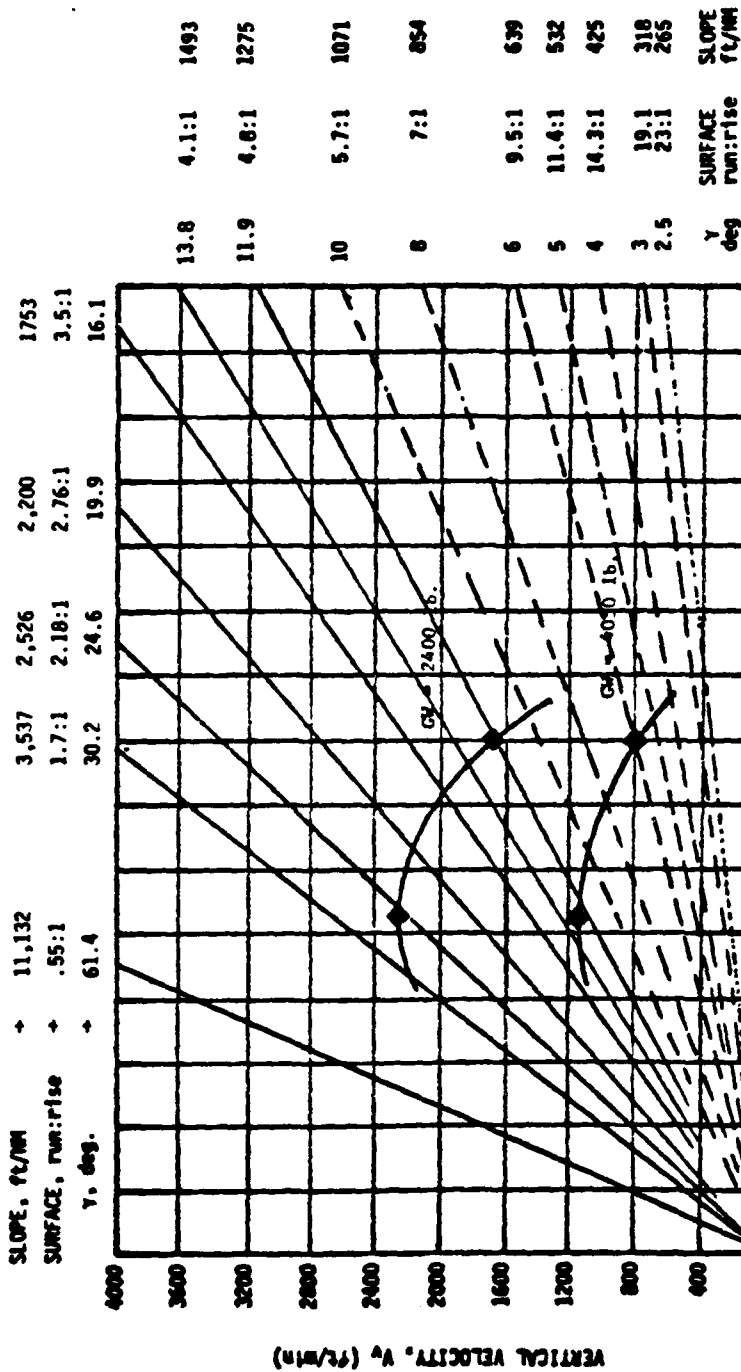
Y, deg. + 61.4
SURFACE, run:rise + 1.7:1
SLOPE, ft/min + 3,537

30.2 24.6 19.9 16.1
1.7:1 2.18:1 2.76:1 3.5:1
3,537 2,526 2,200 1753

◆ Bell supplied data points

Note: Following IFR limits apply: Minimum IFR descent speed, 60 KTAS;
Maximum rate of descent, 1000 ft/min. Maximum precision
glide slope, 3.5°

BELL 206 L-1
STANDARD DAY, SEA LEVEL
MAXIMUM CONTINUOUS POWER



FLIGHT PATH VELOCITY V (knots)

◆ Flight Manual Data Points

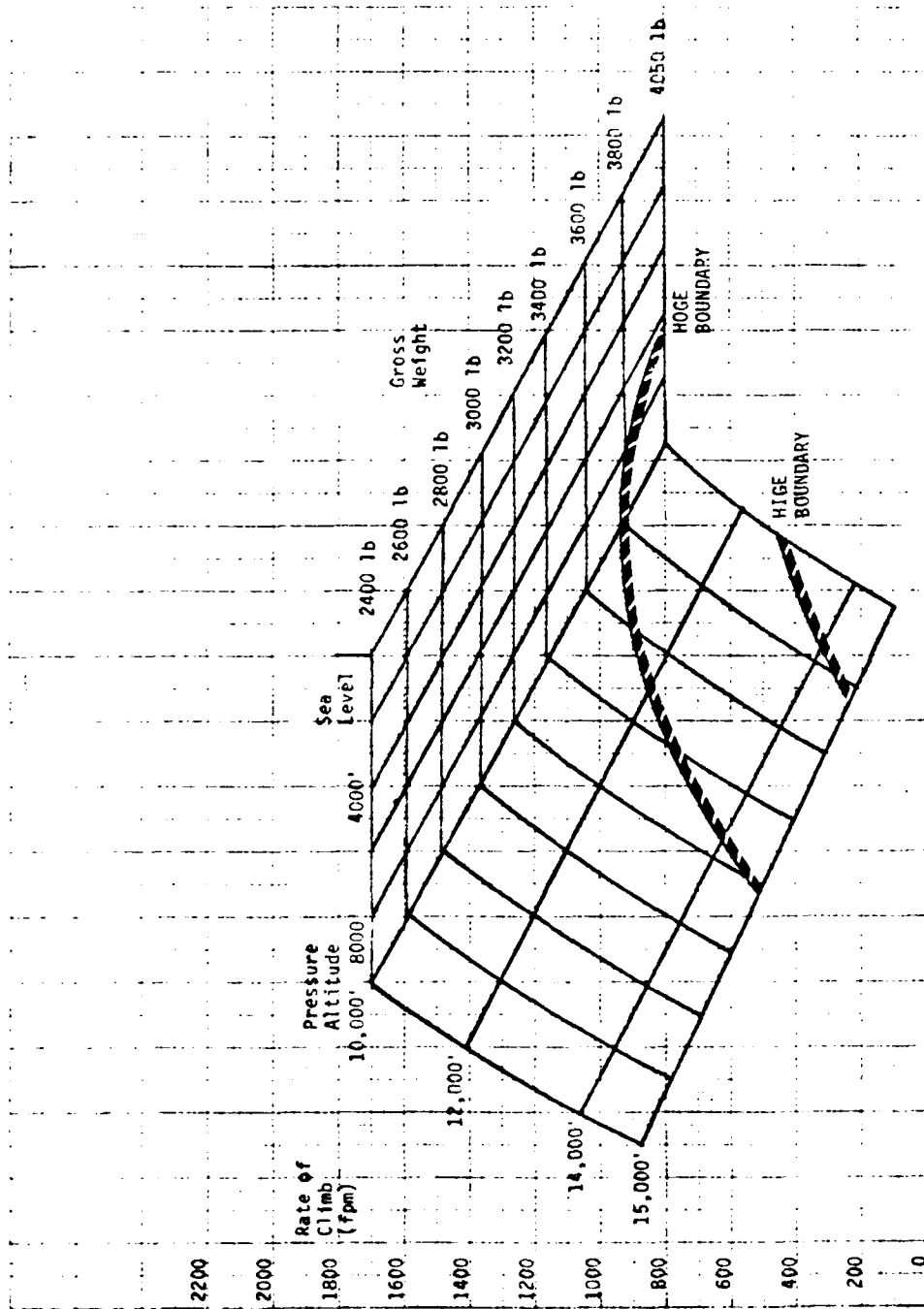
Note: Following IFR limits apply: Minimum climb speed, 70 KIAS;
Maximum rate of climb 1000 ft/min.

Climb Rates

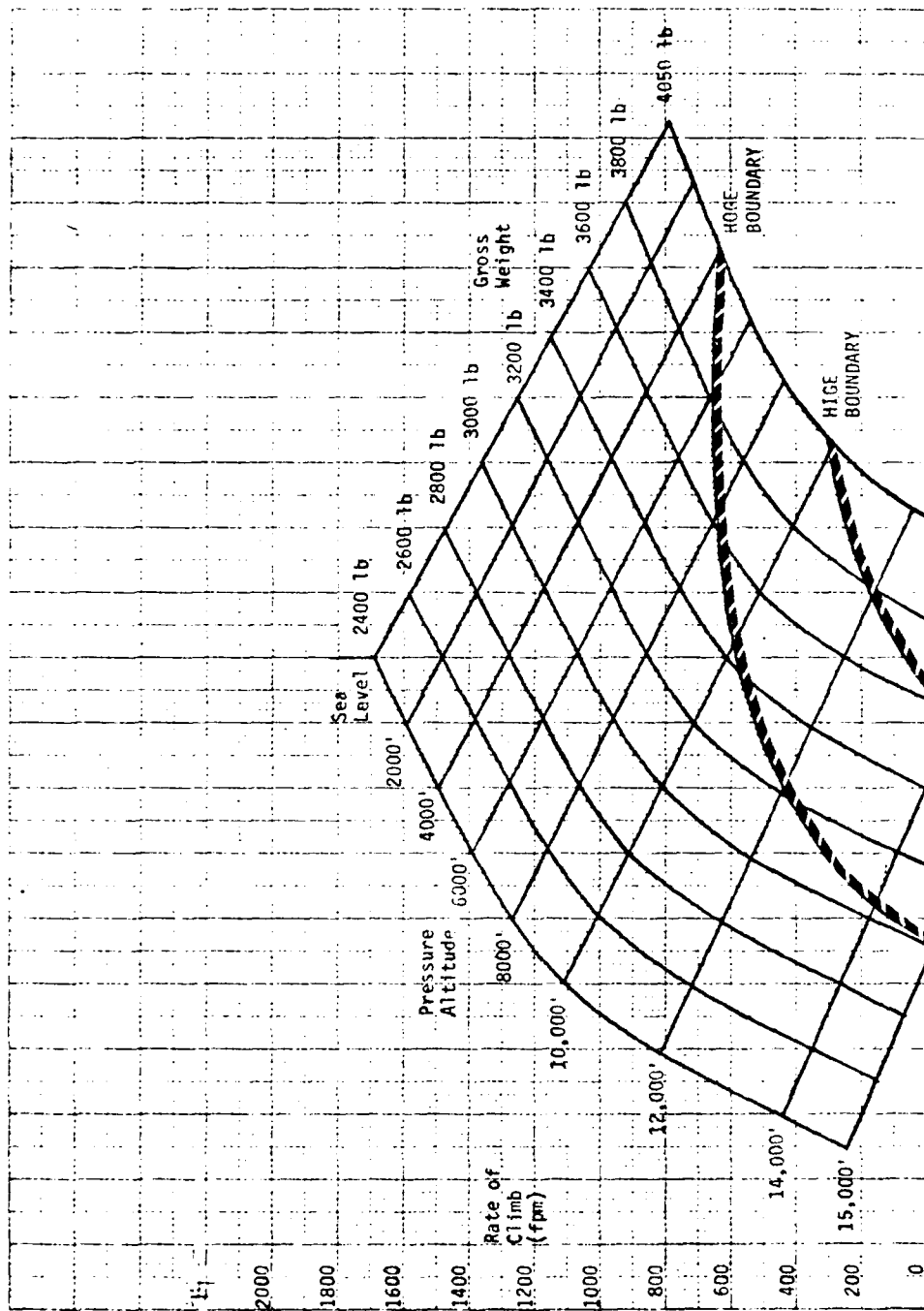
The following two figures present carpet plots of the rate of climb attainable at the recommended IFR climb speed (80 knots CAS) and maximum continuous power for a spectrum of aircraft weights and pressure altitudes. One figure presents data for standard day performance and the other hot dry performance for temperatures uniformly 20°C warmer than standard day at each altitude.

Two traces, one labelled HOGE (hover out of ground effect) Boundary and the other HIGE (hover in ground effect) Boundary cross the carpet plots to identify those combinations of altitude and gross weight at which hover capability becomes correspondingly limited. (Hover performance is based on takeoff power vice maximum continuous power used during climb.)

It can be seen that the IFR climb capability of the Bell 206L-1 does not satisfy the rule of thumb for climb gradient since combinations of gross weight and altitude exist on the hot day plot for which HOGE is possible but rate of climb is insufficient to ensure a 20:1 climb gradient (approximately 100 fpm for each 20 kts of airspeed). Consequently, pilots of this aircraft must also compute expected climb performance and its relationship to a 20:1 missed approach gradient to ensure that an adequate climb profile can be sustained if a missed approach should become necessary. Computation of expected hover performance does not alone provide such assurance as would be the case if the best rate of climb airspeed were within the envelope of acceptable IFR climb speeds.

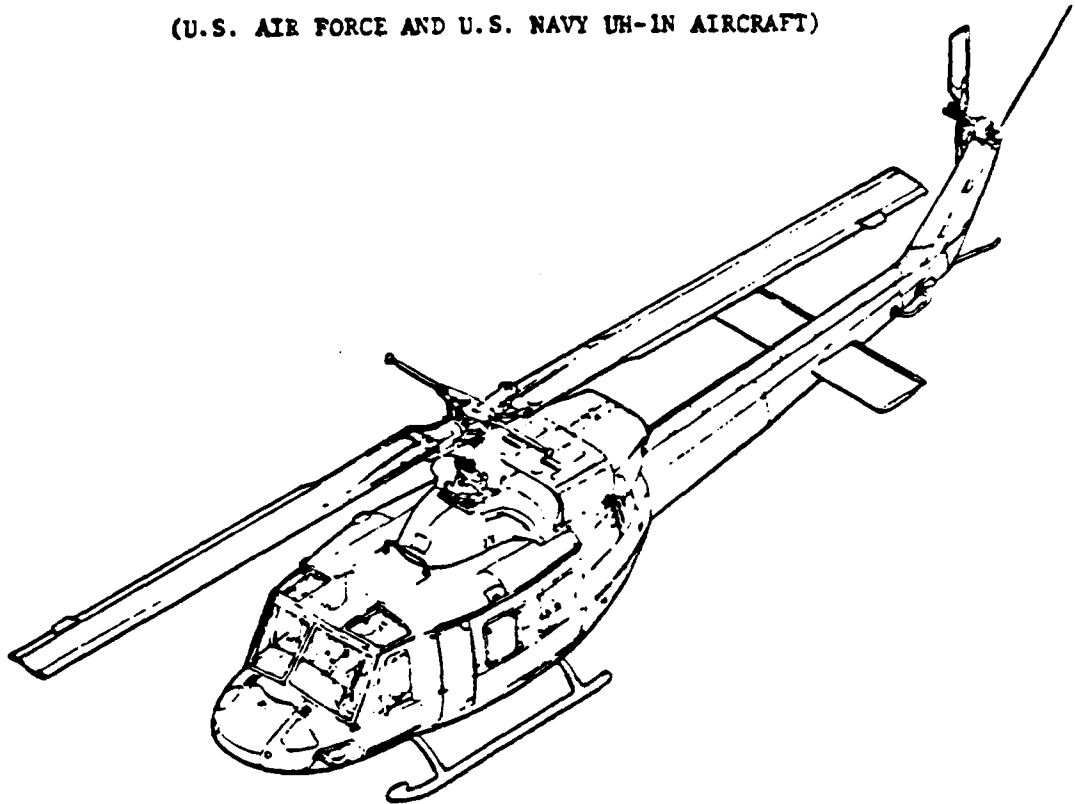


Bell 206L-1 Recommended IFR Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



Bell 206L-1 Recommended IFR Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

**THE BELL TWO-TWELVE (212) TWIN-HELICOPTER
(U.S. AIR FORCE AND U.S. NAVY UH-1N AIRCRAFT)**



MEDIUM WEIGHT HELICOPTER POWERED WITH TWIN TURBINE ENGINES AND DESIGNED FOR GENERAL PURPOSE OPERATIONS.

MANUFACTURER : BELL HELICOPTER TEXTRON

POWER PLANT : Pratt & Whitney 1800 SHP "Twin Pac" derated to 1290 SHP for takeoff and 1130 SHP for continuous operations. (Transmission is Torque Limited to 1340 SHP).

AIRCRAFT UTILITY: FAA Certified for VFR and IFR flight. Military use for VFR and IFR flight.

SEATING CAPACITY: Variable cabin occupancy arrangements with seating configurations for up to 15 persons.

INTRODUCTION

The Two-Twelve Twin is a 15-place medium weight helicopter manufactured by the Bell Helicopter Textron Company. The helicopter is designed for general purpose operations in both the civil sector (Bell 212) and the military (U.S. Air Force and U.S. Navy, UH-1N). Both the civil and military versions are capable of IFR flight. The civil version has been FAA approved for IFR flight in two versions:

- o Bell-212; FAA certified for IFR flight with a two-pilot aircrew with the Bell IFR system installed. The system contains single string, SIMPLEX, stability and control augmentation system, attitude retention autopilot, mechanical control-mixing unit, associated instruments, avionics, and controls.
- o Sperry/Bell-212; FAA certified for IFR flight with a one-pilot aircrew with the Sperry IFR system installed. The system contains redundant actuator strings, DUPLEX, stability and control augmentation systems, attitude-hold systems, associated instruments, avionics, and controls.

The military version, UH-1N, is capable of operation from prepared or unprepared takeoff and landing areas, under visual (VFR) or instrument conditions (IFR), day or night.

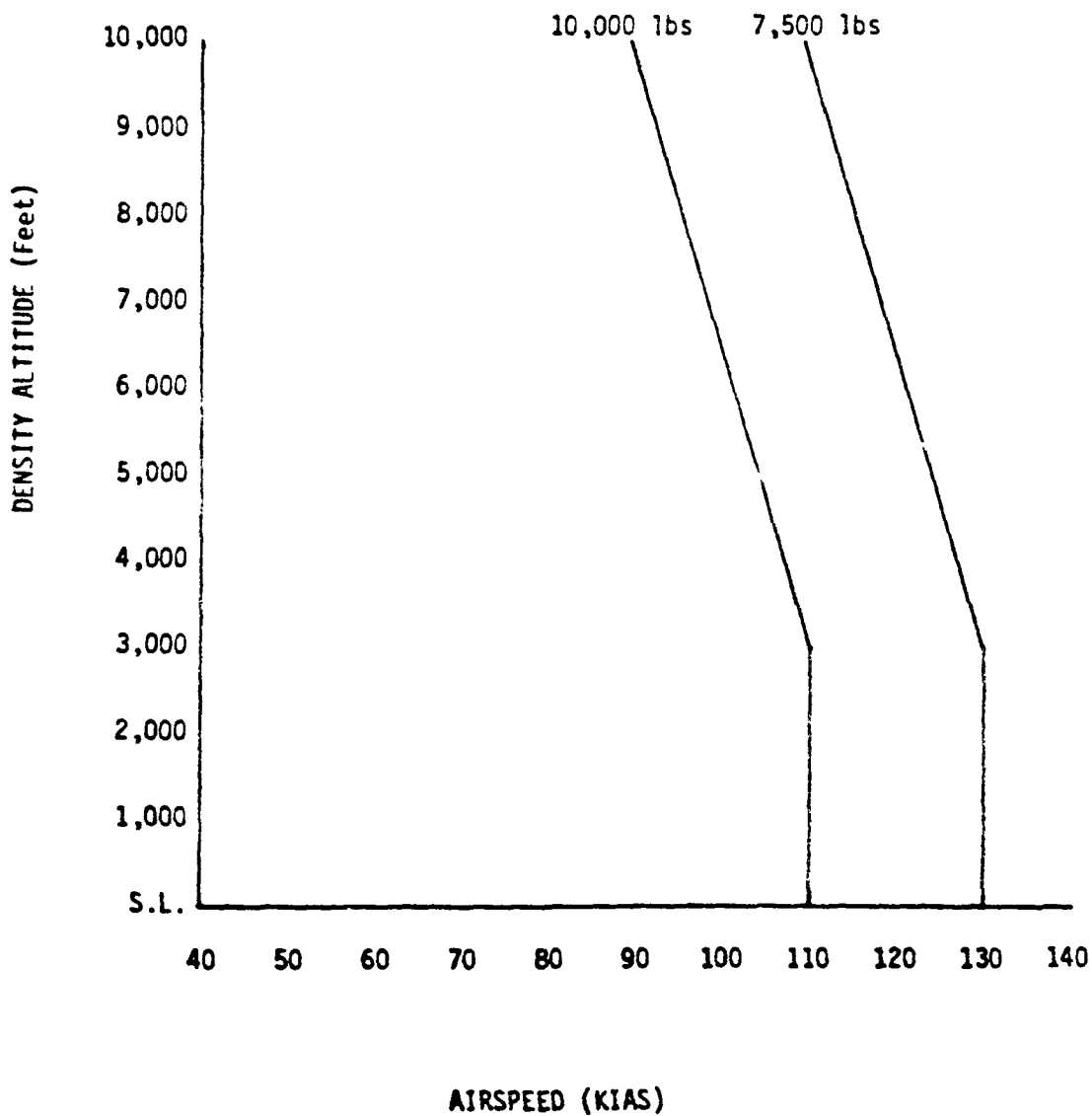
The Two-Twelve is powered by a 1800 SHP Pratt & Whitney "Twin Pac" turboshaft engine system (civil, PT6T-3 or military T400-CP-400). The engine consists of two independent power sections driving into a combining gearbox. The "Twin Pac" is derated to 1290 SHP (for Takeoff Power) and 1130 SHP (for Maximum continuous operation). A torque limiting system prevents power in excess of 1340 SHP from being applied to the transmission in the derated installation. For single engine operation, 900 SHP is available for 30 minutes and 800 SHP for continuous use. Full use was made of performance data on the Bell-212 helicopter as obtained from reports, research data, Motorcraft Flight Manuals, RPM, (IFR Book and VFR Book) as well as other supporting information and data on takeoff, descent, and climb performance as shown in material such as military flight handbooks and NATOPS Flight Manuals. This information was utilized to prepare the general performance data and to construct the PERFORMANCE AND MANEUVER CHARTS AND ENVELOPES shown on the following pages.

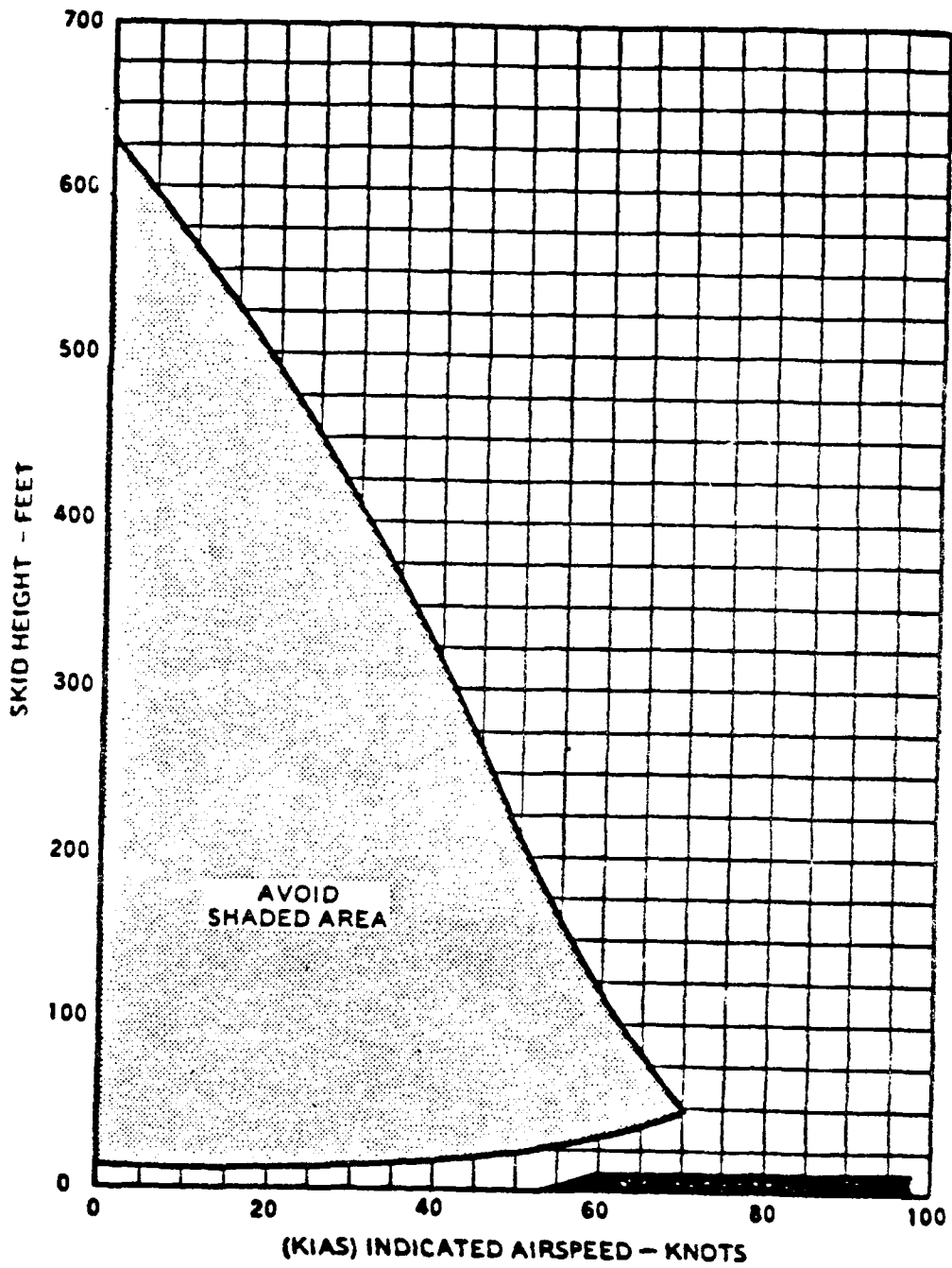
GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	Bell 212	40 KIAS
	Sperry 212	50 KIAS
	UH-1N	50 KIAS
Recommended Climb Speed		70 KIAS
Recommended Approach Speed		80 KIAS
Recommended Max Angle of Bank		30 degrees
Maximum IFR Altitude	Bell 212	20,000
	Sperry 212	14,000
	UH-1N	15,000

VNE vs Density Altitude

Bell 212
UH-1N



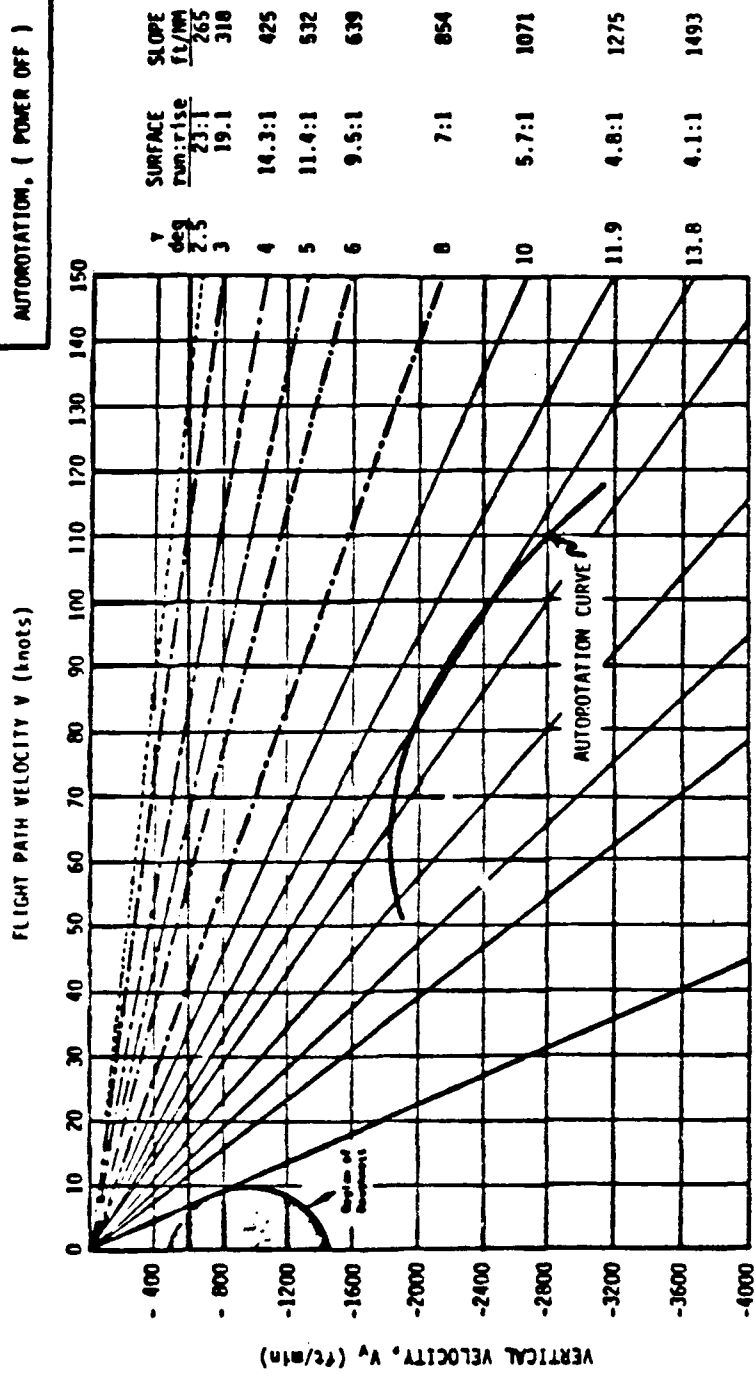


ESTIMATED DATA

REFERENCE: NATOPS FLIGHT MANUAL FOR UH-1N (Bell 212)
NAVAIR 01-110HCE-1 dated 1 MARCH 1977.

Height velocity diagram for dual engine failure

UH - 1H (BELL - 212)
 DENSITY ALTITUDE = 5, 000 ft
 GW = 10, 000 lb
 AUTOROTATION, (POWER OFF)

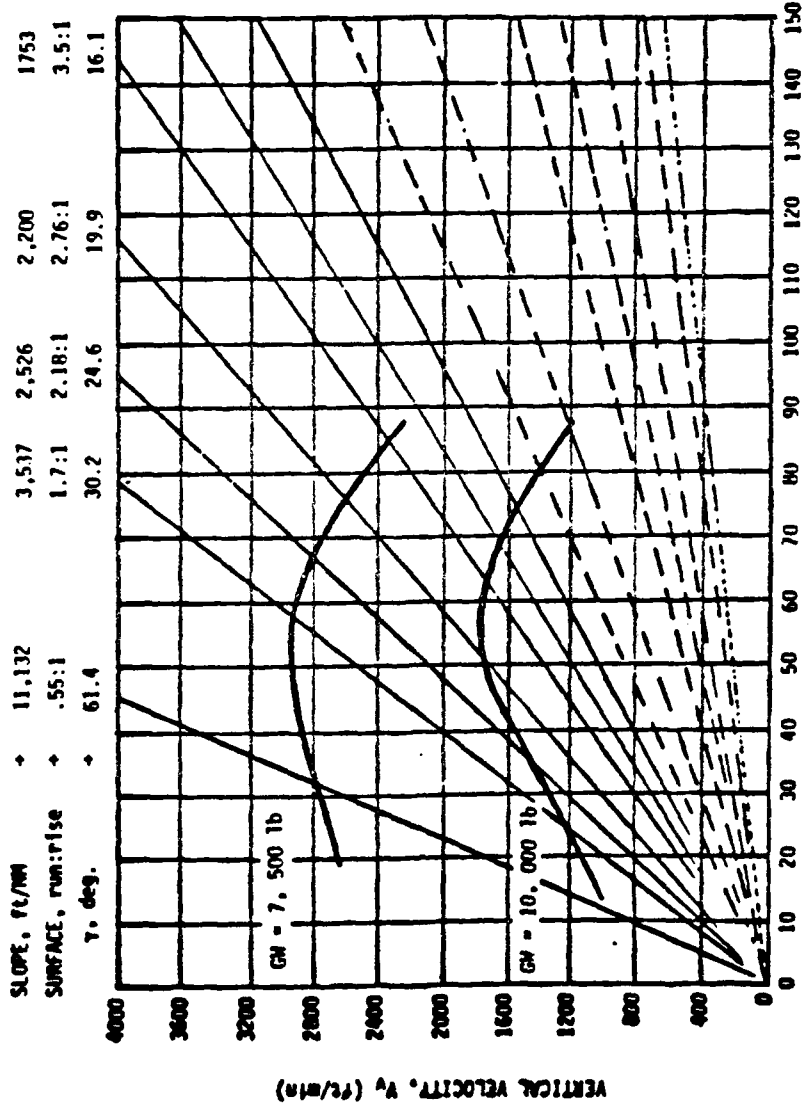


γ , deg. \rightarrow 61.4
 SURFACE, run:rise \rightarrow .55:1
 SLOPE, ft/MM \rightarrow 11,132

30.2 24.6 19.9 16.1
 1.7:1 2.18:1 2.76:1 3.5:1
 3,537 2,526 2,200 1753

DESCENT RATE VS FLIGHT PATH VELOCITY

BELL 212 (UH - 1H)
 STD. DAY, SEA LEVEL
 TAKEOFF POWER



γ	SURFACE	SLOPE
deg	run:rise	ft/NM
13.8	4.1:1	1493
11.9	4.8:1	1275
10	5.7:1	1071
8	7:1	854
6	9.5:1	639
5	11.4:1	532
4	14.3:1	425
3	19.1	318
2.5	23:1	265

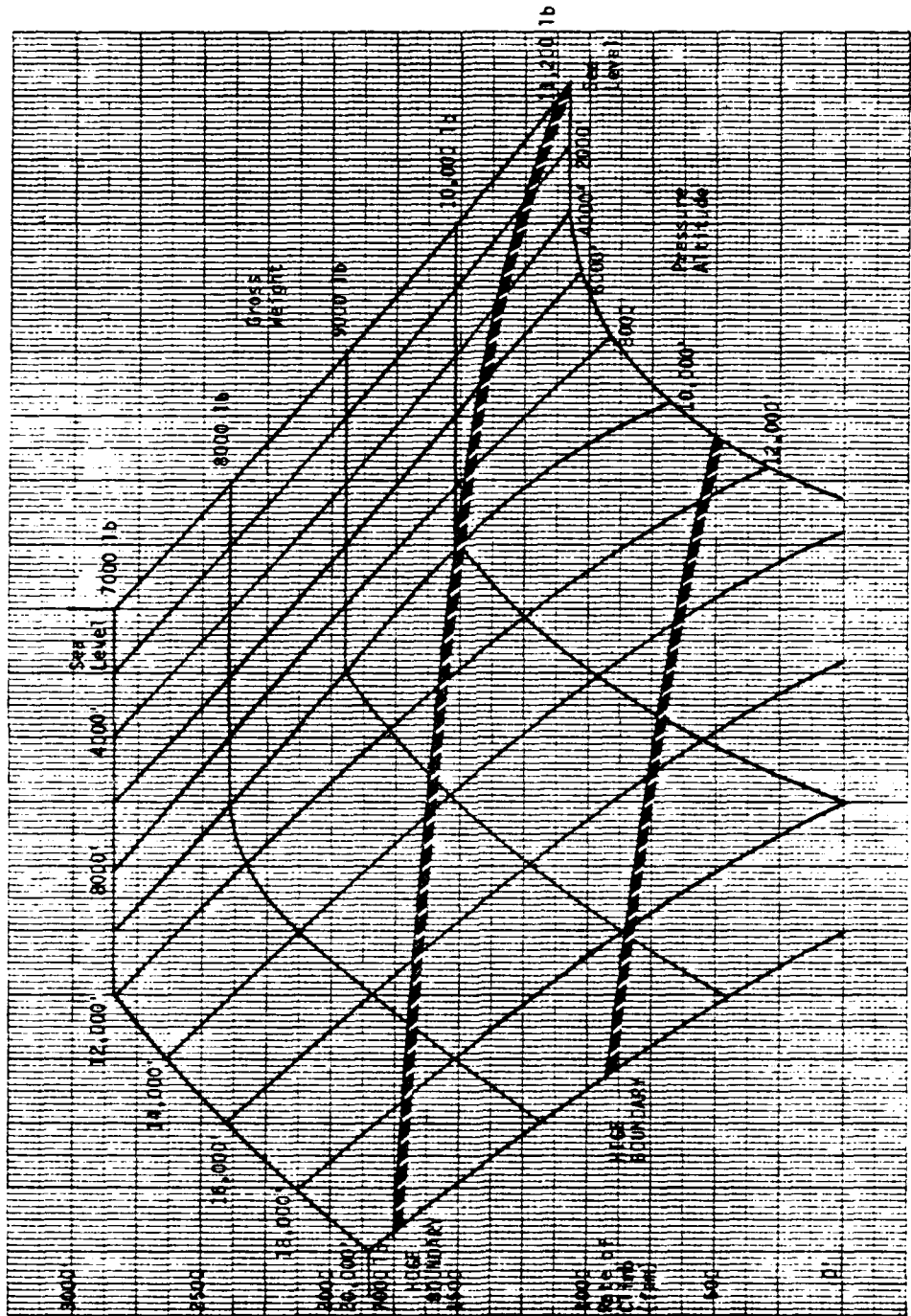
FLIGHT PATH VELOCITY V (knots)

CLIMB RATE VS FLIGHT PATH VELOCITY

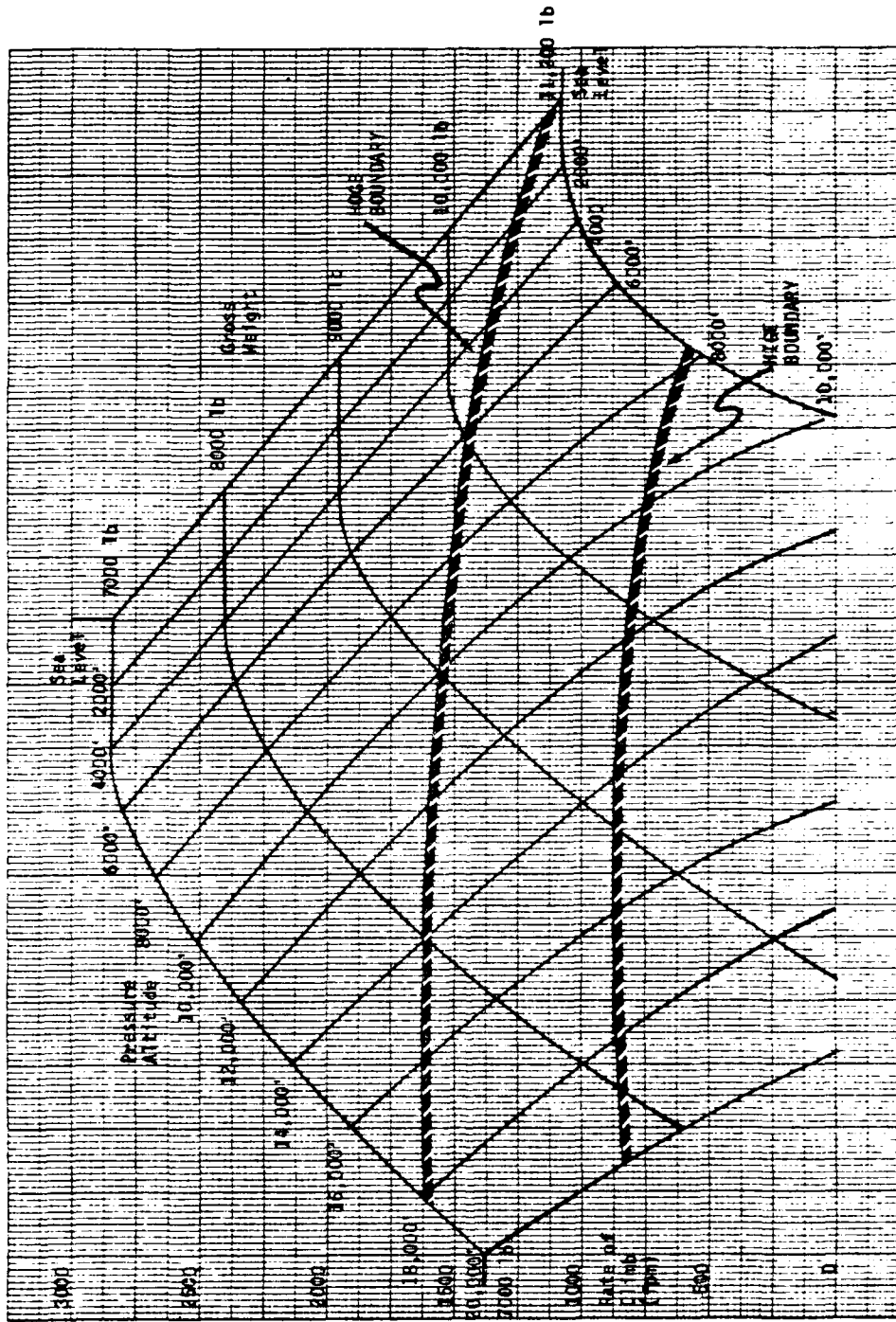
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)

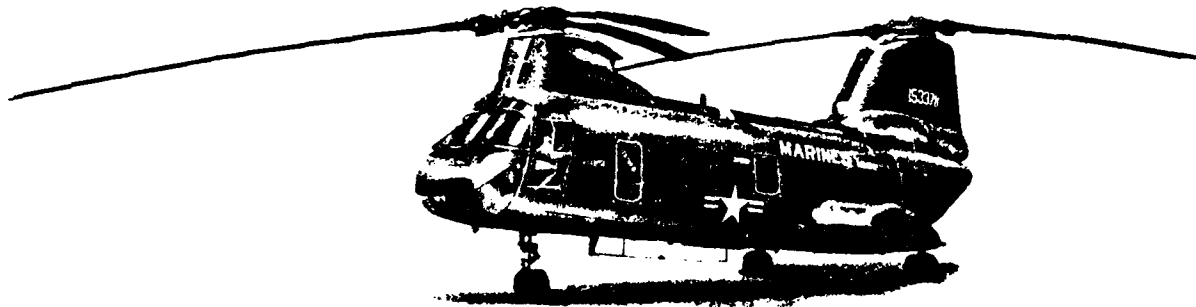


Bell 212 Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



Bell 212 Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

THE BOEING - VERTOL CH-46D (BV-107) HELICOPTER



HEAVY TANDEM ROTOR HELICOPTER POWERED BY TWO TURBINE ENGINES, DESIGNED FOR PERSONNEL AND CARGO.

MANUFACTURER: THE BOEING COMPANY, VERTOL DIVISION

POWER PLANT: Two General Electric T58-GE-10 free turbine engines rated at 1,400 SHP each for takeoff and 1,250 SHP each normal rated (maximum continuous) power.

AIRCRAFT UTILITY: Military configured for IFR flight. Maximum Gross Weight 23,000 lbs. (Civil Model 107-II less powerful with maximum gross weight of 19,000 lbs Cat B and 17,900 lbs. Cat A.)

SEATING CAPACITY: 24 troops plus 3 man crew (civil version maximum of 39 passengers).

INTRODUCTION

The CH-46D is utilized by the military for two distinct missions. The U.S. Marines use it primarily for troop movement as an assault transport with a secondary role of resupply carrying cargo internally or externally. The U.S. Navy uses it primarily for external lift of supplies between support and combatant ships. Cargo hook capacity is 10,000 lbs. (A slightly less powerful civil version, the BV 107 is currently used principally in logging operations.) Both military and civil operations require a minimum crew consisting of pilot and copilot.

The CH-46D has fixed tricycle landing gear for land operations and an emergency water landing capability with integral flotation. The rotor system consists of two three-bladed, fully-articulated rotors of equal diameter arranged in an overlapping tandem configuration. The CH-46D is powered by two T58-GE-10 turboshaft engines employing a single stage free power turbine. These are rated at 1,400 SHP (military power) for 30 minutes or 1,250 SHP (normal power) continuously. (The similar CT58-110-1 engines of the civil version are rated at 1,250 SHP takeoff limit for 5 minutes and at 1,050 SHP for maximum continuous operation. Emergency ratings with one engine inoperative permit 2 1/2 minutes operation at 1,350 SHP or 30 minutes operation at 1,250 SHP.) Both engines drive a transmission mix box located just forward of the aft transmission. The mix box combines the inputs of both engines to drive the aft transmission directly and the forward transmission by means of a synchronizing drive shaft.

The performance data shown herein have been extracted from the military NATOPS (Naval Air Training and Operating Procedures) Flight Manual for CH-46D/F and UH-46D aircraft.

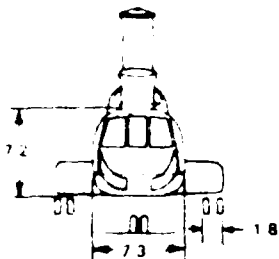
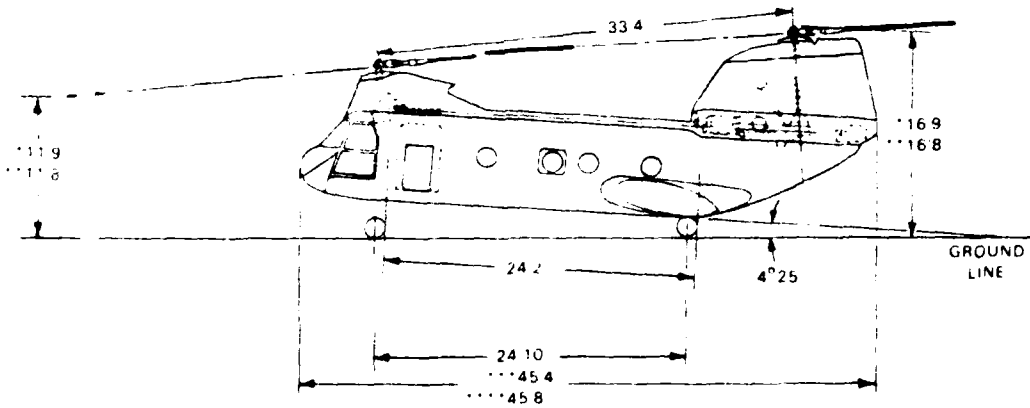
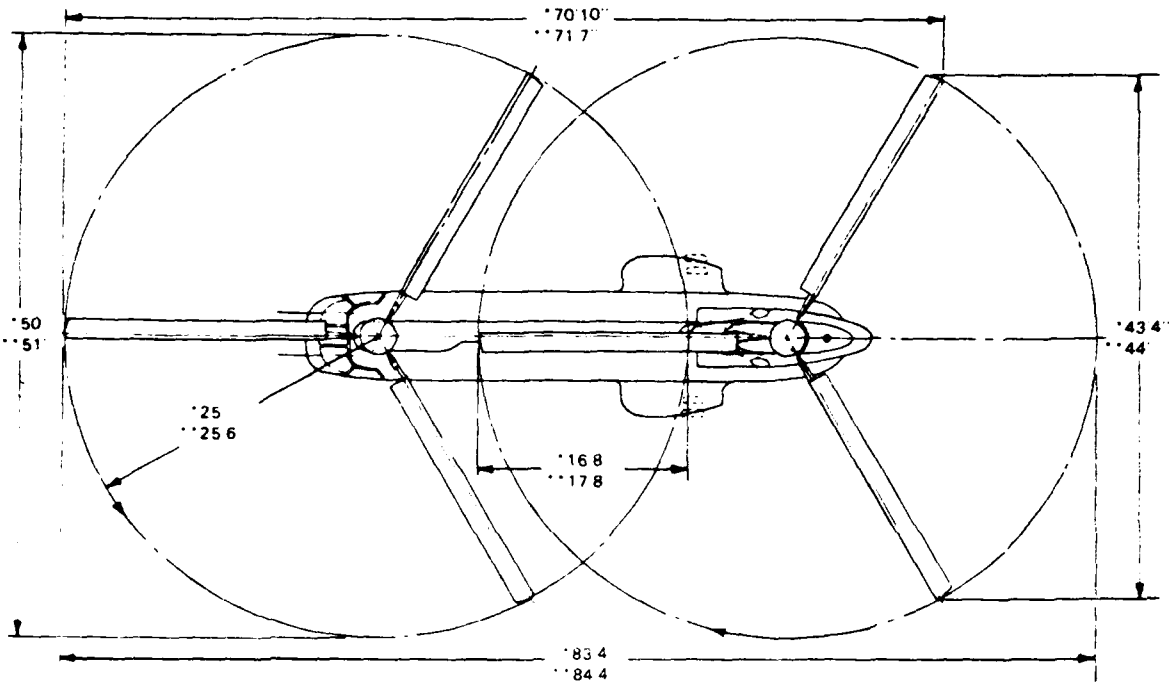
GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	40 KIAS
Recommended Climb Speed	70 KIAS
Maximum Bank Angle for Climbing Turn	20°
VNE	145 KIAS*
Recommended Approach Airspeed	Cruising Speed**

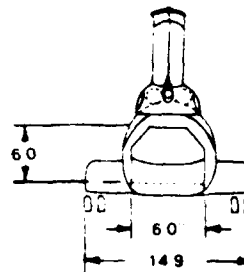
* 145 KIAS limit applies to aircraft equipped with an integral system for determining rotor blade spar integrity. H-46 aircraft not so equipped are limited to not more than 125 KIAS.

** Best range cruise speeds are typically of the order of 100-130 KIAS depending in weight and altitude with the higher speeds associated with lower altitudes. These correspond to 110-130 KTS TAS for standard day conditions. The military recommendation is based on minimization of cross wind effects in approach through use of maximum practical airspeed.

NAVAIR 01-250HDB-1



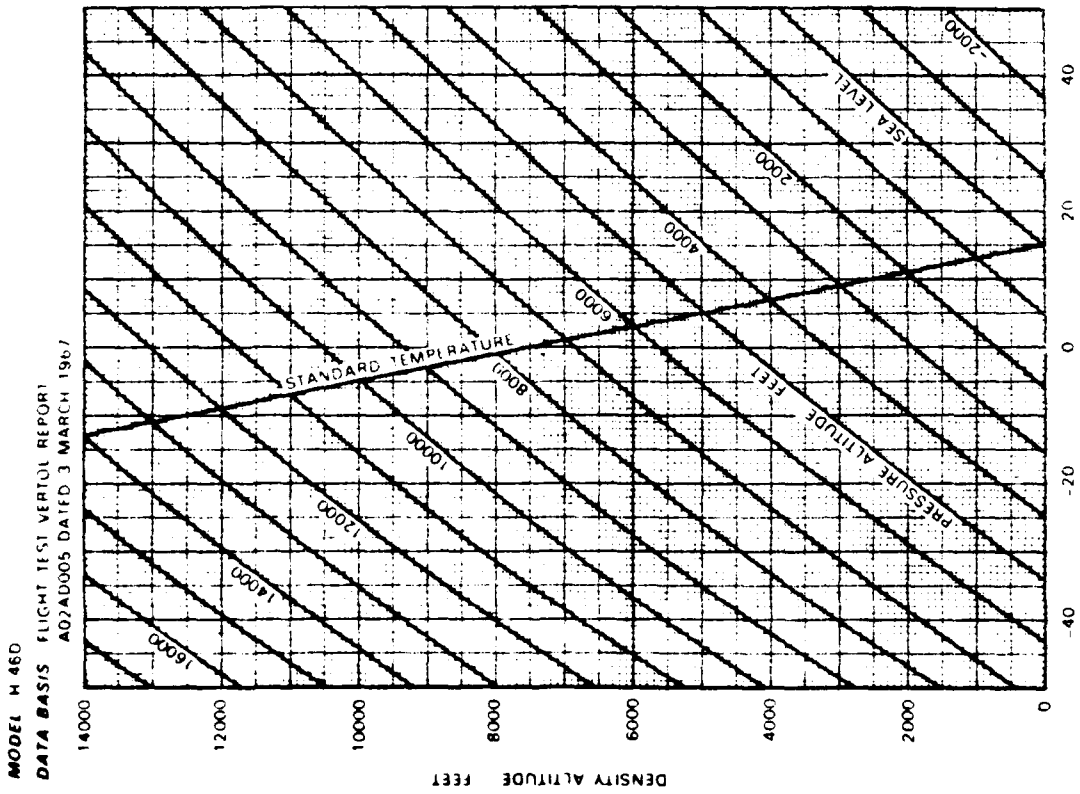
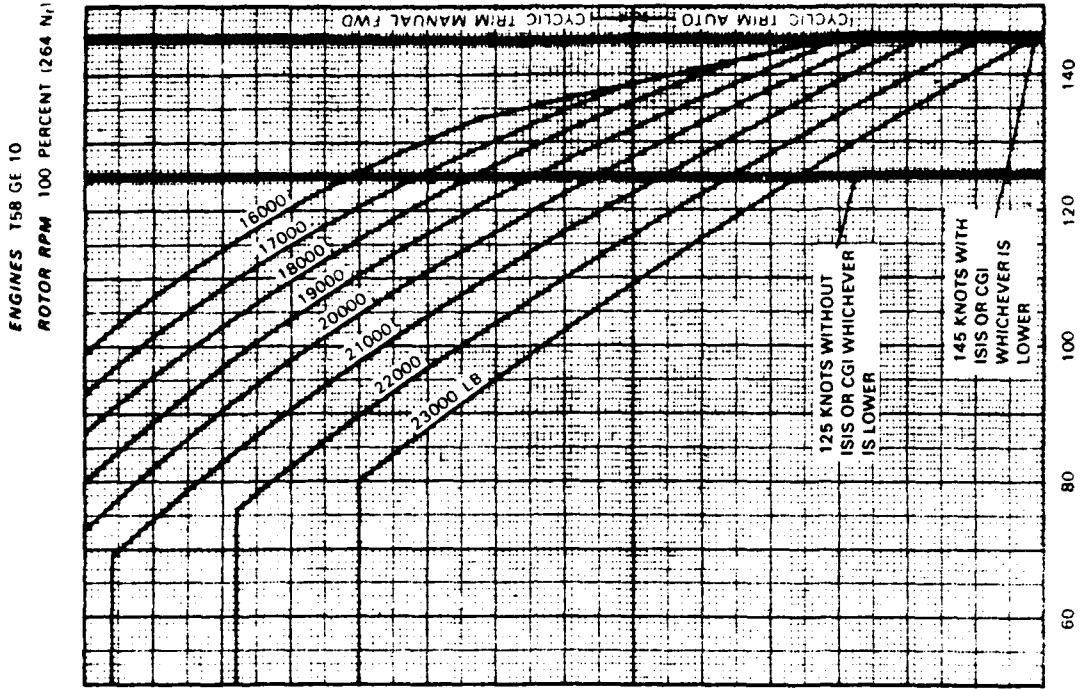
- * SERIAL 152554 THROUGH 152574
- ** SERIAL 152575 AND SUBSEQUENT (UH SERIAL 153404 AND SUBSEQUENT)
- *** SERIAL 152544 THROUGH 153412 (UH SERIAL 153404 AND SUBSEQUENT)
- **** SERIAL 153374 AND SUBSEQUENT



H-46 Dimensions

A-70

INDICATED NEVER EXCEED SPEED
VS. DENSITY ALTITUDE



NOTES: 1 Observe engine and transmission limits.
2 When operating at N₁ below 100%, reduce V_{NE} 6 KTS for each 1% below 100% N₁.

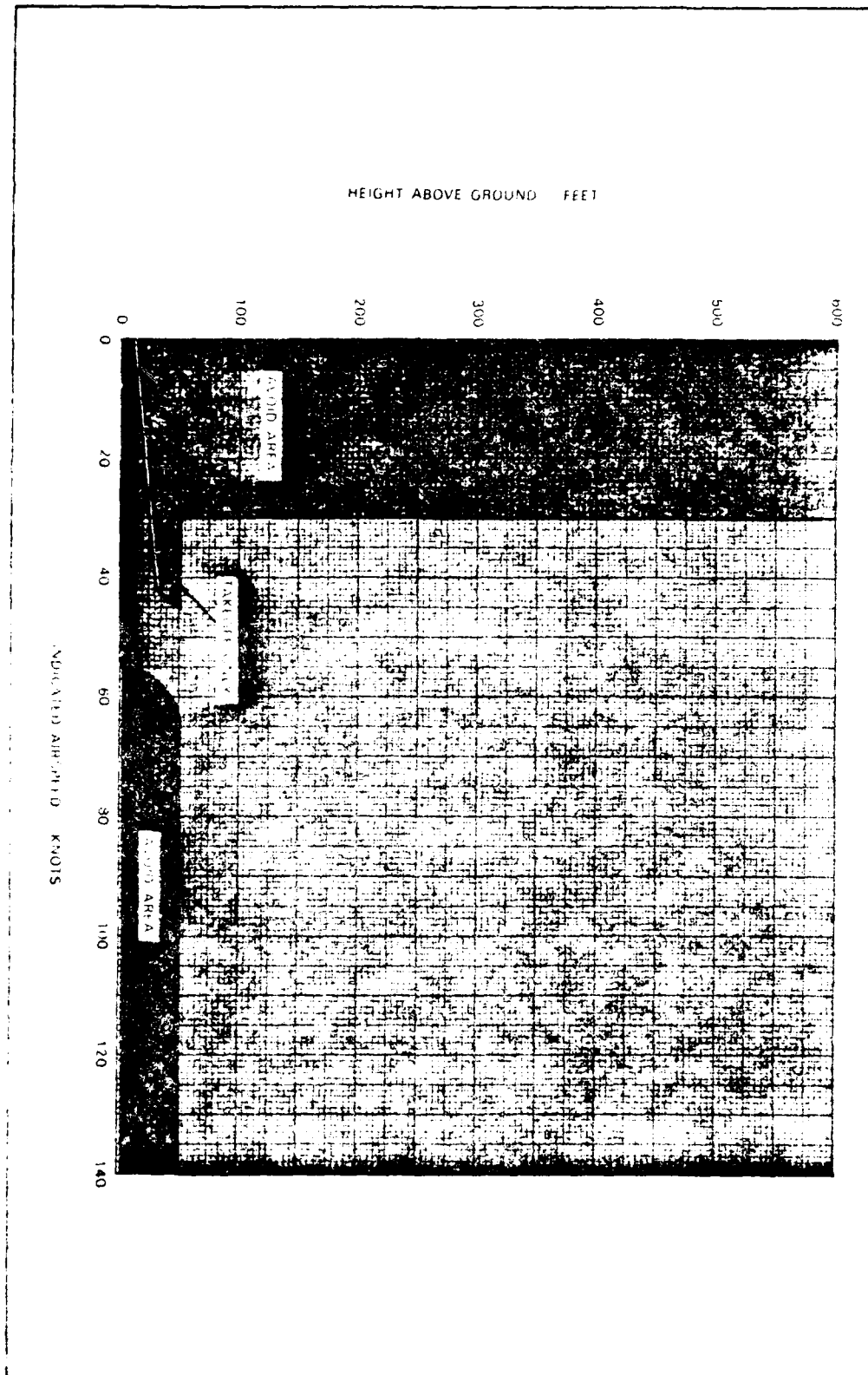
A02B-36-1-G

Airspeed Limitations (H-46D/F)

FOLLOWING SINGLE ENGINE FAILURE - 23,000 LB
GROSS WEIGHT (TAKEOFF AND LANDING
CORRIDOR SINGLE ENGINE FAILURE)

MODEL H-46D
DATA BASIS FLIGHT TEST VERTICAL REPORT
402AD005 DATED 3 MARCH 1967

ENGINE(S) 1 58 1/4 10
RPTG 1 RPM 100 PERCENT
CONDITIONS SEA LEVEL 5.1

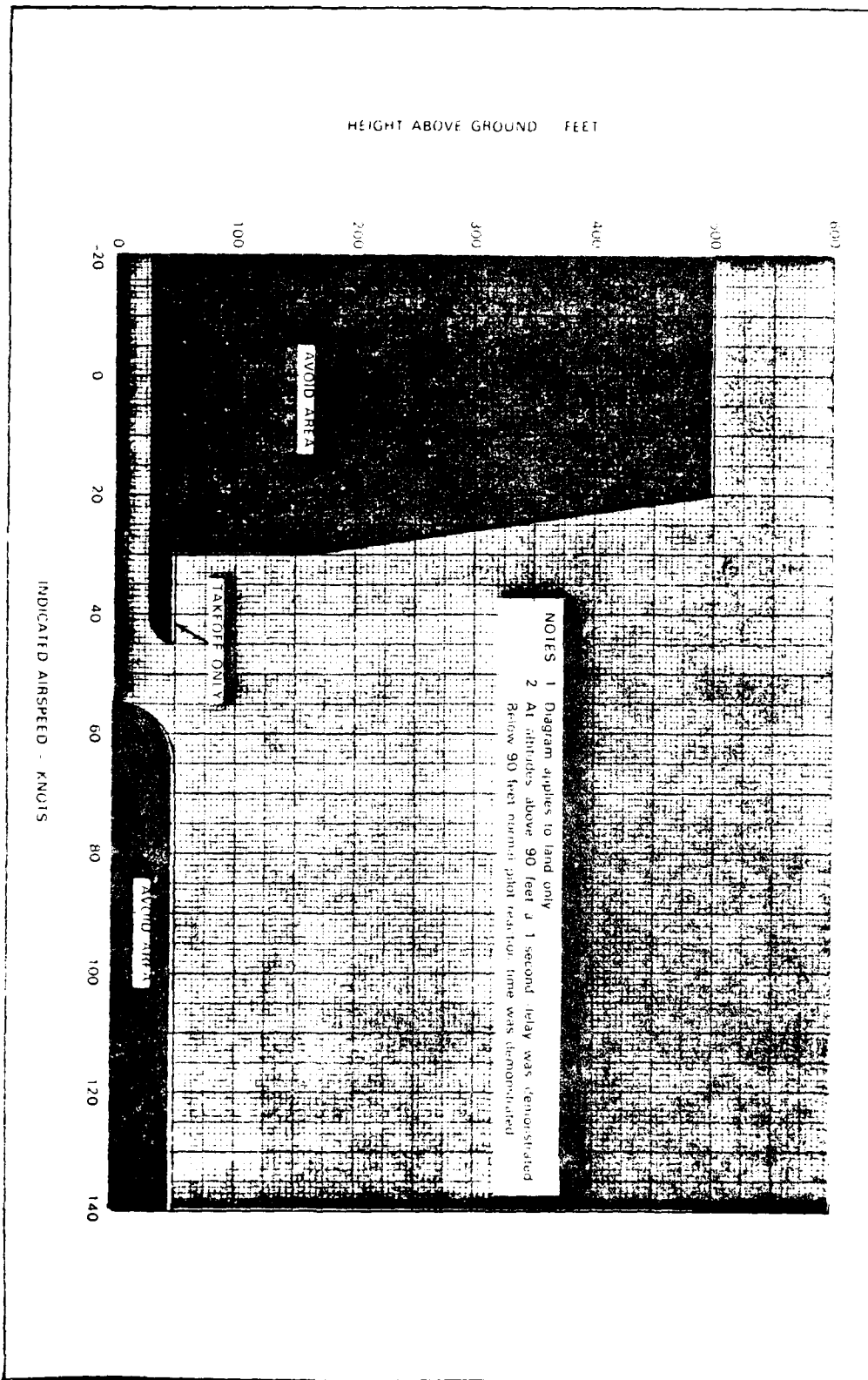


Minimum Height for Safe Landing (H-46D/F)

**FOLLOWING SINGLE FAILURE
— 20,800 LB GROSS WEIGHT**

MODEL H-36D
DATA BASIS: FLIGHT TEST VERTICOL REPORT
402AD0065 DATED 3 MARCH 1967

ENGINE'S T-8 OF 10
ROTOR RPM 100 PERCENT
CONDITIONS SEA LEVEL 95 F



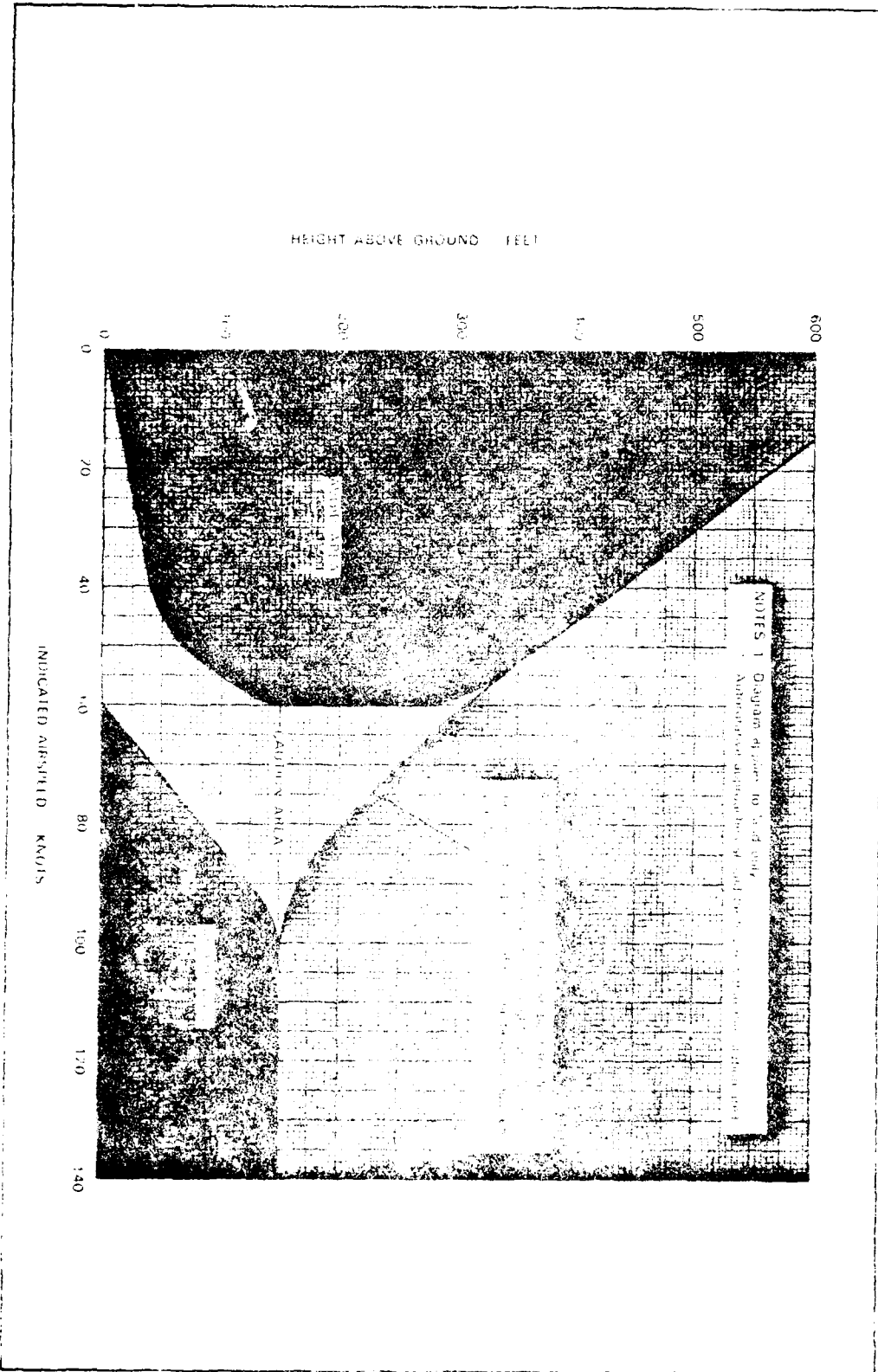
Minimum Height for Safe Landing (H-46D/F)

MOJHL 11-480
 DATA BASIS FLIGHT TEST PERIOD REPORT
 A02A0005 DATED 3 MARCH 1967

FOR: (1) SIMULTANEOUS DUAL ENGINE
 FAILURE OR (2) FAILURE OF SECOND
 ENGINE FROM SINGLE ENGINE
 LEVEL FLIGHT

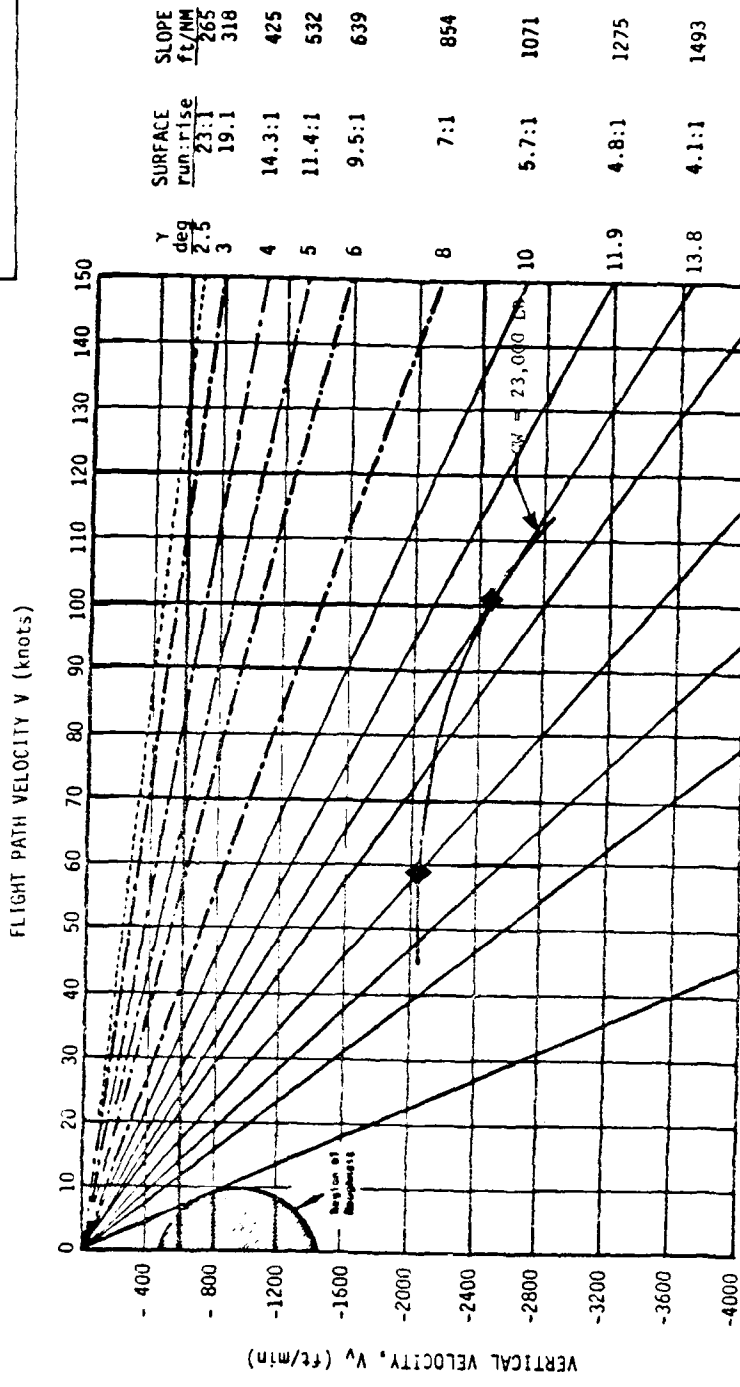
ENGINES 158 GE 10
 ROTOR RPM 100 PERCENT

CONDITIONS SEA LEVEL 19.1
 19 000 TO 23 000 GROSS WEIGHT



Minimum height for safe landing (H-46D/F)

BOEING VERTOL CH-46D
AUTOROTATION (Power off)



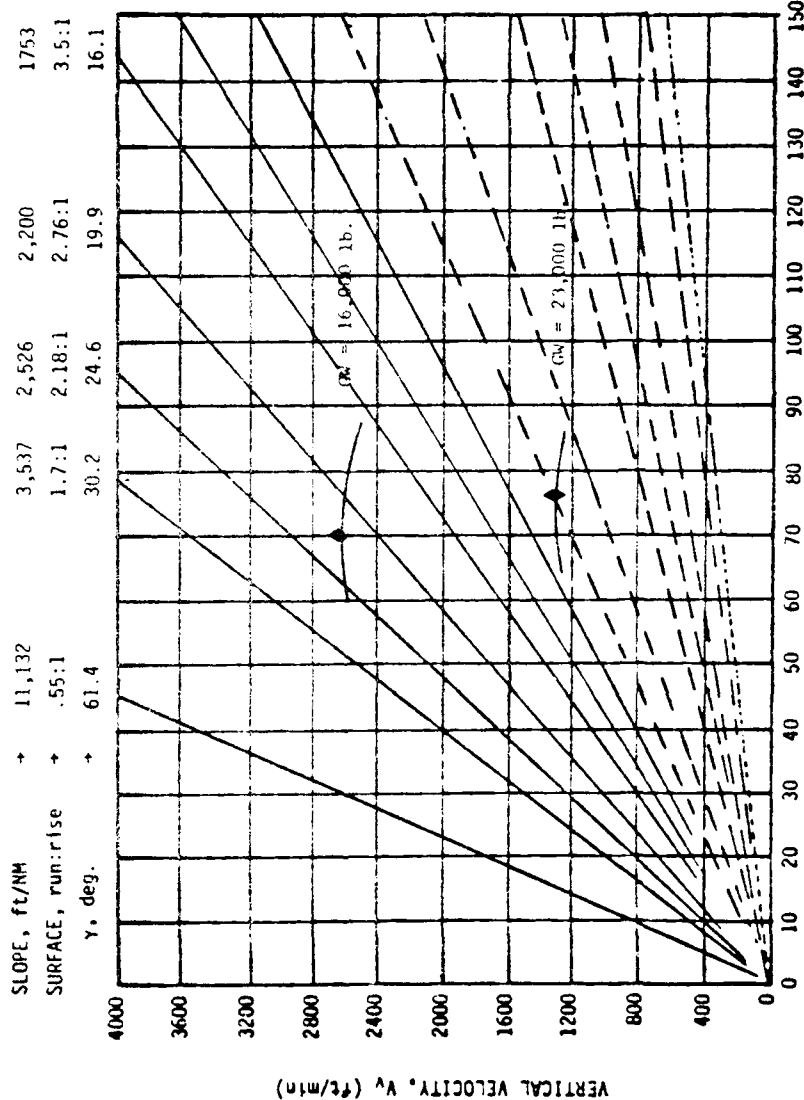
Y, deg.	30.2	24.6	19.9	16.1
SURFACE, run:rise	1.7:1	2.18:1	2.76:1	3.5:1
SLOPE, ft/NM	3,537	2,526	2,200	1753

DESCENT RATE VS FLIGHT PATH VELOCITY

◆ NATOPS Flight Manual Data Points

BOEING VERTOL CH-46D
STANDARD DAY, SEA LEVEL
MAXIMUM CONTINUOUS POWER

Y	SURFACE run:rise	SLOPE
13.8	4.1:1	1493
11.9	4.8:1	1275
10	5.7:1	1071
8	7:1	854
6	9.5:1	639
5	11.4:1	532
4	14.3:1	425
3	19:1	318
2.5	23:1	265



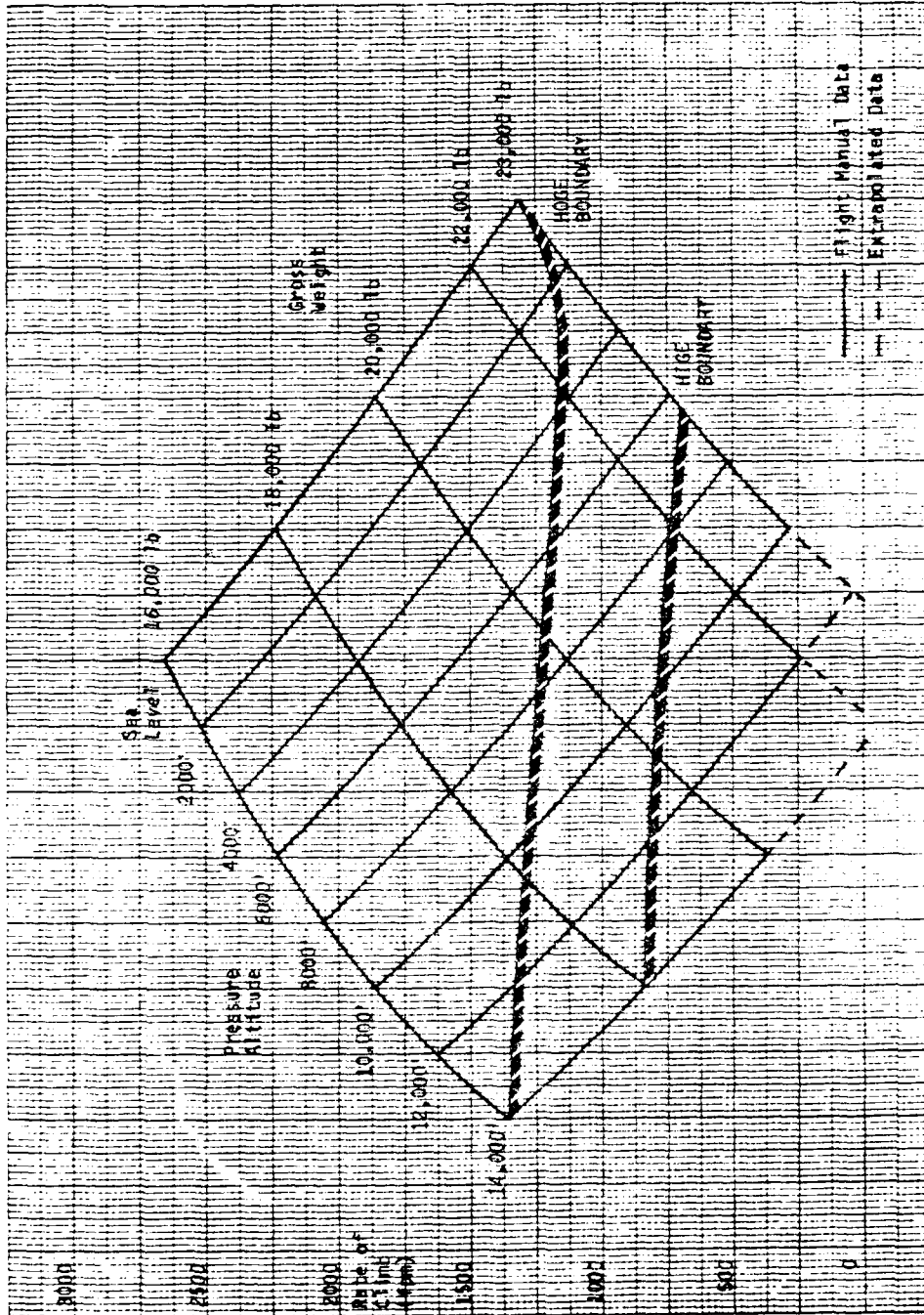
◆ NATOPS Flight Manual Data Points

FLIGHT PATH VELOCITY V (knots)
CLIMB RATE VERSUS FLIGHT PATH VELOCITY

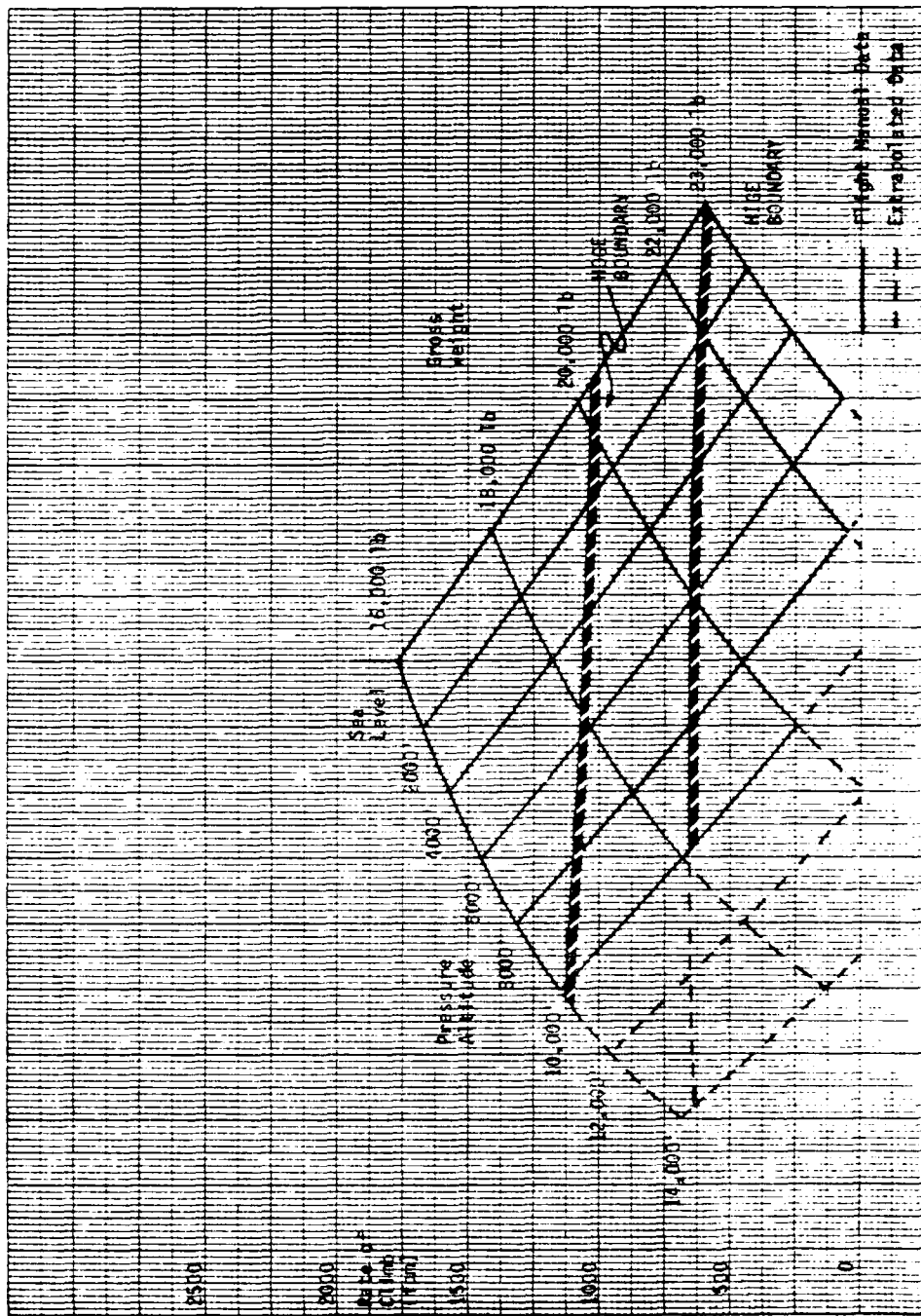
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)



Boeing Vertol CH-46D Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures)



Boeing Vertol CH-46D Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

THE BOEING VERTOL CH-47C HELICOPTER



HEAVY TANDEM ROTOR HELICOPTER POWERED BY TWO
TURBINE ENGINES, DESIGNED FOR MILITARY
TRANSPORTATION OF TROOPS, CARGO AND WEAPONS.

MANUFACTURER: BOEING VERTOL COMPANY, Philadelphia, PA.

POWER PLANT: Two Lycoming T55-L-11 free power turbine, turbo shaft engines each rated at 3750 SHP for takeoff and 3300 SHP for continuous operations. (Transmission is limited to combined power input of about 5650 SHP.)

AIRCRAFT UTILITY: Military approved for day, night operations in both VMC and IMC conditions.

SEATING CAPACITY: Thirty-three passengers plus crew (normal crew is three).

INTRODUCTION

The CH-47C Chinook helicopter is a heavy military transport helicopter used for movement of troops, cargo and weapons. It is employed by the U.S. Army and derivative versions are used in the armed forces of many foreign nations. No civil versions are currently certificated, but development of a civil derivative is underway for deliveries commencing in 1981. The Chinook is manufactured by the Boeing Vertol Company in Philadelphia, Pennsylvania, and by Costruzioni Aeronautiche Giovanni Agusta under license in Italy.

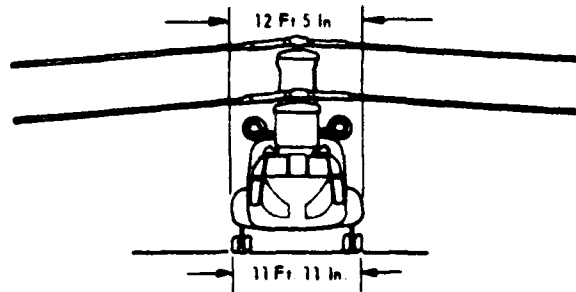
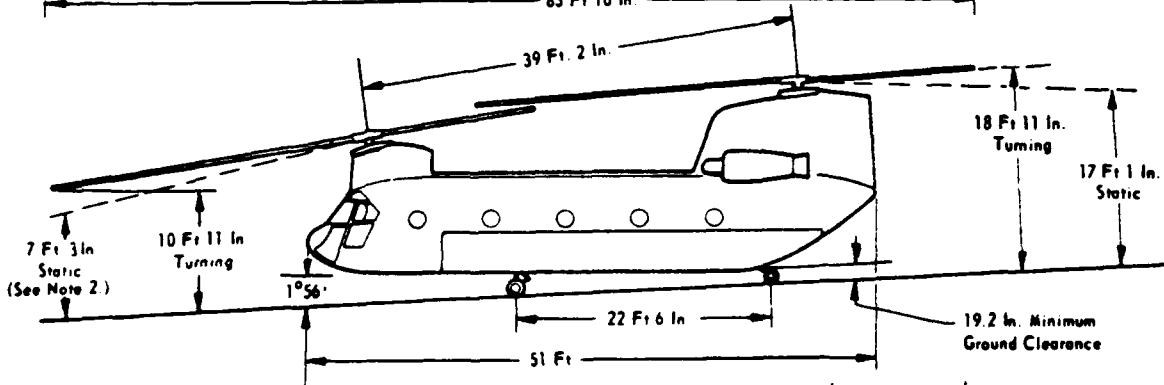
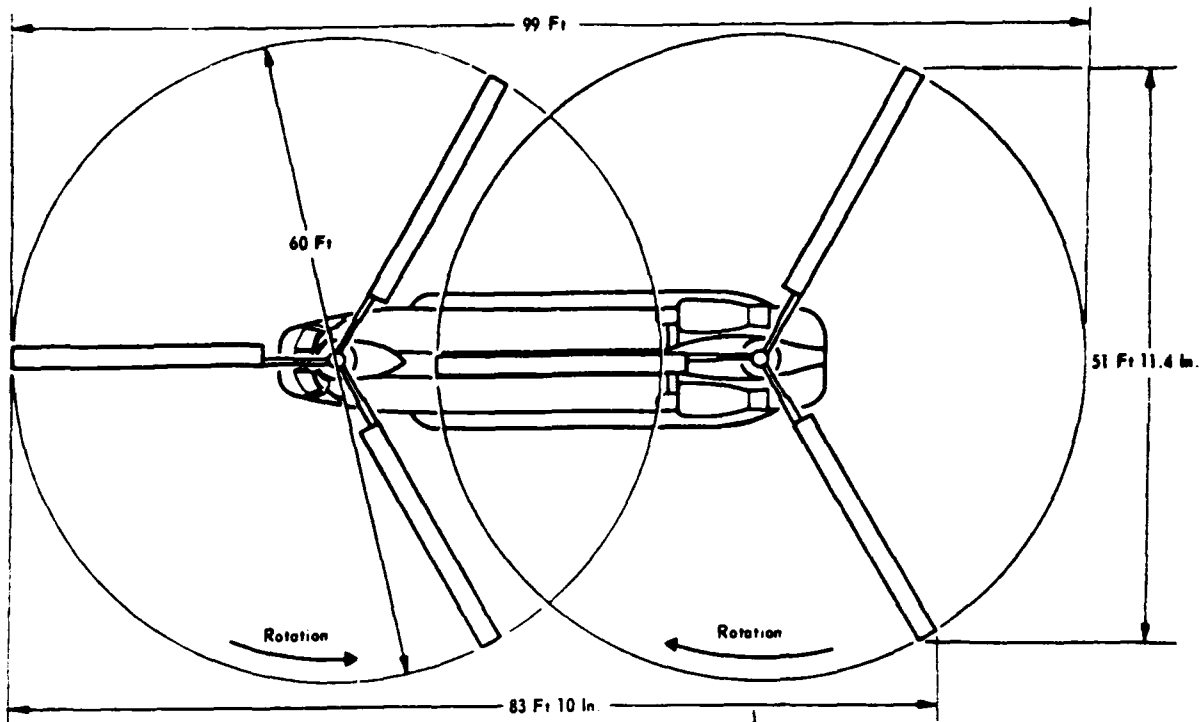
The CH-47C is a tandem rotor, twin engine helicopter with a large cabin volume and rear loading ramp. Landing gear is not retractable. It consists of two fixed forward tandem mounts and two full swiveling single aft mounts, one of which is steerable. The two main rotors each consist of three blades and counterrotate to offset torque effects.

The aircraft reported on is powered by two Lycoming T55-L-11 engines which develop 3750 SHP for takeoff (10 min rating), and sustain the 3750 SHP at military rating (30 min). Maximum continuous power is 3300 SHP. Transmission torque limits are reached at about 5650 SHP for dual engine operations and at 3625 SHP for single engine operations.

Performance data presented herein have been extracted from the U. S. Army CH-47C Operators Manual, TM55-1520-227-10-2 (dated 23 August 1971 with Changes 1 and 2 incorporated).

General IFR Performance Data

Minimum IFR Airspeed	60 KIAS
Recommended IFR Climb Speed	80 KIAS
Recommended Airspeed for Instrument Approach/Holding (unless V_{ne} is less)	100 KIAS
Maximum Pressure Altitude	15,000 ft
Maximum Density Altitude (34,000lb and below) (reduces to 8000 ft. at max. gross weight - 46,000 lb)	17,000 ft
V_{ne} (diminishes with increasing altitude or gross weight)	175 KIAS



Notes:

1. The above dimensions are based on the cyclic stick and directional pedals being centered and the thrust control rod in the 3rd detent.
2. With the flight controls out of neutral, it is possible for the ground to forward rotor blade clearance to be 4 feet 4 inches.
3. All dimensions are approximate.

Overall Dimensions

AIRSPEED OPERATING LIMITS

PROGRAMMED LONGITUDINAL CYCLIC TRIM

245 ROTOR RPM

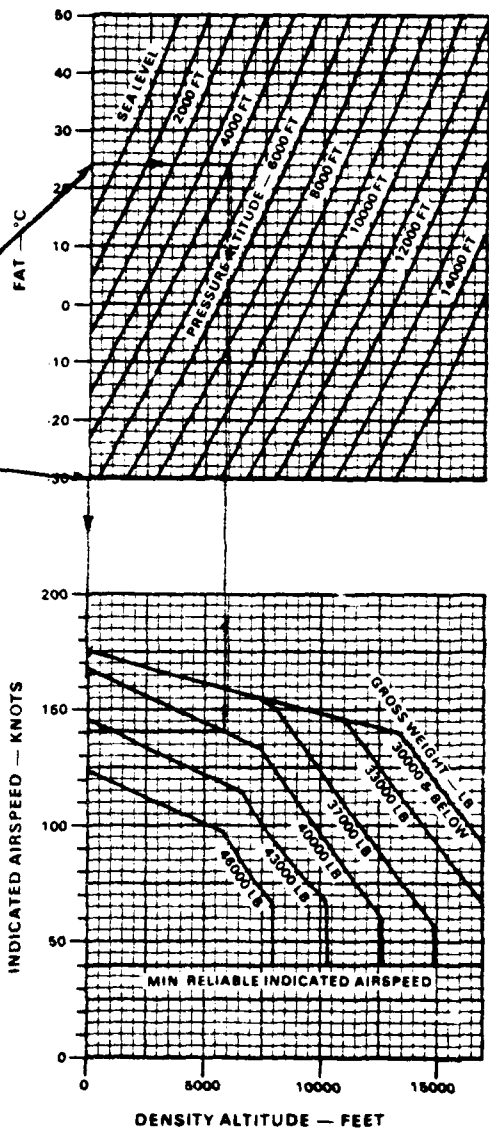
AIRSPEED
OPERATING
LIMITS
CH-47C

EXAMPLE

WANTED
MAXIMUM INDICATED AIRSPEED FOR
VARIOUS TEMPERATURES, PRESSURE
ALTITUDES, AND GROSS WEIGHTS

<u>KNOWN</u>	CASE I	CASE II
FAT	24°C	-30°C
PRESSURE ALTITUDE	4000 FT	4000 FT
GROSS WEIGHT	40000 LB	40000 LB

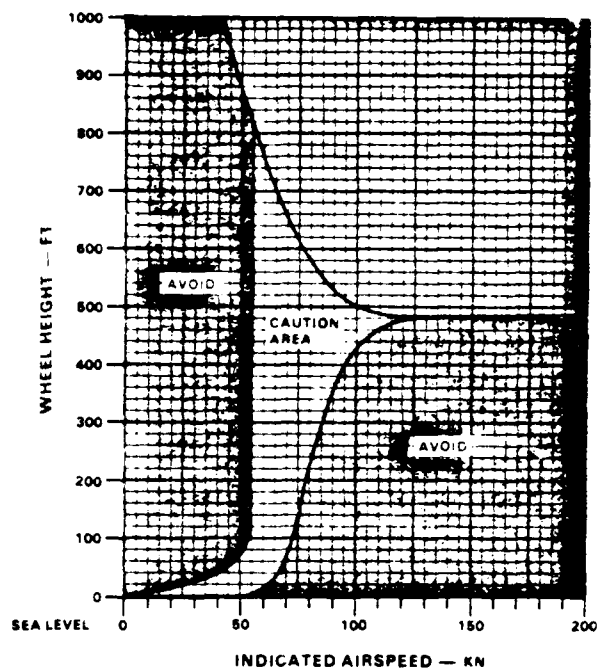
METHOD
ENTER FAT HERE
MOVE RIGHT TO PRESSURE ALTITUDE
MOVE DOWN TO GROSS WEIGHT
MOVE LEFT. READ MAXIMUM ALLOWABLE IN-
DICATED AIRSPEED
CASE I = 141 KN
CASE II = 168 KN



Airspeed Limitations—245 Rotor RPM

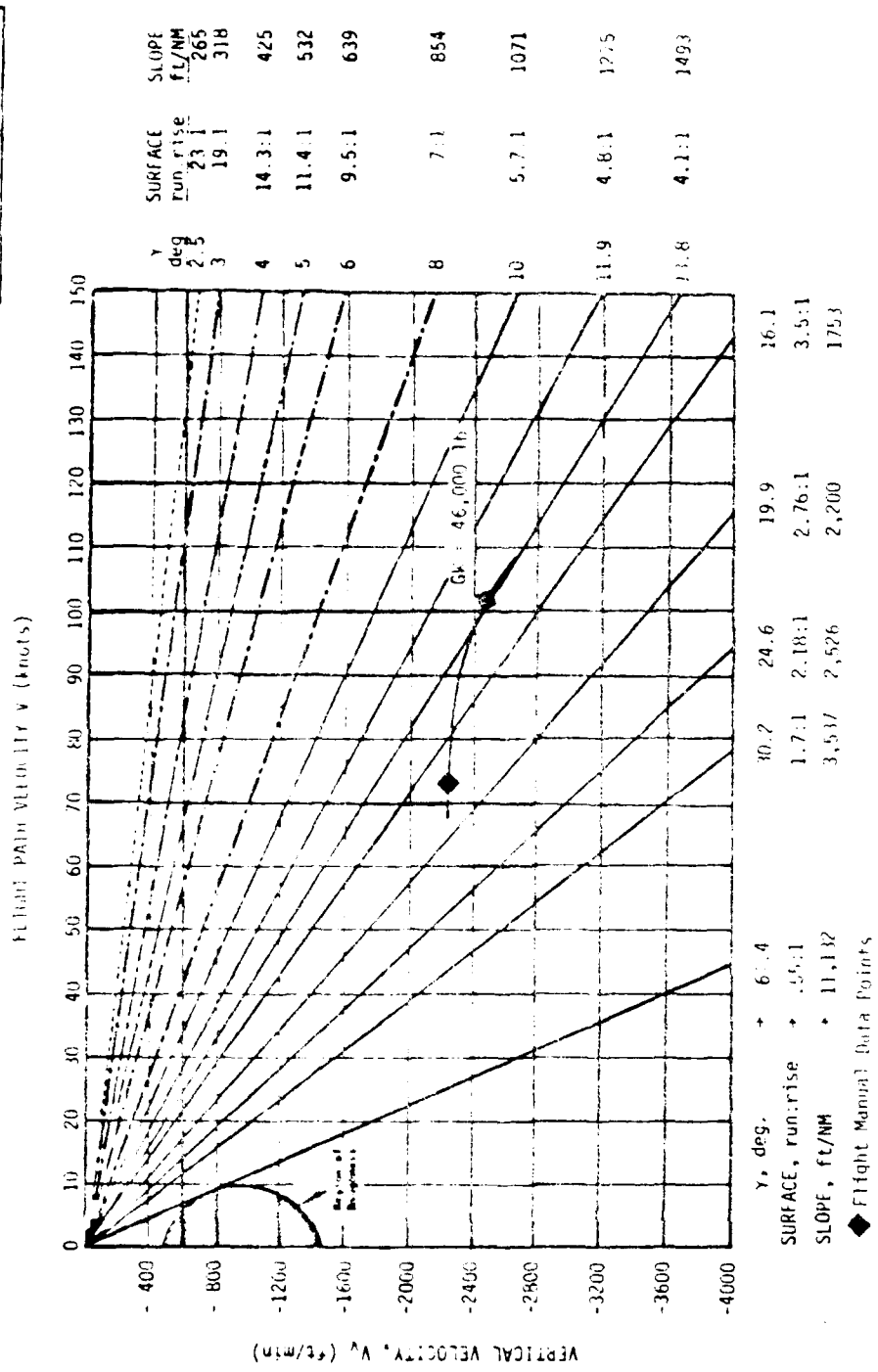
HEIGHT VELOCITY DIAGRAM FOR SAFE LANDING AFTER DUAL ENGINE FAILURE

HEIGHT VELOCITY DIAGRAM
FOR SAFE LANDING AFTER
DUAL ENGINE FAILURE
CH 47C
T55-L-11 SERIES ENGINES



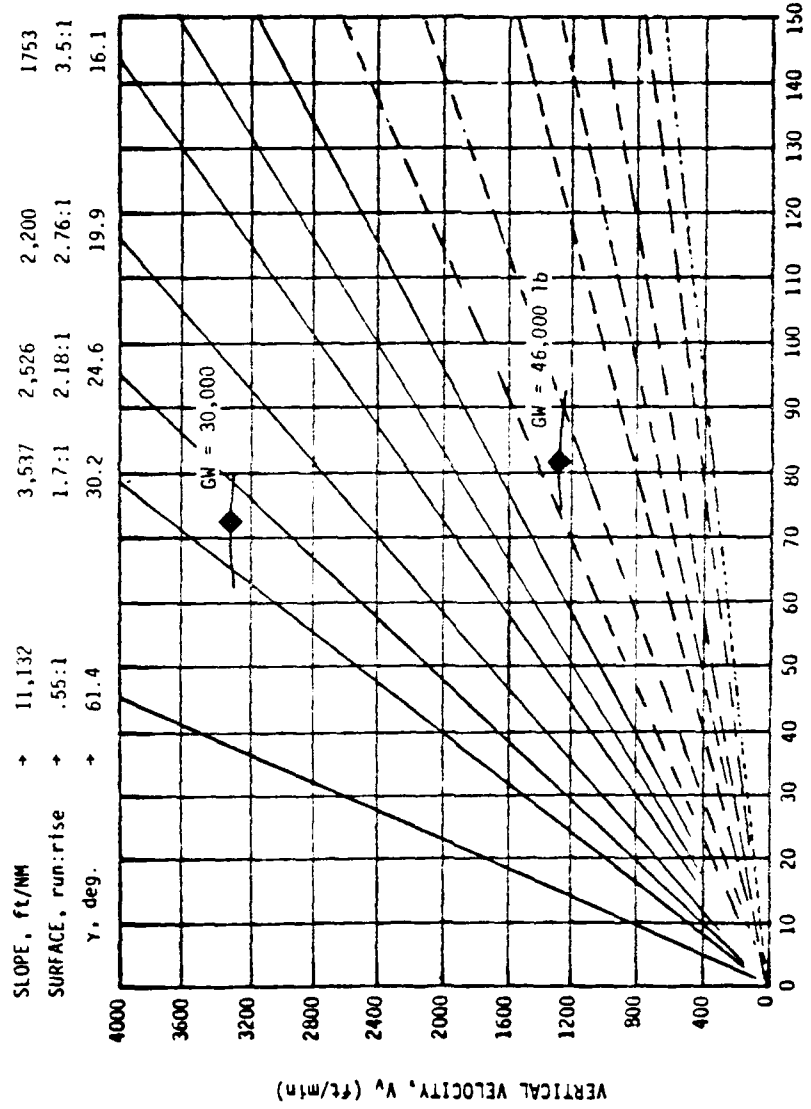
*Height Velocity for Safe Landing After Dual Engine Failure -
T55-L-11 Series Engines*

CH-47C (Minimum
Standard Day, Sea Level)
Autorotation (Power Off)



Descent Rate versus Flight Path Velocity

CH-47C Chinook
Standard Day, Sea Level
Maximum Continuous Power



FLIGHT PATH VELOCITY V (knots)

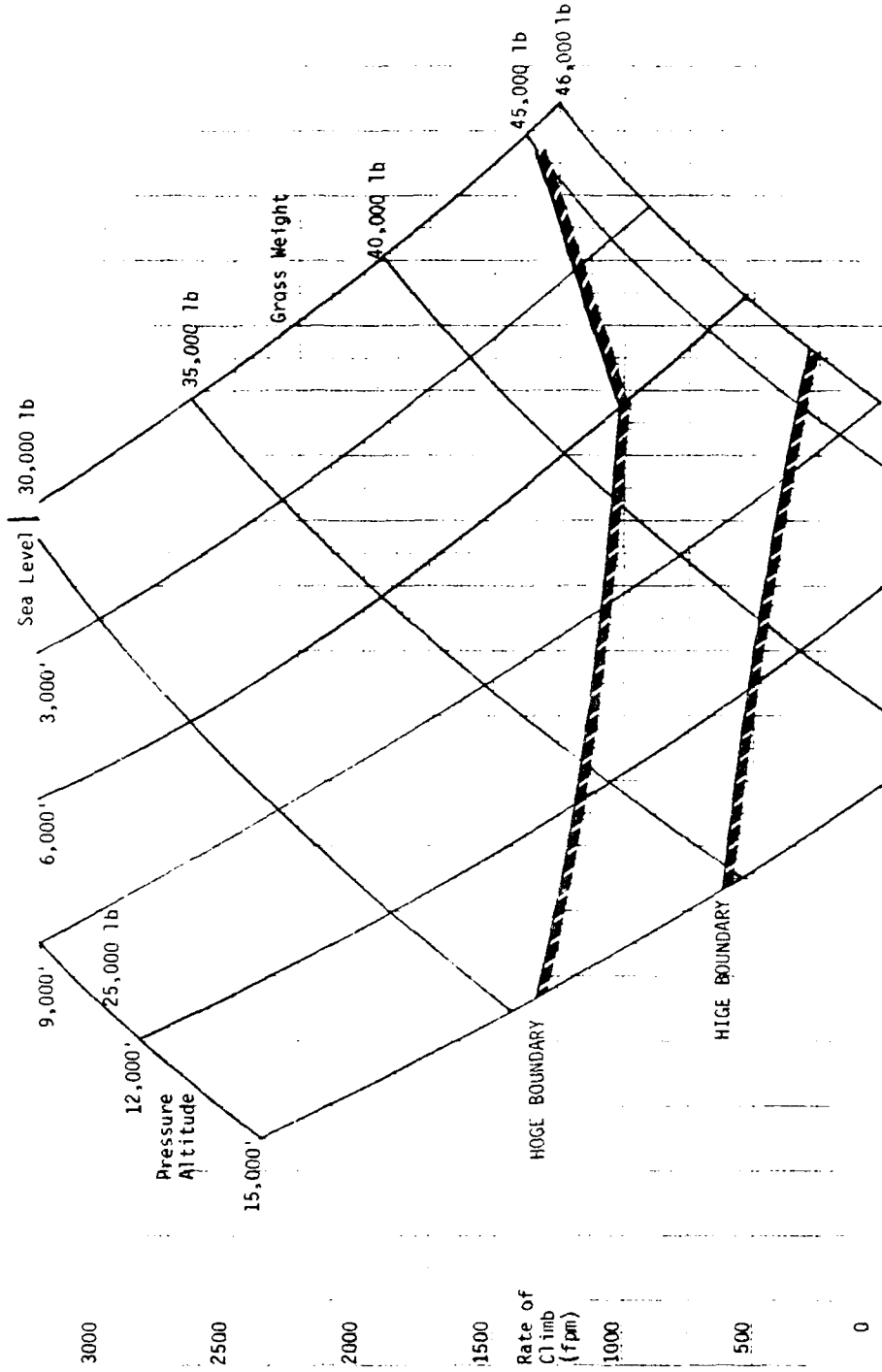
◆ Flight Manual Data Points

Climb Rate versus Flight Path Velocity

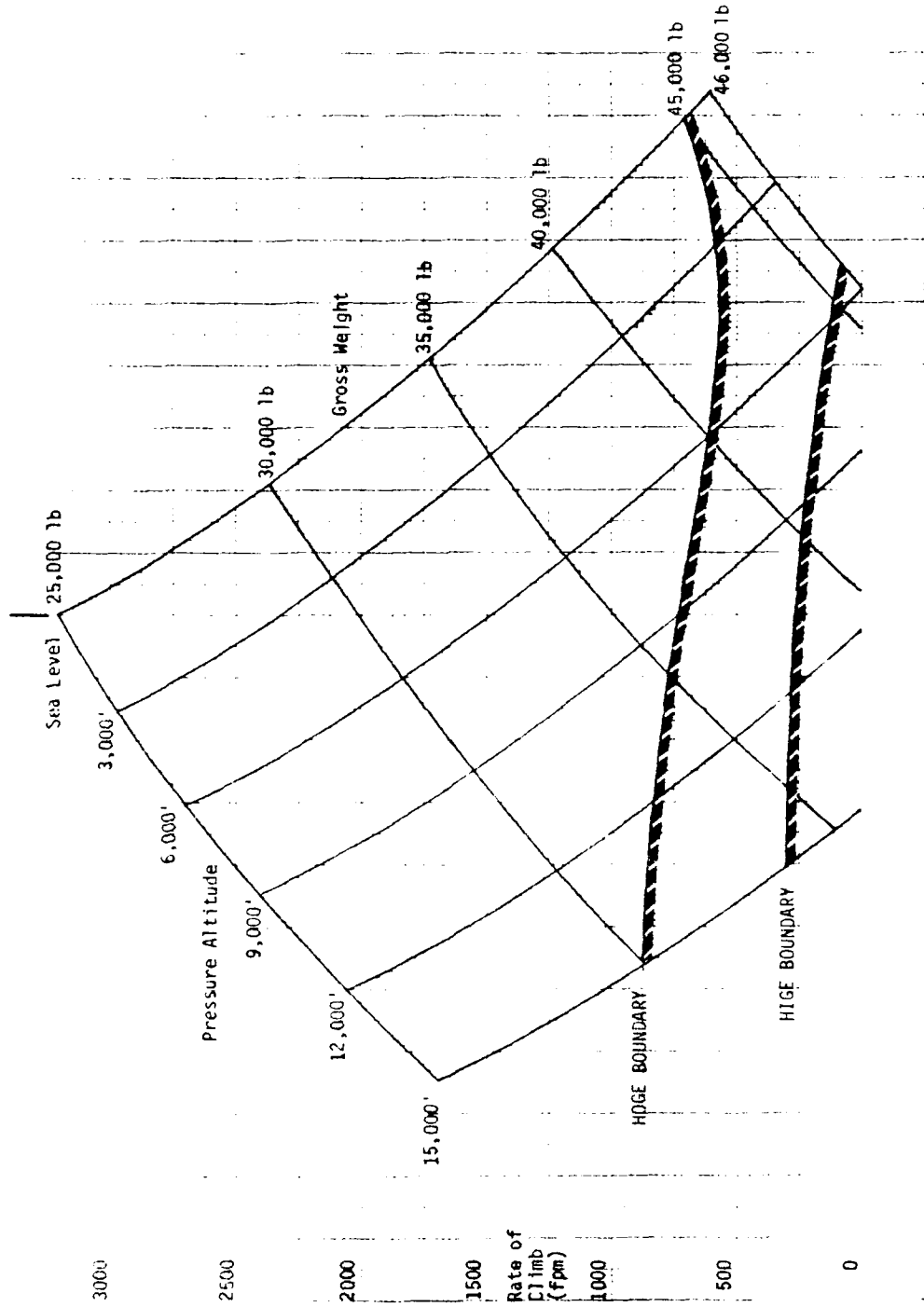
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other hot day performance for temperatures uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other HIGE (hover in ground effect) Boundary cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)



CH-47C Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



CH-47C Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

INTRODUCTION

The S-61N helicopter is designed to transport cargo and passengers both over land and water. Configuration is a single rotary wing, twin turbine powered helicopter with emergency amphibious landing capability. The military version, SH-3 and HH-3 series, comes in several configurations with mission areas in utility, search and rescue, and anti-submarine warfare.

Both the civil and military versions are fully IFR capable with the exception of flying in known icing conditions. All versions have a three directional automatic flight control system (AFCS) and a barometric altitude hold capability. The AFCS is required for flight in instrument conditions.

The S-61N and H-3 are powered by twin turbine engines rated at 1400 SHP each with 1250 SHP for continuous operations. For single engine operations 1400 SHP is available for 30 minutes. Full use was made of performance data as obtained from reports, research data, Rotocraft Flight Manuals, and military flight handbooks. This information was utilized to prepare the general performance data and to construct the Performance and Maneuver Charts shown on the following pages.

THE SIKORSKY S-61
U.S. AIR FORCE, U.S. NAVY, AND U.S. COAST GUARD H-3



HIGH GROSS WEIGHT HELICOPTER WITH TWIN TURBINE ENGINES AND DESIGNED FOR GENERAL TRANSPORT, SEARCH AND RESCUE, AND ANTI-SUBMARINE WARFARE.

MANUFACTURER: SIKORSKY AIRCRAFT, Division of UNITED TECHNOLOGIES

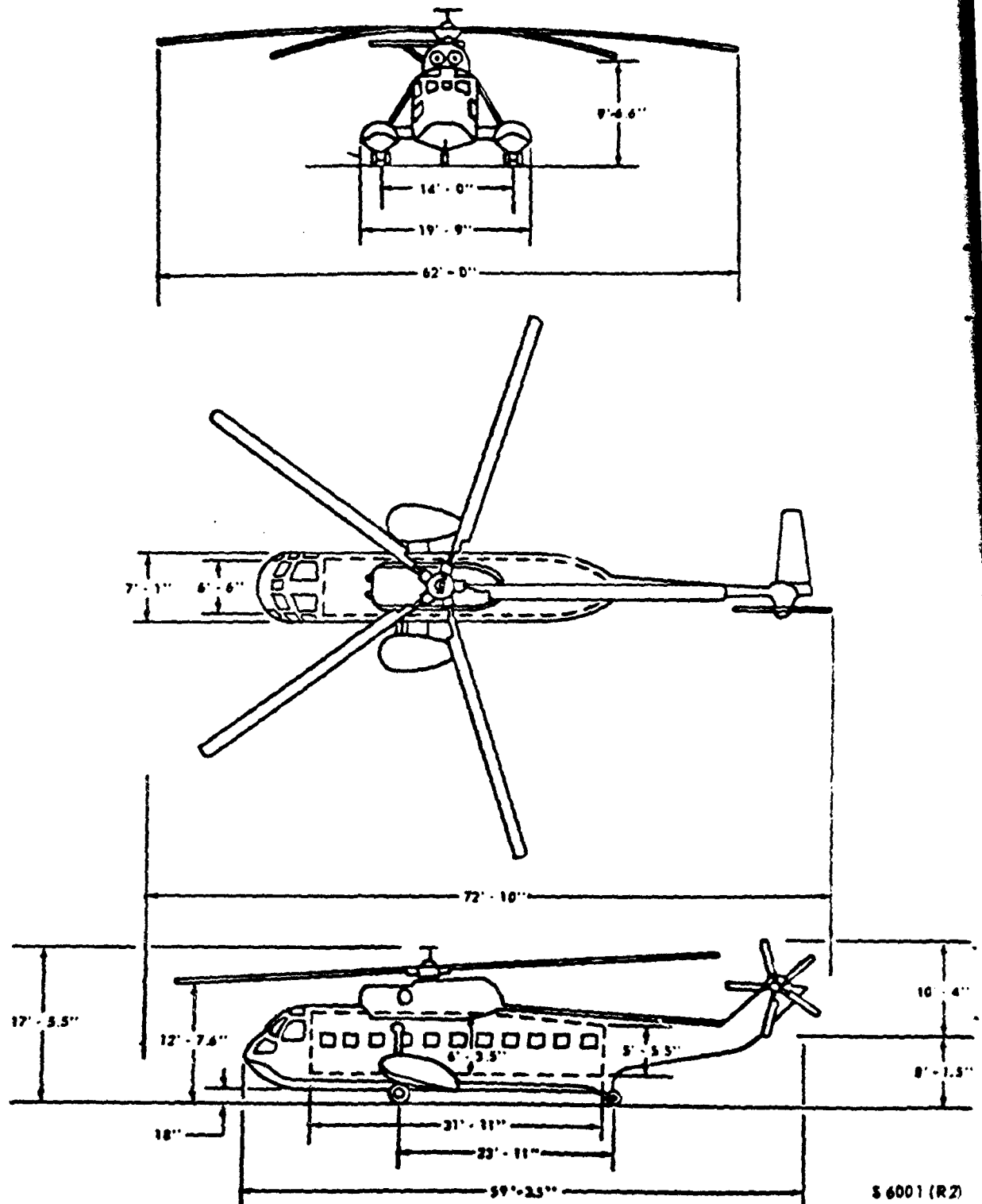
POWER PLANT: S-61N 2GE CT58-140 Rated at 1400 SHP
H-3 2GE T-58-10 Rated at 1400 SHP

AIRCRAFT UTILITY: FAA Certified for VFR and IFR Flight. Not approved for operation in icing conditions. Military use for VFR and IFR flight

SEATING CAPACITY: Variable seating arrangements with seating configuration for up to 28 persons in the S-61N.

GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	S-61N H-3	45 KIAS 60 KIAS
Recommended Climb Speed		70 KIAS
Recommended Approach Speed		90 KIAS
Recommended Max Angle of Bank		30 degrees
Maximum IFR Altitude		12,500 feet



S 6001 (R2)

S-61N Amphibian - Three View Drawing

FAA APPROVED September 9, 1963
Reissued December 17, 1971

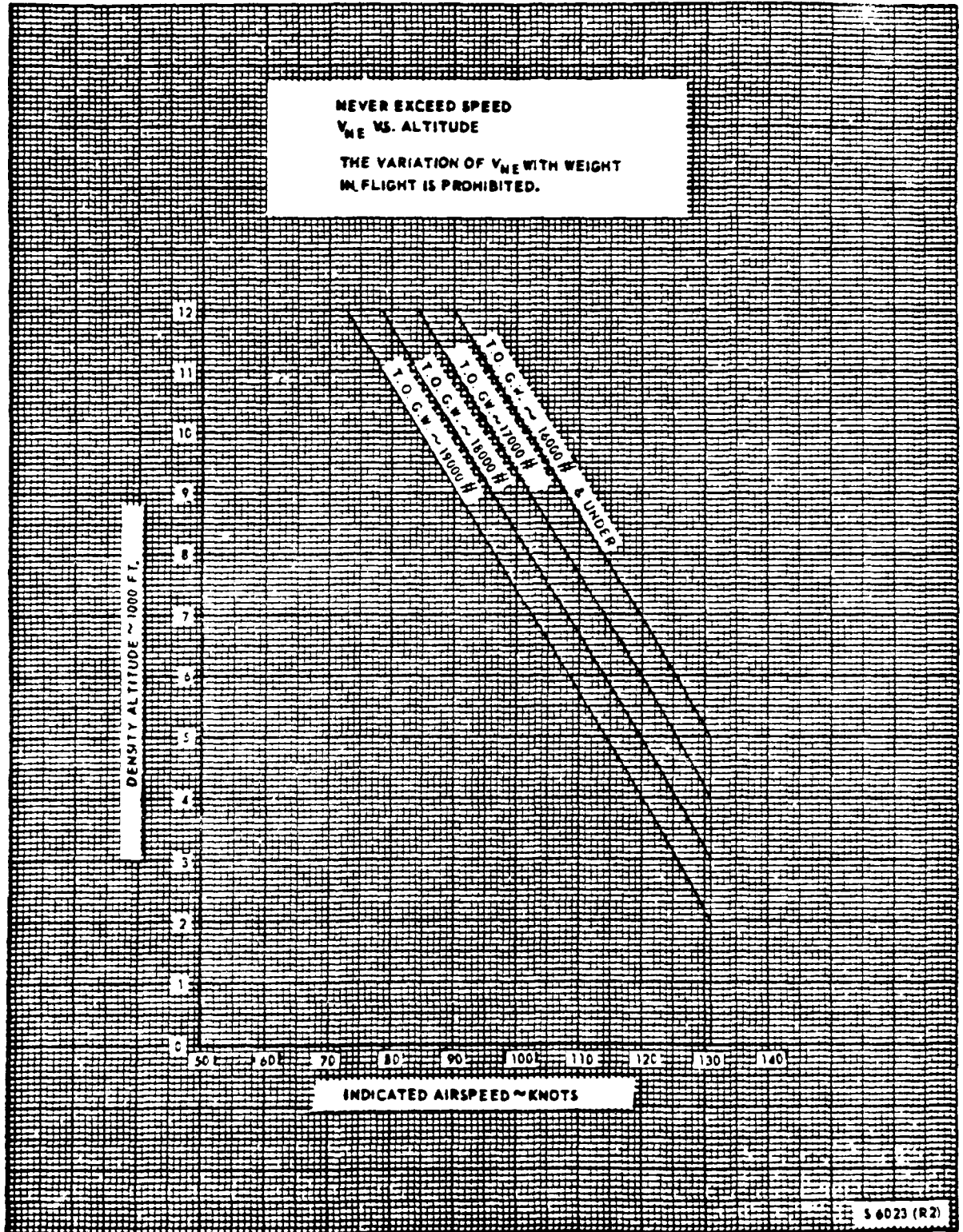


Figure 1-22

FAA APPROVED September 9, 1963
Reissued December 17, 1971

SIKORSKY AIRCRAFT
S-61N FLIGHT MANUAL

CATEGORY "A"
**LIMITING HEIGHTS AND CORRESPONDING SPEEDS FOR SAFE
LANDING AFTER AN ENGINE SUDDENLY BECOMES INOPERATIVE**

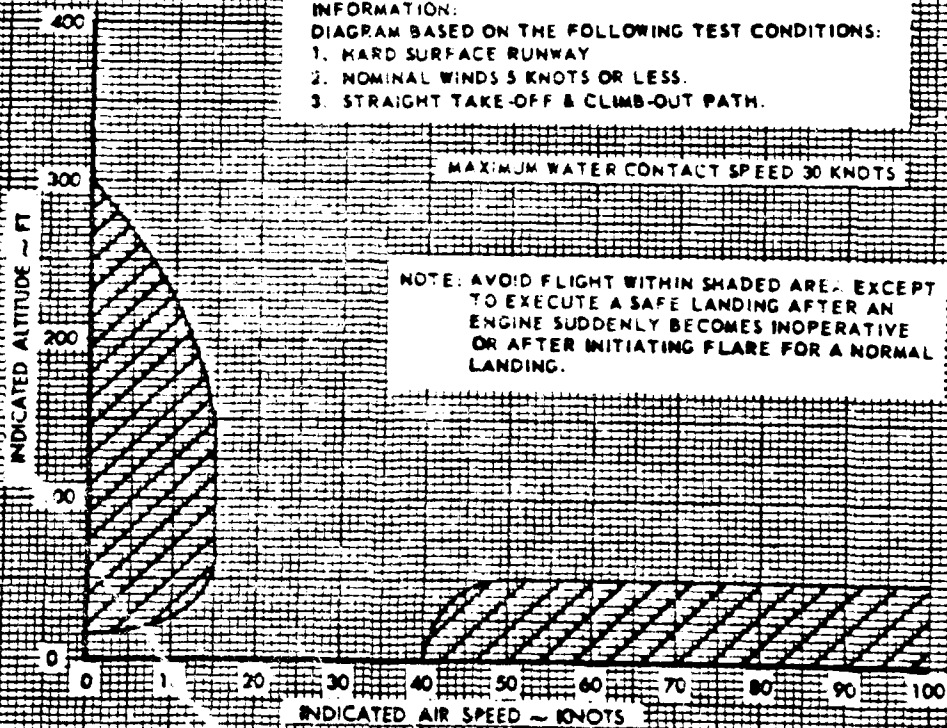
THIS CURVE IS APPLICABLE FOR ALL
ALTITUDES AND TEMPERATURES AT THE
CORRESPONDING ALLOWABLE WEIGHTS
AS PRESENTED ON FIGURES 14 THROUGH
19.

THIS CURVE DOES NOT APPLY TO VERTICAL OPERATIONS
OR ELEVATED HELIPORT EDGE PROCEDURES
SINCE IT HAS BEEN DEMONSTRATED THAT
SAFE OPERATION CAN BE MAINTAINED IF
AN ENGINE SHOULD FAIL AT ANY POINT ALONG
THE TAKE-OFF OR LANDING FLIGHT PATH.

INFORMATION:
DIAGRAM BASED ON THE FOLLOWING TEST CONDITIONS:
1. HARD SURFACE RUNWAY
2. NOMINAL WINDS 5 KNOTS OR LESS.
3. STRAIGHT TAKE-OFF & CLIMB-OUT PATH.

MAXIMUM WATER CONTACT SPEED 30 KNOTS

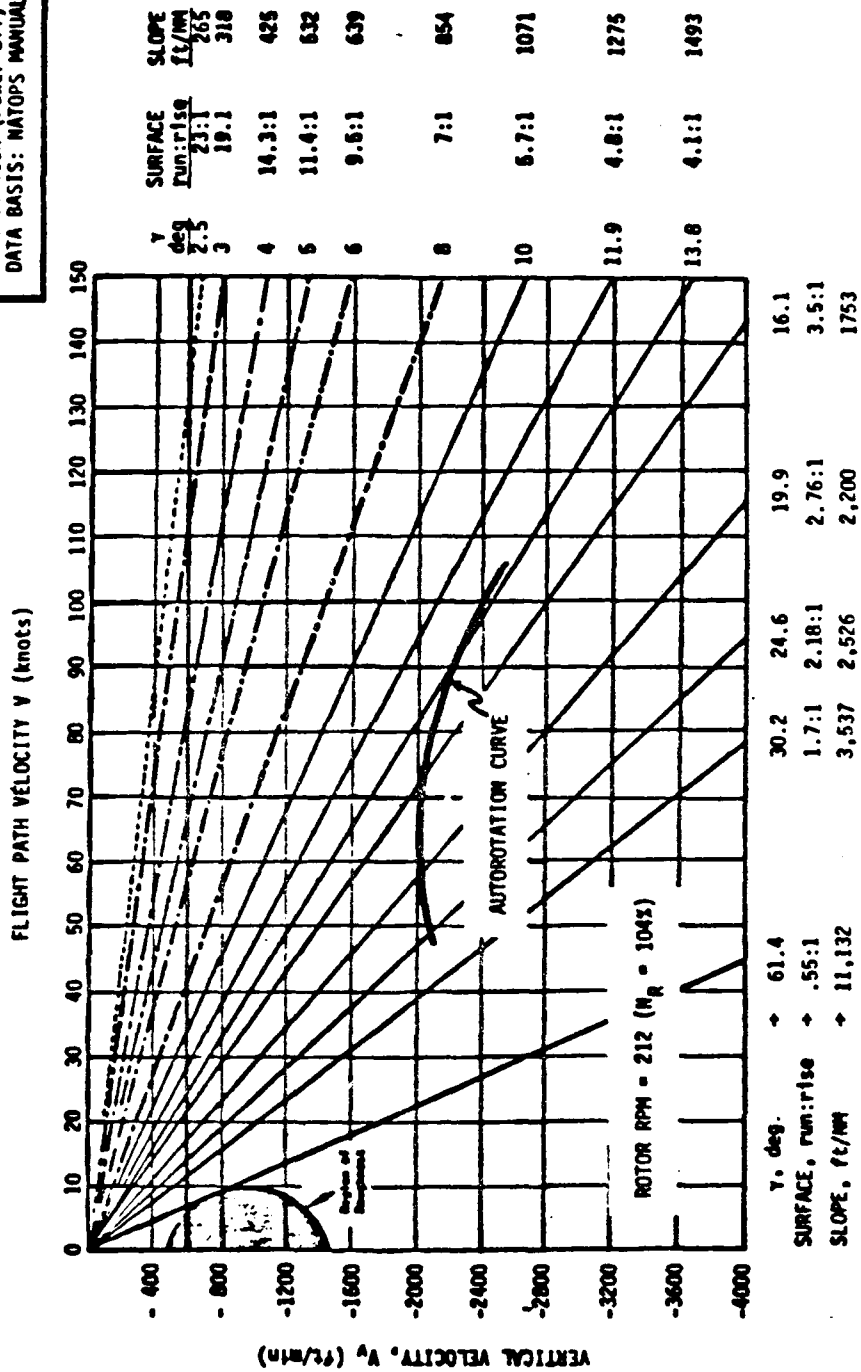
NOTE: AVOID FLIGHT WITHIN SHADED AREA, EXCEPT
TO EXECUTE A SAFE LANDING AFTER AN
ENGINE SUDDENLY BECOMES INOPERATIVE
OR AFTER INITIATING FLARE FOR A NORMAL
LANDING.



S 6020 (R)

FAA Approved, September 9, 1963
Reissued December 17, 1971

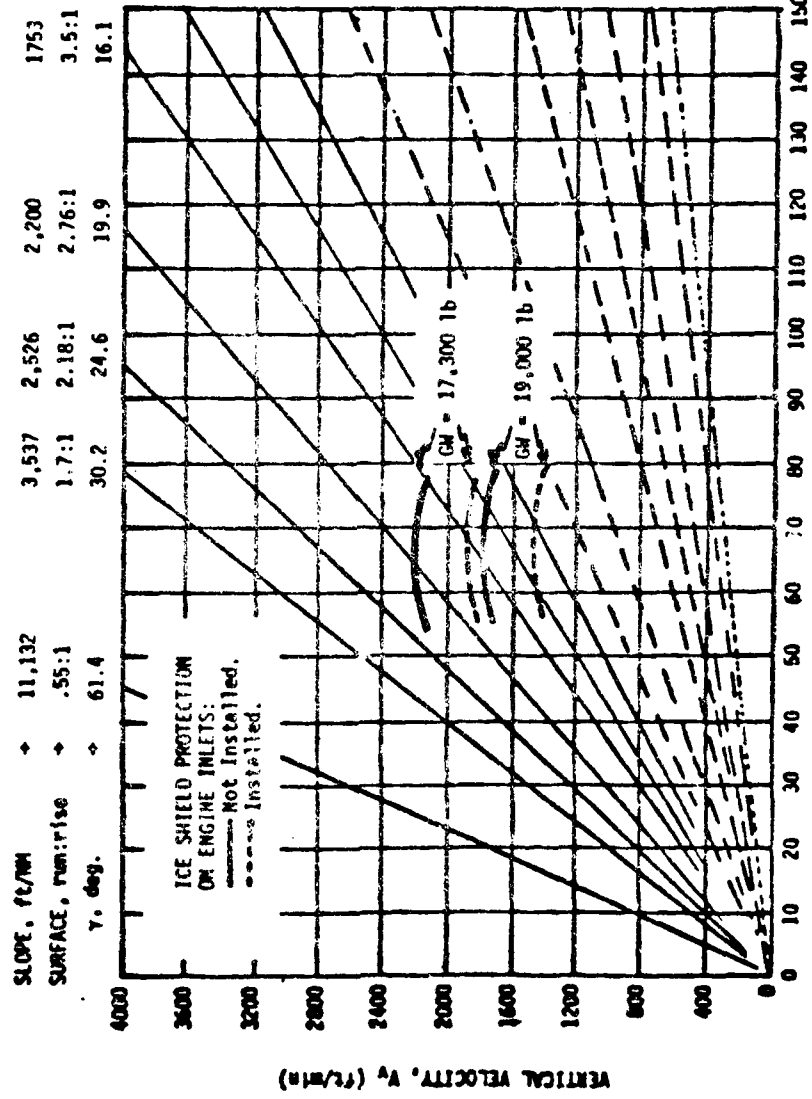
SIKORSKY S-61 (SH-3)
 AUTOROTATION (Power Off)
 DATA BASIS: NATOPS MANUAL



DESCENT RATE VERSUS FLIGHT PATH VELOCITY

SIKORSKY S-61 (SH-3)
STANDARD DAY, SEA LEVEL
MAXIMUM CONTINUOUS POWER
(Normal Power)

Y deg	SURFACE ft:m:rise	SLOPE ft/100ft
13.8	4.1:1	1493
11.9	4.8:1	1275
10	6.7:1	1071
8	7:1	864
6	9.5:1	639
5	11.4:1	532
4	14.3:1	426
3	19.1:1	318
2.5	23:1	265

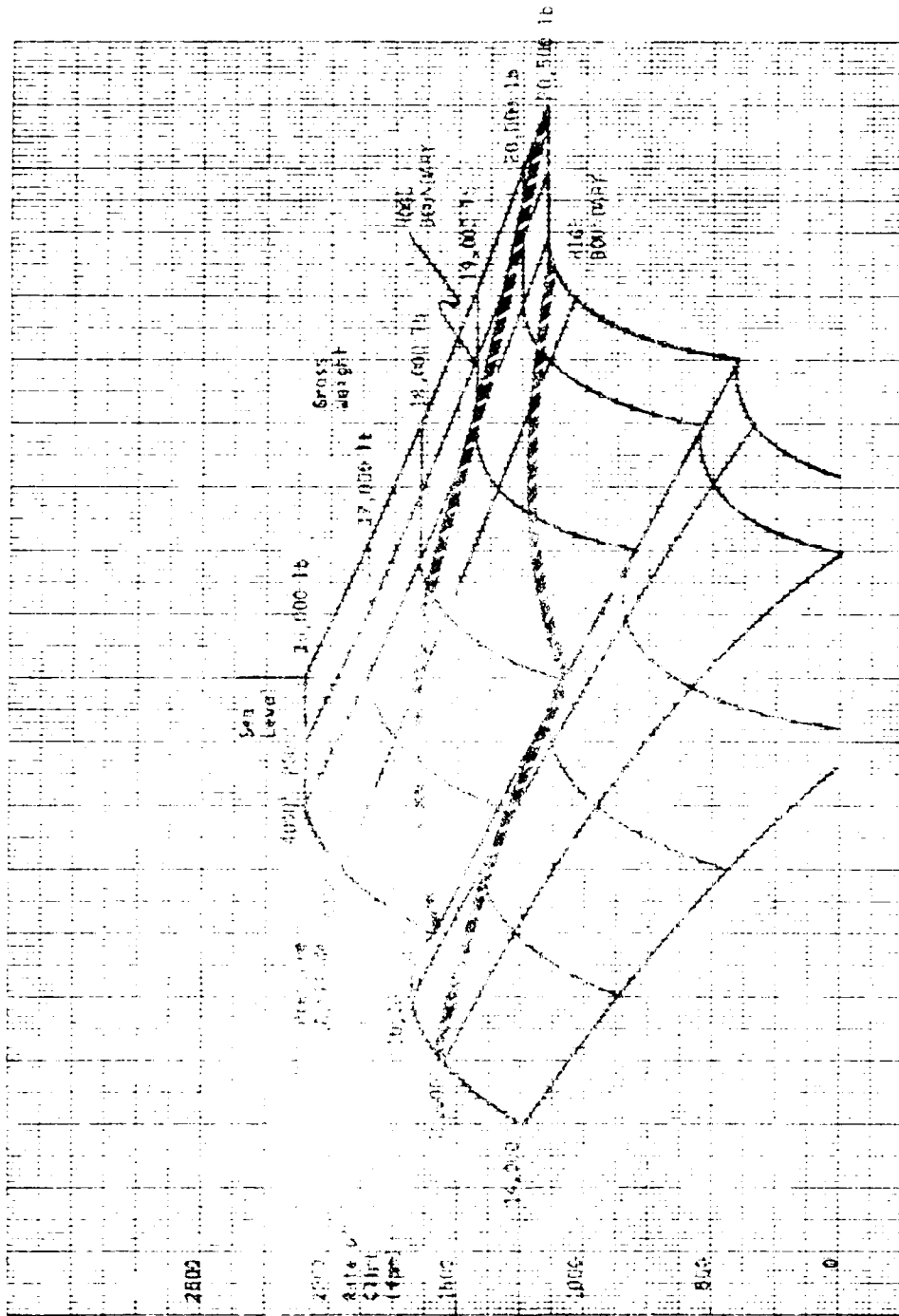


CLIMB RATE VERSUS FLIGHT PATH VELOCITY

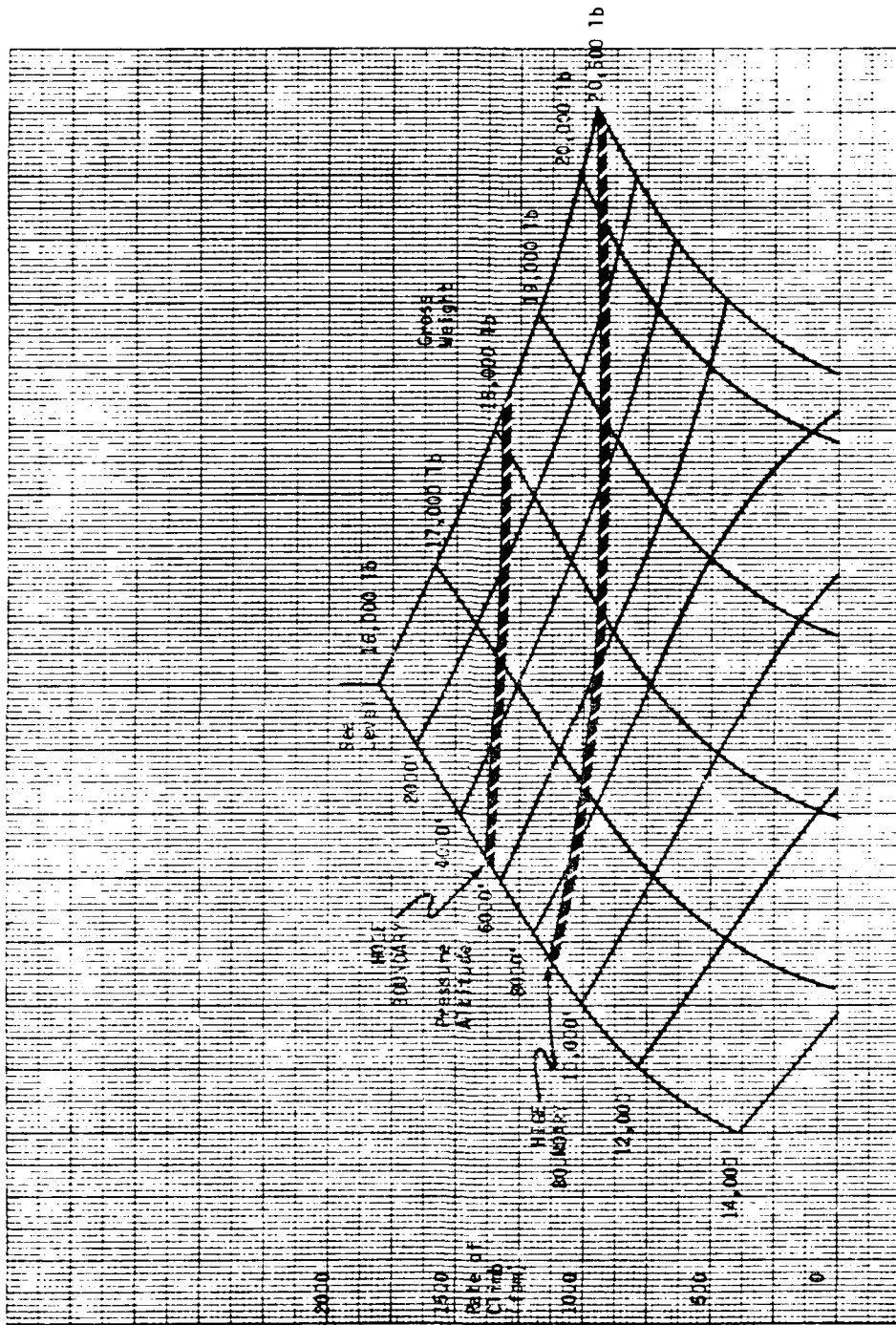
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)



STANDARD S-611 Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



Sikorsky S-61N Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

THE SIKORSKY S-65 (RH-53D) HELICOPTER



HEAVY SINGLE MAIN ROTOR HELICOPTER POWERED BY TWO TURBOSHAFT ENGINES, DESIGNED FOR MILITARY PERSONNEL AND CARGO TRANSPORT, EXTERNAL LIFT AND TOWING OPERATION.

MANUFACTURER: SIKORSKY AIRCRAFT DIVISION OF UNITED TECHNOLOGIES CORPORATION

POWER PLANT: Two General Electric T64-GE-415 turboshaft engines with free power turbines developing a maximum of 4,200 SHP each (10 minute limit) and military rated power of 4,020 SHP (30 minute limit).

AIRCRAFT UTILITY: Not certified for civil use. Military configured for IFR flight. Maximum gross weight of 42,000 lbs.

SEATING CAPACITY: 37 passengers plus 3 man crew.

INTRODUCTION *

The RH-53D is the most powerful of the twin engine versions of the Model S-65, manufactured by Sikorsky Aircraft Division of United Technologies. The helicopter has been adapted from an original design for USMC use as a heavy assault transport. The primary naval mission is mine countermeasures in which the aircraft is employed towing waterborne equipment designed to clear minefields. Secondary missions include cargo lift; externally or internally, and passenger transport. External cargo lift is limited to loads of 25,000 lbs. and towing operations may not exceed 15,000 lbs (using a specialized tow hook, not the cargo hook). The S-65 series of helicopters has not been certificated for civil use, so flight performance data are not completely analogous to data for civil aircraft (e.g. no minimum IFR airspeed has been defined.) Minimum crew for military operations consists of pilot, copilot, and crewman.

In standard configuration, the RH-53D helicopter uses retractable tricycle landing gear; six-bladed fully articulated main rotor and semi-articulated four-bladed tail rotor.

The RH-53D is powered by two General Electric T64-GE-415 turboshaft engines employing two stage free power turbines. Maximum power (10 minute limit) and military power (30 minute limit) limits are defined in terms of gas generator rpm and turbine inlet temperature limits. For sea level standard day conditions, these limits correspond to 4,200 SHP and 4,020 SHP respectively. The transmission is torque limited to 7,560 SHP total or 3,780 SHP per engine (for 30 minutes) and 6,400 SHP total continuously (3200 SHP per engine).**

The limit load factor is 2.38 g's at the maximum gross weight of 42,000 lbs. The limiting load factor increases to 3.0 g's for gross weights of 33,500 lbs. or less.

* All Data contained herein have been extracted from the Naval Air Training and Operating Procedures Standardization (NATOPS) Flight Manual.

** Marine Corps CH-53 aircraft are similar, but with less installed power. CH-53A aircraft utilize T64-GE-6 engines of 3070 SHP maximum and 2890 SHP military rated. CH-53D aircraft (the most widely used) employ T64-GE-413 engines of 4020 and 3500 SHP respectively. Of the performance parameters listed herein only rate-of-climb is affected by these differences. CH-53A are capable of best rate-of-climb of 1600-2300 fpm (42,000 lb GW-30,000 lb GW) and CH-53D are capable of 2100-2900 fpm (42,000 lb GW-30,000 lb GW).

GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	Recommended 40 KIAS *
Normal Climb Airspeed	85 KIAS
Cruise Airspeed Range	115-130 KIAS
VNE	160 KIAS
Precision Approach Airspeed	115 KIAS
Non-Precision Approach Airspeed	90 KIAS
IFR Altitude Limit	Not defined **

* Not defined for military aircraft. Flight manual cites airspeed indication unreliability below 40 KIAS and states, "A minimum speed of 40 knots should be observed to maintain the normal flight characteristics associated with forward flight." Also, loss of coordinated turn feature of AFCS occurs below 60 KIAS.

** Hover and cruise performance charts provided to 14,000 ft. Climb performance charts provided to 20,000 ft.

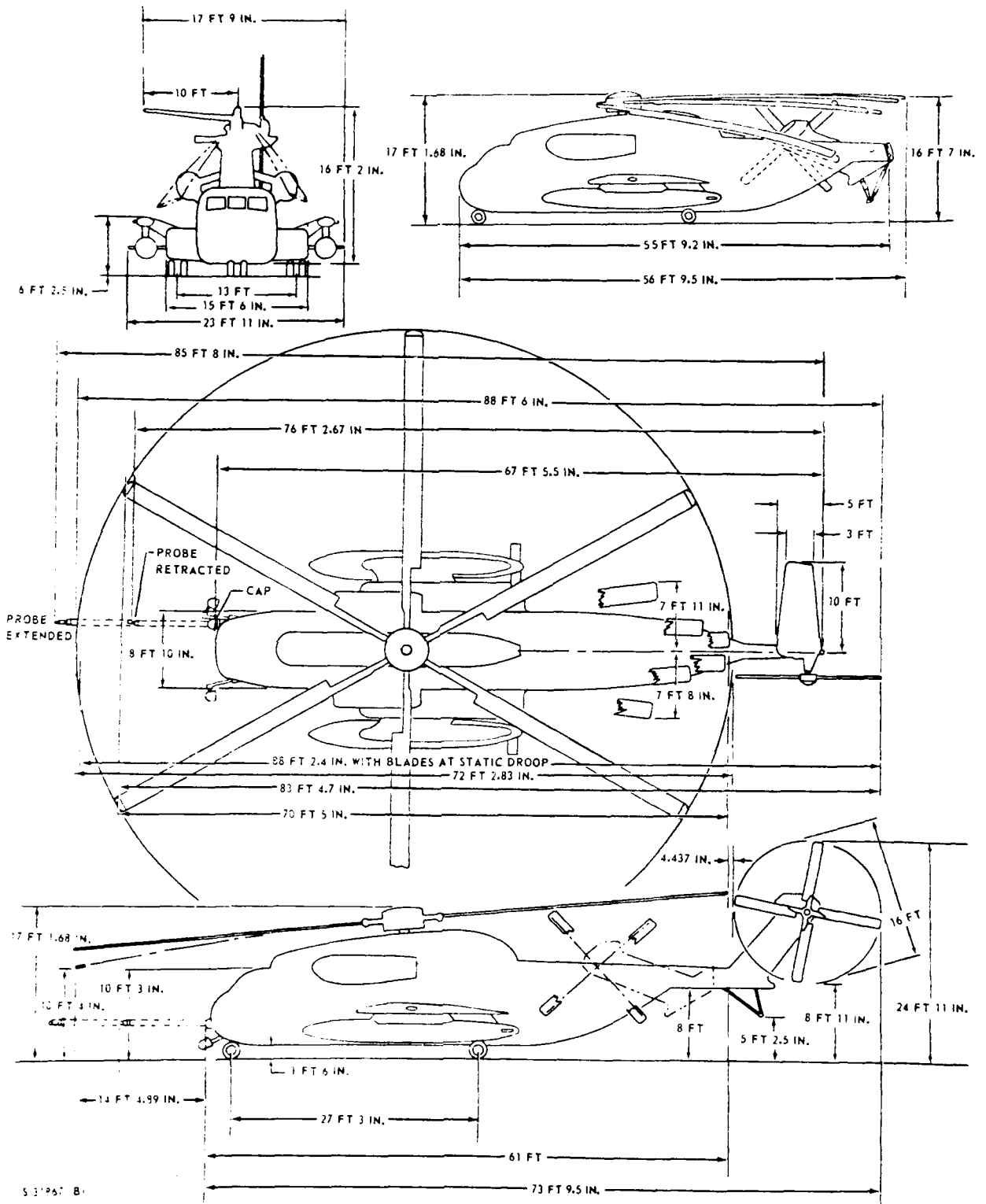


Figure 1-1. Dimension Diagram

INCIPIENT BLADE STALL CHART

MODEL: RH-53D

ENGINES: (2)

DATA AS OF: 15 JANUARY 1966

FUEL GRADE: JP-4

DATA BASIS: FLIGHT TEST

FUEL DENSITY: 6.5 LB/GAL

EXAMPLE: FOR PRESSURE ALTITUDE OF 4000 FEET, OAT 6°C, 100% N₁, 32,500 LB. G.W. AND 30° ANGLE AT BANK, THE INCIPIENT BLADE STALL SPEED IS 168 KNOTS IAS

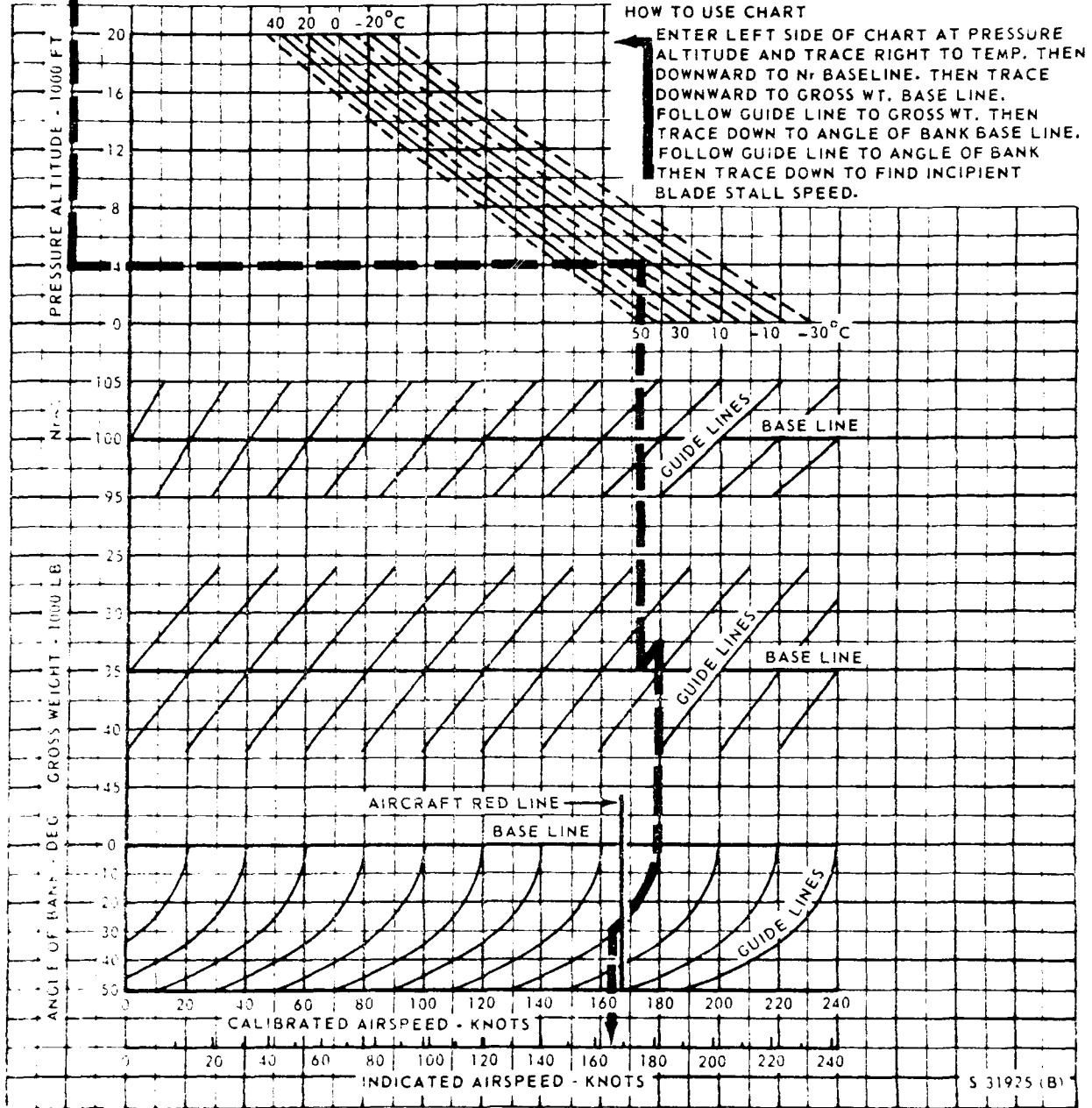


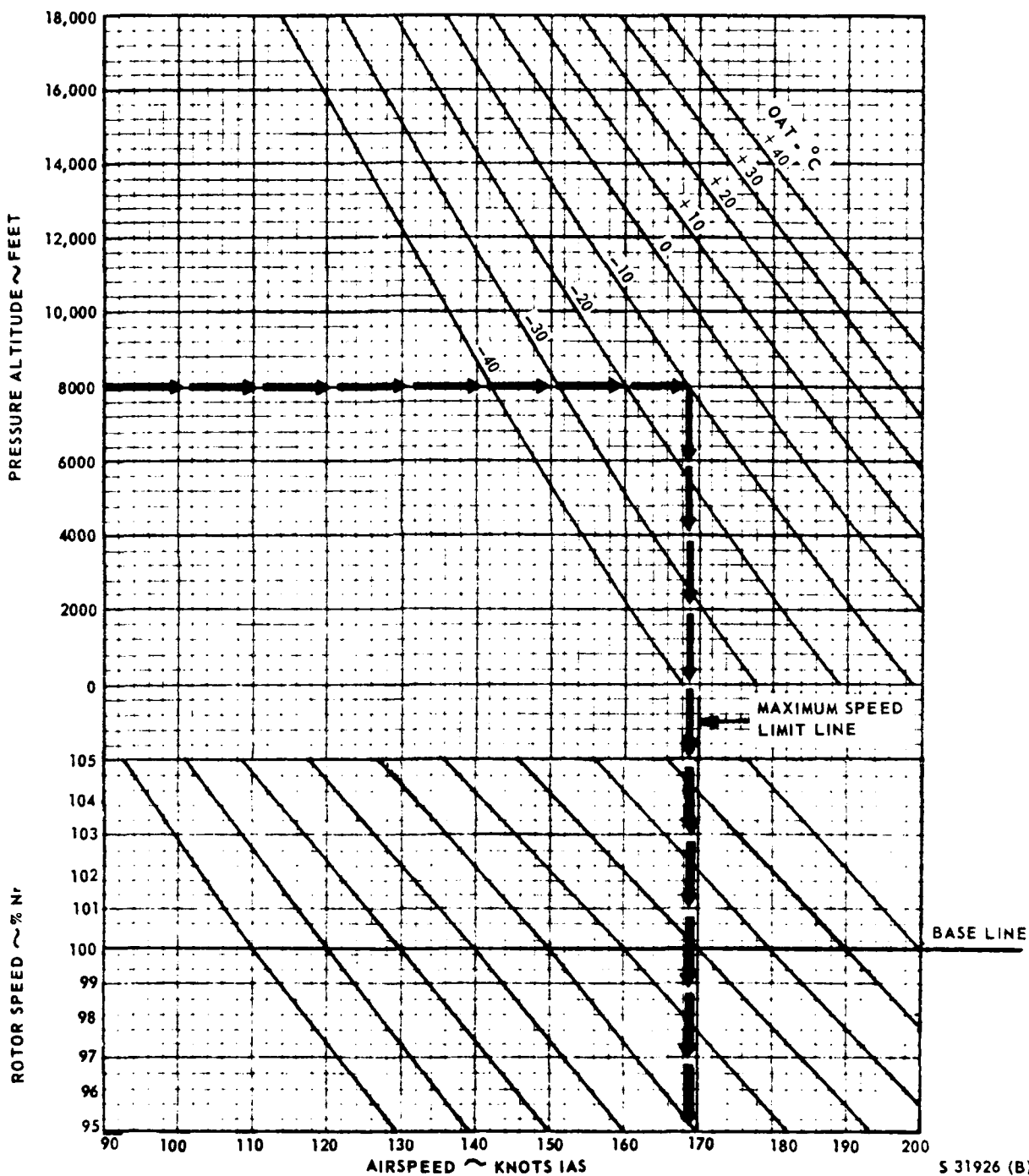
Figure 4-1. Incipient Blade Stall Chart

BLADE TIP MACH

UNACCELERATED LEVEL FLIGHT

MODEL: RH-53D
 DATA AS OF: 15 APRIL 1973
 DATA BASES: ESTIMATED

ENGINES: (2) T64-GE-413A
 FUEL GRADE: JP4/JP5
 FUEL DENSITY: 6.5/6.8 LB/GAL



S 31926 (B)

Figure 4-2. Maximum Airspeed as Limited by Advancing Blade Tip Mach Number

HEIGHT ~ VELOCITY DIAGRAM ~ ONE ENGINE FAILURE

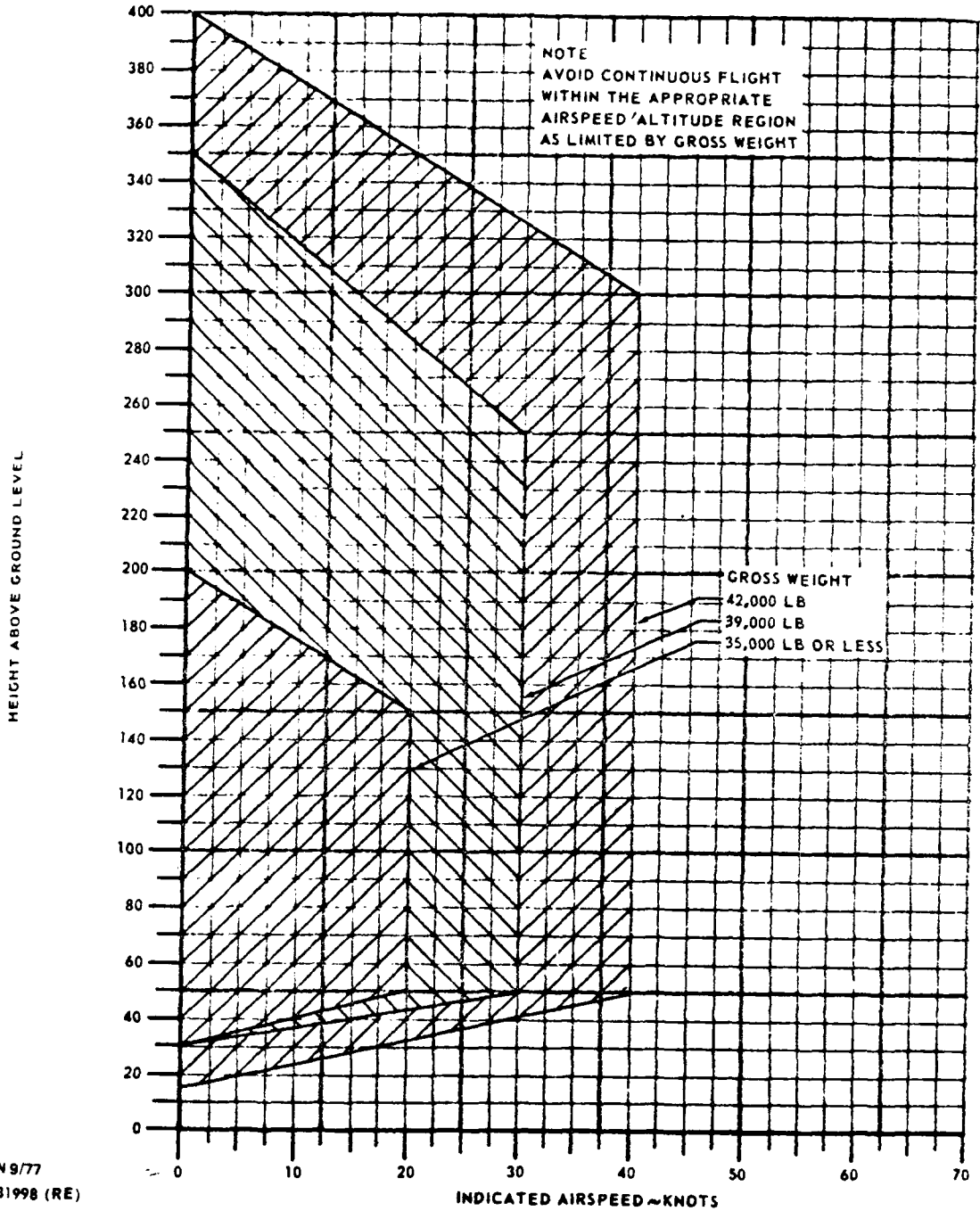
HIGH VELOCITY

ONE ENGINE OPERATING
M₀ N₁

SEA LEVEL 15°C

MODEL: RH-53D
DATA AS OF: 1 AUGUST 1975
DATA BASIS: ESTIMATED

ENGINES: (1) T64-GE-415
FUEL GRADE: JP-4/JP-5
FUEL DENSITY: 6.5/6.8 LBS/GAL



N 4/77
S 31997 (RE)

N 9/77
S 31998 (RE)

Figure 11-21. Height Velocity Diagram - One Engine Failure

NAVAIR 01-H53AAA-1
HEIGHT VELOCITY

HEIGHT ~ VELOCITY DIAGRAM ~ TWO ENGINE FAILURE
SEA LEVEL 15°C

100% N_r
33,500 LB G.W.

MODEL: RH-53D
DATA AS OF: 15 APRIL 1973
DATA BASIS: ESTIMATED

ENGINES: T64-GE-413A
FUEL GRADE: JP-4/JP-5
FUEL DENSITY: 6.5/6.8 LB 'GAL

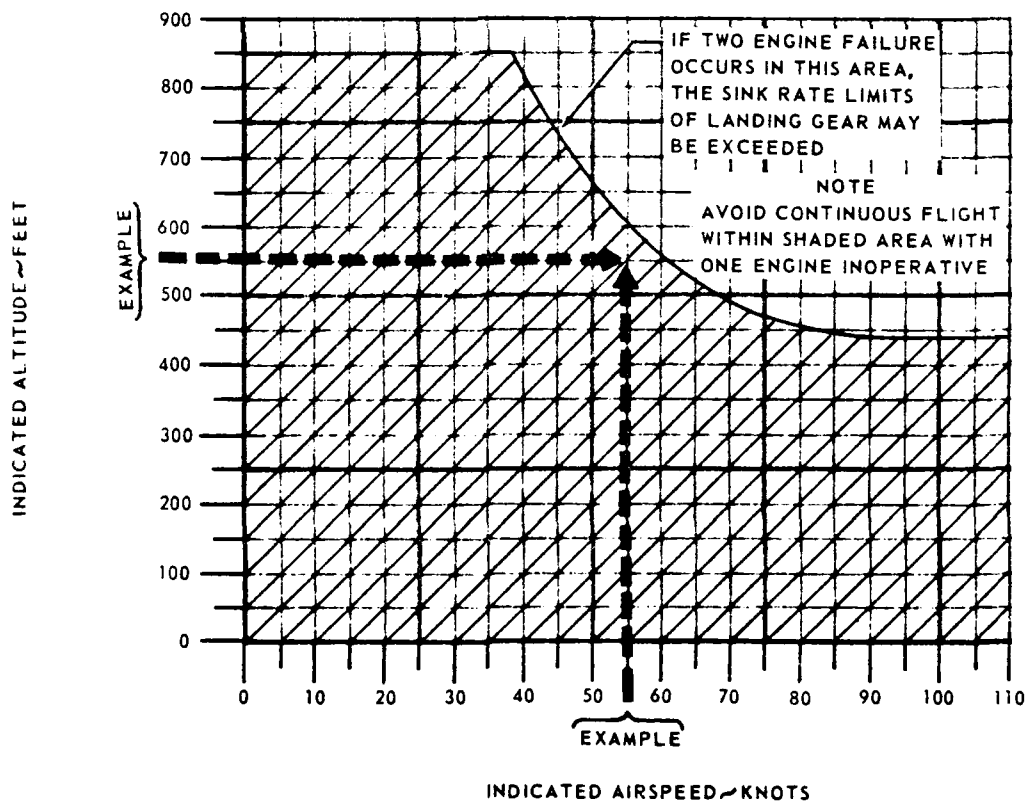
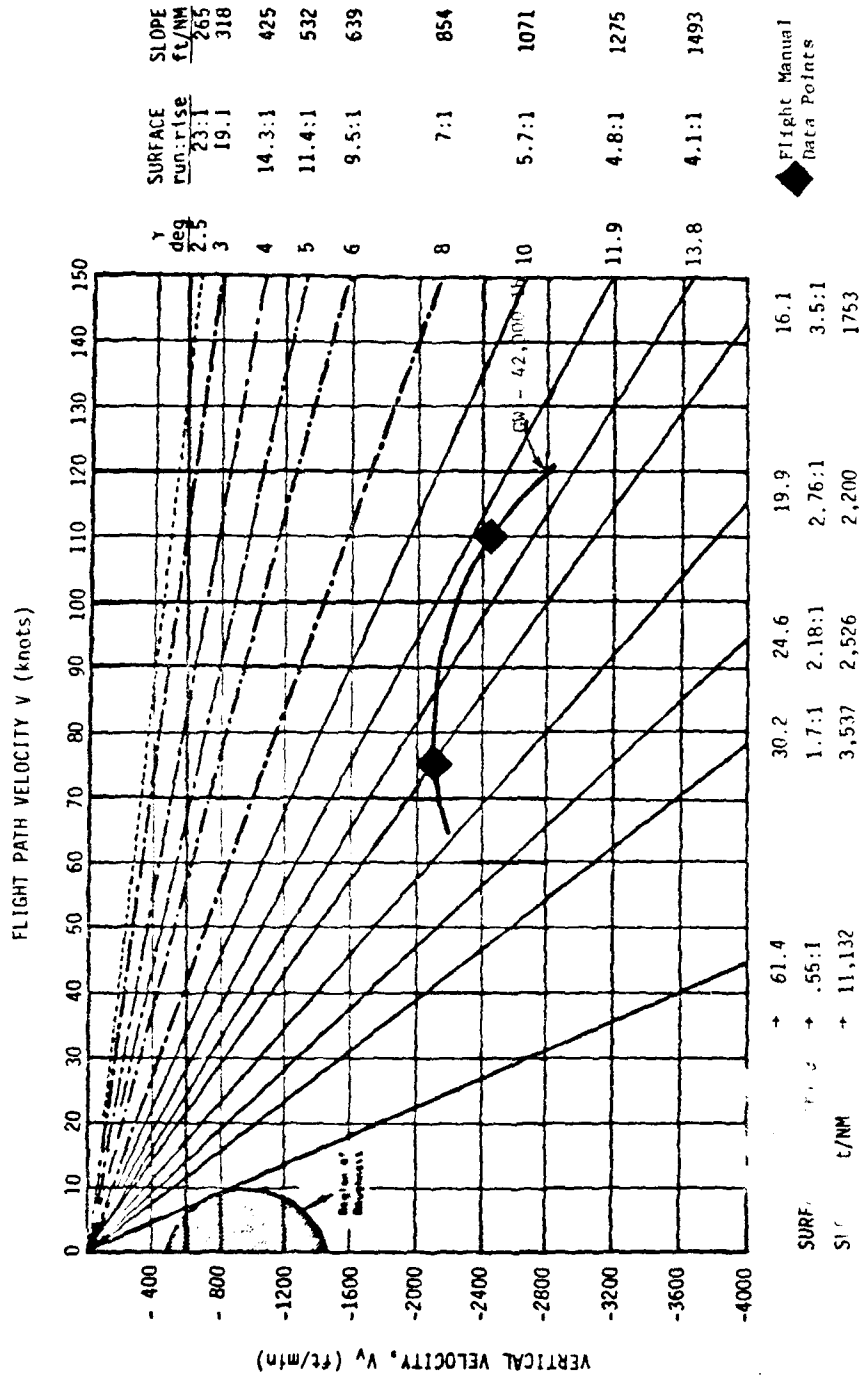


Figure 11-21. Height Velocity Diagram Two Engine Failure

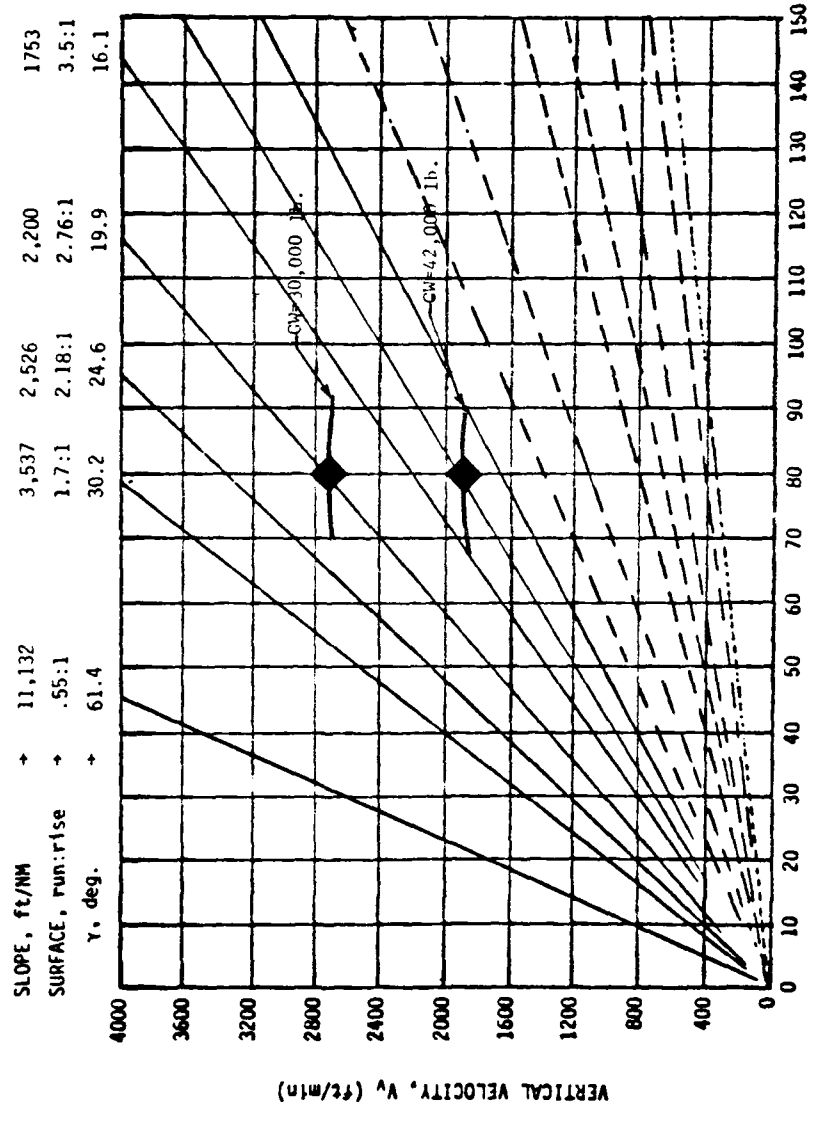
S 31997 (B)

SIKORSKY S-65 (HO-53D)
AUTOROLLATION (Power off)



DESCENT RATE VERSUS FLIGHT PATH VELOCITY

SIKORSKY S-65 (RH-53D)
STANDARD DAY SEA LEVEL
MILITARY POWER (30 MINUTE)



SLOPE, ft/NM → 11,132
SURFACE, run:rise → .55:1
γ, deg. → 61.4

1753
2,200
2,526
3,537
3.5:1
19.9
2.76:1
16.1

13.8 4.1:1 1493
11.9 4.8:1 1275
10 5.7:1 1071
8 7:1 854
6 9.5:1 639
5 11.4:1 532
4 14.3:1 425
3 19.1 318
2.5 23:1 265

Y SURFACE SLOPE
deg run:rise ft/NM

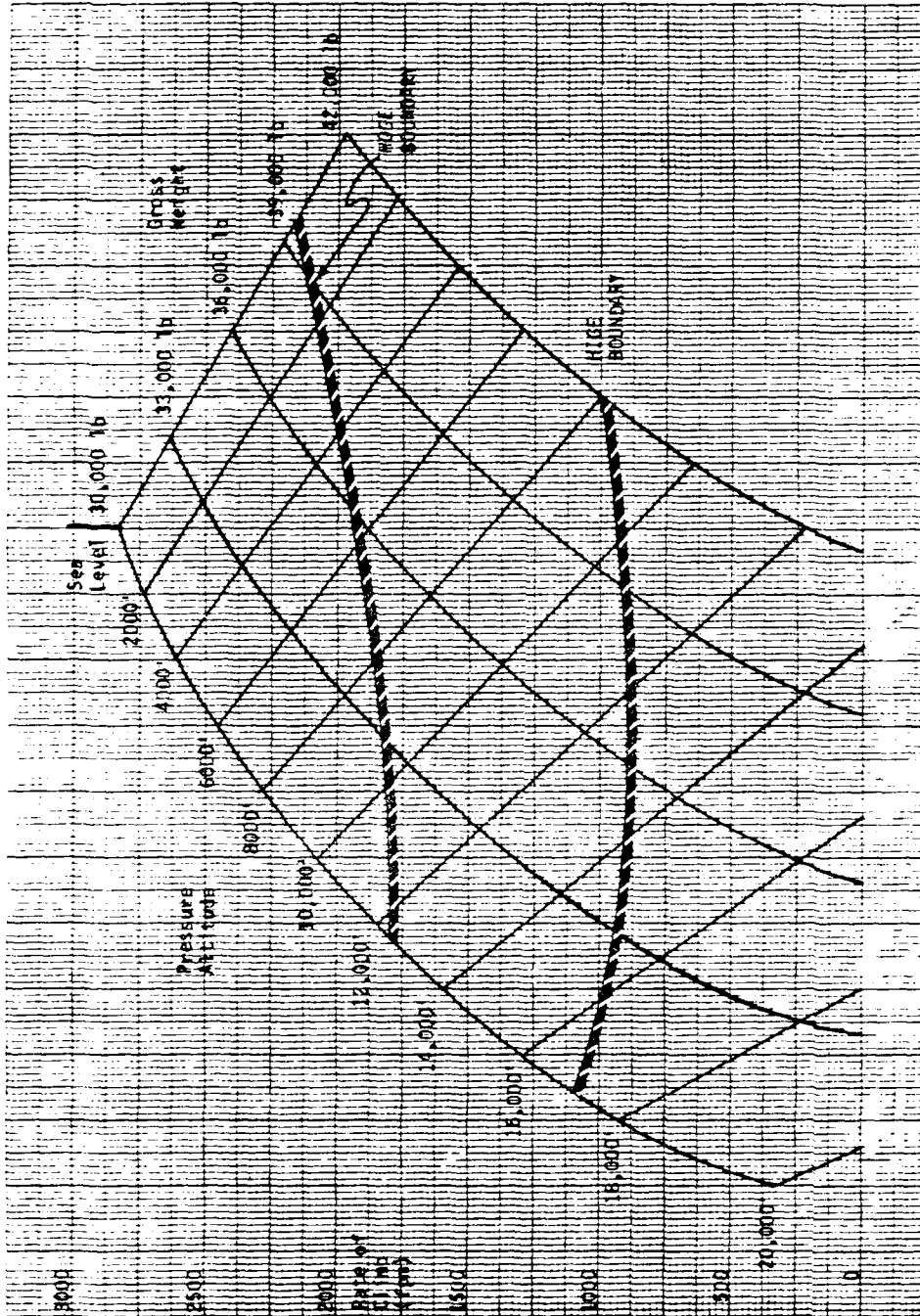
◆ FLIGHT MANUAL DATA POINTS

CLIMB RATE VERSUS FLIGHT PATH VELOCITY

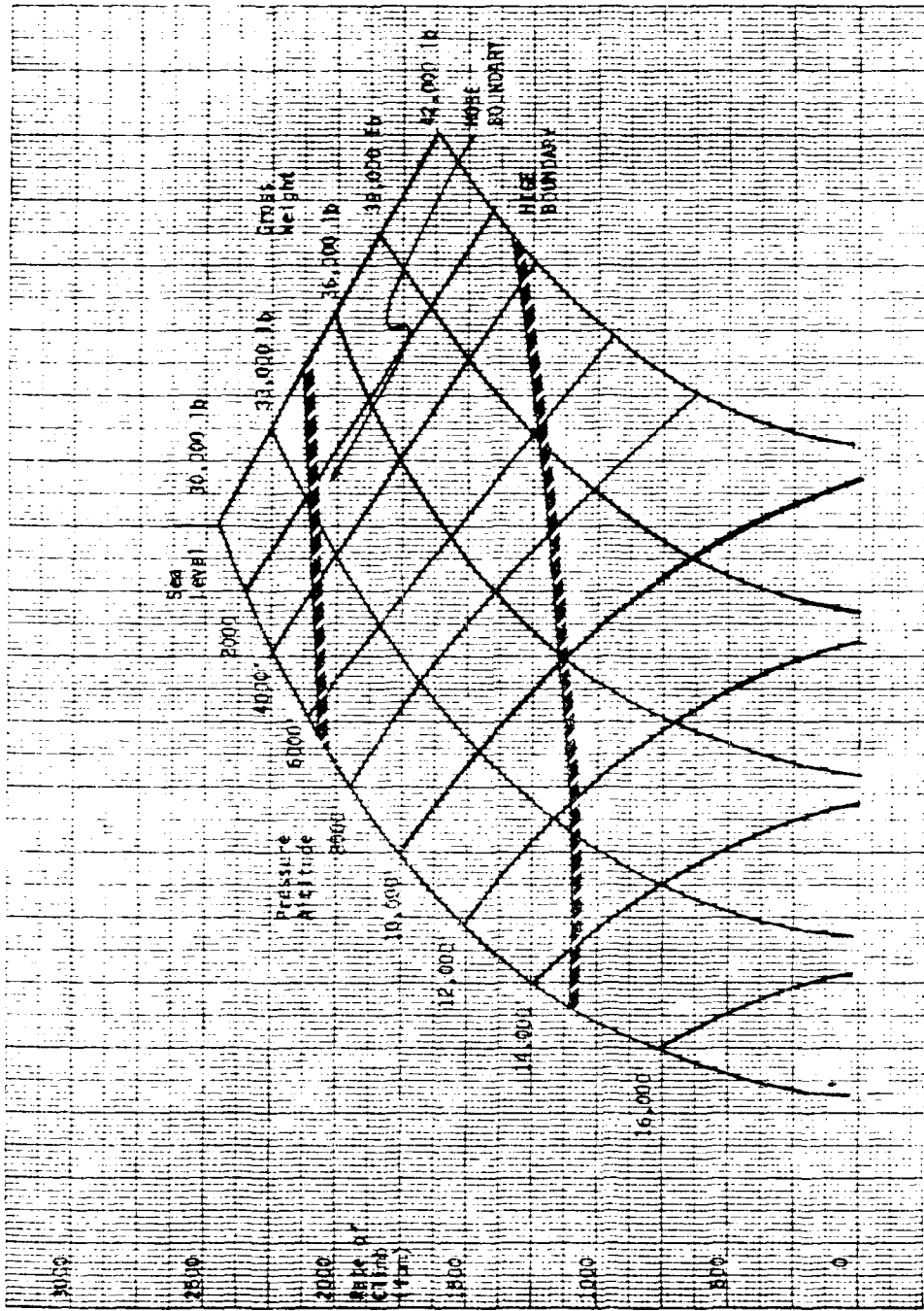
Climb Rates

The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.)

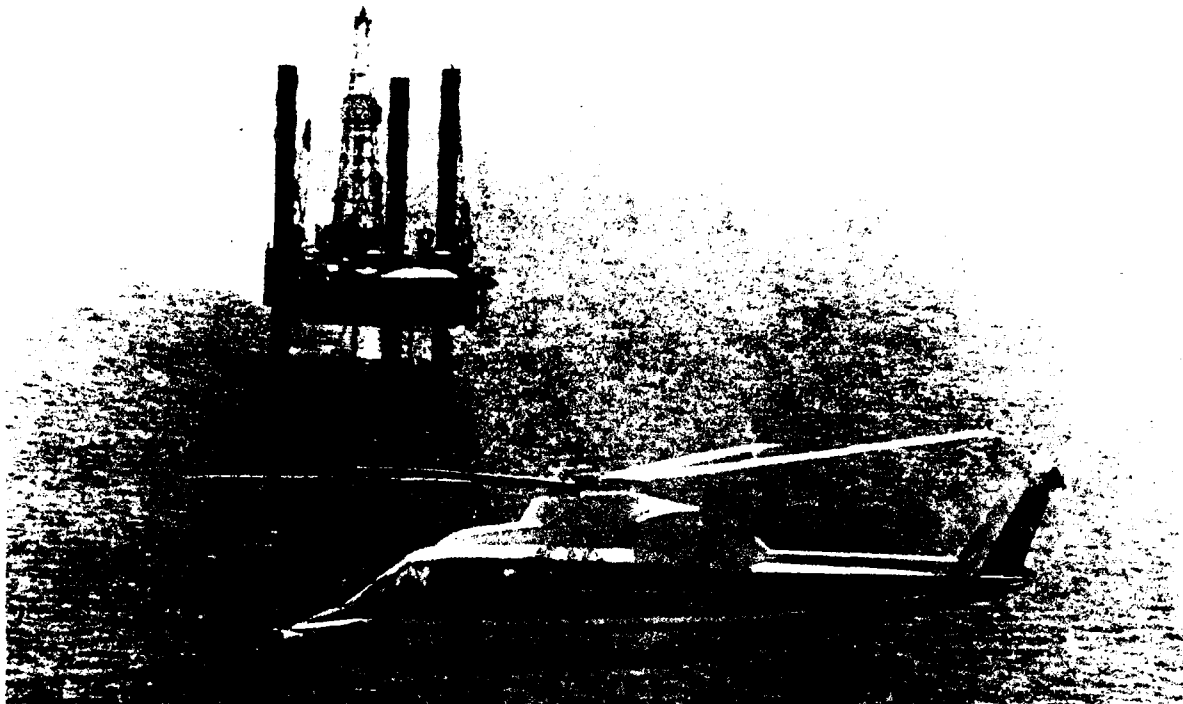


Sikorsky S-65 Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures)



Sikorsky S-65 Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

THE SIKORSKY S-76A SPIRIT HELICOPTER



LIGHTWEIGHT SINGLE MAIN ROTOR HELICOPTER POWERED BY TWO TURBOSHAFT ENGINES.
DESIGNED FOR EXECUTIVE AND UTILITY TRANSPORT.

MANUFACTURER: SIKORSKY AIRCRAFT DIVISION OF UNITED TECHNOLOGIES
CORPORATION

POWER PLANT: Two Detroit Diesel Allison Model 250-C30 free power
turbine engines rated at 650 SHP for both normal two
engine takeoff and maximum continuous operations. The
transmission is torque limited to 650 SHP per engine
for continuous operations.

AIRCRAFT UTILITY: FAA certificated under Type Certificate H1NE Revision
2 of July 26, 1979, for Transport Helicopter, Category
A and Category B. Single pilot operation is authorized
under VMC, but two appropriately qualified pilots are
required for IMC operations.

SEATING CAPACITY: Variable cabin arrangement permits seating for up to
14 persons (crew included).

INTRODUCTION

The S-76A Spirit is a 14-place lightweight helicopter manufactured by the Sikorsky Aircraft Division of The United Technologies Corporation. The helicopter was designed for civil use in executive and utility transport roles. It has no military counterpart. Consequently, the market emphasis has resulted in IFR certification within the basic type certificate.

Standard configuration includes a four-bladed, single, main rotor with anti-torque tail rotor. Landing gear is retractable in tricycle configuration.

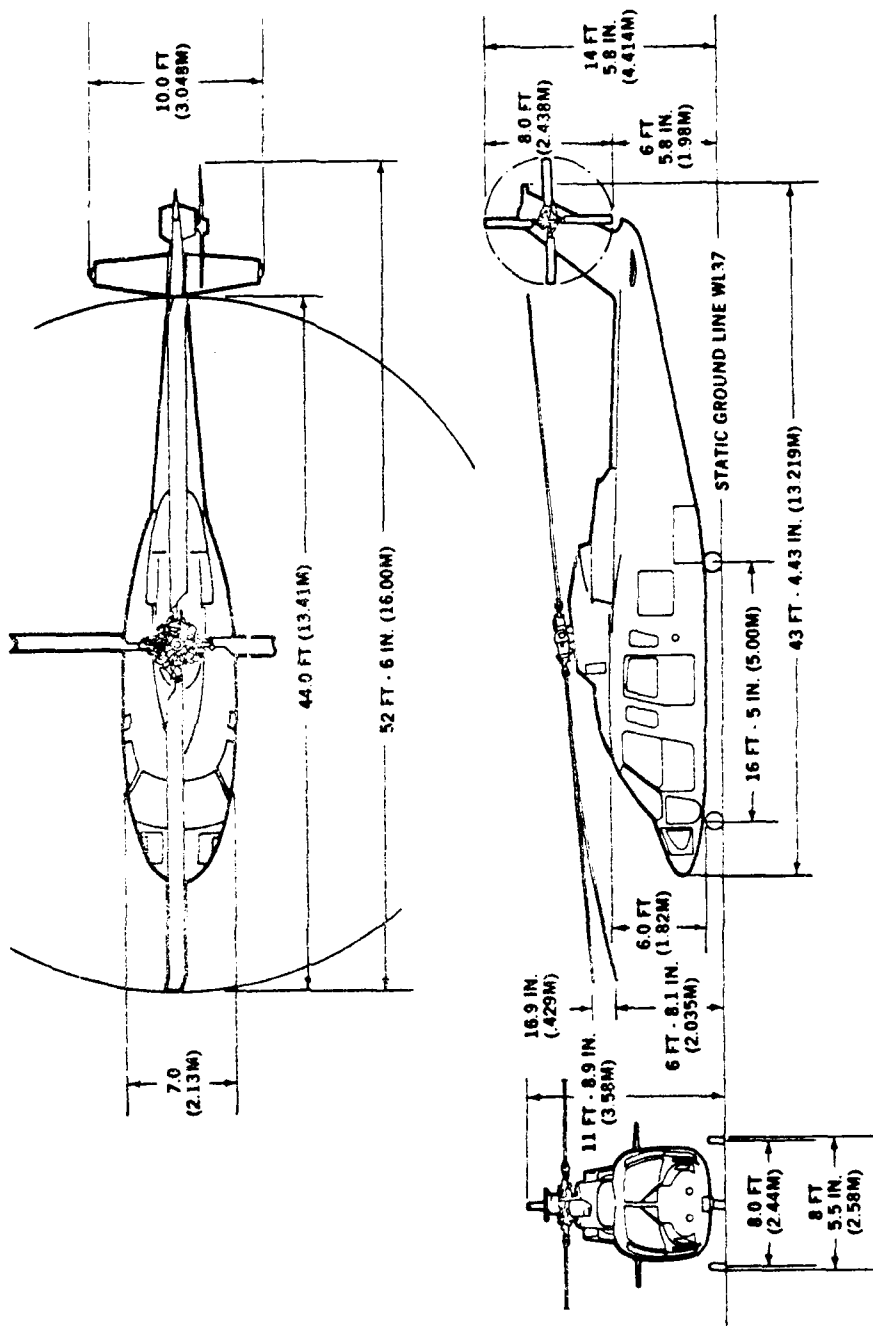
The S-76A is powered by two Detroit Diesel Allison Model 250-C30 turboshaft engines. Engines and transmission are both rated for 650 SHP per engine at takeoff and continuous ratings. Following engine failure, contingency ratings for the remaining engine and transmission permit operation of one engine at 694 SHP for 2 1/2 minutes or 655 SHP for 30 minutes.

Takeoff and landing operations are presently limited to density altitudes at and below 6,900 feet. This limitation results from the extent of demonstration currently reflected in the type certificate. Subsequent demonstration may be expected to result in less restrictive takeoff and landing limitations.

Performance data presented herein have been extracted from the Sikorsky Model S-76A Flight Manual (approval date November 21, 1978, revised October 4, 1979) unless otherwise noted. (Autorotation rate of descent data were not provided in the Flight Manual, but were instead derived from power required curves obtained through Sikorsky marketing.)

GENERAL IFR PERFORMANCE DATA

Minimum IFR Airspeed	60 KIAS
Recommended IFR Approach Speeds	80 - 125 KIAS
Maximum Density Altitude-Landing and Takeoff	6,900 ft.
Maximum Density Altitude-Enroute	15,000 ft.
V _{ne} (diminishes with increasing altitude and gross weight)	155 KIAS



Three View Dimensional Diagram

PRESS ALT	POWER ON 100-107% Nr								
	V_{ne} (IAS) GROSS WT ~ 8750 # & BELOW								
X 1000	-35	-20	-10	0	10	20	30	40	50
-1	OAT ~ °C								
0									
1	155 KTS								
2									
3									
4									
5									
6									
8	153	146	139	132	125	119	114	109	104
10	143	132	125	118	113	108	102	98	93
12	129	118	112	106	101	96	91		
14	115	106	100	95	89				
16	103	94	88						
18	91	FLIGHT NOT ALLOWED							

V_{ne} POWER-ON
TAKEOFF GROSS WEIGHT 8750 POUNDS AND BELOW

PRESS ALT	POWER ON 100-107% Nr								
	V_{ne} (IAS) TO GROSS WT ~ 8751 TO 10,000#								
X 1000	-35	-20	-10	0	10	20	30	40	50
-1	OAT ~ °C								
0									
1	155 KTS								
2									
3									
4									
5									
6									
8	151	138	129	122	114	107	99	92	85
10	134	121	113	105	97	90	82	75	68
12	118	105	96	88	80	74	66		
14	101	87	79	72	64				
16	83	70	62						
18	66	FLIGHT NOT ALLOWED							

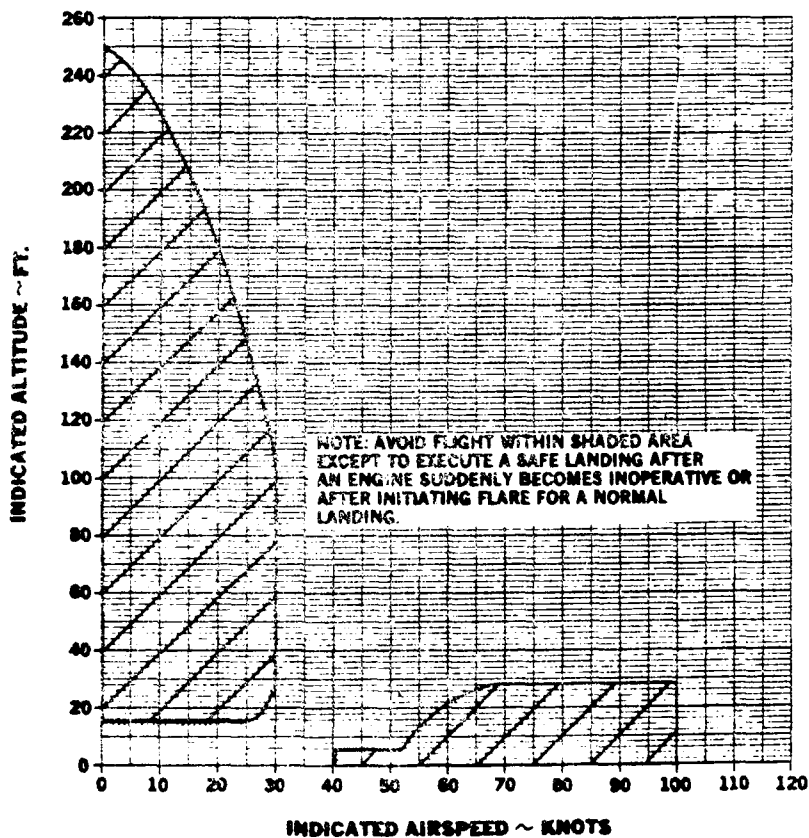
V_{ne} POWER-ON
TAKEOFF GROSS WEIGHT 8751 POUNDS TO 10,000 POUNDS

LIMITING HEIGHTS AND CORRESPONDING SPEEDS FOR SAFE LANDING AFTER AN ENGINE SUDDENLY BECOMES INOPERATIVE

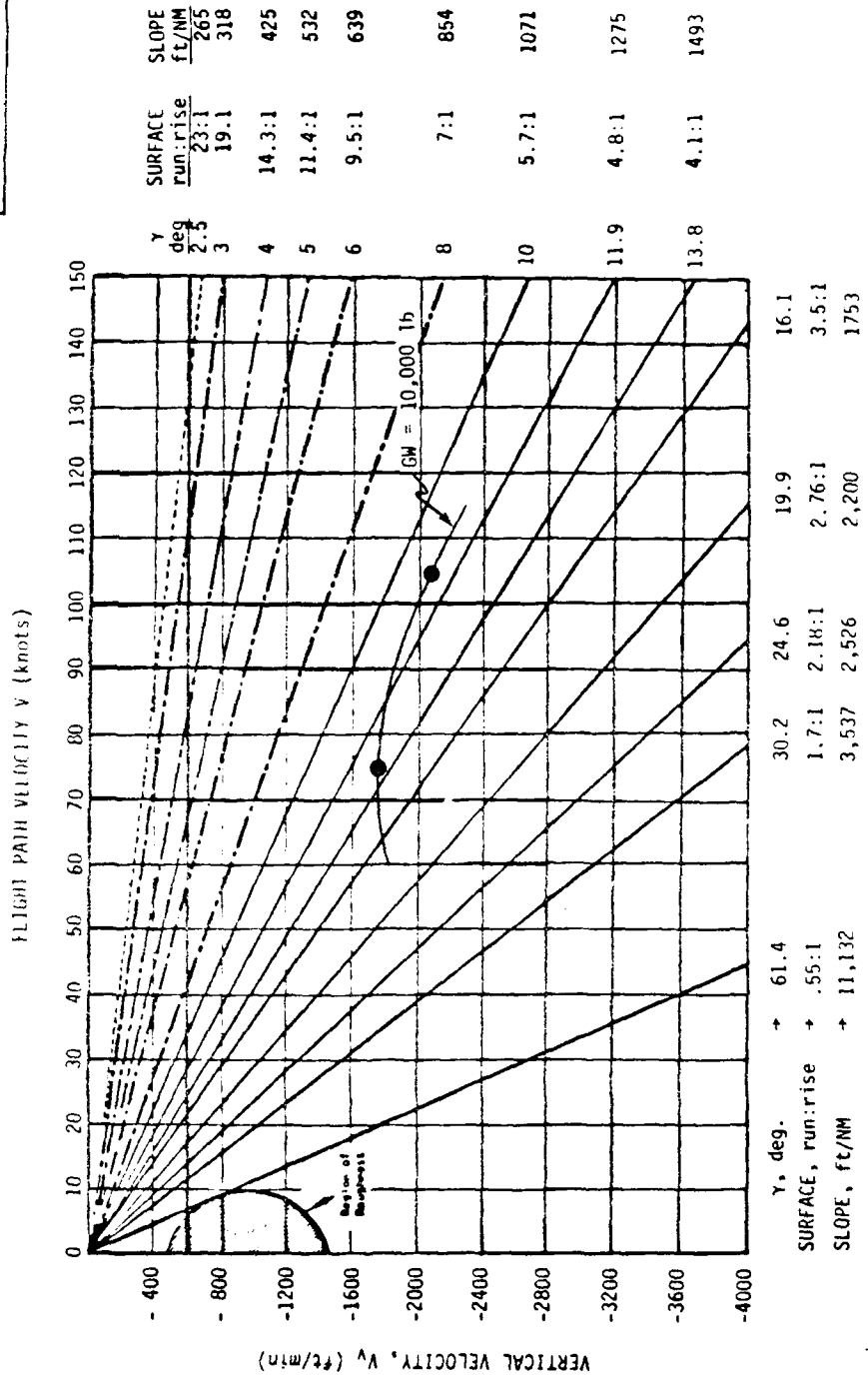
THESE CURVES ARE APPLICABLE TO ALL ALTITUDES AND TEMPERATURES AT THE CORRESPONDING MAXIMUM ALLOWABLE TAKE-OFF GROSS WEIGHT AS DETERMINED FROM FIGURES 1-1 AND 1-2.

INFORMATION ON TEST CONDITIONS:

1. HARD SURFACE RUNWAY
2. WINDS 5 KN. OR LESS
3. STRAIGHT TAKEOFF AND CLIMBOUT PATH
4. GEAR DOWN AT ENTRY
5. 34 KN. BRAKE APPLICATION LIMIT WAS OBSERVED
6. NO BLEED AIR
7. ANTI-ICE OFF



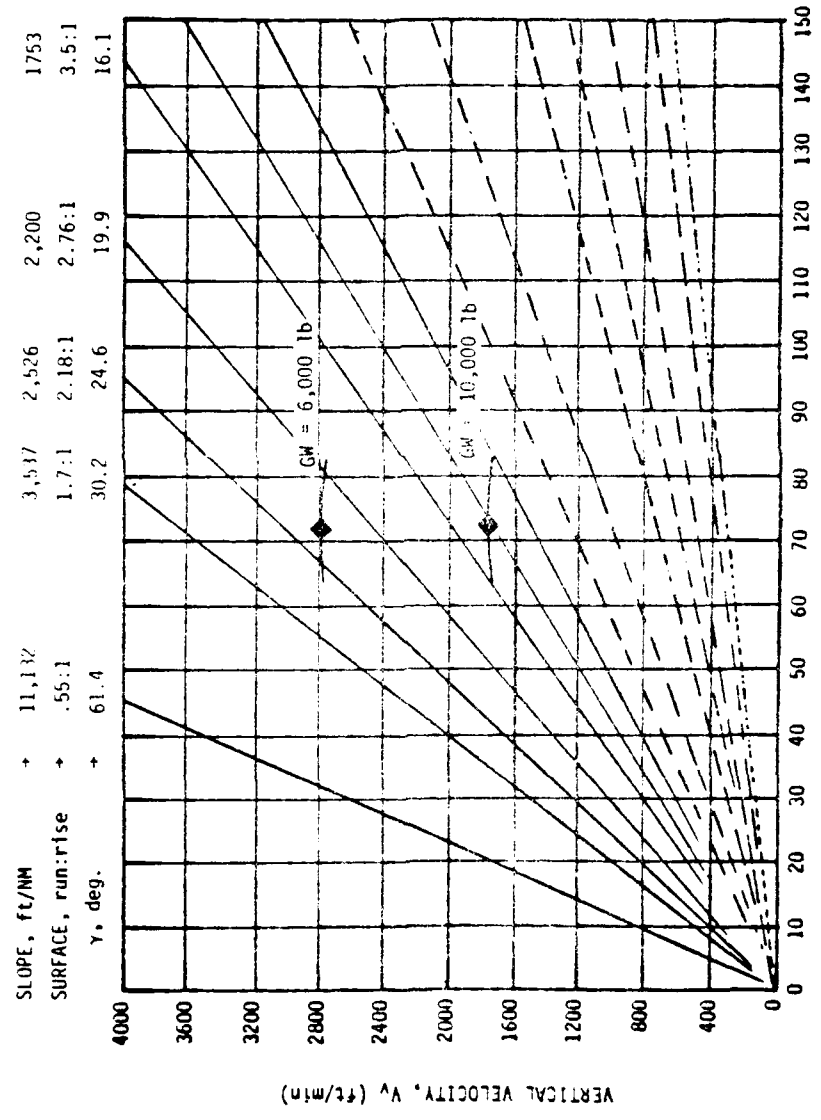
Sikorsky S-76A
 Autorotation (Power Off)
 Sea Level Standard Day



● PACER Engineering Estimates
 of Data Points

Descent Rate versus Flight Path Velocity

Sikorsky S-76A
Standard Day, Sea Level
Maximum Continuous Power



FLIGHT PATH VELOCITY V (knots)

◆ Flight Manual Data Points

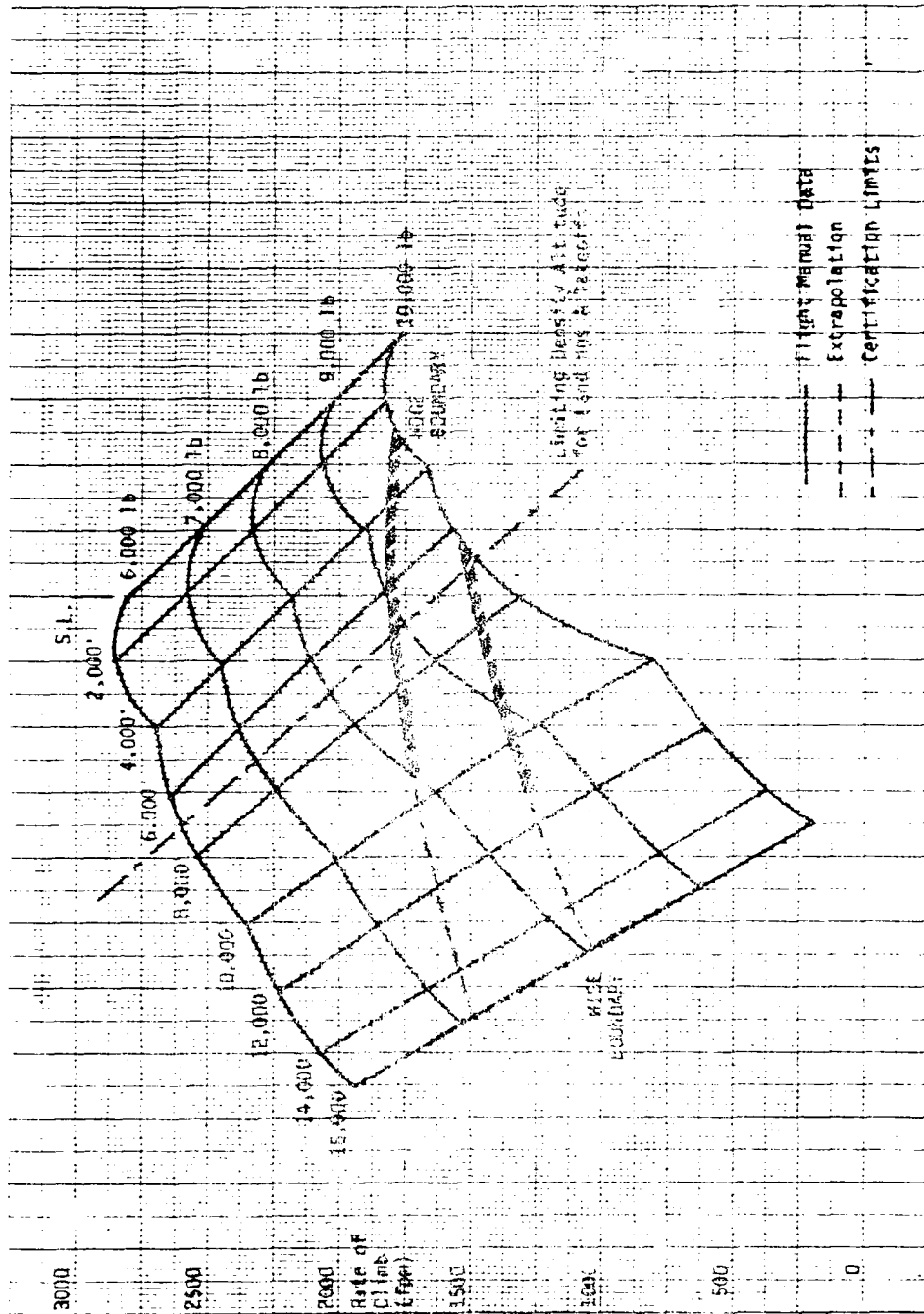
Climb Rate versus Flight Path Velocity

Climb Rates

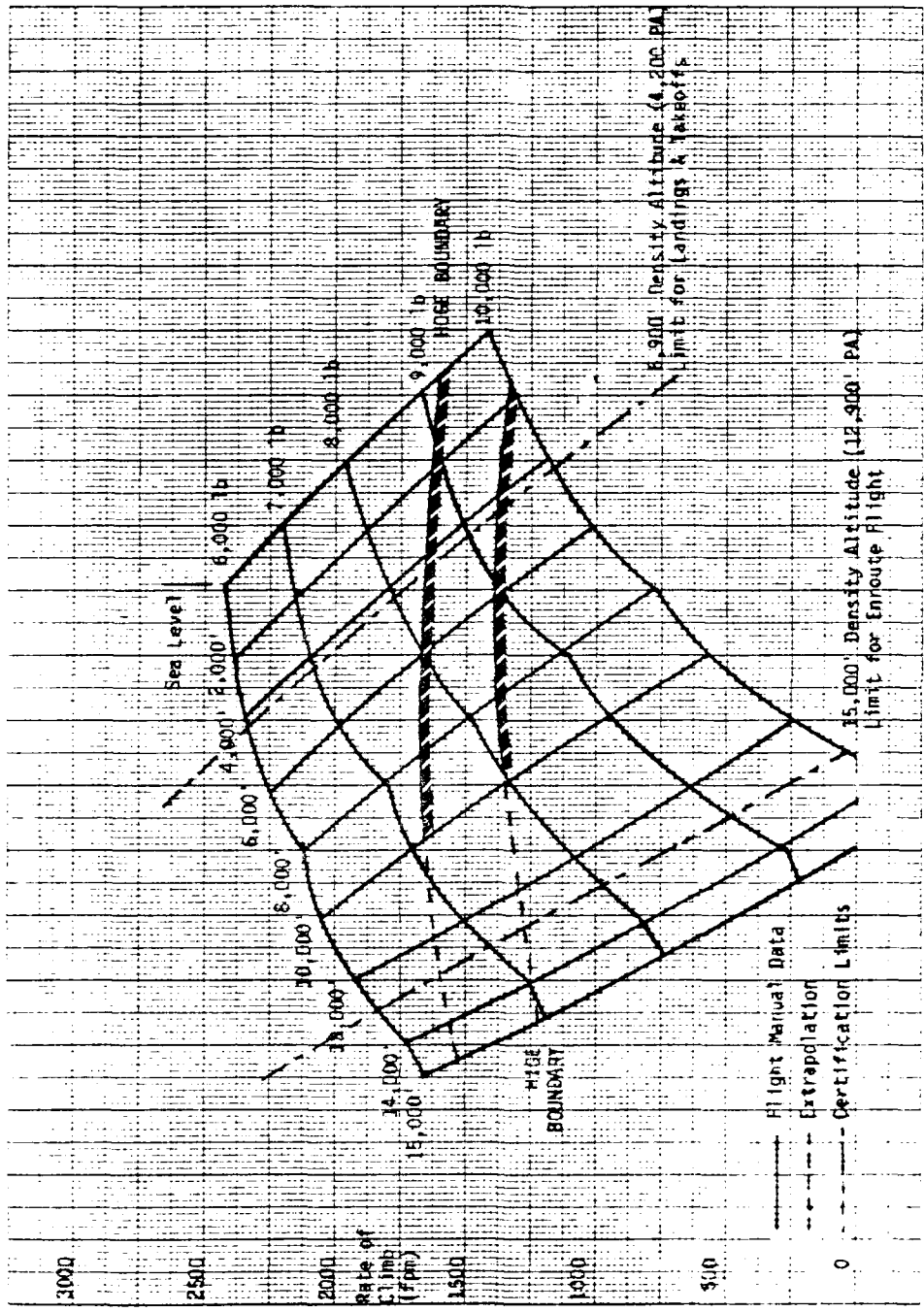
The following two figures present carpet plots of the best rate of climb attainable at optimum climb speed and maximum continuous power for a spectrum of aircraft weight and pressure altitude. One figure presents data for standard day performance and the other, hot day performance when temperatures are uniformly 20°C warmer than standard day at each altitude.

Two traces, one labeled HOGE (hover out of ground effect) Boundary and the other, HIGE (hover in ground effect) Boundary, cross the carpet plots to identify those combinations of gross weight and altitude at which hover capability becomes correspondingly limited. (Hover performance is based on dual engine takeoff power vice maximum continuous power.) For this aircraft data were not presented which permitted identification of the hover boundaries at the highest altitudes for which climb performance data have been presented. Consequently, hover boundaries have been extrapolated to provide an estimate of capabilities. All other data presented in these figures are drawn from published Flight Manual Data except the HIGE Boundary. This information is not contained in the Flight Manual so it was drawn from published Sikorsky marketing information.

The S-76A Spirit has not yet demonstrated landing and takeoff operations for certification purposes above 6,900 feet density altitude nor enroute flight above 15,000 feet density altitude. These heights, therefore, currently limit the certificated operational envelope and are thus, marked on the carpet plots to graphically provide this information.



S-76A Spirit Best Rate of Climb vs. Gross Weight and Pressure Altitude
(Standard Day Temperatures)



S-76A Spirit Best Rate of Climb vs. Gross Weight and Pressure Altitude
 (Standard Day Temperatures +20°C)

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- 5- 2. Demko, Paul S. and Boschma, Capt James H., "Advances in Decelerating Steep Approach and Landing for Helicopter Instrument Approaches", U.S. Army Avionics R&D Activity, paper presented at the 35th Annual National Forum of the American Helicopter Society, Washington, D.C., Preprint No. 79-66, May 1979.