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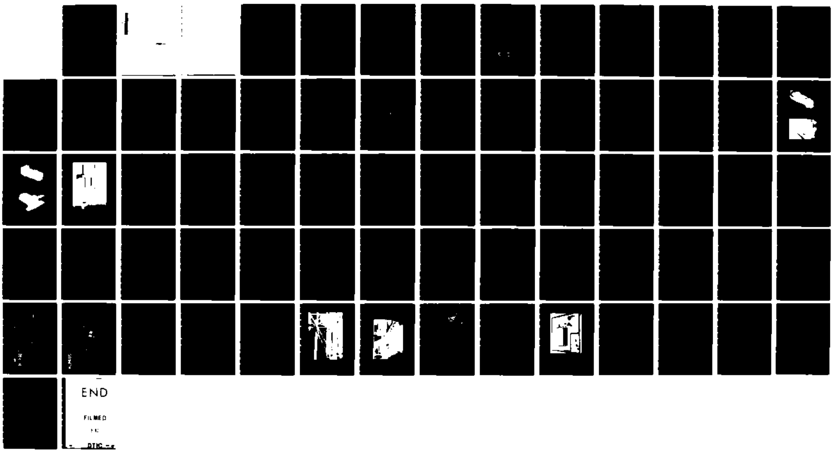

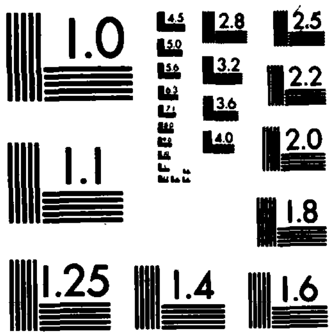
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An exploratory development program was performed to investigate methods of accomplishing low-drag, high-speed descent of platform-mounted airdrop cargos. The approach was to develop a multi-stage airdrop system that employed a stabilization device that deployed immediately after extraction from the aircraft, and was capable of orienting the airdrop assembly into a low-drag attitude and sustaining this condition throughout the descent stage. A number of system concepts were developed and investigated by experiment in the wind

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) tunnel and analytically by modeling for computer simulation of system performance. Using this information a final system concept was established, and design and fabrication of test equipment was accomplished for use in a planned series of government conducted tests.

SUMMARY

It is desirable, in the performance of an airdrop mission, to reduce the vulnerability of the aircraft to surface-to-air missiles. Vulnerability can be reduced if the airdrop can be performed at higher altitudes ranging up to 25,000 feet (7,600 m). The U.S. Army Natick Research and Development Command, NARADCOM, is administering a program to determine the possibility of developing a multi-stage system for airdropping platform-mounted cargo (such as vehicles, artillery weapons, and bulk supplies) from aircraft flying at these high altitudes. Airdrop from these heights requires that the greater portion of the trajectory be traversed at the highest attainable rate of descent so that wind drift error accumulation is minimized. "Staging" in this multi-stage system refers to changes in drag area introduced at various points in the trajectory to provide a low-drag, high-speed stage for minimizing wind drift, and a high-drag, low-speed terminal stage that is compatible with ground impact requirements of the airdropped items.

The drag area of platform-mounted airdrop loads ordinarily can be minimized by orienting them so that the long axis of the platform points into the relative wind. Therefore, a decision was made to examine means for orienting and stabilizing the platform loads in this favorable attitude during the high-speed descent portion of the trajectory. NARADCOM designed and conducted a series of nineteen airdrops, based upon this approach, where the ring slot parachute used for extraction was also used for stabilization. The results indicated merit in the approach. Also a major problem was identified which consisted of a pitch oscillation of considerable magnitude that tended to increase the average drag and slow the descent rate. To resolve this stability problem and examine configurations that would further reduce the descent time, a contractor-conducted exploratory development program was sponosored by NARADCOM.

A six-phase program was planned. This program was designated the HLPADS program for High Level Platform Airdrop System. The first phase was a configuration study during which concepts for the system were developed that possessed attributes designed to accomplish the system's goal of high-speed,

stabilized descent. The second phase provided for the construction of models and conduct of wind tunnel tests for those configurations considered to have the greater merit. The third phase was analytical, where the information derived from the wind tunnel tests were used in mathematical models of the different configurations to determine their theoretical performance. Computations were performed on the computer which simulated the total performance of each configuration. Variations were made to the mathematical models of some of the configurations to obtain information helpful in selecting the designs for final detail development. The fourth phase provided for detail design of the hardware to be used in system tests. The fifth phase provided services for the fabrication and delivery of the test hardware. The sixth phase is a test program designed to evaluate the performance of the HLPADS system concepts. The test program is to be conducted by the government without contractor participation.

PREFACE

This report documents work performed during the period from September 1977 through July 1979 on the exploratory development of a High Level Platform Airdrop System (HLPADS). The work was conducted by the AAI Corporation, Industry Lane, Cockeysville, Maryland 21030, under contract DAAK60-77-C-0073 with the U.S. Army Natick Research & Development Laboratories, Natick, Massachusetts. Mr. Edward J. Giebutowski managed this program for NLABS.

A series of wind tunnel tests were performed with scale models. The test results have been assimilated into laboratory notebooks. These records also contain calculations used in the feasibility determination of various stabilization systems. The results of the testing and calculations may be obtained by contacting the project officer at:

Commander
USANLABS
ATTN: DRDNA-UAS
Natick, MA 01760

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EXPLORATORY DEVELOPMENT OF A HIGH LEVEL AIRDROP SYSTEM FOR PLATFORM MOUNTED CARGOS

I. INTRODUCTION

This report outlines the work conducted by the contractor for the exploratory development of an airdrop system that will enable the airdrop of platform-mounted loads from aircraft operating at altitudes up to 25,000 feet (7,600 m). The work was conducted over the period from September 1977 through June 1979. The purposes of the program were to:

1. Study the problem of pitch instability encountered by platform cargos when airdropped from high levels using a two-stage recovery system.

2. To develop a technique which would reduce pitch oscillations while providing the minimum possible drag to insure a rapid rate of descent.

3. To fabricate prototype equipment for government-run airdrop tests.

Specifically, the tasks involved in the program were to:

1) Review the problems.
2) Generate concepts for solution.
3) Determine necessary aerodynamic characteristics with wind tunnel testing.
4) Simulate the performance of the concepts through mathematical modeling.
5) Evaluate the performance of the various concepts to determine the best overall concept.
6) Fabricate prototype equipment for full-scale airdrop tests.

The study began with a review of movies and data from the High Level Platform Airdrop Tests conducted at El Centro, California. That feasibility test of a two-stage airdrop system showed that platform cargos dropped from high levels are subject to large pitch oscillations unless the location of the cargo c.g. can be placed fairly far forward on the platform, or unless a relatively large parachute (the extraction parachute) is used for stabilization. However, it may not always be possible to rearrange the cargo so that the c.g. is in an ideal position, and the use of large stabilization parachutes increases the overall drag on the cargo which in turn increases the descent time.

Early in the program several stabilizing techniques were considered including deployable monowing and biwing devices as well as various bridle and boom extension arrangements which could be used to increase the efficiency of relatively small stabilizing parachutes. Four platform cargo configurations were selected from "Airdrop of Supplies and Equipment, Reference Data for Airdrop Platform Loads" (FM 10-516) for modeling and wind tunnel testing in conjunction with the stabilizing devices. Effort was made to select cargos which would provide a representative cross section of weights, platform size, platform loading density, and c.g. location. Static wind tunnel tests were made for all combinations of cargo and applicable stabilizing device. Four configurations (two cargos each with biwing and monowing stabilizers) were subjected to dynamic tests to determine pitch damping moment coefficients.

The wind tunnel data was used in a two-dimensional computer model which simulates cargo extraction and descent in order to analyze pitch plane performance of the various stabilizing techniques. Based on the computer results of aerodynamic performance and other considerations such as cost, mechanical design, and safety; a technique which employs an extended structure for attachment of a bridle suspension system was selected as the most probable to successfully meet the design goals in the near term. Prototype equipment was designed and fabricated for full-scale airdrop tests.

II. REVIEW OF GOALS AND REQUIREMENTS

The main performance goals of the platform pitch stabilization system were to limit pitch oscillations to $\pm 20^{\circ}$ with respect to flight path trajectory during the high-speed descent stage, and to minimize drag so that the maximum possible descent velocity could be obtained. It was also desired to maintain as many current rigging techniques, standard hardware items and extraction procedures as possible, although additions and modifications to the platform were allowed. The scope of the investigation was to include consideration of the following:

(1) All platform-mounted cargo as currently described in FM 10-516, Reference Data for Airdrop Platform Loads, dated September 1975.

(2) Cargo rigged weights of 2,500 to 35,000 pounds (1,133 to 15,875 kg).

(3) Platform lengths of eight to twenty-eight feet (2.4 to 8.5m) in increments of four feet (1.2m) and width of nine feet (2.7m).

(4) Compatibility with the physical confines, restraint requirements, and operating procedures of the C-130 aircraft equipped for airdrop/cargo handling.

(5) Launch speeds of up to 150 knots indicated airspeed (77m/sec) at altitudes covering the range between 5,000 and 25,000 feet (1,500-7,600m) above sea level (assumed ground level).

(6) Compatibility with extraction forces between 3,270 and 46,400 pounds (14,545-206,400 N).

(7) Compatibility with extraction of the payload from the aircraft and the deployment of subsequent stages of parachutes, i.e., the configuration of any first stage stabilization scheme must not complicate nor jeopardize any function of the system which must be performed preceding or following the stabilized high-speed stage.

(8) Limitation of the design of stabilizing devices to passive types which inherently increase stability when in their deployed position. Active controls involving use of feedback information, as, for instance, the monitoring of attitude and deflection of control surfaces to maximize stabilizing moments accordingly were to be considered outside the scope of this investigation for reasons of cost and complexity.

(9) Retention of as many standard airdrop components as possible. In particular, it was desired to retain the current and developmental airdrop platforms with the exception that an additional platform length not exceeding four feet would be allowed to accommodate attachment of some types of stabilization devices.

III. TECHNICAL CONSIDERATION

A. Study Methodology

1. Platform Cargo Characteristics

Early in the program, a survey was made of rigged platform cargo characteristics in Army FM 10-516 "Airdrops of Supplies and Equipment, Reference Data for Airdrop Platform Loads". The manual contains dimensional data, weight, c.g. location from platform leading edge, extraction technique information, and other information. Additional data required such as the height of the c.g. above the platform and the pitch plane mass moment of inertia about the c.g. were calculated using information available and estimates obtained by scaling from photographs. This information is summarized in Table 1. It was from this data that the configurations for wind tunnel modeling were selected.

2. Stabilization Concepts

Several concepts were considered for stabilizing platform cargos during the high-speed descent phase of the staged airdrop system. The basic theory behind all of them was to increase the magnitude of aerodynamic restoring moments needed to overcome the overturning moments on the cargo without unnecessarily increasing the overall drag. One technique was to improve the efficiency of a stabilizing parachute by using various extensions and bridle suspension systems at the aft of the cargo platform. Such devices increase the effective moment arm for providing restoring torque and allow the use of smaller parachutes. A second technique was to use deployable wing stabilizers mounted behind the cargo platform. These devices provide lift as well as drag. The moment created by the lift force supplies significant restoring torque without greatly increasing drag. The concepts considered are briefly described below.

a. Rigid Boom

The rigid boom is one of the simplest improvements that can be made to the platform cargo configurations. Basically it consists of extending the attachment point for the extraction parachute aftward by a fixed amount. One of the primary contract goals imposes a limit of 4 ft. to

Table 1

TABULATION OF MASS PROPERTIES - PLATFORM AIRDROP CARGOES

DESCRIPTION	PLATFORM TYPE	PLATFORM LENGTH	WEIGHT	ACCOMP. WEIGHT	HEIGHT	LENGTH	OVERHANG FRONT	OVERHANG REAR	CG (FROM FRONT EDGE OF PLAT.)	CG (HT FROM PLAT. BASE)	MOMENT OF INERTIA ABOUT CG	LOAD L.F. HEIGHT	PLAT. L.F. HEIGHT	CG LOAD LF	CG PLAT LF
M116 CARGO CARRIER	MODULAR	16 FT.	10,350#		96 IN.	221 IN.	14 IN.	15 IN.	80 IN.	57 IN	7878 SLUG-FT²	2.50	2.00	.45	.42
M113 ARMORED PERS. CARR.	MODULAR	20	22,150		91	254		14	117	48	15814	2.79	2.64	.46	.49
M114 ARMORED PERS. CARR.	MODULAR	16	16,850		92	192			108	46	8352	2.09	2.09	.56	.56
16 FT. PLASTIC ASSAULT BOAT	MODULAR	12	4,856		89	208	54	10	76	44	1781	2.34	1.62	.63	.55
AN/MRC-107A IN M101 TL.	MODULAR	12	4,795		76	147		3	75	32	1745	1.93	1.89	.51	.52
AN/MRC-108A IN M416 TRAILER	MODULAR	8	#2,650	605#/1,180#	74	116		20	72	38	334	1.57	1.30	.62	.75
AN/VSC-2 IN M151 TRUCK	MODULAR	12	3,960		72	144			77	35	1061	2.00	2.00	.53	.53
AN/MRC-46A IN S-144B SHELTER	MODULAR	8	# 2,670	546#	60	105	7		50	26	382	1.49	1.39	.55	.52
AN/GRC-46B IN S-144B SHELTER	MODULAR	8	# 2,670	328	81	105	7		48	33	382	1.27	1.19	.53	.50
7-TON AIRBORNE CRANE SHOVEL	MODULAR	24	18,884		96	288			136	60	17224	3.00	3.00	.47	.47
3/8 CU YD CRANE SHOVEL ATTACH.	MODULAR	8	3,900		55	96			48	24	495	1.75	1.75	.50	.50
210 CFM DAVEY AIR COMP.	MODULAR	16	10,390		92	210		18	84	53	4544	2.28	2.09	.40	.44
250 CFM DAVEY AIR COMP.	MODULAR	16	10,680		98	210		18	84	56	4658	2.14	1.96	.40	.44
BRIDGE DECK BALK	MODULAR	24	25,154		90	288			150	49	20748	3.20	3.20	.45	.45
BRIDGE PLATES	MODULAR	8	3,429		43	96			48	14	241	2.25	2.25	.50	.50
BRIDGE DECK SECTIONS	MODULAR	12	7,360		68	170		26	74	30	2969	2.50	2.12	.44	.51
BRIDGE PONTOON BOATS	MODULAR	24	7,510		99	288			165	54	7006	2.91	2.91	.57	.57
MURRAY EARTHMOVING SCRAPER	MODULAR	24	15,550		94	291		3	160	35	9872	3.10	3.06	.55	.56
MRS-100 EARTHMOVING SCRAPER	MODULAR	24	20,830		96.5	388	38	12	129	38	23504	4.02	2.98	.43	.45
ENGINEER TOOL OUTFIT	MODULAR	12	3,793	TBD INC.	81	164		20	72	42	805	2.02	1.78	.44	.50
5KW GENERATOR SET	MODULAR	8	# 2,520	158	69	96			52	24	327	1.39	1.39	.54	.54
LANDING FIELD MAT	MODULAR	12	7,530		46	154	7	5	78	17	2619	3.35	3.13	.55	.54
M212 ROAD GRADER	MODULAR	24	18,234		88	297		9	133	44	28455	3.38	3.27	.45	.46
M220 ROAD GRADER	MODULAR	24	19,053		92	316		28	114	50	24405	3.45	3.13	.36	.40
330 HAD ROAD GRADER	MODULAR	2	24,200		99	341	9	44	127	55	29767	3.44	2.91	.40	.44
7-35-TON PNEU. TIRED ROAD ROLLER	MODULAR	2c	15,110		93	250		10	108	48	12812	2.69	2.98	.43	.45
W/2 SHEEPSFOOT ROAD ROLLER	MODULAR	12	7,825		74	163		19	68	40	1613	2.20	1.95	.42	.47
MG5AM SCOOP-TYPE LOADER	MODULAR	24	17,958		95	288			156	54	15813	3.05	3.05	.54	.54
645 M SCOOP-TYPE LOADER	MODULAR	24	29,650		99	327	34		158	57	39244	3.50	2.91	.53	.48
D4 FULL-TRACKED TRACTOR	MODULAR	16	20,158		86	197	5		90	41	10826	2.29	2.23	.48	.47
D6B FULL-TRACKED TRACTOR	MODULAR	20	24,475		96	240			129	46	12962	2.50	2.50	.54	.54
HD-6M FULL-TRACKED TRACTOR	MODULAR	16	18,795		89	198		6	91	53	5322	2.22	2.16	.46	.47
M450 FULL-TRACKED CRAWLER TRAC.	MODULAR	16	12,125		80	192			96	45	4473	2.40	2.40	.50	.50
553 FULL-TRACKED TRACTOR	MODULAR	20	19,130		85	250		10	143	41	11272	2.94	2.82	.57	.60
MRS-100B WHEELED TRACTOR	MODULAR	20	19,000		91	241	1		112	6T	13394	2.65	2.64	.47	.47
MRS-100NC WHEELED TRACTOR	MODULAR	24	24,800		98.5	288			132	62	23077	2.92	2.92	.46	.46
2-500GAL TANKS W/50GPM DISP.	MODULAR	12	8,900		82	144			72	29	2491	1.76	1.76	.50	.50
1-500GAL TANK W/50GPM DISP.	MODULAR	8	4,985		73	105		8	48	35	818	1.41	1.32	.47	.50
SUPPLY LOAD ON 8FT PLAT.	MODULAR	8	4,250		41	96			50	16	472	2.34	2.34	.52	.52
SUPPLY LOAD ON 12FT PLAT.	MODULAR	12	7,250		54	144			74	24	2059	2.67	2.67	.51	.51
M416 OR M100 1/4T. TRAILER	MODULAR	8	3,600		80	123		27	52	39	781	1.54	1.20	.42	.54
M101 3/4T. TRAILER	MODULAR	12	5,030		81	162	14	4	97	35	1222	2.00	1.78	.69	.67
M104 OR M105A1 1 1/2T TRAILER	MODULAR	12	7,030		76	166		22	71	40	2059	2.18	1.89	.43	.49
WELD SET IN M104 OR M105 TRAILER	MODULAR	12	5,850		94	180	14	22	67	57	1936	1.91	1.53	.45	.47
CB COLL. PROT SHELT. IN TRAILER	MODULAR	12	6,600		98	168	7	17	58	52	2559	1.71	1.47	.39	.40
1 1/2T WATER TANK TRAILER	MODULAR	12	6,960		85	164		20	67	52	1441	1.95	1.88	.41	.47
M296 2 1/2T. POLE-TYPE TRAILER	MODULAR	12	5,470		70	176	13	19	63	48	1045	2.51	2.06	.43	.44
M796 2 1/2T. BOLSTER TRAILER	MODULAR	16	6,340		65	211		18	80	32	4226	3.25	2.95	.38	.42
M151 1/4T. TRUCK	MODULAR	8	# 3,240		80	134	24	14	55	38	1131	1.88	1.20	.59	.57
M38A1 1/4T. TRUCK	MODULAR	12	4,180		78	144			84	37	1420	1.85	1.85	.58	.58
M170 1/4T. FRONTLINE AMBULANCE	MODULAR	12	4,400		77	161	13	4	79	40	1787	2.09	1.87	.57	.55
M718 1/4T. FRONTLINE AMBULANCE	MODULAR	12	4,285		73	148		4	74	34	1061	2.03	1.97	.50	.51
M274 1/2T. TRUCK	MODULAR	8	4,500	1,700	74	102	3	3	48	38	1091	1.38	1.30	.50	.50
M561 1 1/4T. TRUCK	MODULAR	20	8,960		94	240			124	37	7653	2.55	2.55	.52	.52
M561 1 1/4T. TRUCK W/SUPPLY LOAD	MODULAR	20	11,760	2,352	94	240			131	45	9642	2.55	2.55	.55	.56
M792 1 1/4T. FRONTLINE AMBULANCE	MODULAR	20	9,400		94	240			120	45	7707	2.55	2.55	.50	.50
M35A2 2 1/2T. TRUCK	MODULAR	24	18,817	2,400	89	299	11		139	47	34614	3.36	3.24	.50	.48
M36A2 2 1/2T. TRUCK	MODULAR	24	19,790	1,340	97	345	10	45	148	55	42409	3.54	2.97	.46	.51
M34A2 2 1/2T. TRUCK (DUMP)	MODULAR	24	18,200		96	295		7	156	48	24689	3.07	3.00	.53	.54
4.2 IN MORTAR W/2 1/4T TRUCKS	MODULAR	8	4,598		72	103	1	6	48	34	768	1.43	1.35	.48	.50
20 MM VULCAN GUN (M167)	MODULAR	12	6,740	1,300	90	177	4	29	72	49	1661	1.97	1.60	.43	.50
M101A1 105 MM HOWITZER	MODULAR	16	8,626	1,800	75	228	14	22	78	38	4085	3.04	2.56	.40	.41
M102 105 MM HOWITZER	MODULAR	16	6,852	2,040	75	212		20	106	34	4690	2.83	2.56	.50	.55
M40A1 RECOILLESS RIFLE ...	MODULAR	12	5,640		92	169	8	17	67	41	2261	1.84	1.57	.44	.47
M551 ARMORED RECON. AR. VEH.	MODULAR	24	35,100		101.25	288			153	54	42883	2.84	2.84	.53	.53
REDEYE MSLS. IN M151 1/4T. TK.	MODULAR	8	# 3,336	76	77	134	24	14	53	31	656	1.74	1.25	.57	.55
REDEYE MSLS IN M416 TRAILER	MODULAR	8	# 2,980		91	123	3	24	47	72	470	1.35	1.05	.41	.49
SHILLELAGH MISSILES	MODULAR	8	3,560		58	104	4	4	51	39	1374	1.79	1.66	.53	.53
TOW ON M151A2 1/4T. TRUCK	MODULAR	12	4,100		76	160	16		60	36	1066	2.11	1.89	.48	.42
TOW ON M274 1/2T. TRUCK	MODULAR	8	4,250	450	75	102	3	5	49	38	695	1.36	1.28	.51	.51
MISSILE CARR. 1/4T. TRUCK	MODULAR	12	4,210		72	144			70	35	1172	2.00	2.00	.49	.49
CASE 1150 FULL-TRACKED TRACTOR	MODULAR	20	26,175		92	240			126	51	18463	2.61	2.61	.53	.53
[illegible] FULL-TRACKED TRACTOR	MODULAR	20	18,800		85	250		10	188	49	12694	2.94	2.82	.75	.78

\# NOTE: WHEN RIGGED FOR DROP FROM C-141 AIRCRAFT, THE LOAD MUST WEIGH AT LEAST 3,500#.

any addition to the rigged cargo length as stowed in the aircraft. Using this restriction as a guideline, a configuration was considered in which the platform rails would be extended and an extra 4-ft. platform section added. The configuration assumes that a rigid member would be attached to the extraction pintle of the cargo to carry the extraction and suspension loads from the stabilizing parachute. Structure added to the rails of both the extension and cargo-carrying portion of the platform would be attached to the member connected to extraction pintle to enable restoring moments provided by the parachute to be transferred to the cargo. Bulk cargos and other loads which use platform extraction would have the stabilizing parachute attached directly to the structure, and all of the restoring moments would be transferred to the platform rails.

Early in the program, consideration was given to "telescoping" concepts which would allow the boom to be extended beyond the stowed configuration. However, it was found that significant rigidity could not be obtained without greatly increasing weight and size, so the telescoping concepts were abandoned.

Computer analyses revealed that the rigid boom extension with its single attachment point for the stabilizing parachute was not efficient enough to reduce oscillations to the desired range without using a relatively large drag area. In addition, the structure needed to support the boom would have to be almost as complex as that for other more efficient schemes. For these reasons the rigid boom concept was not given detailed design consideration.

b. Bridle Attachment

Attaching a stabilizing parachute to the cargo by means of a bridle arrangement of suspension slings has the advantage of increasing the moment arm for restoring torque and distributing the suspension force more uniformly. A four-point attachment scheme was considered whereby the parachute forces were applied through a structure attached to the platform rails. The device is shown schematically in Figure 1. For cargos which are "platform extracted", the extraction force can be applied directly through the bridle

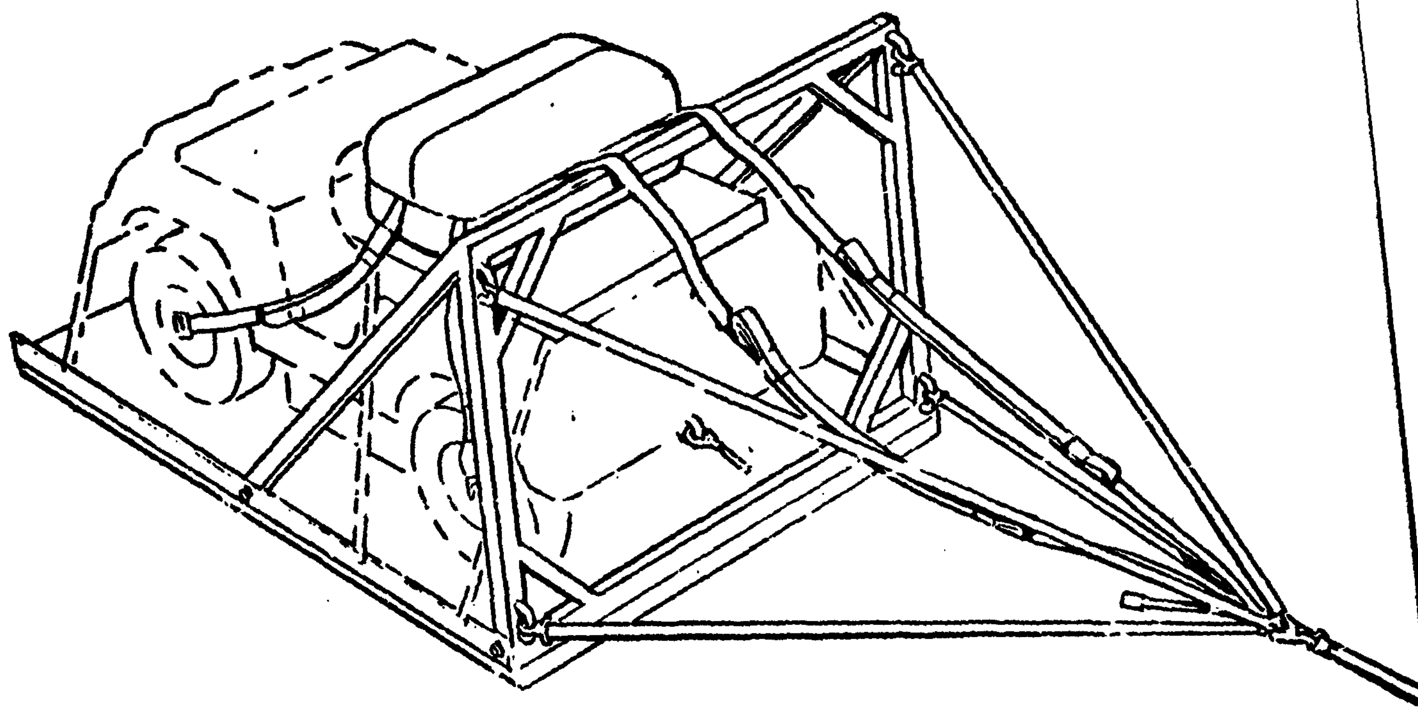


Figure 1.
Basic Bridle Attachment Concept

attachment structure. For heavier cargos in which the extraction parachute is attached to the cargo itself, the open construction of the bridle structure would allow attachment to the load pintle without interference. Both extraction techniques would require a two-stage operation in which the load from the relatively high-drag extraction parachute is transferred to a smaller low-drag stabilization parachute.

Computer analysis of the simple four-point bridle concept showed that it is not efficient enough to limit oscillations to within the range of the design goals without the use of a relatively large parachute.

c. Extended Bridle Attachment

The extended bridle attachment concept combines the advantages of both the boom extension and the bridle suspension configuration. It is illustrated schematically in Figure 2. The bridle attachment arrangement on the extended structure enables the restoring torque to be applied through a moment arm equal to the diagonal from the cargo c.g. to the corners of the extension structure. The open center of the extension structure allows extraction from either the platform or the cargo. Closing the top and bottom of the extension structure with a "membrane" of aluminum provides strength and rigidity to the structure and also creates some restoring torque from lift and drag on these surfaces.

The extended bridle structure was one of the configurations modeled for wind tunnel tests. Computer analysis using wind tunnel data showed that this concept is relatively effective in reducing pitch oscillations with a small parachute. Its effectiveness and relatively simple design made this concept very attractive. Additional analysis and design details are presented in subsequent sections.

d. Monowing

The monowing concept uses a structure similar to that for the extended bridle attachment system to support two small wings extending into the airstream. The basic concept is shown in Figure 3. The wings are equipped with rollers and mounted in tracks in the extension structure. While stowed in the aircraft, the wings are retracted in the tracks so that they do

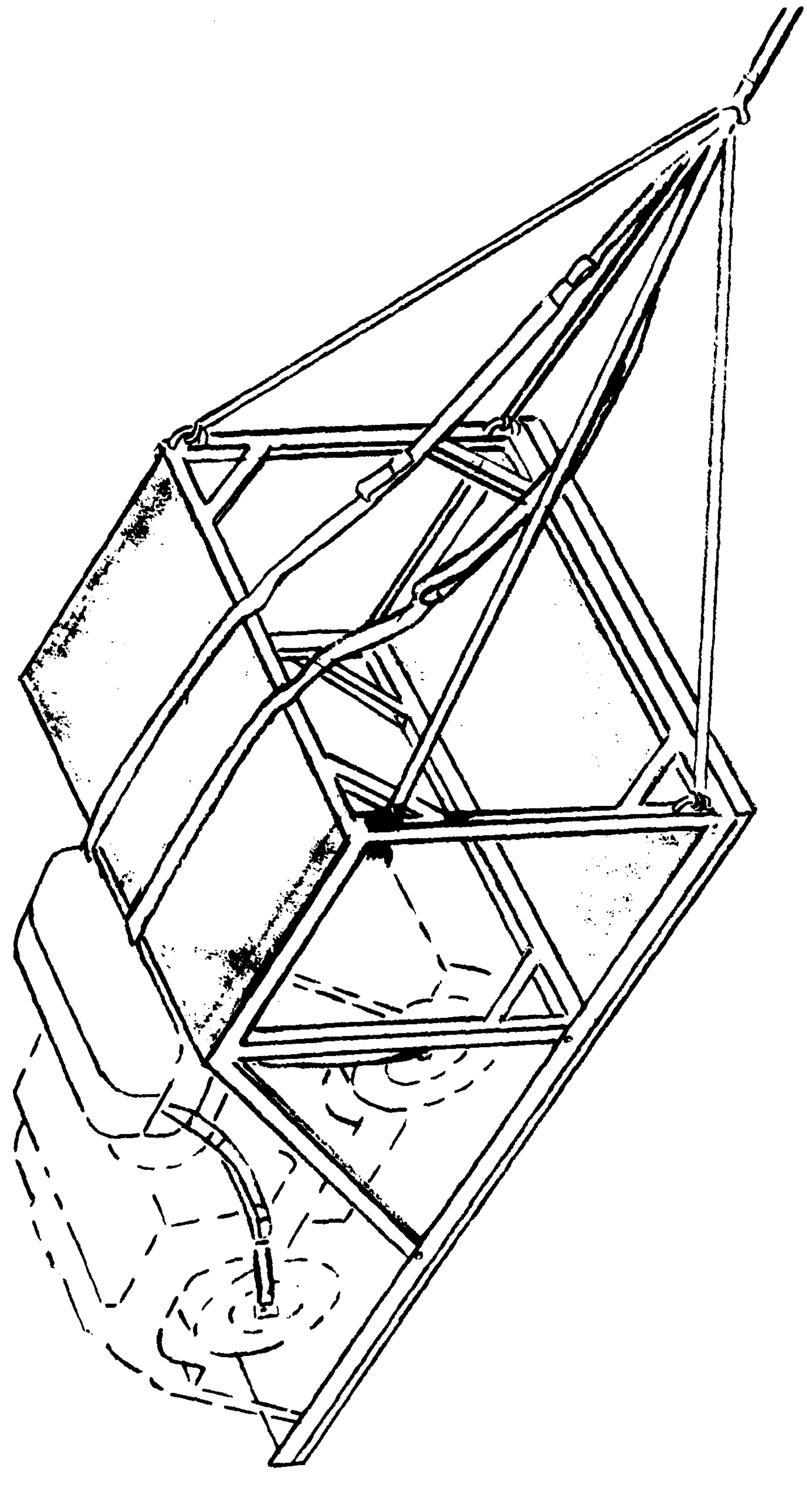


Figure 2.

Extended Bridle Attachment Concept

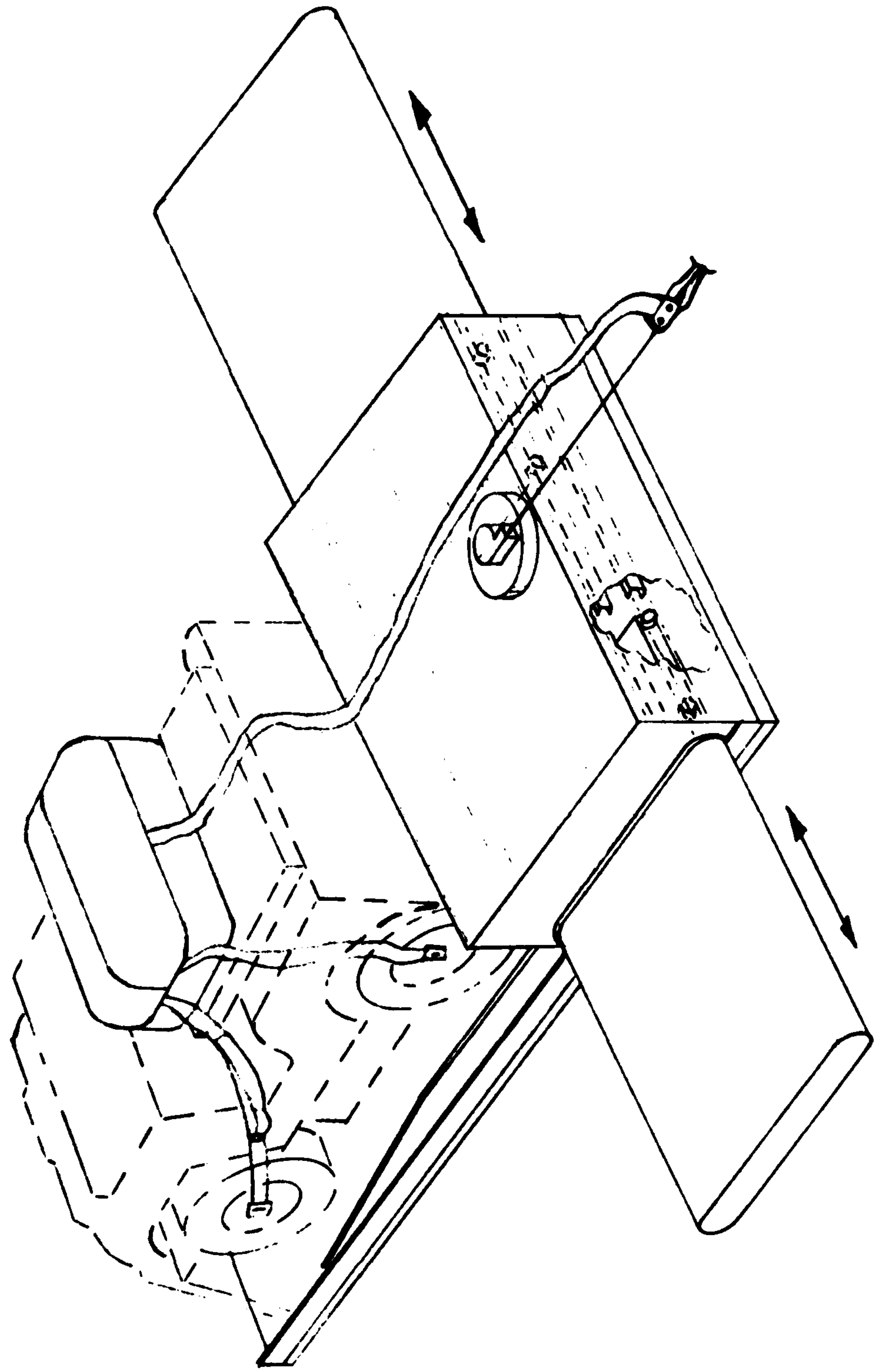


Figure 3.

Basic Monowing Concept

not protrude beyond the side of the cargo. Shortly after extraction, force is transferred to a small drogue parachute. The force from the drogue slides the wings outward to either side and locks them into place. The drogue is retained throughout the first stage of the descent and is later used to deploy the main recovery parachutes.

Using the 4-ft. allowance for rearward extension as a guide-line, each wing can be made 4 ft. by 9 ft. When deployed, each wing extends 6 ft. to either side, leaving 3 ft. engaged in the tracks to provide support. Weight is kept to a minimum by constructing the wings from aluminum skin bonded to a plastic foam core.

The monowing stabilizer was one of the configurations modeled for wind tunnel test. Data used with math model analyses showed that the monowing is effective in reducing pitch oscillations and its low drag configuration allows a high rate of descent. In addition, the structure required to mount, deploy, and support the wings is relatively simple. For these reasons, the monowing stabilizer was considered a relatively attractive concept.

e. Biwing

The biwing stabilizer is similar to the monowing concept in that it uses wings extending to the side of the cargo from a structure mounted on the back of the platform. The difference is that the biwing system uses two sets of wings; one set low along the plane of the platform and one set mounted at the top of the extension structure. The basic concept is illustrated in Figure 4.

The original concept called for a double set of sliding wings, but it was found that the weight was high. To reduce the overall weight, a "folding" wing scheme was developed. With this arrangement, the wings are mounted along the top and bottom edge of the extension structure. Each wing rotates about its inside edge so that when stowed in the aircraft, the wings are folded flat along the side of the extension structure. Diagonally opposed wings are linked so that they have to act in unison. This linkage helps to balance the aerodynamic forces acting on the wings during deployment.

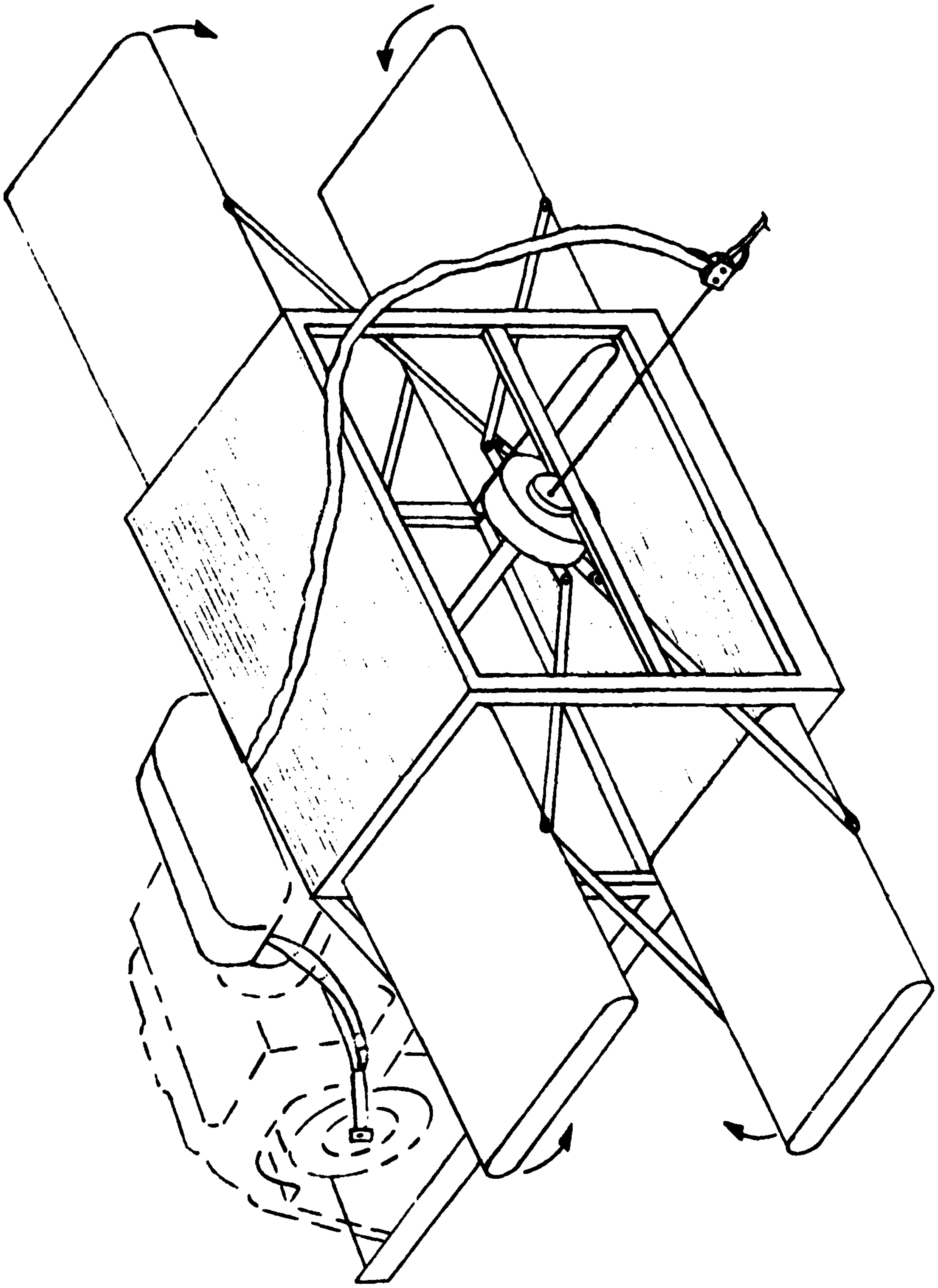


Figure 4.
Basic Biwing Concept

That is, an aerodynamic force tending to open one wing (possibly causing an impact overload from too high an opening rate) is counterbalanced by the aerodynamic force on the diagonally opposed wing which acts to retard the rate of opening.

Both sets of wings are opened by the force of a small drogue parachute deployed shortly after extraction. The force is applied to a large diameter drum/crank linked to the wings, and causes them to rotate open and lock in place with support struts. The use of support struts with this system greatly reduces the bending loads on the wings and allows a thinner wing profile. However, the center mounted drum/crank increases the difficulty in applying the extraction load directly to the cargo.

The biwing concept was modeled for wind tunnel test, and the data was used for computer analysis. The large restoring moments and aerodynamic symmetry make the biwing the most aerodynamically efficient system. Pitch oscillations are held to a minimum, damping is rapid, and trim angles are small. The low drag associated with the system allows a high rate of descent. However, because of the added weight, complexity of deployment mechanism, and problems associated with extraction, this concept could not be recommended.

3. Wind Tunnel Tests

a. Models

Four cargo configurations were chosen to be tested with each of the stabilization concepts. The configurations were selected on the basis of size, weight, shape, and c.g. locations as well as estimated airdrop frequency and applicability of the cargo under a variety of military operations. The selection process was largely qualitative, but with an effort to pick extremes as well as representative configurations. The platform sizes represented lengths of 24, 20, 12 and 8 feet. The configurations selected are summarized in Table 2. It was felt that all of the cargos selected would be appropriate for a variety of combat and non-combat operations. The M38A1 ¼-ton truck represents one of the least stable c.g. locations of all of the cargos in Table 1. The 500-gallon tank with dispenser represents the heaviest

Table 2

Cargo Configurations Used For Wind Tunnel Models

Criteria	Selected for Static Test			
			Static and Dynamic Test	
	M561 1¼ Ton Truck With Supply Load (Fig. 3-57; FM 10-516)	M36A2 2½ Ton Truck (Fig. 3-60; FM 10-516)	One 500-Gal Tank With 50 GPM Dispenser (Fig. 3-40; FM 10-516)	M38A1 ¼ Ton Truck (Fig. 3-52; FM 10-516)
Platform Size	20 Ft.	24 Ft. (Longest)	8 Ft. (Shortest)	12 Ft. (Most Frequently Used)
Weight	11700 lb.	18817 lb.	4983 lb.	4180 lb.
Mass Distribution	cg 50% from platform leading edge	cg 51% from platform leading edge	cg 50% from platform leading edge	cg 58% from platform leading edge
pitch plane I_{cg}	9833 slug-ft^2	42409 slug-ft^2	818 slug-ft^2	1363 slug-ft^2

load for an 8-ft. platform. The M561 ¼-ton truck and M36A2 2½-ton truck represent virtually median weights for their respective platform lengths and near mid-point c.g. locations.

Wind tunnel models were 1/8th scale to facilitate handling and mounting, and to minimize interference caused by proximity to the walls of the tunnel test section. The reference length used for all models was the platform width which remained the same for all models. The reference area for each model was its nominal platform area. Contract requirements called for a minimum Reynolds number of 1.8×10^6. The wind tunnel airspeed used to meet this requirement was 256 fps (175 mph).

Models were constructed by the University of Maryland wind tunnel shop according to sketches supplied by AAI. The cargo models were made of white pine. The platform models and various stabilizing devices were made of aluminum. Stabilizing devices were constructed to be interchangeable among all of the cargo models and were mounted to the platform with bolts through a series of holes along the platform edges. The mounting holes made it relatively easy to change from one stabilizing device to another and to make adjustments to certain test parameters such as rearward setback of wings, different wing profiles, etc. Pictures of the models with various stabilizing structures attached are shown in Figures 5 through 9. In the interest of time and funds, the overall envelope of the cargo was modeled, but no attempt was made to provide minute detail or to model the rigging. It was felt that the non-detailed nature of the models helped to simulate the "aerodynamic roughness" caused by the rigging.

For several reasons, no attempt was made to mount parachutes on the bridle attachment structures. The number of possible combinations of parachute size and riser line length would have greatly increased the number of tests required, and in some cases the mounted parachute could have extended beyond the tunnel test section. The performance characteristics of standard parachute configurations are well documented, and so the effect of adding a parachute could be easily simulated with mathematical modeling once the characteristics of the cargo forebody were known.

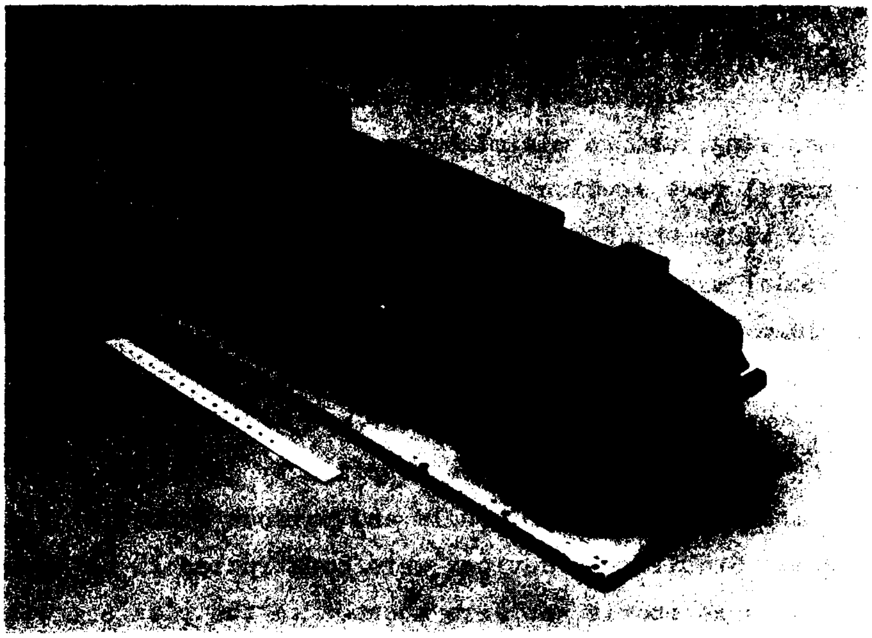


Figure 5. M36A2, 2½-Ton Truck Model

M38A1, 1/4-Ton Truck Model With Simulated Simple Rigid Boom

Figure 6.

Figure 7. M561 1-1/4-Ton Truck Model

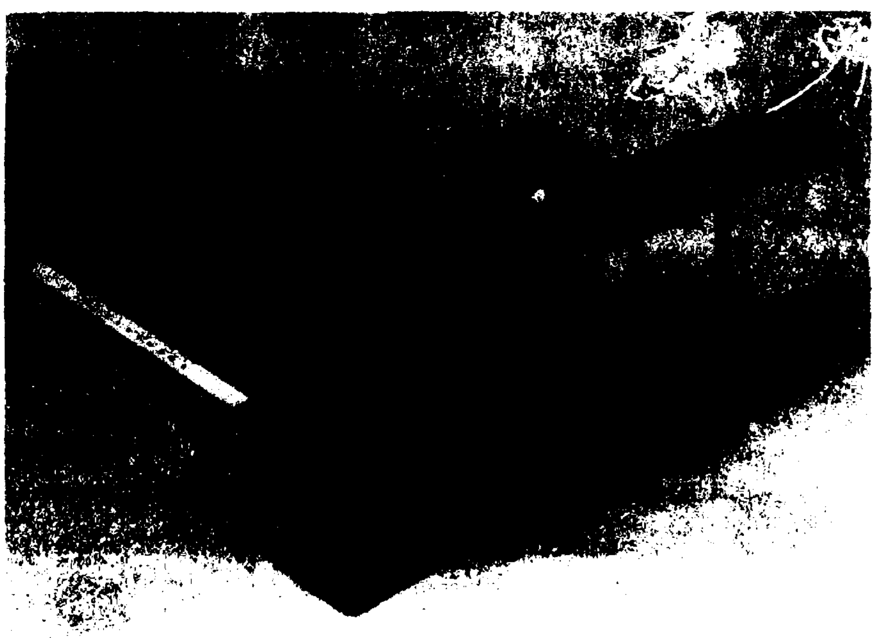


Figure 8. M561, 1-1/4-Ton Truck Model With Biwing

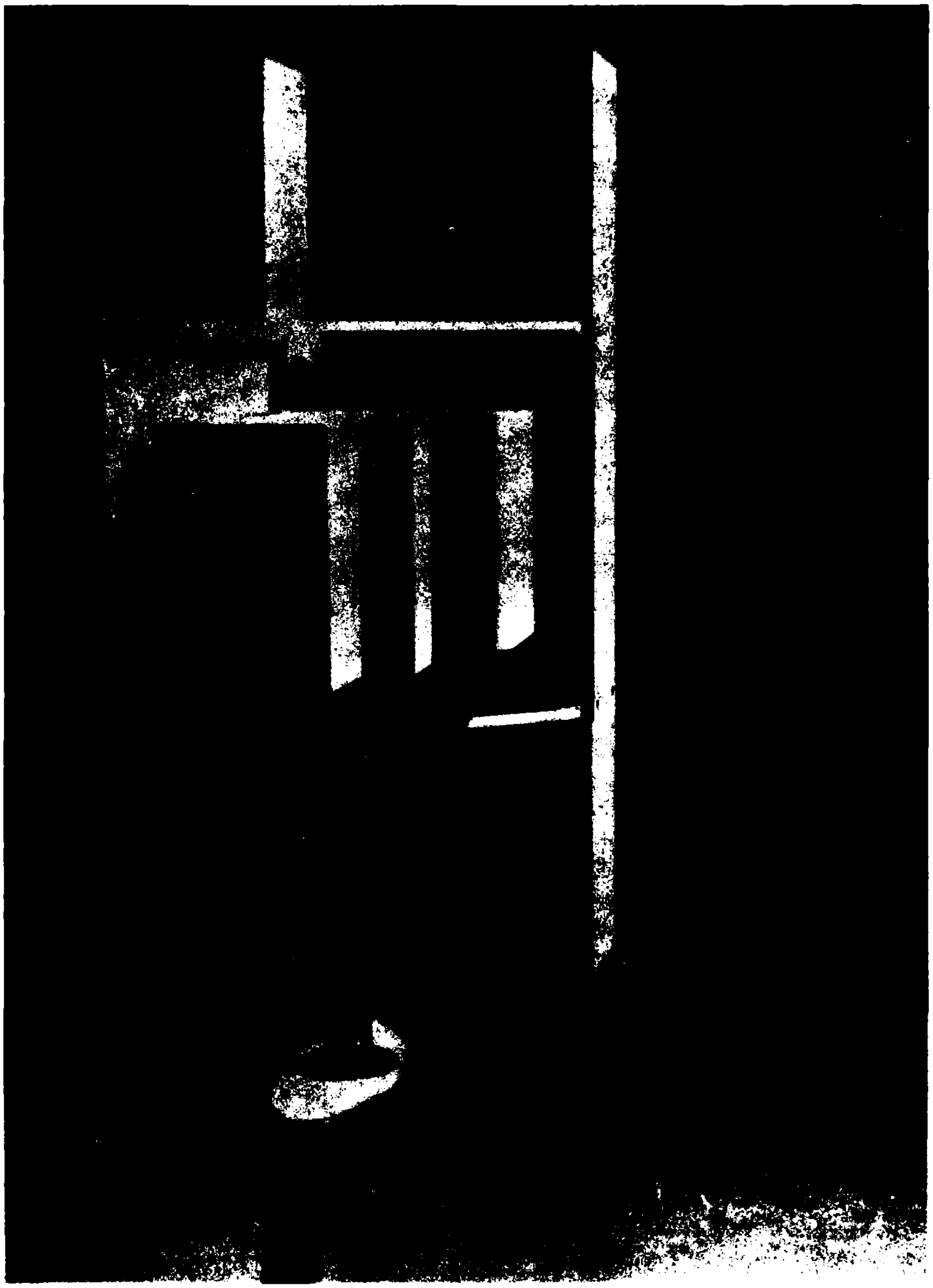


Figure 9. Wind Tunnel Model Mounted on Support Strut.

Each model designated for static testing only was fitted with rigid mounting plate in its sides, as shown in Figure 5. The mounting plate was located to position the wind tunnel mounting strut at the c.g. of the full scale configuration. Models were mounted "sideways" in the tunnel test section so that pitch angle measurements were actually "yaw" angles with respect to the tunnel force balance system. This mounting arrangement was used to eliminate any gravitational pitching moments caused by the fact that the actual model c.g. might not correspond to the c.g. location of the full scale model. The models designated for dynamic tests as well as static tests were equipped with bearings, as shown in Figure 6. The bearings allowed them to pivot freely on the mounting strut. For static tests, the dynamic models were attached rigidly to the strut with bolts into the bearing mounting plate in the model.

b. Test Procedure

Static tests and dynamic tests were performed in the University of Maryland wind tunnel facility at College Park, Maryland. As previously mentioned, models were mounted on their side so that they would pivot about the axis corresponding to the full scale cargo c.g. location. This mounting technique was used to avoid possible problems associated with "gravitational moments" created if the c.g. of the model did not coincide with the location of the full scale c.g.

(1) Static Tests

Static tests were used to determine lift coefficient, drag coefficient, moment coefficient, and center of pressure data as a function of angle of attack. The range for angle of attack was limited to $\pm$ 30 degrees. Initially, readings were taken at two-degree increments with angle of attack sweeps from both negative-to-positive and positive-to-negative. However, it was found that the data increments could be increased and that a single angular sweep could be used with no loss of accuracy. It was also found that an "image strut" attached to the model on the opposite side from the mounting strut was unnecessary. Force and moment data were recorded automatically by computer and also manually as a back-up record. The force and moment data were automatically converted to coefficient form by the computer.

Some of the variables that were specified for examination were the effects of rearward setback of the monowing and biwing and the relative difference in performance between "flat plate" wing stabilizers and "airfoil" wings. As tests progressed, several other variations were examined such as mounting the monowing at a height corresponding to the top of the cargo, rather than the bottom, and reversing the cargo on the platform. The effect of Reynolds number was checked by running one configuration at velocities 25 mph above and below the nominal test speed of 175 mph.

In general, the static tests showed that cargos with no stabilizing device were unstable. Cargos with the extended bridle attachment structure alone (no parachute attached) were marginally unstable. Most cargos with the monowing and biwing stabilizers were statically stable. The ¼-ton truck was unstable with the normal monowing. The overall performance of the "flat plate" wing stabilizers was better than that for the "airfoil" wing stabilizers. It is felt that this was a result of the large range of angle-of-attack and a greater contribution of drag to the restoring moment provided by the stabilizer. Variations of the air speed showed that there was no significant difference in aerodynamic characteristics within the range of Reynolds numbers tested.

The schedule of cargo/stabilizer configurations tested is shown in Table 3.

(2) Dynamic Tests

Dynamic tests were performed to determine pitch damping moment coefficients for the monowing and biwing stabilizers. Models used for dynamic testing were fitted with bearings along the pitch plane c.g. axis and were mounted sideways on the mounting strut so that they were free to rotate. Angular displacements were sensed with a potentiometer and automatically plotted as a function of time by a strip chart recorder. A free oscillation technique was used whereby the model was given an initial angular displacement and released. An initial angular displacement of $\pm 30^{\circ}$ was achieved by restraining the model with a lanyard extending through a small hole in the wind

TABLE 3

SUMMARY INDEX OF WIND TUNNEL TEST CONFIGURATIONS

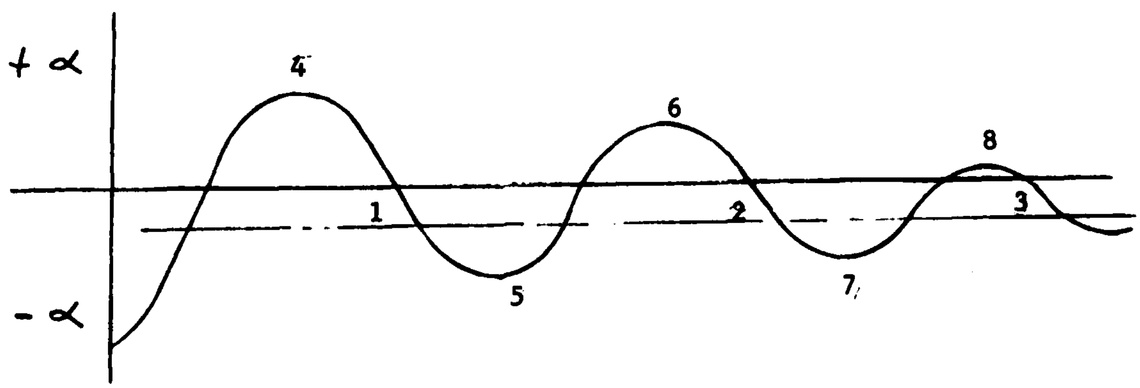
University of Maryland Test Series No. 803 Feb. 13-17, 1978
(All runs at V = 175 MPH unless otherwise noted)

Run No.	Configuration
1	1/4 Ton Truck/Platform + Image Strut
2	1/4 Ton Truck/Platform; Image Strut off.
3	1/4 Ton Truck/Platform (Rerun of #2 working from negative to positive)
4	1/4 Ton Truck/Platform + Attachment Structr.
5	1/4 Ton Truck/Platform + Attachment Structr. + Lower Flat Wing
6	1/4 Ton Truck/Platform + Attachment Structr. + Biwing (Flat)
7	1/4 Ton Truck/Platform + Attachment Structr. + Biwing (Airfoil)
8	1/4 Ton Truck/Platform + Attachment Structr. + Biwing (Airfoil) + Image Strut
9	1/4 Ton Truck/Platform; Attachment Structr. off + Lower Airfoil Wing.
10	1/4 Ton Truck/Platform + Lower Flat Wing
11	1/4 Ton Truck/Platform + Lower Flat Wing/6" Gap
12	500 Gal. Tank/Dispenser/Platform + Image Strut
13	500 Gal. Tank/Dispenser/Platform; Image Strut off
14	500 Gal. Tank/Dispenser/Platform + Attachment Structr. 1-3/8" Gap
15	500 Gal. Tank/Dispenser/Platform + Attachment Structr. + Biwing (Flat) 1-3/8" Gap
16	500 Gal. Tank/Dispenser/Platform + Off Off + Low Wing 1-3/8" Gap
17	500 Gal. Tank/Dispenser/Platform + Low Wing 0" Gap
18	500 Gal. Tank/Dispenser/Platform + Low Wing 6" Gap
19	500 Gal. Tank/Dispenser/Platform + Structr. + Biwing (Flat) + 30° Dynamic 1-3/8" Gap
20	500 Gal. Tank/Dispenser/Platform + Single Low Wing (Flat) + 30° Dynamic 0" Gap
21	1/4 Ton Truck/Platform + Structr. + Biwing (Flat) + 30° Dynamic
22	1/4 Ton Truck/Platform Off + Single Low Wing + 30° Dynamic
23	1-1/4 Ton Truck/Platform + Image Strut
24	1-1/4 Ton Truck/Platform; Image Strut off
25	1-1/4 Ton Truck/Platform + Attachment Structr.
26	1-1/4 Ton Truck/Platform + Attachment Structr. + Biwing (Flat)
27	1-1/4 Ton Truck/Platform; Attachment Structr. off + Single Low Wing 0" Gap
28	1-1/4 Ton Truck/Platform + Single Low Wing 6" Gap
29	1-1/4 Ton Truck/Platform + Single Low Wing 12" Gap
30	1-1/4 Ton Truck/Platform + Single Low Wing (V = 150 MPH) 0" Gap
31	1-1/4 Ton Truck/Platform + Single Low Wing (V = 200 MPH)
32	1-1/4 Ton Truck/Platform + Attachment Structr. + Single High Wing (V = 175 MPH)
33	1-1/2 Ton Truck/Platform + Image Strut
34	2-1/2 Ton Truck/Platform; Image Strut off
35	2-1/2 Ton Truck/Platform + Attachment Structr. + Biwing 6" Gap
36	2-1/2 Ton Truck/Platform; Attachment Str. off + Single Low Wing (Flat) 6" Gap
37	2-1/2 Ton Truck/Platform + Attachment Structr. + Biwing (Structr. Raised one inch) 0" Gap
38	2-1/2 Ton Truck/Platform + Attachment Structr. + Low Wing (Structr. Raised one inch) 0" Gap
39	2-1/2 Ton Truck/Platform + Attachment Structr. + High Wing (Structr. Raised one inch) 0" Gap
40	2-1/2 Ton Truck/Platform + Attachment Structr. 0" Gap
41	1/4 Ton Truck/Platform + Parachute on Boom Static
42	1/4 Ton Truck/Platform + Parachute on Boom Dynamic
43	1-1/4 Ton Truck/Platform Rear Forward Orientation 0°
44	1-1/4 Ton Truck/Platform + Low Wing Rear Forward Orientation 0°

tunnel wall. The lanyard was released when the tunnel air speed reached steady state. The time history of the oscillations was used with the moment of inertia and reference dimensions of the model to compute the pitch damping coeeficients.

Aerodynamic damping is related to aerodynamic moments that are a function of the rate of change of angle of attack. The actual damped oscillation history of a given body is a function of its aerodynamic properties and inertial properties. If it were desired to obtain an actual "scaled" oscillation/time history of some aerodynamic body, it would be necessary to scale the inertial properties of the model as well as the physical dimensions. Such a technique would allow the direct measurement of full-scale damping behavior from the oscillation history of the model. However, a great deal of effort would be necessary to scale down the weight distribution and inertial properties of the model exactly. This problem can be avoided by solving for the pitch damping moment coefficient which is related only to the aerodynamic properties of the item. The angular displacement vs time history of the model would not necessarily duplicate that of the actual item. However, the relative effect of aerodynamic damping which governs the stabilization of the model expressed in coefficient form could be used along with the inertial properties of the full-scale item to predict its performance mathematically.

The oscillation histories of the models obtained in the wind tunnel were of the form of a damped cosine about some trim angle as shown below.



The general form of the equation governing this type of motion is

$$\ddot{x} + 2\zeta\omega_o\dot{x} + \omega_o^2 x = f(t) \tag{1}$$

where: ζ = the damping ratio

ω_o = angular frequency (1/sec)

$f(t)$ = driving function

The general equation for the pitching motion of the aerodynamic body is

$$I_p\dot{q} = M_{aerodynamic} = M_\alpha\alpha + M_{\dot{\alpha}}\dot{\alpha} + M_q q + M_\alpha(t) \tag{2}$$

where: $q = \dot{\theta}$ = time derivative of the pitch angle (θ)

α = angle of attack

I_p = mass moment of inertia about the pitch axis

In the wind tunnel environment, the pitch angle and angle of attack coincide i.e., $\alpha = \theta$, $\dot{\alpha} = \dot{\theta} = q$. Thus, the pitching moment equation can be rewritten as

$$I_p\ddot{\theta} - (M_{\dot{\alpha}} + M_q)\,\dot{\theta} - M_\alpha\theta = M_\alpha(t) \tag{3}$$

Dividing through by I_p, the equation becomes

$$\ddot{\theta} - \left(\frac{M_{\dot{\alpha}} + M_q}{I_p}\right)\dot{\theta} - \left(\frac{M_\alpha}{I_p}\right)\theta = \frac{M_\alpha(t)}{I_p} \tag{4}$$

This fits the form of (1) where

$$2\zeta\omega_o = -(M_{\dot{\alpha}} + M_q)/I_p \text{ and} \tag{5}$$

$$\omega_o^2 = -M_\alpha/I_p \tag{6}$$

Values for ω_o can be measured from the wind tunnel traces. The average period is

$$T = \tfrac{1}{2}[(t_2-t_1) + (t_3-t_2)] \tag{7}$$

$$\omega_o = 2\pi/T \tag{8}$$

The value for I_p is the moment of inertia for the model about the pitch c.g. axis. To solve for $(M_\alpha + M_q)$ it is necessary to know $\mathcal{L}$. Equation (4) can be solved yielding a general solution

$$\theta = e^{-\mathcal{L}\omega_o t} \cos(\omega_o t \sqrt{1-\mathcal{L}^2} + \varphi) \qquad (9)$$

At the boundary conditions presented by points 4, 6, 8, etc (peak positive amplitudes) $\cos(\omega_o t \sqrt{1-\mathcal{L}^2} + \varphi) = 1$. Thus:

$$\theta_4 = e^{-\mathcal{L}\omega_o t_4} \text{ and } \theta_6 = e^{-\mathcal{L}\omega_o t_6}$$

$$\frac{\theta_4}{\theta_6} = e^{\mathcal{L}\omega_o (t_6 - t_4)}$$

$$\ln(\theta_4/\theta_6) = \mathcal{L}\omega_o(t_6 - t_4)$$

Finally,

$$\mathcal{L} = \ln(\theta_4/\theta_6)/\omega_o(t_6 - t_4) \qquad (10)$$

Using equations (5), (7), (8), and (10) it is possible to solve for $(M_{\dot\alpha} + M_q)$

The pitch damping coefficient

$$C_{mq} = \frac{\partial C_m}{\partial q}$$

where $C_m = \frac{M}{\frac{1}{2}\rho A \quad v^2}$

In the wind tunnel, $\dot\alpha$ and q are coupled such that

$$(C_{m\dot\alpha} + C_{mq}) = \frac{\partial \frac{M}{\frac{1}{2} A \quad v^2}}{\partial q}$$

$$(C_{m\dot\alpha} + C_{mq}) = \frac{(M_{\dot\alpha} + M_q)}{\frac{1}{2} \rho A \ell v^2}$$

where:

$(C_{m\dot{\alpha}} + C_{mq})$ is the pitching damping coefficient

A = reference area of model

ℓ = reference length of model

v = tunnel air speed

Pitch damping coefficient thus obtained were used in conjunction with the static aerodynamic coefficients, dimensions, and inertial properties of the full-scale cargo as inputs to a math model to predict actual performance. The pitch damping moment coefficients calculated for the various trials of the "500-gal tank" and "¼-ton truck" models are shown in Table 4. Coefficients for the monowing mounted on the 500-gal tank could not be computed because the steady state oscillations were on the order of the initial displacement.

4. Math Modeling

a. Math Model and Computer Analysis

Mathematical models were developed for computer simulation of the performance of the different airdrop configurations. These models were designed to investigate the pitch plane motion of the system. Two different models were developed; one for the bridle configuration and one for the boom configuration. The major difference in the models is the treatment of the interaction of the line tension forces and the cargo. Also a special treatment of the bridle configuration was developed to determine if part of the bridle reached a slack condition. Either model can be used for the wing configurations.

The analysis is a two-dimensional study incorporating the interaction which occurs between airplane, cargo, and parachute. As developed, three performance phases have been accounted for. The first phase, called extraction, involves the motion of the cargo within the airplane. This phase begins when the extraction parachute is fully inflated and ends when the

TABLE 4. PITCH DAMPING MOMENT COEFFICIENTS

Trial	$(C_{m\dot{\alpha}} + C_{mq})$ 500-Gal. Tank Biwing Run 803-19	500-Gal. Tank Low Single Wing Run 803-20	M38A1 1/4-ton truck Biwing Run 803-21	M38A1 1/4-ton truck Low Single Wing Run 803-22
	(Sec)		(Sec)	(Sec)
1	-.00349	*	-.00725	-.00209
2	-.0036		-.00404	-.00184
3	-.00293		-.00483	-.00187
4	-.00284		-.00529	-.00261
Avg.	-.00322	0.0 *	-.00535	-.00210
α_t	-6 Deg	-15 Deg	-3 Deg	-12 Deg

*Damping moment coefficients for this configuration could not be computed because the natural oscillation amplitude of the system was on the same order of the initial angular displacement. The pitch oscillations were on the order of ± 15 degrees about a trim angle of -15 degrees.

reaction between the cargo and the cargo ramp reaches the ramp edge. The second phase, called tip-off, involves the motion of the cargo at the ramp edge. This phase ends when the cargo is no longer in contact with the ramp edge. The third phase invòlves the motion of the cargo and parachute during free-fall.

b. Results

The first group of cargo/stabilizer configurations examined with the computer simulation consisted of those which were tested in the wind tunnel. Certain estimates had to be made to establish moments of inertia and locations of c.g.'s of cargos with stabilizing structures attached. Weight estimates for the various stabilizer structures were:

Biwing	500 lb
Monowing	400 lb
Extended Bridle Structure	300 lb
Simple Boom or Bridle Attachment	100 lb

The following assumptions were made for the first round of computer analysis:

(1) The height of the biwing structure is 7 feet.

(2) Each folding wing extension is 4 ft (chord) x 6 ft.

(3) The monowing is mounted low on the platform extension from the aft of the cargo.

(4) Each wing extension from the side of the structure is 4 ft (chord) x 6 ft.

(5) The small drogue used to deploy the biwing and monowing is a 4 ft diameter ringslot.

(6) The attachment point of the drogue is 1 ft above the floor of the platform.

(7) Deployment of the wings occurs instantaneously after tipoff.

(8) The height of the bridle attachment structure is 7 ft.

(9) The length of each bridle line is 8 ft (6 ft projected in the pitch plane.

(10) The riser line to the stabilization parachute is 60 feet long.

(11) The stabilization parachute used for the "500-gal. tank" and the "M38A1 ¼-ton truck" configuration is a 10-ft-diameter ringslot. The stabilization parachute used for the "M561 1¼-ton truck" and the "M36A2 2½-ton truck" configuration is a 15-ft-diameter ringslot.

(12) Deployment of the stabilization parachute occurs instantaneously after tipoff.

(13) Initial altitude is 10,000 ft.

(14) Aircraft velocity is 150 KIAS.

Pitch damping moment coefficients for the 500-gal tank and ¼-ton truck equipped with the biwing and monowing stabilizers were calculated from wind tunnel tests as described in section III-3-b. The coefficient for the monowing on the 500-gal tank was assumed to be zero because damping in the wind tunnel test was not significant enough to be measured. Damping moment coefficients for the 1¼-ton truck and the 2½-ton truck were estimated by linearly extrapolating the measured values. The damping moment coefficient for the bridle extension structure alone was assumed to be half the value obtained by multiplying the relevant coefficient for the biwing times the ratio of top and bottom surface area of the extension structure to the bi-wing surface area. For the 500-gal tank configuration, the damping moment coefficient for the bridle extension structure was assumed to be zero because of the problem associated with the monowing in the wind tunnel test. These estimates are merely first approximations but are accurate enough for prototype design analysis.

Results of initial computer runs revealed a problem created by the two-dimensional math model that had not been anticipated. Lift force on some of the cargo/stabilizer configurations is significant, and causes considerable velocity in the direction of the lift vector to accumulate as descent time increases. The problem is accentuated with stabilizing configurations such as the monowing which generate high lift forces and create relatively large non-zero trim angles. The problem was not particularly noticeable during HLPAT airdrops because the cargos tended to roll slowly. Roll changes the direction of the lift vector so that lift-created velocity does not accumulate in one direction. Instead, the lift-oriented velocity creates a spiral trajectory about an ideal ballistic-type trajectory. However, in the two-dimensional program, the lift created velocities become additive and make the cargo "sail" beyond or behind the no-lift trajectory.

The sensitivity of the problem was examined by computer runs for cargo/stabilizer configurations for the M38A1 ¼-ton truck with and without considering lift. The most dramatic difference was encountered with the monowing stabilizer as illustrated by the trajectories plotted in Figure 10. The cargo with the monowing trimmed about an angle of attack of -10 degrees, allowing the lift force to decrease the trajectory radius of curvature. In the early phases of the trajectory, the cargo is driven downward faster than would be expected from just the effect of gravity. As the trajectory angle steepens, the cargo is driven back toward the release point. The situation is also illustrated by the change in the vertical component of velocity as a function of time as shown in Figure 11.

In spite of the limitation of the two-dimensional model, it was decided to consider the lift force in subsequent analyses because it was felt that the results would be representative if the monowing provided some roll stability or produced very slow roll rate. In addition, prediction of actual cargo trajectories is beyond the scope of this program and was not considered as a major decision criterion. The main decision factors were the oscillation performance; the overall descent rate; the simplicity of fabrication; and adaptability of the system to current hardware, rigging, and airdrop procedures.

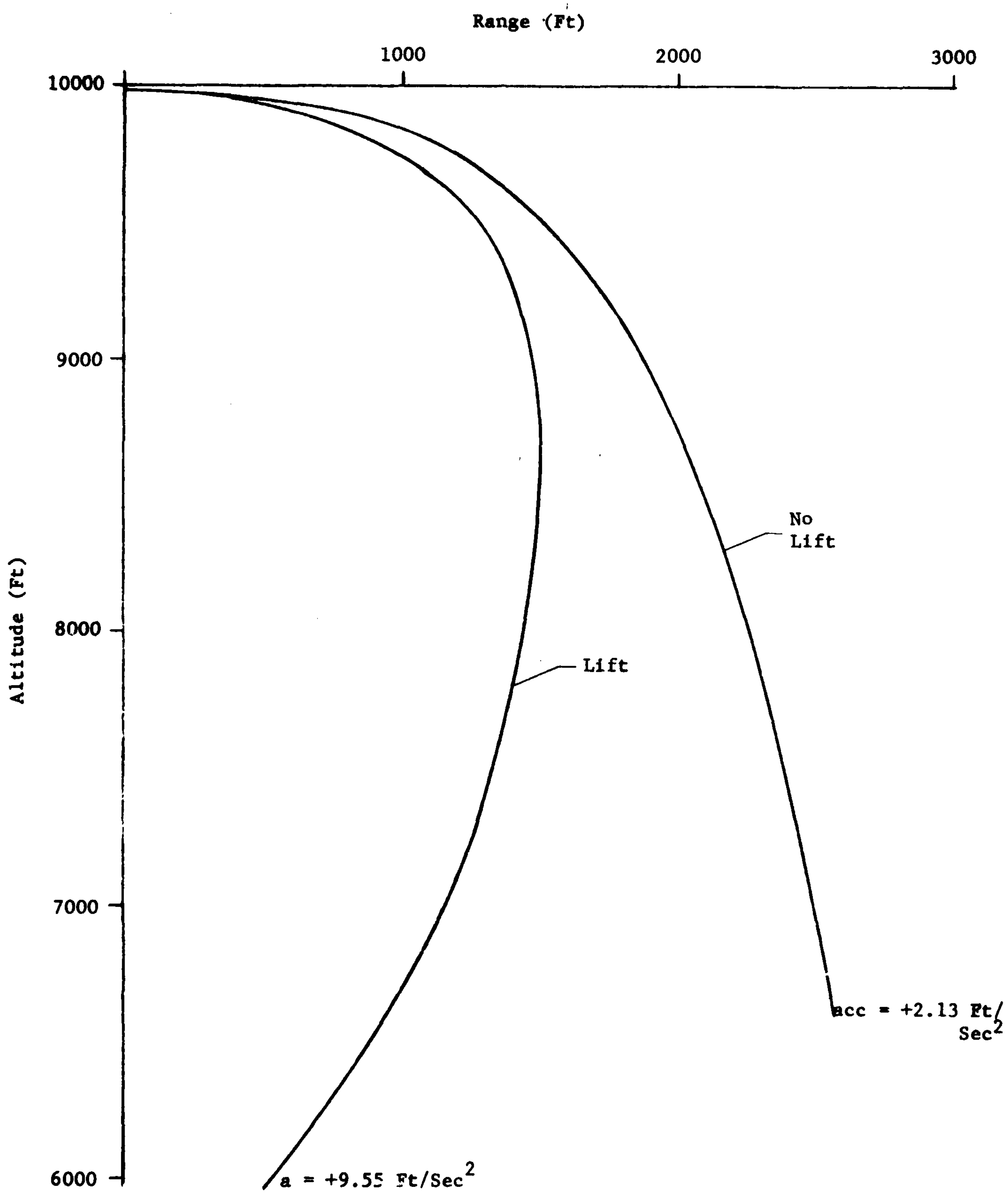


Figure 10.

Effect Of Lift On Trajectories In 2-D Program
(1/4-Ton Truck w/Monowing)

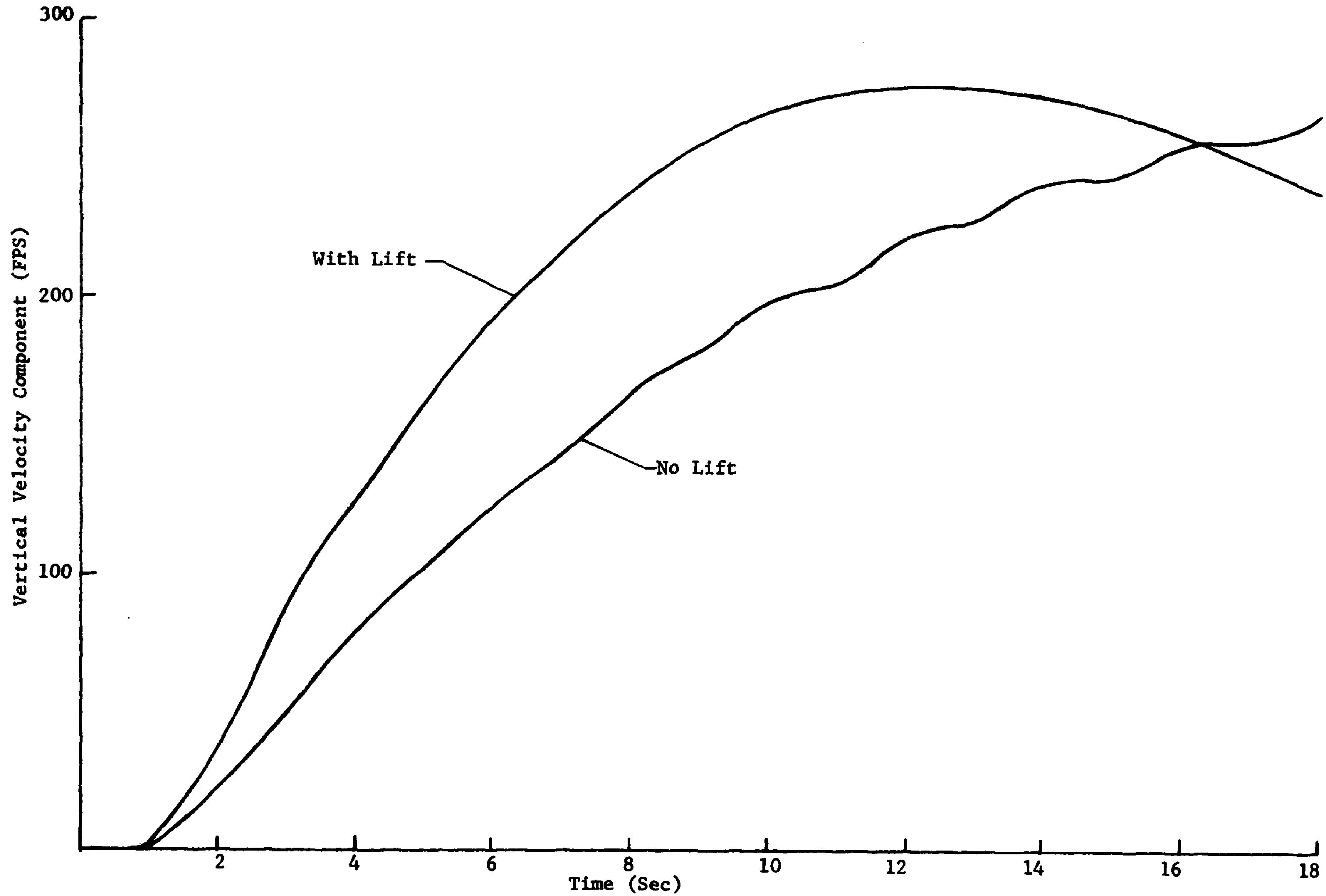


Figure 11.

Effect Of Lift On Vertical Velocity Component Vs. Time
(1/4-Ton Truck w/Monowing)

Criteria that were isolated for decision analysis were:

(1) Maximum initial angular oscillation after tipoff.

(2) Angular oscillation after 20 seconds of flight.

(3) Trim angle.

(4) Altitude after 20-sec. flight.

(5) Vertical component of velocity.

(6) Total velocity after 20-sec. flight.

Results for the four cargo configurations are shown in tables 5 through 9.

Performance of the simple boom extension and non-extended bridle attachment was not satisfactory. Neither system was efficient enough to reduce oscillations to the desired range in a reasonable flight time without the use of a relatively large parachute.

The biwing stabilizer produced the best flight characteristics in terms of the highest terminal velocities, smallest trim angle, and smallest pitch oscillations. However, design problems become severe, especially when trying to adapt the system to the Type II platform and existing extraction techniques. Bending loads imparted by the biwing cannot be carried by the Type II platform without extensive modification. It is doubtful that either the Type V or METRIC platform can carry the large longitudinal bending moments without considerable modification. In addition, the mechanism needed to deploy and support the biwings is heavy and complex and clutters the path needed for direct-cargo-attachment of extraction equipment. Extraction of heavy cargos through the biwing structure would require added strength for both the structure and the platform.

In most cases the overall performance of the monowing and extended bridle attachment system were comparable as to pitch plane oscillation and trim angle. However, the basic low-mounted monowing did not stabilize the M561 1½-ton truck. There may be other cargo loads in the inventory that could not be stabilized. Wind tunnel tests showed that mounting the monowing approximately seven feet off the floor of the platform would provide a stable configuration as would extending the low-mounted monowing

TABLE 5

CARGO CONFIGURATION 500 Gal. Tank w/Dispenser

INITIAL ALTITUDE 10000 AIRCRAFT SPEED 150 KIAS

SELECTION CRITERIA	STABILIZING TECHNIQUE				
	4-FT. BOOM EXTENSION	10 Ft.Dia.R.S. w/ BRIDLE ATTACHMENT	10 Ft.DiaR.S. w/ EXTENDED BRIDLE ATTACHMENT	MONOWING	BIWING
Max. Angular Oscillation (Deg.)	—	+3.5 -15.5	+3.0 -7.5	+1.0 -20.5	+1.0 -4.5
Angular Oscillation After 20 Sec. Flight (Deg.)	—	-5.0 -8.0	-2.5 -2.5	-6.5 -6.5	-2.0 -2.0
Initial Oscillation Frequency (CPS)	—	.833	1.111	.714	1.25
Trim Angle (Deg.)	—	-6.5	-2.5	-6.5	-2.0
Altitude After 20 Sec. Flight (Ft.)	—	6444	6446	5659	5656
Vertical Velocity Component After 20 Sec. Flight (FPS)	—	256	252	319	316
Total Velocity After 20 Sec. Flight (FPS)	—	256	253	334	322

TABLE 6

CARGO CONFIGURATION M38A1 1/4-Ton Truck; Lift Component Neglected

INITIAL ALTITUDE 10,000 AIRCRAFT SPEED 150 KIAS

SELECTION CRITERIA	STABILIZING TECHNIQUE				
	10 Ft.Dia.R.S. w/ 4-FT. BOOM EXTENSION	10 Ft.Dia.R.S. w/ BRIDLE ATTACHMENT	10 Ft. Dia.R.S. w/ EXTENDED BRIDLE ATTACHMENT	MONOWING	BIWING
Max. Angular Oscillation (Deg.)	+1.5 -46	Was Not	+6 -19	+2 -30	+1 -3.5
Angular Oscillation After 20 Sec. Flight (Deg.)	-28.5 -33.5	Run Because	-4 +12	-5.5 -17.5	-1 -1
Initial Oscillation Frequency (CPS)	.715	It Did Not	.55	.525	1.25
Trim Angle (Deg.)	31.0	Appear Much	-8	-11.5	-1
Altitude After 20 Sec. Flight (Ft.)	6900	Better Than The	6799	6604	6443
Vertical Velocity Component After 20 Sec. Flight (FPS)	224	Simple Boom	239	272	284
Total Velocity After 20 Sec. Flight (FPS)	226		241	275	289

TABLE 7

CARGO CONFIGURATION M38A1 1/4-Ton Truck

INITIAL ALTITUDE 10,000 Ft. AIRCRAFT SPEED 150 KIAS

SELECTION CRITERIA	STABILIZING TECHNIQUE				
	10 Ft. Dia. R.S. w/ 4-FT. BOOM EXTENSION	10 Ft.Dia.R.S. w/ BRIDLE ATTACHMENT	10 Ft.Dia. R.S. w/ EXTENDED BRIDLE ATTACHMENT	MONOWING	BIWING
Max. Angular Oscillation (Deg.)	+1.5 -46	+6 -41.5	+6 -17.5	+2 -28	+1.5 -3.0
Angular Oscillation After 20 Sec. Flight (Deg.)	-22 -38	-14 -37	-8 -9	-9.5 -10.5	+1.5 -3.0
Initial Oscillation Frequency (CPS)	.71	.56	.625	.405	1.25
Trim Angle (Deg.)	-30	-25.5	-8.5	-10.0	-.75
Altitude After 20 Sec. Flight (Ft.)	6546	6531	6476	5968	6477
Vertical Velocity Component After 20 Sec. Flight (FPS)	216	219	231	220	280
Total Velocity After 20 Sec. Flight (FPS)	226	230	241	280	287

TABLE 8

CARGO CONFIGURATION M561 1-1/4-Ton Truck

INITIAL ALTITUDE 10,000 AIRCRAFT SPEED 150 KIAS

SELECTION CRITERIA	STABILIZING TECHNIQUE				
	4-FT. BOOM EXTENSION	15 Ft.Dia.R.S. w/ BRIDLE ATTACHMENT	15 Ft.Dia.R.S. w/ EXTENDED BRIDLE ATTACHMENT	MONOWING	BIWING
Max. Angular Oscillation (Deg.)	Unstable	+6.5 -34.0	+7.0 -18.0	Unstable	+3.5 -7.5
Angular Oscillation After 20 Sec. Flight (Deg.)		-7.0 -20.0	-5.0 -8.0		-2.5 -2.5
Initial Oscillation Frequency (CPS)		.312	.435		.625
Trim Angle (Deg.)		-13.5	-6.5		-2.5
Altitude After 20 Sec. Flight (Ft.)		6348	6382		5167
Vertical Velocity Component After 20 Sec. Flight (FPS)		275	260		408
Total Velocity After 20 Sec. Flight (FPS)		275	262		409

TABLE 9

CARGO CONFIGURATION M36A2 2-1/2-Ton Truck

INITIAL ALTITUDE 10,000 AIRCRAFT SPEED 150 KIAS

SELECTION CRITERIA	STABILIZING TECHNIQUE				
	4-FT. BOOM EXTENSION	15 Ft.Dia.R.S. w/ BRIDLE ATTACHMENT	15 Ft.Dia.R.S. w/ EXTENDED BRIDLE ATTACHMENT	MONOWING	BIWING
Max. Angular Oscillation (Deg.)	Unstable;	+10.5 -45.0*	+10.0 -25.5	+5 -26.5	+4.5 -11.5
Angular Oscillation After 20 Sec. Flight (Deg.)	Oscillations	-10.0 -28.0	-5.5 -15.0	-9.0 -12.0	-4 -4.5
Initial Oscillation Frequency (CPS)	Outside	.179	.227	.208	.323
Trim Angle (Deg.)	Of Known	-17.0	-10.25	-10.5	-4.25
Altitude After 20 Sec. Flight (Ft.)	Aerodynamic	5997	5947	5072	5047
Vertical Velocity Component After 20 Sec. Flight (FPS)	Data	307	328	418	440
Total Velocity After 20 Sec. Flight (FPS)		310	328	424	440

*Required Extrapolation of Data Outside of Known Values.

aftward one chord length or reversing the cargo on the platform. However, these configurations were not subjected to computer analysis. It is felt that the structural problems that would be presented by either the raised monowing or biwing would render them unsuitable. The practicality of reversing the cargo on the platform would be a function of the problems encountered in extracting from the front of the cargo and in retraining riggers.

Based on flight performance characteristics, cost, practicality, design simplicity, and compatibility with current airdrop systems, the extended bridle attachment technique emerged as the most practical near-term configuration for a staged,high-level,platform airdrop system.

Following the initial computer analysis needed to identify the best candidate, additional simulations were run to examine cargos weighing up to 35,000 lb and release altitudes of 25,000 ft. In order to consider a "worse case condition" for stabilization, all simulations for 25,000 ft release altitude were done for a 130 KIAS aircraft speed rather than the 150 KIAS as were those for the initial runs. Only large cargo/platform conditions were considered for the 25,000 ft. release analysis. These were:

- 2½-ton truck - 24-ft platform
- ARAAV - 24-ft platform
- D5 Full Tracked Tractor - 20-ft platform
- 1¼-ton-truck - 20-ft platform

Some liberties had to be taken in establishing the aerodynamic characteristics of the ARAAV and D5 tractor. The wind tunnel aerodynamic characteristics for the 2½-ton truck were used for the ARAAV and the wind tunnel results for the 1¼-ton truck were used for the D5 tractor. Parachutes considered were a 12-ft diameter ringslot, 15-ft diameter ringslot, and 22-ft diameter ringslot.

To assess the possibility of using 12-ft diameter parachutes for the larger loads, a simulation for the 1¼-ton truck was run with a 12-ft diameter configuration at 10,000-ft altitude and 150 KIAS. As would be expected, the results showed that, in general:

1) The 12-ft diameter stabilization parachute allows larger oscillations than does the 15-ft diameter parachutes. The difference is on the order of 25-30%. However, for the larger, heavier loads such as the ARAAV and 2½-ton truck, the magnitude of the initial oscillations becomes very undesirable, i.e., greater than -45°.
2) Reducing the aircraft velocity from 150 to 130 KIAS causes an increase in initial oscillations (approximately 25-30%).
3) Descent velocities from 25,000-ft release altitudes are significantly higher (approximately 100 fps) than descent velocities from 10,000-ft. It should be noted that descent velocities presented are for 20 seconds of flight time and that, from the 25,000-ft release point, they have not reached peak. From the curves generated by the plotter, it appears that velocities could increase about another 20-40 fps before beginning to decrease under the influence of increasing air density.
4) Increasing the size of the stabilizing parachute decreases the oscillations but also decreases the descent velocity.

The smallest allowable stabilization parachute is a function of the physical and aerodynamic characteristics of the cargo as well as the performance criteria chosen to limit the selection, such as initial oscillation, the rate of oscillation reduction, terminal velocity, etc. Based on the simulations examined, the primary characteristic that drives parachute selection appears to be mass moment of inertia about the c.g. Table 10 summarizes some pertinent results of the computer simulations. The important

Table 10
Summary of HLPADS Simulations

Cargo	Platform Length (Ft)	Cargo Wgt (Lb)	I_{cg} (Slug-Ft)	Parachute Diameter (Ft)	A/C Speed (KIAS)	Total Range Initial Pitch Angle (A) (DEG)	Total Range Pitch Angle At 20 Sec (DEG) (B)	Oscillation Ratio (B)/(A)
500 Gal Tank	8	5,000	818	10	150	10.5	~0	0
1/4-Ton Truck	12	4,180	1,363	10	150	23.5	1	.042
1-1/4-Ton Truck	20	11,760	9,831	12	150	34.4	6	.176
	20	11,760	9,831	15	150	25.0	6	.120
	20	11,760	9,831	12	130	43.5	11	.253
	20	11,760	9,831	15	130	33.5	8.5	.254
D-5 Tractor	20	26,175	18,453	15	150	31.0	6.5	.210
	20	26,175	18,453	12	130	53.5	20.0	.374
	20	26,175	18 453	15	130	41.5	13.5	.325
	20	26,175	18,453	22	130	30.0	7.0	.233
2-1/2-Ton Truck	24	19,790	42,409	15	150	35.5	9.5	.267
	24	19,790	42,409	15	130	49.0	20.5	.418
ARAAV	24	35,000	47,341	22	150	23.5	6.5	.277
	24	35,000	47,341	15	130	51.0	22.0	.431
	24	35,000	47,341	22	130	32.5	6.0	.185

results are for the total range of initial pitch angle (plus-to-minus amplitude), the range of pitch angle after 20 seconds flight time, and the oscillation ratio, defined as the "20-sec pitch range" divided by the "initial pitch range". The oscillation ratio gives an indication of the rate of stabilization.

Examination of Table 10 reveals several things:

1) The magnitude of the pitch angle range and the oscillation ratio are affected by the aircraft speed at extraction as well as the size of the stabilization parachute.

   The slower aircraft speeds reduce extraction force. In fact, the results are relatively sensitive to aircraft speed and every effort should be made to conduct airdrops at airspeeds at the upper end of the allowable range (150 KIAS).

2) There is a general requirement for larger stabilization parachutes as platform length and cargo weight increase. However, implicit in these increases is also an increase in moment of inertia. For example, in Table 10, the results for the 20-ft platform cargos indicate that larger parachutes would be needed for the D-5 tractor than for the 1½-ton truck to maintain performance even though the platforms are the same length. In this case weights and moments of inertia for the two cargos remain proportional. On the other hand, the ARAAV is nearly twice as heavy as the M36A2 2½-ton truck, but its mass moment of inertia is comparable because of the extended length of that model truck. The pitch performance results for the ARAAV and 2½-ton truck are comparable. Thus, mass moment of inertia seems to be the basis for stabilization parachute selection.

3) The oscillation ratio remains relatively constant for a given parachute size and aircraft speed regardless of the initial pitch angle range. Thus, to reduce oscillations to the minimum possible in the shortest time, it is desirable to keep the initial pitch oscillation range as small as possible consistent with structural limitations of the bridle extension system.

The results are plotted graphically in Figure 12. From this, recommendations for stabilization parachute size are obtained and presented in Table 11.

B. Recommended Configuration

Based on consistency of performance, simplicity of function, and compatibility with current airdrop operations, the extended bridle attachment technique was recommended as the best stabilization candidate for prototype fabrication and full-scale testing.

The basic system operation and an artist's concept of the rigged configuration are shown in Figures 13 and 14. The structure is made of 2.5 in.x 2.5 in.x 1/8 in.square tubing of ASTM A-500 steel Grade C. Design of the structure is such that the loads are distributed through two 18-in.high tubular steel trusses which are attached to the existing platform rails. The top member of the trusses is a square tube 3 in.x 3 in.x 1/4 in. thick. The upper members of the extension structure are connected by an aluminum honeycomb panel. The main purpose of the panel is to provide a "ramp" surface over which the packed recovery parachutes travel during their deployment in the final recovery phase. This panel also contributes an aerodynamic effect that aids the stabilization of the airdrop assembly.

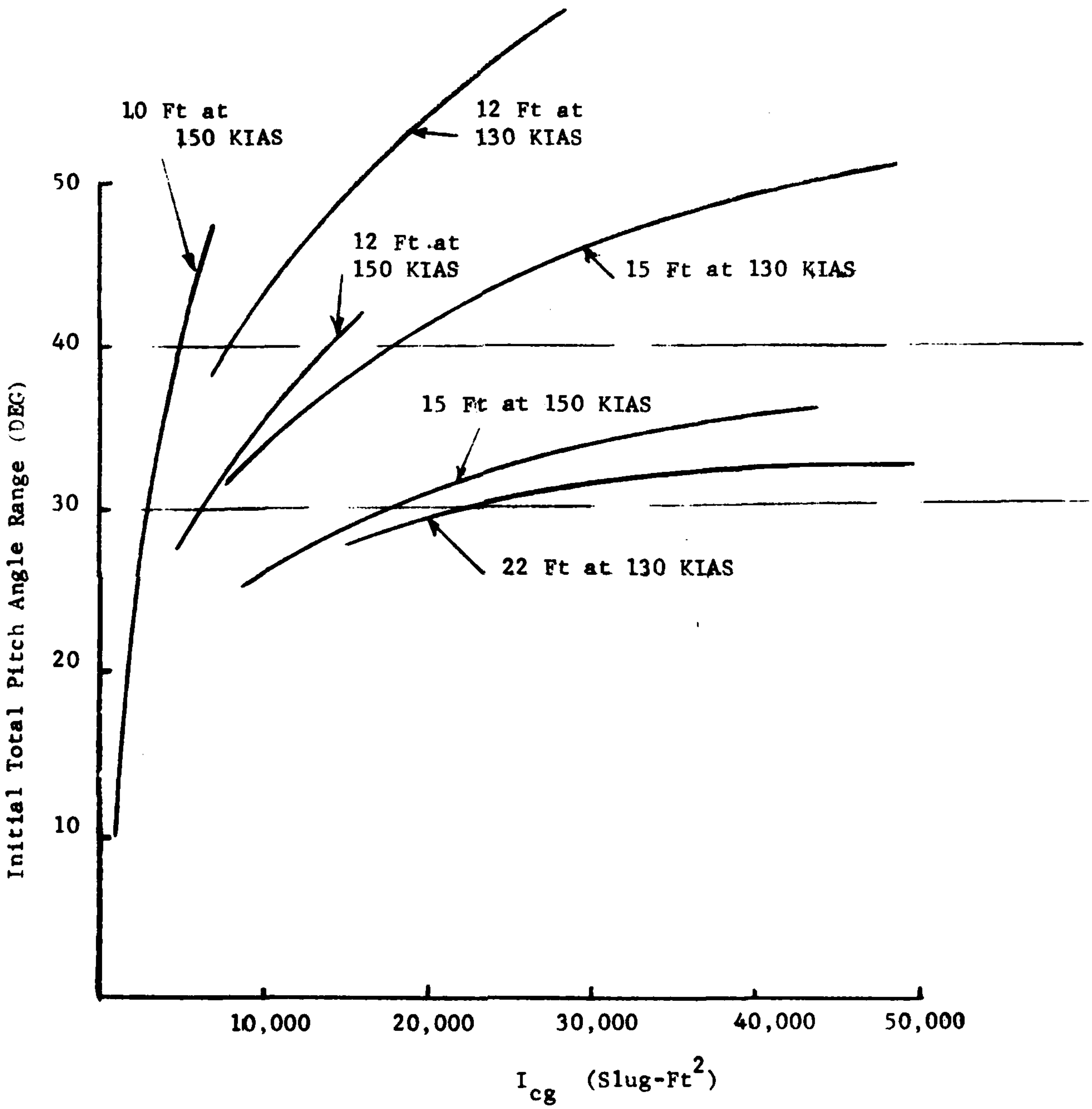


Figure 12. Initial Pitch Angle Range vs I_{cg} Of Cargos

Table 11.

Minimum Stabilization Parachute Sizes

Ringslot Stabilization Parachute Diameter (ft)	Aircraft Speed (KIAS)	To maintain initial pitch angle range to within the values indicated, the I_{cg} of the rigged cargo must be less than the values indicated: 30° I_{cg} (Slug-Ft^2) less than:	40° I_{cg} (Slug-Ft^2) less than:
10	130		
	150	3,000	4,500
12	130	4,000	8,000
	150	5,500	13,000
15	130	6,500	18,000
	150	17,000	50,000
22	130	21,000	
	150	47,000	

Special Note: The bridle attachment structure was not designed to carry the load from parachutes as large as 22 ft. diameter under the extreme 45° pitch - 45° yaw design-criteria discussed in the following section. Analysis shows that the structure will carry the loads under the smaller pitch oscillations indicated by the computer simulation. However, any testing with the 22-ft. diameter parachute should be deferred until stresses imposed by smaller parachutes can be measured and documented.

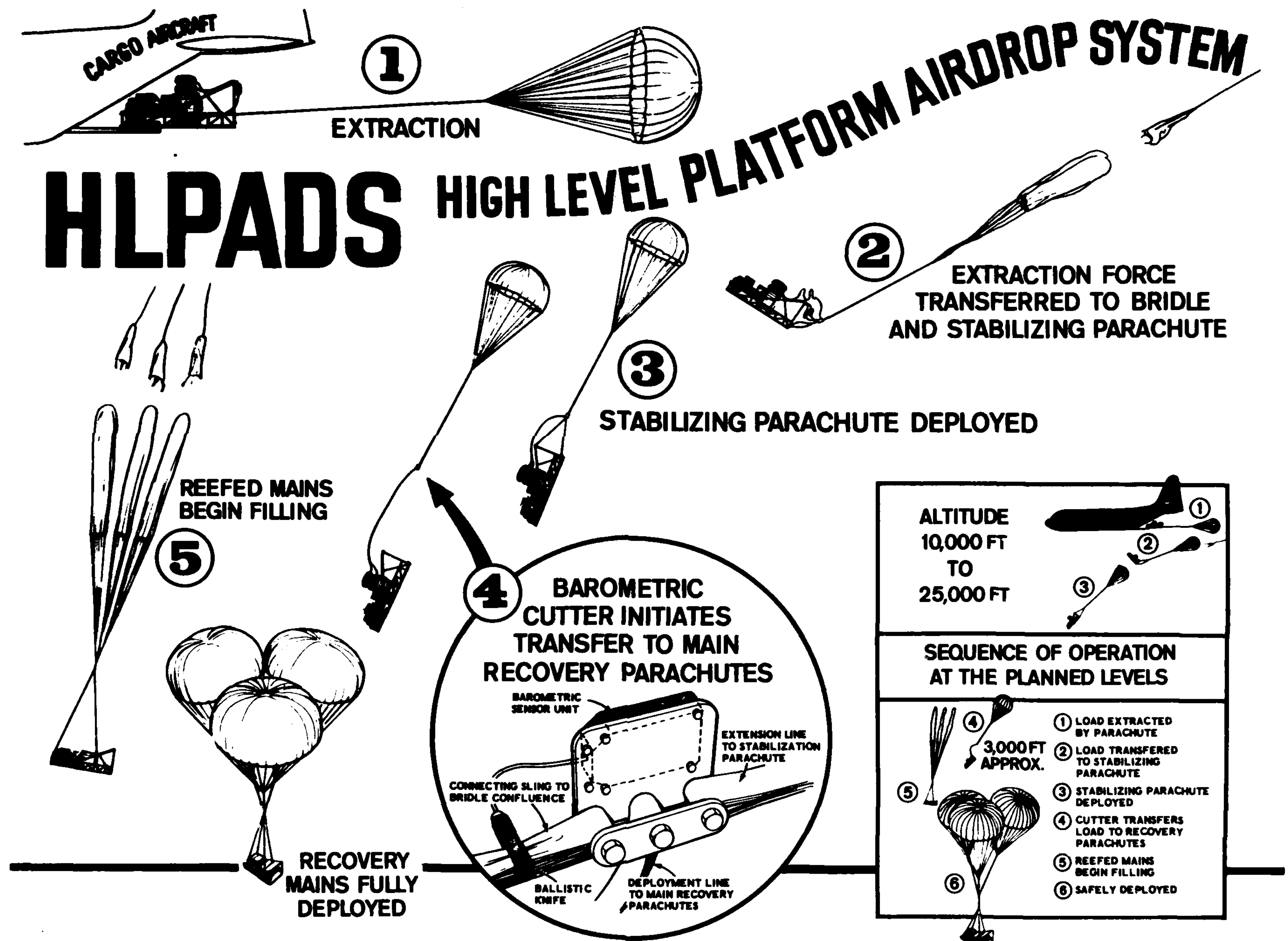


Figure 13.
High Level Platform Airdrop System - Sequence of Events

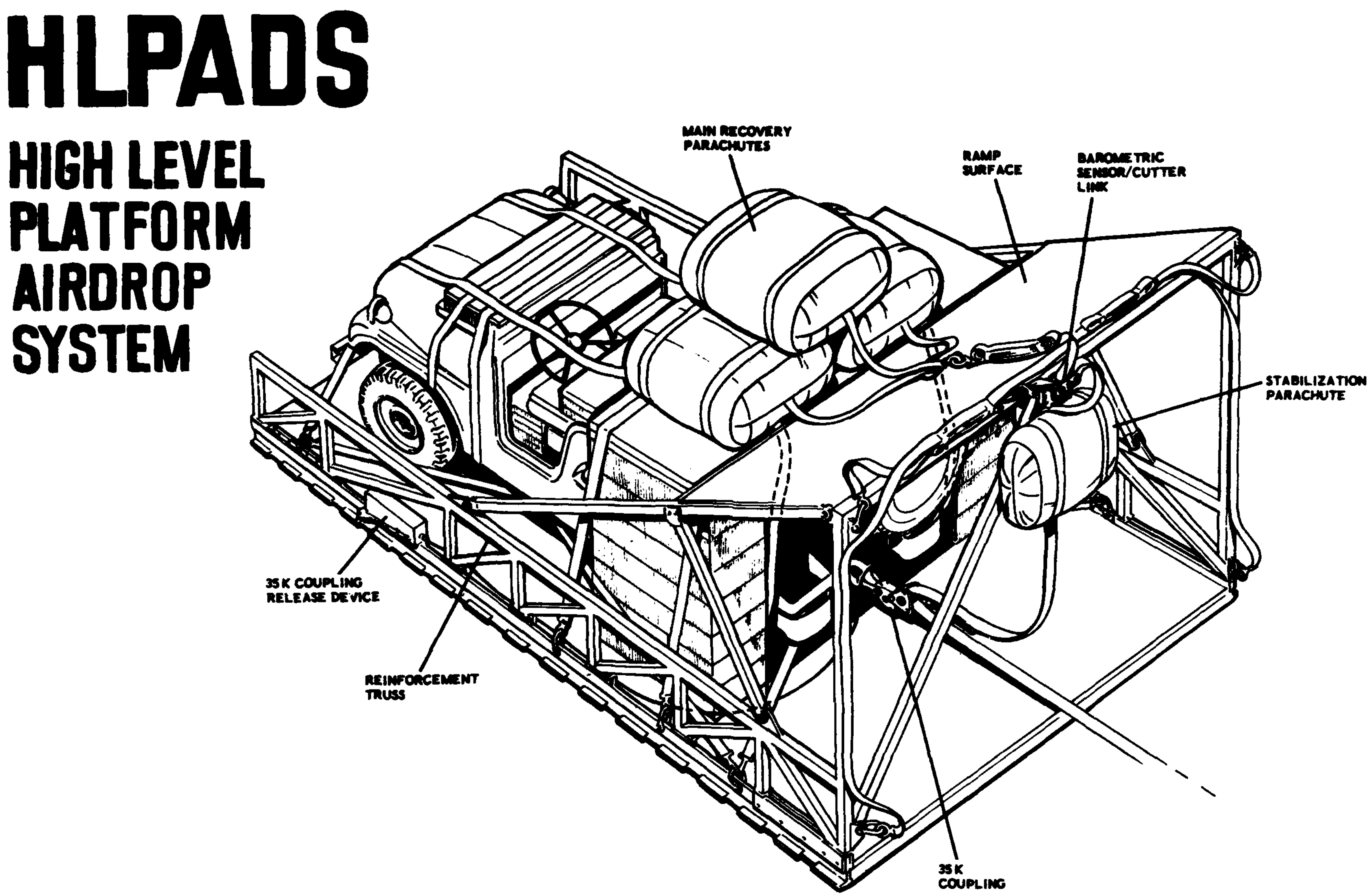


Figure 14.
High Level Platform Airdrop System - Rigged Configuration

C. Structural Design

Structural design calculations were based on the assumption that restoring torque from the stabilizing device is transmitted to the cargo through the platform rails, honeycomb, and tiedowns. Restoring torque must be resisted by the platform rails (reinforced) until a point is reached where the torque can be reacted by the honeycomb or tiedowns. It was assumed that the restoring torque would be reacted at two points rather than distributed over the length of the platform. The actual distribution of forces and moments along the platform is very complicated because of the multiplicity of honeycomb supports and tiedowns. The assumption of a two-point honeycomb support configuration is conservative and made it possible to examine the structure by conventional analytical methods. A sketch describing the model used in the structural analyses is shown in Figure 15. This model was developed for the M561 1¼-ton truck which was judged to be the most critical case because the first major block of honeycomb support is 4 feet forward of the interface with the bridle extension structure. The support at the end opposite the bridle extension was assumed to be two feet from the end of the platform thus providing the model shown in the sketch. Also, the pull of the parachute was assumed to be oriented so that its force was applied through a single bridle element whose projection described an angle of 45 degrees to the plane of the bridle attachment frame in both the plan and side elevation views. The geometry of the bridle is such that at this attitude only one element will be taut.

Using the model shown in Figure 15 and the 7050-lb (31,360 N) pull of a 15-foot (4.5M) ring slot parachute at 150 KIAS, the structure was analyzed with the parachute load applied at both the top and bottom of the bridle frame. The parachute load applied at the bottom of the frame, combined with the expected air loads on the platform, was found to be the critical condition. In performing the structural analyses, the applied load was multiplied by a 1.65 safety factor to

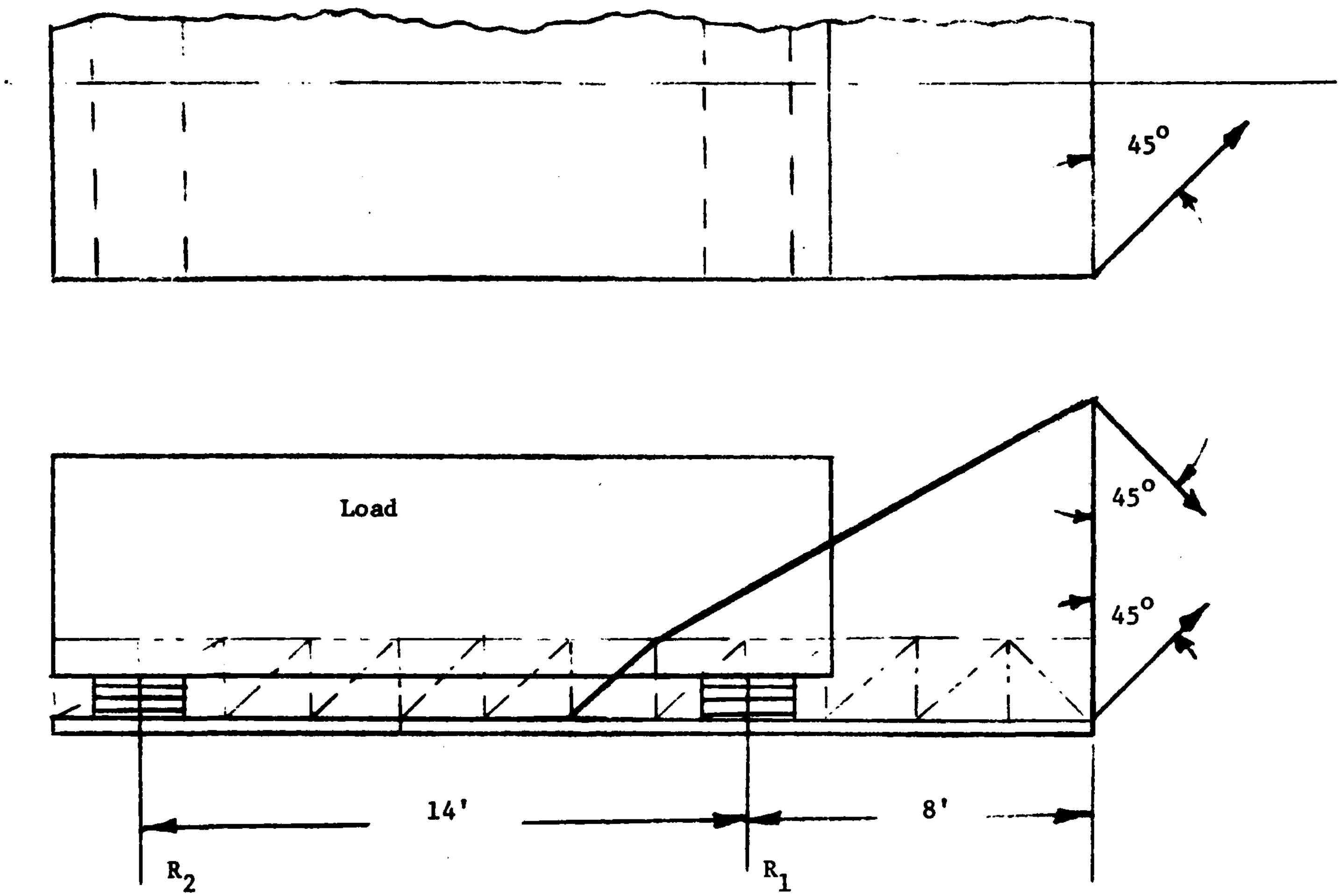


Figure 15. Structural Model

obtain the design load. The stresses produced by this design load were compared with the yield allowables of the materials. A positive margin of safety obtained from these calculations was employed as an indication of acceptable design.

D. Test Equipment

Two sets of test equipment were fabricated and delivered to the Yuma Proving Ground for use in a government conducted test program. Each set consisted of the following:

1 - 12-foot platform assembly

1 - 16-foot platform assembly

1 - 24-foot platform assembly

These lengths include the four-foot extension added to each platform to which the bridle elements are connected. Views of 12-foot and 24-foot platform assemblies are shown in Figures 16, 17 respectively.

A schematic of the stabilizing system rigging is shown in Figure 18. While in the aircraft the extraction parachute is attached directly to the cargo through a 35K coupling. The coupling release mechanism is mounted on the platform rail in an opening designed into the reinforcement truss. One spool of the 35-K coupling link is connected to the packed stabilization parachute so that when the link is released from the cargo, force from the extraction parachute deploys the stabilization parachute and extends the bridle suspension lines.

The bridle lines and stabilization parachute are connected with a three-spool link which contains a barometrically actuated ballistic-knife line cutter. The cutter is used to sever the line connecting the stabilization bridle confluence to the stabilization parachute link at a predetermined altitude. A third line connects the stabilizing parachute link to the packed recovery parachutes so that when the line to the bridle is severed, the force from the stabilizing parachute is transferred to the recovery parachutes.

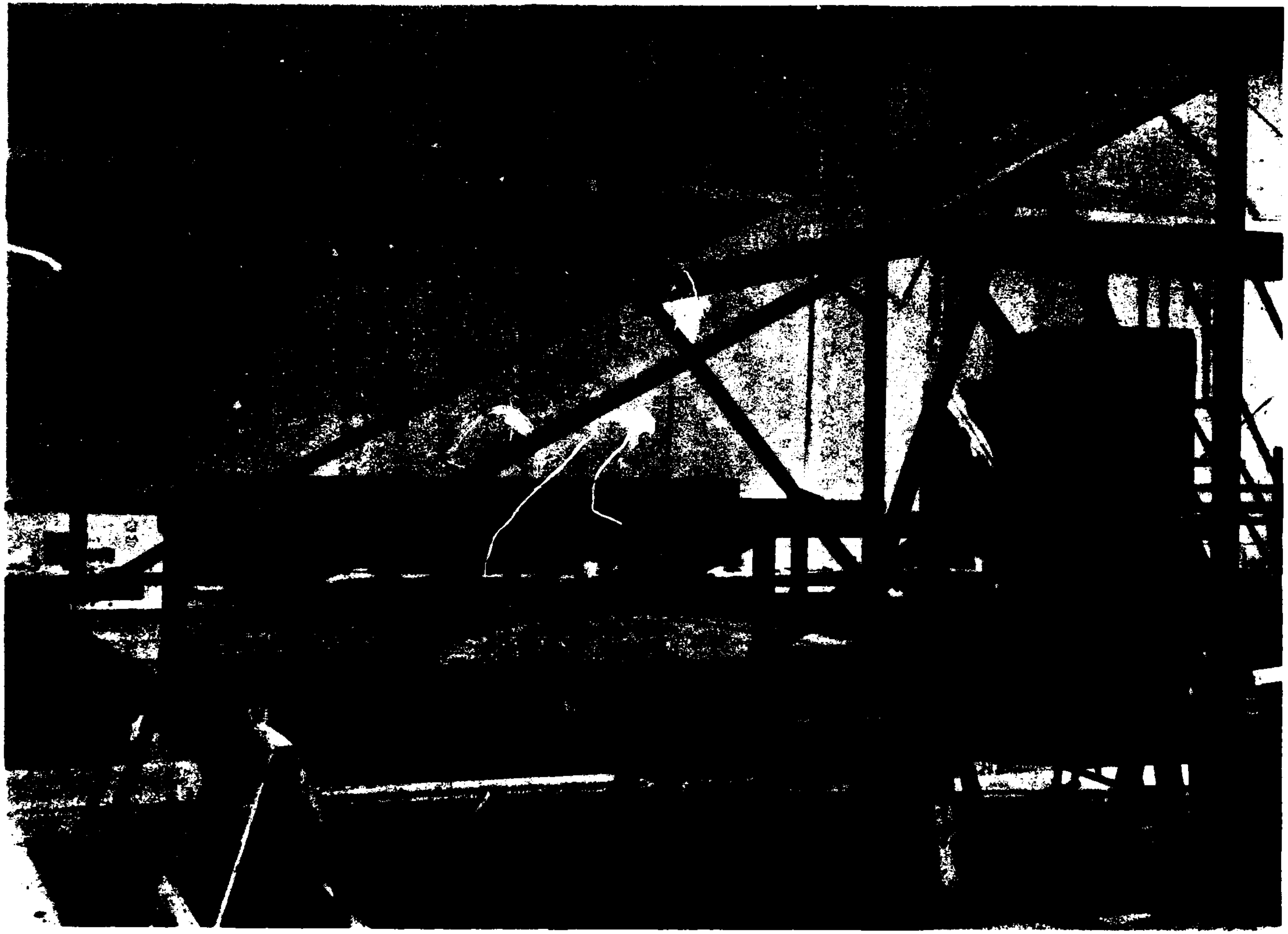


Figure 16. View of 12 Foot Platform Assembly

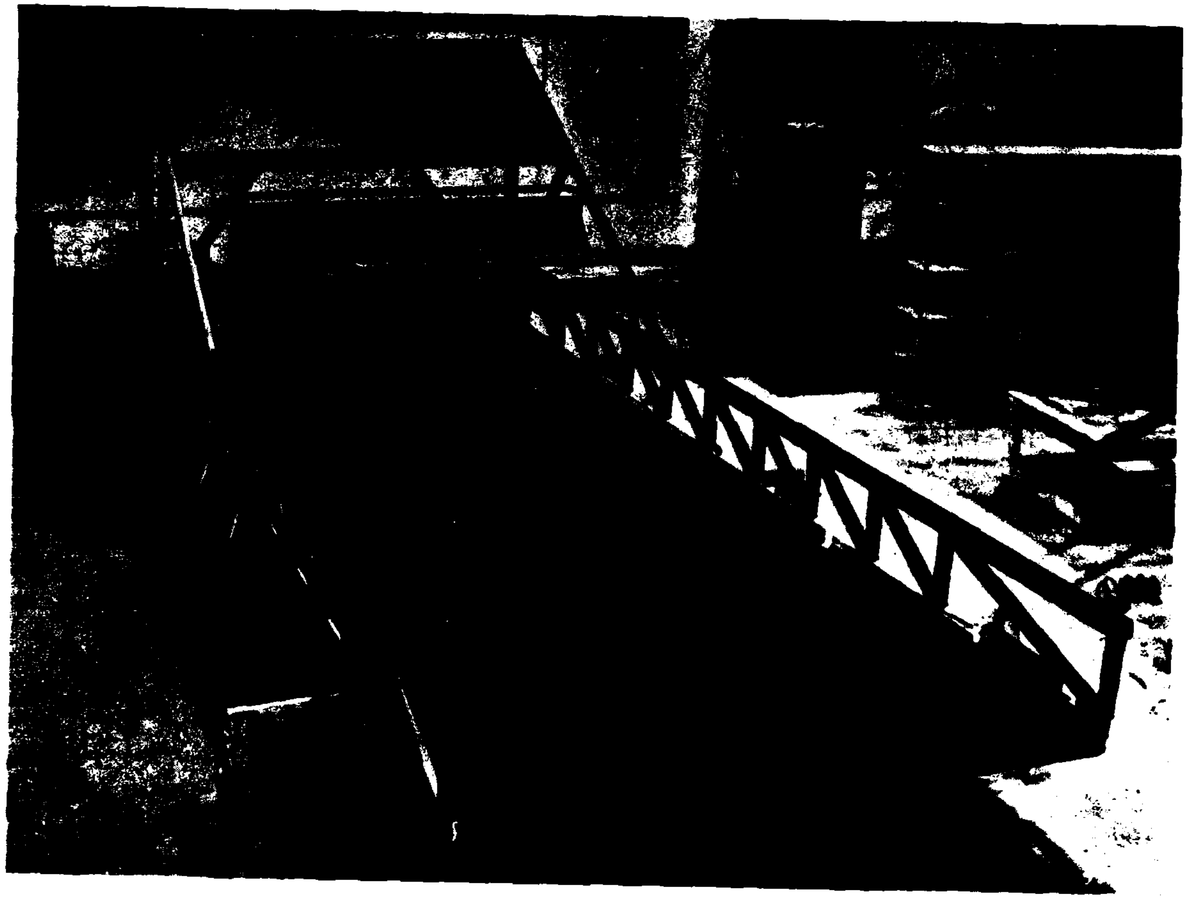


Figure 17. View of 24 Foot Platform Assembly

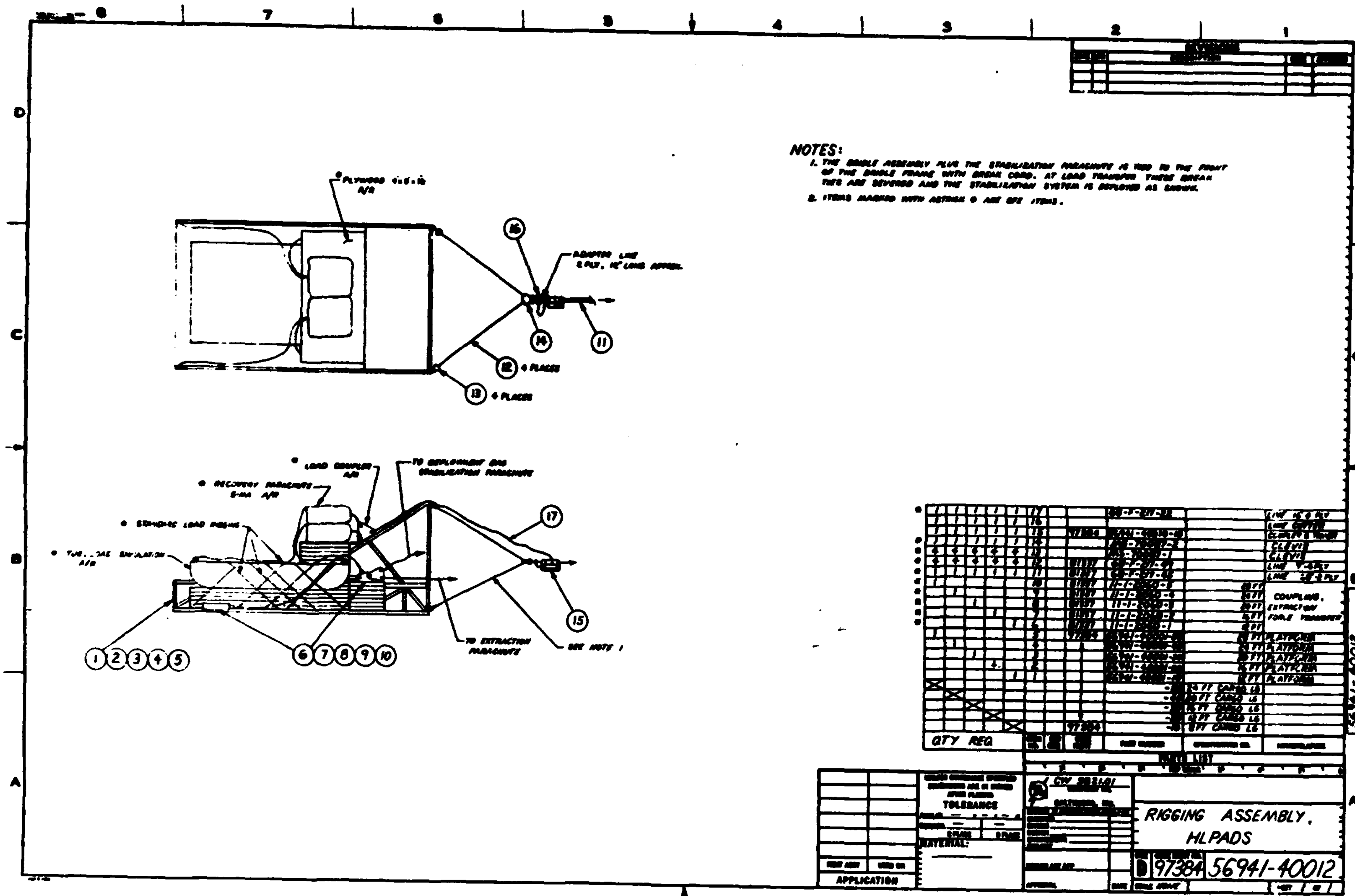


Figure 18.
Schematic of HLPADS Rigging Components

E. Instrumentation

In order to acquire information that will be useful in future refinements of the system, it is desirable to measure the actual loads imposed on the principal members of the bridle and truss structures. An on-board instrumentation system was provided to measure and record these loads.

A rugged eight-channel recorder was acquired that was capable of surviving 15g accelerations in any direction. Eight channels of strain information is recorded on this instrument. The recorder operates on 115-volt, 60-Hz power, which presented a problem since the only source of electric power aboard the load must be a battery. A system was designed that employed a standard 12-volt storage battery as the prime energy source. An inverter was provided to convert the D.C. of the battery to the A.C. form required by the recorder. Other features of the design were the inclusion of a resistance type heater and thermoswitch to maintain the temperature inside the box above a 60-degree minimum, and a variable time switch to shut down the system after a set time period. This time is variable from 15 seconds minimum to 30 seconds maximum. Provisions have been made to start the recorder upon first motion of the load. A view of this instrumentation assembly is shown in Figure 19.

It was necessary to protect the recorder from overshock at load touchdown. This was accomplished by designing a mount for the instrumentation package that constrained the motion of the assembly in all except the vertical direction. In the vertical direction, the assembly rests on a stack of honeycomb material that is configured to control the peak deceleration to 15g's at a 30-foot-per-second touchdown velocity.

IV. CONCLUSIONS AND RECOMMENDATIONS

Theoretical analysis has shown that the four-point extended bridle structure equipped with a relatively small parachute is capable of significantly reducing pitch oscillation of the cargo and maintaining a low-drag stable orientation during the high-speed descent phase of a two stage airdrop system. Stress and functional analyses have indicated that

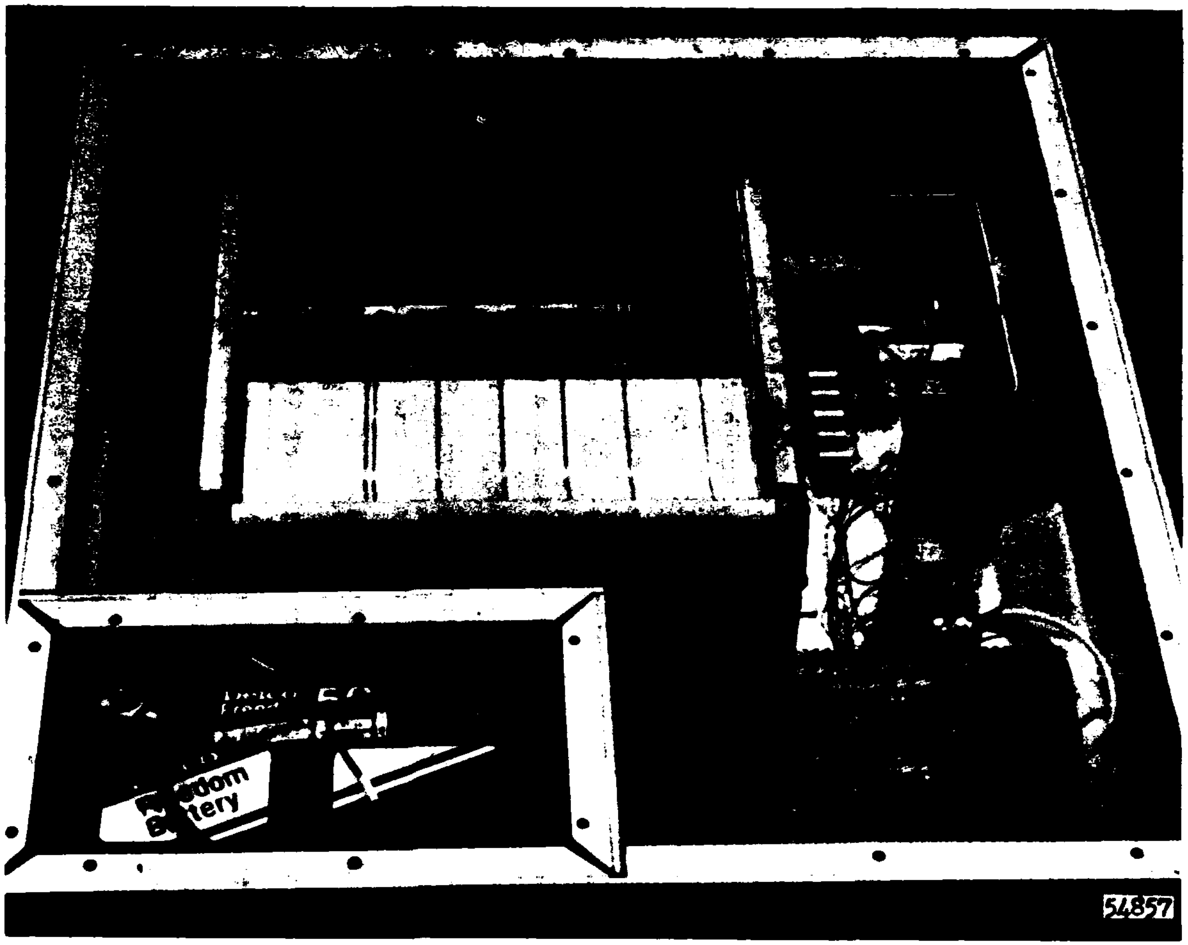


Figure 19. View of Instrumentation Assembly

the recommended configuration is structurally sound and will perform successfully in the airdrop environment. However, as in any system of this type, the proof lies in field testing. Areas of concern that must be verified include:

- The sequencing of events in the total system from extraction through final recovery.
- The amplitude, frequency, and rate of damping of the cargo pitch oscillation as a function of cargo weight, size, and moment of inertia, and the size of the stabilizing parachute.
- The stresses imparted to various key structural components.

Fabrication of prototype hardware was accomplished as part of the contract requirements and a series of airdrop tests is being planned. It is recommended that initial airdrop tests be conducted with relatively lightweight test tubs on 12-ft platforms. Once functioning of the system is verified, the length and weight of the cargo can be increased and instrumentation should be added to monitor loads in the structure. It is expected that test results will show that the size of the reinforcement trusses can be reduced so that rigging and de-rigging can be simplified and overall weight can be reduced.

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