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LIMITATIONS OF THE CH-47 HELICOPTER IN PERFORMING TERRAIN FLYING WITH EXTERNAL LOADS

Boeing Vertol Company
P. O. Box 16858
Philadelphia, Penn. 19142

August 1977

Final Report for Period July 1976 - April 1977

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Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report provides a reasonable quantification of many of the limitations and shortcomings of the CH-47 in terrain flying with external loads. Much of the data was computer generated and has not been confirmed through flight testing. Promising external cargo handling system concepts that will improve the capabilities of the CH-47 in terrain flying with external loads were identified. This work will provide the basis for further design and evaluation efforts of the identified concepts to increase the survivability and utilization of the CH-47.

Thomas B. Allardice and Major Billy V. Genter of the Military Operations Technology Division served as project engineers for this effort.

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Terrain Flying Limitations
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Lateral Terrain Avoidance
Load Sway Motion
Load Stabilization
(AAELSS) Active Arm External Load Stabilization System

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Quantitative limitations of the CH-47 helicopter performing terrain flying with external loads have been developed using a fully coupled total force and moment simulation math model of the helicopter and external load. Load sway motion and susceptibility to pilot induced oscillations in night/instrument meteorological conditions were identified as the prime source of these limitations. Masking considerations were determined for various external load configurations, including an 8x8x20-foot MILVAN and a 155mm

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Self-Hoisting Cargo Interface Device
Load Snubbing
MILVAN
Gondola
155mm Howitzer
Pilot-Induced Oscillation (PIO)
Forward Looking Infrared (FLIR)
Short Sling Suspensions
Masking Height Requirements
VFR Collision Plane Avoidance
Load Snag
Visionic Systems
Night Vision Goggles (NVG)

Abstract (Continued)

howitzer. Incorporation of load stabilization (AAELSS), coupled with a shortened sling suspension or a Self-Hoisting Cargo Interface Device, offers the best potential for alleviating the limits identified, while providing improved masking requirements and reductions in pilot workload. In addition, the levels of maneuverability possible with the present state-of-the-art visionic systems (including FLIR and NVG) were defined for terrain flying during night operations.

PREFACE

This report presents the quantitative limitations of the CH-47 helicopter in performing around-the-clock terrain flying with external loads. Analytical results and preliminary designs for several concepts which can be used to alleviate these limitations are also provided.

The work was sponsored by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia, and was performed by the Boeing Vertol Company, Philadelphia, Pennsylvania, under Contract DAAJ02-76-C-0028, during the period from July 1976 through April 1977.

The Army technical representatives were Mr. T. Allardice and Major B. V. Genter. The contributions of Army personnel to this effort are gratefully acknowledged.

The following Boeing Vertol personnel contributed to this program:

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1.0 SUMMARY

1.1 BACKGROUND AND APPROACH

Current U.S. Army doctrine related to deployment of helicopter units in the high threat environment postulated for mid-intensity battlefields of the future, is defined in Field Manual (FM) 90-1 (Reference 1). This document indicates that virtually all helicopters, regardless of type, will be required to terrain fly using techniques described in FM 1-1 (Reference 2), in order to survive and accomplish assigned missions in the anticipated hostile battlefield environment.

Although the medium lift CH-47 assault-support helicopter is not expected to fly in the most lethal airspace immediately adjacent to the Forward Edge of the Battle Area (FEBA), the aircraft will nevertheless operate from other forward positions where terrain flying must be employed to remain below the enemy air defense threat. Typical of such missions described in FM 90-1 are the repositioning and resupply of Forward Area Refuel and Rearm Points (FARRP), which may be as close as 15 kilometers to the FEBA.

To facilitate accomplishment of the assault-support task, the CH-47 can easily carry heavy external payloads when required. This mode of operation reduces exposure time in the forward area during offloading, permits movement of oversized loads too big for internal storage, and increases productivity appreciably when large quantities of prerigged cargo are to be transported. Maximizing CH-47 combat support effectiveness, however, will not only require terrain flying with external loads, but also the potential for performing such missions around the clock and in IMC. Improved load suspension systems, such as the dual hook installation developed for the Chinook over the past several years, provide increased capability for executing terrain flying missions with external cargo.

This report presents the results of a study conducted by Boeing Vertol, to assess the limitations of the CH-47 helicopter in performing terrain flying with external loads. In addition to defining limitations, potential solutions are also developed.

Limitations evaluated in the study fall into several broad areas,including:

- Those associated with providing adequate clearance from obstacles while maneuvering close to the terrain
- Those resulting from load motion and/or aircraft maneuverability and speed capability with the load attached
- Those related to providing masking (which is the ability to hide the aircraft behind cover during maneuvers)
- Those resulting from aircraft handling qualities, performance, or structural capability.

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1. Field Manual 90-1, EMPLOYMENT OF ARMY AVIATION UNITS IN A HIGH THREAT ENVIRONMENT, Headquarters, Department of the Army, Washington, D.C., 30 September 1976.
2. Field Manual 1-1, TERRAIN FLYING, Headquarters, Department of the Army, Washington, D.C., 1 October 1975.

Additional limits resulting from night and all-weather operations were also assessed.

Specific limitations associated with load acquisition or deposit, and those which accrue from navigational or communication requirements do exist; they were not explored in-depth, as those limitations were already being addressed in other U.S. Army research programs.

The CH-47 terrain flying study consisted of two separate phases of activity. The first dealt with the determination of aircraft and system limits, as defined by an unpiloted flight simulation of selected terrain flying maneuvers. With these limitations defined, candidate concepts for cargo and visionics systems (intended to remove as many of the limits as practical) were developed and ranked. These concepts were then reviewed with U.S. Army personnel to provide guidance for the second phase activities.

The second or System Definition phase consisted of executing preliminary design trade studies for the two cargo handling systems selected at the end of Phase I work. These were an improved, lightweight, self-contained/removable version of the previously flight tested Active Arm Load Stabilization concept, and a Self-Hoisting (Container Handling) Interface Device for snubbing the load against the aircraft bottom in order to minimize masking requirements and to eliminate load motion.

1.2 TERRAIN FLYING MANEUVERS

Helicopter terrain flying is normally divided into the three separate modes of operation illustrated in Figure 1. These include:

- Nap-of-the-Earth (NOE) flight – where the aircraft generally tries to stay masked below available cover by flying *around* obstacles.

- Contour flying – where the helicopter remains masked whenever possible during maneuvers, but flies *over* obstacles which are not easily flown around.

- Low-level flight – where the aircraft flies *above* all obstacles at relatively constant airspeed and altitude.

Rigorous definitions for each terrain flying mode have varied from time to time over the past few years, as battle tactics changed. At present, the NOE and contour modes are both generally understood to include maneuvers in which airspeed and altitude may be varied to avoid obstacles. Rigid distinction between maneuvers and flight modes is not important,however,when determining the capability of an aircraft to successfully terrain fly to complete its mission. Accordingly, a series of maneuvers were chosen for the terrain flying study (and then grouped as shown in Figure 1), which were thought to best illustrate the varied nature of the obstacles which might be encountered on a typical terrain flight.

Maneuvers selected for simulator evaluation were:

- THE LONGITUDINAL DASH – in which the aircraft is accelerated from a hover to rapidly traverse an area where cover may be lacking. The acceleration phase is followed by a rapid deceleration to a masked hover.

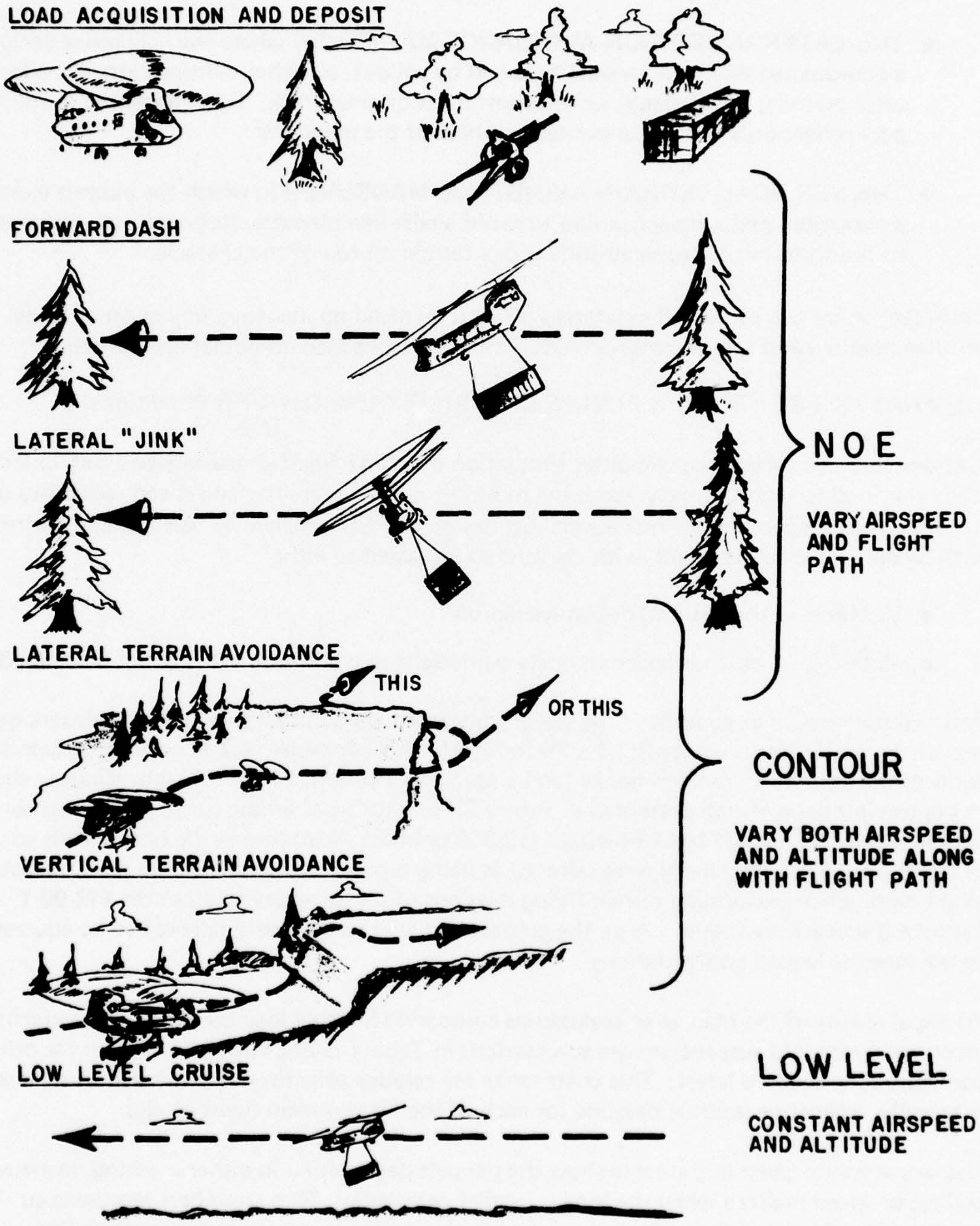


FIGURE I. TERRAIN FLIGHT DEFINTIONS

- THE LATERAL JINK which is similar to the longitudinal dash, but is executed in a sideward rather than forward direction.

- THE LATERAL TERRAIN AVOIDANCE MANEUVER where the helicopter performs a coordinated turn and reversal followed by rollout, to either continue straight ahead after avoiding the obstacle, or to return to its original track. Data presented in the report reflect only the initial avoidance phase of the maneuver.

- THE VERTICAL TERRAIN AVOIDANCE MANEUVER in which the aircraft executes a maximum performance pullup to avoid a cliff-like obstacle, followed by a pushover to return to initial cruise altitude above terrain on top of the obstacle.

Low-level cruise was evaluated separately, since it involved no maneuvering, in order to determine masking and speed characteristics with the various load combinations carried.

1.3 ANALYSIS OF TERRAIN FLYING CAPABILITY (For Day/VFR Conditions)

A comprehensive total force computer simulation of CH-47 flight characteristics with external loads was used to quantitatively assess the masking, maneuverability, and speed capability of the aircraft as it executed the maneuvers just described. Each maneuver was initially performed with baseline internal payloads, with the aircraft ballasted to either:

- 33,000 lb – the CH-47C design weight or
- 45,000 lb – which is approximately equivalent to a 500 fpm vertical climb capability.

After completing an evaluation of the various internal load configurations, all maneuvers were repeated with either an empty 8-x 8-x 20-foot MILVAN container (4,700 pounds) suspended beneath the aircraft on tandem hooks (and employing standard 22- and 20-foot slings as shown in the top left hand sketch presented in Figure 2), or with an alternate single point load consisting of the 155-mm M114A1 howitzer (12,000 pounds) illustrated in the bottom left corner of the figure. Both sling loads were selected as being typical of the type which the Chinook might carry while performing terrain flying missions of the type described in the FM 90-1 battlefield scenario examples. Also, the aircraft and load weight were selected to be equivalent to the internal loaded configurations.

Principal results of the maneuver evaluations comparing internal load baselines with external loads using standard suspensions are summarized in Table I (along with information for other configurations covered later). This chart ranks the relative effectiveness of transporting loads externally, against an internal baseline for each of the three terrain flight modes.

Numerical values given in the table show the percent degradation in either masking, maneuverability, or speed realized when the load is carried externally. These numbers represent an average taken for all of the various maneuvers executed for each terrain flight mode (see Figure 1 for maneuver grouping by mode). As an illustrative example of NOE masking at 33,000 pounds design weight, the 102.5 percent assessment represents the ratio of external to internal load height requirement, compiled from an unweighted average of the overall height of aircraft and load, and minimum altitude required to execute the dash, jink, and lateral avoid maneuvers.

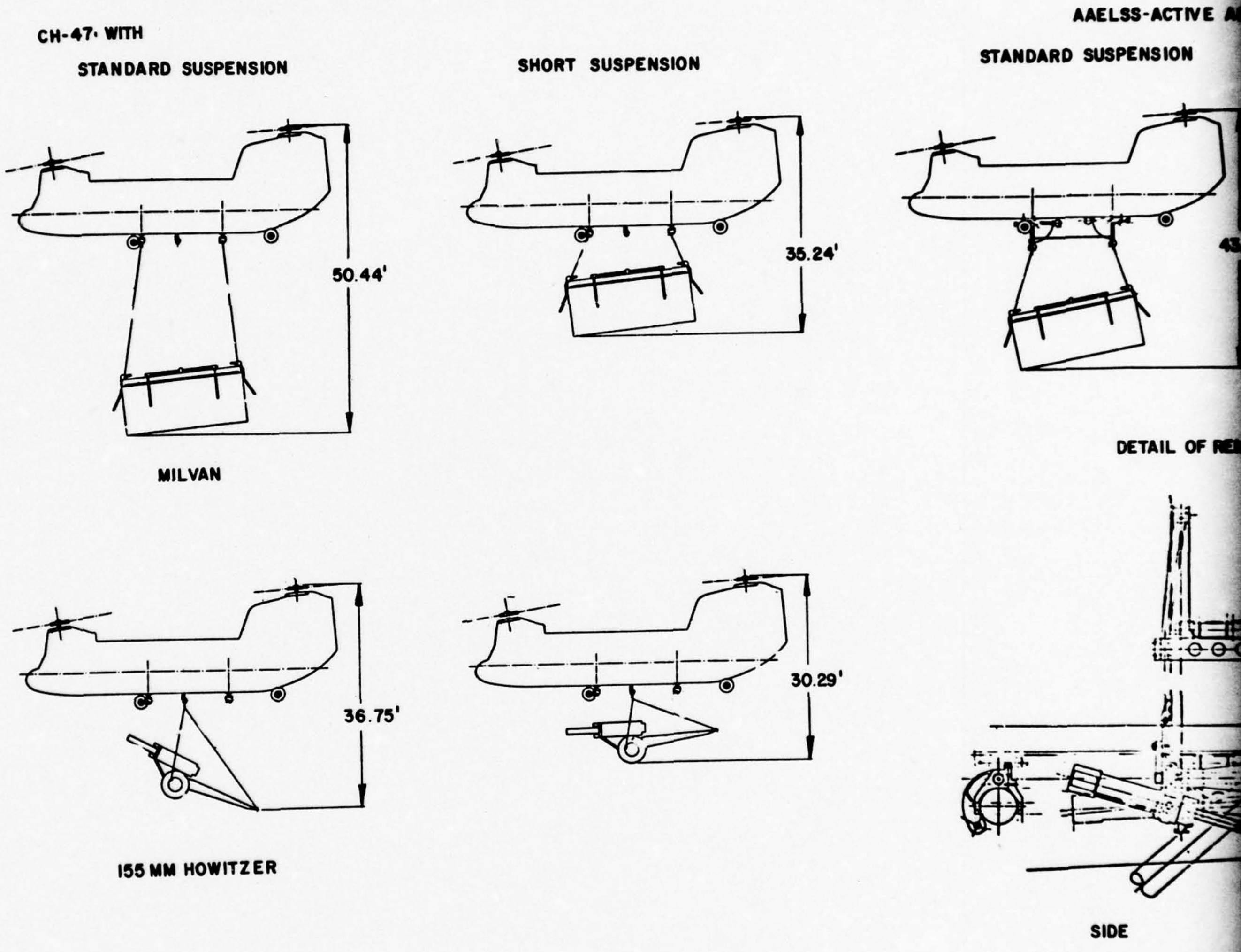
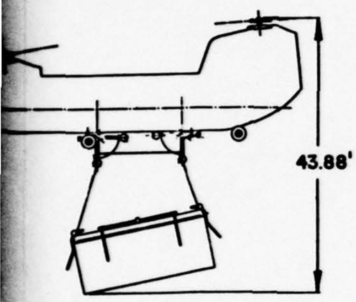


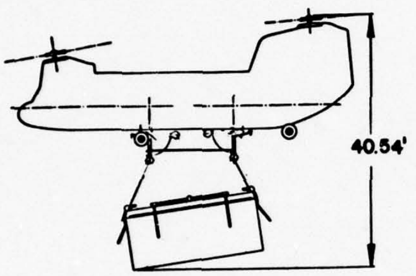
FIGURE 2. LOAD CONFIGURATIONS FOR CH-47 TERR

AAELSS-ACTIVE ARM LOAD STABILIZATION SYSTEM

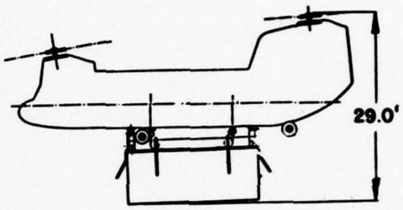
STANDARD SUSPENSION



SHORT SUSPENSION

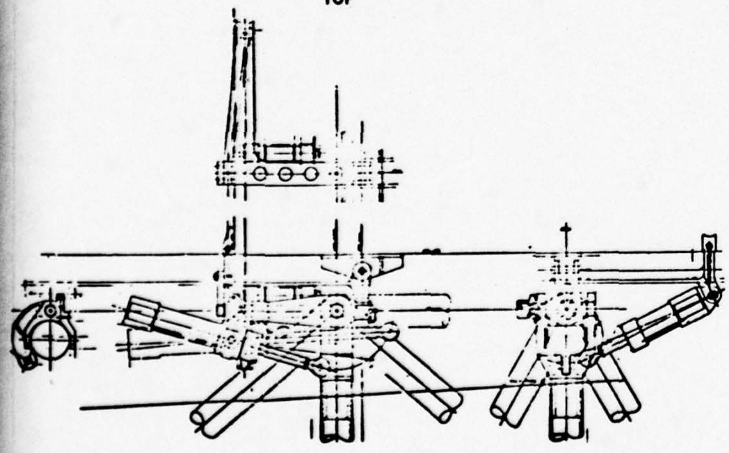


SELF HOISTING CONTAINER/AIRCRAFT INTERFACE DEVICE



DETAIL OF REMOVABLE FORWARD ARM MODULE

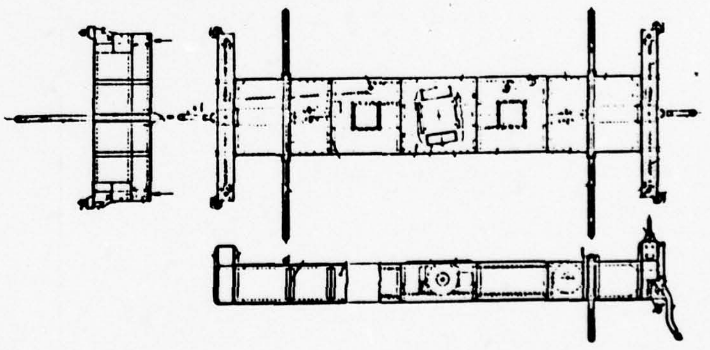
TOP



SIDE

LOOKING FORWARD

DETAIL OF
SELF HOISTING CONTAINER/AIRCRAFT INTERFACE DEVICE



S FOR CH-47 TERRAIN FLYING STUDY

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TABLE I. CH-47 TERRAIN FLYING EFFECTIVENESS

			NAP OF THE EARTH		CONTOUR		LOW LEVEL		NIGHT/IMC PIO SUSCEPTABILITY
			MASKING	MANEUVERABILITY	MASKING	MANEUVERABILITY	MINIMUM CG ALTITUDE	SPEED	
33,000-LB GR WT	INTERNAL LOAD BASELINE		0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
	MILVAN	STD SUSPENSION	102.5% (4)	41.2% (4)	94.5% (4)	16% (4)	251% (5)	50% (4)	HIGH WITH INCREASED LOAD WEIGHTS
		STD SUSPENSION WITH LSS	110.5% (5)	0% (1)	94.5% (4)	4.7% (3)	216% (4)	30% (3)	NEGLIGIBLE
		SHORT SUSPENSION	43.5% (2)	73.2% (5)	57.5% (2)	16.3% (5)	163% (3)	50% (4)	HIGH WITH INCREASED LOAD WEIGHTS
		SHORT SUSPENSION WITH LSS	58.5% (3)	8.3% (3)	57.5% (2)	4% (2)	137% (2)	27% (1)	NEGLIGIBLE
		SNUBBED LOAD	29.6% (1)	0% (1)	26.5% (1)	2.3% (1)	89% (1)	27% (1)	NONE
45,000-LB GR WT	INTERNAL LOAD BASELINE		0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
	155MM HOWITZER	STD SUSPENSION	68.5% (4)	0% (1)	57% (3)	1% (2)	138% (3)	13% (2)	POSSIBLE
		STD SUSPENSION WITH LSS	67% (3)	0% (1)	57% (3)	0% (1)	139% (4)	16% (4)	NEGLIGIBLE
		SHORT SUSPENSION	28% (1)	66% (4)	31.5% (2)	7% (3)	96% (2)	12% (1)	POSSIBLE
		SHORT SUSPENSION WITH LSS	35% (2)	0% (1)	30.5% (1)	7% (3)	94% (1)	15% (3)	NEGLIGIBLE

NUMERICAL ORDERING

% PERFORMANCE DEGRADATION FROM INTERNAL LOADED BASELINE

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In addition the configurations are also ordered from one to five by the numbers in parentheses, with the value one representing the configuration with the least degradation from the baseline.

This ranking assumes equal weighting for all terrain flight maneuvers, since no specific mission scenario was followed in evaluating overall capability. Ranking schemes applied in this study may be adjusted in future application of the results to fit any desired terrain flight scenario, by simply applying the appropriate weighting factors.

Returning to the table, it is apparent from the standard suspension results that performing the various maneuvers with external loads degrades capability substantially. Masking suffers approximately 100 percent in the NOE and contour modes, due to the addition of the external load. Maneuverability is also restricted particularly for the light MILVAN load. For low level cruise, minimum cg altitude is used in place of masking and reflects the sling length. The percentage of degradation is large, however the absolute levels as shown in Figure 2 are not too significant for this flight mode.

A number of schemes for recovering the internal load capability while flying with external loads were considered, and several were analyzed. The most promising of these are illustrated in the center and right hand side sketches on Figure 2 and include the use of Short Suspensions, Automatic Load Stabilization, and Load Snubbing Schemes.

Short Slings – *Initial attempts to improve overall* performance by shortening the external slingload suspension were reasonably successful in the area of masking, as shown in Table 1. For example, in the NOE environment the MILVAN load exhibits a 102.5 percent degradation in masking with standard suspension and only 43.5 percent with the shortened concept. Maneuverability, on the other hand, was further restricted than with the standard suspension. Load motion was not significantly attenuated with the short slings, resulting in fuselage/load interference with milder maneuvers because the load was closer to the aircraft bottom.

Automatic Load Stabilization – An alternative solution considered for the masking and maneuverability problems was to employ an active arm external load stabilization system of the type shown in Figure 2. This active arm (AAELSS) concept has been thoroughly evaluated in two previous developmental flight test programs, and would therefore incur low risk for production implementation. As illustrated in Table 1, an AAELSS system used in concert with a shortened suspension would virtually eliminate the degradation in maneuverability experienced with the standard load. The weight penalty associated with this installation would be approximately 700 pounds. The slight degradation in masking shown in the NOE table summary, when load stabilization is used, occurs because aircraft pitch and roll maneuverability has been restored with AAELSS, and thus more height is required to hide the overall aircraft/load combination.

Self-Hoisting Cargo Interface Device – A third approach toward improving terrain flight masking and maneuverability involves snubbing the load against the aircraft bottom with a self-hoisting interface device like the one shown in Figure 2. This concept uses an electrically powered winching system mounted on the interface adapter, which raises the entire load to a point where probes on the device intercept tandem receptacles on the fuselage lower surface. The load is then locked in place on a liquid spring suspension system that provides vibration isolation between the fuselage and load. The interface adapter developed during this study has been sized for carrying MILVAN or Gondola payloads, but the concept is readily applicable to other load configurations. Projected weight of the production system shown in the figure (including aircraft structural modifications) would be on the order of 2,140 pounds.

As indicated in Table 1, the snubbed load arrangement would essentially retain the maneuverability of the internal load, and masking would be superior to that of the other external cargo configurations considered. Ranking order among individual systems is annotated in the table with the number enclosed in parenthesis behind the percent degradation figure.

Comparison of the snubbed load and active arm load stabilization approaches shows that snubbing is undoubtedly superior for certain load configurations. The snubbing system is, however, somewhat heavier than AAELSS, is less universal in terms of loads that it can carry, and will probably require more aircraft structural modification for installation. Balancing the advanced developmental maturity and payload flexibility of AAELSS against the obvious advantages of the snubbing approach, it is recommended that both systems be developed further as an adjunct to improved terrain flight capability.

1.4 EVALUATION OF A TYPICAL LONGITUDINAL DASH MANEUVER

Summary information presented in Table 1 was generated from detailed analytical simulations of each terrain flight maneuver. An example of the type of data developed during the study is shown in Figures 3, 4, and 5 for a typical longitudinal dash. Figure 3 represents capability with an internal load, and Figures 4 and 5 depict performance with a MILVAN slingload on long and short slings, both with and without active arm automatic load stabilization. Similar presentations were worked up for all load-maneuver combinations studied.

Internal Load Baseline – At the top of Figure 3 are the dash distances and time required to complete the maneuver for four different fuselage pitch attitude changes varying from 5 degrees to 20 degrees. For a constant dash length, increasing pitch attitude rotation reduces maneuver time, but this also increases the masking height requirement as shown in the center plot in Figure 3. Masking height reflects the maximum distance from the uppermost rotor tip down to the lowest point on the aircraft experienced during the maneuver.

Plotted at the bottom of the figure are maximum speeds achieved during the acceleration phase. Crossplots of these velocities at 30 and 60 knots appear at the top of the figure. The significance of these two speeds is covered later in discussion of night and IMC flight characteristics.

External Loads – Illustrated at the top of Figure 4 are dash lengths and time for the longitudinal dash maneuver flown with external loads. Beneath this plot are depictions of load sway angles for the long and short sling suspensions, and associated sway angle limits beyond which load excursions are not permitted. Translating the sway angle limits into maximum body attitudes permitted during the maneuver reveals that maneuverability is cut roughly in half when flying with external payloads.

This reduction in maneuvering capability, and an increase of about 20 feet in masking height required to complete the maneuver with an external cargo (shown at the top of Figure 5), adds substantially to potential aircraft vulnerability on a hostile battlefield. The terrain flying study did not evaluate vulnerability per se, but has generated the baseline data upon which an analysis of this type could be based.

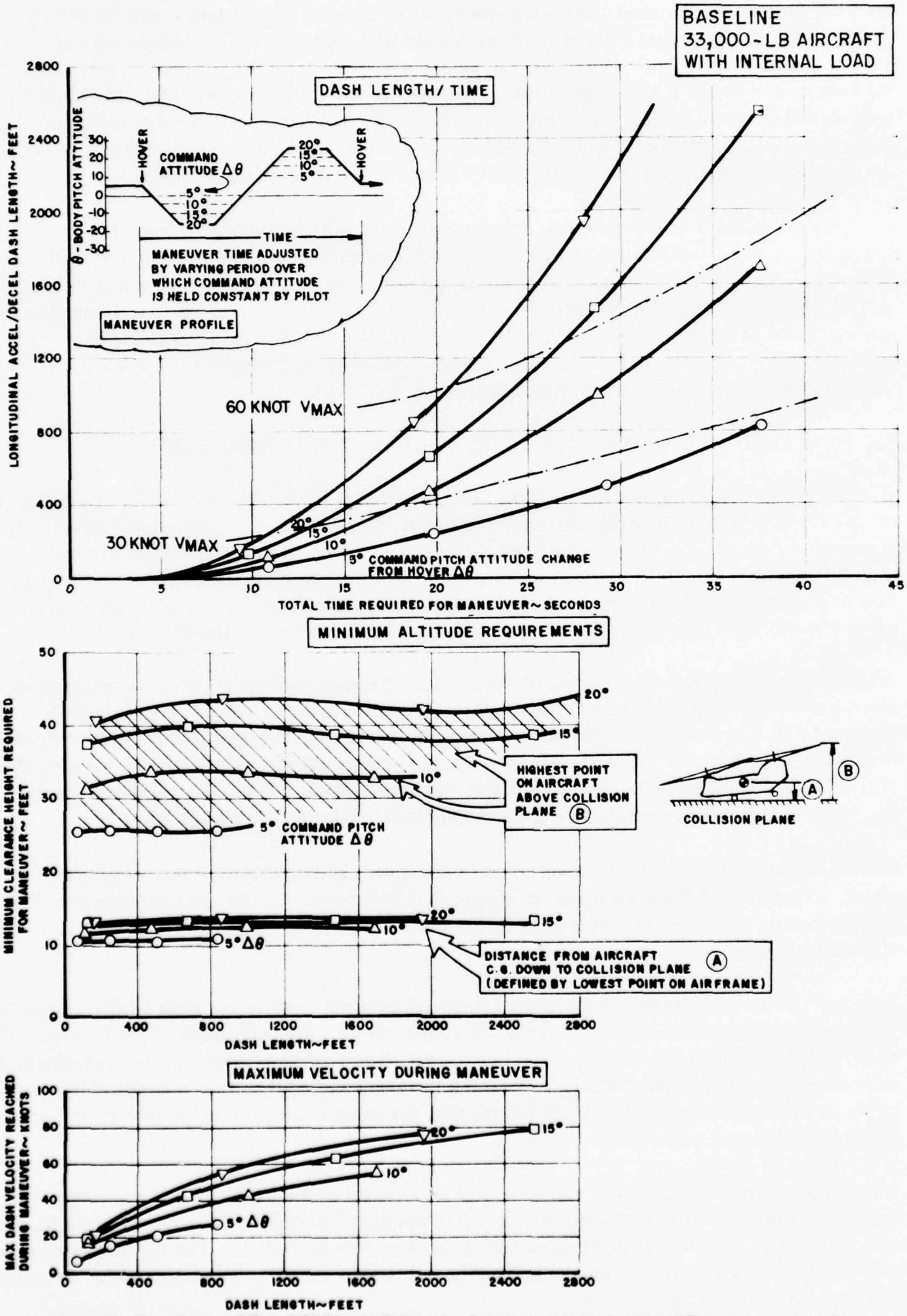
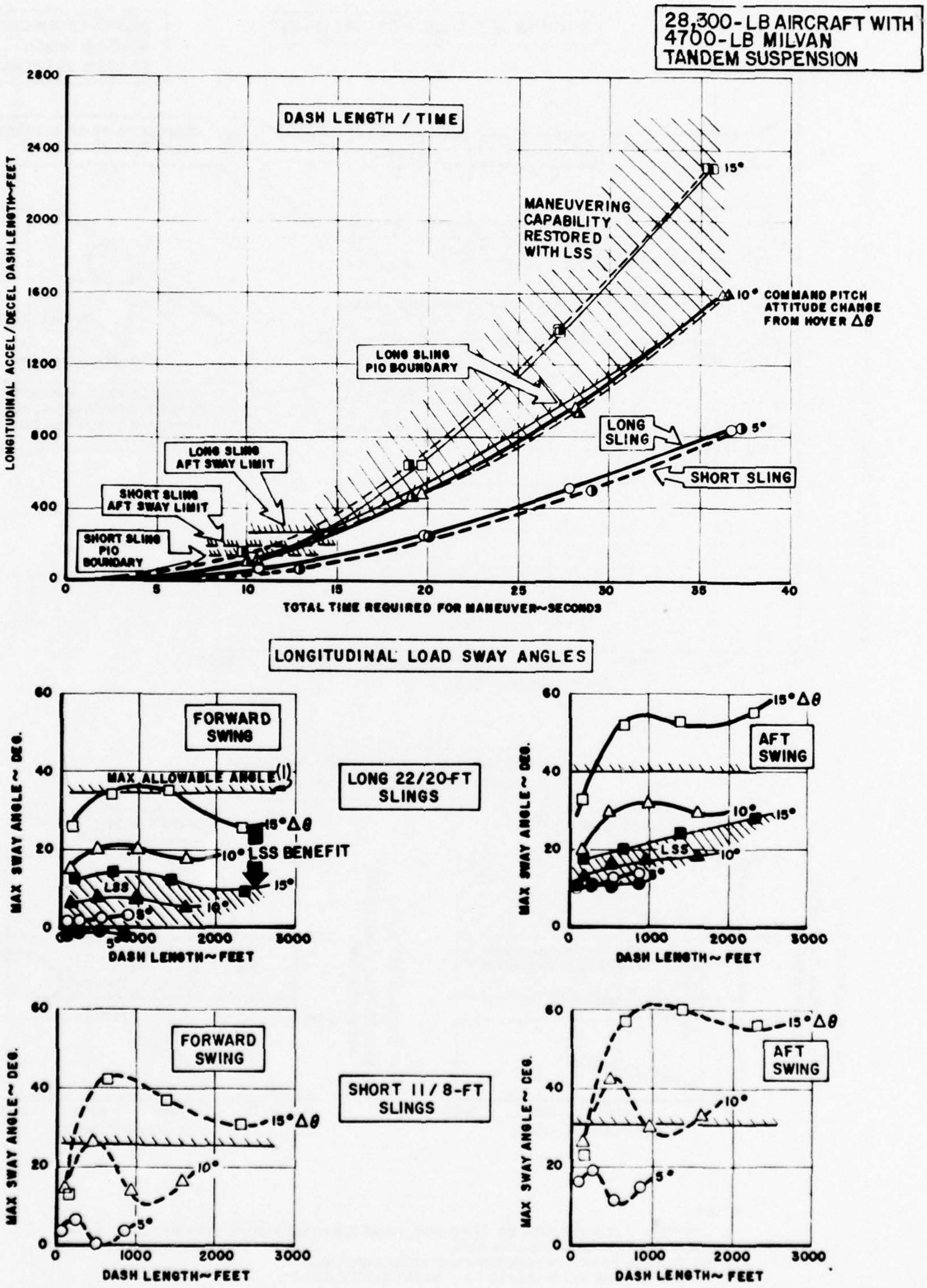


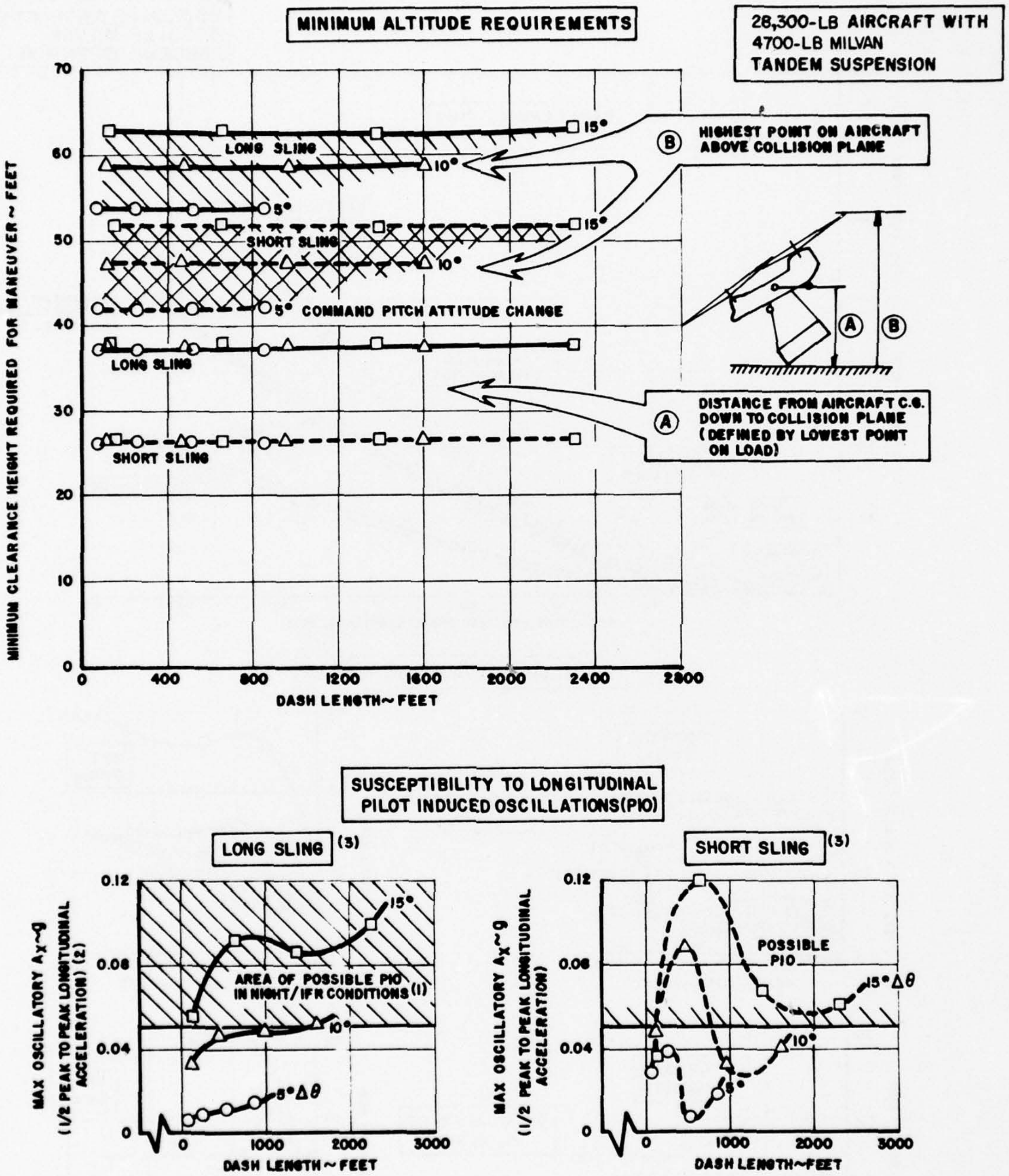
FIGURE 3. CH-47 LONGITUDINAL DASH WITH INTERNAL LOAD



NOTES:

1. LOAD SWING ANGLES LIMITED BY AIRCRAFT AND HOOK STRUCTURAL LIMITS; AND LOAD INTERFERANCE WITH FUSELAGE

FIGURE 4. CH-47 LONGITUDINAL DASH WITH AN EMPTY MILVAN



NOTES:

1. CRITERIA FOR PIO BASED ON $A_X = 0.05g$, FROM AAELSS I FLIGHT TEST RESULTS WITH PILOT UNDERHOOD (SIMULATED IFR)
2. 1/2 PEAK TO PEAK A_X RESULTING FROM LOAD SWAY ONLY
3. STANDARD LONG SLING 22/20 FT., SHORT SLINGS 11/8 FT.

FIGURE 5. CH-47 HEIGHT REQUIREMENTS AND PIO SUSCEPTIBILITY WITH AN EMPTY MILVAN

Returning to the load sway curves shown in the middle of Figure 4, it is apparent that an automatic load stabilization system has the potential for reducing load motion substantially. This improvement, in turn, will allow the aircraft to regain lost maneuverability, as shown at the top of the figure. The system also eliminates the possibility of encountering longitudinal pilot induced oscillation (PIO) of the load, in night or instrument weather as discussed below.

1.5 IMPACT OF NIGHT AND IMC ON TERRAIN FLIGHT

The tendency for PIO with certain loads under reduced visibility conditions is well known from experimental flight test work with different load suspensions. Testing documented in References 3, 4, and 5 has shown that PIO can occur whenever load motions create oscillatory longitudinal accelerations perceived by the pilot that exceed ±0.05g. Such accelerations produce a confusing motion cue pattern for the pilot; this in turn increases his workload appreciably and may result in control inputs which excite rather than attenuate load motion. For successful terrain flying, it is imperative that load motion not create additional pilot workload.

PIO potential for all terrain maneuvers was evaluated by comparing levels of alternating longitudinal acceleration with the 0.05g criteria, as shown at the bottom of Figure 5. Results of this analysis showed reduced visibility PIO boundaries to fall in about the same region as the load sway limits. That is, PIO would probably not be a limiting factor for the MILVAN load flown in the study, unless cargo weight was increased. Loads heavier than those chosen (especially for the MILVAN) would reduce the speeds or maneuver level at which PIO could occur in poor visibility. Automatic load stabilization eliminates the possibility of encountering PIO.

Susceptibility to night or IMC-associated PIO of the load is annotated for all cargo configurations studied in the right hand column of Table 1. Levels of susceptibility listed reflect the potential occurrence of PIO in low level terrain flight primarily, or what might be expected if load weights were increased for the NOE and contour mode maneuvers.

At present, it is possible to perform some limited night terrain missions with external loads. This capability varies from load to load, and depends heavily upon such things as available moon or starlight, pilot proficiency, and/or familiarity with courses to be traversed. Of necessity, speeds flown would be quite low,since obstacles must be seen and control inputs introduced

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3. Nagata, J.I., CH-47 TANDEM CARGO HOOK DEMONSTRATION, USAASTA Project No. 72-39, U.S. Army Aviation Systems Test Activity, Edwards Air Force Base, California, May 1973.

4. Smith, J.H., Allen, E.M., and Vensel, D., DESIGN, FABRICATION AND FLIGHT TEST OF THE ACTIVE ARM EXTERNAL LOAD STABILIZATION SYSTEM FOR CARGO HANDLING HELICOPTERS, Boeing Vertol Company; USAAMRDL Technical Report 73-73, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, September 1973, AD 773025.

5. Garnett, T.S., Jr., and Smith, J.H., ACTIVE ARM (EXTERNAL CARGO) STABILIZATION SYSTEM FLIGHT DEMONSTRATION, Boeing Vertol Company; USAAMRDL Technical Report 76-23, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

soon enought to avoid them. Obviously, on a perfectly dark night (or in IMC), some additional capability to "see" potential obstacles must be provided, before terrain flying in the NOE and contour modes becomes a practical reality.

To explore what might be possible for future CH-47 night/IMC terrain flight operations, a survey of available visionics (vision systems) with associated capabilities was performed. Results are depicted in Figure 6.

The three systems selected for application in the terrain flying maneuver analysis were:

- Night Vision Goggles – with 40-degree field of view
- 360 Line Forward-Looking Infrared (FLIR) – with 30 degree by 40 degree field of view helmet-mounted display (also called PNVS – pilot night vision system)
- Laser Obstacle Terrain Avoidance and Warning System (LOTAWS) – for wire avoidance.

The night vision goggles and FLIR allow the pilot to see larger obstacles permitting flight path control under reduced visibility.

Experimental versions of these systems have been extensively flight tested with results published in a number of documents, including References 6 and 7. Both systems are being refined for installation on the YAH-64 armed attack helicopter, and would therefore be likely candidates for future application in any CH-47 night terrain flying visionics package. Each is essentially a light or infrared amplification device which is intended primarily for nighttime use. FLIR has some capability in IMC conditions, but performance degrades in cloud conditions due to cold-soaking effects. Microwave radiation systems such as FLMRAD,noted in Figure 6,will be more effective for IMC work, but are only in early stages of development at present.

The resolution of FLIR or NVG systems is not sufficient for detection of wires in the flight path of the aircraft. The LOTAWS system, on the other hand, which is currently under development by the U.S. Army, has improved resolution, and appears to offer the greatest potential for wire detection.

Although LOTAWS is an active system, it could easily be operated in bursts from a trigger (on the aircraft control stick). As envisioned for application in a terrain flying visionics display, the LOTAWS image could be superimposed on the FLIR display, and then used with some type of image holding feature which is updated each time the trigger is depressed. The pilot would "look" ahead for wires as often as he thought necessary, but would not be constrained to continuous LOTAWS use in areas where the air defense threat was high.

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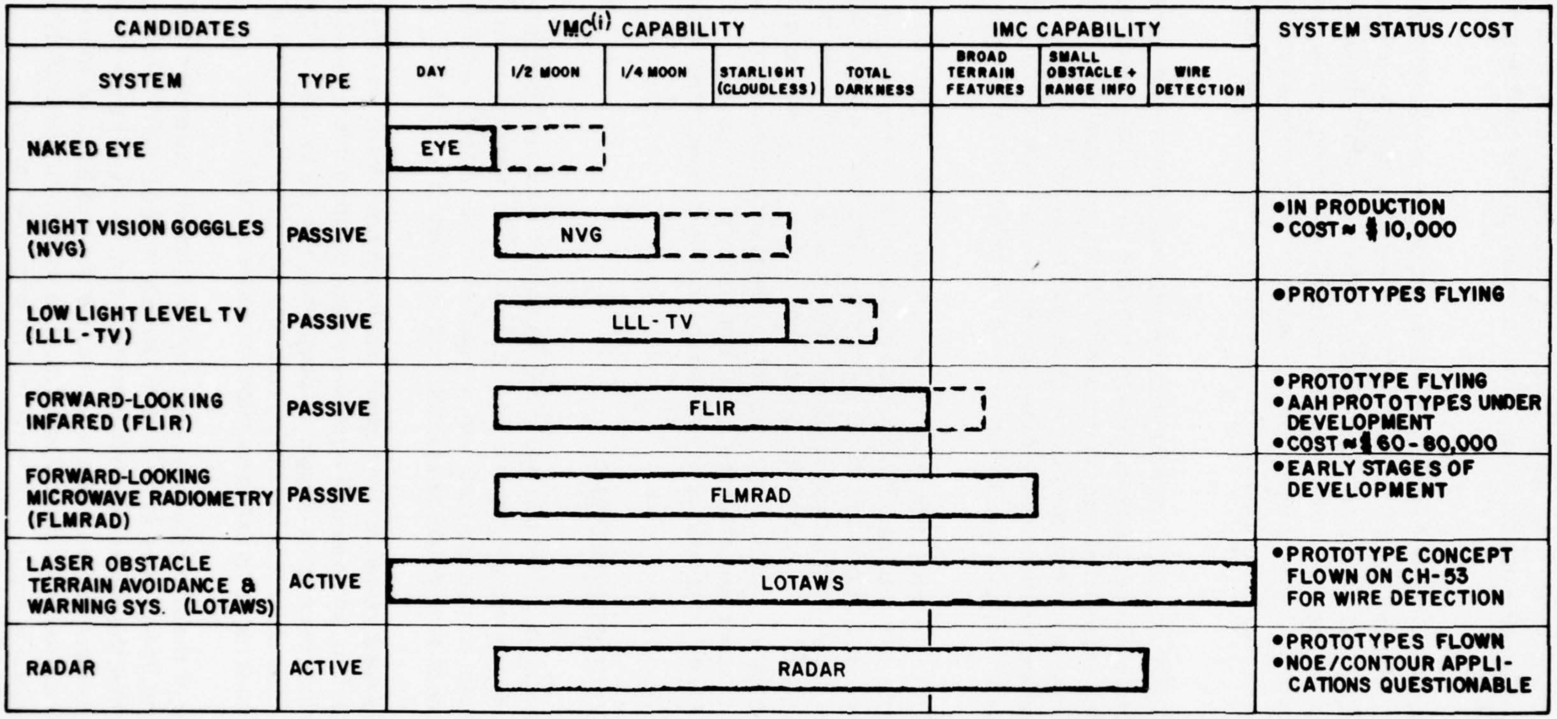
6. Bauer, R.W., and Pettit, G.D., AIR SCOUT NIGHT GOGGLE TEST, Technical Memorandum 14-74, AM CMS code 612106.11.81900, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, July 1974.

7. Stich, K., and Palmer, J., INVESTIGATION OF NIGHT VISION EQUIPMENT AS A HELICOPTER FLIGHT AID; LOW LEVEL NIGHT OPERATIONS WITH LLLTV AND FLIR SYSTEMS, U.S. Army Electronics Command, Night Vision Laboratory, Fort Belvoir, Virginia, November 1973.



CANDIDATES		VMC[(i)] CAPABILITY					IMC CAPABILITY			SYSTEM STATUS/COST
SYSTEM	TYPE	DAY	1/2 MOON	1/4 MOON	STARLIGHT (CLOUDLESS)	TOTAL DARKNESS	BROAD TERRAIN FEATURES	SMALL OBSTACLE + RANGE INFO	WIRE DETECTION	
NAKED EYE		EYE								
NIGHT VISION GOGGLES (NVG)	PASSIVE		NVG							• IN PRODUCTION • COST ≈ $ 10,000
LOW LIGHT LEVEL TV (LLL-TV)	PASSIVE			LLL-TV						• PROTOTYPES FLYING
FORWARD-LOOKING INFARED (FLIR)	PASSIVE				FLIR					• PROTOTYPE FLYING • AAH PROTOTYPES UNDER DEVELOPMENT • COST ≈ $ 60-80,000
FORWARD-LOOKING MICROWAVE RADIOMETRY (FLMRAD)	PASSIVE				FLMRAD					• EARLY STAGES OF DEVELOPMENT
LASER OBSTACLE TERRAIN AVOIDANCE & WARNING SYS. (LOTAWS)	ACTIVE				LOTAWS					• PROTOTYPE CONCEPT FLOWN ON CH-53 FOR WIRE DETECTION
RADAR	ACTIVE				RADAR					• PROTOTYPES FLOWN • NOE/CONTOUR APPLICATIONS QUESTIONABLE

(I) VISUAL METEOROLOGICAL CONDITION

FIGURE 6. POTENTIAL VISIBILITY IMPROVEMENT CANDIDATES

Terrain-following or avoidance radar systems were not considered due to their continuous "active" nature, and because of obvious problems in presenting the pilot with a display suitable for NOE maneuvering.

To quantify how well the terrain flying maneuvers might be performed while using the visionics systems just described, range capability for each device was developed for several different obstacle (target) sizes at various levels of probability. The night mid-European environment was used. Using an arbitrary level of 75-percent probability of being able to see two selected obstacles of different size, range information was generated for the three systems. This data was then plotted on the various maneuver distance curves as shown in the Figure 7 longitudinal dash example.

In interpreting the plot, it is useful to note that the pilot would be able to see at least as far as the distances annotated for each system 75 percent of the time. That is, with night vision goggles, he could see a tracked vehicle up to about 320 feet, and small terrain features to 480 feet, etc. Since it is assumed that the pilot must be able to see his destination before starting a maximum performance maneuver of the type plotted, the maneuver envelope available with the vision system is then simply the portion of the curve below the vision range line.

With the 75-percent probability assumption in mind, Night Vision Goggles provide maneuver capability to roughly 30 knots, and FLIR to 60 knots or more. Speed capabilities for the other maneuvers examined were also in this 30-60 knot range. This fact may seem somewhat conservative in view of actual field testing flown at higher speeds. The apparent discrepancy is resolved, however, when it is realized that most night terrain flying,because of training safety considerations, has taken place in better weather and light conditions which have substantially lower probability of occurrence than the 75 percent assumed for this study. In addition, most night terrain flight testing has been conducted in the low-level mode rather than in true NOE or contour modes.

1.6 LOAD SNAG CONSIDERATIONS

In addition to assessing day VFR and night/IMC potential for terrain flight, the problem of how to handle load snags was also addressed during the study. The question posed was whether or not the aircraft would crash if the load were snagged on some obstacle; and if it did not impact the ground, how much time would be available to effect successful jettison?

Two types of snags were looked at: one where maximum hook loads are exceeded, and the suspension or hook fails, and a second type where loads go up to max allowable and remain at this level as if the load were being dragged through trees, etc. In the case where the hook or slings break, very little altitude is lost during recovery, and the aircraft will probably fly out of the maneuver without requiring excessive pilot corrective control inputs.

On the other hand, if the suspension remains intact and no pilot corrective action is taken, the aircraft will descend, rotate nose down, and hit the load in about 1-1/2 seconds. Limited analysis indicates that this descent and pitch attitude can, however, be controlled with longitudinal stick and collective control inputs, until either the load becomes free or the pilot manually jettisons the load. Additional work must be done to firmly establish whether or not automatic load jettison is required for terrain flying with external cargo.

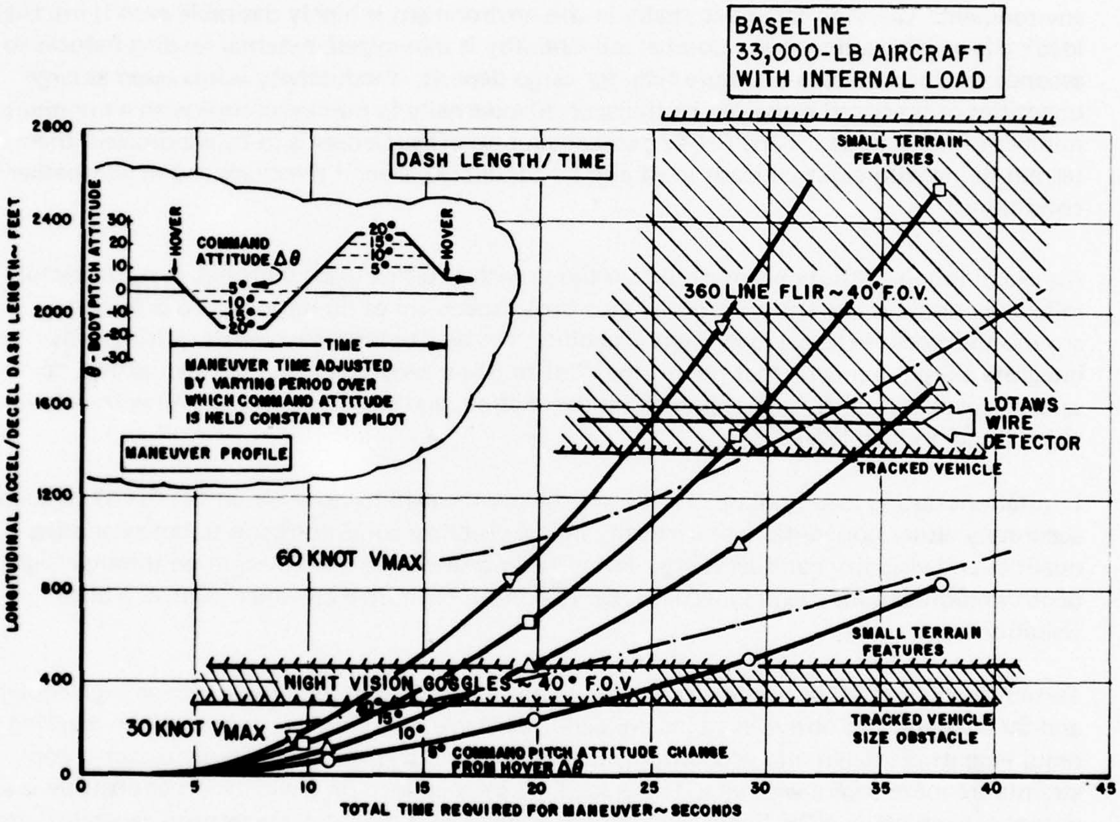


FIGURE 7. DASH POTENTIAL WITH NIGHT VISION SYSTEMS

2.0 INTRODUCTION

Current Army doctrine, as defined in References 1 and 2, provides for the employment of the CH-47 helicopter in a combat support role on a mid-intensity battlefield. Terrain flying with the CH-47 will be necessary if it is to survive and complete its mission in the high threat environment. Carrying cargo externally in this environment is highly desirable even if internal loading is a viable alternative. Combat vulnerability is minimized; external loading reduces to seconds the forward area exposure time for cargo deposit. Productivity is increased as large quantities of prerigged cargo can be transported externally in minimum time with a minimum number of helicopters. If the CH-47 combat support effectiveness is to be maximized, then terrain flying with external loads must also be conducted around the clock and in all weather conditions.

An examination of the concept of terrain flying with external loads indicates that successful mission conduct is currently restricted by a broad spectrum of limitations. To provide an around-the-clock external load flight capability, the helicopter system must satisfactorily integrate all requirements that permit the pilot to hover accurately for load acquisition, to safely depart, terrain fly and approach his destination, and deposit the cargo; all within acceptable pilot workload levels.

Limitations during load hookup result from the pilot's inability to position the CH-47 helicopter accurately either horizontally or vertically in low visibility conditions,due to both handling qualities and visibility considerations. Potential improvements can be achieved through flight control modifications such as inertial velocity control or limited crewman control and/or visibility aids.

Terrain flying limitations result from many factors. The helicopter must be flown high enough and far enough from obstacles to insure load-to-obstacle or ground clearance. When masking requirements are taken into account, maneuverability limits result. Obviously,masking constraints are more severe with an external load. A snagged load on a wire or other obstacle is a potential problem in NOE flight, perhaps requiring revised hook-release jettison capability or wire detection electronics to prevent loss of the aircraft. Aircraft speed and low altitude capability are limited by aerodynamic load instabilities and by reduced maneuverability due to potential load to airframe collisions.

Improvements can result from shortening sling restraints which minimize overall size and load instability, and through application of automatic load stabilization,which prevents load-to-aircraft collisions during large pitch and roll maneuvers, and at the same time improves flying qualities.

Further speed restrictions and low altitude terrain flight limitations result from reduced visibility available during all ambient night lighting conditions and IMC. Load motions create aircraft linear accelerations which represent a confusing motion cue pattern to the pilot under reduced visibility. Flight testing has shown that the pilot can interact in a destabilizing fashion when responding to these cues,resulting in pilot induced oscillations (PIO). The pilot also requires visual information as close to day VFR as possible, in order to take cover, maneuver to avoid obstacles enroute, deliver the load, and return to base.

The CH-47 currently employs no visual enhancement systems. Improved capability can be achieved through passive sight amplification systems such as FLIR and night vision goggles, or through active systems using laser and radar technology, such as terrain-avoidance/terrain-following radar. Active systems provide improved penetration under IMC, and superior range and azimuth-to-obstacle information for maneuver cues. As yet,displays suitable for NOE maneuvering to avoid obstacles remain to be developed. Cockpit lighting for night operations must also be considered with respect to controls and displays, in order to eliminate the glare from reflective surfaces, and thereby create an environment in which NVG and FLIR systems can be utilized most effectively.

The workload imposed upon pilots during terrain flight is very demanding and can lead to flight limitations. Pilots have indicated that 2 hours of NOE flight time is roughly equivalent to 8 hours of normal flight time. The overwhelming majority of the pilot's time is spent with his head out of the cockpit,and any additional systems such as obstacle avoidance displays, which increase visual workload,will not improve overall terrain flying capability.

Limitations also result from a lack of suitable navigation information,particularly in the NOE environment. Short-(1/4 mile) and medium-range (2 to 3 miles) terrain information is desired for flight and ground path selection, location and/or bearing to destination, and obstacle identification (such as poles, towers, etc).

An improved CH-47 capability will result primarily from technical approaches involving the cargo system, flight control system, visionics and navigation. The U.S. Army has active programs underway in helicopter terrain flying, including training, night operations, visionics and navigation considerations as summarized in Aircrew Performance in Army Aviation,Reference 8, "Staying Power" Symposium, Reference 9, and the AGARD conference on The Guidance and Control of V/STOL Aircraft and Helicopters at Night and in Poor Visibility, Reference 10.

The emphasis of this study was to determine how the addition of an external load limits the ability of the CH-47 helicopter to perform its support mission close to the ground. Cargo suspension and handling qualities improvements are defined and analyzed with the objective of restoring as much of the day VFR internal load capability as practical. Visionic system characteristics from existing programs, including those mentioned above, were integrated into the study to establish potential night capability.

This report presents the limitations of the CH-47 helicopter in performing terrain flying with external loads. The limitations are quantified using the results of computer simulations of selected terrain flight maneuvers. In addition, candidate concepts are identified for correcting these limitations and a preliminary system definition of selected cargo system candidates is provided.

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8. AIRCREW PERFORMANCE IN ARMY AVIATION, Conference Proceedings, U.S. Army Aviation Center, Fort Rucker, Alabama, 27-29 November 1973.
9. STAYING POWER SYMPOSIUM, U.S. Army Aviation Center, Fort Rucker, Alabama, 8-10 July 1975.
10. THE GUIDANCE AND CONTROL OF V/STOL AIRCRAFT AND HELICOPTERS AT NIGHT AND IN POOR VISIBILITY, AGARD Conference Proceedings No. 148, Stuttgart, Germany, 14-16 May 1974.

3.0 LIMITATION ANALYSIS AND CONCEPT EVALUATION

3.1 MANEUVER SIMULATION DESCRIPTION AND AIRCRAFT/LOAD STUDY CONFIGURATIONS

From initial concepts involving the use of helicopters on a mid-intensity battlefield, and early use of the phrase "nap-of-the-earth flight", several definitions have evolved describing the technique of terrain flying. For purposes of this study, the descriptions of terrain flight described below have been used. Terrain flying involves flight close to the ground, and utilizes the tactical application of nap-of-the-earth, contour, and low level flight techniques to limit the enemy's capability to acquire, track, and engage the aircraft.

- Nap-of-the-earth is flight as close to the earth's surface as vegetation or obstacles permit, to stay masked below available cover, while generally following the contours of the earth. Airspeed and flight path variations are common to this phase.
- Contour flight is flight at low altitude conforming generally, and in close proximity, to the contours of the earth. It is characterized by varying airspeed and varying altitude along with flight path.
- Low level flight is flight conducted at a selected altitude above all obstacles and along a straight path at constant airspeed.

3.1.1 Terrain Flight Maneuvers Analyzed

In defining the terrain flight limitations of the CH-47 helicopter, each segment of the cargo mission was systematically analyzed. A series of maneuvers as portrayed and grouped in Figure 8 were selected,which were thought to best illustrate typical terrain flight requirements. Maneuvers include:

1. Load Acquisition and Deposit – Although not a terrain flying maneuver per se, the load acquisition phase has been considered due to its impact on flight control accuracy requirements and pilot workload. Any workload reduction in flight phases other than terrain flight will undoubtedly provide an improvement in the terrain flying segment where workload demands are high.
2. Forward "Dash" – Defined as an NOE task, this maneuver reflects the rapid horizontal translation of the helicopter in an area where cover may be lacking. The maneuver consists of an initial hover, a pitch down rotation to accelerate the aircraft, and finally a pitch up to decelerate back to a masked hover position.
3. Lateral "Jink" – Similar in concept to the forward dash but performed in a sideward direction.
4. Lateral Terrain Avoidance – This maneuver can be associated with either NOE or contour flight. It is projected as a lateral displacement of the aircraft for obstacle avoidance in forward flight by appropriately varying bank angle and heading. The aircraft is effectively flown around the obstacle in this maneuver.

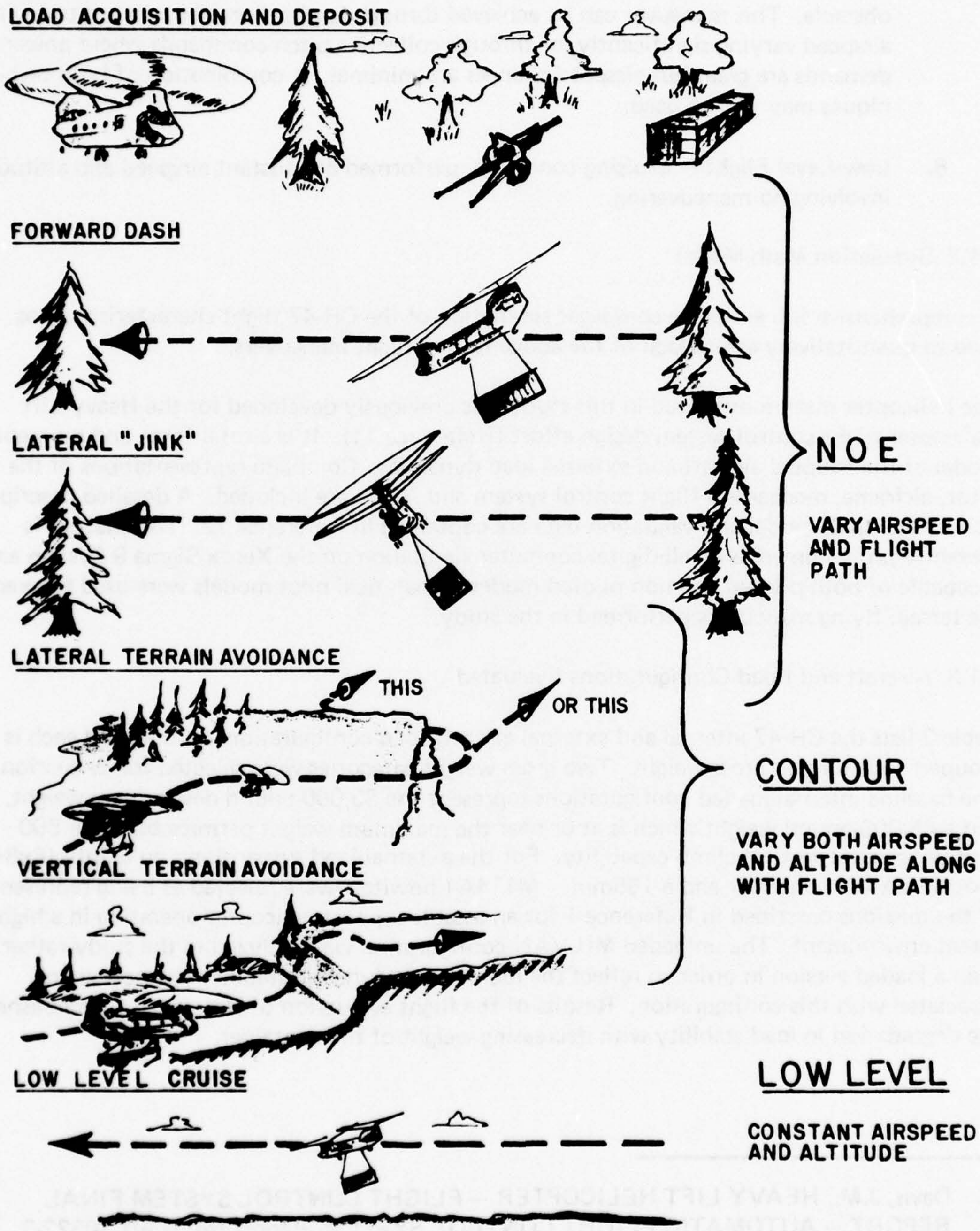

FIGURE 8. TERRAIN FLIGHT MANEUVERS

5. Vertical Terrain Avoidance – Typical of what might be encountered during contour flying and consisting of a vertical displacement of the aircraft in order to clear an obstacle. This maneuver can be achieved through application of cyclic control with airspeed varying significantly, or through collective pitch commands where power demands are great but airspeed changes are minimal. A combination of both techniques may also be used.

6. Low-Level Flight – Cruising condition, performed at constant airspeed and altitude, involving no maneuvering.

3.1.2 Simulation Math Model

A comprehensive full envelope computer simulation of the CH-47 flight characteristics was used to quantitatively assess each of the above terrain flight maneuvers.

The helicopter math model used in this study was previously developed for the Heavy Lift Helicopter flight control system design effort (Reference 11). It is a total force and moment model of the coupled aircraft and external load dynamics. Complete representations of the rotor, airframe, mechanical flight control system and AFCS are included. A detailed description of the math model and validation data are contained in Reference 12. The analysis is presently programmed as an all-digital computer simulation on the Xerox Sigma 9 System and is capable of both piloted and non-piloted modes. Analytical pilot models were used to execute the terrain flying maneuvers performed in the study.

3.1.3 Aircraft and Load Configurations Evaluated

Table 2 lists the CH-47 internal and external aircraft/load configurations studied and each is grouped according to gross weight. Two gross weight categories were selected for evaluation. The baseline internal-loaded configurations represent the 33,000-pound design gross weight, and a 45,000-pound weight which is at or near the maximum weight permissable for a 500 foot-per-minute vertical climb capability. For the external-load suspensions, an empty (8x8x20 foot) MILVAN container and a 155mm M114A1 howitzer were selected as being representative of the missions described in Reference 1 for an assault support helicopter operating in a high-threat environment. The unloaded MILVAN configuration was analyzed in the study rather than a loaded version in order to reflect the more severe dynamic stability characteristics associated with this configuration. Results of the flight evaluation of Reference 5, established the degradation in load stability with decreasing weight of the container.

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11. Davis, J.M., HEAVY LIFT HELICOPTER – FLIGHT CONTROL SYSTEM FINAL REPORT – AUTOMATIC FLIGHT CONTROL SYSTEM, Report No. D301-10322-3, Boeing Vertol Company, Philadelphia, Pennsylvania, 24 June 1976.

12. Cogan, C., Gajkowski, B.J., and Garnett, T.S., FULL FLIGHT ENVELOPE MATH MODEL FOR 347/HLH CONTROL SYSTEM ANALYSIS, Report No. D301-10148-1, Boeing Vertol Company, Philadelphia, Pennsylvania, 24 June 1972.

TABLE 2. CH-47 HELICOPTER TERRAIN FLIGHT SIMULATION CONFIGURATIONS

CONFIGURATIONS	AIRCRAFT GROSS WEIGHT (LB)	EXTERNAL LOAD (LB)	SUSPENSION CONFIGURATION	SLING LENGTH
BASELINE INTERNAL (DESIGN GROSS WEIGHT)	33,000	----	----	----
• MILVAN (8 BY 8 BY 20)	28,300[(1)]	4,700 (EMPTY)	DUAL POINT	STANDARD (22/20 FT) SHORT (11/8 FT)
BASELINE INTERNAL (500 FPM VERTICAL R/C)	45,000	----	----	----
• 155MM – M114A1 HOWITZER	33,000[(1)]	12,000	SINGLE POINT	STANDARD (22/20 FT) SHORT (8/14 FT)

NOTE: (1) AIRCRAFT WEIGHT WITHOUT EXTERNAL LOAD

The M114A1, 155mm howitzer was chosen because it is in the 12,000-pound weight range, and therefore cannot be transported by any other active U.S. Army assault support helicopter except the CH-47.

For both external loads the aircraft weight was adjusted such that the total aircraft and load weight was equivalent to one of the internal loaded baseline,as shown in Table 2,for direct data comparison.

The MILVAN was suspended using the dual-point tandem hook CH-47D configuration on standard sling lengths of 22 feet forward and 20 feet aft, because load instabilities occur at very low speed with single-point suspension,as will be shown later. The howitzer was evaluated using single-point hook up, as its aerodynamics do not create speed-related instabilities.

In addition to the standard suspension lengths, shortened restraints are also listed. These slings represent a new approach but utilize standard Army slings currently available, and are discussed in Section 3.3.1.

The loads and rigging were selected from References 13 and 14.

3.1.4 CH-47 Load Sway Limits

In order to establish load sway angle limits for the CH-47 aircraft, while carrying the empty MILVAN container and 155mm howitzer external loads used in the terrain flying simulation study, three types of restraining criteria were considered. These included limitations imposed by:

- Aircraft local structure or hook design loads for various load sway conditions
- Hook impingement on internal (built in) sway angle stops, or on aircraft structure
- Load or load suspension interference with aircraft structure such as landing gear, etc.

Each category of sway limitation was looked at in depth, to determine the amount of load pendular sway motion permitted in the longitudinal and lateral axes prior to reaching a limit. Hook configurations examined included both the CH-47C and -D production center hooks, and an ERC (Eastern Rotorcraft Corp) tandem hook installation of the type used for the SRD-84 tandem hook demonstration (Reference 3). The final configuration of the tandem hooks for the YCH-47D is expected to produce sway angle limits similar to those used in the study.

In Table 3, load and hook configurations are annotated first, followed by the type of sling, direction of sway, magnitude of sway limit, and an indication of what parameter caused the

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13. Technical Manual 55-450-11, AIR TRANSPORT OF SUPPLIES AND EQUIPMENT; HELICOPTER EXTERNAL LOADS RIGGED WITH AIR DELIVERY EQUIPMENT, Headquarters, Department of the Army, Washington, D.C., 21 June 1968.

14. Technical Manual 55-450-12, AIR TRANSPORT OF SUPPLIES AND EQUIPMENT; HELICOPTER EXTERNAL LOADS FOR SLING, NYLON AND CHAIN, MULTIPLE LEG (15,000-POUND CAPACITY), Headquarters, Department of the Army, Washington, D.C., 3 June 1969.

TABLE 3. CH-47 LOAD SWAY ANGLE LIMITATIONS

LOAD/SUSPENSION CONFIGURATION	SLING LENGTH		LONGITUDINAL SWAY ANGLE LIMIT		LATERAL SWAY ANGLE LIMIT		LIMITING PARAMETER
	STD SLING	SHORT SLING	STD SLING	SHORT SLING	STD SLING	SHORT SLING	
EMPTY (4700 LB) MIL VAN ON TANDEM HOOK SUSPENSION	22/20 FT	11/8 FT	FWD SWAY + 35° AFT SWAY - 40°	FWD SWAY + 27° AFT SWAY - 31°	BOTH DIR ± 45°	BOTH DIR ± 31.5°	EASTERN ROTORCRAFT HOOKS HIT INTERNAL BOLT STOPS FWD SLING HITS EXTENDED FWD GEAR
155 MM HOWITZER (12,000 LB) ON SINGLE POINT CH-47C HOOK & BEAM	12/20 FT	8/14 FT	FWD SWAY + 30° AFT SWAY - 49°	FWD SWAY + 26° AFT SWAY - 22°	BOTH DIR ± 22°	BOTH DIR ± 22°	STRUCTURAL LIMIT AFT SLING HITS AFT GEAR RECOIL TUBE HITS FWD GEAR AFT SLING HITS AFT GEAR HOOK HITS LATERAL BEAM ROLLER STOPS
155MM HOWITZER (12,000 LB) ON SINGLE POINT YCH-47D HOOK & BEAM	12/20 FT	8/14 FT	FWD SWAY + 33° AFT SWAY - 49°	FWD SWAY + 26° AFT SWAY - 22°	BOTH DIR ± 33°	BOTH DIR ± 33°	GUN BARREL HITS FUSELAGE AFT SLING HITS AFT GEAR RECOIL TUBE HITS FWD GEAR AFT SLING HITS AFT GEAR STRUCTURAL LIMIT

limit to occur. Limiting criteria applied in the simulation maneuver study were taken from this table.

3.2 TERRAIN FLYING MANEUVER ANALYSIS

3.2.1 Longitudinal Dash

The longitudinal dash is depicted in Figure 9 with a summary of the general limitations associated with the maneuver. The maneuver consists of an initial hover, a pitch down rotation to accelerate the aircraft, followed by a pitch up to decelerate back to a hover.

Basically, the restrictions which result with external loads on conventional suspensions are severe and increase the time required to transverse a given distance. Specifically, load dynamic characteristics associated with poor inherent damping levels produce either large angular excursions of the load (proportional to maneuver severity) or result in a tendecy for PIO during night/IMC conditions. This PIO tendency has even been encountered in VFR operations, and can lead to load/airframe collisions, or requirements that the pilot jettison the cargo to preclude loss of aircraft control.

Pilot workload levels experienced during mild maneuvering conditions are normally higher when operations are conducted with external cargo. Constant awareness of the load and its motion are ever present, while the desire for maximum masking during terrain flying, and visibility requirements during night/IMC conditions place even higher demands on the pilot.

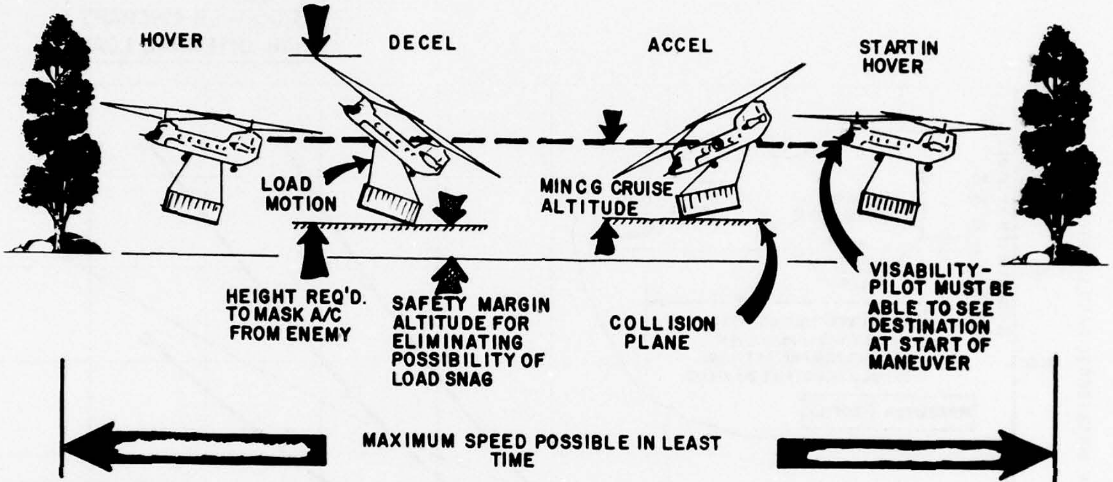
Minimizing exposure of the aircraft to the enemy threat is obviously what necessitates terrain flying. Masking considerations, indicative of the requirements to hide the aircraft behind appropriate cover, increase above the internal loaded configuration, reflecting the additional height required for sling length and load, maneuver level, and safety margins to prevent load snags on obstacles. The use of shortened suspensions and load snubbing concepts can offer a means of reducing the penalty incurred by external loads.

In addition to masking, the amount of time required for translation reflects the potential degree of exposure to the enemy. Maneuver limits established from load motions or visual capability minimize dash speeds and lengths while increasing the time required for mission completion.

Longitudinal acceleration/deceleration maneuvers from a hovering condition were performed as illustrated by the commanded maneuver profiles in Figure 10, for mean longitudinal acceleration/deceleration levels of 0.087, 0.174, 0.25, 0.34 g. These values correspond to nominal pitch attitude changes of ±5, ±10, ±15, ±20 degrees, respectively. Varying dash lengths were obtained for each maneuver by increasing the period over which the attitude change was held.

3.2.1.1 Internal Baseline (33,000-Pound) and MILVAN Container Results

Figure 10 presents the resultant longitudinal distances traversed for the internally loaded baseline configuration as functions of total maneuver time, and commanded pitch attitude change. Aircraft safety and masking considerations are presented in Figure 11 as minimum clearance heights required for the maneuver.



LIMITATIONS:

MANEUVERABILITY

- LOW-SPEED PERFORMANCE
- LOAD MOTION (SEVERE RESTRICTION)
  - POORLY DAMPED LONGITUDINAL SWAY
  - LOAD-TO-FUSELAGE STRIKES OR STRUCTURAL LIMITS
- PILOT INDUCED OSCILLATIONS (PIO)
  - POTENTIAL HIGH IN NIGHT/IMC
  - ALSO EXPERIENCED IN VFR OPERATIONS

WORKLOAD (VERY HIGH)

- HANDLING QUALITIES
- LOAD MOTION
- VISIBILITY

MASKING (OBSTACLE HEIGHT REQUIRED TO HIDE AIRCRAFT)

- AIRCRAFT AND LOAD HEIGHT
- MANEUVER SEVERITY (LARGE ALTITUDE CHANGES)
- SAFETY MARGIN TO PREVENT LOAD SNAGS

SPEED/TIME

- AIRCRAFT MANEUVERABILITY
- DASH LENGTH
- VISIBILITY - OBSTACLE AVOIDANCE

NAVIGATION/COMMUNICATIONS

(NOT EMPHASIZED IN THIS STUDY)

- GENERALLY NOT COMPATIBLE WITH NOE/CONTOUR AND HIGH THREAT
  - SYSTEMS REQUIRE LINE OF SIGHT
  - JAMMABLE

FIGURE 9. FORWARD DASH MANEUVER

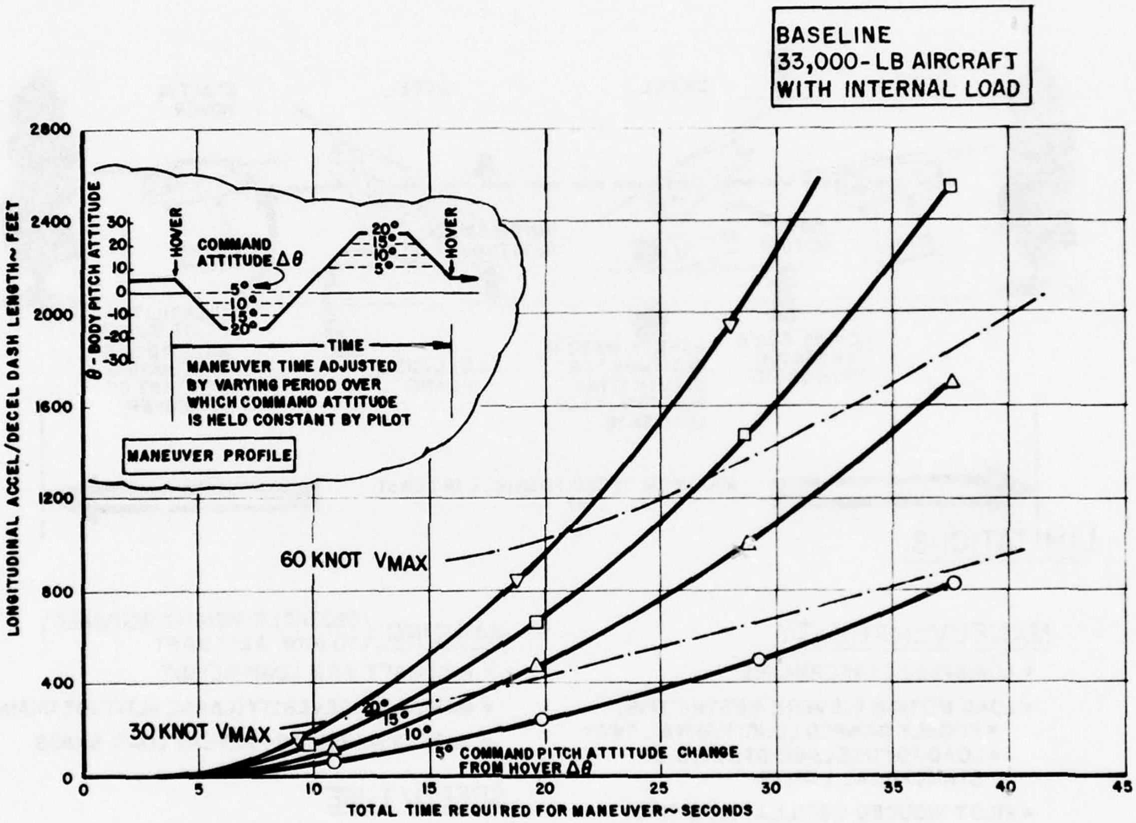


FIGURE 10. CH-47 DASH LENGTH/TIME INTERNAL LOAD BASELINE

Height (A), reflecting aircraft altitude, is defined as the distance from the center of gravity to the lowest point on the aircraft where collision plane contact would occur. Height (B), indicative of the masking requirement, is defined by the distance from the collision plane to the highest point on the aircraft. This distance is a direct function of maneuver severity, with the tip of the rotor disk plane protruding further and further above the collision plane as greater pitch attitude excursions are used. Both heights (A) and (B) do not, however, include a safety margin which would be required to eliminate any possibility of load snags or contact with undetectable obstacles. No attempt has been made in this study to determine what degree of safety margin is required, as it is a function of pilot training level, terrain familiarity, type of load, etc.

The time to translate over a specific dash lengtn obviously decreases with increasing acceleration/deceleration levels. Referring to Figure 10, maneuvering 800 feet with a nominal acceleration/deceleration of 0.087 g ($5^{\circ}\Delta\theta$) would take approximately 37.5 seconds, whereas increasing the level to 0.34 g ($20^{\circ}\Delta\theta$) would require 19 seconds. To accomplish this translation in a shorter period of time does, however, result in an increase of 20 feet in masking height (Figure 11. The maximum speeds achieved during the acceleration phase are plotted at the bottom of Figure 11. Crossplots of these velocities at 30 and 60 knots appear on Figure 10.

The resultant dash lengths associated with a particular maneuver time and command pitch attitude do not change with addition of the empty MILVAN as shown in Figure 12, since the acceleration is directly proportional to $\Delta\theta$. The minor changes observed are a result of the pilot model fidelity only. However, limitations due to load dynamics result in severe reductions in the maximum acceleration/deceleration levels permissible. The limiting factors stem from two sources which are:

- Increasing sway motion with maneuver severity
- PIO susceptibility from lightly damped load oscillations.

The peak sway motions (forward and aft) are plotted in Figure 13 for sling lengths of 22/20 feet (long) and 11/8 feet (short), both on dual hook suspensions. The hook sway limits from Section 3.1.4 are superimposed. Note that the sway limits were not included in the model and the data shown are the angles through which the load would traverse if no load or hook interference occured. Translating the sway angle limits into maximum permissible body attitudes or acceleration/deceleration levels reveals that the maneuverability is roughly cut in half, being limited to about 13 degrees for the long slings and 8 degrees for the short. These limits are reflected on the revised dash length versus time plot, Figure 14.

Masking height requirements with external loads (under the same levels of maneuverability) are of necessity increased over the baseline configuration as shown in Figure 15. For the long sling suspension, the required increase is nominally 25 feet for both masking and clearance heights. Adopting a short sling suspension reduces this increase to approximately 14 feet. When compared at their respective maneuverability limits, the required masking height increase with the external load is lower due to the reduced pitch attitude. The reduction in aircraft maneuverability and increase in masking requirements with the external load reduces the aircraft survivability on a hostile battlefield.

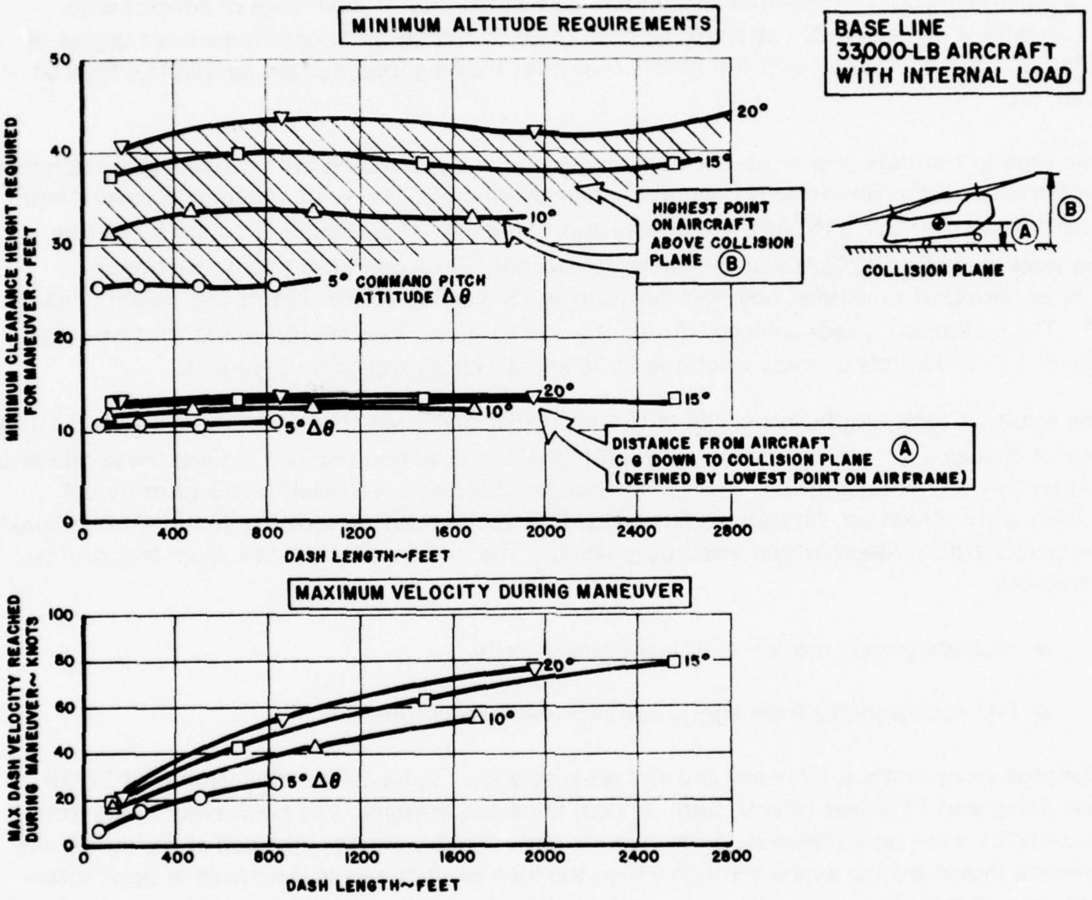


FIGURE 11. BASELINE HEIGHT REQUIREMENTS AND PEAK VELOCITIES FOR DASH MANEUVER

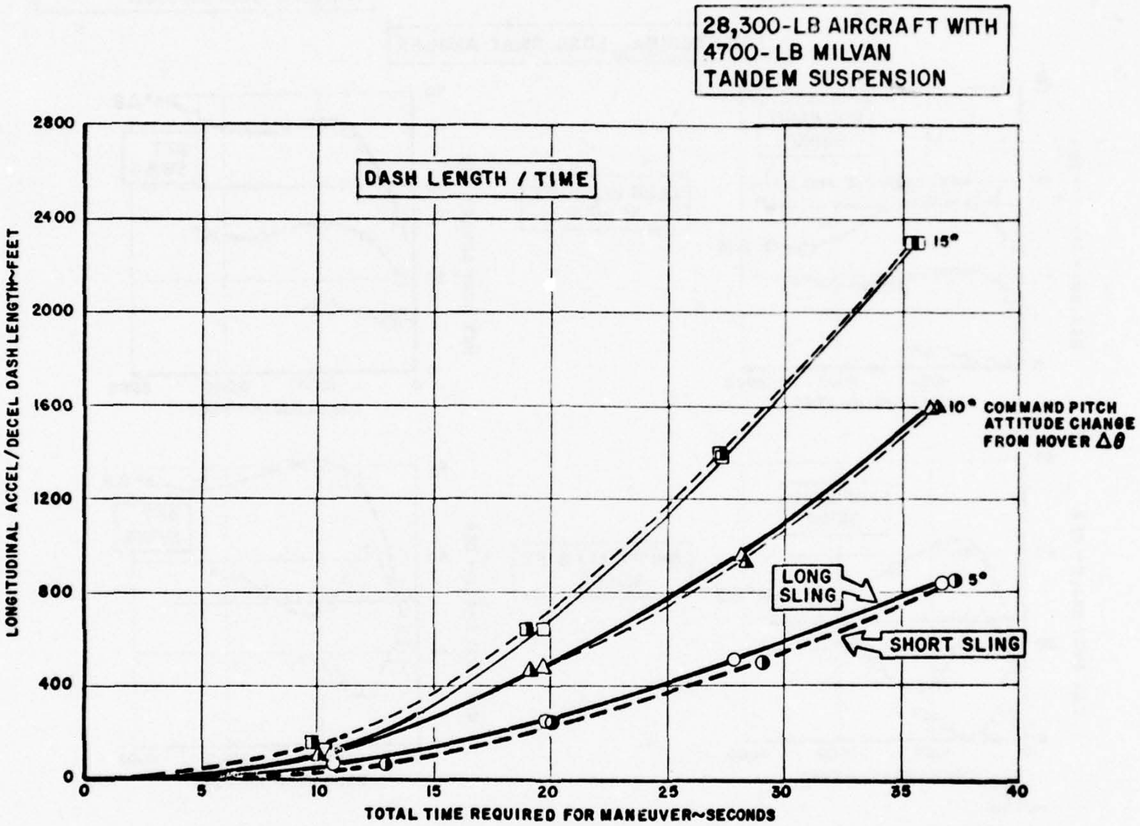
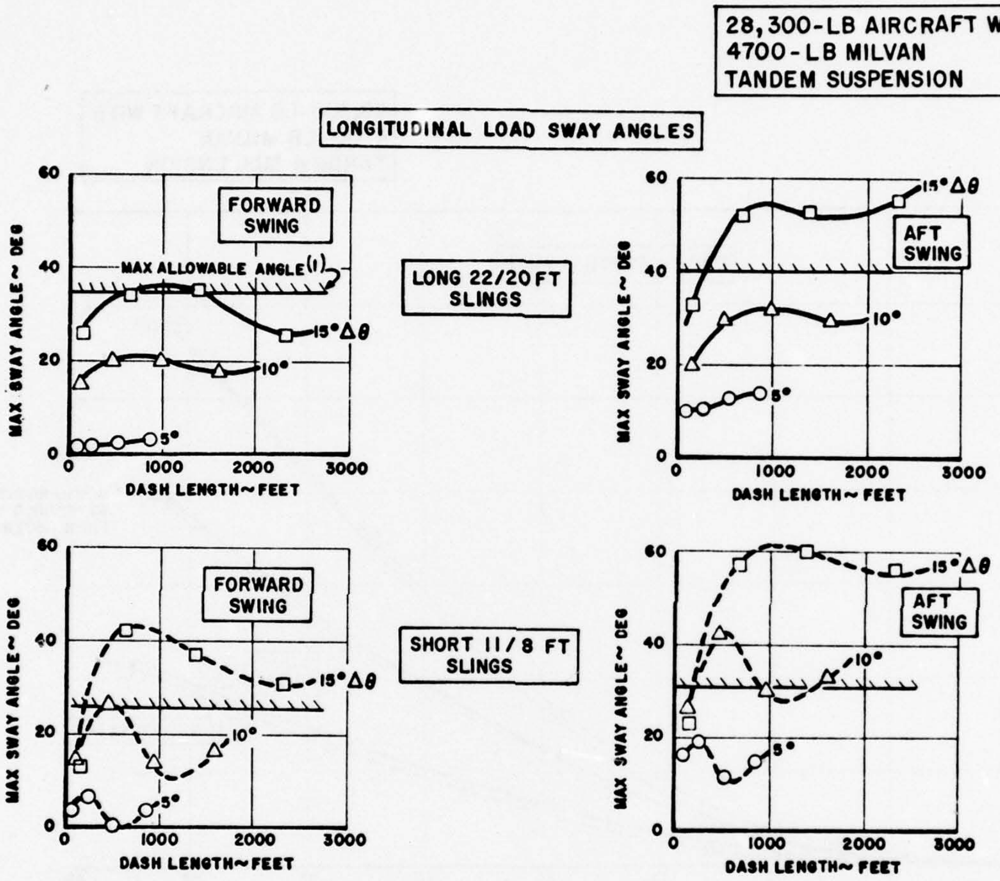


FIGURE 12. DASH MANEUVER WITH THE 8x8x20 MILVAN



NOTES:

1. LOAD SWING ANGLES LIMITED BY AIRCRAFT AND HOOK STRUCTURAL LIMITS, AND LOAD INTERFERANCE WITH FUSELAGE

FIGURE 13. PEAK SLING LOAD SWAY ANGLES DURING DASH MANEUVER (8x8x20 MILVAN)

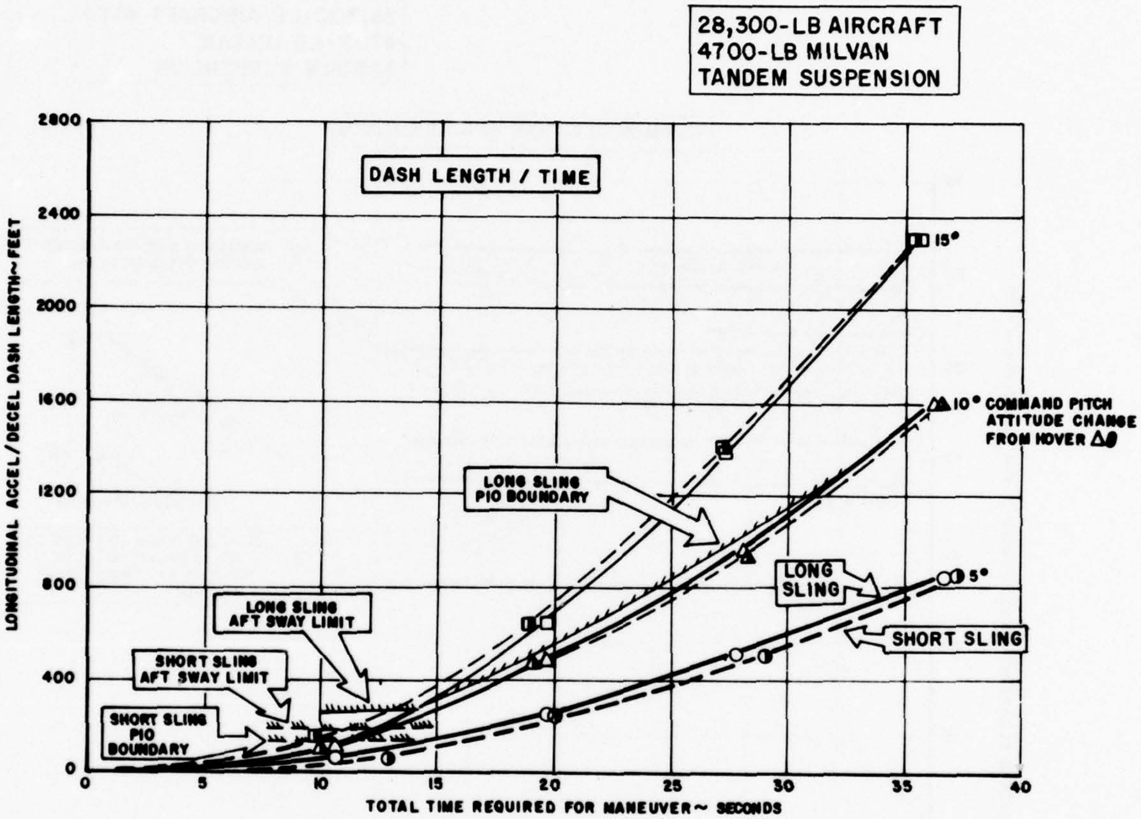


FIGURE 14. DASH MANEUVER LIMITATIONS ASSOCIATED WITH THE 8x8x20 MILVAN

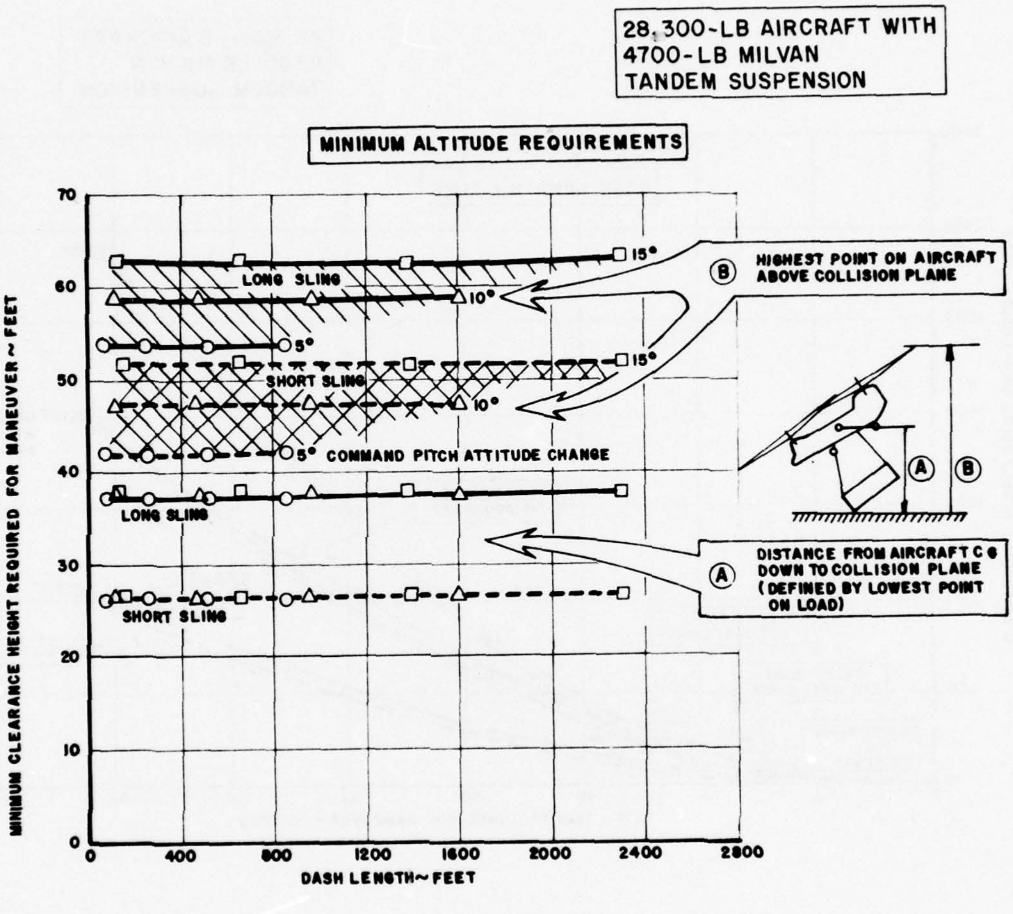


FIGURE 15. HEIGHT REQUIREMENTS INCURRED WITH THE 8x8x20 MILVAN DURING DASH MANEUVERS

In addition to the restrictions imposed by the sway limits, limitations may also occur as a result of PIO due to load motion, particularly at night or under reduced visibility conditions. The load motion creates longitudinal and lateral accelerations in the helicopter, producing a confusing motion cue pattern for the pilot. This can result in pilot control inputs which excite rather than damp out the load motion.

Airframe longitudinal accelerations resulting from the dash maneuver are presented in Figure 16. A maximum of 0.05 g is associated with the onset of PIO in IFR or night conditions based on the flight test results of Reference 4. For the light MILVAN, these reduced visibility PIO boundaries fall in the same region as the sway limits. The severity of this characteristic grows substantially as the load-to-aircraft weight ratio increases.

3.2.1.2 Internal Baseline (45,000 Pounds) and 155mm Howitzer Results

The dash length versus time required data for this configuration is shown in Figure 17 as a function of pitch attitude. The basic data is similar to that shown on Figure 12 for the MILVAN, as acceleration levels are dependent only on attitude changes.

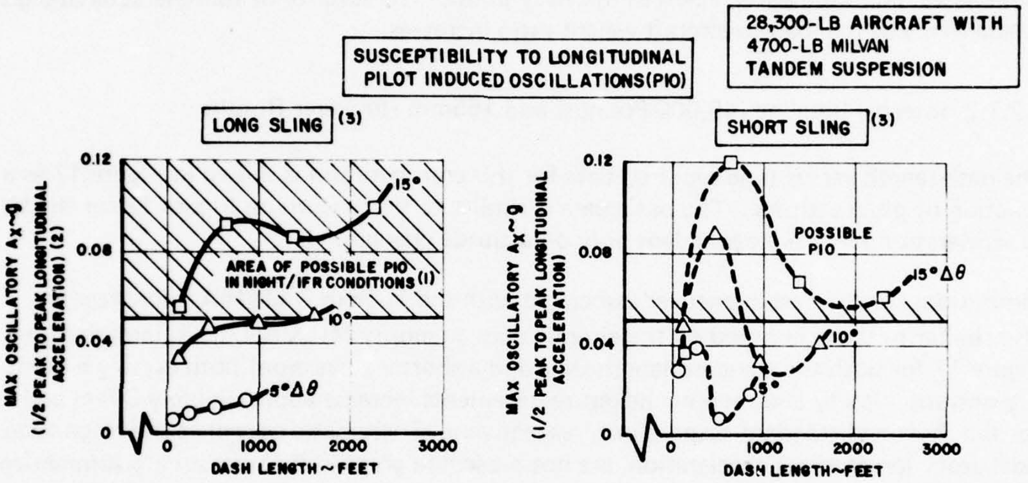
Limitations for the dash maneuver associated with the 155mm – M114A1 howitzer are also similar to those imposed on the aircraft with an empty MILVAN, (as summarized on Figure 17 for both the standard length sling and a shortened version) both on single point suspensions. Safety and masking height requirements increase approximately 8 feet and 13 feet for the short and standard suspensions, respectively. These data, as well as the magnitude of oscillatory longitudinal acceleration, are not presented graphically here but are summarized in the Section 3.3 ranking analysis.

3.2.2 Lateral Jink

Lateral acceleration/deceleration maneuvers were simulated in a manner analogous to the longitudinal dash. Figure 18 illustrates the lateral jink translation and summarizes the major limitations associated with the maneuver. Commanded bank angles of 5, 10, and 15 degrees were evaluated with increasing maneuver time to produce variations in lateral displacement. Limitations evolved from analysis of these maneuvers are similar to those discussed previously for the dash. Here again, load motion and its inherently low damping restrict full usage of aircraft capability. In this case, however, the CH-47 pilot's handbook limit restricts maximum sideward speeds to 35 knots, and so the percentage reduction available for safe maneuvering with external loads is less than with the dash.

Requirements for masking the aircraft are less severe for this maneuver in relation to those required by the longitudinal acceleration/deceleration. This difference is due to the smaller linear displacement of the rotor resulting from angular rotation about the roll axis as compared to rotation about the pitch axis.

Figure 19 presents the computed lateral displacements as a function of total time required to execute the maneuver. The sideward flight velocity restriction of 35 knots is indicated. Execution of the maneuver with the empty MILVAN as an external load produced the peak sway angles presented in Figure 20. Comparison of load motion with standard (long) and short suspensions indicates that slightly larger excursions in load angle result with the shortened sling.



NOTES:

1. CRITERIA FOR PIO BASED ON $A_X = 0.05$g, FROM AAELSS I FLIGHT TEST RESULTS WITH PILOT UNDERHOOD (SIMULATED IFR)
2. 1/2 PEAK TO PEAK A_X RESULTING FROM LOAD SWAY ONLY
3. STANDARD LONG SLING 22/20 FT., SHORT SLINGS 11/9 FT.

FIGURE 16. PIO SUSCEPTIBILITY DURING DASH MANEUVER WITH THE 8x8x20 MILVAN

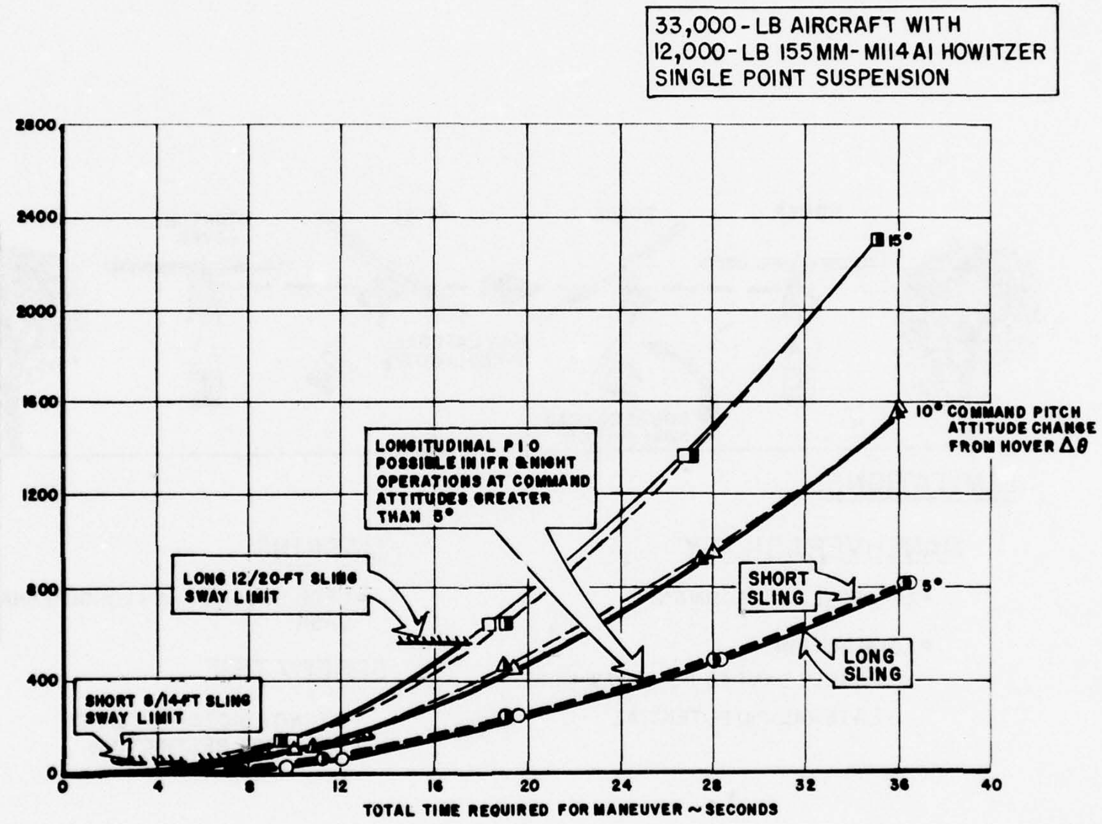
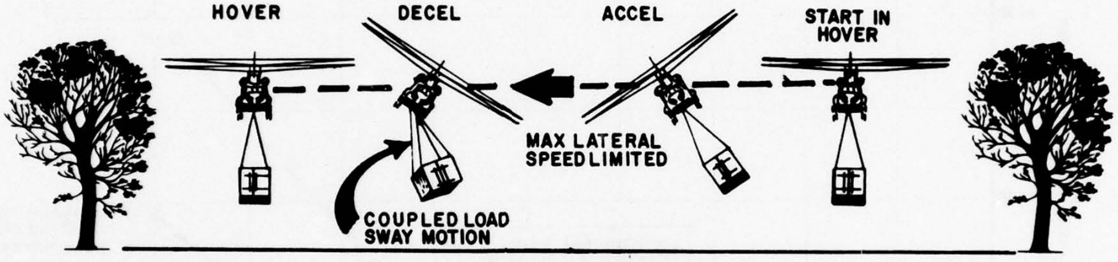


FIGURE 17. DASH MANEUVER RESTRICTIONS IMPOSED BY A 155 MM HOWITZER



LIMITATIONS:

MANEUVERABILITY

- LOW SPEED PERFORMANCE
- LOAD MOTION
  - POORLY DAMPED ROLL-YAW MODE
  - LATERAL PIO POTENTIAL

MASKING

- LESS SEVERE THAN LONGITUDINAL DASH

SPEED / TIME

- 35-KNOT SIDEWARD FLIGHT ENVELOPE RESTRICTION

FIGURE 18. LATERAL JINK MANEUVER

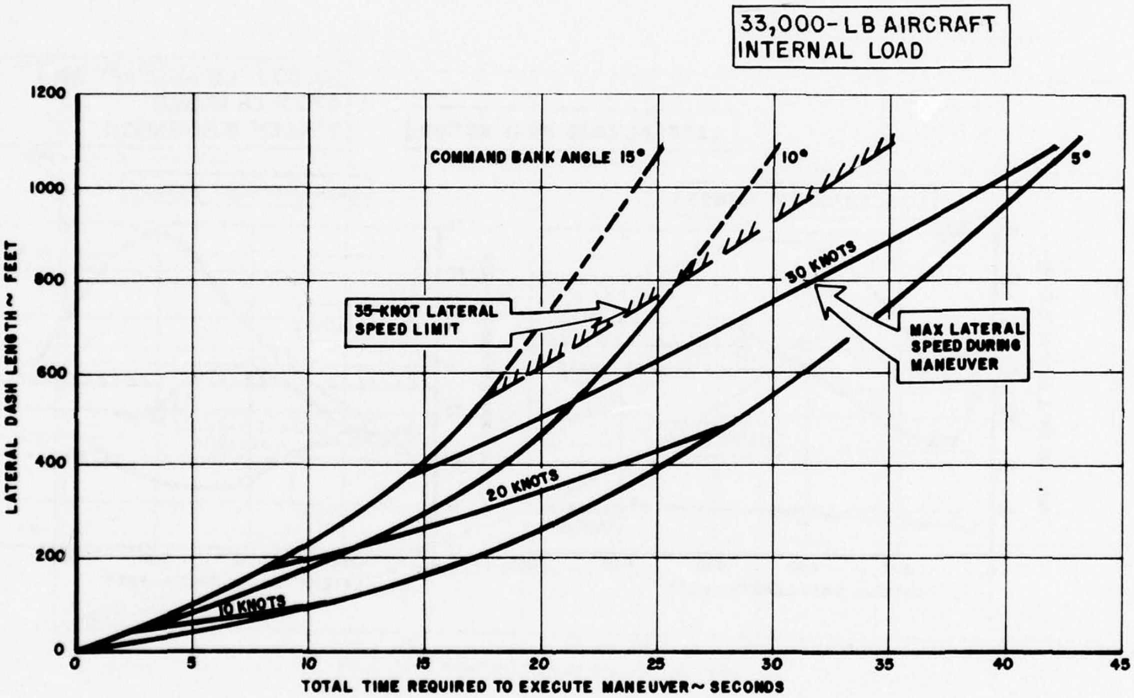


FIGURE 19. LATERAL JINK LENGTH/TIME, INTERNAL LOAD-BASELINE

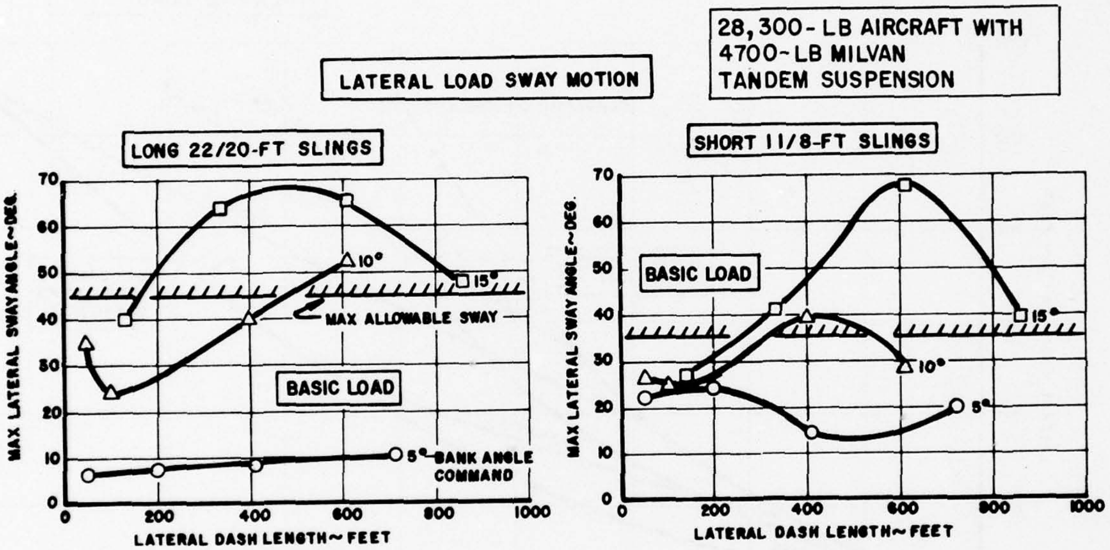


FIGURE 20. PEAK SLING SWAY ANGLES DURING LATERAL JINK MANEUVER, 8x8x20 MILVAN

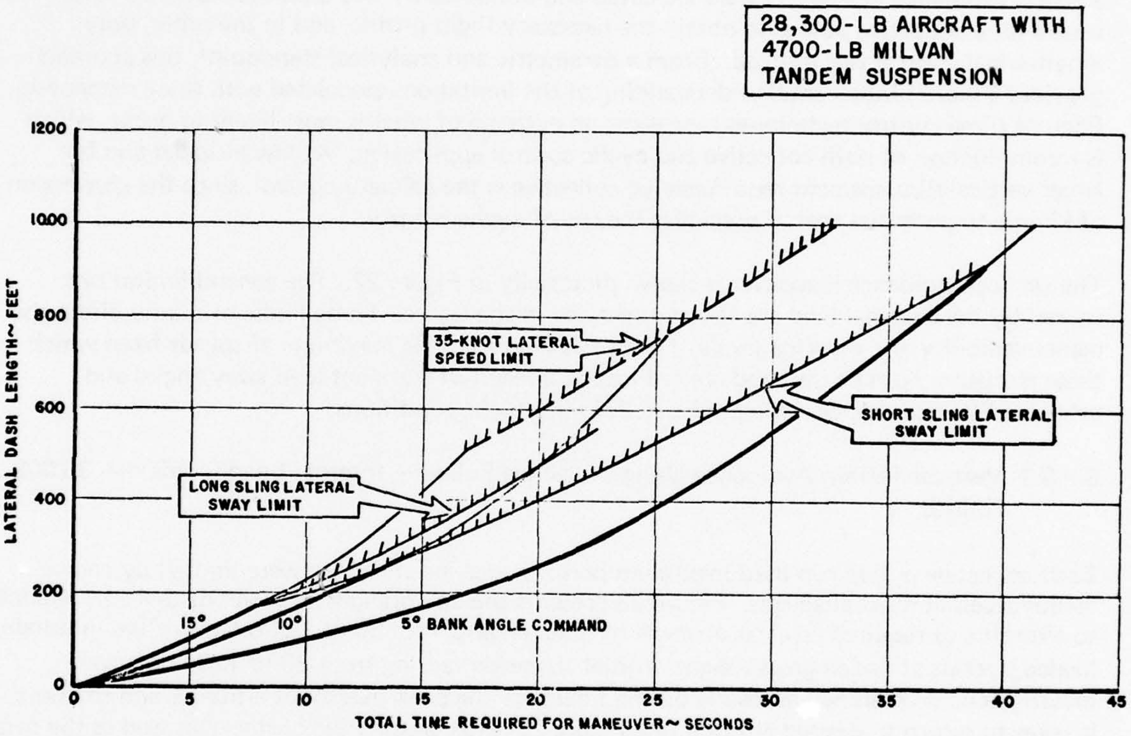


FIGURE 21. LATERAL JINK MANEUVER LIMITATIONS WITH THE 8x 8x 20 MILVAN

Load sway limits are shown which have been translated on to Figure 21 to present the permissible maneuver envelope with the MILVAN. This reflects an approximate 25 to 40 percent reduction in maneuver capability because of load motion.

3.2.3 Vertical Terrain Avoidance

Vertical avoidance maneuvers were executed and evaluated by two separate methods. One used a pure collective pullup to obtain the necessary flight profile, and in the other, only longitudinal control was utilized. From a parametric and analytical standpoint, this approach provides a more fundamental understanding of the limitations associated with these maneuvers. Each of these control techniques represents an extreme of what is most likely to occur, which is a combination of both collective and cyclic control application. At low airspeed and for larger vertical displacement requirements, collective is the primary control, since the conversion of kinetic to potential energy precludes the use of cyclic control.

The vertical avoidance maneuver is shown pictorially in Figure 22. The general limitations caused by the external load are also summarized in the figure. These limits primarily effect the maneuverability and masking levels of the basic aircraft. The maximum airspeeds from which these maneuvers can be initiated are reduced as a result of transient load sway angles and probable PIO occurrence during reduced visibility flight conditions.

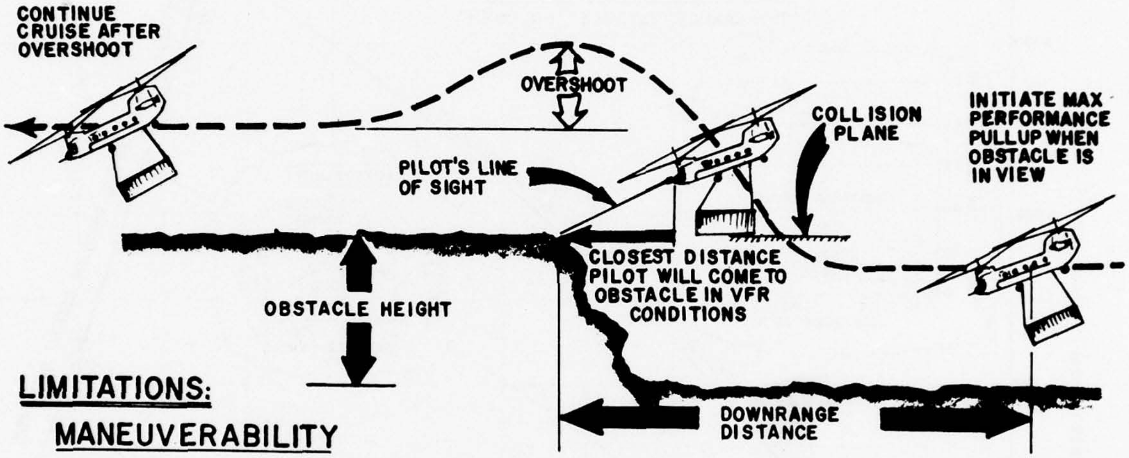
3.2.3.1 Vertical Terrain Avoidance Using *Collective* Pullup – Internal Load Baseline – 33,000 Pounds

Each collective pullup run used maximum performance inputs which were limited by engine torque levels at most airspeeds. Figure 23 presents the downrange maneuver distance (referenced to aircraft c g) required to clear obstacle heights ranging from 50 to 1,000 feet for the internally loaded aircraft at design gross weight. Initial airspeeds varying from 30 to 120 knots were investigated. Also shown as inserts on the figure are the peak overshoot altitudes and the time it takes to return to desired altitude (see Figure 22) after passing the obstacle, as well as the total time to clear the obstacle.

Figure 24 defines the minimum clearance heights for the baseline collective pullup. These distances, referred to as (A) and (B) in the sketch, are independent of obstacle height, since the attitude changes which occurred during the maneuvers were negligible. Slight changes with airspeed are noted, reflecting the differences in initial trim pitch attitude. Again, a safety margin altitude is required to provide adequate clearance throughout the maneuver. The magnitude of this margin would be dependent upon pilot proficiency and terrain familiarity.

Parameters (C) and (D) in Figure 24 define the additional downrange distances required for VFR collision plane avoidance. This distance reflects the minimum distance through which the pilot can maintain visual contact with the obstacle. At this distance he will normally make sure he is above the obstacle. Clearance (C) accounts for the distance from the obstacle to the nose of the aircraft, while clearance (D) accounts for the distance to the cg position. These distances must be included in downrange distance requirements.

Vertical Terrain Avoidance with MILVAN Load – The vertical pullup maneuvers were repeated with an empty MILVAN. Load sway angle data and longitudinal accelerations resulting from



LIMITATIONS:

MANEUVERABILITY

- AIRCRAFT PERFORMANCE WITH EXTERNAL LOAD
  - LOAD DRAG/RATE OF CLIMB OF THE AIRCRAFT
- DOWNRANGE DISTANCE TO CLEAR OBSTACLE
  - VISABILITY INFLUENCE
    - VFR
    - NIGHT/IMC
- LOAD MOTION
  - PIO
  - SPEED RESTRICTION

WORKLOAD

- HIGH, BUT LESS SEVERE THAN DASH AND JINK

MASKING

- OVERSHOOT ADDS TO AIRCRAFT-LOAD MASKING REQUIREMENTS
- SAFETY MARGIN ALTITUDE REQ'MTS INCREASE WITH SPEED
  - LOAD SNAG

SPEED/TIME

- LOAD STABILITY
- VISIBILITY
- OBSTACLE SIZE

FIGURE 22. VERTICAL TERRAIN-AVOIDANCE MANEUVER

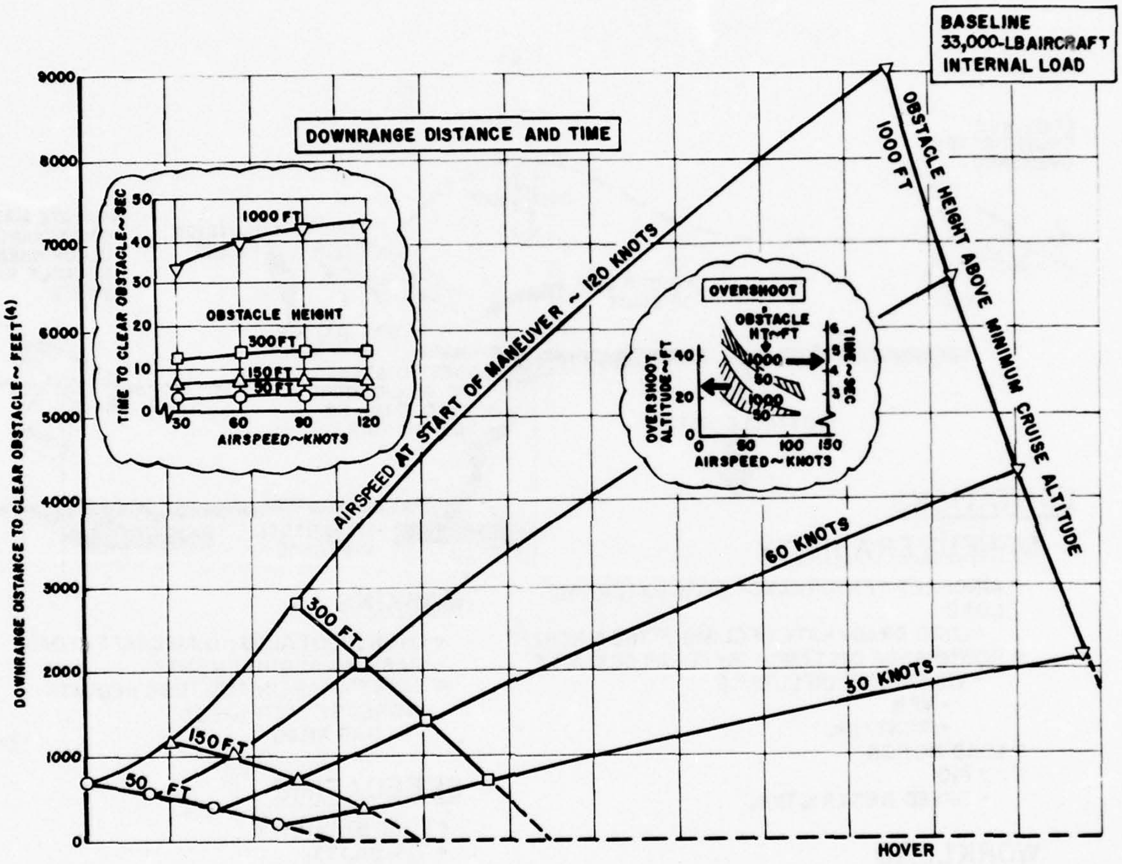
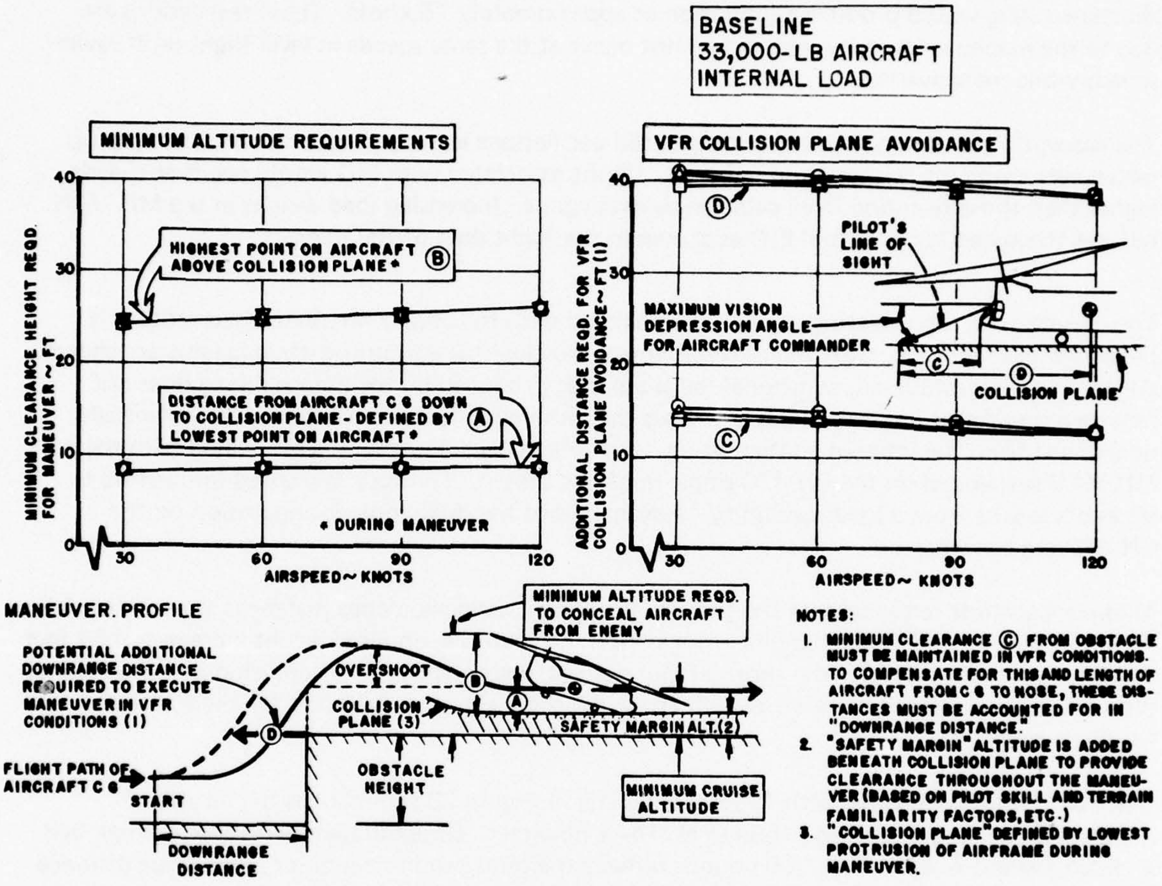


FIGURE 23. DOWNRANGE DISTANCE REQUIREMENTS FOR VERTICAL TERRAIN AVOIDANCE, INTERNAL LOAD - BASELINE



NOTES:

1. MINIMUM CLEARANCE Ⓒ FROM OBSTACLE MUST BE MAINTAINED IN VFR CONDITIONS. TO COMPENSATE FOR THIS AND LENGTH OF AIRCRAFT FROM C G TO NOSE, THESE DISTANCES MUST BE ACCOUNTED FOR IN "DOWNRANGE DISTANCE."
2. "SAFETY MARGIN" ALTITUDE IS ADDED BENEATH COLLISION PLANE TO PROVIDE CLEARANCE THROUGHOUT THE MANEUVER (BASED ON PILOT SKILL AND TERRAIN FAMILIARITY FACTORS, ETC.)
3. "COLLISION PLANE" DEFINED BY LOWEST PROTRUSION OF AIRFRAME DURING MANEUVER.

FIGURE 24. CLEARANCE REQUIREMENTS DURING VERTICAL TERRAIN AVOIDANCE, INTERNAL LOAD - BASELINE

the maneuvers are shown in Figure 25,together with the associated limits. Load sway motion again restricts the capability of the CH-47. For the standard (long) dual hook suspension, vertical pullups above 90 knots would result in exceeding the sway angle limit, while the shortened sling would produce a limitation at approximately 75 knots. These restrictions are due to the maneuver severity, and would not occur at the same speeds in level flight or at lower speeds while maneuvering.

The susceptibility to longitudinal pilot induced oscillations is less pronounced for these pullup maneuvers than with the longitudinal dash. Limits associated with PIO would result at speeds higher than those resulting from cable angle excursions. Increasing load weight in the MILVAN reduces the speed for potential PIO as shown in the flight data of Reference 5.

The reduction in maneuvering capability associated with the empty MILVAN load motion is presented in Figure 26. Downrange requirements to clear the various obstacle heights are shown. At the airspeeds evaluated, additional flat plate drag produced by the external load does not require a significant increase in power. Thus the distances required to clear remain essentially unchanged from the internal configuration. For reference,airspeed limits associated with the MILVAN suspended on the CH-47C single hook are shown. The very low speed limit of 40 to 50 knots results from a load instability. Advantages of the dual hook configuration on the CH-47D are obvious.

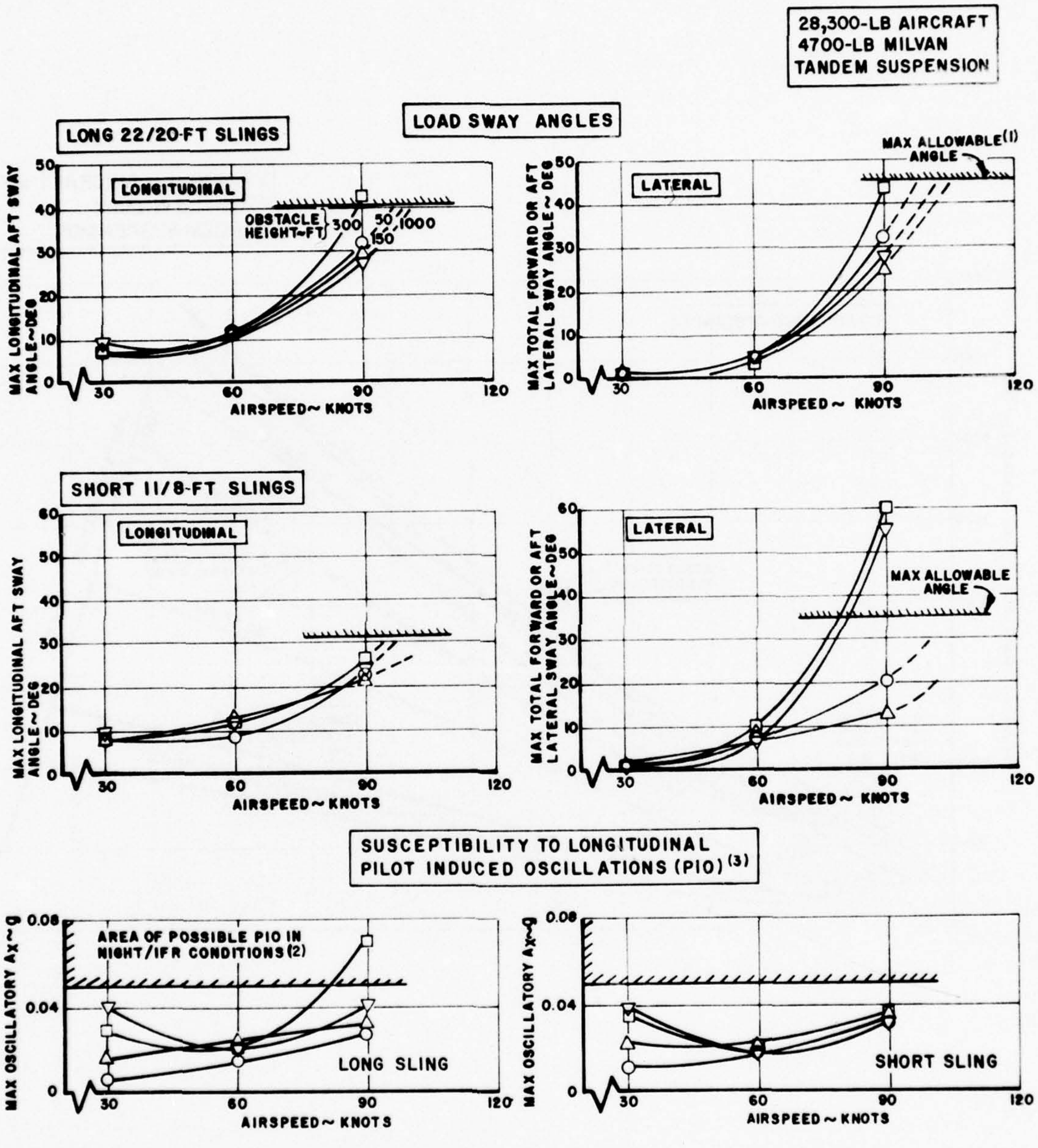
Minimum altitude requirements and the VFR collision plane avoidance distances are presented in Figure 27. Compared to the baseline information in Figure 24, nominal height increases of 18 feet and 34 feet are required for the short and long slings, respectively. VFR collision plane avoidance distances have increased as much as 45 feet for the short slings, and 70 feet for the standard length suspension.

Vertical Terrain Avoidance with 155mm Howitzer – Figure 28 summarizes the results of maneuvers conducted with the 155mm-M114A1 howitzer. Data obtained with the internal load at an equivalent weight of 45,000 pounds reflects the same requirements for downrange distance with obstacle height, as shown for the externally loaded configuration. As such, only the results obtained with the external load are presented. Comparison with the downrange requirements obtained at design gross weight (33,000 pounds) on Figure 23 indicates that the required distances increase with higher weights. This trend is attributed to higher initial levels of power required at heavy weight, and the associated lower rates of climb. The resultant increase approximately doubles the downrange distance requirement for a 35-percent increase in gross weight.

The limitations connected with this configuration are not as severe as those produced by the empty MILVAN. The load sway motions for either sling length do not exceed allowable limits until reaching approximately 120 knots. By comparison, maneuvering with the MILVAN was limited above 75 knots.

3.2.3.2 Vertical Terrain Avoidance Using Longitudinal Cyclic Control

The use of longitudinal cyclic control for flight path obstacle avoidance is not as effective as the collective technique at terrain flying speeds typical of those used by a cargo transport helicopter. This is evident from the results contained in Figure 29, where large obstacles cannot be cleared at low speeds. The conversion of kinetic energy to potential energy for altitude changes is effective



NOTES:

1. LOAD SWING ANGLES LIMITED BY AIRCRAFT AND HOOK STRUCTURAL LIMITS, HOOK SWAY STOPS, AND LOAD INTERFERANCE WITH FUSELAGE.
2. LONGITUDINAL PIO PROBABLE IN IFR/NIGHT CONDITIONS $A_x > 0.05$ g.
3. BASED ON AAELSS I FLIGHT TESTING.

FIGURE 25. LOAD SWAY ANGLES AND PIO SUSCEPTIBILITY DURING VERTICAL TERRAIN AVOIDANCE, 8x8x20 MILVAN

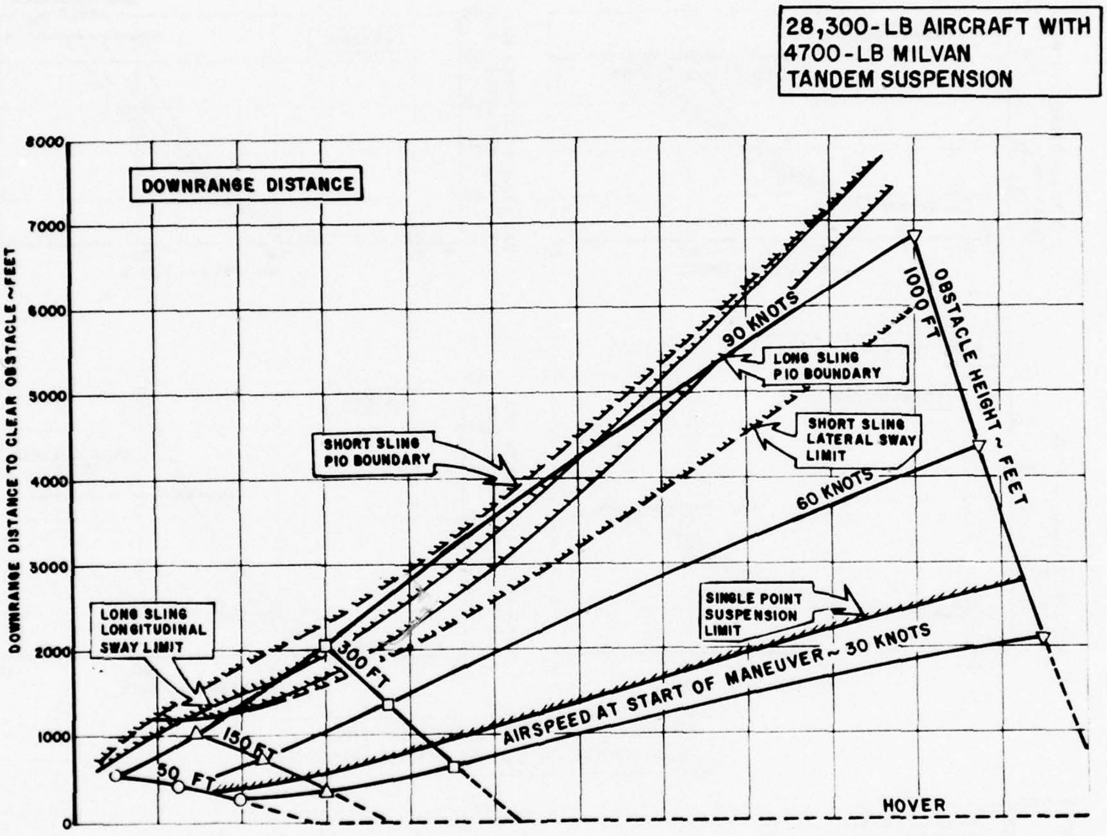
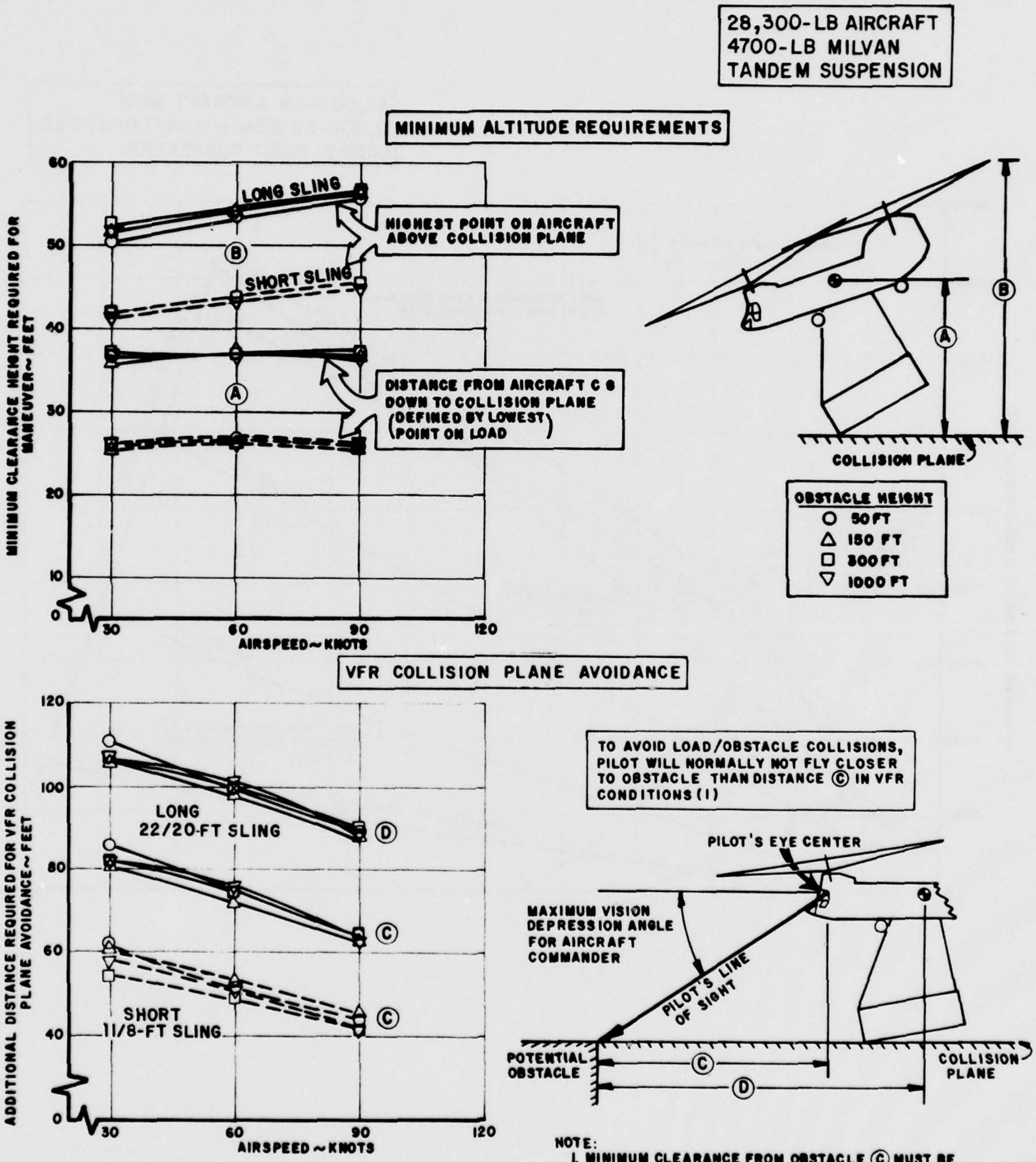


FIGURE 26. LIMITATIONS IMPOSED ON VERTICAL TERRAIN AVOIDANCE WITH THE 8x8x20 MILVAN



TO AVOID LOAD/OBSTACLE COLLISIONS, PILOT WILL NORMALLY NOT FLY CLOSER TO OBSTACLE THAN DISTANCE Ⓒ IN VFR CONDITIONS (1)

NOTE:
1. MINIMUM CLEARANCE FROM OBSTACLE Ⓒ MUST BE MAINTAINED FOR VFR MANEUVERING. TO COMPENSATE FOR THIS AND LENGTH OF AIRCRAFT FROM CG TO NOSE, THESE DISTANCES MUST BE ACCOUNTED FOR IN DOWNRANGE DISTANCE.

FIGURE 27. CLEARANCE REQUIREMENTS DURING VERTICAL TERRAIN AVOIDANCE WITH THE 8x8x20 MILVAN

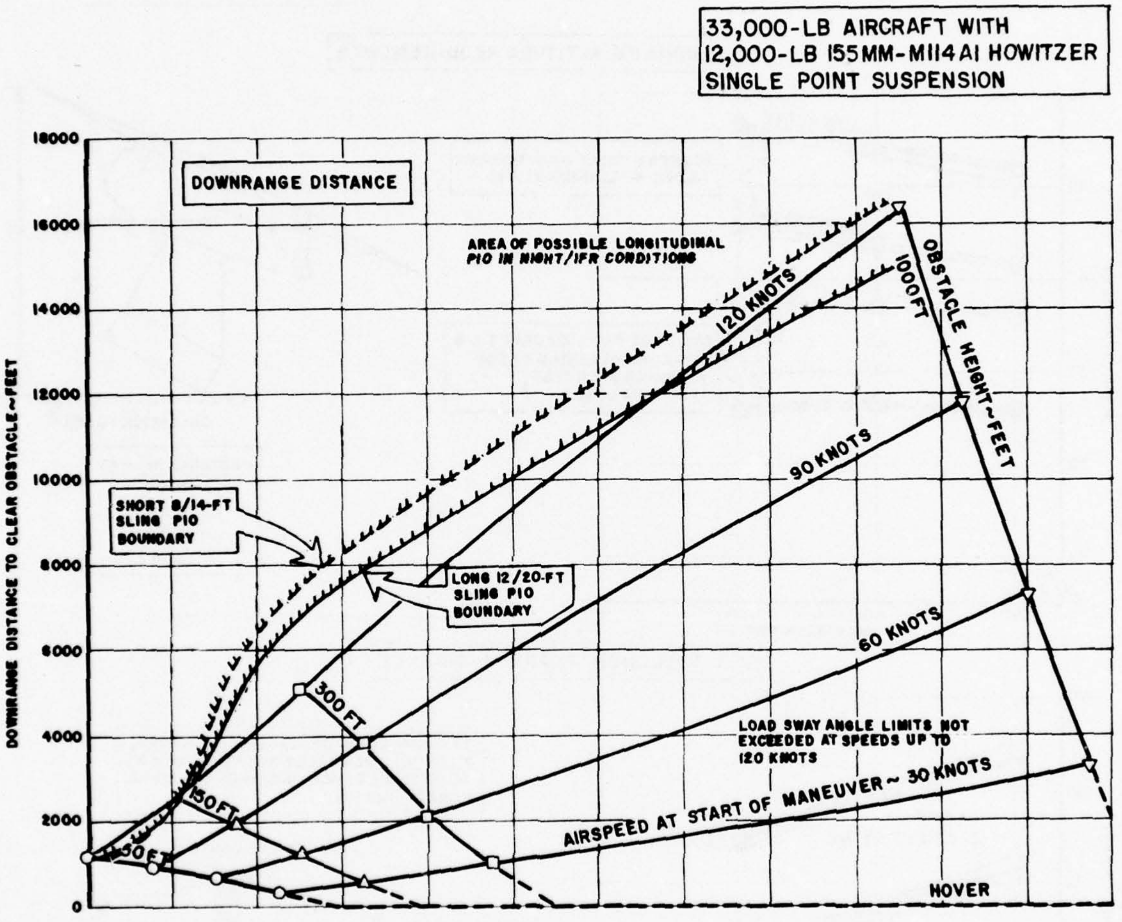


FIGURE 28. LIMITATIONS IMPOSED ON VERTICAL TERRAIN AVOIDANCE WITH 155 MM HOWITZER (45,000-LB GR WT)

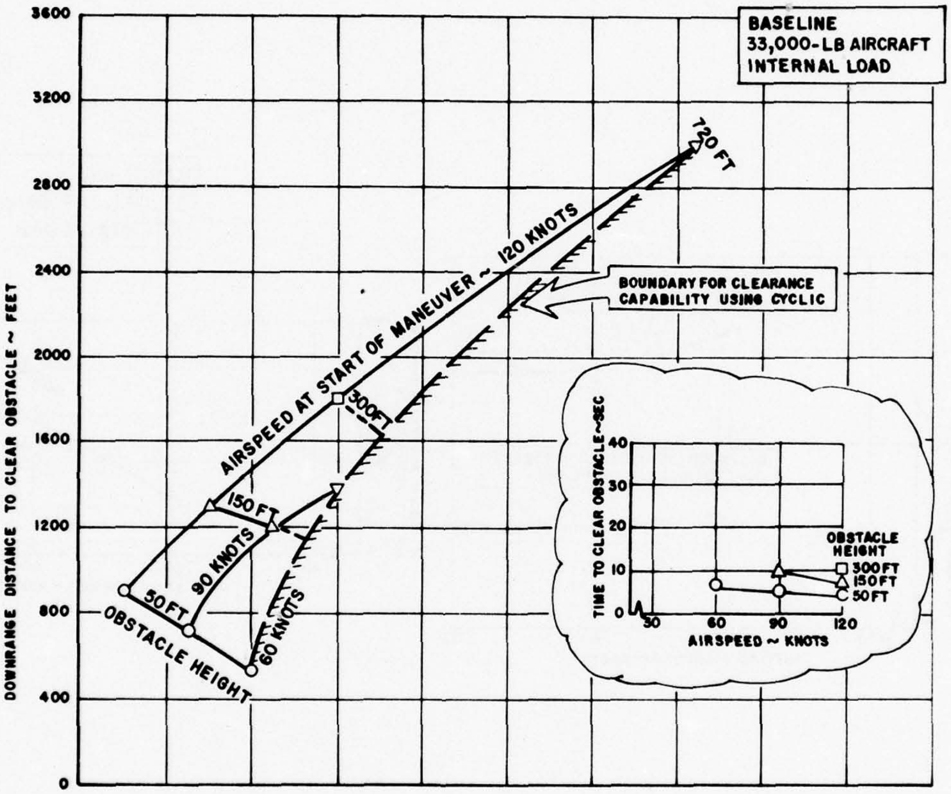
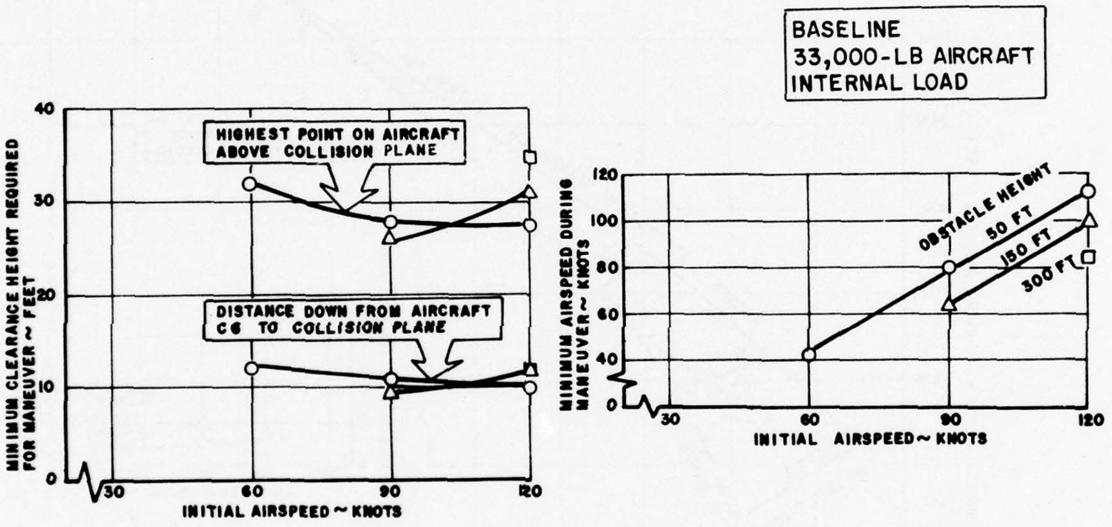


FIGURE 29. DOWNRANGE REQUIREMENTS FOR VERTICAL TERRAIN AVOIDANCE USING CYCLIC CONTROL INTERNAL LOAD - BASELINE



BASELINE
33,000-LB AIRCRAFT
INTERNAL LOAD

FIGURE 30. CLEARANCE REQUIREMENTS AND SPEED CHANGES DURING VERTICAL TERRAIN-AVOIDANCE UTILIZING CYCLIC CONTROL

at the higher airspeeds only in providing a reduction in downrange distance requirements, when compared to the pure collective control pullup. In the latter technique, energy is applied to the system through an increase in available engine torque. The reduction in downrange distance requirements, however, results only from the decrease in airspeed, as noted in Figure 30. A combination of cyclic and collective inputs may show a slight improvement over the pure collective use.

3.2.4 Lateral Terrain Avoidance

Lateral terrain-avoidance maneuvers were analyzed parametrically by varying bank angle and total maneuver time. The maneuver is sketched in Figure 31, and was evaluated maintaining constant airspeed and altitude. Speeds of 30, 60, and 90 knots were selected for analysis with an extension to hover represented by the previously described jink maneuver. Limitations are listed in the figure.

Downrange distance requirements for lateral displacements varying from 100 to 1,000 feet are shown in Figure 32. The data indicates that reductions in downrange distances occur with increasing bank angle, and decreasing airspeed. The boundary labeled as minimum possible downrange distance reflects the maximum bank angle which can be commanded to produce a particular lateral displacement. Further increases in the bank angle would result in a larger lateral displacement. The downrange distance performance is the same with or without the load, for similar aircraft gross weights.

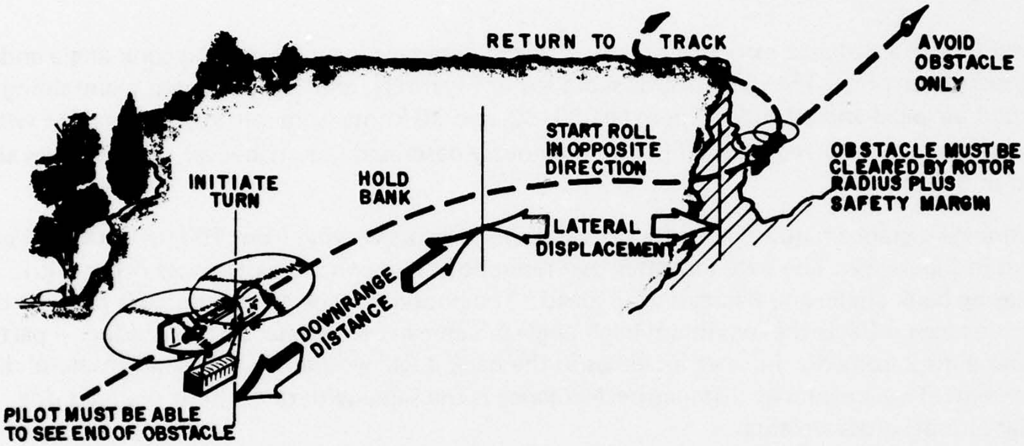
Peak angular excursions of the MILVAN are presented in Figure 33 for both suspension lengths for the 60-knot maneuver. Degradations in load sway motion (particularly longitudinal) result with steeper turn angles. Variations with lateral displacement at fixed bank angle are minimal. The resulting limitations reflecting the permissible maneuver bank angle with airspeed are summarized in Figure 34. At 90 knots the limiting bank angle is approximately 40 degrees, but diminishes to about 25 degrees at 30 knots, where the ability to coordinate turns has lessened. Difficulty in turning leads to large variations in local sideslip angle for the load, as well as for the aircraft. This leads to large load oscillations because of poor inherent lateral/directional load stability characteristics.

3.2.5 Low Level Terrain Flight

As illustrated in Figure 35, low-level flight is conducted at a selected altitude where detection or observation of an aircraft is avoided or minimized. The route is preselected and conforms generally to a straight line and a constant airspeed and indicated altitude.

In this mode of terrain flight, aircraft level-flight speed characteristics are strongly influenced by external loads. Load drag slows the aircraft down when flying at either a power or transmission limit, and increased overall height of the aircraft/load combination requires higher cruise altitude. Cruise altitude requirements are further increased when flying at high speed, in order to provide an adequate safety margin between the load and the ground.

The external load drag penalty is often as large as total helicopter parasite drag itself, and sometimes exceeds twice that of the aircraft for bluff body cargo shapes such as MILVAN containers. The overall effect of adding external loads to the CH-47 in level flight is shown in Table 4,



LIMITATIONS:

MANEUVERABILITY

- LATERAL/DIRECTIONAL LOAD MOTION LIMITS AIRCRAFT BANK ANGLE
- DOWNRANGE/LATERAL DISPLACEMENT DISTANCE
  - VISIBILITY

MASKING

- SIMILAR TO OTHER MANEUVERS

SPEED/TIME

- OBSTACLE SIZE
- VISIBILITY

FIGURE 31. LATERAL TERRAIN-AVOIDANCE MANEUVER

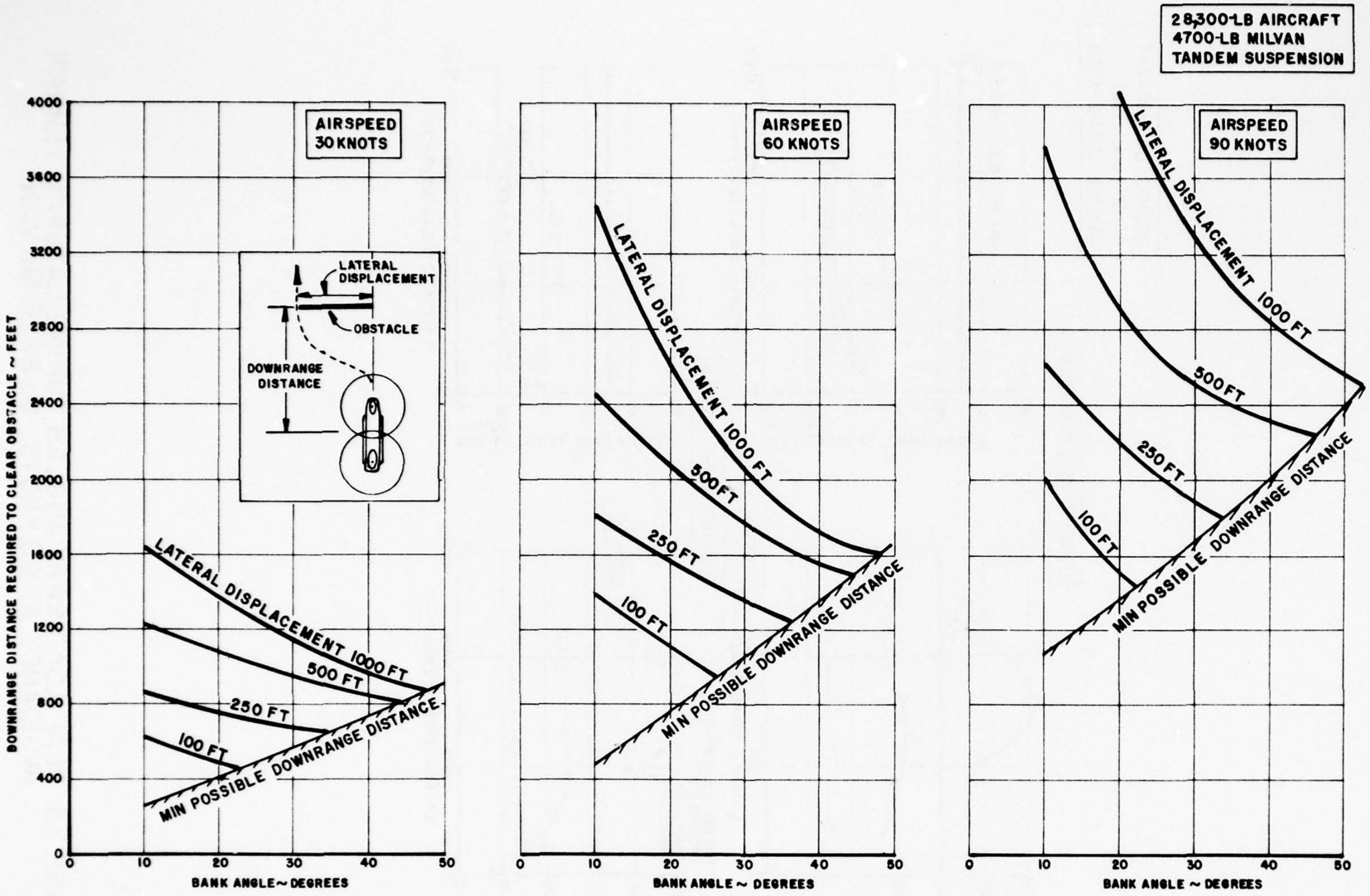


FIGURE 32. DOWNRANGE REQUIREMENTS FOR LATERAL TERRAIN AVOIDANCE WITH THE 8x8x20 MILVAN

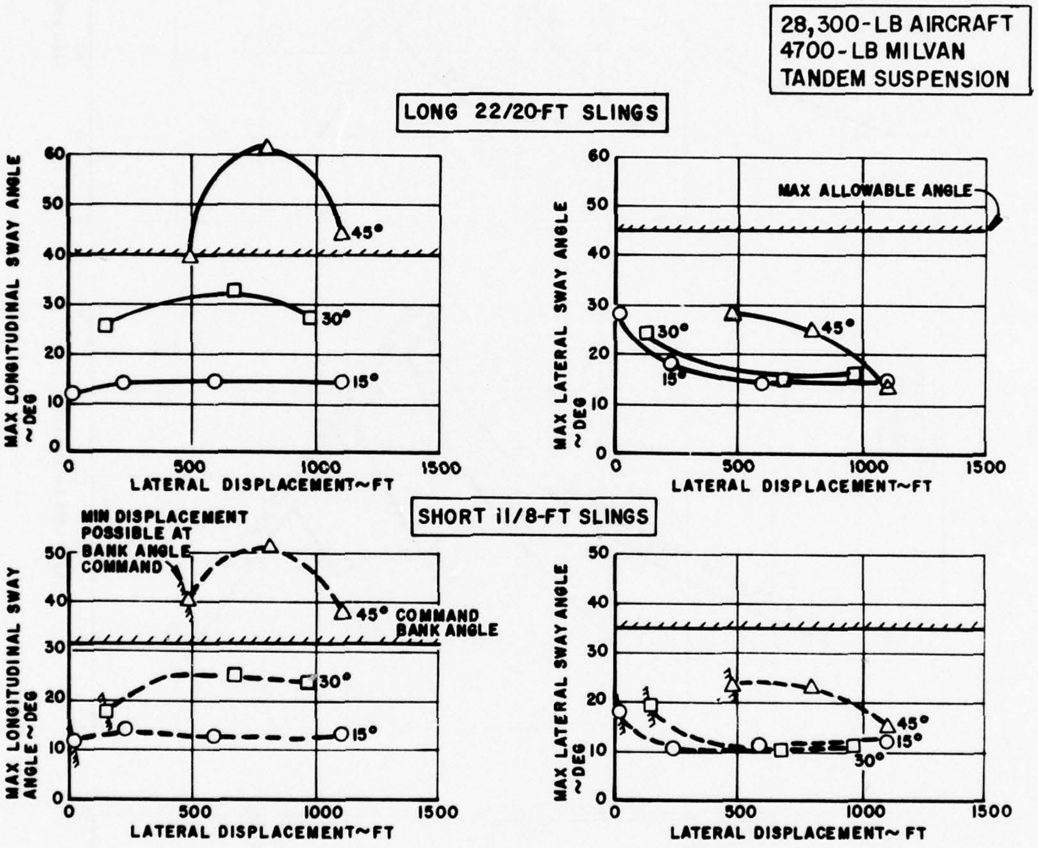


FIGURE 33. PEAK LOAD SWAY ANGLES DURING LATERAL TERRAIN AVOIDANCE AT 60 KNOTS, 8 x 8 x 20 MILVAN

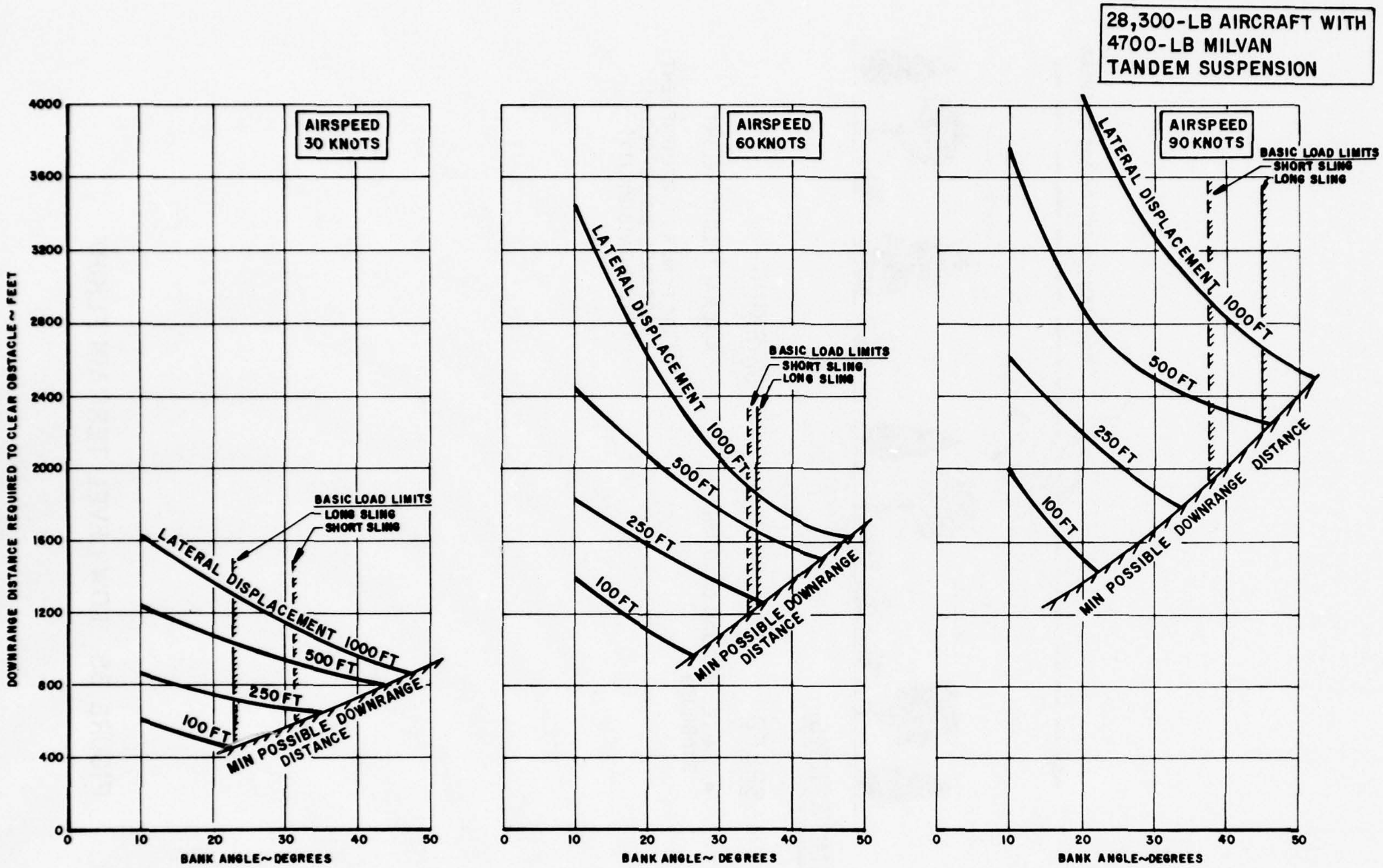
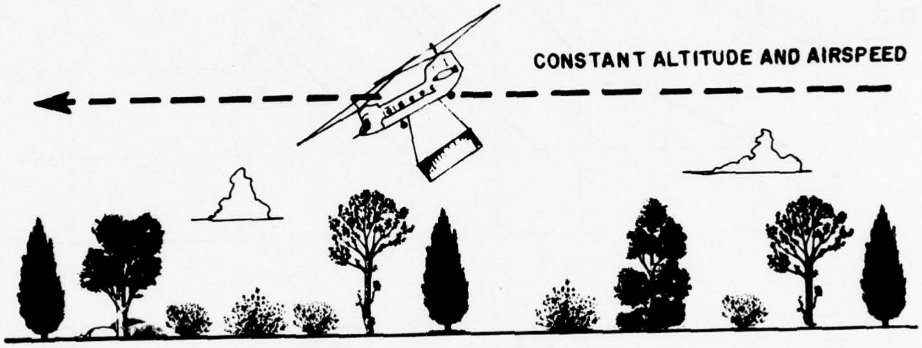


FIGURE 34. LIMITATIONS IMPOSED ON LATERAL TERRAIN AVOIDANCE WITH THE 8x8x20 MILVAN



LIMITATIONS:

SPEED

- LIMITED BY LOAD DRAG AND STABILITY

MASKING

- AIRCRAFT LOAD HEIGHT
- SAFETY MARGIN REQUIREMENT (INCREASES WITH SPEED AND REDUCED VISIBILITY)

FIGURE 35. LOW LEVEL TERRAIN FLIGHT

TABLE 4. CH-47 LOW LEVEL CRUISE SUMMARY

			LOAD DRAG - EQUIVALENT FLAT PLATE AREA (FEET^2)	MAX LEVEL FLIGHT CRUISE SPEED AS LIMITED BY XMSN TORQUE (KNOTS)	MINIMUM CRUISE ALTITUDE - CG TO LOAD BOTTOM (FEET)
33,000-LB GR WT	INTERNAL LOAD - BASELINE		0	165	9.1
	EMPTY MILVAN	LONG (STD) SUSPENSION	96	130(1)/110(2)	31.9
		LONG (STD) SUSPENSION WITH AAELSS	104	127	28.8
		SHORT SUSPENSION	84	133(1)/110(2)	23.9
		SHORT SUSPENSION WITH AAELSS	92	130	21.6
		SNUBBED LOAD	92	130	17.2
45,000-LB GR WT	INTERNAL LOAD - BASELINE		0	146	9.0
	155MM HOWITZER	LONG (STD) SUSPENSION	56	129	21.4
		LONG (STD) SUSPENSION WITH AAELSS	64	126	21.5
		SHORT SUSPENSION	54	130	17.6
		SHORT SUSPENSION WITH AAELSS	62	127	17.5

(1) XMSN LIMIT SPEED

(2) MAX DEMONSTRATED SPEED IN FLIGHT TEST

which compares transmission limited cruise speeds for all cargo configurations investigated in the terrain flying maneuver study.

The estimated equivalent flat plate drag area (f_e) values for each load at its cruise angle of attack are shown in the first column of the table. To develop the total parasite drag penalty associated with carrying the load externally, f_e were corrected to account for aircraft drag variations caused by the increased nosedown pitch attitudes flown to overcome load drag. Parasite power required for each load was added to level flight total power required (as defined by CH-47C performance flight test results noted in Reference 15), to determine the cruise speed limits shown in the second columnof the table. Note that airspeed is reduced 32 to 38 knots when carrying the MILVAN externally, and diminished 16 to 20 knots for the 155mm howitzer.

In the case of the empty MILVAN, two cruise speeds are shown, with the lower representing the maximum demonstrated in flight test, to date, on a CH-47 equipped with a tandem hook. Speeds faster than 110 knots may be possible with this load, but should be explored in a buildup fashion to ensure adequate load stability.

As shown in the right column in Table 4, addition of the MILVAN load increases cruise altitude requirement by up to 22 feet with the suspended load, and 8 feet with the snubbed configuration. Carrying the howitzer increases the cruise altitude anywhere from 8.5 to 12.5 feet.

3.2.6 Load Snag Considerations

Terrain flight with external loads leads to the obvious possibility of snagging the load on wires or dragging the load across the tops of trees. To assess the criticality of this problem, the simulation model was modified to include the effects of a load snag. Figure 36 presents the aircraft and load dynamic time histories following the snag of a MILVAN load suspended on standard 22-foot/20-foot slings. Two different snag conditions are shown.

The first type of snag, denoted by the long and short dash line time histories, represents an obstacle strike wherein the load in the suspension exceeds the hook ultimate capability of 85,000 pounds. In this case, the load breaks away, and aircraft attitude and altitude are easily controlled with normal pilot inputs.

The second and most serious load snag is shown by the other two time histories. Here the suspension load peaks below the ultimate load and does not break away, as might be the case when dragging the load through the trees. If no pilot corrective control action is taken (short dash time history) the aircraft will descend, pitch down, and hit the load in about 1-1/2 seconds as noted. The solid line time history shows that this descent and nose down attitude can be arrested with reasonable control activity, until the load either becomes free or is manually jettisoned. The minimum clearance between the load and aircraft was approximately 13 feet.

The time to impact without the necessary pilot corrections and the minimum clearance achieved

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15. Gormont, R., ANALYSIS OF CH-47C PERFORMANCE FLIGHT TEST, Company Report 114-FT-712, Boeing Vertol Company, Philadelphia, Pennsylvania, January 1969.

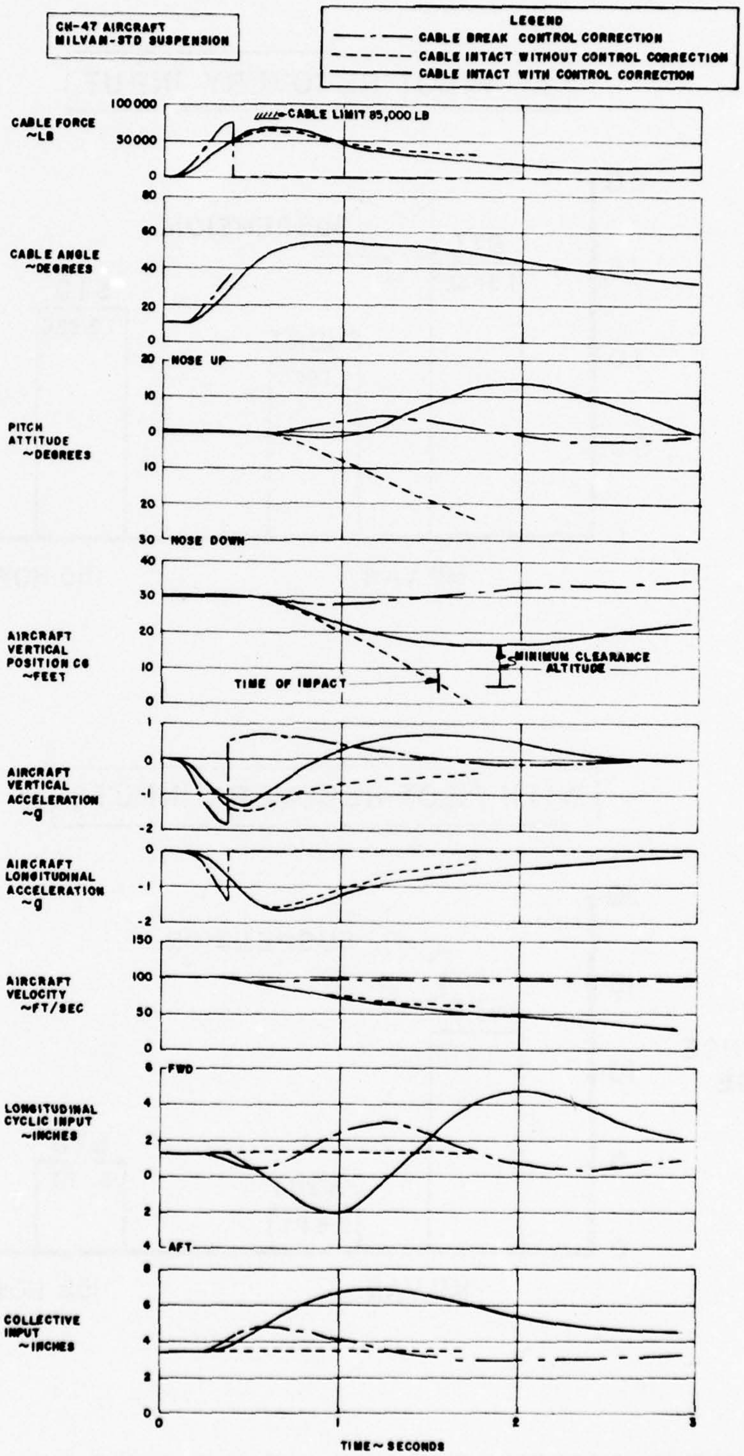
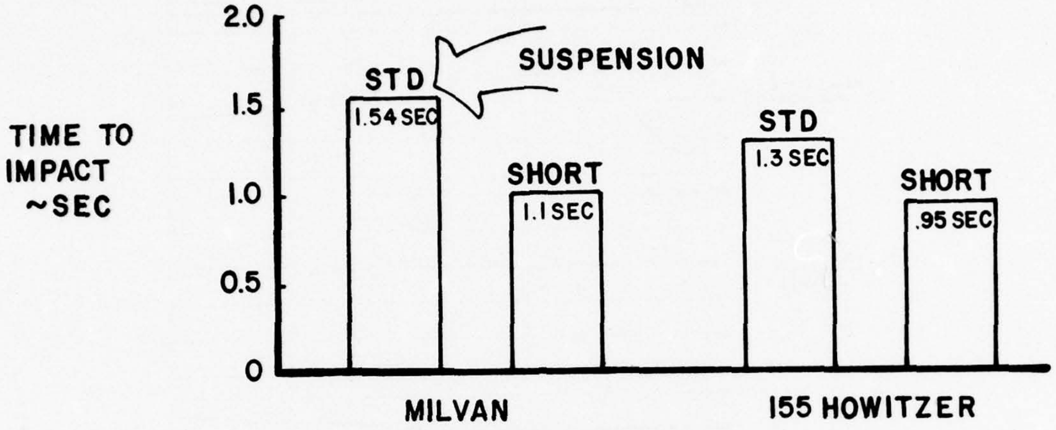


FIGURE 36. SIMULATED LOAD SNAG TRANSIENT RESPONSE, 8 x 8 x 20 MILVAN

NO PILOT RECOVERY INPUT



WITH PILOT RECOVERY INPUTS

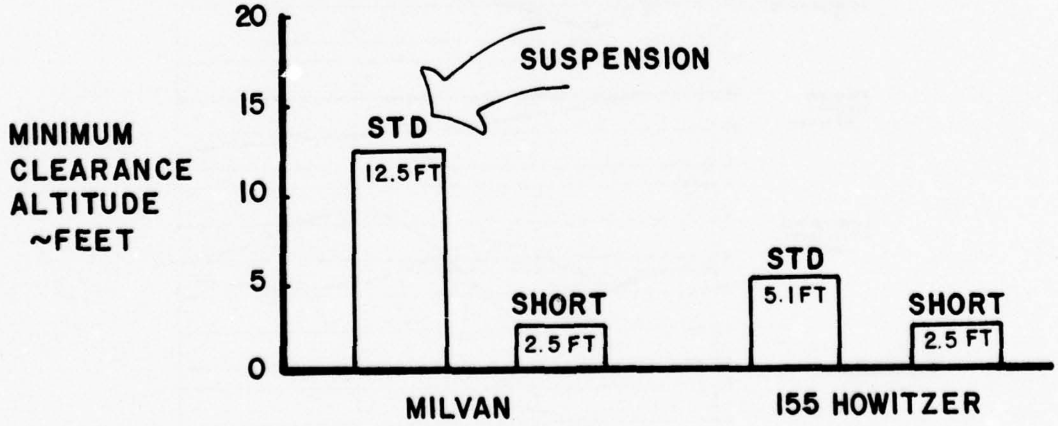


FIGURE 37. SUMMARY OF LOAD SNAG RESPONSE CHARACTERISTICS WITH 8 x 8 x 20 MILVAN

with control inputs is summarized in Figure 37 for the loads and suspension lengths being considered. The results of this preliminary snag simulation indicate that an automatic jettison system may not be required. The control power appears to be adequate to maintain aircraft control.

It is also noted from the time histories that a snag load near the maximum allowable results in a high longitudinal deceleration level ($\approx$ 1.5 g). To prevent the pilot from being accelerated forward in his seat, (with attendant difficulty in applying aft control inputs to arrest the maneuver), the shoulder harness should be locked manually during all NOE or contour terrain flight.

3.3 TECHNOLOGY APPLICATION

Limitations and vision requirements for performing terrain flying have been identified in the previous sections. In general, minimizing the identified limitations requires subsystems which fall into four specific areas. These include:

1. Cargo: suspension restraints which improve load stability and load placement accuracy and minimize masking requirements.
2. Visionics: to provide and/or improve vision capability in IMC or night operations.
3. Flight control: control systems which aid low-speed handling qualities and reduce pilot workload during external cargo acquisition and terrain flying.
4. Navigation: to improve navigational capability, particularly short- and medium-range terrain information for flight and ground-path selection, location, and/or bearing to destination. Obstacle detection and identification (such as poles, towers, etc) are also desired.

Table 5 lists the candidate concepts which offer potential for minimizing the terrain flight limitations of the CH-47.

3.3.1 Cargo System Concepts

Primary restrictions to CH-47 terrain flight capability are associated with the basic coupled motions of the external load, increases in required minimum operational altitudes, and susceptibility to load snags. Improvements in these areas are required before full utilization can be made of CH-47 terrain flying capability. The cargo system concepts identified as offering a potential solution toward this end include the following:

1. Dual hook restraints
2. Shortened suspension lengths
3. Load snubbing through a self-hoisting adapter
4. Load stabilization

TABLE 5. CANDIDATE CONCEPTS FOR MINIMIZING TERRAIN FLIGHT LIMITATIONS

MAJOR SUBSYSTEMS			
CARGO	FLIGHT CONTROL	VISIONICS	NAVIGATION
SUSPENSION RESTRAINTS • DUAL HOOK • SLING LENGTH • SNUBBING LOAD STABILIZATION JETTISON CAPABILITY – SNAG • AUTOMATIC • MANUAL	STABILITY • HOVER HOLD • GROUND SPEED HOLD • ALTITUDE HOLD CONTROL • GROUND SPEED • CREWMAN CONTROL	COCKPIT LIGHTING REQUIREMENTS WINDSHIELD GLARE REDUCTION PASSIVE SIGHT AMPLIFICATION • NIGHT VISION GOGGLES • LLL-TV • FLIR • FLMRAD WIRE DETECTION • LOTAWS	SELF-CONTAINED • DOPPLER • INERTIAL • AIR-DATA NAV SYS GROUND COOPERATIVE • LORAN • OMEGA
SYSTEMS NOT CONSIDERED			
LOAD CONTROL	GUIDANCE • AUTO APPROACH • AUTO DEPARTURE • TERRAIN FOLLOWING • TERRAIN AVOIDANCE DISPLAYS • FLIGHT DIRECTOR • GROUND SPEED	ACTIVE SIGHT AMPLIFICATION • TERRAIN-CLEARANCE RADAR • TERRAIN-FOLLOWING RADAR • TERRAIN-AVOIDANCE RADAR	DISPLAYS • MOVING MAP

3.3.1.1 Dual Hook System

Current production helicopters with external cargo capability presently use some form of single-point load suspension. This sling configuration severely limits the usefulness of the helicopter because of load dynamic instability. Generally, airspeeds above 40 knots in forward flight are prohibited for loads exhibiting aerodynamic instabilities,such as the MILVAN container. In addition, poor inherent damping and load swinging (and yawing) tendencies preclude rapid precision placement of loads such as the howitzer.

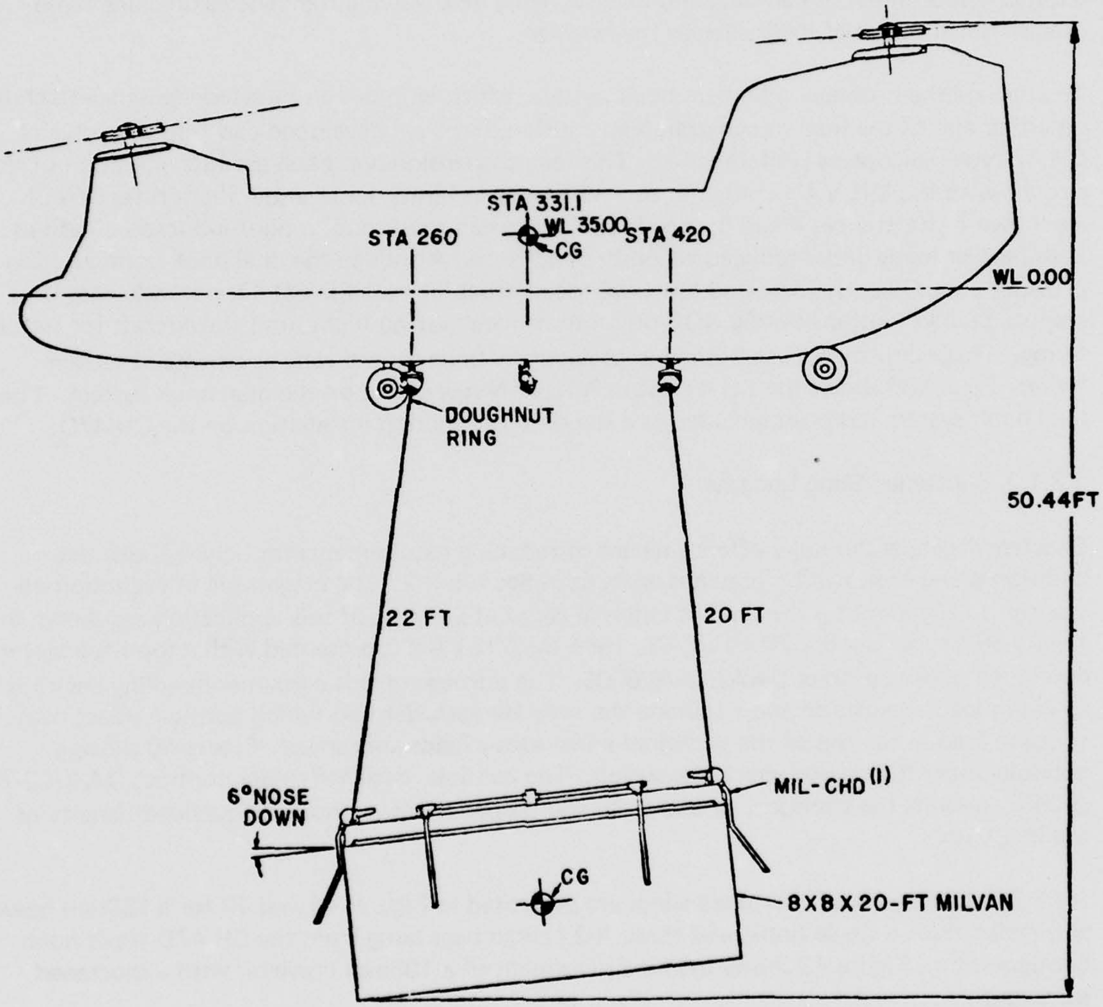
To alleviate the problem, a tandem hook system, which employs an inverted-vee sling attachment on either end of the load to constrain yaw motion, has been developed and tested on several CH-47 type helicopters (Reference 3). This load suspension approach permits operation of the aircraft with the MILVAN container to near its power limits under visual flight rules (VMC). As shown in References 4 and 5, speed restrictions can result due to pilot-induced ocillations with heavier loads under reduced visibility conditions. Although the dual hook configuration provides a significantly increased low level speed capability for the CH-47, potential large-amplitude load motions during NOE or contour maneuvering flight limit the aircraft for terrain flying. These limits were established in previous sections for the various aspects of terrain flying. Figure 38 shows the CH-47 with a MILVAN suspended on the dual hook system. The dual hook system has been included as a standard production installation on the CH-47D.

3.3.1.2 Shortened Sling Lengths

Shortened sling technology offers a means of reducing requirements for height above the collision plane as shown by previous analysis in Section 3.2. The magnitude of reduction obviously is dependent on the type of external cargo. Examples of this application are shown in Figure 39 for the 8 x 8 x 20 MILVAN. Here the MILVAN is presented with a top-lift adapter developed under contract DAAJ02-76-0005. The purpose of this container-handling device is to aid in load acquisition and eliminate the need for spreader bars which normally react compression load in the top of the container when heavy loads are carried. Figure 40 shows a gondola under the revised short suspension. The gondola, designed under contract DAAJ02-76-C-0007, permits the transport of odd-sized and shaped loads, without the payload penalty of the MILVAN.

Additional examples of shortened slings are presented in Figures 41 and 42 for a 155mm howitzer suspended from a single hook, and three A-22 cargo bags hung from the CH-47D triple hook configuration. Figure 43 shows the load placement of a 105mm howitzer with a shortened suspension.

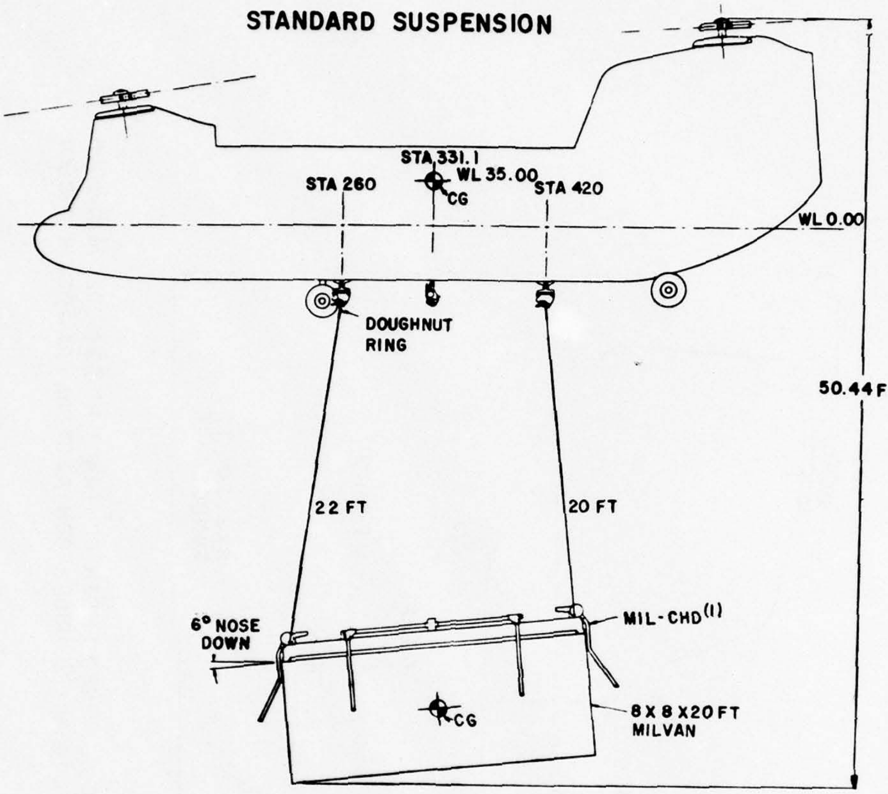
A comparison of typical changes in height requirement available through shortened suspensions (as obtained from the data shown in Section 3.2) is presented in Table 6. While improvements are noted in projected height requirements, anticipated reductions in load instability and associated peak load motions did not materialize. This result, coupled with reductions in permissible load sway angle prior to airframe collision, reduces the maneuverability and precludes application of sling shortening as the sole item used in achieving a full terrain flying capability with external loads. Load stabilization was then considered to regain the lost maneuverability.



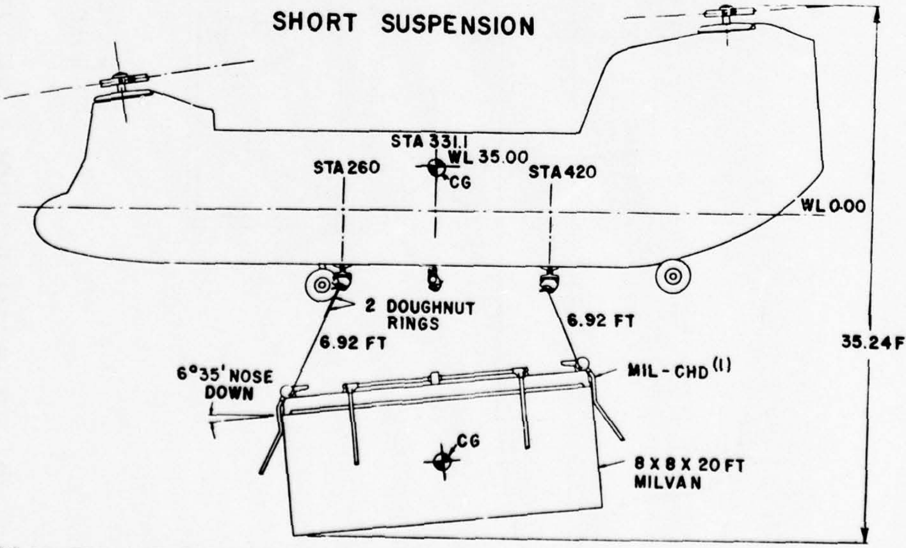
(1) MILITARY CONTAINER HANDLING DEVICE DESIGNED UNDER CONTRACT NO. DAA J02-76-C-0005

FIGURE 38. CH-47 WITH AN 8x8x 20 MILVAN, STANDARD SLING SUSPENSION AND TANDEM HOOK SYSTEM

STANDARD SUSPENSION

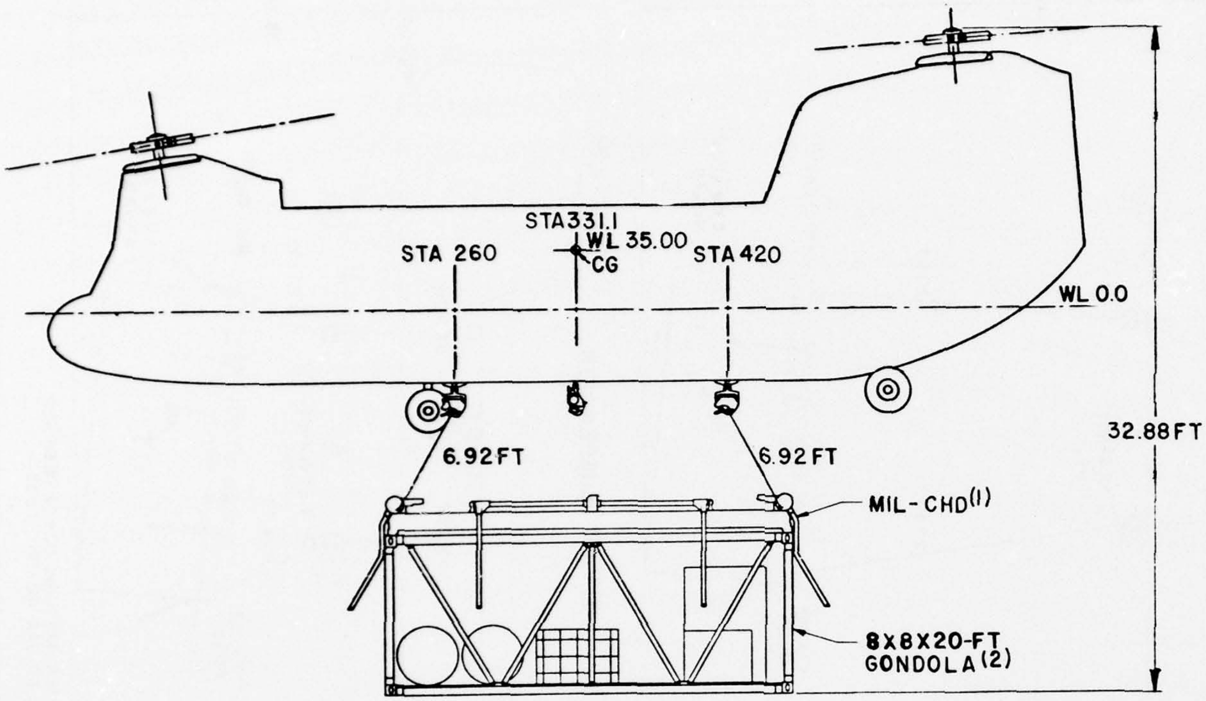


SHORT SUSPENSION



(1) MILITARY CONTAINER HANDLING DEVICE DESIGNED UNDER CONTRACT NO. DAA J02-76-C-0005

FIGURE 39. COMPARISON OF LONG (STANDARD) AND SHORT SUSPENSIONS FOR 8x8x20 MILVAN



(1) MIL-CHD DESIGNED UNDER CONTRACT NO. DAA J02-76-C-0005
(2) GONDOLA DESIGNED UNDER CONTRACT NO. DAA J02-76-C-0007

FIGURE 40. CH-47 WITH GONDOLA, SHORT SUSPENSION AND TANDEM HOOK SYSTEM

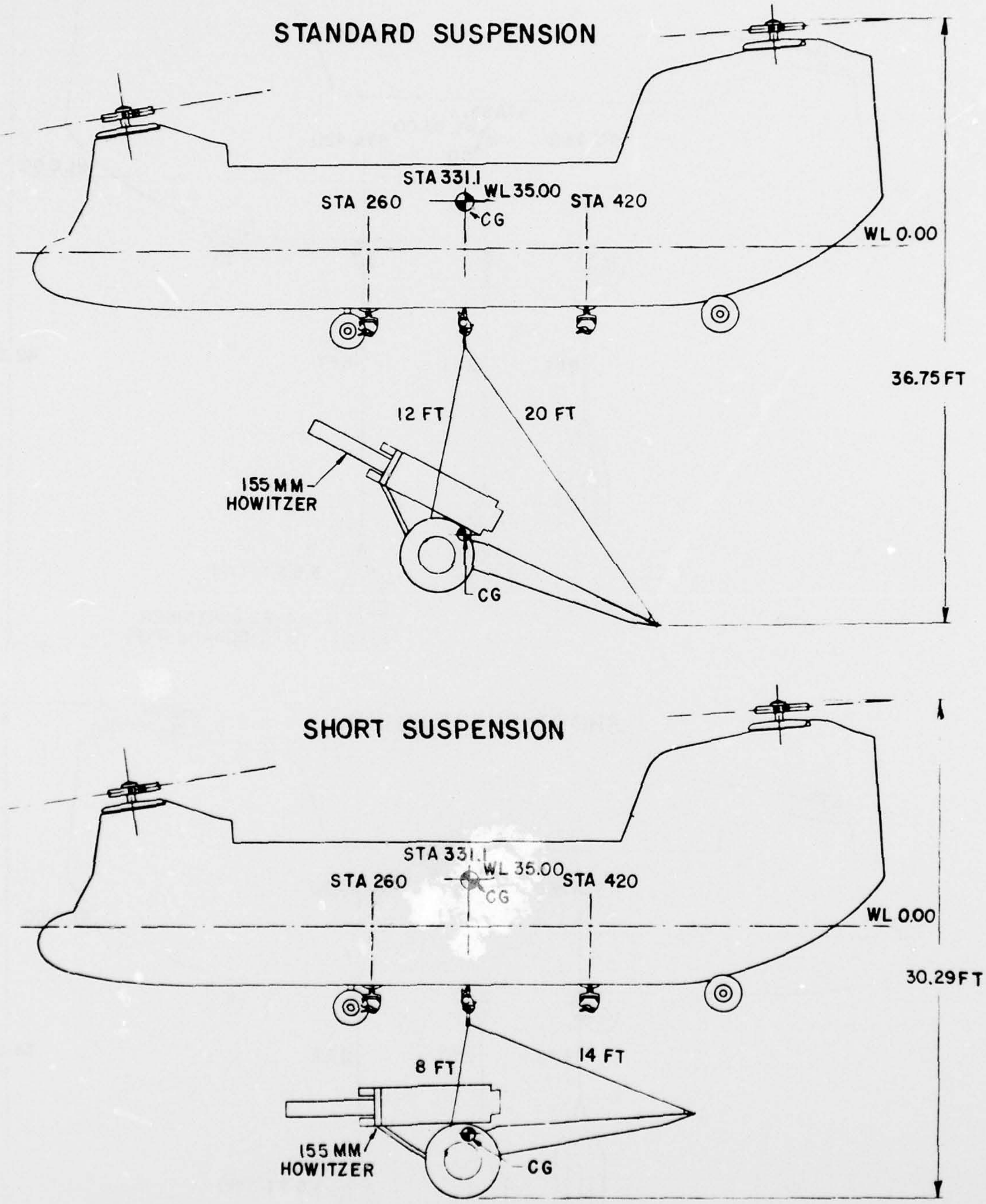
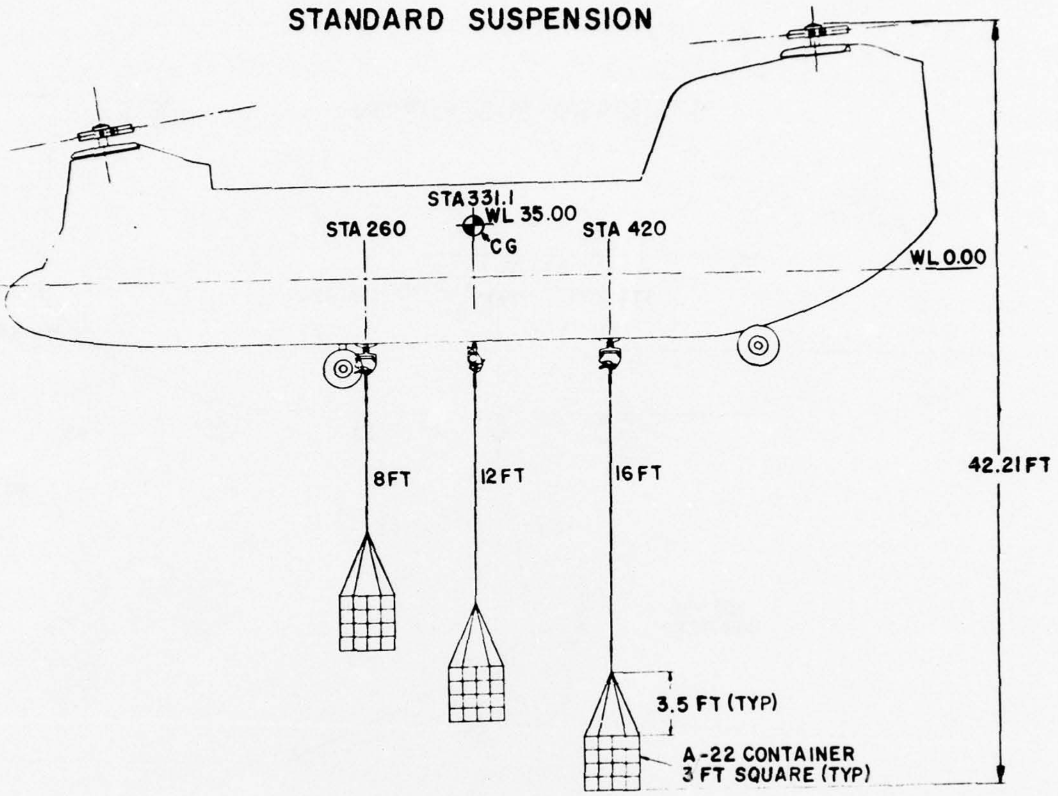


FIGURE 41. COMPARISON OF LONG (STANDARD) AND SHORT SUSPENSIONS WITH THE 155MM-M114A1 HOWITZER


STANDARD SUSPENSION

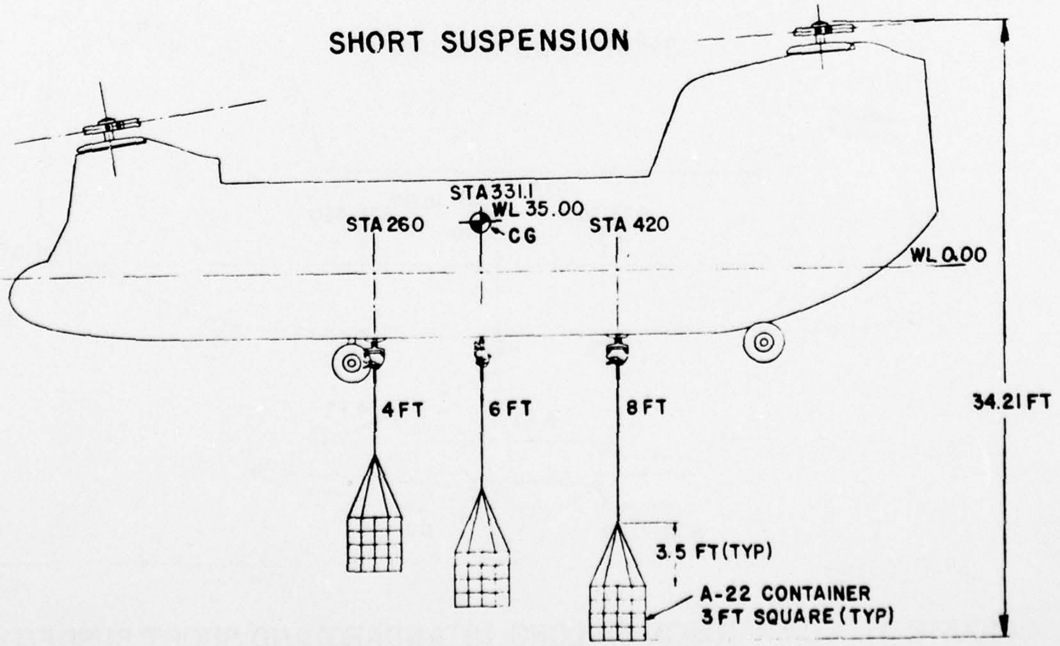

SHORT SUSPENSION

FIGURE 42. COMPARISON OF LONG (STANDARD) AND SHORT SUSPENSIONS WITH A-22 AMMUNITION BAGS AND TRIPLE HOOK SYSTEM

FIGURE 43. 105MM HOWITZER WITH SHORT SINGLE POINT SUSPENSION

TABLE 6. SUMMARY OF MINIMUM HEIGHT REQUIREMENTS

LOAD CONFIGURATION	SLING LENGTH	MANEUVER	MASKING HEIGHT REQUIREMENTS (FT)	COLLISION PLANE HEIGHT REQUIREMENT (FT)
INTERNAL	–	LONGITUDINAL DASH USING ±10° PITCH	33	13
8x8x20 MILVAN	SHORT		48	26
8x8x20 MILVAN	STD LONG		59	38
INTERNAL	–	VERTICAL AVOIDANCE	25	9
8x8x20 MILVAN	SHORT		45	26
8x8x20 MILVAN	STD LONG		55	37

3.3.1.3 Load Stabilization System

The technology for providing automatic load stabilization has been developed and extensively flight-evaluated for use on CH-47 helicopters. This concept, known as the Active Arm External Load Stabilization System (AAELSS), has been demonstrated twice in the past 5 years on two CH-47-type aircraft (see References 4 and 5). The system utilizes two hydraulically powered arms mounted below the helicopter which automatically move in response to load pendulum motion, to provide load dynamic damping ratios of approximately 30 percent of critical. The system has the potential for reducing peak load sway angles to approximately 33 percent of unaugmented levels, and at the same time eliminates any tendency toward pilot-induced oscillation in IMC or night operations. AAELSS also provides an appreciable reduction in pilot workload. This load-stabilization concept is not confined to any particular cargo configuration since it can readily carry MILVANS, gondolas, guns, or cargo bags without relying on any additional adapter-type devices. An AAELSS configuration suitable for use with the 8 x 8 x 20 MILVAN is shown in Figure 44. About 5 feet of additional height is required for the arms. A detailed definition of this system is presented in a subsequent report section.

In order to determine the potential improvements in maneuver capability with load stabilization, each segment of the terrain flying profile was reevaluated with a damping level commensurate with AAELSS. Figure 45 compares the sway-angle data for the longitudinal dash maneuver with and without load stabilization. The sway angles are significantly reduced with automatic load stabilization, restoring the lost maneuver capability as shown in Figure 46.

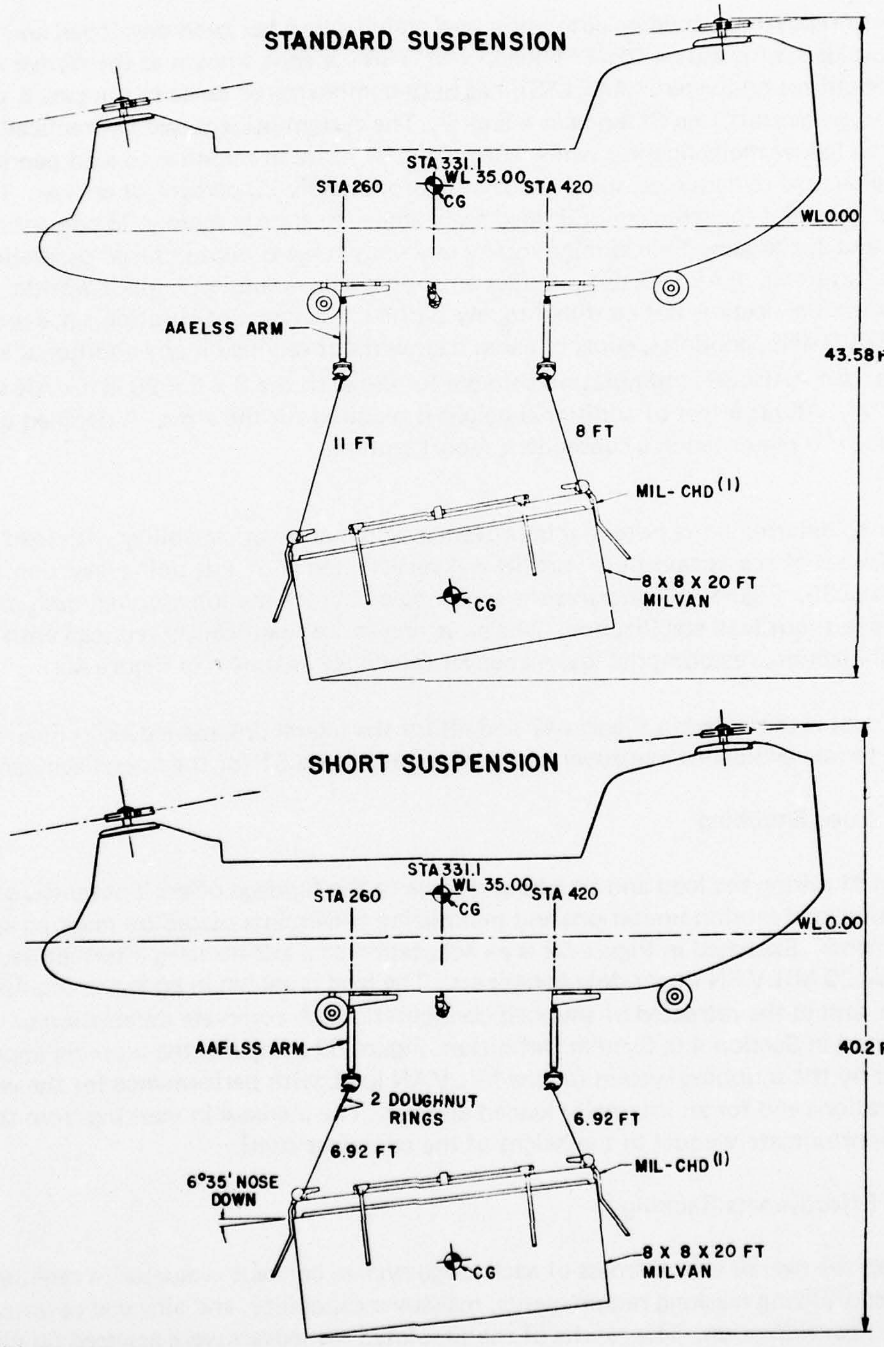
Similar data is presented in Figures 47 and 48 for the lateral jink maneuver, in Figure 49 for the vertical terrain-avoidance maneuver, and in Figures 50 and 51 for the lateral avoidance maneuver.

3.3.1.4 Load Snubbing

A means of raising the load and snubbing it close to the fuselage offers a potential solution for eliminating load motion limitations and minimizing constraints placed on masking and height requirements. Sketched in Figure 52 is an adaptation of a self-hoisting interface device for the 8 by 8 by 20 MILVAN or gondola containers. The load is shown in both the acquisition/deposit position, and in the retracted or snubbed configuration. A complete description of the system is presented in Section 4.0, System Definition. Figure 53 compares the masking improvement afforded by the snubbing system for the MILVAN load, with performance for the various sling configurations and for an internally loaded aircraft. The increase in masking from the internal load is approximately equal to the height of the container itself.

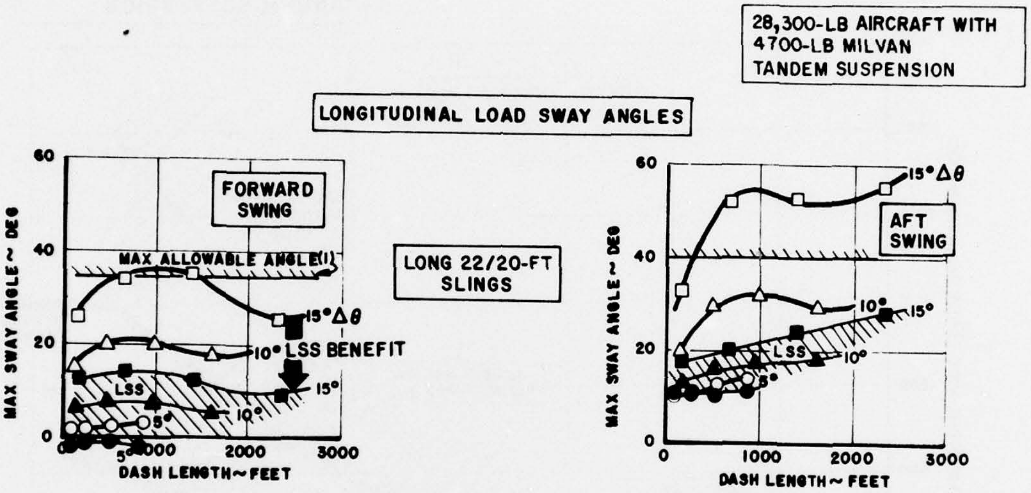
3.3.1.5 Effectiveness Ranking

To reflect the overall effectiveness of each cargo system concept evaluated, a ranking scheme was developed, utilizing masking requirements, maneuver capability, and airspeed as primary parameters of consideration. The results of the simulated maneuvers were assessed relative to the capability of the aircraft with the internal load baseline. A representative displacement or obstacle-avoidance height was selected for each of the various terrain flying modes. Longitudinal and lateral translations of 500 feet and a vertical-avoidance distance of 150 feet, were chosen for the ranking process.



(1) MILITARY CONTAINER HANDLING DEVICE
DESIGNED UNDER CONTRACT
NO. DAA J02-76-C-0005

FIGURE 44. 8x8x20 MILVAN CONFIGURED WITH AAELSS



NOTE:

1. LOAD SWING ANGLES LIMITED BY AIRCRAFT AND HOOK STRUCTURAL LIMITS; AND LOAD INTERFERANCE WITH FUSELAGE

FIGURE 45. DASH MANEUVER COMPARISON WITH AND WITHOUT LOAD STABILIZATION

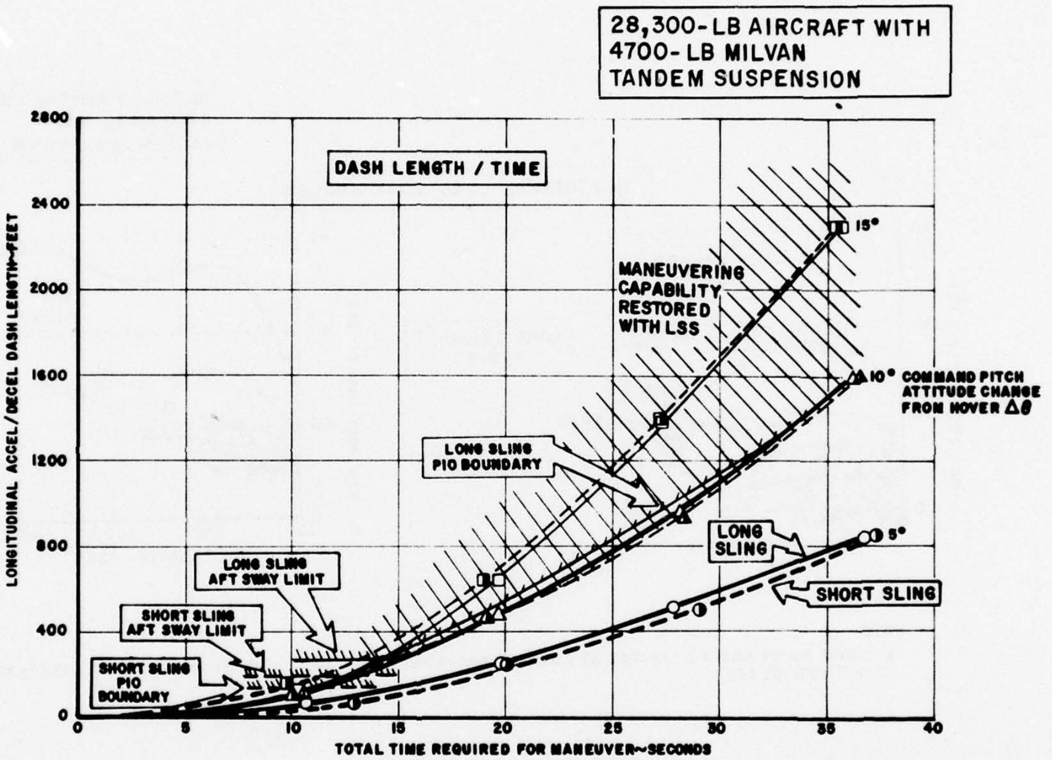


FIGURE 46. DASH MANEUVER CAPABILITY WITH LOAD STABILIZATION INCORPORATED, 8x8x20 MILVAN

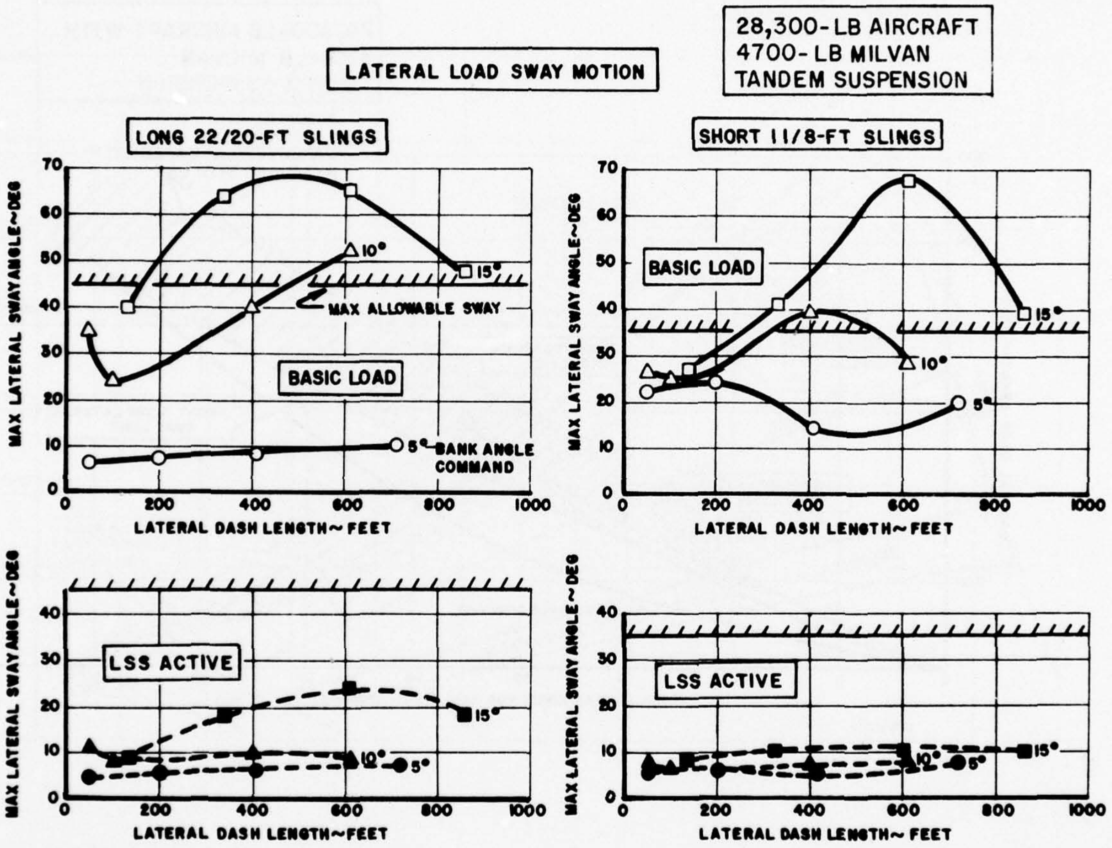


FIGURE 47. LATERAL JINK MANEUVER COMPARISON WITH AND WITHOUT LOAD STABILIZATION

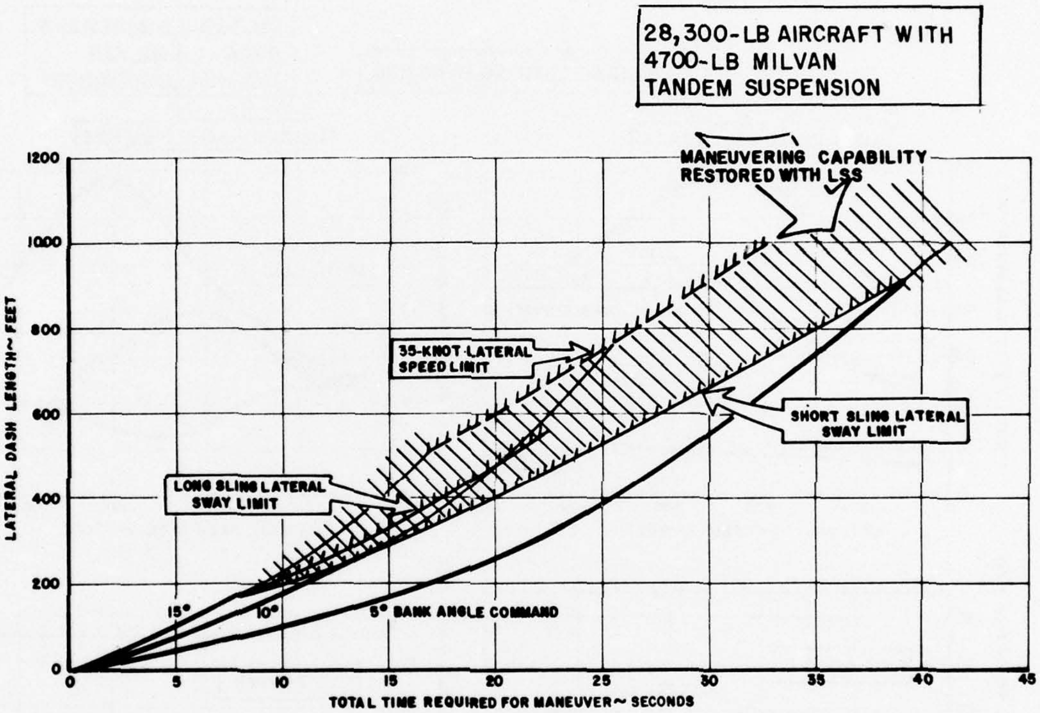


FIGURE 48. LATERAL JINK MANEUVER CAPABILITY WITH LOAD STABILIZATION, 8x8x20 MILVAN

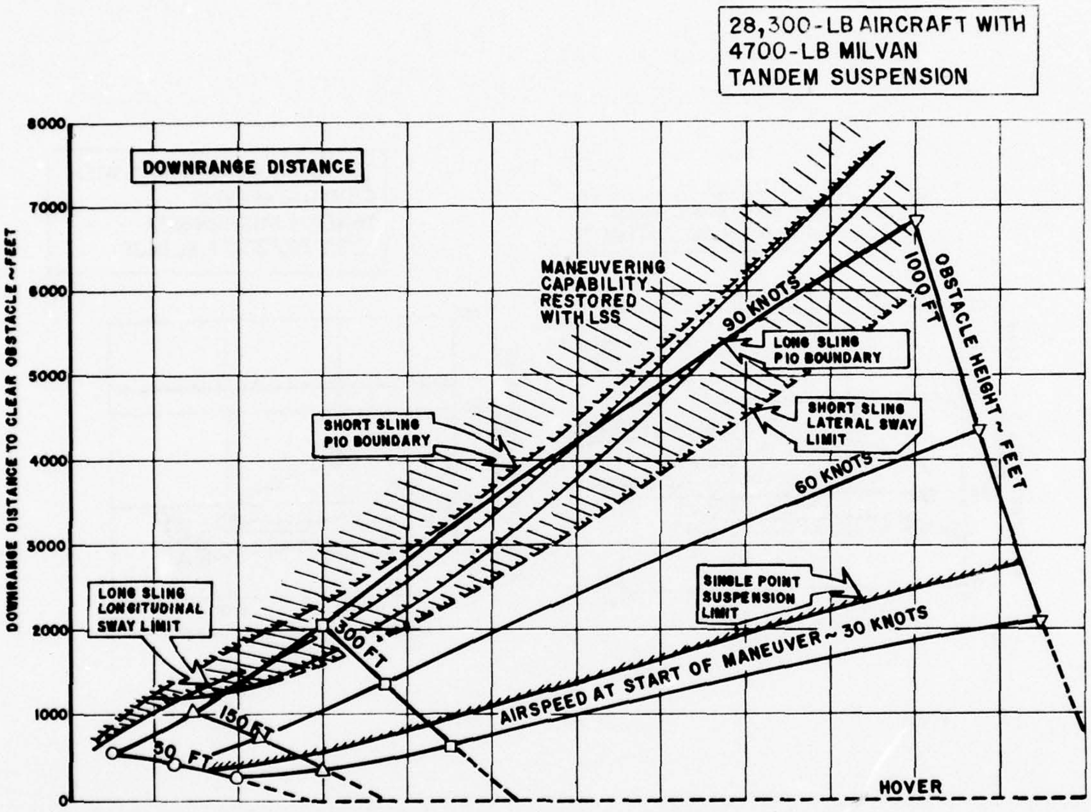
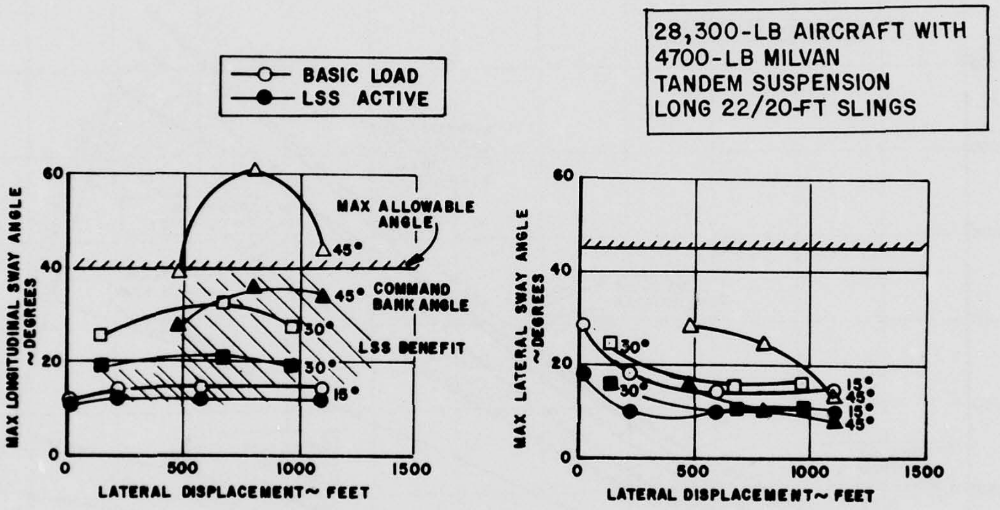


FIGURE 49. VERTICAL TERRAIN-AVOIDANCE CAPABILITY WITH LOAD STABILIZATION, 8x8x20 MILVAN



28,300-LB AIRCRAFT WITH
4700-LB MILVAN
TANDEM SUSPENSION
LONG 22/20-FT SLINGS

FIGURE 50. LATERAL TERRAIN-AVOIDANCE COMPARISON WITH AND WITHOUT LOAD STABILIZATION AT 60 KNOTS, 8x8x20 MILVAN

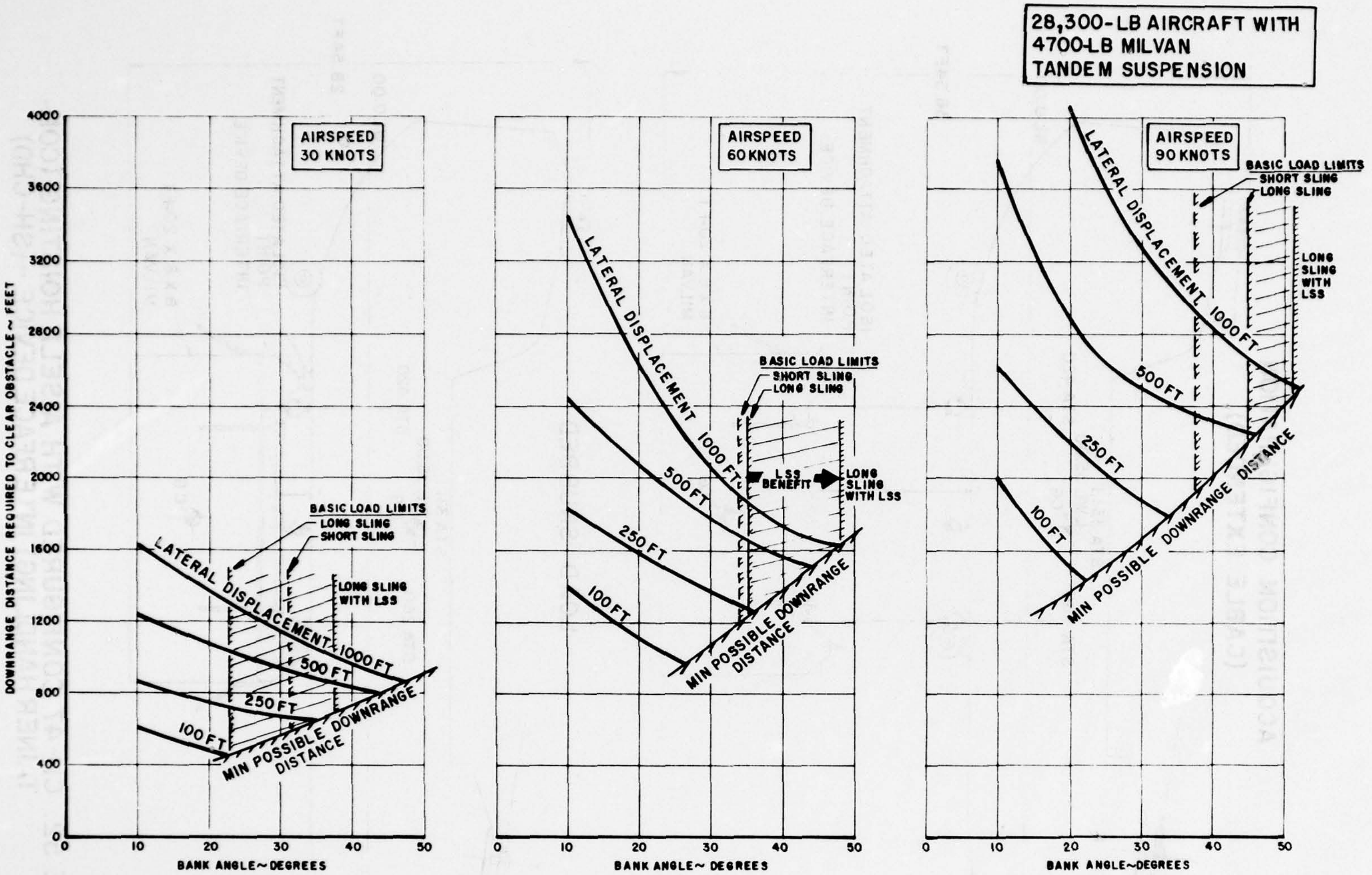


FIGURE 51. LATERAL TERRAIN-AVOIDANCE CAPABILITY WITH LOAD STABILIZATION

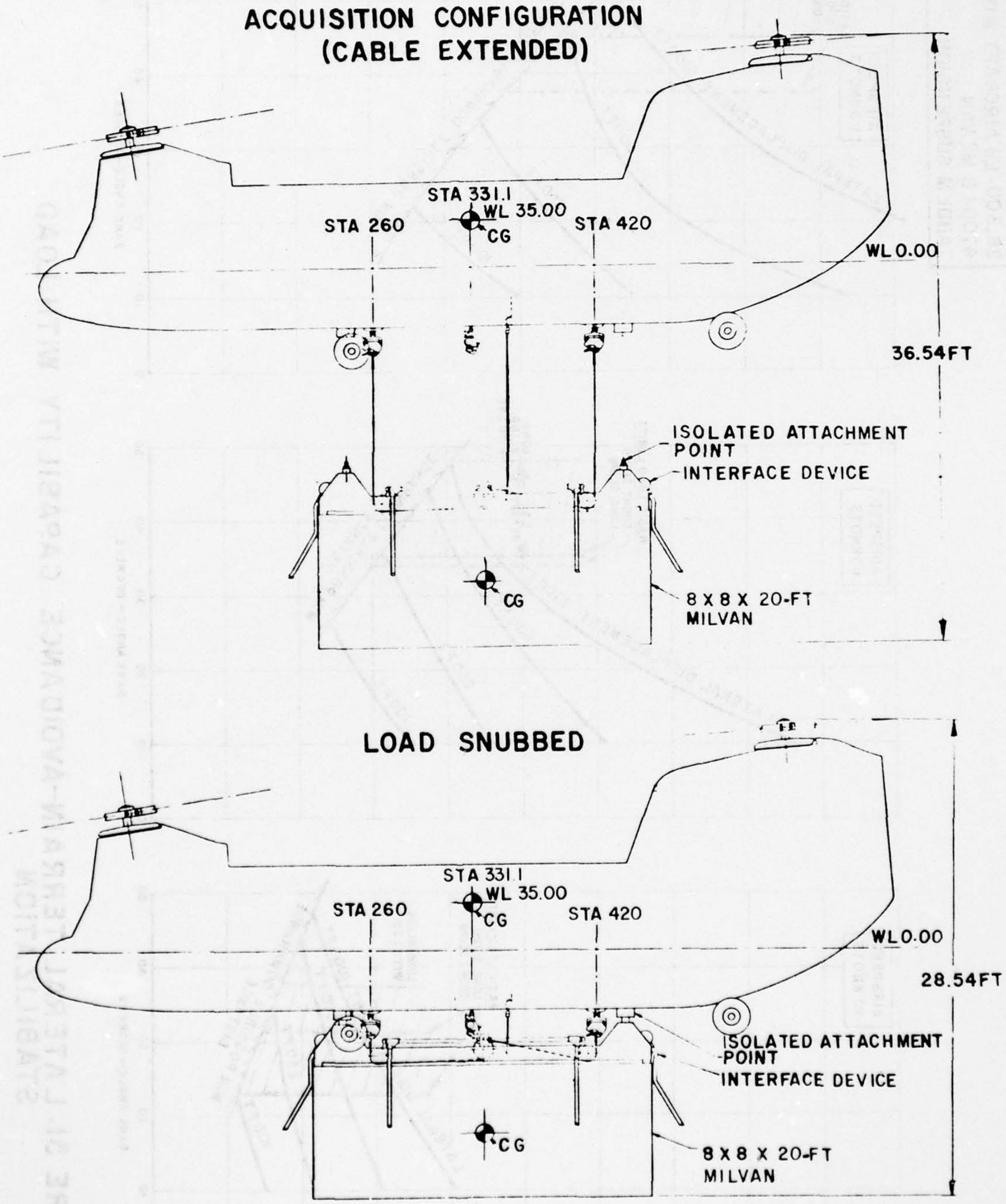


FIGURE 52. CH-47 CONFIGURED WITH A SELF HOISTING (CONTAINER HANDLING) INTERFACE DEVICE - (SH-CHD)

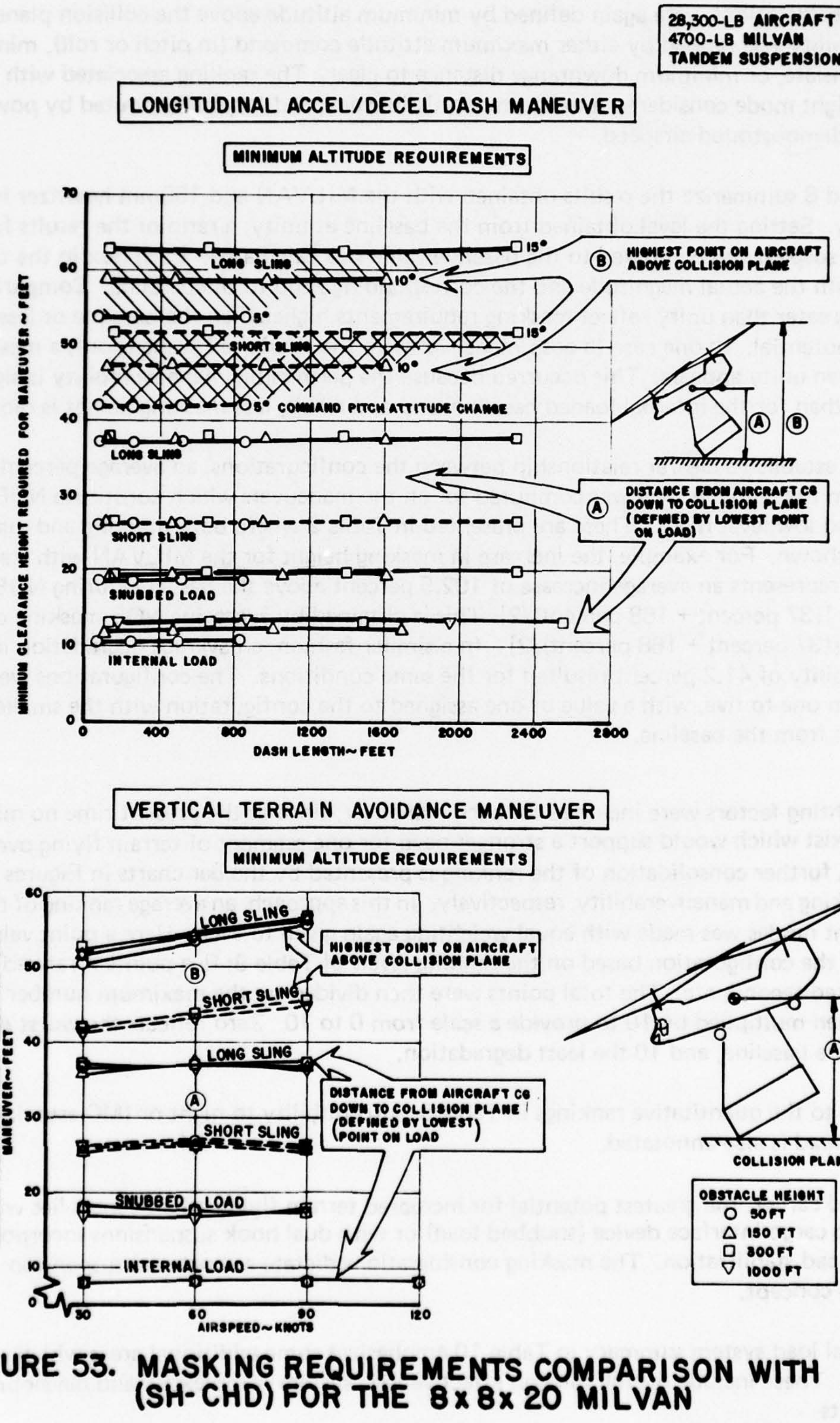


FIGURE 53. MASKING REQUIREMENTS COMPARISON WITH (SH-CHD) FOR THE 8x8x20 MILVAN

Masking considerations were again defined by minimum altitude above the collision plane. Maneuverability was ranked by either maximum attitude command (in pitch or roll), minimum time to translate, or minimum downrange distance to clear. The ranking associated with the low-level-flight mode considered maximum permissible airspeed (typically limited by power) or maximum demonstrated airspeed.

Tables 7 and 8 summarize the results obtained with the MILVAN and 155mm howitzer loads, respectively. Setting the level obtained from the baseline at unity, a ratio of the results for each of the load suspensions compared to the baseline value was calculated. Each box in the table contains both the actual magnitude and the corresponding ratio to the baseline. Comparisons which are greater than unity reflect masking requirements higher than the baseline or less maneuver potential. In one case (a dash maneuver with the shortened suspension), a masking level less than unity appears. This occurred because the permissible maneuverability is significantly less than for the internal loaded baseline, and as a result, less masking height is required.

In order to establish a clearer relationship between the configurations, an average percentage change from the baseline level was computed for all the maneuvers which constitute NOE, contour, and low level flight. These are presented in Table 9 where both masking and maneuverability are shown. For example, the increase in masking height for the MILVAN with standard suspension represents an average increase of 102.5 percent above the baseline during NOE maneuvers, [(37 percent + 168 percent)/2]. This is obtained by averaging NOE masking columns of Table 7 [(37 percent + 168 percent)/2]. In a similar fashion, an average degradation in maneuverability of 41.2 percent resulted for the same conditions. The configurations were then ranked from one to five, with a value of one assigned to the configuration with the smallest degradation from the baseline.

Equal weighting factors were included for each maneuver, since at the present time no mission scenarios exist which would support a stronger need for one segment of terrain flying over another. A further consolidation of the ranking is presented by the bar charts in Figures 54 and 55 for masking and maneuverability, respectively. In this approach, an average ranking of the three terrain flight modes was made with equal weighting again given to each. Here a point value was assigned to the configuration based on the ranking levels of Table 9; five points if ranked first, four if ranked second, etc. The total points were then divided by the maximum number possible (15) and then multiplied by 10 to provide a scale from 0 to 10. Zero reflects the worst degradation from the baseline, and 10 the least degradation.

In addition to the quantitative rankings in Table 9, susceptibility to night or IMC-associated PIO of the load is also annotated.

As indicated earlier, the greatest potential for increased terrain flying effectiveness lies with the self-hoisting cargo interface device (snubbed load) or with dual hook suspensions incorporating automatic load stabilization. The masking considerations dictate a shortened suspension length for the LSS concept.

The external load system summary in Table 10 emphasizes some additional areas which were considered. These include overall mission effectiveness, system complexity, and developmental requirements.

TABLE 7. COMPARISON OF MANEUVER REQUIREMENTS FOR THE VARIOUS SUSPENSION CONCEPTS ANALYZED WITH THE 8x8x20 MILVAN

		NAP OF THE EARTH								CONTOUR						LOW LEVEL	
		LONGITUDINAL DASH				LATERAL JINK		LATERAL AVOIDANCE		VERTICAL AVOIDANCE			LATERAL AVOIDANCE			CONSTANT ALTITUDE	
		OVERALL AIRCRAFT + LOAD HEIGHT (FT)(1)	MINIMUM CG HEIGHT (FT)	MAXIMUM PITCH ATTITUDE (DEG)	MINIMUM TIME (SEC)	MAXIMUM ROLL ATTITUDE (DEG)	MINIMUM TIME (SEC)	MAXIMUM ROLL ATTITUDE (DEG)	MINIMUM DOWN-RANGE DISTANCE (FT)	MINIMUM ALTITUDE ABOVE OBSTACLE (ROTOR FT)	MINIMUM ALTITUDE ABOVE OBSTACLE (CG FT)	MINIMUM DOWN-RANGE DISTANCE (FT)	MAXIMUM ROLL ANGLE (DEG)	MINIMUM DOWN-RANGE DISTANCE (FT)		MINIMUM CG ALTITUDE (FT)	MAXIMUM SPEED (KT)
33,000-LB GR WT	INTERNAL LOAD BASELINE	43 1.0	14 1.0	>20 1.0	14.5 1.0	>20 1.0	14.5 1.0	44.5 1.0	1500 1.0	41 1.0	24 1.0	740 1.0	44.5 1.0	1500 1.0		9.1 1.0	165 PWR 1.0
WITH MILVAN	STD SUSPENSION	59 1.37	37.7 2.68	13 1.54	17.6 1.21	10 2.0	20 1.38	35.5 1.25	1640 1.09	69 1.68	53 2.21	848 1.14	35.5 1.25	1640 1.09		31.9 3.51	110 MAX DEMO 1.5
	STD SUSPENSION WITH LSS	66 1.53	37.5 2.68	20 1.0	14.5 1.0	20 1.0	14.5 1.0	44.5 1.0	1500 1.0	69 1.69	53 2.21	848 1.14	44.5 1.0	1500 1.0		28.8 3.16	127 PWR 1.3
	SHORT SUSPENSION	42 .98	26.5 1.87	8 2.5	22.3 1.54	8 2.5	21.5 1.48	35.0 1.27	1650 1.10	59 1.44	41 1.71	829 1.12	35.0 1.27	1650 1.10		23.9 2.63	110 MAX DEMO 1.5
	SHORT SUSPENSION WITH LSS	55 1.28	26.5 1.89	15 1.33	17 1.17	20 1.0	14.5 1.0	44.5 1.0	1500 1.0	59 1.44	41 1.71	829 1.12	44.5 1.0	1500 1.0		21.6 2.37	130 PWR 1.27
	SNUBBED LOAD	50 1.16	20 1.43	20 1.0	14.5 1.0	20 1.0	14.5 1.0	44.5 1.0	1500 1.0	49 1.20	32 1.33	790 1.07	44.5 1.0	1500 1.0		17.2 1.89	130 PWR 1.27
		MASKING		MANEUVERABILITY						MASKING		MANEUVERABILITY					
		500-FT LONGITUDINAL TRANSLATION				500-FT LATERAL TRANSLATION		500-FT DISPLACEMENT AT 60 KT		150-FT OBSTACLE AVOIDANCE AT 60 KT			500-FT DISPLACEMENT AT 60 KT			VMAX = TORQUE LIMIT OR MAX DEMO IN TEST	

(1) HEIGHT USED IS CONSISTENT WITH MAXIMUM PITCH ATTITUDE

ACTUAL MAGNITUDE → XXX

X.XX ← COMPARISON TO BASELINE

TABLE 8. COMPARISON OF MANEUVER REQUIREMENTS FOR THE VARIOUS SUSPENSION CONCEPTS ANALYZED WITH THE 155MM HOWITZER

			NAP OF THE EARTH				CONTOUR			LOW LEVEL	
			LONGITUDINAL DASH				VERTICAL AVOIDANCE			CONSTANT ALTITUDE	
			OVERALL AIRCRAFT + LOAD HEIGHT (FT)	MINIMUM CG HEIGHT (FT)	MAXIMUM PITCH ATTITUDE (DEG)	MINIMUM TIME (SEC)	MINIMUM ALTITUDE ABOVE OBSTACLE		MINIMUM DOWN-RANGE DISTANCE (FT)	MINIMUM CG ALTITUDE (FT)	MAXIMUM SPEED (KT)
							(ROTOR FT)	(CG FT)			
45,000-LB GR WT	INTERNAL LOAD BASELINE		40.5 1.0	13.3 1.0	15.0 1.0	16.0 1.0	35.7 1.0	19.5 1.0	1260 1.0	9.0 1.0	146 PWR 1.0
	155MM HOWITZER	LONG SUSPENSION	52.6 1.30	27.5 2.07	15.0 1.0	16.0 1.0	50.2 1.41	33.8 1.73	1271 1.01	21.4 2.38	129 PWR 1.13
		LONG SUSPENSION WITH LSS	52.6 1.30	27.1 2.04	15.0 1.0	16.0 1.0	50.2 1.14	33.8 1.73	1260 1.0	21.5 2.39	126 PWR 1.16
		SHORT SUSPENSION	48.0 1.18	18.3 1.38	8.0 1.88	22.8 1.42	43.8 1.23	27.3 1.40	1345 1.07	17.6 1.96	130 PWR 1.12
		SHORT SUSPENSION WITH LSS	48.0 1.18	20.2 1.52	15.0 1.0	16.0 1.0	44.0 1.22	27.0 1.38	1346 1.07	17.5 1.94	127 PWR 1.15
			MASKING		MANEUVERABILITY		MASKING		MANEUVERABILITY		
			500-FT LONGITUDINAL TRANSLATION				150-FT OBSTACLE AVOIDANCE AT 60 KT			V_{MAX} = TORQUE LIMIT OR MAX DEMO IN TEST	

ACTUAL MAGNITUDE → XXX

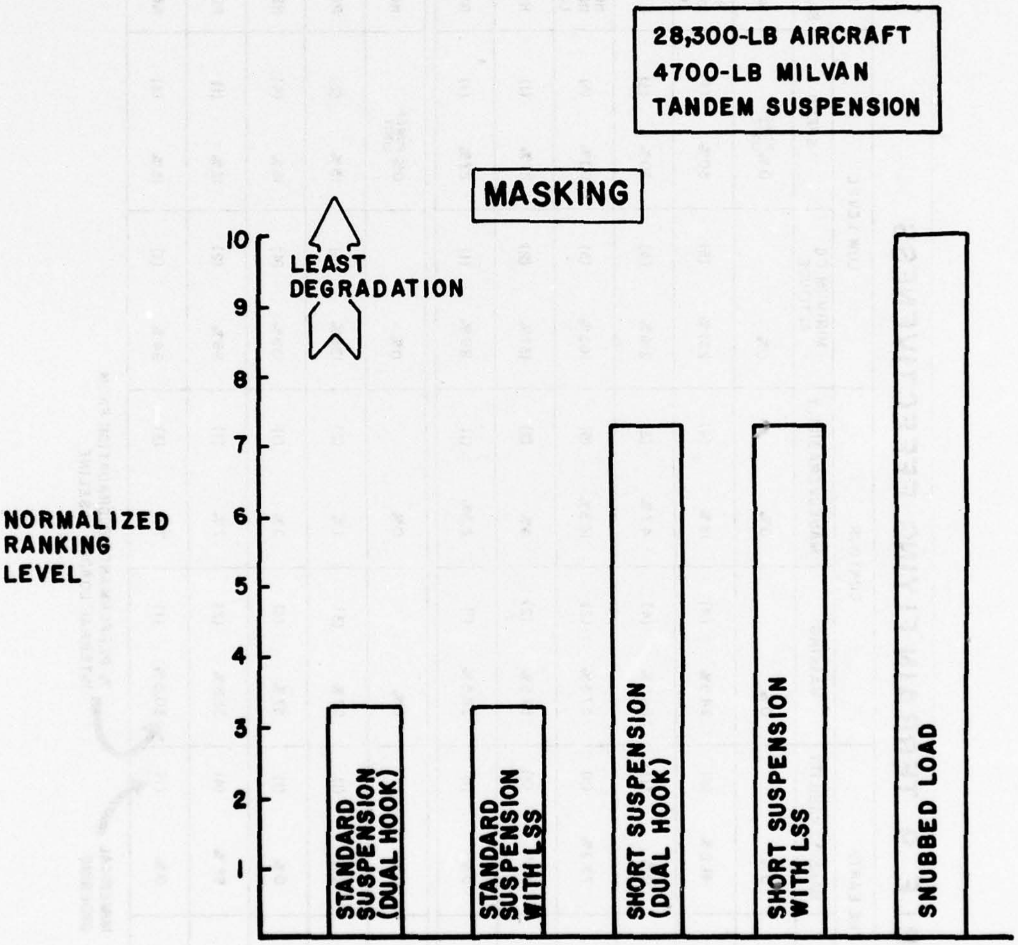
COMPARISON TO BASELINE → X.XX

TABLE 9. TERRAIN FLYING EFFECTIVENESS

			NAP OF THE EARTH		CONTOUR		LOW LEVEL		NIGHT/IMC PIO SUSCEPTABILITY
			MASKING	MANEUVERABILITY	MASKING	MANEUVERABILITY	MINIMUM CG ALTITUDE	SPEED	
33,000-LB GR WT		INTERNAL LOAD BASELINE	0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
	MILVAN	STD SUSPENSION	102.5% (4)	41.2% (4)	94.5% (4)	16% (4)	251% (5)	50% (4)	HIGH WITH INCREASED LOAD WEIGHTS
		STD SUSPENSION WITH LSS	110.5% (5)	0% (1)	94.5% (4)	4.7% (3)	216% (4)	30% (3)	NEGLIGIBLE
		SHORT SUSPENSION	43.5% (2)	73.2% (5)	57.5% (2)	16.3% (5)	163% (3)	50% (4)	HIGH WITH INCREASED LOAD WEIGHTS
		SHORT SUSPENSION WITH LSS	58.5% (3)	8.3% (3)	57.5% (2)	4% (2)	137% (2)	27% (1)	NEGLIGIBLE
		SNUBBED LOAD	29.6% (1)	0% (1)	26.5% (1)	2.3% (1)	89% (1)	27% (1)	NONE
45,000-LB GR WT		INTERNAL LOAD BASELINE	0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
	155MM HOWITZER	STD SUSPENSION	68.5% (4)	0% (1)	57% (3)	1% (2)	138% (3)	13% (2)	POSSIBLE
		STD SUSPENSION WITH LSS	67% (3)	0% (1)	57% (3)	0% (1)	139% (4)	16% (4)	NEGLIGIBLE
		SHORT SUSPENSION	28% (1)	66% (4)	31.5% (2)	7% (3)	96% (2)	12% (1)	POSSIBLE
		SHORT SUSPENSION WITH LSS	35% (2)	0% (1)	30.5% (1)	7% (3)	94% (1)	15% (3)	NEGLIGIBLE

NUMERICAL ORDERING

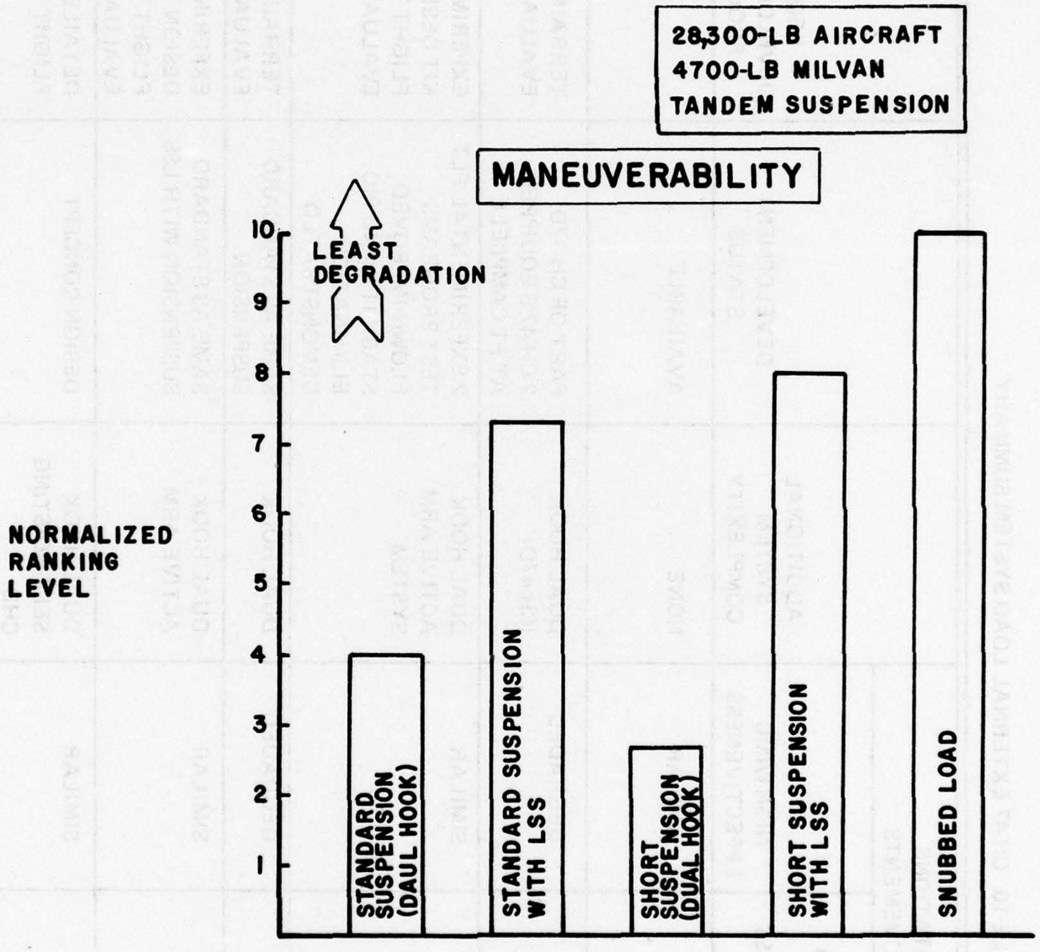
% PERFORMANCE DEGRADATION FROM INTERNAL LOADED BASELINE



NOTES

- HIGHEST LEVEL REFLECTS LEAST DEGRADATION FROM THE INTERNALLY LOADED CONFIGURATION
- NORMALIZED CONSIDERING ALL TERRAIN FLYING MODES WITH EQUAL WEIGHING FACTORS

FIGURE 54. COMPARISON OF TERRAIN FLYING MASKING REQUIREMENTS, 8x8x20 MILVAN



NOTES

- HIGHEST LEVEL REFLECTS THE LEAST GRADATION FROM THE INTERNALLY LOADED CONFIGURATION
- NORMALIZED CONSIDERING ALL TERRAIN FLYING MODES WITH EQUAL WEIGHING FACTORS

FIGURE 55. COMPARISON OF TERRAIN FLYING MANEUVER CAPABILITY, 8x8x20 MILVAN

TABLE 10. CH-47 EXTERNAL LOAD SYSTEM SUMMARY

		LIMITATIONS IMPROVEMENTS				
		DAYTIME REDUCTION IN EFFECTIVENESS (%)	NIGHT/IMC EFFECTIVENESS	ADDITIONAL SYSTEM COMPLEXITY	DEVELOPMENT STATUS	REQUIRED DEVELOPMENTAL PROGRAM
MILVAN	33,000-POUND INTERNAL LOAD BASELINE	0	SIMILAR	NONE	AVAILABLE	
	STANDARD SUSPENSION	92.5	DEGRADED	DUAL HOOK (CH-47D)	PART OF CH-47D 2 CH-47'S EQUIPPED AT FT CAMPBELL	TERRAIN FLIGHT EVALUATION
	STANDARD SUSPENSION WITH LSS	76.0	SIMILAR	DUAL HOOK ACTIVE ARM SYSTEM	2 EXPERIMENTAL FLT TEST PROGRAMS FLOWN-IMPROVED STABILITY AND PIO ELIMINATION DEMONSTRATED	EXPERIMENTAL KIT DESIGN & FAB FLIGHT TEST EVALUATION
	SHORT SUSPENSION	67.2	DEGRADED	DUAL HOOK	SAME AS STANDARD SUSPENSION	TERRAIN FLIGHT EVALUATION
	SHORT SUSPENSION WITH LSS	48.7	SIMILAR	DUAL HOOK ACTIVE ARM	SAME AS STANDARD SUSPENSION WITH LSS	EXPERIMENTAL KIT DESIGN & FAB FLIGHT TEST EVALUATION
	SNUBBED LOAD	29.1	SIMILAR	DUAL HOOK SELF-HOISTING CHD	DESIGN CONCEPT	DETAILED DESIGN FLIGHT EVALUATION

TABLE 10 – CONTINUED

		LIMITATIONS IMPROVEMENTS				
		DAYTIME REDUCTION IN EFFECTIVENESS (%)	NIGHT/IMC EFFECTIVENESS	ADDITIONAL SYSTEM COMPLEXITY	DEVELOPMENT STATUS	REQUIRED DEVELOPMENTAL PROGRAM
155MM HOWITZER	45,000-POUND INTERNAL LOAD BASELINE	0	SIMILAR			
	STANDARD SUSPENSION	46.2	DEGRADED	SINGLE OR DUAL (CH-47D)		
	STANDARD SUSPENSION WITH LSS	46.5	SIMILAR	DUAL HOOK ACTIVE ARM	SAME AS ABOVE	
	SHORT SUSPENSION	40.1	DEGRADED	SINGLE OR DUAL		
	SHORT SUSPENSION WITH LSS	30.2	SIMILAR	DUAL HOOK ACTIVE ARM		

The overall mission effectiveness for daytime operations was determined by averaging the masking and maneuverability ratings for all terrain flight modes from Table 9. Here again, the snubbed load and short suspension with LSS offer the highest potential for improvement. At the same time, each of these systems would provide similar night and IMC capability with respect to the internally loaded baseline aircraft, by elimination of any PIO tendency.

System complexity and developmental requirements contain common elements among the various configurations. These include the utilization of the dual hook concept and the need for a terrain flight evaluation. Qualification and development of the dual hook are presently planned for the CH-47D prototype test program. Active arm load stabilization has been test flown previously, demonstrating improved stability and PIO elimination, but has not been evaluated for terrain flight maneuvering potential as yet. By comparison, the self-hoisting cargo handling device is presently only a design concept, and would require further developmental refinement and definition before reaching a state for flight qualification.

As evidenced by the preceding rankings, incorporation of either the self-hoisting container handling device or active arm load stabilization system offers the greatest potential for minimizing the limitations caused by external load operations during terrain flying. For this mode of flight, the superior concept is probably the load snubbing device, because of its capability to provide optimum masking with an external load. These two candidate systems were compared against each other to assess the advantages and disadvantages of each. Table 11 summarizes the key elements of this comparison.

Basically the active arm load stabilization system offers a substantially lower risk because of its previously successful developmental and flight evaluation programs. It can also accommodate any external load which the aircraft is capable of lifting, and incurs a weight penalty approximately 1,400 pounds less than the snubbing device as shown in Section 4. On the other hand, in addition to not providing optimum masking, it does require hydraulic power connection to the aircraft. CH-47 airframe modifications are required for both systems.

The major disadvantages associated with the self-hoisting container handling device, in addition to its unknown risks because of concept infancy, are the requirement for precision control during load acquisition necessitating higher pilot workload and increasing mission time, as well as its configuration not being suitable for all loads, i.e., guns, cargo, fuel bags, etc. This disadvantage is, however, minimized with the gondola device. Assessing the obvious benefits offered by the snubbing device against the advanced developmental maturity and payload flexibility of AAELSS, it is recommended that both systems be further developed as a means of fulfilling the objective of maximizing Chinook terrain flying capability with external loads. Both systems were carried over and further refined in the Phase II System Definition study presented in Section 4.

3.3.2 Vision Enhancement

3.3.2.1 Visionics Systems

At present, the capability for performing limited nighttime terrain flying missions with external loads exists to some degree, but varies considerably from load to load. Such factors as the availability of moonlight or starlight influence the success of these missions, along with pilot

TABLE 11. COMPARISON OF LOAD STABILIZATION SYSTEM AND SELF-HOISTING CONTAINER HANDLING DEVICE

CANDIDATE SYSTEM	ADVANTAGES	DISADVANTAGES
ACTIVE ARM LOAD STABILIZATION SYSTEM	LOW RISK – PROVEN CONCEPT ADAPTABLE FOR ALL LOAD SHAPES	MASKING NOT OPTIMUM AIRCRAFT MODS REQUIRED (COULD BE PART OF -47D TANDEM HOOK MOD) WEIGHT ELECTRICAL AND HYDRAULIC INTERFACE WITH AIRCRAFT
SELF-HOISTING CONTAINER HANDLING DEVICE	MASKING OPTIMUM FOR EXTERNAL LOAD ELECTRICAL INTERFACE WITH AIRCRAFT ONLY	AIRCRAFT MODS REQUIRED NOT APPLICABLE TO ALL LOADS REQUIRES MORE CONTROL PRECISION FOR HOOKUP SAFETY CONSIDERATIONS FOLLOWING LOAD SNAG – DIFFICULT TO JETTISON RISKS UNKNOWN – VIBRATION – AERODYNAMIC INTERFERENCE WEIGHT PENALTY GREATER

proficiency and/or familiarity with the terrain over which the flight is to be conducted. Most night VFR terrain flights must be flown at very low speed in order to provide sufficient time for terrain avoidance after obstacles are identified.

When nighttime ambient lighting conditions are poor due to overcast sky or lack of moonlight, etc., terrain flight becomes progressively more difficult until finally complete darkness or IMC conditions preclude terrain flying altogether. In view of the long-standing U.S. Army desire for an around-the-clock/all-weather aviation capability, the Army has been sponsoring development of visionics systems over the past several years which aid the pilot in seeing outside the aircraft at night or in inclement weather.

To explore what might be possible as regards future CH-47 terrain flight operations in night and IMC conditions, a survey of potential visionics systems and their capabilities was made. This survey included a visit to the U.S. Army Night Vision Laboratory (NVL) at Fort Belvoir, Virginia, to confirm estimated visionics system performance (described later), and to determine what new systems were currently under development. Figure 56 summarizes the relative VMC and IMC performance of the systems surveyed and gives an indication of current developmental status and cost.

Three of the systems described in Figure 56 were selected for application in the terrain flying study. These included:

- AN/PVS-5 Night Vision Goggles (NVG) with 40-degree field of view
- 360-line forward-looking infrared (FLIR) with 30-by 40-degree field of view using a helmet-mounted display
- Laser obstacle terrain avoidance and warning system (LOTAWS) for wire avoidance.

The first two of these systems permit the pilot to see well enough to avoid larger obstacles when performing terrain flight at night, but their resolution is generally inadequate for detecting very small objects in the path of the aircraft such as wires. To accomplish this task, the Army has been developing the LOTAWS concept (Reference 16), which has the potential for identifying 1/8-inch standard Army telephone wire at ranges up to 1,500 feet.

Experimental Night-Vision Goggles and FLIR systems have been flown on a number of aircraft in terrain flight experiments of the type described in References 6 and 7. Improved versions of both systems will be standard equipment on the YAH-64 Armed Attack Helicopter currently being developed by the Army. Two types of FLIR's are being installed on this aircraft; a pilot's night-vision system (PNVS) for pilot navigation and terrain avoidance, and a target-acquisition/designation system (TADS) for the copilot.

Uprated third-generation night-vision goggle systems, employing an improved image intensifier

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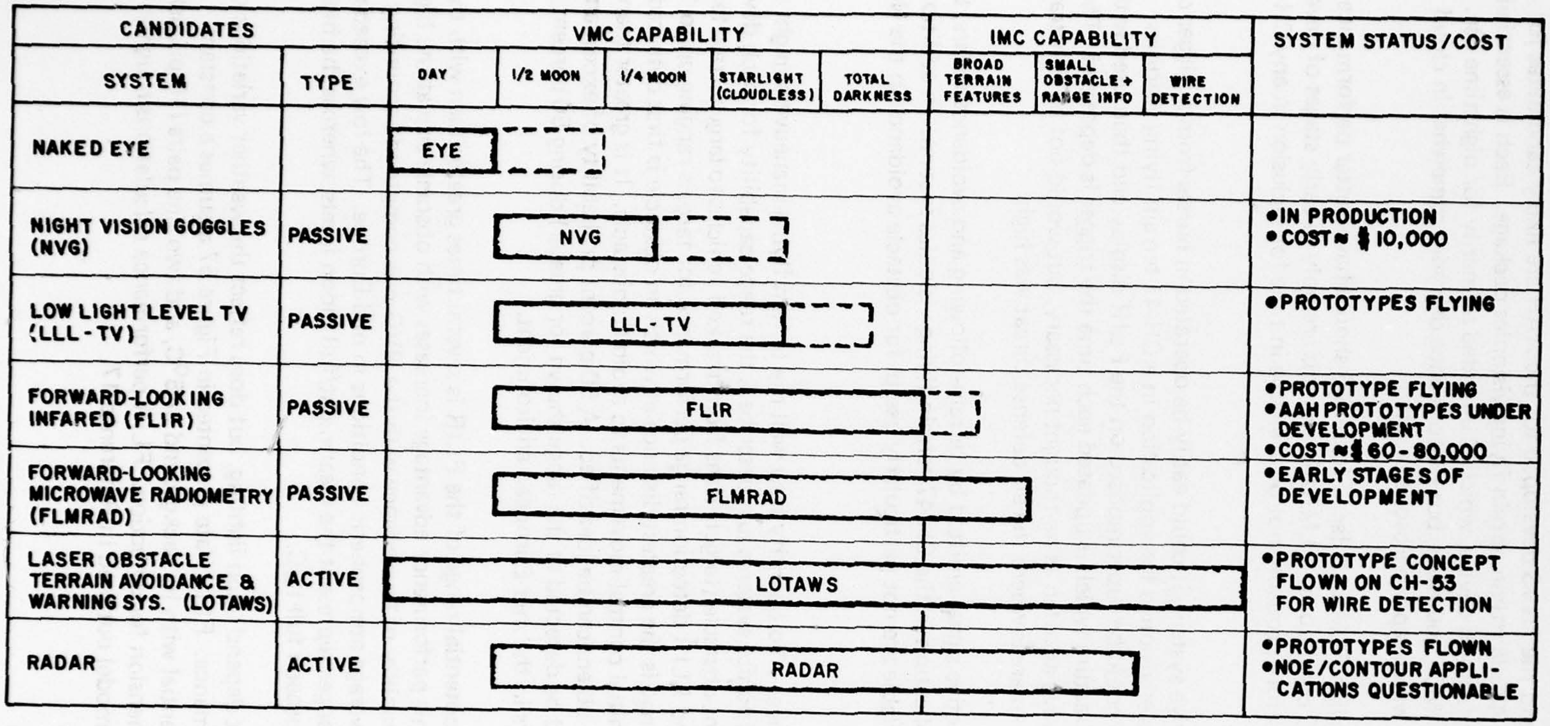
16. Del Boca, R. L., et al, THE DEVELOPMENT AND TESTING OF A LASER OBSTACLE TERRAIN AVOIDANCE WARNING SYSTEM (LOTAWS), United Technologies Research Center; Technical Paper Pursuant to Contract No. DAA-B07-72-C-0415, U. S. Army Electronics Command, Fort Monmouth, New Jersey, June 1976.



CANDIDATES		VMC CAPABILITY					IMC CAPABILITY			SYSTEM STATUS/COST
SYSTEM	TYPE	DAY	1/2 MOON	1/4 MOON	STARLIGHT (CLOUDLESS)	TOTAL DARKNESS	BROAD TERRAIN FEATURES	SMALL OBSTACLE + RANGE INFO	WIRE DETECTION	
NAKED EYE		EYE								
NIGHT VISION GOGGLES (NVG)	PASSIVE		NVG							•IN PRODUCTION •COST ≈ $ 10,000
LOW LIGHT LEVEL TV (LLL-TV)	PASSIVE			LLL-TV						•PROTOTYPES FLYING
FORWARD-LOOKING INFARED (FLIR)	PASSIVE				FLIR					•PROTOTYPE FLYING •AAH PROTOTYPES UNDER DEVELOPMENT •COST ≈ $ 60-80,000
FORWARD-LOOKING MICROWAVE RADIOMETRY (FLMRAD)	PASSIVE				FLMRAD					•EARLY STAGES OF DEVELOPMENT
LASER OBSTACLE TERRAIN AVOIDANCE & WARNING SYS. (LOTAWS)	ACTIVE				LOTAWS					•PROTOTYPE CONCEPT FLOWN ON CH-53 FOR WIRE DETECTION
RADAR	ACTIVE				RADAR					•PROTOTYPES FLOWN •NOE/CONTOUR APPLICATIONS QUESTIONABLE

FIGURE 56. POTENTIAL VISIBILITY IMPROVEMENT CANDIDATES

tube to increase either resolution or field of view, are being developed specifically for aviation applications. These goggles and the PNVS developed for the AAH are likely candidates for future application in any CH-47 nighttime terrain flying visionics package. Each is essentially a passive light or infrared amplification device, which is intended primarily for nighttime use. FLIR has some capability in IMC conditions, but performance degrades somewhat in cloud (as influenced by such things as water-vapor aerosol size, etc.)

Microwave radiation systems like FLMRAD (see Figure 56) should have better performance than current FLIR systems in IMC conditions. FLMRAD systems are only in early stages of development, however, and will therefore probably not be available in time for inclusion in any CH-47 visionics package.

Although LOTAWS is an active system, it could easily be operated in bursts from a trigger on the aircraft control stick. As envisioned for application in a CH-47 terrain flying visionics display, the LOTAWS image could be superimposed on the FLIR display and then used with some type of image-holding feature which is updated each time the trigger is depressed. The pilot could look ahead for wires as often as he thought necessary, but would not be constrained to continuous LOTAWS use in areas where the air defense threat was high.

Because of the continuous active signal emitted by terrain-following and avoidance radars, they were not considered for application in the CH-47 terrain flying visionics system. In addition, radar displays currently available are not particularly useful for obstacle avoidance in the NOE mode.

3.3.2.1.1 System Performance – To quantify how well the terrain flying maneuvers might be performed while using the visionics systems just described, the range capability for each device was estimated for several different obstacle (target) sizes from tracked vehicles to large terrain features. Figure 57 compares NVG and FLIR detection range performance for targets ranging up to 100 meters square. Detection range is the greatest distance at which an obstacle is first detected and where a pilot might put in initial control movements to avoid an obstacle. It is greater than the recognition range where the object can be identified. A 50-percent probability of exceedance means that the object would be detected at the range shown (or greater) during 50 percent of the available nighttime hours in the mid-European environment.

As shown in the figure, the potential range of the FLIR is several times greater than with the Night-Vision Goggles, and this performance advantage increases with obstacle size at the higher probability levels. The probability of exceedance with the NVG was computed accounting for the nighttime lighting and average atmospheric conditions in mid-Europe. The low exceedance probabilities or the higher ranges represent the clear night/full moon levels, whereas the higher exceedance probabilities approach full IMC.

FLIR performance does not depend upon lighting, but does reflect the weather variations used to develop the NVG performance. FLIR data presented in Figure 57 assumes a constant obstacle temperature differential with its background of 5°C, and two line pairs (16 pixels) across the target critical dimension for detection. FLIR performance calculations roughly followed the mathematical model outlined in Reference 17.

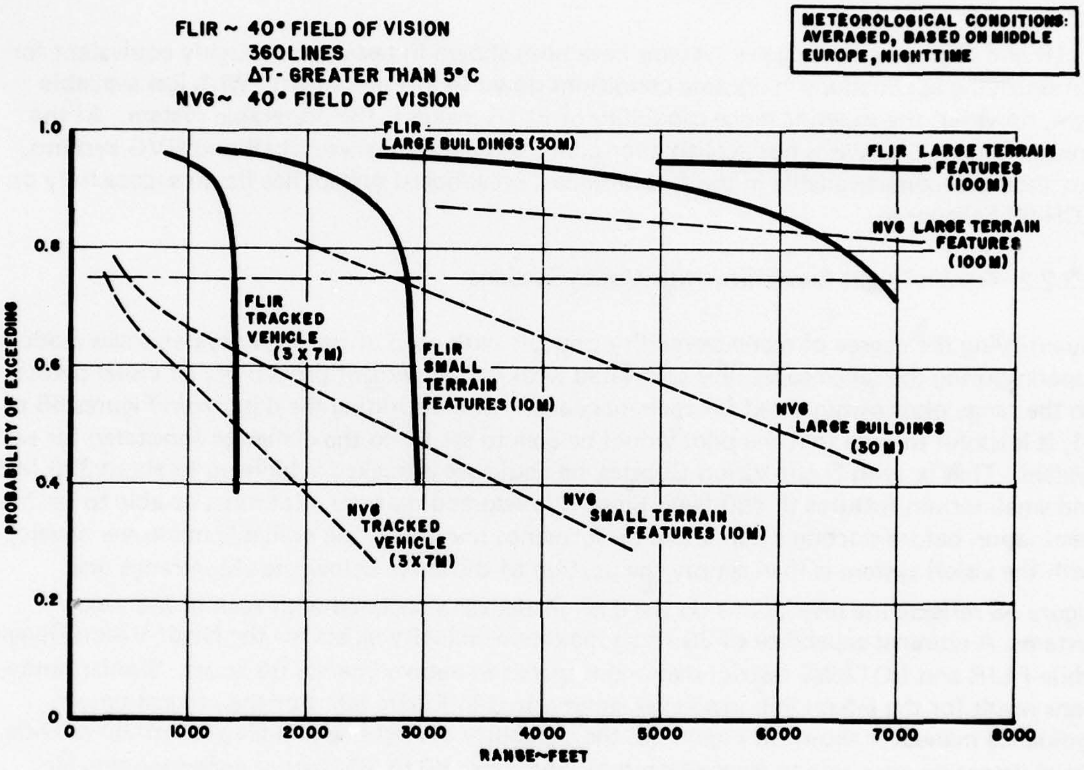


FIGURE 57. FLIR AND NVG SYSTEM PERFORMANCE-DETECTION OF OBJECTS

Using an arbitrarily selected 75-percent probability of exceedance level of being able to see the two smallest obstacles shown in Figure 57, range information was generated for the visionics systems used in evaluating nighttime maneuver capability. These obstacles would be about the size of typical trees or houses which might be encountered in NOE flight. Night-Vision Goggles should be able to detect the 3x7-meter obstacle at about 320 feet and the larger 10x10-meter target at around 480 feet. FLIR performance permits detection of the smaller obstacle at 1,380 feet and the larger at almost 1/2 mile.

FLIR and Night-Vision Goggles systems have been shown in tests to be roughly equivalent for terrain flying applications in lighting conditions down to 1/4 moonlight. With less available light, however, the superior range capability of FLIR makes it the preferable system. At the present time, LOTAWS is not available for combined use with these FLIR and NVG systems, but should become available in the future since a breadboard system has flown successfully on a CH-53 helicopter.

3.3.2.2 Terrain Flight Capability With Vision Systems

Quantifying the degree of maneuverability possible with each of the above systems was made by superimposing the range capability associated with the 75-percent probability of visual detection on the range plots summarized for each maneuver. In interpreting the data from Figures 58 to 61, it is useful to note that the pilot would be able to see up to the distances annotated for each system. That is, with Night-Vision Goggles, he could see a tracked vehicle up to about 320 feet and small terrain features to 480 feet. Since it is assumed that the pilot must be able to see his destination before starting a maximum-performance maneuver, the available maneuver envelope with the vision system is then simply the portion of the curve below the vision range line.

Figure 58 reflects the restrictions on the dash maneuver associated with each of the vision systems. A nominal capability of 30 knots maximum velocity exists for the Night-Vision Goggles, while FLIR and LOTAWS restrict maximum speeds to approximately 60 knots. Similar limitations result for the lateral jink maneuver summarized in Figure 59. For the vertical terrain-avoidance maneuver shown in Figure 60, the capability of Night-Vision Goggles would provide visual detection adequate to clear obstacle heights from 50 to 300 feet at corresponding airspeeds from 120 down to 30 knots. That is, as the obstacle height increases, the maximum permissible speed decreases. With FLIR, obstacle height vision capability varies from approximately 300 feet at 120 knots to 1,000 feet at 30 knots.

Figure 61 reflects the visual detection ranges associated with these systems for the forward flight lateral avoidance maneuvers. In this terrain flying mode, Night-Vision Goggles provide a limited 30-knot envelope, while FLIR offers greater than 60-knot capability.

It is noted that these projected speeds may seem lower than some actual demonstrations. The 75-percent performance level, however, represents a more stringent environment than has existed for most tests to date.

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17. NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL FOR THERMAL VIEWING SYSTEMS, Research and Development Technical Report Ecom 7043, U.S. Army Electronics Command, Fort Monmouth, New Jersey, April 1975.

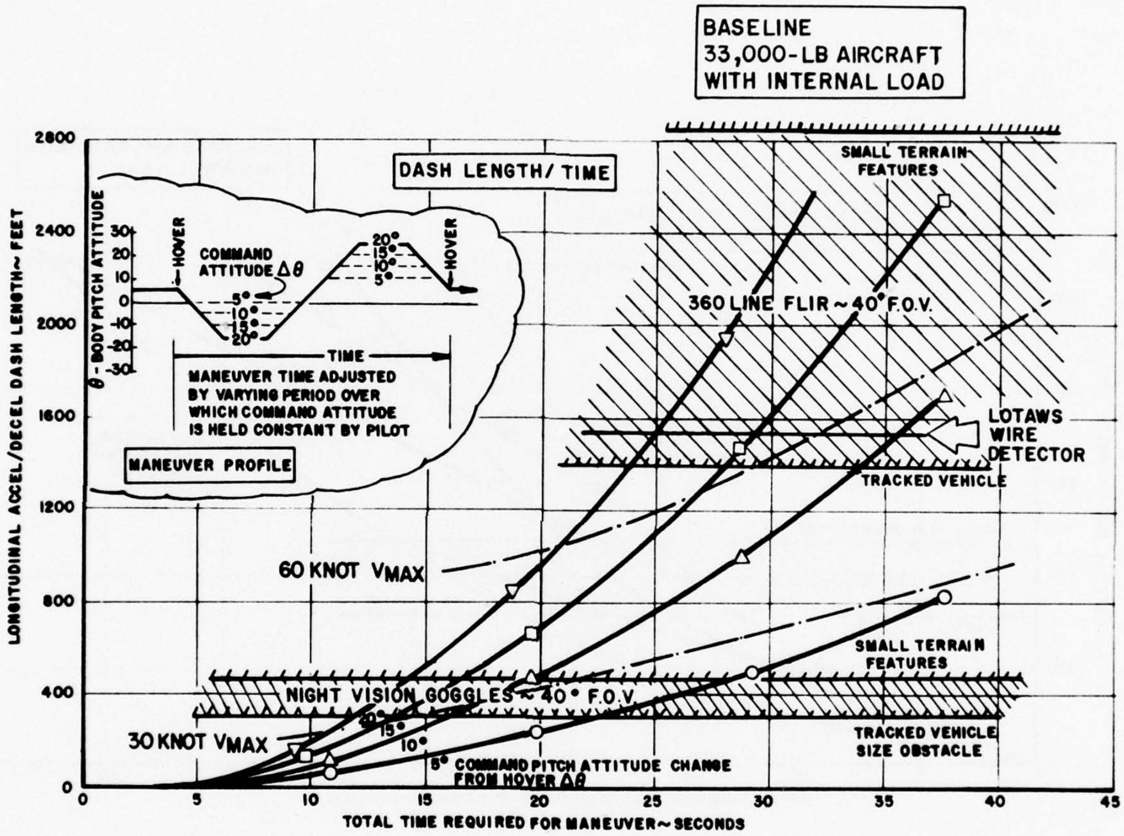

FIGURE 58. DASH MANEUVER CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEMS

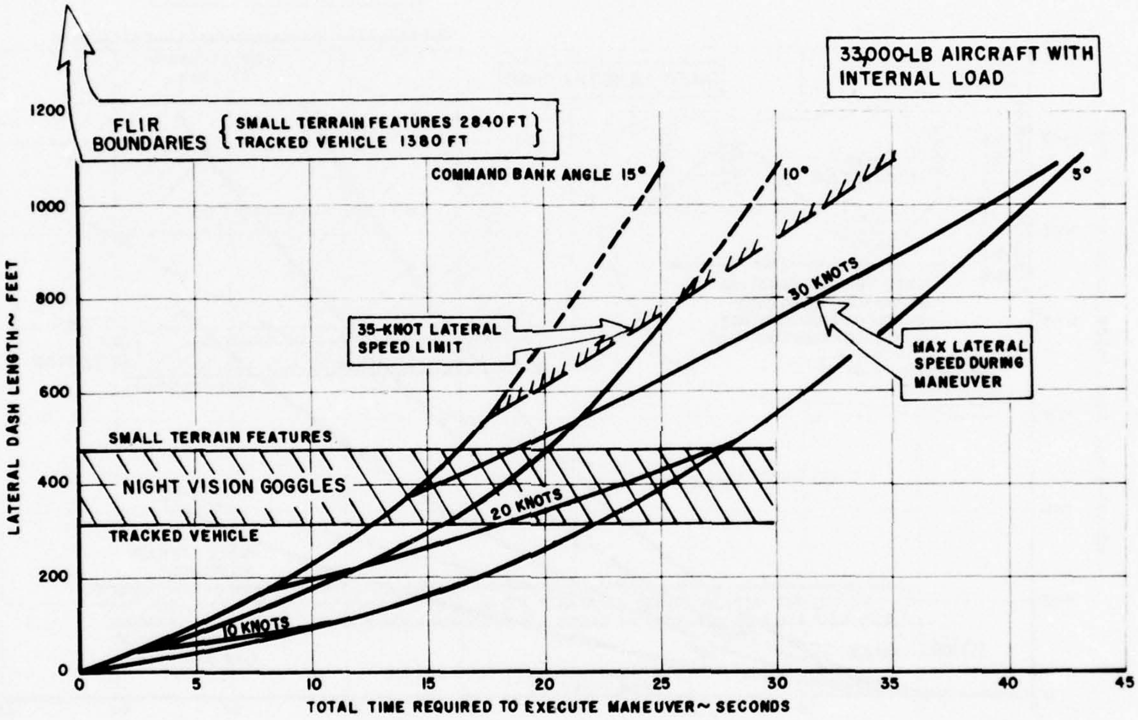

FIGURE 59. LATERAL JINK CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEMS

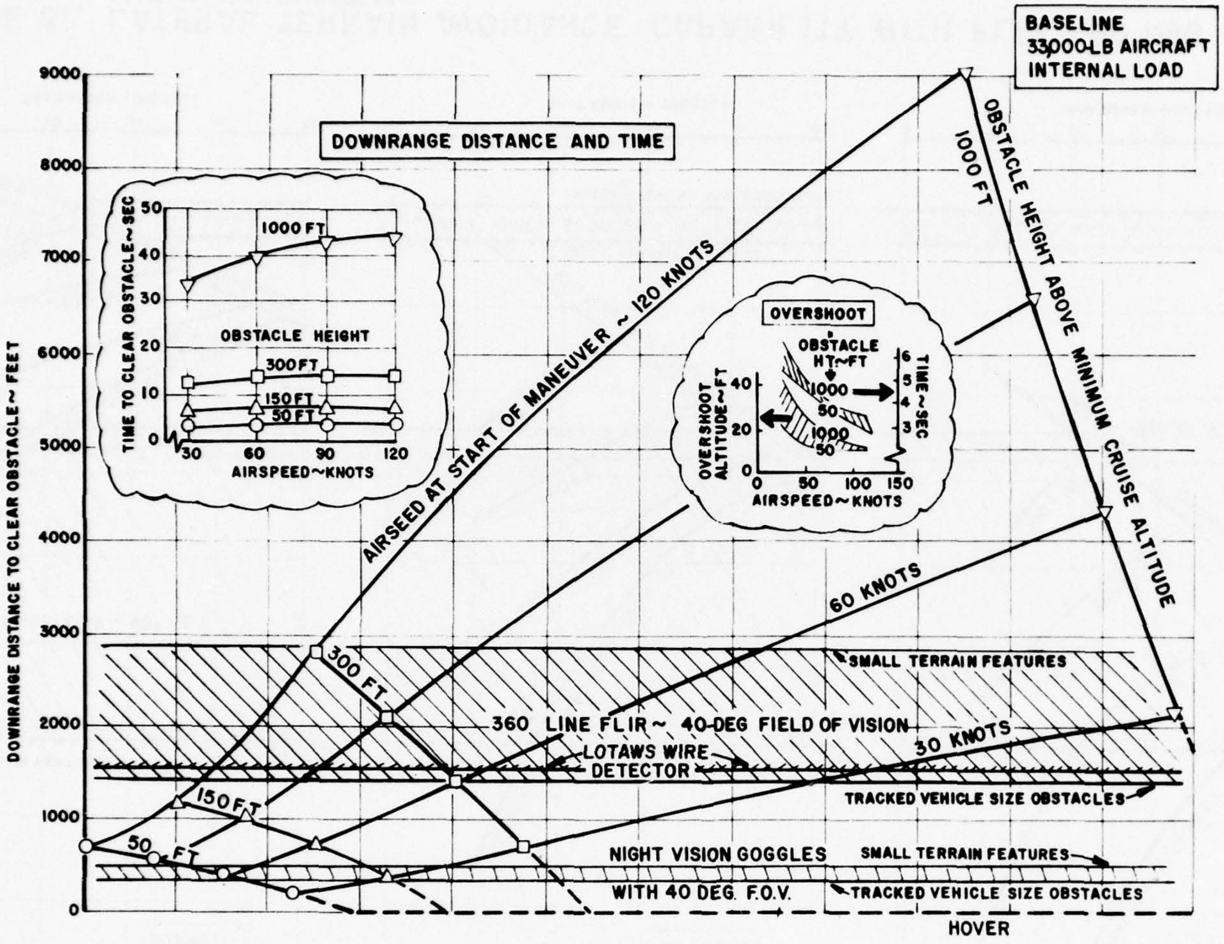

FIGURE 60. VERTICAL TERRAIN AVOIDANCE CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEM

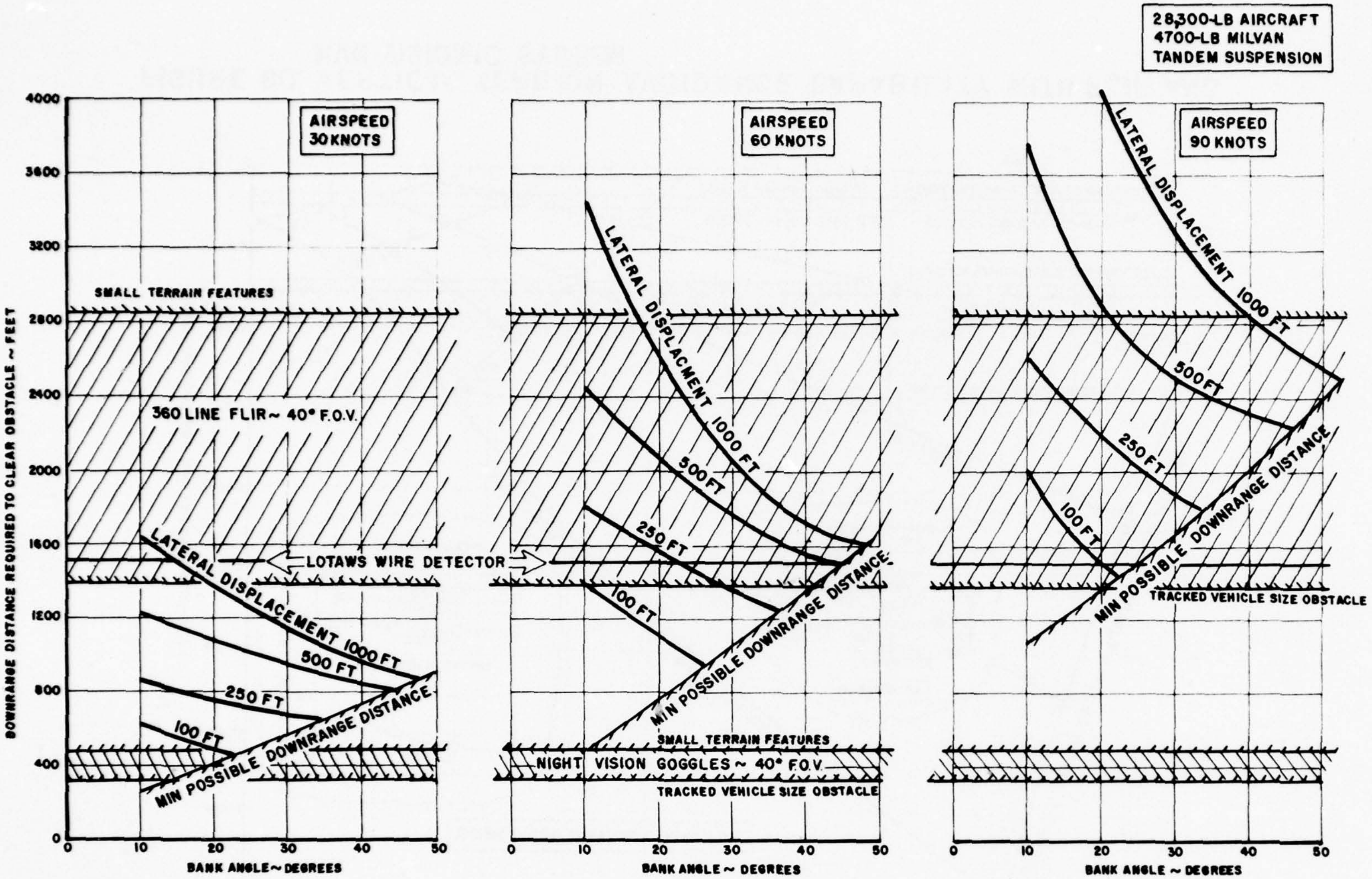

FIGURE 61. LATERAL TERRAIN AVOIDANCE CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEMS

3.3.2.3 Cockpit Modifications

A study was conducted to assess illumination characteristics of the CH-47 cockpit during night operations. Several problem areas were determined which would affect the general ability of the pilot to perform at night, with or without night-vision devices. These problem areas center around the following:

- Reflections leading to obstructed vision through the windshield, and decreased performance of night-vision systems
- Glare causing degraded vision and producing additional fatigue
- Poor instrument readability resulting in reading errors and additional fatigue.

Table 12 summarizes these considerations and defines potential areas of improvement or redesign.

The primary impact of these shortcomings is a potential degradation in performance of the aircrew while using systems which aid or provide visual sighting during night/IMC conditions. In addition, an increase in pilot fatigue also occurs which undoubtedly affects safety as well as performance. Problems covered in this table are being addressed in development of the CH-47D aircraft.

3.3.3 Flight Control/Handling Qualities

As previously discussed, the handling qualities of the CH-47 can restrict hover and low-speed operations as illustrated in Figure 62 at night and in reduced visibility, particularly while using night-vision devices. The lack of peripheral visual cues makes the hovering task very demanding with the CH-47's rate control system. Control accuracy is not adequate for safe load acquisition in this environment.

Precision maneuver techniques for flight close to the ground require considerable pilot concentration and skill even in a VFR day environment. Addition of IMC or night requirements in a hostile environment adds a significant increment to the pilot workload. Figure 63 projects the relative magnitude of pilot effort required for terrain flying and precision hover; increases of 100 percent can be expected for similar tasks when conducted during night operations.

Candidate solutions for the night/IMC handling qualities limitations that have been flight tested include the use of hover/approach displays with command symbology (Reference 18) or ground velocity control and stabilization techniques (Reference 11). Table 13 summarizes these systems, with advantages and disadvantages noted. Two ground velocity concepts are shown, with the second including a remote crewman control to aid low-visibility hookup. The ground-speed control system has significant advantages over the hover displays as noted, and can be extended to include all low-speed maneuvering.

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18. Milelli, R. J., Johnson, D. C., Tsoubanous, C. M., MANUAL PRECISION HOVER WITH SUPERIMPOSED SYMBOLOGY ON A FLIR IMAGE, AHS Paper 922, American Helicopter Society, Washington, D. C., May 1975.

TABLE 12. COCKPIT CONSIDERATIONS FOR NIGHT VISIBILITY

PROBLEM	EFFECTS ON PERFORMANCE	CANDIDATE SOLUTIONS
REFLECTIONS		
FLOOR CONSOLE LIGHTS REFLECT ON WINDSHIELD	OBSTRUCTS VISION	RELOCATE FLOOR CONSOLE LIGHT CONTROL SWITCH/RHEOSTAT FOR ACCESSIBILITY DIMMING/EXTINGUISHING CONSOLE LIGHTS IMPROVES/ELIMINATES CONDITION LIGHT CONTROL TECHNOLOGY APPLICATION – SUCH AS LIGHT CONTROL FILM – EFFECTS REDUCTION OR ELIMINATION OF REFLECTIONS REDESIGN GLARE SHIELD TO ELIMINATE REFLECTIONS
GLARE	DEGRADES NIGHT VISION AND CAUSES FATIGUE	
ATTITUDE INDICATOR	DUE TO LARGE SURFACE OF WHITE AREA MORE LIGHT IS REFLECTED THAN FROM THE OTHER INSTRUMENTS GIVEN THE SAME LIGHT SETTING	PROVIDE DEDICATED RHEOSTAT CONTROL CHANGE INST DESIGN
XMSN IND SELECTOR	CANNOT DIM TO ACCEPTABLE LEVEL	CHANGE ILLUMINATION LEVEL OF THE SELECTOR INDICATOR REDESIGN THE INDICATOR
CABIN LIGHTING	ILLUMINATION OF CABIN FOR CREW ACTIVITIES IS A SOURCE OF VERY OBJECTIONABLE GLARE PROBLEM – DEGRADES NIGHT EXTERNAL VISION	DOOR OR CURTAIN TO SEPARATE CABIN FROM COCKPIT

TABLE 12 – CONTINUED

PROBLEM	EFFECTS ON PERFORMANCE	CANDIDATE SOLUTIONS
MAP LIGHT	USE OF MAP LIGHT RESULTS IN DEGRADATION OF NIGHT VISION WHEN WHITE LIGHT IS REQUIRED FOR MAP READING	USE OF MAPS WHICH CAN BE READ UNDER RED LIGHTING NAV DISPLAY THAT WOULD ELIMINATE OR AT LEAST ALLEVIATE THE REQUIREMENT FOR FREQUENT REFERENCE TO THE MAP
<u>INSTRUMENT READABILITY</u>	FATIGUE AND/OR INCORRECT READINGS OR GLARE DUE TO INCREASED LIGHT LEVELS	
ILLUMINATION IMBALANCE	FATIGUE AND INCORRECT READINGS DUE TO LACK OF ADEQUATE ILLUMINATION OF CERTAIN INSTRUMENTS WITH OTHER INSTRUMENTS SET AT COMFORTABLE LIGHT LEVEL	CORRECT IMBALANCE BY EVALUATION AND ADJUSTMENT OF INDIVIDUAL INST ILLUMINATION LEVELS INTEGRAL LIGHTING APPLICATION TO REPLACE POST LIGHTING
INADEQUATE DISTRIBUTION OF LIGHT OVER INSTRUMENT FACE	FATIGUE AND INCORRECT READINGS OR INCREASED GLARE	INTEGRAL LIGHTING
AIRSPEED IND ALTIMETER ROTOR TACH		
INST POSTION	FATIGUE AND INCORRECT READINGS	REPOSITION INST
TURN & BANK IND		

LIMITATIONS:

CONTROL ACCURACY

- HANDLING QUALITIES
  - RATE/ ATTITUDE CONTROL RESPONSE
  - NO ALTITUDE HOLD
- NO PILOT-TO-LOAD VISIBILITY
- DRIFTING UNDETECTABLE IN LOW VISIBILITY

WEAPON PLACEMENT ACCURACY

- LOAD SUSPENSION
  - NO YAW RESTRAINT WITH SINGLE POINT
  - LOAD SWAY MODES LIGHTLY DAMPED

WORKLOAD VERY HIGH

- HANDLING QUALITIES
- REDUCED VISIBILITY
- HOOK UP SAFETY

FIGURE 62. LOAD ACQUISITION AND DEPOSIT

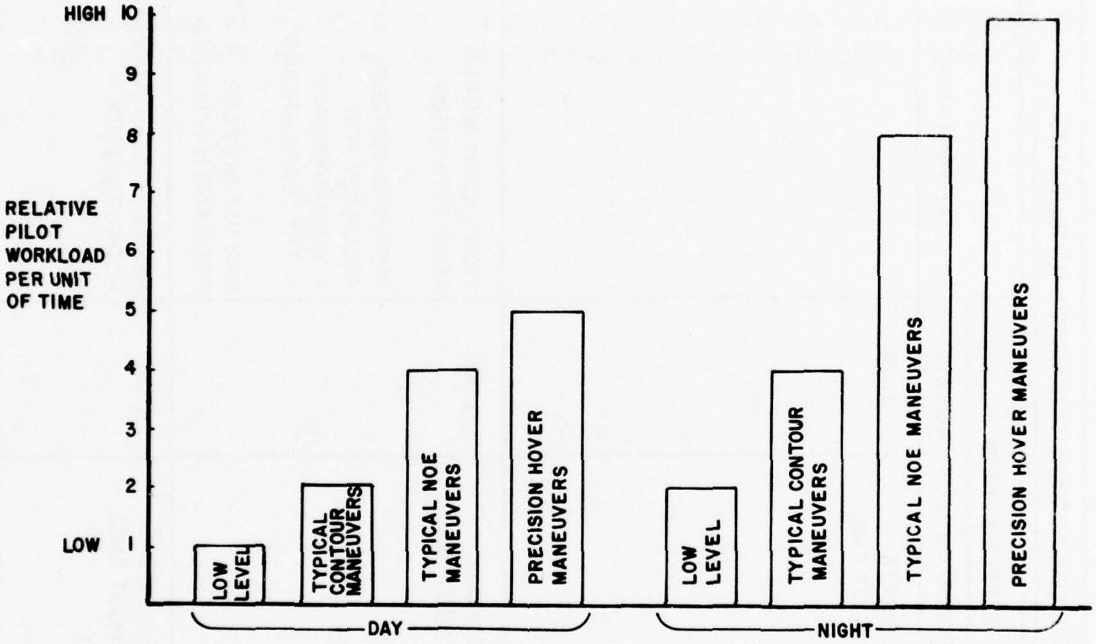

FIGURE 63. DAY/NIGHT COMPARISON OF RELATIVE PILOT WORKLOAD

TABLE 13. NIGHT/IMC LOAD ACQUISITION HANDLING QUALITIES

CANDIDATES	ADDITIONAL SYSTEM COMPLEXITY	EFFECTIVENESS		ADVANTAGES	DISADVANTAGES
		CONTROL ACCURACY	WORKLOAD		
HOVER DISPLAY	TV DISPLAY COMMAND SYMBOLOGY – VELOCITY – ACCELERATION HOVER MOTION SENSOR – OPTICAL/IR TRACKER ELECTRONIC PROCESSING	ADEQUATE (<2 FOOT RMS)	HIGH		NO WORKLOAD REDUCTION INCOMPATIBLE WITH NIGHT VISION DEVICES AS PILOT MUST FOCUS ON DISPLAY
HOVER GROUND-SPEED HOLD SYSTEM WITH PILOT VERNIER CONTROL	DOPPLER/INERTIAL SENSOR ELECTRONIC PROCESSING FOR SCAS	ADEQUATE (<1 FOOT RMS)	LOW	SIGNIFICANT WORKLOAD REDUCTION IMPROVES CONTROL ACCURACY FOR – BOB UP/REMASK – TAKEOFF/LANDING CAN USE DOPPLER REQD FOR NAVIGATION	
HOVER GROUND-SPEED HOLD SYSTEM WITH REMOTE CREWMAN CONTROL	ABOVE PLUS A 3 OR 4 AXES CONTROLLER FOR CREWMAN	ADEQUATE (<1 FOOT RMS)	LOW	ABOVE PLUS ADDITIONAL HOOKUP SAFETY	

3.3.4 Navigation

The navigation requirements for the CH-47 operating under terrain flight restrictions have not been addressed in this study; they are the subject of many on going programs highlighted in Reference 19. For completeness, a simplified chart summarizing the tradeoffs among the various alternative navigation systems is reproduced from this reference, with some additions, in Table 14. The Doppler/compass system appears to be the most likely choice. As shown previously, the velocity information is suitable for ground-speed control implementation.

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19. A TECHNICAL APPROACH TO THE EVALUATION OF NAVIGATION SYSTEMS FOR ARMY HELICOPTERS, Report No. 266-1, ANACAPA Sciences, Inc., May 1976.

TABLE 14. ALTERNATIVE NAVIGATION SYSTEMS

SYSTEM TYPE	FAVORABLE	UNFAVORABLE	COMMENTS
VOR RADIO BEACONS TACAN DECCA	LOW COST LIGHTWEIGHT	SHORT RANGE MARGINAL ACCURACY VULNERABLE TO ECM MULTIPLE GROUND STATIONS LINE-OF-SIGHT LIMITATIONS	
OMEGA	MODERATE COST LIGHTWEIGHT WORLDWIDE COVERAGE	MARGINAL ACCURACY VULNERABLE TO ECM VULNERABLE TO PHYSICAL DESTRUCTION VULNERABLE TO POLITICAL SHUTDOWN	
NAVSTAR GLOBAL POSITIONING SYSTEM	HIGHLY ACCURATE WORLDWIDE COVERAGE	NOT OPERATIONAL VULNERABILITY UNKNOWN COST UNKNOWN	
LORAN C LORAN D	MODERATE COST ACCURATE	VULNERABLE TO ECM VULNERABLE TO PHYSICAL DESTRUCTION NEEDS CALIBRATION AND RATE-AIDING	
INERTIAL	SELF-CONTAINED, SECURE PASSIVE	HIGH COST, HIGH UPKEEP HEAVY EQUIPMENT TIME-DEPENDENT ERROR NEEDS PREFLIGHT ALIGNMENT	
AIR DATA/COMPASS	LOW COST LIGHTWEIGHT SELF-CONTAINED, SECURE PASSIVE	INACCURATE	
DOPPLER/COMPASS	MODERATE COST SELF-CONTAINED ACCURATE VELOCITY	ACCURACY DEPENDS ON COMPASS NEEDS GOOD MAGNETIC DEVIATION, COMPASS SWING PROPAGATES SIGNAL	SELECTED FOR DEVELOPMENT BY ARMY
INERTIAL STRAPDOWN	SELF-CONTAINED, SECURE		
OPTICAL CORRELATORS		LACKS ADEQUATE RESOLUTION FOR NOE/ CONTOUR FLIGHT REQUIRES PREPROGRAMMING	

REF: AVSCOM CONTRACT NO. DAAJ01-75-C-0633

4.0 SYSTEM DEFINITION

This section of the report describes Phase II work associated with preliminary design of a lightweight, removable Active Arm External Load Stabilization System (AAELSS), and a Self-Hoisting Interface (container handling) Device for snubbing external loads against the aircraft bottom. Both systems will enhance CH-47 terrain flying capability substantially, by either reducing or stopping load motion completely, or by improving masking characteristics of the aircraft/load combination.

Significant design features of both devices are pointed out, along with information on how each system interfaces with the various aircraft subsystems. Preliminary component weight estimates have been prepared and are discussed. Where relevant, applicable design and test specifications are also cited.

Assessment of CH-47 terrain flight performance using either AAELSS or the snubbing device is presented in Section 3.3.

4.1 REMOVABLE ACTIVE ARM EXTERNAL LOAD STABILIZATION SYSTEM (AAELSS)

4.1.1 Design Criteria

Preliminary design trade studies have been carried out to define overall configuration and sizing of major AAELSS components, structural load paths, hydraulic and electrical power requirements, etc. The principal design objective was to develop a lightweight, removable system that could be installed on the aircraft in a relatively short period of time, by removing the forward and aft tandem cargo hooks and then bolting the AAELSS units to the existing hook mounting structure.

AAELSS would be installed on the aircraft principally for terrain flying or night/IMC missions. The system is quite similar in concept to the flight tested AAELSS II device described in Reference 5, except that the units are removable when not required, and cargo capacity is increased from 20,000 pounds to 25,000 pounds. Design criteria followed in development of this improved system concept are as follows:

- Load Capacity – Same as for tandem hooks going into the YCH-47D, with a 25,000-pound capacity and a 60-by 40-percent load-sharing split – 2g limit load with 1.5 safety factor.
- System Weight – Including equipment and structure permanently installed in the aircraft, it should be on the order of one-third of the AAELSS II figure.
- Maximum Load Sway Angles – Lateral – 30 degrees in either direction, Longitudinal – 45 degrees forward direction; 50 degrees aft direction (greater because of allowance for load drag)
- Hydraulic Power – Arms to be powered by servo-controlled hydraulic cylinders in the longitudinal and lateral axes, using aircraft utility hydraulic system supply (which has an uprated 16 GPM flow capacity for YCH-47D). See details of system hydraulics design in Section 4.1.3.

- Electrical Power – For system feedback control law electronics, angle sensor excitation, hydraulic servo valve control, cockpit displays and system controls, etc., aircraft 115V/400 Hz AC and 28V DC power are required. Circuit breaker protection is necessary where AAELSS power is drawn from the AC and DC electrical bus systems.

- Load Damping – Damping of load motion to 30 percent of critical is required over the same load displacement range as used for the AAELSS II design (2 feet).

- System Control – All AAELSS functions are to be controllable from the cockpit by either pilot. Load jettison functions provided the crew are to be identical to those used with the tandem hook system on the YCH-47D. An emergency AAELSS shutdown capability will also be provided the crew chief at the mid-cabin crew station.

- System Redundancy – Redundancy level requirements must be established for any production implementation of AAELSS, based on analysis of desired system usage. That is, if unstable loads are to be carried, or normally stable cargo beyond the stable airspeed range, system redundancy must be adequate to safely handle initial failures in both the electrical and hydraulic AAELSS subsystems.

- Failure Warning/Control – The pilots will be provided warning lights for both axes of each AAELSS unit, to indicate failure of hydraulic and electrical components. Capability to shut down the lateral axes of both units together, or either longitudinal axis will be provided.

4.1.2 AAELSS Arm, Arm Articulation, and Structural Attachment Framing Design

Sketches of the upper arm articulation scheme, showing the techniques employed for pivoting the arm and providing hydraulic power, and the method of attachment to the fuselage are presented in Figure 64 for the forward AAELSS unit. Figure 65 shows both arms installed on the aircraft in deployed and retracted positions, and Figure 66 details a typical lower arm and hook installation.

System operating principles are identical to those used in AAELSS II, with the arms driven longitudinally and laterally by hydraulic cylinders to attenuate longitudinal, lateral, and yawing motion of the load. When load sway occurs, the arms rapidly move out over the load and then wash out motion to the original trim position as described in Reference 5.

4.1.2.1 Upper Arm and Mounting Structure

As illustrated in Figure 64, the cylindrically shaped rigid arm structure is pivoted (to swing in a fore or aft direction) from a longitudinally oriented trunnion arm pivot assembly which is supported on bearings at either end. These bearings permit lateral arm motion, which is restricted to ±30 degrees by extension and retraction of the lateral actuator shown in the right hand sketch.

The right hand end bearing shown in the side view of the unit takes longitudinal thrust loads as well as arm tensile loads, and transfers these directly into the structural mounting frame and on into the tandem hook mount installed on the aircraft bottom. Moments produced by lateral and longitudinal arm or load motions are transferred as vertical shear forces into the

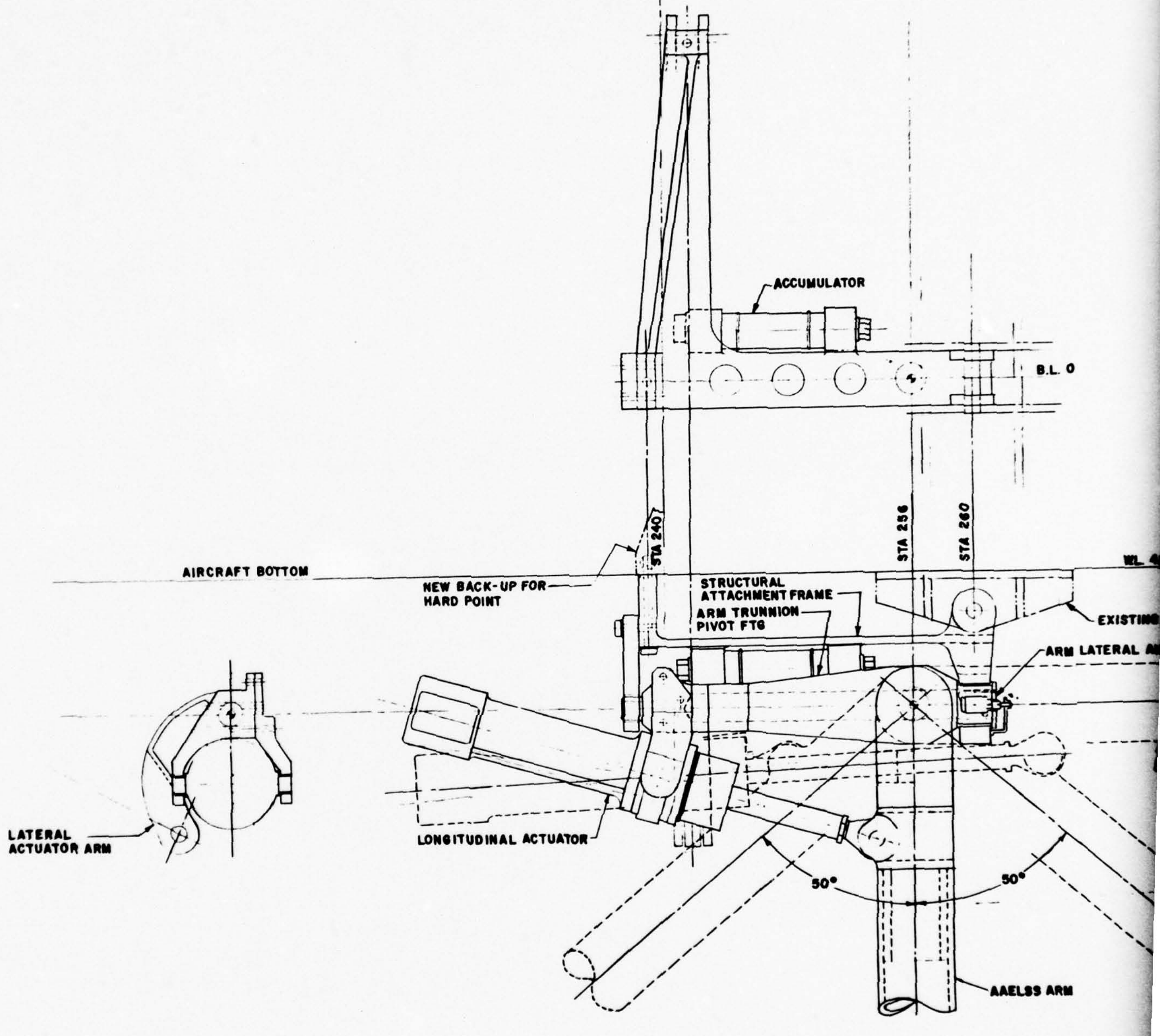
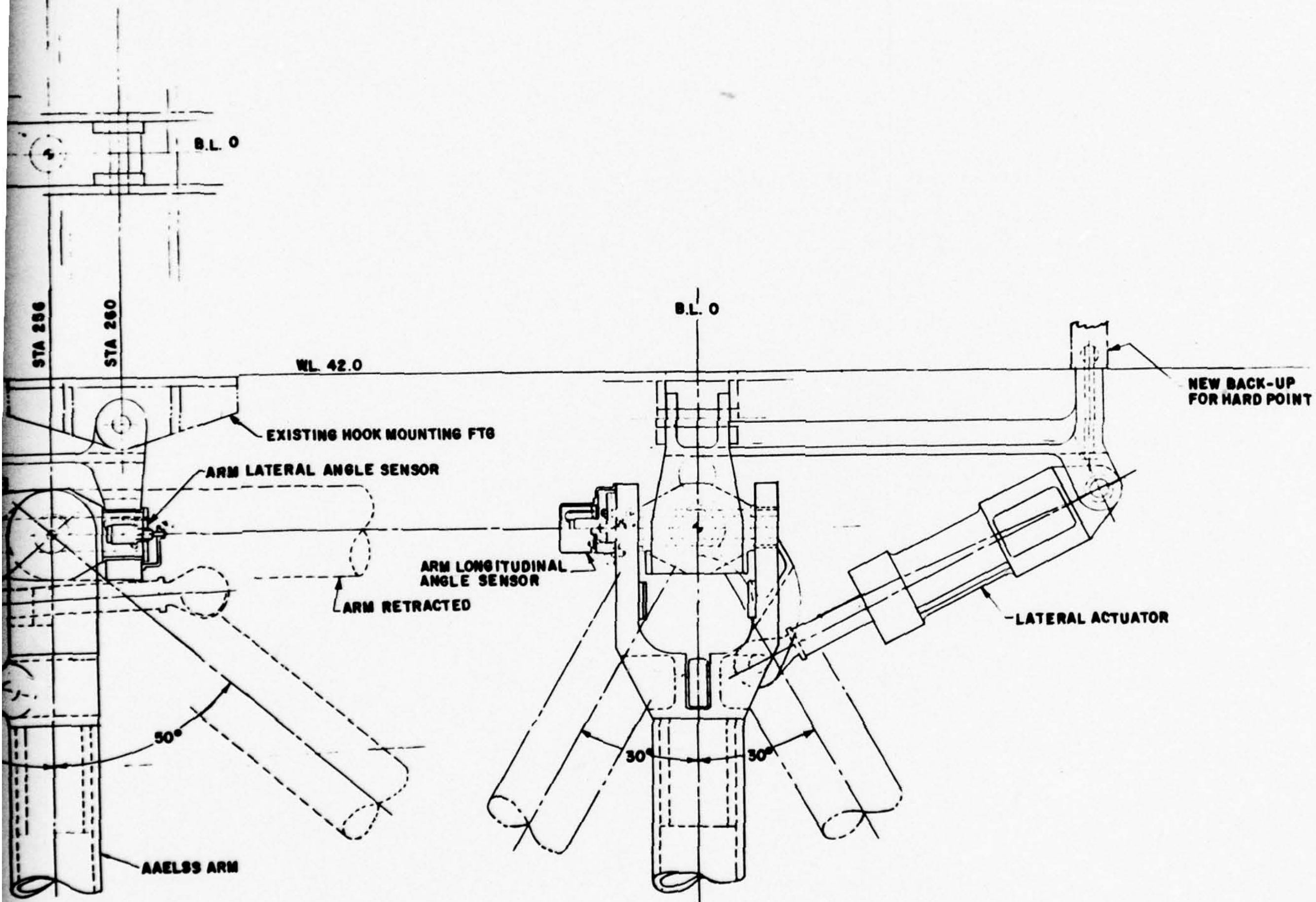


FIGURE 64. AAELSS ARM ARTICULATION AND AT



CULATION AND ATTACHMENT ARRANGEMENT

2

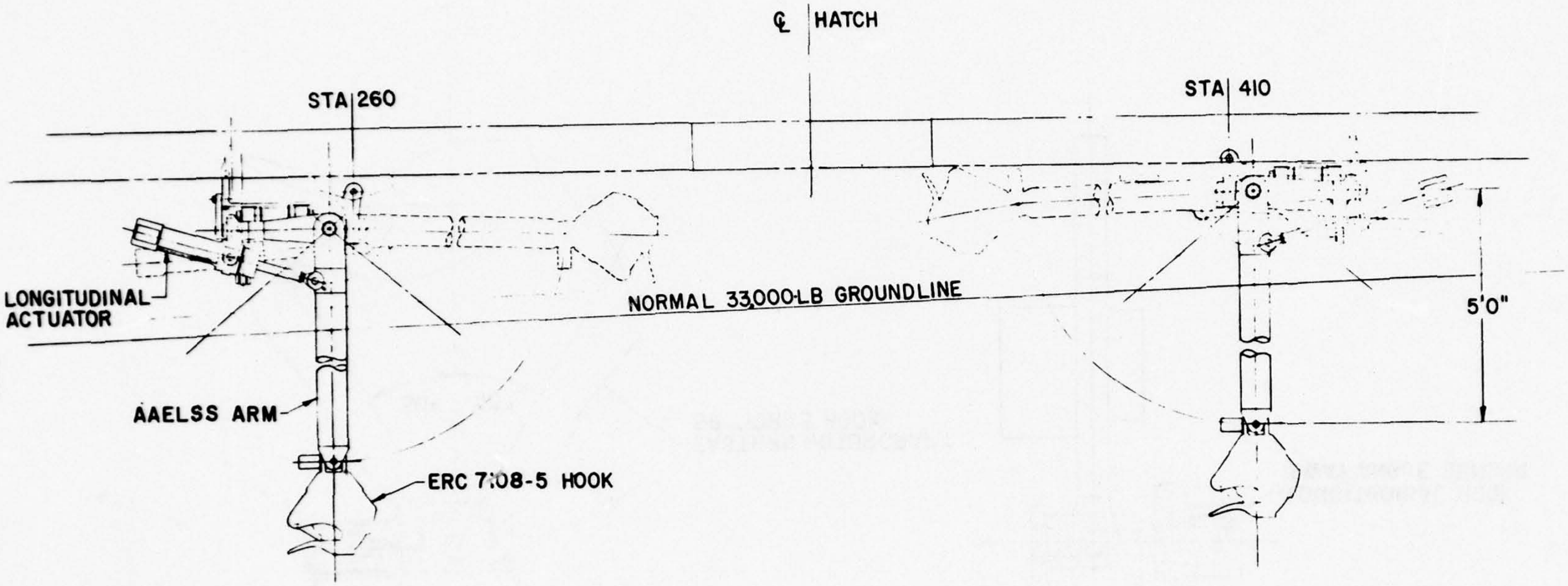


FIGURE 65. AAELSS SYSTEM INSTALLATION ON CH-47 AIRCRAFT

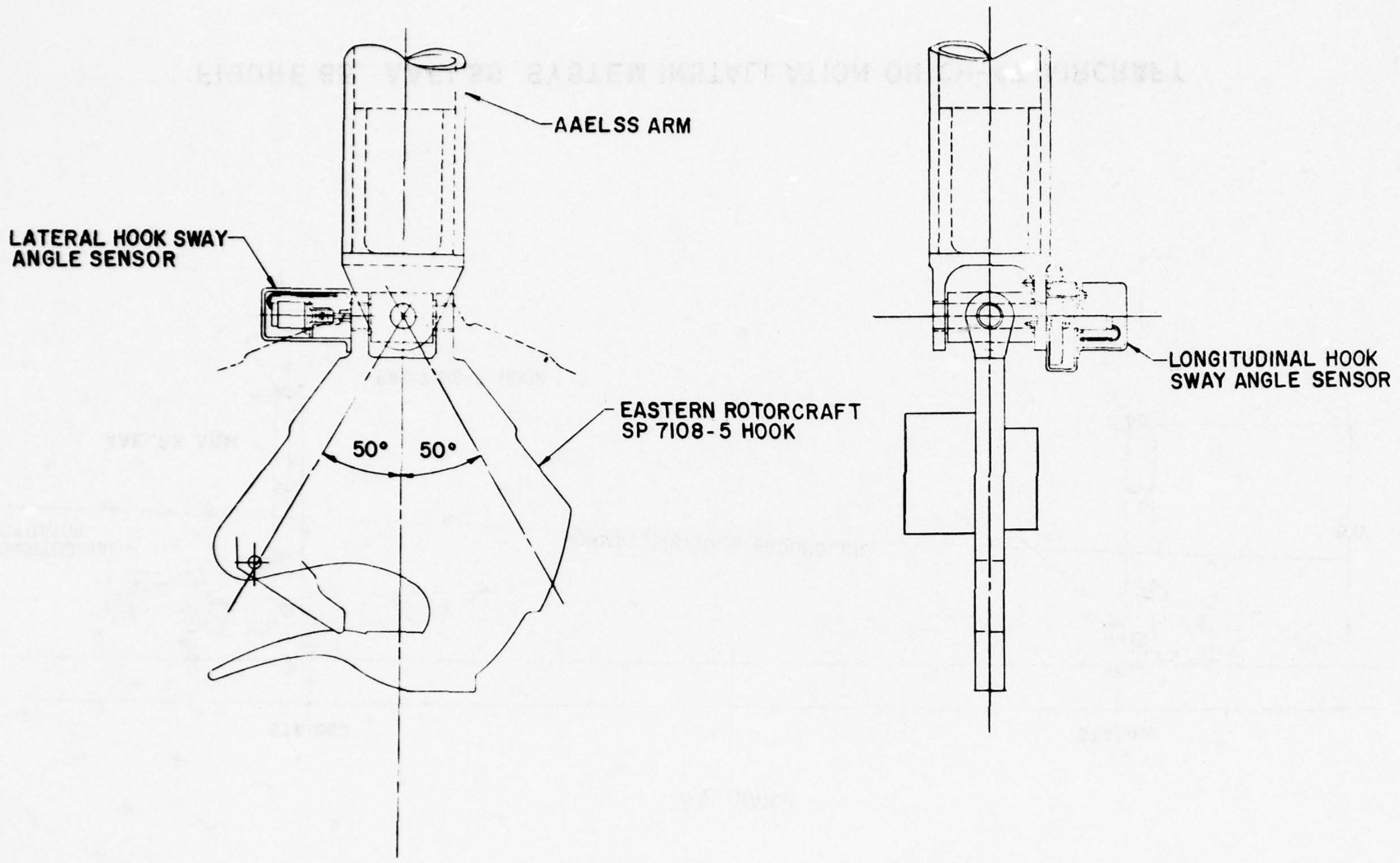


FIGURE 66. AAELSS LOWER ARM HOOK MOUNTING

aircraft structure through bolted connections on the centerline and outboard edges of the L shaped attachment frame (detailed in the top view). These bolted connections require backup hard points to be built into the fuselage frame cap and web structure.

The hard points represent essentially the only structural modifications required on the aircraft for AAELSS installation, except for small striker plates which are to be located on the fuselage skin above the hooks (when retracted) to prevent hook droop. Minor structural changes may also be required for mounting AAELSS subsystem electronics and hydraulic packages within the aircraft.

Substantial effort went into development of schemes for saving weight and for reducing the overall size of the arm articulation and mounting frame structure. The longitudinal actuator drives the arm from beneath its pivot point rather than above as in AAELSS II. This produces an appreciable reduction in the height of the unit in the retracted mode, which is a strong consideration in providing required ground clearance with collapsed oleo struts and flat tires on one side of the aircraft. Total longitudinal travel extends from 45 degrees forward to approximately 90 degrees aft for retraction of the forward unit. The aft arm moves from 50 degrees aft to approximately 90 degrees forward for stowage.

4.1.2.2 Lower Arm/Hook Assembly

The lower arm and hook sketch in Figure 66 shows how the hook is universally pivoted to follow load motion. Hook sway angle travels are the same as for the arm: (±)30 degrees lateral, and (+)45 degrees/(–)50 degrees longitudinal. Each hook axis is provided with a sway angle sensor. Information from these sensors, and from the two shown in Figure 64 for the upper arm pivot,are combined to produce total load pendular sway angle information which is used in the automatic control laws.

Not shown in the Figure 66 sketch is a small longitudinal lever arm bolted to the hook, which forces the hook axis to remain parallel to the arm when the arm is retracted (to eliminate droop and hook impingement on the ground). This lightweight centering concept was employed in the AAELSS I flight system (Reference 4).

4.1.2.3 Arm Jam Protection

Although both arms are configured with an emergency backup retraction scheme (described in the next section), some small possibility of an actuator jam (or hydraulic lock) exists which could prevent retraction. To overcome this problem, several schemes have been worked out to release the jammed actuator; and thus allow the pilot to make a slow roll on landing which would force the arm to collapse in an aft direction. Actuator release could be effected by application of either pyrotechnic bolt technology, or through an overcenter mechanical locking device which could be lanyard operated by the crew chief. Failure modes of such an emergency release system would not be severe, since an inadvertent actuation would merely render a single longitudinal axis inoperative, with a resultant reduction in longitudinal system load damping of about 50 percent.

4.1.3 Hydraulic System Design

AAELSS-associated hydraulic systems fall into two general categories including: components mounted on each removable unit to power the arms, and those elements installed on the aircraft which interface the existing utility hydraulic supply and two external units.

4.1.3.1 Actuator System Design and Requirements

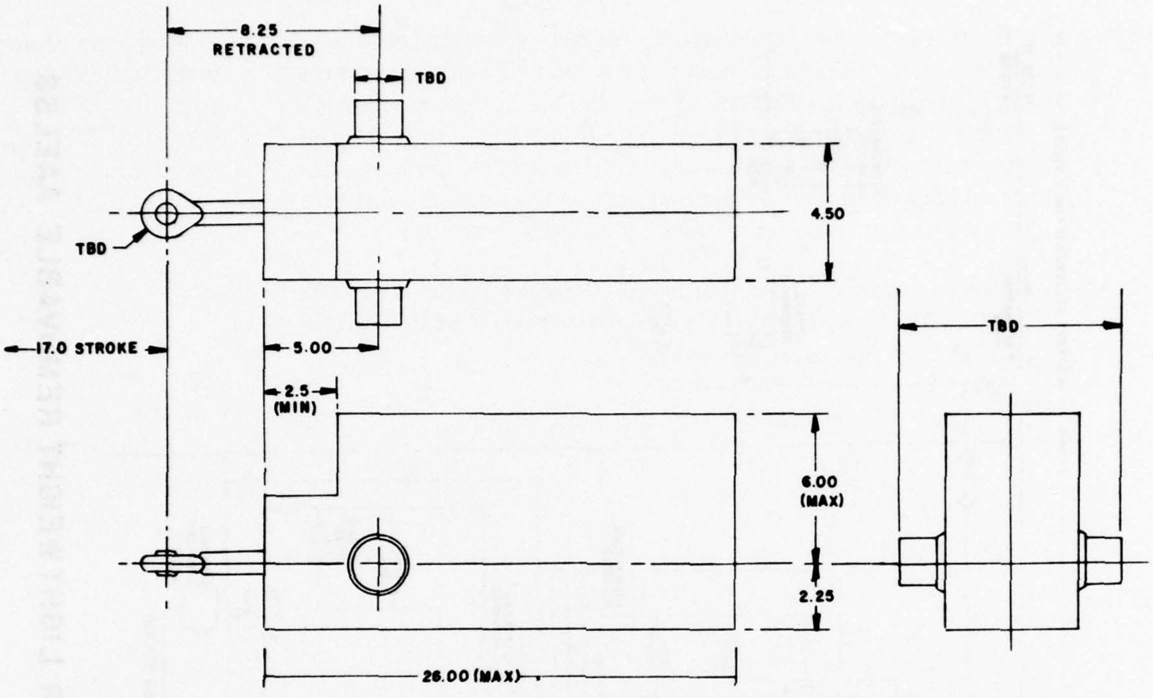
Separate longitudinal and lateral actuators are provided for each arm with the (–1) longitudinal cylinder trunnion mounted as shown at the top of Figure 67, and the (–2) lateral actuator end mounted as shown in the bottom sketch. Both actuators are controlled by electrohydraulic servo valves, mounted on the cylinder manifold along with relief valves which prevent excessive system pressure when the arm is being overpowered by the load. Longitudinal actuators also incorporate locking devices for arm stowage in the retracted position, which operate hydraulically or manually and may be released by hydraulic pressure.

Detail design and test of the actuator assemblies would be in accordance with MIL-H-8775C and MIL-C-5503, for operation in a system per MIL-H-5440F class 3000 psi, Type II. Other pertinent actuator design requirements include:

- Pressure – Operating – 3000 psi
  Proof – 4500 psi
  Burst – 7500 psi
- Return Pressure – 50 psi
- Actuator Piston Area – Sized to meet following conditions:
  - External applied stall load of 19,700 pounds minimum for (–1) longitudinal actuator; 21,600 pounds minimum for (–2) lateral actuator
  - In unloaded condition, minimum velocity 3.0 in./sec
  - At 50 percent stall load, minimum velocity 2.0 in./sec
- Rated Flow – 5 gpm maximum
- Actuator Stroke – 18 inches – Longitudinal
  – 9.3 inches – Lateral
  – each end of the actuator to provide a 1/2-inch cushion
- Electro Hydraulic Servo Valve (EHV) – Similar to Vertol 114H5580 and shall meet requirements of MIL-H-8775 and MIL-STD-461 Class 1D.
- Relief Valves – Designed per MIL-H-8775 and MIL-V-8813 to meet the following: cracking pressure = 3750 psi, full flow pressure (5 gpm) = 4050 psi, and reset pressure = 3450 psi
- Accumulator – 6 in.^{3} volume precharged to 1500 psi required for each arm to assist during periods of maximum flow demand

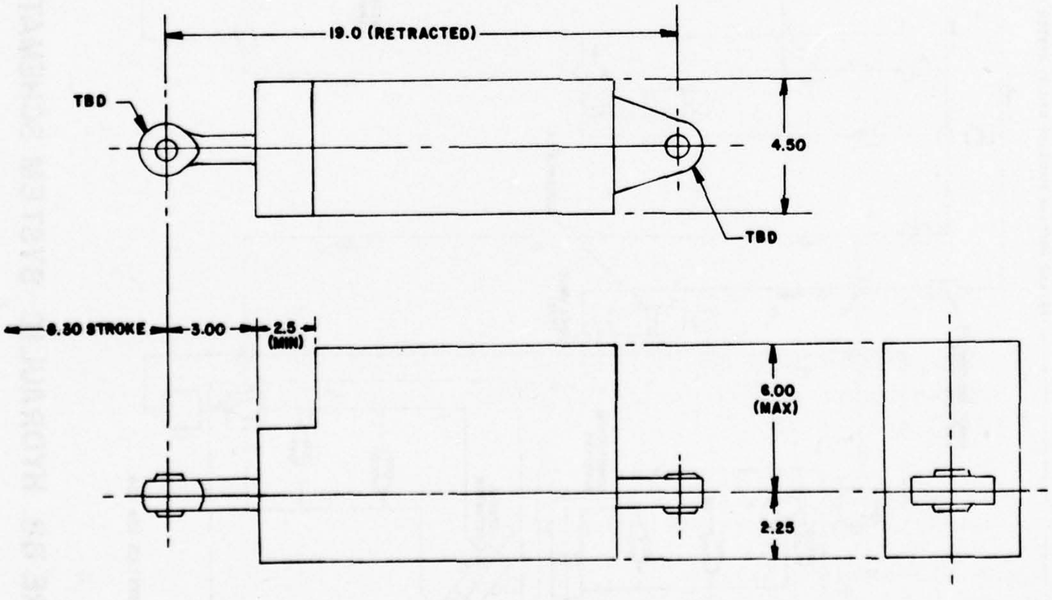
4.1.3.2 Aircraft Interface System

A schematic of the overall AAELSS hydraulic system is included in Figure 68. On the left hand side of this drawing are shown the components installed outside the aircraft on the removable units. These are attached to the aircraft system through quick-disconnect couplings on each unit, similar to those defined by spec numbers 145HS700 for the pressure side, and 145HS701 (minus the relief valve) for the return side.



NOTE: DIMENSIONS IN INCHES

−1 ACTUATOR (LONGITUDINAL)



−2 ACTUATOR (LATERAL)

FIGURE 67. HYDRAULIC ACTUATORS FOR LIGHTWEIGHT REMOVABLE AAELSS

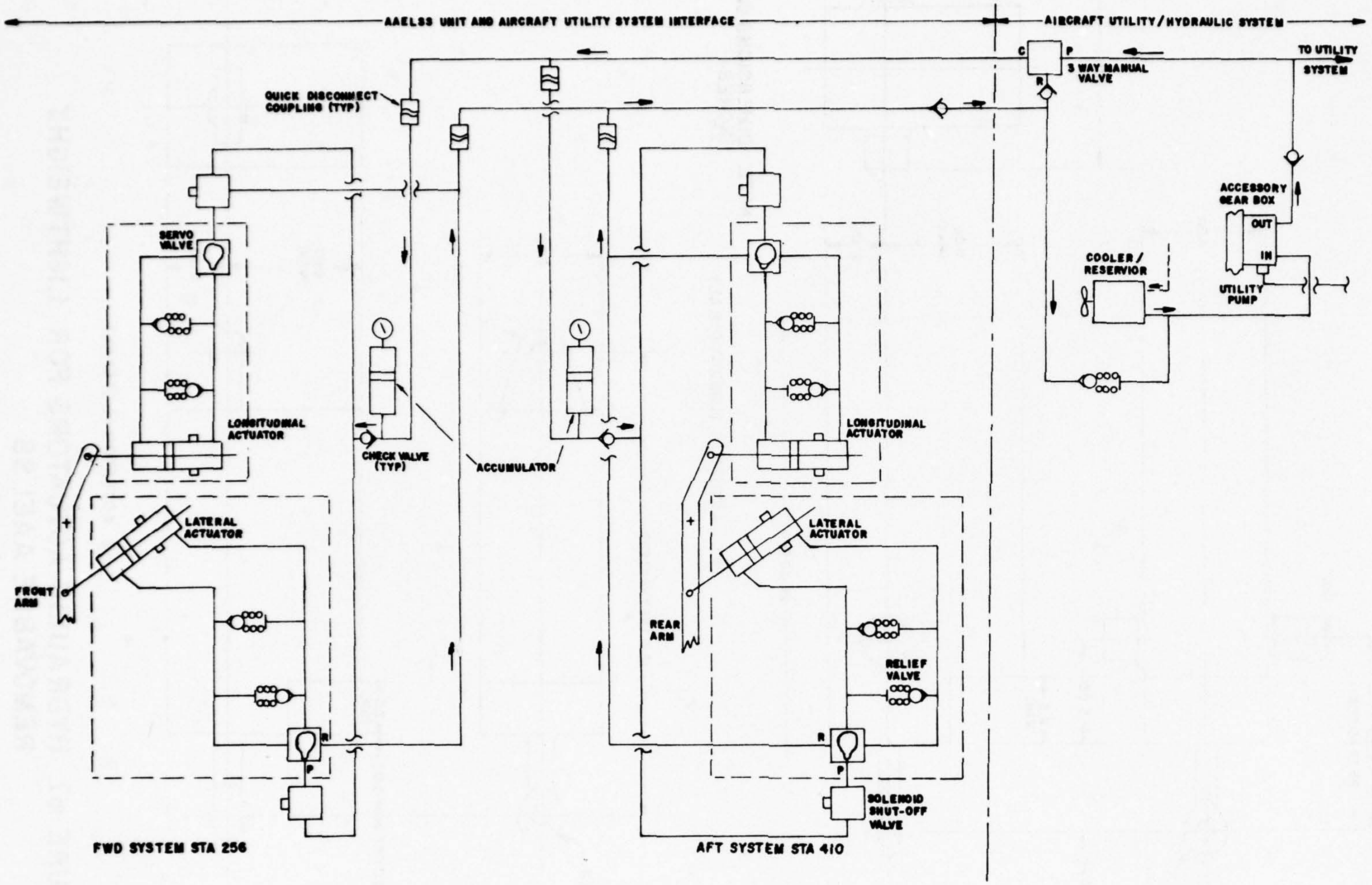


FIGURE 68. HYDRAULIC SYSTEM SCHEMATIC FOR LIGHTWEIGHT REMOVABLE AAELSS

Quick-disconnect receptacles on the lower aircraft skin adjacent to the AAELSS installations are connected to the utility system through a three-way two-position manual shut-off valve shown on the right hand top side of Figure 68. This valve can be operated inflight to prevent system loss of fluid in the event of a leak on either unit, and it is used to shut-off flow when AAELSS is removed. The utility aircraft system is tied into AAELSS supply lines in the area of the tunnel on top of the fuselage, and from there pressure and return lines extend downward to both units located at fuselage stations 256 and 410.

4.1.3.3 Emergency Arm Retraction

An optional scheme for emergency back-up retraction of the arms in the event of EHV electrical failure (and other malfunctions) has been developed. This emergency function permits direct transfer of pressure to the retract (extension) side of the actuator piston, and also opens up the other side of the actuator to return flow (through use of a five-way three-position solenoid valve). This valve replaces the on-off solenoid valves shown for the longitudinal actuators in Figure 68.

4.1.4 Electrical and Control System Design

The AAELSS electrical system is similar to the one used with AAELSS II, except for the fact that the mid-cabin flight engineer control and test panels have been removed, and the system will have to incorporate redundancy levels commensurate with mission requirements as mentioned earlier. In the event that loads must be carried beyond the speeds to which they would otherwise be stable with a standard sling suspension (which AAELSS would essentially revert to in the event of a system failure), some type of system redundancy must be provided to ensure safety. This includes both electrical and hydraulic components. If terrain flying mission dictates do not indicate a requirement for flying loads beyond stability limits, requirements for redundancy are minimized as in the case of the AAELSS II demonstration system.

Figure 69 presents a schematic of major electrical system components proposed for the AAELSS package. The cockpit control panel with its various functions is shown in Figure 70. As shown in this figure, failure warning lights for each AAELSS axis are provided, along with switches for disabling the entire lateral axis of both units, or each longitudinal axis separately for partial system operation. Extend, operate, and retract switching is included on the panel and operates in conjunction with the master power switch shown in the top left hand corner of the control console.

An optional load cable angle and arm angle display may be included among cockpit information presented in the plot, if flight testing with such a device indicates that it helps the pilot modulate maneuver severity or diagnose system failure modes more rapidly.

4.1.5 System Weight Breakdown

Table 15 presents an estimated weight breakdown for the removable AAELSS just described. The 698-pound weight increment for system installation satisfactorily meets design objectives for reducing weight, since the sytem will weigh about 1/3 of that test flown during the AAELSS II program. The estimated AAELSS weight penalty is significantly less than the projected weight of the snubbing device (2,140 pounds).

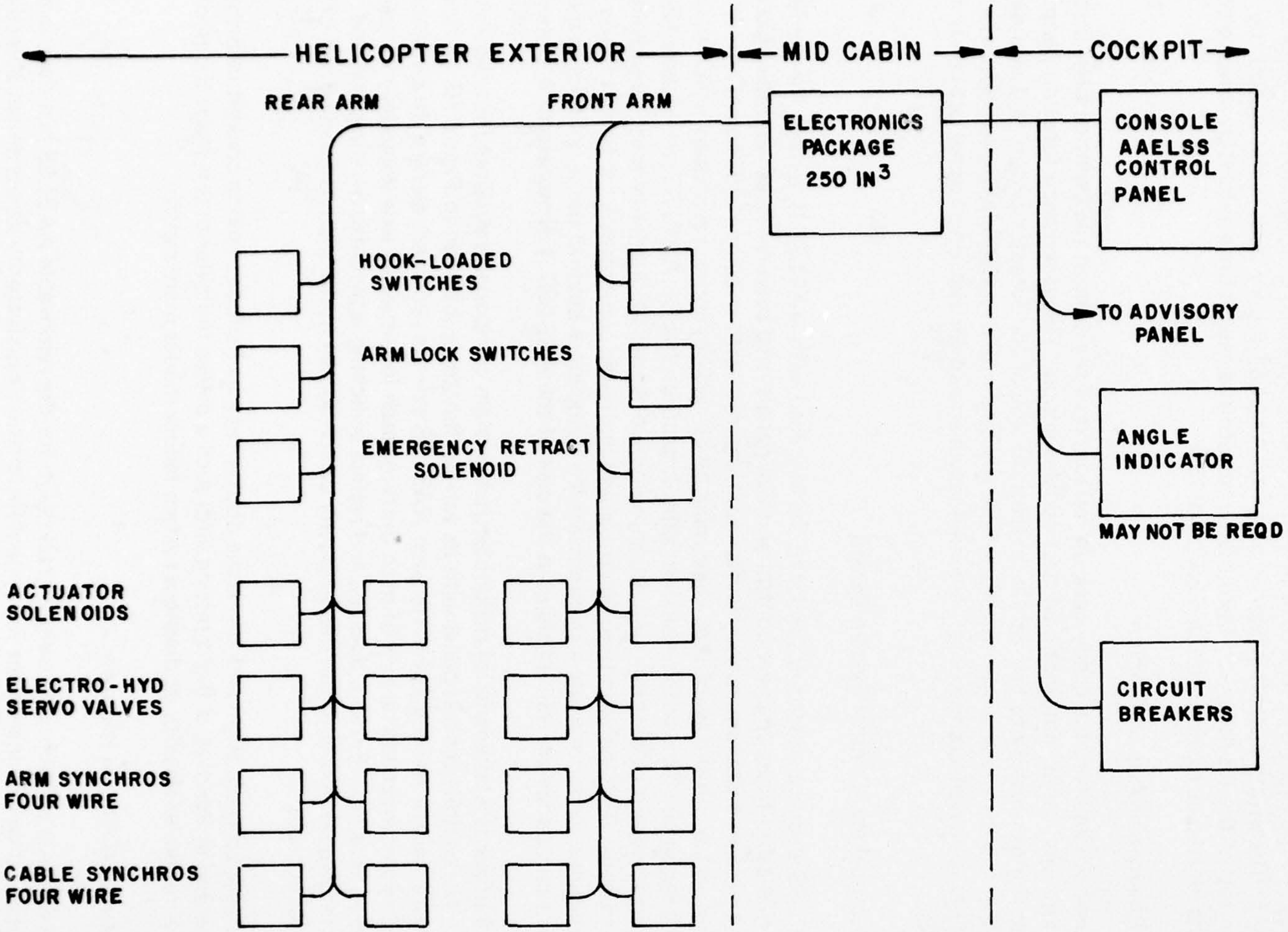


FIGURE 69. AAELSS ELECTRICAL SYSTEM

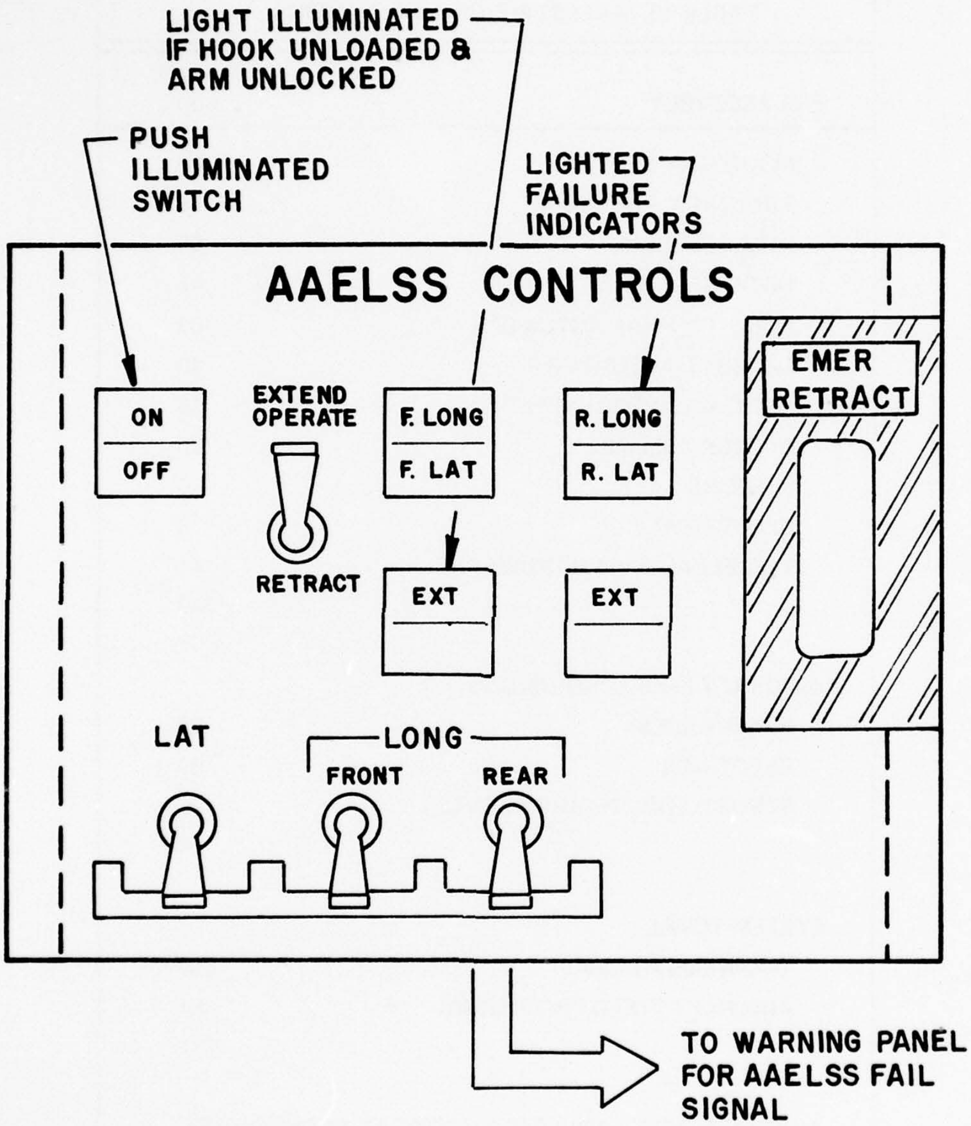


FIGURE 70. LIGHTWEIGHT-REMOVABLE AAELSS COCKPIT CONTROL PANEL

TABLE 15. AAELSS WEIGHT BREAKDOWN

PER ASSEMBLY		WEIGHT (LB)
MOUNTING BRACKET		30
TRUNNION FITTING		28
ARM ASSEMBLY		65
HOOK ASSEMBLY		47
LONGITUDINAL ACTUATOR		50
LATERAL ACTUATOR		40
HYDRAULIC EQUIPMENT		16
UPLOCK ASSEMBLY		20
SENSORS		6
ELECTRICAL		6
MISCELLANEOUS HARDWARE		41
		349
AIRCRAFT FIXED PROVISIONS		
HYDRAULICS		38
ELECTRICS		30
STRUCTURAL REQUIREMENTS		26
		94
SYSTEM TOTAL		
TWO ARMS AT 349	=	698
AIRCRAFT FIXED PROVISIONS	=	94
		792
AIRCRAFT DELTA 792 LESS 2 HOOKS AT 47 EACH = 698		

4.2 SELF-HOISTING INTERFACE (CONTAINER HANDLING) DEVICE

4.2.1 System Concept and Operation

A second concept investigated for minimizing masking and load motion while terrain flying snugs the load against the fuselage lower surface as shown in Figure 52. Application of the snugging (or snubbing) technique produces the lowest overall height of load and aircraft possible for masking (except with internal cargo), and stops load sway motion relative to the fuselage to improve aircraft maneuverability.

The Self-Hoisting Interface Device (SH-CHD) concept has been developed primarily for use with MILVAN and gondola payloads on a tandem hook configured CH-47, but with modification is applicable to other types of cargo. It consists of five major components:

- A toplift adapter frame with twistlock corner attachments to secure the load to the frame.
- Guide arms to position the device over the MILVAN or gondola.
- Vibration-isolation attachment fittings on either end, to interface with tandem receptacles mounted on the aircraft underside.
- An electrically powered hoist with two drums, pulleys, and cable assemblies.
- An electrical umbilical cord and control system for the device.

Operation of the system is as follows:

- The device would normally be positioned initially on the ground or on a truck bed, supported by its six guide arms. Both cables would be extended fully, providing about ten feet of length between the cable pulley on the device, and the eye end of the cable which is to be connected to the aircraft forward and aft tandem cargo hooks.
- With the CH-47 hovering over the device, the umbilical cable would be connected to the helicopter, and the two cables attached to the aircraft hooks. The aircraft would lift the device, fly to the load with cables extended, and then acquire the load as shown in the sketch on Figure 52.
- With the device locked, the aircraft would lift the load clear of the ground, and while in hover the hoist would be energized to raise the load and device to intercept the attachment receptacles on the fuselage. When the device is fully engaged in the attachment points, the hoist would be stopped and the vibration isolating attachment probes locked. After locking, the hoist is reversed to unload the cables.
- Depositing the load would require the operation to be reversed, so that release is accomplished with the device suspended on its hoisting cables.

4.2.2 Design Criteria

Design guidelines followed in the development of the SH-CHD considered weight, payload and load factor requirements, aircraft interfacing, cargo handling device configuration, and desired operating life.

4.2.2.1 Weight

The device, and modifications required in the aircraft to accept and carry it, was to be as light as practical,consistent with functional requirements, structural integrity, and normal use associated with repeated helicopter external container handling operations.

4.2.2.2 Payload – Load Factor

Several approaches were explored in defining payload and load factor requirements for the SH-CHD. One of these considered reducing load factor requirements for the hoist and cable elements, in an attempt to lower the overall weight penalty of the system. The use of a reduced 1.5g load factor (instead of 2.0g) for hoisting operations would be a reasonable alternative, if all hoisting were to be conducted in hover, and the aircraft not transitioned into forward flight. This approach, although viable from an operational tradeoff standpoint, was not found to be a significant weight saving and was therefore eliminated from consideration.

The final criteria adopted for design of the device were essentially the same as those applied in development of the tandem hook system on the YCH-47D. Using the same 2.0g load factor for both the hoist and other system components allows the aircraft to fly away during hoisting operations should such a necessity arise. The major payload/load factor criteria include:

- Overall payload – 25,000 pounds
- Max load either suspension – 15,000 pounds (60 percent/40 percent split)
- Cable departure angle 30 degrees – 1.15 (safety factor)
- Limit load factor – 2.0g (same as hooks)
- Ultimate load factor – 1.5 x 2.0g = 3.0g

4.2.2.3 Aircraft Interface

A primary goal in defining aircraft interface structure was to minimize the number of required airframe modifications (with associated weight penalties), and use existing tandem hook support structure where possible.

4.2.2.4 Self-Hoisting Interface Device Configuration

The device was to be configured for ease of manufacture and simple functional operation. Use of advanced state-of-the-art structural techniques, including sandwich construction, and new lightweight cable assemblies, were to be considered in system design implementation.

4.2.2.5 System Life

The system design life goal was to permit 50,000 hoisting cycles with the cable/hoist combination.

4.2.3 Preliminary Design Study

Preliminary design studies were conducted to establish an overall configuration for the device and its aircraft interface hardware. Trade studies were also done for both the cable and hoist assemblies. Results of this initial investigation are illustrated in Figures 71 and 72, and in Table 16.

4.2.3.1 Suspension Scheme

Initial layouts considered snubbing the load on vibration isolators located above each of the four corners of the load. Examination of potential variations in the load/fuselage interception angle caused by cg offset and load rolling motions (as shown in the right hand Figure 71 sketch) revealed that the four point suspension scheme would require excessively large receptacles on the fuselage to ensure attachment probe capture. Accordingly, a simplified approach was adopted which utilized only two alignment attachment points for the load; both located on the aircraft centerline with one in front of the forward tandem hook, and the other behind the aft hook as shown on the bottom of Figure 71.

This attachment configuration utilizes some of the tandem hook backup structure already in the aircraft, and is therefore more weight efficient than the 4-point design. It does,however, require some additional fuselage structure under the four corners of the load (as illustrated in Figure 71), to provide striker plates for lateral load sway-bracing stabilizer devices.

4.2.3.2 Cable Trade Studies

Cable design is the basis for combined suspension and hoist designs, since it greatly influences size and weight of the lifting part of the SH-CHD system. Design considerations driving cable selection include:

- minimizing diameter and maximizing flexibility
- providing high strength-to-weight ratio
- providing adequate fatigue life

Recent work done with cable design in the Heavy Lift Helicopter program has established that the cable criteria stated above can be met with new configurations in metallic and nonmetallic cable construction. Either would provide substantial improvement in diameter reduction and weight over use of standard MIL-W-1511 or 5424 cable.

Of the criteria listed, diameter is the most critical to overall system weight. The minimum diameter and high strength-to-weight combination is best met with a 36 by 7 swaged strand metallic cable. While a nonmetallic Kevlar cable would have a 4:1 strength-to-weight ratio, present technology does not permit use of diameters as small as with the 36 by 7 steel cable. Lengths somewhat greater than those used with the system are required before the Kevlar weight advantage can be used.

Two cable designs satisfying the 15,000 pound/2g load carrying capacity requirements (and alternatives described earlier) are reviewed in Table 16. These include a 9/16-inch diameter 36 by 7 swaged strand electro-galvanized carbon steel cable, and a PS-29-6 by 19 Kevlar (impregnated strand) 25/32-inch diameter cable. The configurations selected as best for CHD application are designed to support loads of 52,500 pounds. In addition to sizing information, the table also lists appropriate cable weight figures, drum and sheave diameters, and comparable MIL-W-1511/5424 cable characteristics (at the bottom) for comparison.

Selection of either the steel or Kevlar cables for application in a prototype SH-CHD would probably depend upon availability and delivery dates. Suitable cable end fittings which permit 100 percent efficient load transfer were developed during the HLH program for steel cable, but are still under development for application with Kevlar.

Developmental status of end fittings for the lighter Kevlar cable would have to be assessed prior to selecting cable material for a CHD suspension system.

TABLE 16. CABLE DESIGN ANALYSIS

CABLE WEIGHT/STRENGTH STUDY

PAYLOAD	OFFSET ΔCG	CABLE ANGLE FACTOR	LIMIT LOAD FACTOR	ULT LOAD FACTOR	STRENGTH (TOD)	BENDING FACTOR	F_{TU}	REMARKS
(1,000 LB)	%				(1,000 LB)		(1,000 LB)	
25[1]	0.60	---	1.5	1.5	33.8	1.015	34.3	NO FLY AWAY ALLOWANCE
↓	↓	1.15	2.0	↓	51.8	↓	52.5	BASIS: = A/C STRUCTURAL CRITERIA
33.3		----	↓		60.0		60.9	BASIS: TANDEM HOOK CAPABILITY

CABLE ALTERNATIVES – HIGH STRENGTH/WEIGHT DESIGNS

	STEEL[2]						KEVLAR[5]					
F_{TU}		d[3] (IN.)	D/d	D (IN.)	WT (LB/FT)	LIFE		d (IN.)	D/d	D (IN.)	WT (LB/FT)	LIFE
34.3	15/32	0.472	25	11.8	0.45	50K	5/8	0.632	29	18.3	0.121	50K
52.5	9/16	0.585	↓	14.6	0.69	↓	25/32	0.783	20.5	16.0	0.186	↓
61.0	5/8	0.631		15.75	0.78		27/32	0.85	18.5	15.7	0.219	
66.5[4]	7/8	0.875		21.86	1.43	---		---	---	---	---	

REF:

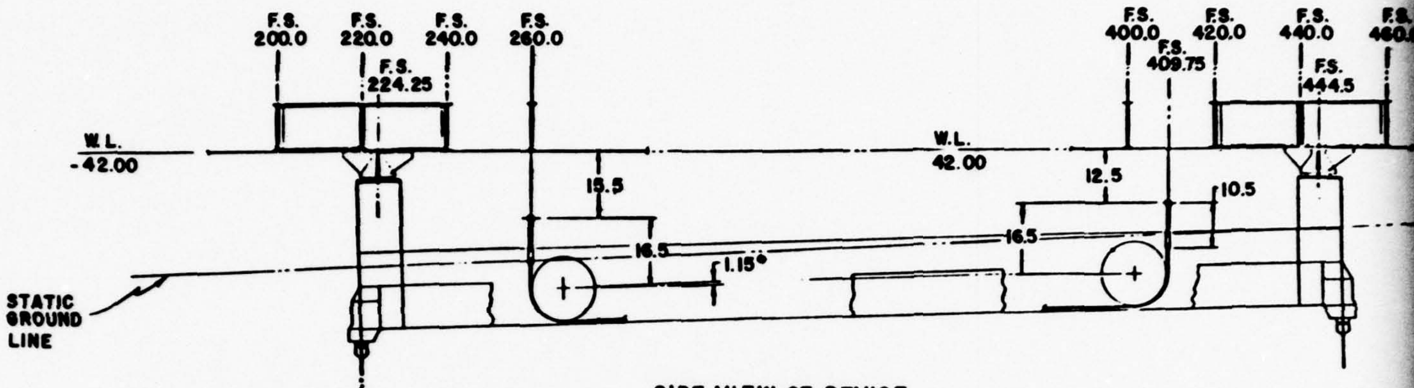
1 CH-47D STRL CRIT DOC 145-SS-603 (PG 20) AGW = 50,000 LB PAYLOAD = 25,000 LB

2 TR 74-97C (PG 273) 36X7 EGCS, SWAGED, 0.78 IN. DIA F_{TU} = 93,500 LB, F_{TOD} = 92,300 LB, WT = 1.219 LB/FT

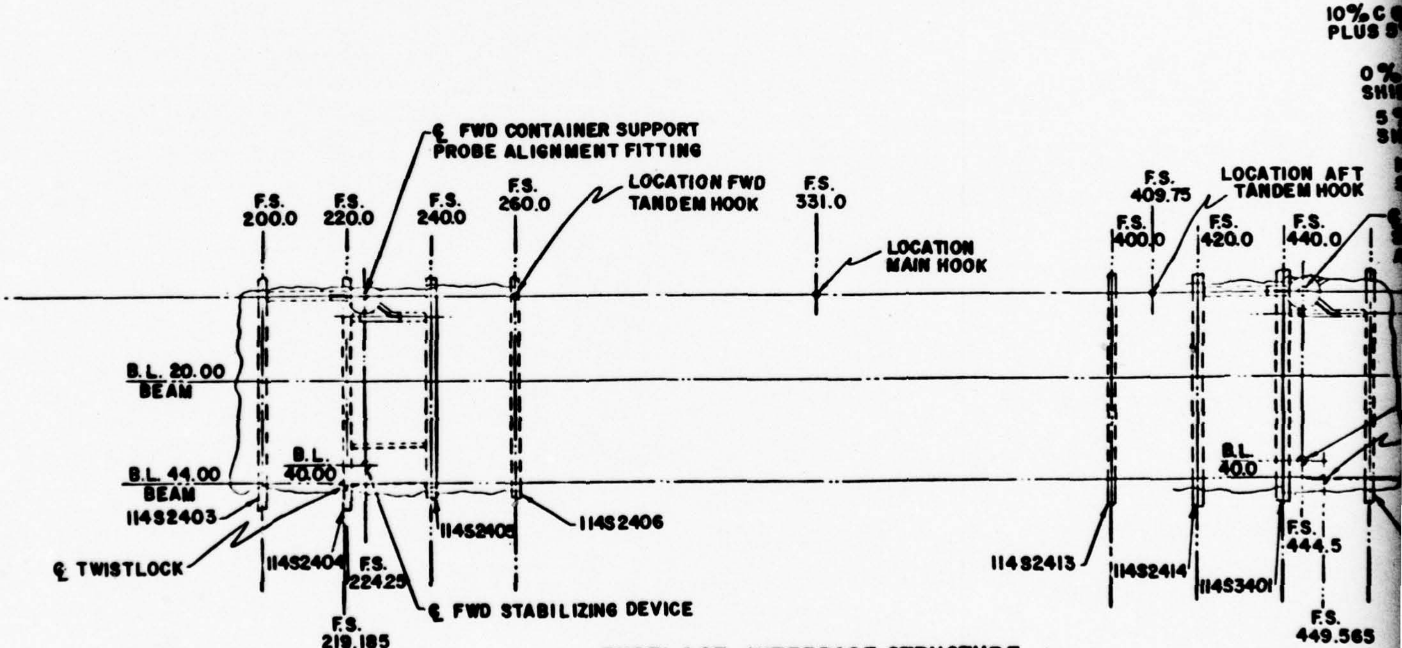
3 $d_2 = d_1 \sqrt{F_{TU_2}/F_{TU_1}}$

4 MIL-C-1511 EGCS & 5424 CRSS, 6x19 IWRC

5 BASIS: PS29 6x19x0.70, MBS 42,000 LB, WT 135 LB/1,000 FT + 10% FOR JACKET = 0.149/FT ASSUME 1.5% BEND. LOSS

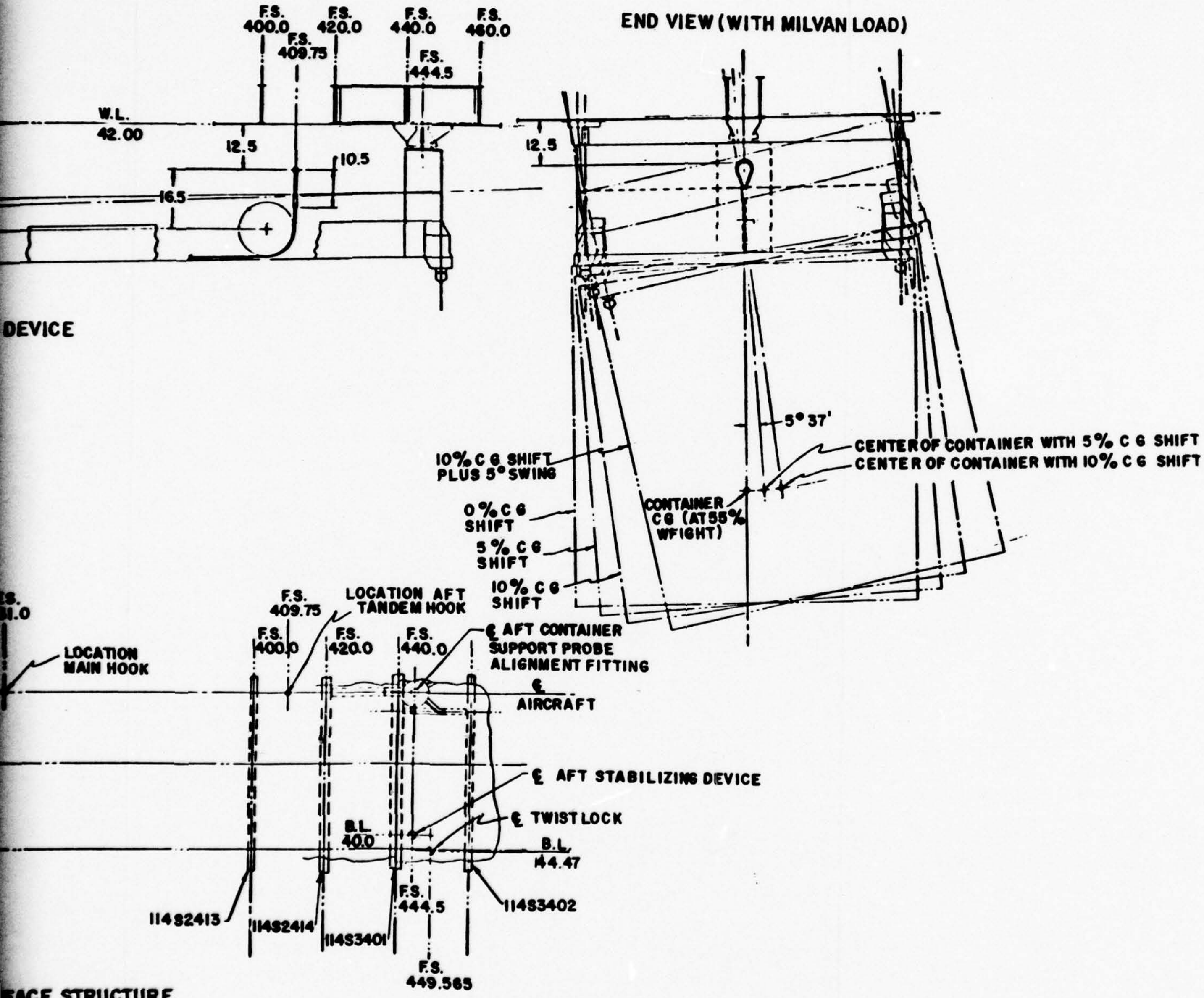


SIDE VIEW OF DEVICE



FUSELAGE INTERFACE STRUCTURE

FIGURE 71. PRELIMINARY DESIGN STUDY FOR SELF-HOISTING (
INTERFACE DEVICE



DEVICE

FACE STRUCTURE

DESIGN STUDY FOR SELF-HOISTING (CONTAINER HANDLING)
EVICE

2

4.2.3.3 Hoist

A constant speed 115V, 400 Hz, three-phase AC powered hoist, delivering 10 HP, was selected for application on the CHD, as shown in Figure 72. The AC electric motor drives dual drums (through a bevel gear train and brake assembly) in opposite directions to reel in each cable. The multi-plate brake system is designed to engage when load torque exceeds motor torque. Several candidate drum, hoist, and gear train combinations were studied to produce the final configuration shown in Figure 72. Incremental weight breakdown for the various hoist components shows an overall minimum weight achievable to be in the range of 500 pounds as shown below:

	Weight – Lb
Motor, high speed gearbox and brake	38
Low-speed gearing	182
Drum and end supports	80
Support assembly	127
Cable assemblies	48
Holddown rollers	25
Total	500

These weight increments are predicated upon scaling down hoist components from the dual drum 28-ton HLH hoist described in Reference 20.

As shown in Figure 72, the hoist assembly is mounted at an angle to the CHD centerline. This configuration resulted from preliminary hoist studies, which indicated a need to minimize cable fleet angle (fleet angle is the angle that the cable makes with the drum or pulley sheave when looking down on the hoist assembly). Minimizing fleet angle reduces component wear, and conditions that place undesirable sideloads on the cable and sheave assemblies.

4.2.4 Final System Design Concept

Figure 73 presents a layout of the interface device in its final terrain flying study configuration. Aircraft structural modifications required to support and stabilize the snubbed load are shown in Figures 74 and 75. Design concepts shown in these sketches have considered prospective load transfer paths, approximate sizing of components, and functional layout of system elements to achieve design objectives. A detail analysis of system requirements; along with in-depth design, structural, and application analysis must be performed in implementing these design concepts for a prototype SH-CHD unit.

4.2.4.1 Interface Device

As seen in Figure 73, the structure of the lifting frame would consist of two box-type end frames connected by a rectangular structure housing the hoist and pulley sheaves. The vertical panels would be of aluminum honeycomb sandwich construction with sheet and extended aluminum caps and formers. Upper and lower panels of the rectangular center structure would be honeycomb panels in areas of high shear stress, and aluminum sheet in areas of lower stress level.

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20. Campbell, R., et al, Heavy Lift Helicopter – CARGO HANDLING ATC PROGRAM – VOLUME 1, DETAIL DESIGN,STRUCTURAL AND WEIGHT ANALYSIS, AND STATIC AND DYNAMIC LOAD ANALYSIS, Boeing Vertol Company, USAAMRDL Technical Report 74-97A, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1976, AD A030072.

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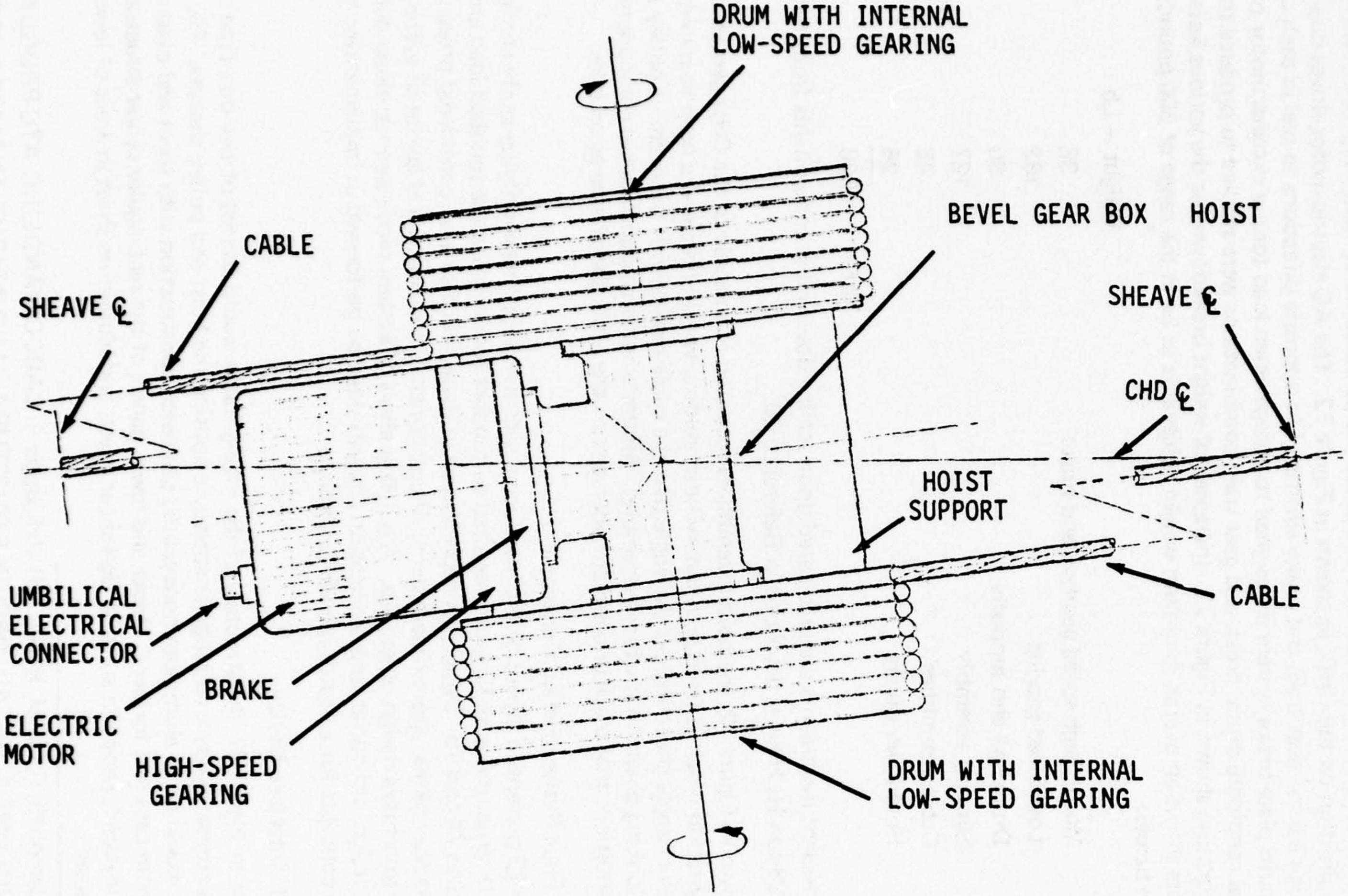


FIGURE 72. SCHEMATIC - DUAL DRUM HOIST FOR SELF-HOISTING (CONTAINER HANDLING) INTERFACE DEVICE

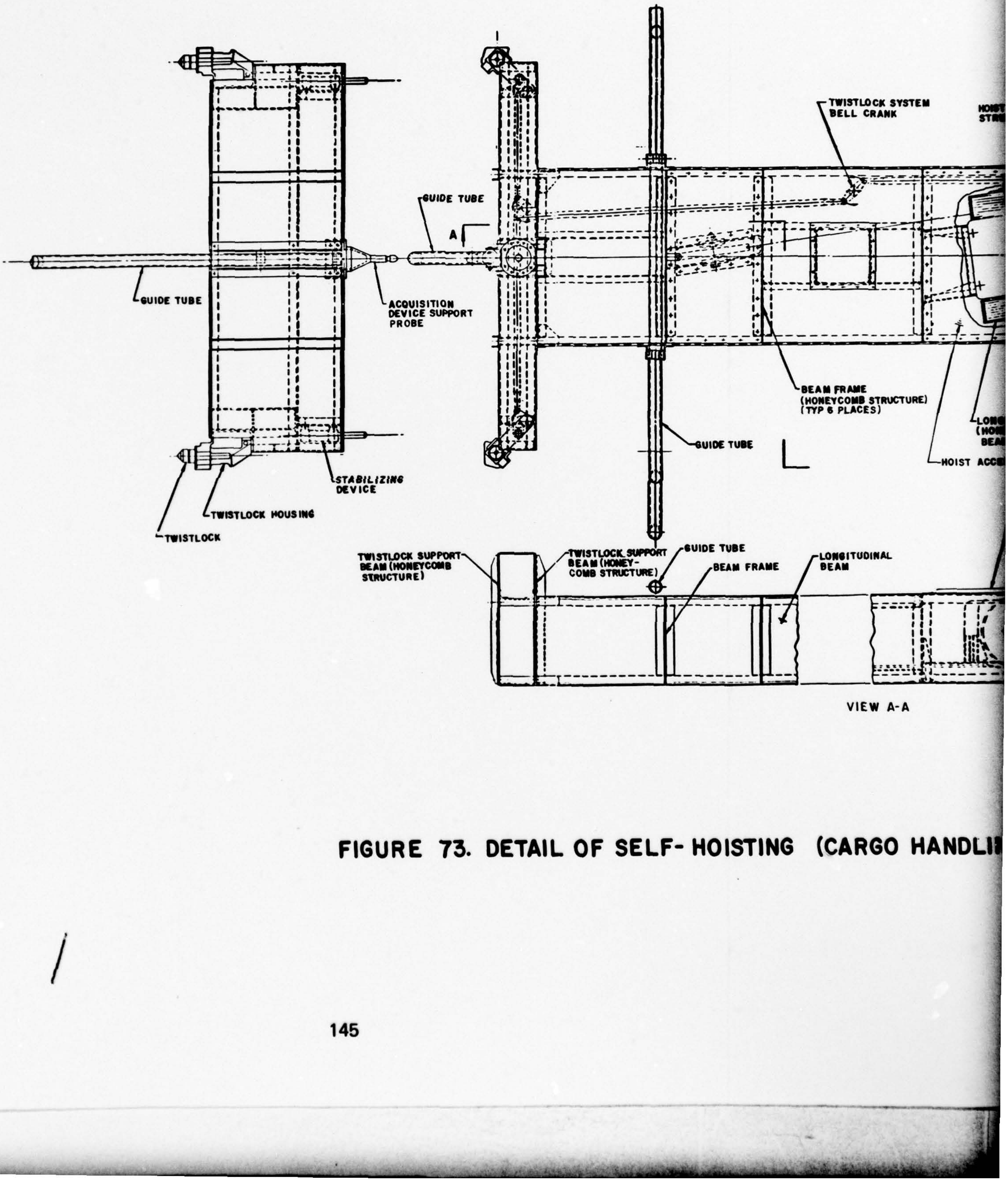
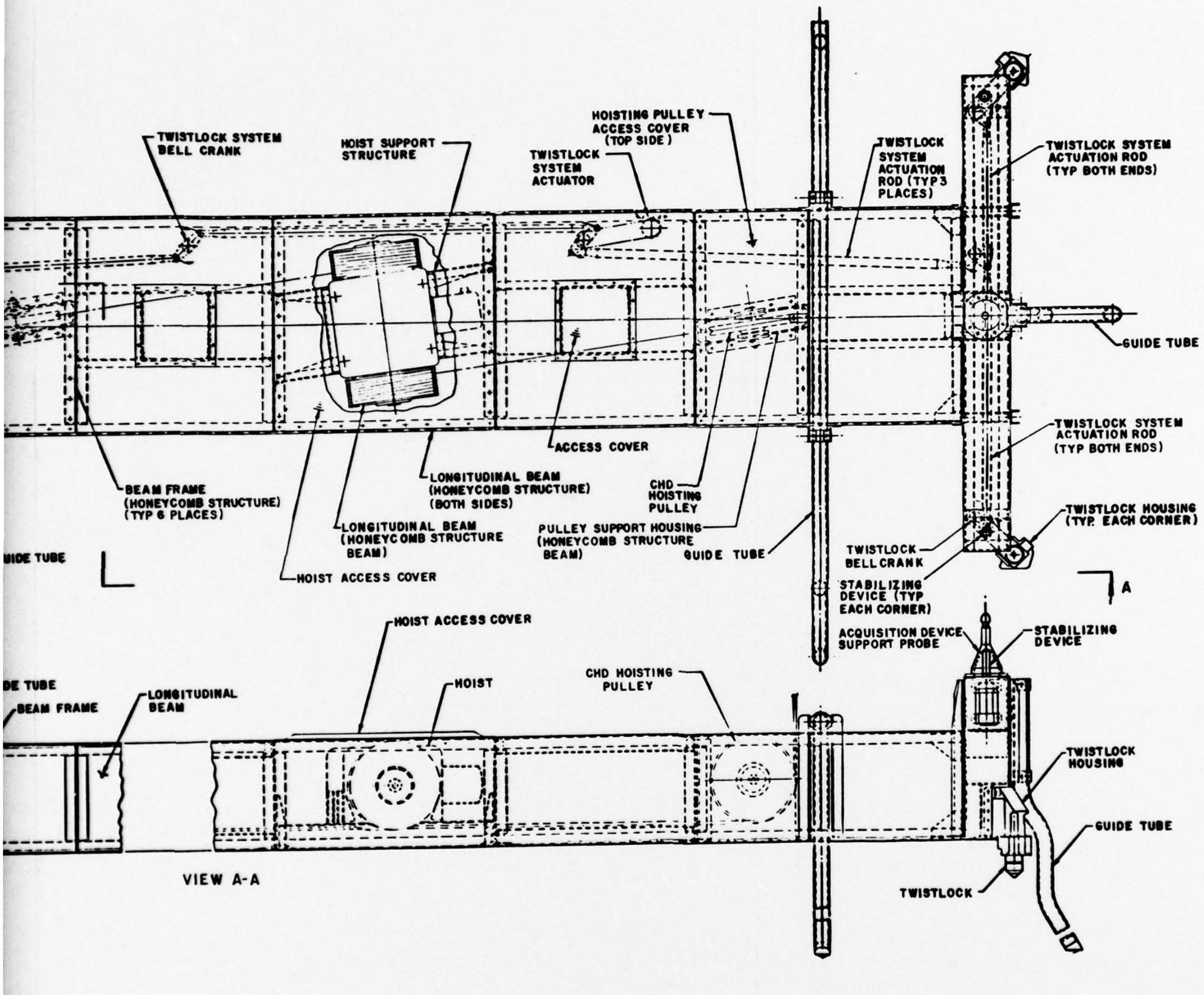


FIGURE 73. DETAIL OF SELF-HOISTING (CARGO HANDLI



OISTING (CARGO HANDLING) INTERFACE DEVICE

2

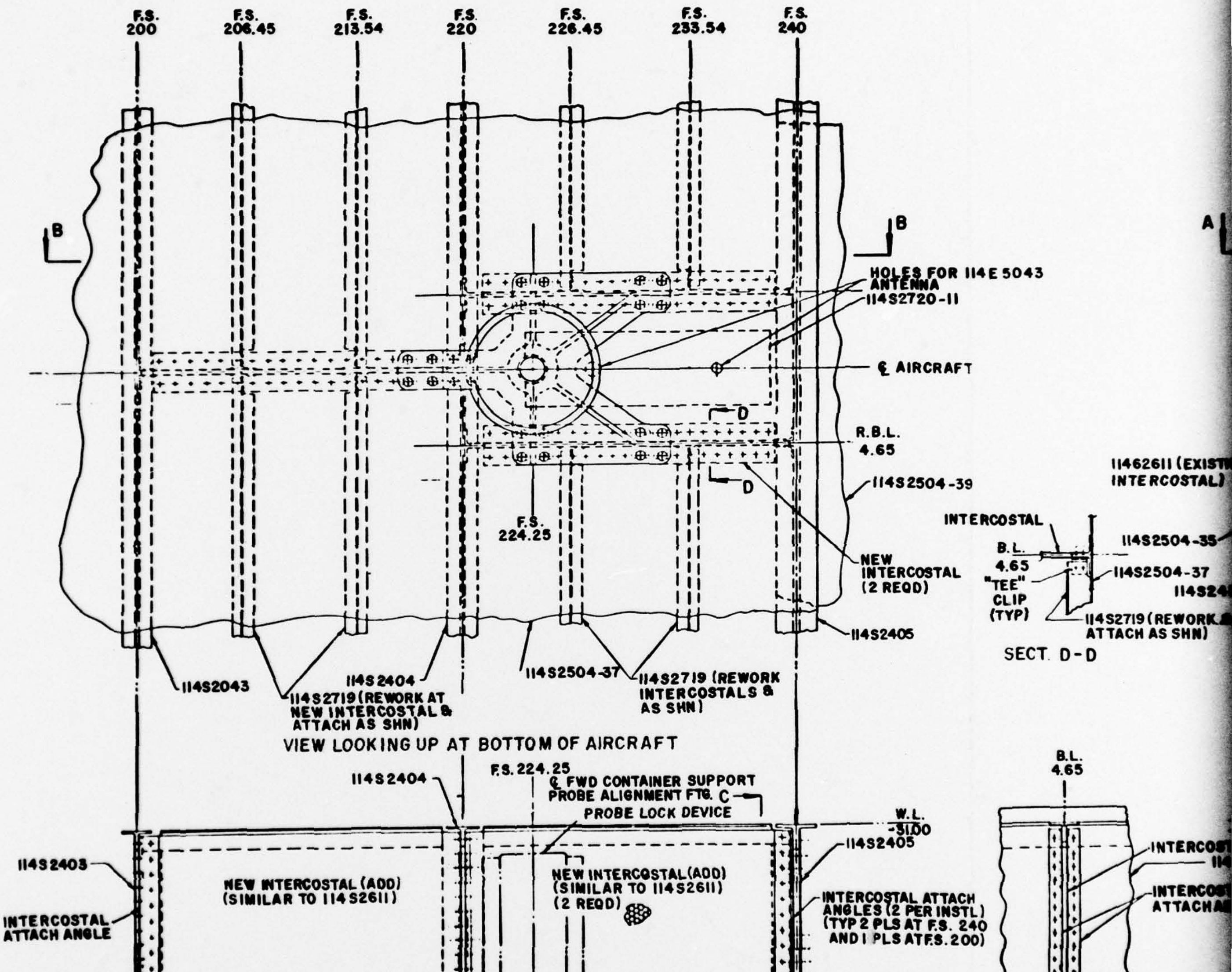
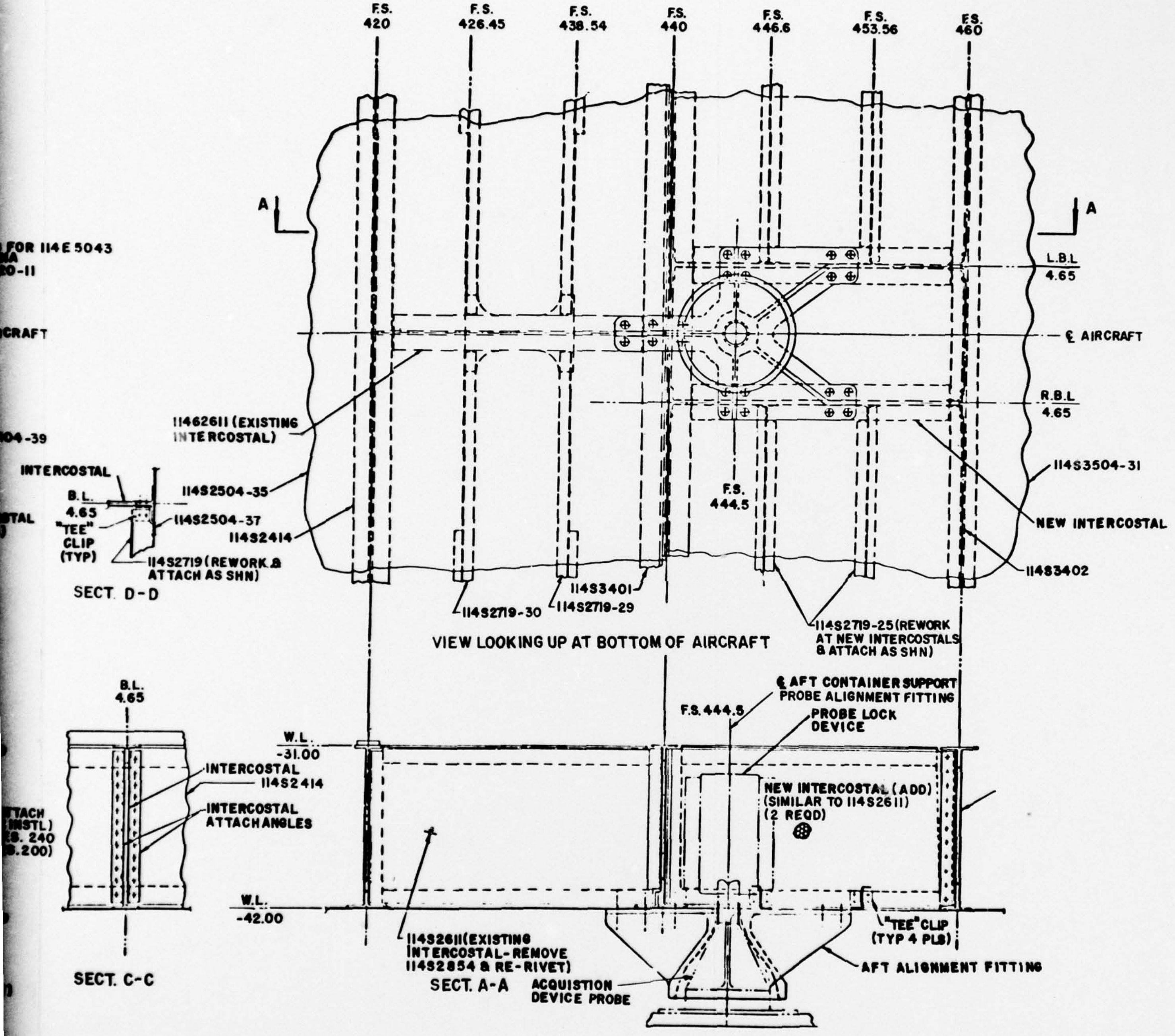


FIGURE 74. AIRCRAFT STRUCTURAL BACKUP FOR



RAL BACKUP FOR SH-CHD ALIGNMENT/ ATTACHMENT RECEPTACLE

2

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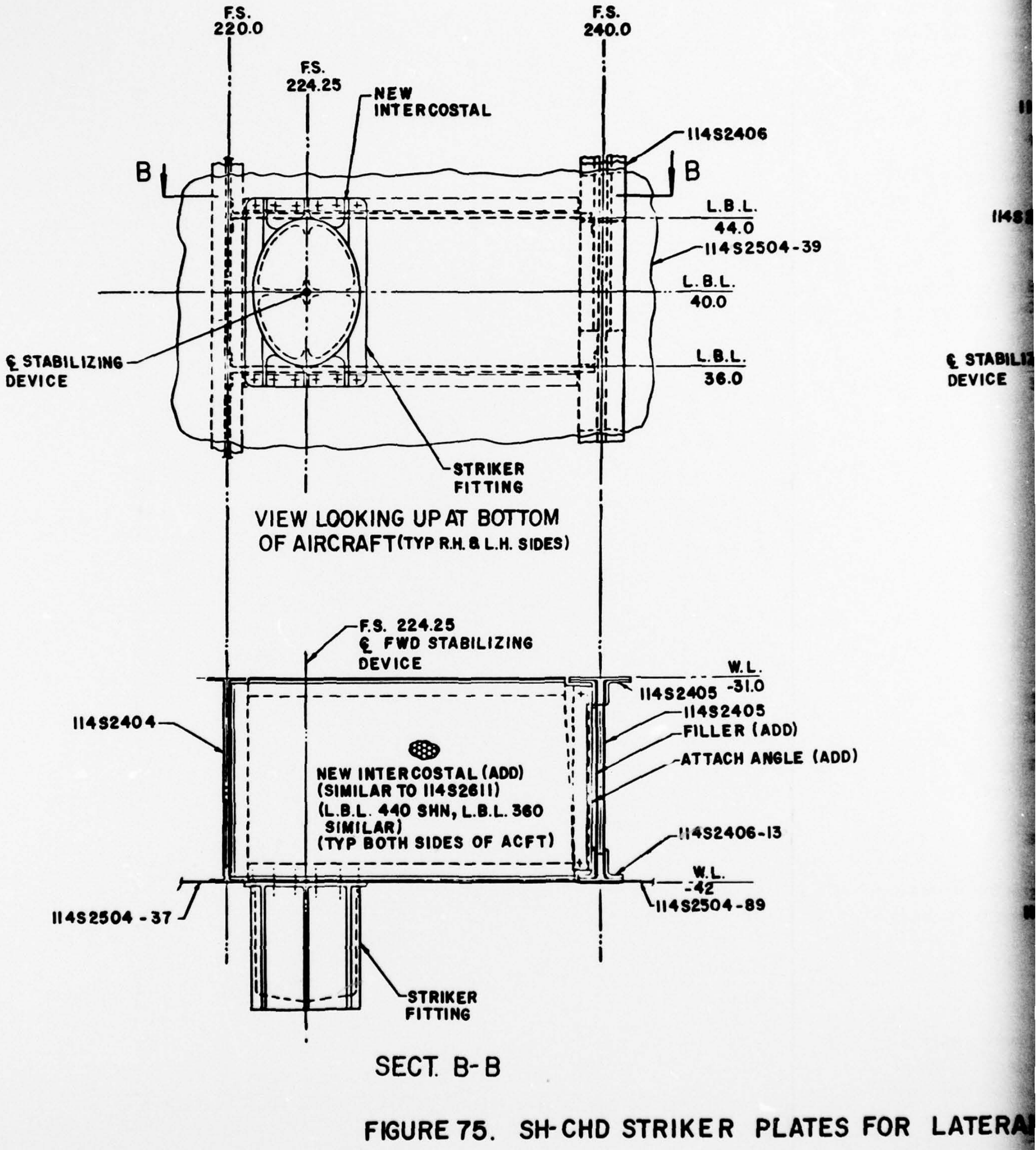


FIGURE 75. SH-CHD STRIKER PLATES FOR LATERA

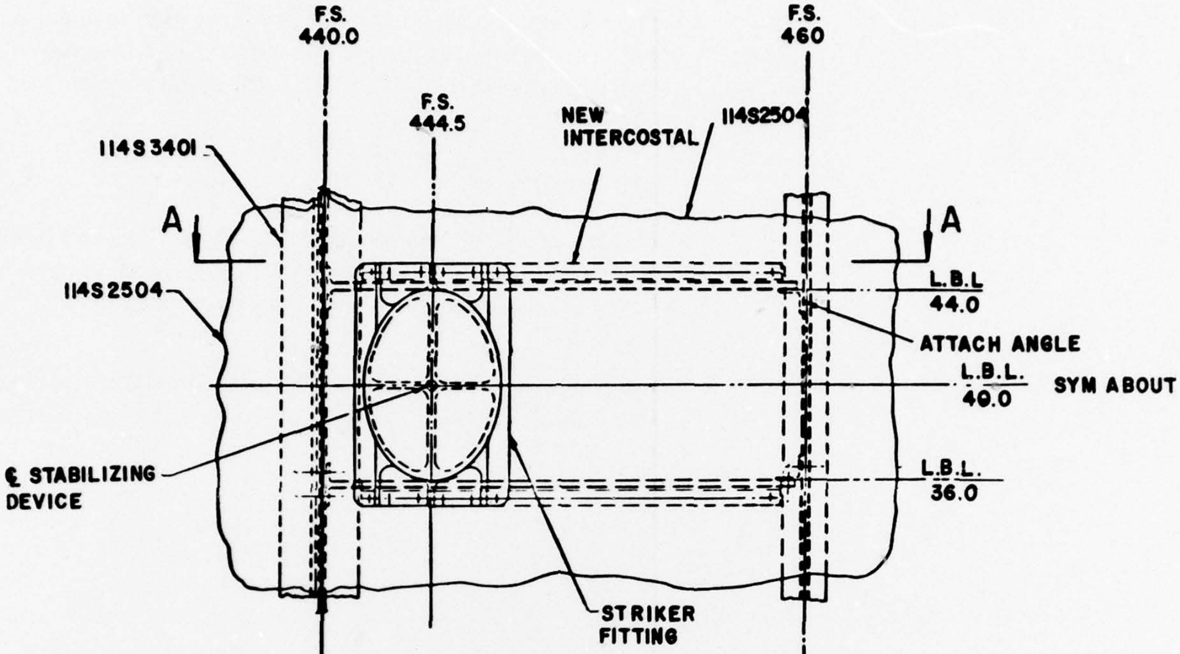
06

L.
5
2504-39

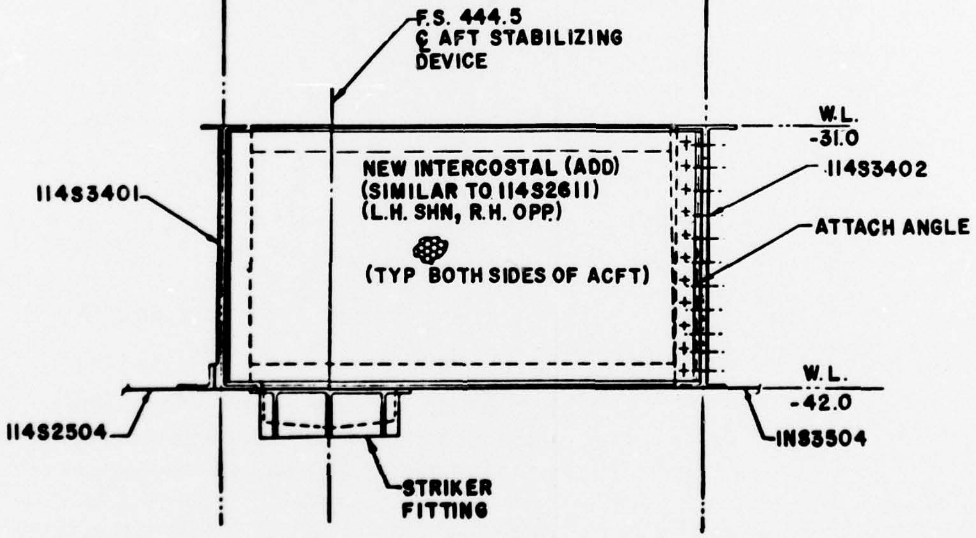
L.
1.0
05
(ADD)
ANGLE (ADD)

6-13

39



VIEW LOOKING UP AT BOTTOM OF AIRCRAFT (TYP BOTH SIDES OF ACFT)



SECT. A-A

PLATES FOR LATERAL LOAD STABILITY

2

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Electrically actuated twistlock corner attachments to fasten the load to the interface device would be identical to components designed for the Militarized Container Handling Device (MIL – CHD). Unlike components on the MIL – CHD, the guide arms are not retractable, but are readily removable if required.

4.2.4.2 Load Isolation and Attachment

Vibration isolation attachment probes shown at either end of the CHD in Figure 73 consist of a liquid spring cylinder assembly attached to the device structure, and a piston-rod probe which is shaped to suit the airframe-mounted alignment and locking receptacle.

The liquid spring will incorporate an air-or nitrogen-charged temperature compensation unit, to reduce the effect of dynamic spring rate variation due to temperature. Design of this unit would be based upon technology developed for the HLH hoist load isolator.

Aircraft structural modifications required include installation of two attachment/alignment receptacles and four striker plate assemblies shown in Figures 74 and 75. The attachment receptacles would include tapered bellmouth lead-in guides to direct the piston rod end into an integral locking mechanism. Striker stabilization devices shown at the corners of the device in Figure 73 consist of springloaded pistons, with travel limited so as to transmit compression loads resulting from load rocking motions.

4.2.4.3 *Electrical Power and Control*

Electrical power and control signals are transferred from the aircraft to the SH-CHD through an umbilical cable mounted on a constant-tension reel attached to the device. A breakaway fitting is included at the aircraft to allow the device to be jettisoned.

Two emergency release modes are provided electrically: one jettisons the container or gondola from the handling device and leaves the CHD attached to the aircraft, and the other mode simultaneously releases both attachment locks and aircraft hooks to drop both the device and payload together. Requirements to release the device in the event of snagging the load on an obstacle while maneuvering in terrain flight need to be explored in any prototype design implementation.

A block diagram outlining SH-CHD electrical system components and requirements is presented in Figure 76. Control functions are provided through 28V DC power, and both the hoist and corner twistlock units are 115V/400 Hz AC powered.

4.2.5 System Weight Breakdown

Preliminary estimates for SH-CHD and aircraft associated system component weights are given in Table 17. Total weight penalty for the snugging system is on the order of 2,144 pounds, with 1,899 pounds of this representing the hoistable adapter. Structure permanently mounted in the aircraft would weigh about 215 pounds and the electrical system 30 pounds. Some of the electrical/control system could be designed to be removed from the aircraft when not in use.

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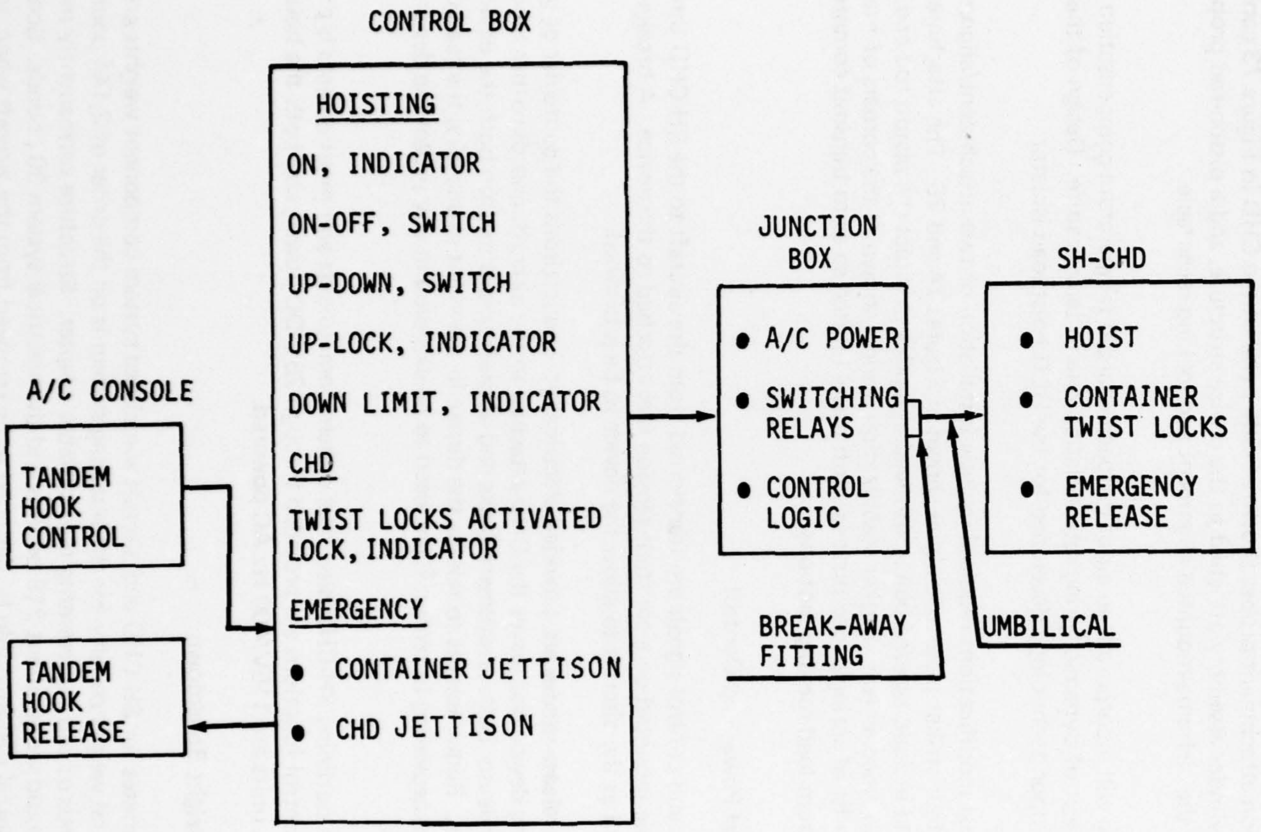

FIGURE 76. SCHEMATIC - INTEGRATED CONTROLS FOR CH-47D AND SELF-HOISTING (CONTAINER HANDLING) INTERFACE DEVICE

TABLE 17. SELF-HOISTING CONTAINER HANDLING DEVICE WEIGHT BREAKDOWN

	WEIGHT – LB	
DEVICE STRUCTURE	816	
HOIST SYSTEM	500	
GUIDES	268	
TWIST-LOCK SYSTEM	120	
ISOLATORS	60	
SHEAVES	40	
UMBILICAL REEL	25	
ELECTRICAL SYSTEM	40	
	1,869	
CONTROL PANEL & UMBILICAL	30	
TOTAL REMOVABLE		1,899
FIXED STRUCTURAL PROVISIONS IN AIRCRAFT	215	
FIXED ELECTRICAL REQUIREMENTS IN AIRCRAFT	30	
	245	
TOTAL FIXED PROVISIONS		245
SYSTEM TOTAL		2,144

4.2.6 Prototype Implementation

Additional items requiring analysis as a part of implementing any prototype SH-CHD design effort include:

- A dynamic analysis of the aircraft/load combination to establish requirements for a load isolation system. If isolation is found to be necessary and desirable as expected, criteria for its design and operation must be formulated.
- A study of antenna pattern degradation, as influenced by the snugged load, must be conducted. New locations for adversely affected antennas must be found, and designs developed for relocating these items.
- A design study to determine aircraft/load locking configurations with redundant release systems must be made.
- A handling qualities study to define potential effects of load aerodynamic interference on airframe stability, and the principal effects of increased aircraft inertia (due to the load) on maneuverability should be evaluated.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Results obtained from this study have determined that the addition of an external load need not reduce the effectiveness of the CH-47 helicopter, as an assault transport on the mid-intensity battlefield. The CH-47 exhibits a good terrain flight potential with external loads, when limitations associated with current suspensions are alleviated. These limitations include:

1. Masking constraints as a result of sling lengths
2. Maneuverability restrictions due to load motion and load/aircraft collisions
3. Speed restrictions due to load instability or drag increase

Cargo suspension system concepts have been identified to minimize the current deficiencies, including the CH-47D dual hook system, shortened suspension lengths, automatic load stabilization, and load snubbing. Conclusions relative to these concepts are:

1. Contour and low level speed capability is significantly improved for aerodynamically unstable loads (MILVAN) with the dual hook system.
2. Short suspensions or snubbed loads improve terrain flight masking, but shortening sling suspensions reduces the maneuvering capability.
3. Active load stabilization can be used with the short suspension to restore aircraft maneuverability. It also removes potential limitations occurring in night/IMC operations due to pilot-induced oscillations, and reduces pilot workload.
4. Load snubbing provides the maximum masking improvements and also eliminates any maneuvering restrictions due to load motion,such as PIO or load-to-airframe collisions.

A preliminary design study of the two most effective concepts including an "Active Arm External Load Stabilization System" and a "Self Hoisting Interface (Container Handling) Device" shows that the weight penalty for the AAELSS approach is about 1/3 of the SH-CHD (698 pounds vs 2,144 pounds). Advantages and disadvantages of each approach are discussed in Section 3.3.1.5. Both concepts should be carried forward to a terrain flight demonstration.

Utilization of the CH-47 in a terrain flight environment at night or in reduced visibility requires solutions for the following additional limitations:

1. Pilot visibility for flight path control and obstacle avoidance
2. Pilot-induced oscillations incurred by light damping of load disturbances

3. Inadequate hover accuracy for load acquisition/placement

4. High pilot workload levels during hover/NOE/contour maneuvers.

Analysis and/or flight experience has shown that both the load stabilization and snubbing systems remove the PIO susceptibility.

Improvements in pilot night vision can be achieved either through use of Night Vision Goggles (NVG) or a forward looking infrared (FLIR) system. Night Vision Goggles provide a limited NOE/contour maneuver capability up to approximately 30 knots, whereas FLIR can provide visual capability permitting NOE/contour maneuvering to 60-80 knots. For wire avoidance the Laser Obstacle Terrain Avoidance and Warning System (LOTAWS) possesses a wire detection range compatible with FLIR, and in conjunction with FLIR provides for safe night/IMC terrain flying. The glare and reflection problems identified in the CH-47 require corrections as noted, before satisfactory night operations can be conducted using NVG or FLIR systems.

Incorporation of ground velocity stabilization and control (derived from 347/HLH concepts) offers a high potential for reducing pilot workload during hover and low speed flight while providing the necessary control accuracy for cargo acquisition and placement. The lightweight doppler navigation system currently under development by U.S. Army can be used as the velocity signal source. As the doppler also appears to be required for terrain flight navigation, no additional sensor costs are incurred.

5.2 RECOMMENDATIONS

Fulfillment of the potential around-the-clock, external load terrain flight capability of the CH-47 requires continued development and evaluation of modifications to the cargo handling and flight-control systems and incorporation of visionic/obstacle avoidance systems. The following recommendations do not address visionics, as that development is being conducted for the Advanced Attack Helicopter.

5.2.1 Recommended Cargo Handling Programs

1 Conduct short suspension restraint flight testing on the available dual hook CH-47 helicopters to verify the reduced maneuverability and PIO susceptibility boundaries in NOE and contour flight modes.

2. Design, fabricate, and flight test a prototype Removable Active Arm External Load Stabilization System.

3. Continue development of the Self-Hoisting Interface (Container Handling) Device to reduce potential risks,including

   - Detail design study
   - Vibration isolator design requirements study
   - Aerodynamic interference wind tunnel program

5.2.2 Recommended Flight Control System Programs

1. Conduct a piloted flight simulation program to establish stability and control augmentation system concepts suitable for NOE/contour flight under reduced visibility. Stability and control improvements represent the only viable approach to workload reduction in this environment.

2. Design and flight test a control system using groundspeed stabilization concepts, with the lightweight doppler navigation system providing the necessary signal source. Evaluate in hover and terrain flight modes.

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