CODE IDENT NO. 25500

GOODYEAR AEROSPACE CORPORATION

AKRON 15, OHIO

AD 672737

HIGH ALTITUDE TETHERED BALLOON SYSTEMS STUDY

TASK REPORT NO 2

SCHEDULE SUB-LINE ITEM 1AB

GER-13552 30 November 1967

Jerome J. Vorachek, Project Engineer

CONTRACT F19628-67-C-0145

SPONSORED BY

ADVANCED RESEARCH PROJECTS AGENCY

DEPARTMENT OF DEFENSE

AFCRL PROJECT MONITORS: MR. LEWIS GRASS
EDWARD YOUNG, CAPTAIN, USAF

MONITORED BY

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

UNITED STATES AIR FORCE

BEDFORD, MASSACHUSETTS

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REF: ENGINEERING PROCEDURE S-017

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FOREWORD

This research was supported by the Advanced Research Projects Agency, and was monitored by the Air Force Cambridge Research Laboratories under Contract No. F 19628-67-C-0145.

The project is being carried out under the direction of Mr. Lewis Grass and Captain Edward Young as Contract Monitor for the Air Force Cambridge Research Laboratories. Mr. Jerome Vorachek is the Goodyear Aerospace Project Engineer. Technical assistance was provided by Mr. William Conley, Mr. Louis Girard, Mr. Bradford Johnson, Mr. Paul Sherburne and Mr. John Bezbatchenko.

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SECTION I - INTRODUCTION

The investigation of tethered balloon systems for extremely high (50,000 to 100,000 foot) altitude operation has continued. Initial results of this investigation are reported in Task Report Number 1 (Reference 1). An important part of Reference 1 is the presentation of data on balloons and cable parameters in such a manner that a performance comparison can be made of many possible balloon and tether cable combinations. Various tethered balloon systems for carrying a 500 pound payload at float altitudes of 50,000 and 100,000 feet (neglecting ascent and descent conditions) can be defined using this parametric data. Balloon designs defined by this parametric data are based on the dynamic pressure at float altitude for Summer I and Winter I wind conditions.

This interim technical report (Task Report Number 2) presents additional information which has been compiled and generated for development of extremely high altitude tethered balloon systems. These data will be useful in establishing balloon systems and planning estimates. This report includes information on tether cables, balloon materials and balloon configurations. Results of analyses of superpressure natural shape balloons which are reefed as they ascend to and from float altitude are given. Aerodynamic coeffients for a natural shape balloon obtained in wind tunnel tests are also presented. An extensive set of cable and balloon parameter curves is provided for use in establishing multiple balloon systems with natural shape balloons, Class C balloons and Glastran E glass stranded cable. These curves provide cable and balloon data for intermediate altitudes between sea level, 50,000 feet and 100,000 feet. Workable cable-balloon combinations (neglecting ascent and descent conditions) for Summer I and Winter I wind conditions are defined as examples.

Further work required to establish feasible extremely high altitude balloon system configurations includes tests of the natural balloon reefing concept and analytical investigations of the ascent and descent problem.

SECTION II - TETHER CABLE & BALLOON MATERIAL SURVEY

A. TETHER CABLES

Five materials were selected to be examined for their potential use as high altitude tether cables. The five materials and their manufacturers were Glastran (Packard Electric, Division of General Motors), rocket wire (American Chain and Cable Company, ACCO), braided nylon rope (Samson Cordage Works), Mylar rope (U. S. Plastic Rope Company) and Nolaro (Columbian Rope Company). Physical data was obtained from the vendors and is given in Table I. Some of the more important properties have been graphed and are displayed in Figures 1, 2 and 3. Note: The strengths of the cables are based on the minimum breaking strengths, rather than normal obtained breaking strengths. Glastran has the highest strength-to-weight of the five materials studied, while for equivalent breaking strengths, rocket wire has the smallest cross sections. The synthetic ropes exhibit strength-to-weights and diameter-to-weights requiring large cross sections to support high tensions. These large areas would be subjected to high aerodynamic forces which when combined with their heavy weight make these ropes less desirable for high altitude use.

Since Glastran and rocket wire have the best properties of the materials investigated, a parametric study was conducted using identical conditions to determine the performance of each. The inputs used were Winter I wind, 100,000 foot altitude, L_N = 49,000 pounds, L_N/D_N = 26, and a factor of safety = 2. The Glastran cable was 110,000 feet long, weighed 39,286 pounds, had a blowdown distance of 50,200 feet and ended up at 20,600 feet MSL. The rocket wire cable was 104,000 feet long, weighed 44,000 pounds, had a blowdown distance of 44,450 feet and ended up at 21,600 feet MSL. The two cables were then compared at 21,600

TABLE I - CANDIDATE TETHE

NAME	MANUFACTURER	MATERIAL DESCRIPTION	SIZES AVAILABLE (INCHES)	STRENGTH (LBS)	ELONG
GLASTRAN CABLE	PACKARD ELECTRIC COMPANY	CONTINUOUS FILAMENTS OF HIGH-STRENGTH "E" GLASS IMPREGNATED WITH EPOXY RESIN	1/16 - 1	500 72,500	19 AT ING STR
ULTRA HIGH STRENGTH STRAND (ROCKET WIRE)	AMERICAN CHAIN & CABLE COMPANY	HIGH STRENGTH CARBON WIRE	1/4 - 1	14 050 - 166 000	1.25 AT BREAKING
NOLARO	COLUMBIA ROPE COMPANY	PARALLELED POLYESTER AND POLYPROPYLENE FIBERS UNDER EQUAL TENSION PROTECTED BY PLASTIC JACKET	1/4 - 1-1/4	1750 - 65,000	5.6 AT 7 BREAKING
2-IN-1 NYLON	SAMSON CORDAGE WORKS	INNER NYLON ROPE COVERED BY AN OUTER NYLON COVER	1/4 - 2-1/8	2100 - 132,000	27 5 AT
MYLAR POLYESTER FILM ROPE	UNITED STATES PLASTIC ROPE, INC	1 MIL MYLAR FILM FASHIONED INTO YARNS AND COMES IN CABLE OR ROPE FORM	1/8 - 1-5/8	500 - 42,700	10 AT BR

(1) MECHANICAL TESTING OF GLASS-EPOXY AND STEEL CABLES - FINAL REPORT
MONSANTO RESEARCH CORPORATION
JOB NO. (MRC): 2560-4
1 OCTOBER 1967

(2) COMPARATIVE FATIGUE TEST ON GLASTRAN AND STEEL CABLE
ORENDA LIMITED LABORATORIES
APRIL 12, 1967

STATIC LOAD = 2400 LBS
CYCLIC LOAD = ±1000 LBS

A

LONGATION %	SPLICING EFFICIENCY % B.S.	END EFFICIENCY % B.S.	FATIGUE ENDURANCE CYCLES	TAPERED CONSTRUCTION	COMMENTS
AT 70% BREAK-STRENGTH ①	70 - 90 (NOT YET PERFECTED)	100	511 200 - 608 000 AT (26% B.S.) ②	THEORETICALLY POSSIBLE - WOULD REQUIRE PROTOTYPE CONSTRUCTION STUDY PROGRAM	ABRASION IS CRITICAL MUST HAVE SPECIAL HANDLING, WEATHERING DOES NOT EFFECT STRENGTH; PROBLEM OF PASSING TAPERED CABLE THROUGH SHEAVES MUST BE INVESTIGATED.
AT 60% OF ① KING STRENGTH	100	100	390 600 - 1 103 400 AT (25% B.S.) ②	STEPPED TABLE HAS BEEN MADE FOR AERIAL TOW LINES	GOOD HANDLING AND FATIGUE PROPERTIES; NOT AS GOOD AS STAINLESS STEEL FOR HIGH ALTITUDES; SUSCEPTIBLE TO SPOTTY BRITTLENESS; [illegible]
AT 70% OF KING STRENGTH		70 - 80			NO HANDLING OR ABRASIVE PROBLEMS. IS RADIO TRANSPARENT.
AT BREAK	92	99		TAPERED NYLON ROPE CAN BE MADE	NO ABRASION OR HANDLING PROBLEMS [illegible] BECOMES HEAVIER WHEN USED IN MOIST ATMOSPHERE; HAS VERY HIGH ELONGATION AT BREAK
T BREAK	90 - 95	90 - 95	INTACT AFTER 270 000 CYCLES AT 14.5% B.S.		NO PROBLEMS IN HANDLING OR ABRASION, WEATHERABILITY CHARACTERISTICS GOOD; AVAILABLE IN CABLE FORM; FOUR TIMES COST OF NYLON

B

DATE ______________
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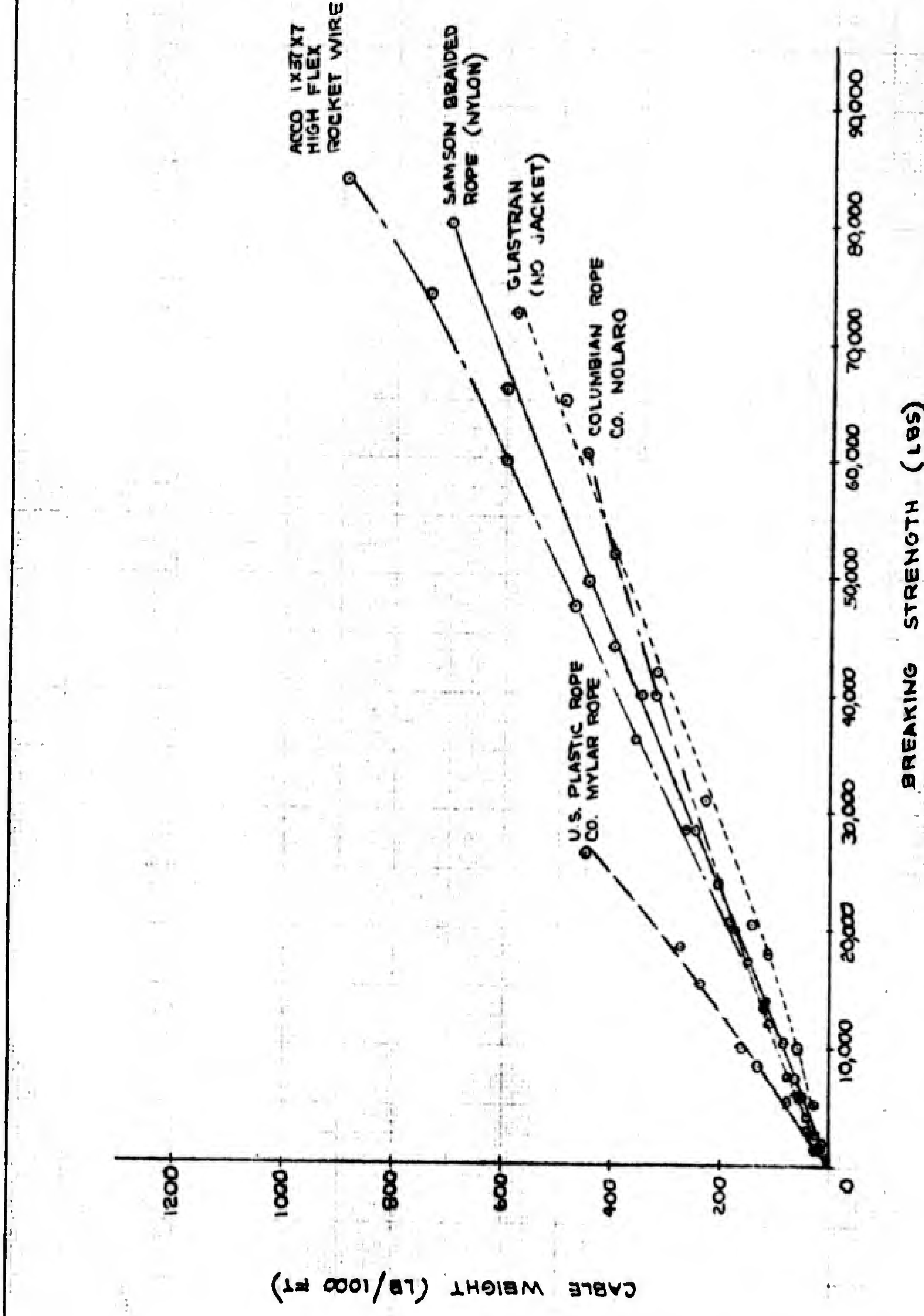


FIGURE 1. CABLE WEIGHT VS BREAKING STRENGTH FOR VARIOUS TETHER CABLE MATERIALS

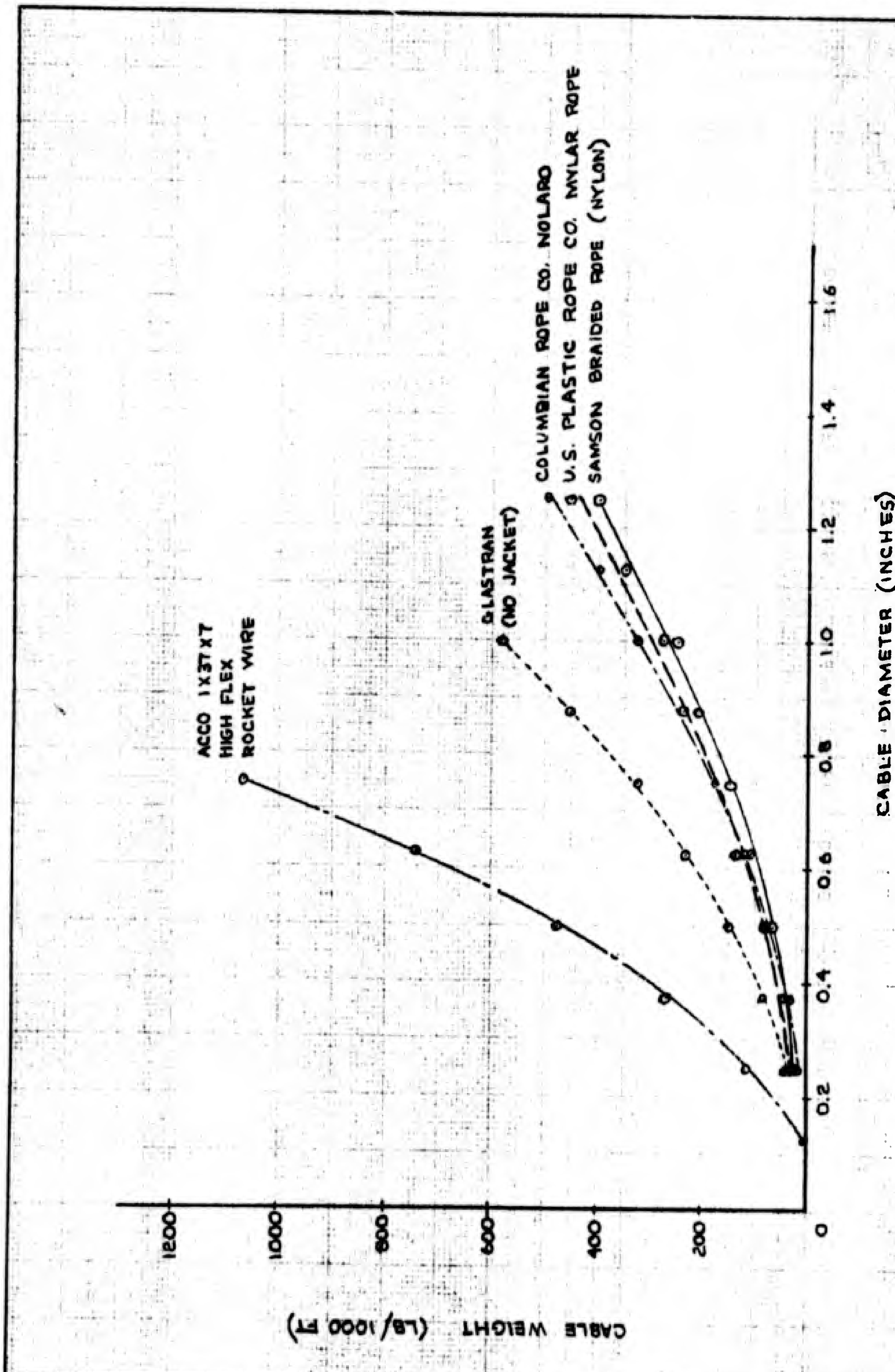


FIGURE 2. CABLE WEIGHT VS CABLE DIAMETER FOR VARIOUS TETHER CABLE MATERIALS

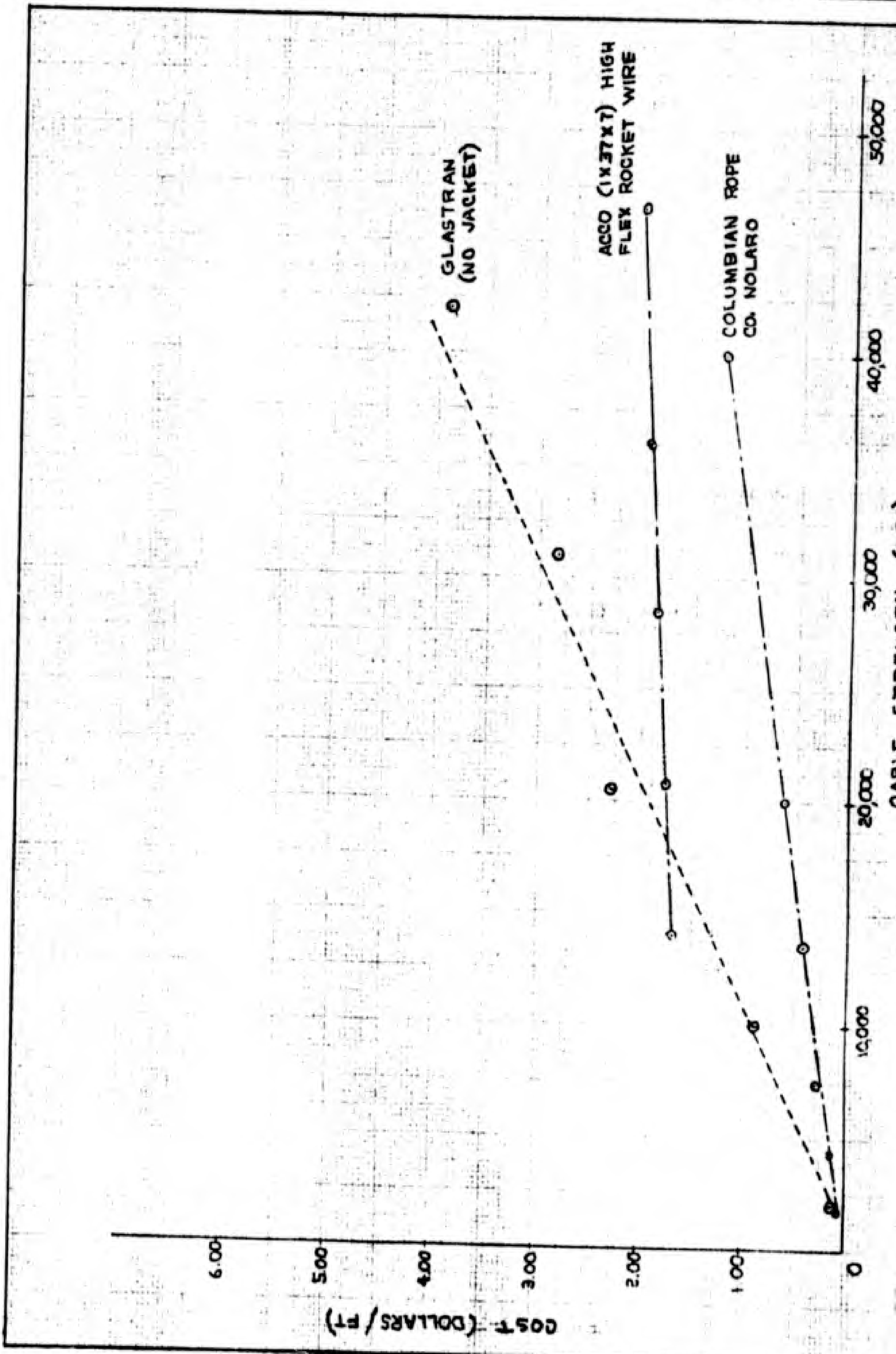


FIGURE 3. COST VS CABLE STRENGTH FOR VARIOUS TETHER CABLE MATERIALS

feet MSL where the Glastran cable was 98,000 feet long, weighed 36,300 pounds and had a blowdown distance of 38,200 feet. The Glastran had less blowdown distance, and weighed less than the rocket wire. Even at the 20,600 foot altitude, the Glastran cable still weighed less although its blowdown distance and total length were more. See Appendix A for computer printouts of cables.

Although present Glastran cables are more expensive than rocket wire for equivalent strengths, Glastran does excel rocket wire in performance and has the possibility of being ideally tapered. For these reasons, Glastran cable was selected as the tether cable to be used in a further parametric study.

Information on titanium wire was requested from a vendor who was known to have produced it, but due to the company's labeling of the physical properties as "proprietary", no data are available for this report.

1. Glastran Cable

Glastran is a glass fiber cable made of continuous filaments of high strength E glass impregnated with an epoxy resin. The filaments are gathered into strands and the strands cabled together similar to conventional rope. It is excellent for tethering balloons since it possesses the qualities most desired in a tether cable: high tensile strength, high strength-to-weight, low drag, low stretch, non-corrosive, and highly resistant to moisture absorption.

Glastran has been used in previous balloon applications and has proved quite successful as a tether cable material. By improving their manufacturing techniques, Packard Electric has brought the strength of E glass to within 20 per cent of S glass (used in Aerostrand - Monostrand) while maintaining a unit price many times lower than S glass. With E glass cable, single nicks do not impair the strength of the whole cable as in the case of Aerostrand - Monostrand filament.

Handling of Glastran requires special procedures. Since it is unjacketed, protective gloves should be worn to avoid glass splinters. Handling should be kept to a minimum as Glastran has low strength in shear. Protective measures must also be taken to ensure that the cable is not dragged along the ground or walked upon. Given proper care, the cable should not weaken through normal ground handling.

Splicing techniques have not yet been thoroughly perfected, but efficiencies in the range of 70 - 90 per cent are deemed feasible. End efficiencies, on the other hand, are 100 per cent the rated breaking strength of the cable when an epoxy end fitting is used.

A study was conducted to determine the creep-rupture characteristics of Glastran (Reference 2). Loaded to 70 per cent of the ultimate tensile strength, the cable failed after 200 hours, loaded to 60 per cent of the ultimate tensile strength breakage occurred after 550 hours, and at a loading of 50 per cent of the ultimate tensile strength, there was no failure after 30 days. In all cases, the elongation was less than 0.20 per cent for a gage length of 27 to 28 inches. Since the systems study used a safety factor of two for the maximum wind condition which the cable is subjected 90 per cent of the time or less, it is felt that the cable is sufficiently strong to last longer than a month.

A study to determine the feasibility of a tapered Glastran cable was made by Packard Electric using Summer I winds at 100,000 feet. Their report showed that it was theoretically possible to make the cable. In their process, 19 parallel tapered strands, made by starting with 17 or 18 ends and tapering down to 4 or 5 ends, would be twisted together to form one strand. (An end is one of the filaments from which a strand is made.) Seven of these strands would then be twisted together to form the cable.

The 140,000 to 150,000 foot cable could not be made from continuous strands due to limited reel capacity, but would require two to three interruptions in each of the 19 ropes. By careful placement of these interruptions at 100 foot intervals, the strength of the cable would not be seriously affected. It should be noted that this tapering process has never been done except theoretically and a study program would be required first in which a prototype cable of 20,000 to 30,000 feet would be made and tested.

Mating the cable with the winch does not seem to present major problems. The reel to hold all the cable would be 96 inches in diameter, have a 96 inch traverse, and a 48 inch barrel. The winch should have a capstan to relieve the tension and prevent crushing the cable on the take-up reel. The sheave diameter should be at least forty times the diameter of the cable and should have a polyurethane coating to prevent chafing and degradation. Repeated weekly winchings in and out should not deteriorate the cable.

Since Glastran presents the best characteristics from an analytical standpoint, it has been decided to use this material as the tether cable for the parametric study being conducted.

2. Rocket Wire

Rocket wire is a high strength carbon wire which has been used as a balloon tether cable and a tow line for aerial tow targets. It has very high tensile strengths, but relatively lower strength-to-weight compared to Glastran. Rocket wire has good abrasion resistance, but is susceptible to spotty brittleness at low temperatures.

A study was undertaken to compare creep-rupture characteristics of Glastran with those of a steel cable similar to rocket wire, but of less strength (Reference 2). The results for the wire cable were: loaded to 70 per cent of the ultimate tensile strength the cable failed in 25 hours; at 60 per cent ultimate tensile it broke in 555 hours; and at 50 per cent ultimate tensile strength no failure occurred at the end of 30 days. The elongations for the three loadings were 1.20, 1.25 and 0.95 per cent respectively for a 27 - 28 inch gage length. These results, of course, were not on rocket wire itself.

Splicing and end termination techniques have been developed which yield 100 per cent efficiency. Using these splicing methods, stepped cable is possible to manufacture. Although tapered cable has never been made, stepped cable using music wire has been produced for use as aircraft tow lines. The process of making 140,000 to 150,000 feet of this stepped cable using rocket wire is still theoretical, but ACCO feels sure that they can make it.

Goodyear Aerospace made a preliminary design of a stepped cable using ACCO's 1 x 37 x 7 rocket wire for Winter I wind, 100,000 foot altitude, L_N = 49,000 pounds, and L_N/D_N = 26. The weight arrived at in this study was nearly 6,000 pounds heavier than calculated in the computer solution. It should be noted that this study used only existing diameter wires and does not take into consideration the use of special diameter wires. (See Figure 4.)

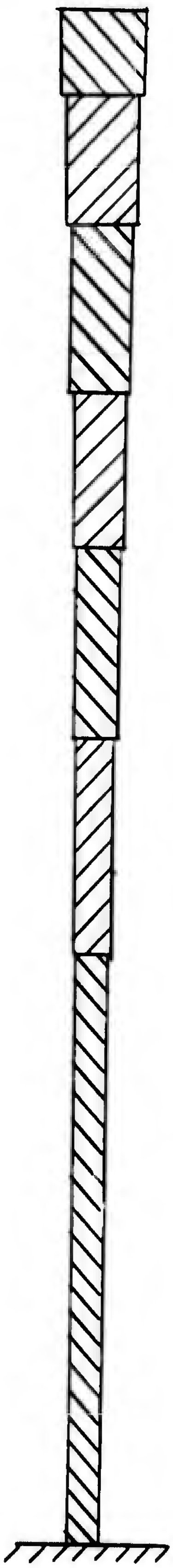


FIGURE 4 - GAC APPROXIMATION FOR A STEPPED CABLE USING ACCO 1 x 37 x 7 ROCKET WIRE IN WINTER I WIND AT 100,000 FT. ALTITUDE.

The facts that rocket wire is relatively heavier than Glastran (for a design where weight is so critical) and Glastran outperforms rocket wire in the parametric study suggests concentration on Glastran for this study.

3. Nylon

Samson's two-in-one braided nylon is actually two ropes in one. An inner core of nylon is encased in an outer nylon cover adding extra strength and safety. This two-in-one braided construction eliminates twisting and untwisting when loads are applied or removed from the rope.

Nylon has been used in balloon systems, but mainly for low altitude flights below 10,000 feet. Two-in-one rope has been made in tapered form, but due to its high elongation and low strength-to-weight, it is not being considered for use as an extremely high altitude tethered cable.

4. Nolaro

Nolaro has no "lay" as does conventional rope. This eliminates the problem of fibers internally cutting into each other when under loads. Nolaro consists of high strength continuous filament synthetic fibers bundled into slack twisted yarns which are then paralleled under equal tension and held together and protected by an extruded plastic jacket.

Although Nolaro has good handling and abrasion characteristics, its lower strength for a given diameter excludes it from the study at this time.

5. Mylar Rope

Mylar rope is made from ribbon-type Mylar film one mil thick. It is fashioned into a yarn in a process which also prestretches it before forming the threads into strands and the strands into rope.

Mylar rope has been used as guy lines for antenna towers and support cables for parabolic antennas. Mylar is highly resistant to moisture, bacteria and fungus, and solvents. It has very low elongation, but also has very low strength-to-weight. Since it is so heavy, it has been eliminated from the survey at this time.

B. BALLOON MATERIALS

Figure 29 of Reference 1 lists typical balloon materials from several vendors. The survey of these materials (presented in Table II) has been expanded and includes films, film-cloth laminates, cloth with spread coats, and cloth with spread coats plus film laminates. The specification of the vendors for the materials investigated are GX - Goodyear Aerospace Corporation; GT - G.T. Schjeldahl Company; Mylar - E. I. DuPont de Nemours and Company, Incorporated; Visqueen - Ethyl Corporation; and Stratofilm - Winzen Research, Incorporated.

At this time, no one material or group of materials has been selected as best. This table has been established to present a survey of some materials that are available.

GAC-sponsored tests are currently underway to study the physical properties of high stretch fabric made from a combination of Lycra Spandex and polyester yarns.

Sealing techniques commonly used on these materials are given in Table II. The efficiencies of these seals are 100 percent

TABLE II - CANDIDATE BA

SPECIFICATION NO	DESCRIPTION	WEIGHT OZ/SQ YD		BREAKING STRENGTH (W/F) (LB/IN MIN)		PLY AD (LB/I
		SPEC	TEST	SPEC	TEST	SPEC
GX30[illegible]781	2 PLY DACRON HYPALON NEOPRENE BUTYL COATING	7.8 ± .5	7.93	90/95(1)	92/98(1)	5.0
GX302HNB0861	2 PLY DACRON HYPALON NEOPRENE BUTYL COATING	8.6 ± .5	9.27	75/65(1)	79/65(1)	5.0
GX302HNB1351	2 PLY DACRON, HYPALON NEOPRENE BUTYL COATING	13.5 ± .5	13.6	200/200(1)	203/221(1)	5.0
GX302[illegible]	2 PLY DACRON, HYPALON NEOPRENE BUTYL COATING	6.6 ± .5	7.06	60/70(1)	75/72(1)	5.0
GX302[illegible]	2 PLY DACRON BUTYL COATING (1 SIDE)	9.5 ± .5	[illegible]	110/95(1)	[illegible](1)	5.0
GX302HN[illegible]	2 PLY DACRON HYPALON, NEOPRENE COATING	11.0 ± [illegible]		120/105(1)		5.0
GX311 0541	2 PLY (1 DACRON 1 FILM) POLYURETHANE COATING	5[illegible] ± [illegible]	5.24	75/75(1)	76/85(1)	5.0
GX2210[illegible]	3 PLY (1 NYLON 2 FILM)	[illegible] ± .5	2.719	41/41(1)	50/47(1)	3.0
GX211P0[illegible]11	2 PLY (1 NYLON, 1 FILM) POLYURETHANE COATING	3.0[illegible] ± .5		45/45(1)		5.0
GX311P0311	2 PLY (1 DACRON, 1 FILM) POLYURETHANE COATING	3.1 ± .5		[illegible]/40(1)		5.0
GX2120351	3 PLY (1 NYLON, 2 FILM)	3.5 ± .5		65/[illegible](1)		3.0
GX301U0451	1 PLY DACRON UNCOATED	4.5 ± .5	4.9	65/75(T)	108/81(1)	N/A
GX301N0510	1 PLY DACRON, NEOPRENE COATING	5.1 ± .5	5.58	120/110(1)	156/154(1)	N/A
GX301N0511	1 PLY DACRON, NEOPRENE COATING	5.1 ± .5		120/110(1)		N/A
GX311P0631	2 PLY (1 DACRON 1 FILM) POLYURETHANE COATING	6.34 ± .5	6.59	80/80(1)	86/80(1)	5.0
GX201N1601	1 PLY NYLON, NEOPRENE COATING	16		450/357(1)		N/A
GX311P0481	2 PLY (1 DACRON, 1 FILM) POLYURETHANE COATING	4.8 +0 -.5	4.7	45/50(1)	58/63(1)	5.0
GX301U0541	1 PLY DACRON, UNCOATED	5.4 ± .5		75/65(1)		N/A
MYLAR (TYPE A) (1 MIL)	POLYESTER FILM	1.0		25/25(2)		N/A
VISQUEEN X-124 (1 MIL)	POLYETHYLENE FILM	0.694		.5/2(2)		N/A
STRATOFILM (0.7 MIL)	POLYETHYLENE FILM	0.475		3/3(2)		N/A
GT-12	MYLAR LAMINATED TO DACRON SCRIM	1.6	1.56	45/25	40/20	1.5
GT-31	TRILAMINATE (1 DACRON, AND 2 MYLAR)	2.1		45/45		3.0
GT-73	MYLAR & 1 LAYER OF DACRON LAMINATE OF NYLON FABRIC BONDED TO MYLAR FILM	1.9		50/50		3.0
GT-74	NYLON FABRIC BONDED TO NYLON FABRIC	7.3		275/275		4.0
GT-76	METALLIZED MYLAR LAMINATED TO NYLON FABRIC	2.1		55/55		3.0

A

LY ADHESION (LB/IN MIN)		COATING ADHESION (LB/IN MIN)		PERMEABILITY (L/SQ M/24 HR)		MATERIAL WIDTH (INCHES)		SEALING TECHNIQUES
EC	TEST	SPEC	TEST	SPEC	TEST	SPEC	TEST	
5.0	5.6	7.5	8.3/8.8	2.0 (HE)	1.1 (H_2)	43.0	44.1	GOODYEAR C-25 PROCESS
5.0	8.7	7.5	9.6/9.5	2.0 (HE)	1.6 (H_2)	43.0	43.5	GOODYEAR C-25 PROCESS
5.0	5.4	7.5	7.2/9.6	2.0 (HE)	1.2 (H_2)	42.0	42.0	GOODYEAR C-25 PROCESS
5.0	[illegible].3	7.5	10.9/7.6	2.0 (HE)	1.7 (HE)	43.0	43.5	GOODYEAR C-25 PROCESS
5.0	7.6	7.5	10.8/11.1	2.0 (HE)	[illegible] (HE)	40.0	41.5	GOODYEAR C-25 PROCESS
5.0		7.5		2.0 (HE)		44.0		GOODYEAR C-25 PROCESS
5.0	6.8	7.5	7.7	2.0 (HE)	1.4 (H_2)	44.0	44.5	GOODYEAR C-25 PROCESS
3.0	5.4	N/A		4.0 (HE)	1.4 (HE)	40.5	40.5	GOODYEAR PE-207 ADHESIVE (HEAT SEALING TAPE)
5.0		7.5		2.0 (HE)		44.0		GOODYEAR C-25 PROCESS
5.0		7.5		2.0 (HE)		44.0		GOODYEAR C-25 PROCESS
3.0		N/A		2.0 (HE)		40.0		GOODYEAR PE-207 ADHESIVE HEAT SEALING TAPE)
N/A		7.5	9.4/11.4	2.0 (HE)		44.0	40.8	GOODYEAR C-25 PROCESS
N/A		7.5	7.6/7.7			40.0	42.5	GOODYEAR C-25 PROCESS
N/A		7.5				40.0		GOODYEAR C-25 PROCESS
5.0	6.4	7.5	14.1	2.0 (HE)	0.7 (H_2)	40.0	40.9	GOODYEAR C-25 PROCESS
N/A		20						GOODYEAR C-25 PROCESS
5.0	6.9	7.5	9.6	2.0 (HE)	1.2 (H_2)	44.0	44.8	GOODYEAR C-25 PROCESS
N/A		7.5		2.0 (HE)		40		GOODYEAR C-25 PROCESS
N/A		N/A		<1.0 (HE)		66		SCHJELDAHL GT300 & GT100 HEAT SEALING TAPE
N/A		N/A		<1.0 (HE)		54		HEAT SEALING (PROPRIETARY)
N/A				NOT AVAILABLE		54		HEAT SEALING (PROPRIETARY)
1.5		N/A		1.75 (H_2)		58	58	GOODYEAR PE-207 ADHESIVE (HEAT SEALING TAPE)
3.0		N/A		1.0 (H_2)				GOODYEAR PE-207 ADHESIVE (HEAT SEALING TAPE)
3.0		N/A		2.0 (H_2)				GOODYEAR PE-207 ADHESIVE (HEAT SEALING TAPE)
4.0		N/A		1.0 (H_2)				GOODYEAR PE-207 ADHESIVE (HEAT SEALING ADHESIVE)
3.0		N/A		1.0 (H_2)				GOODYEAR PE-207 ADHESIVE (HEAT SEALING ADHESIVE)

FOOTNOTES:

N/A - NOT APPLICABLE

① - TESTED AT STANDARD ATMOSPHERIC TEMPERATURE

② - TESTED AT 25 DEGREES C

B

of strength of the materials when the proper seam width for each material is used. Three common assembly techniques are displayed in Figure 5.

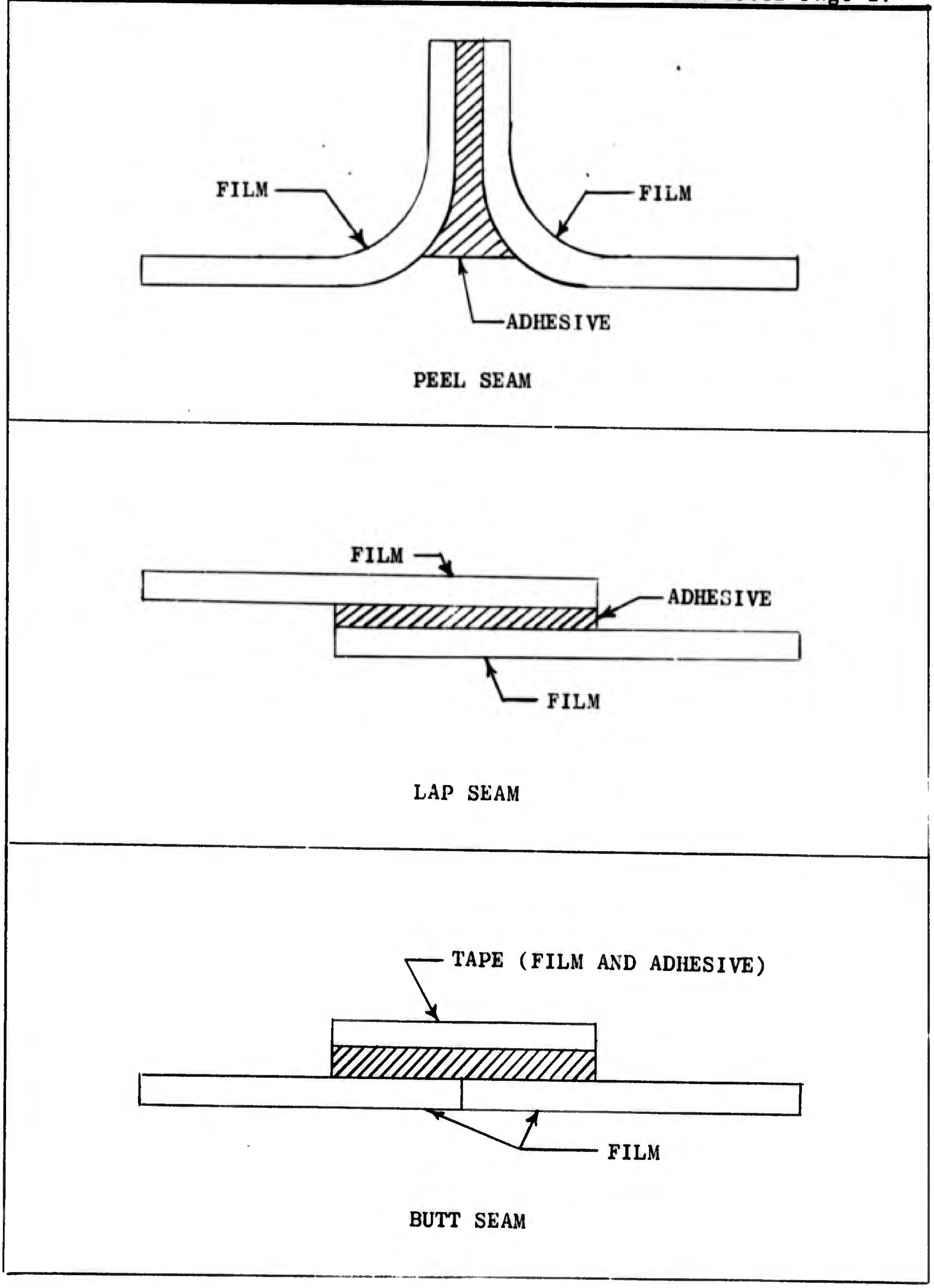


FIGURE 5 - THREE TYPICAL ASSEMBLY TECHNIQUES FOR FILMS

SECTION III - BALLOON CONFIGURATIONS & CHARACTERISTICS

A. GENERAL

Tethered balloon configurations applicable to the extremely high altitude mission are discussed herein. Two typical streamlined balloon types; the single hull balloon and the Vee balloon, and a natural balloon with reefing to control volumetric change with altitude are described. An evaluation of various streamlined balloon types based on weight and performance data generated and reported in Reference 1 is also included. Static and dynamic stability of balloons is discussed and some additional aerodynamic characteristics obtained in wind tunnels are given.

B. DESCRIPTION OF BALLOON CONFIGURATIONS

1. Single Hull Balloon

The following description of a single hull balloon is based on the Navy Class C design. This shape was selected as containing the typical characteristics of a streamlined single hull balloon.

The single hull balloon (Figure 6) consists essentially of an aerodynamically shaped hull with three inflated fins mounted in the form of a "Y" on the aft end of the hull. These fins provide longitudinal and lateral stability for the balloon. At the present time all three fins are assumed to be helium inflated at altitude; however, making the bottom fin air inflated to permit collapsing for ease in bedding down the balloon is worthy of consideration.

Each fin is compartmented from the hull with manifolds connecting the fins to the hull. The manifolds are located on the trailing edge of the fin. The fins are inflated at the same time the hull is inflated.

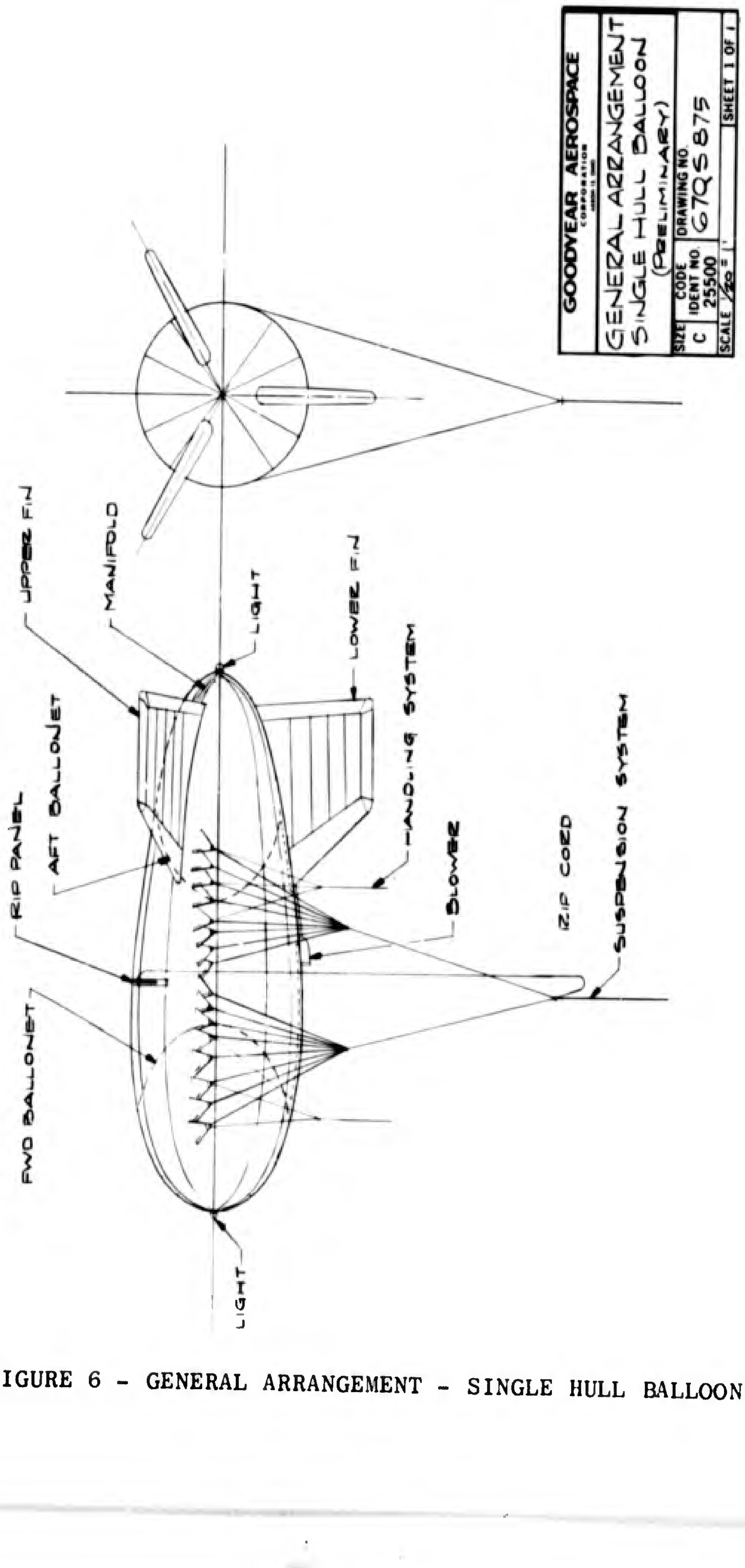


FIGURE 6 - GENERAL ARRANGEMENT - SINGLE HULL BALLOON

The pressurization system consisting of ballonet in the nose and tail of the hull envelope and blower and battery system allows the balloon helium to expand with temperature, pressure and altitude changes and maintains the internal pressure at a constant level. The balloon is equipped with a rip panel which permits quick deflation of the balloon in case of emergency such as a breakaway. The balloon can also be deflated by pyrotechnic devices which are actuated either from the ground or by a barometric switch located in the airborne unit.

Four handling lines hold the balloon on the ground during and after inflation and before launch. These handling lines are also used for bedding down the balloon.

The balloon is attached to the tether cable by means of the suspension or bridle system, which spreads the tether line load over the entire balloon.

2. Vee Balloon

The Vee balloon (Figure 7) consists essentially of two aerodynamically shaped envelopes intersecting at an angle of 35 to 40 degrees and joined at the nose. An inflated horizontal tail, which joins the two envelopes at the aft part, provide longitudinal stability. Two manifolds connect the horizontal fin to the hulls. The manifolds are located on the trailing edge and adjacent to each hull. Two smaller vertical tail surfaces are located under each hull to provide directional stability. Manifolds connect the vertical fins to the hull at the trailing edge.

Both the horizontal and vertical tail surfaces are inflated at the same time the main envelopes are inflated.

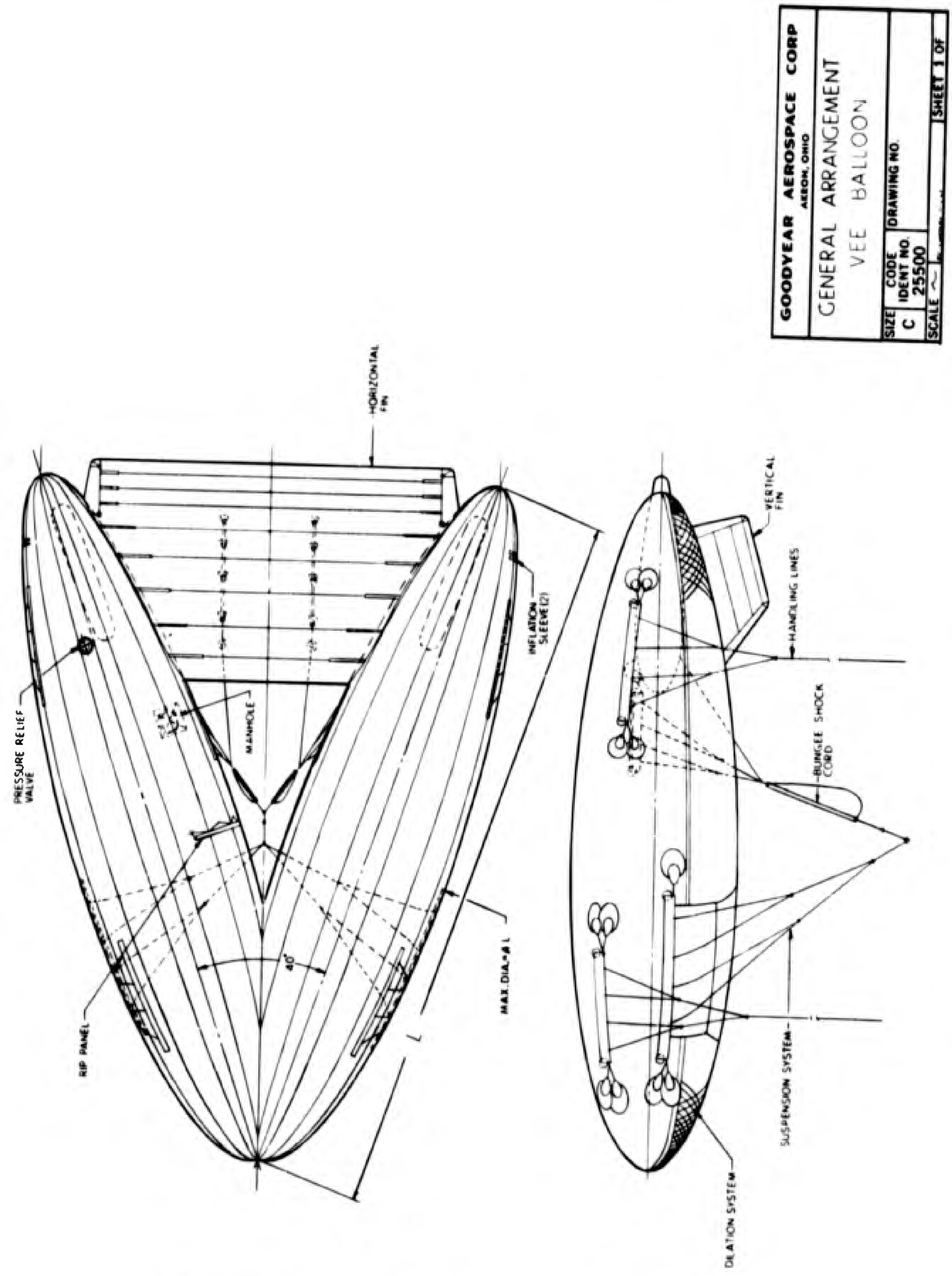


FIGURE 7 - GENERAL ARRANGEMENT - VEE-BALLOON

The pressurization system assumed for the Vee balloon for the analysis in Reference 1, was also of the ballonet - blower type similar to that of the single hull design. Moderate altitude (10,000 foot) Vee balloons which have been constructed have used dilation systems as depicted in Figure 7.

Four handling lines hold the balloon on the ground during and after inflation and before launch. These handling lines are also used for bedding down the balloon.

The balloon is attached to the tether cable by means of the suspension or bridle system which spreads the tether line load over the entire balloon.

Usually the Vee balloon suspension system contains a bungee type expansion member which allows automatic adjustment of the angle of attack of the balloon under various wind conditions.

3. Natural Shape Balloon with Reefing

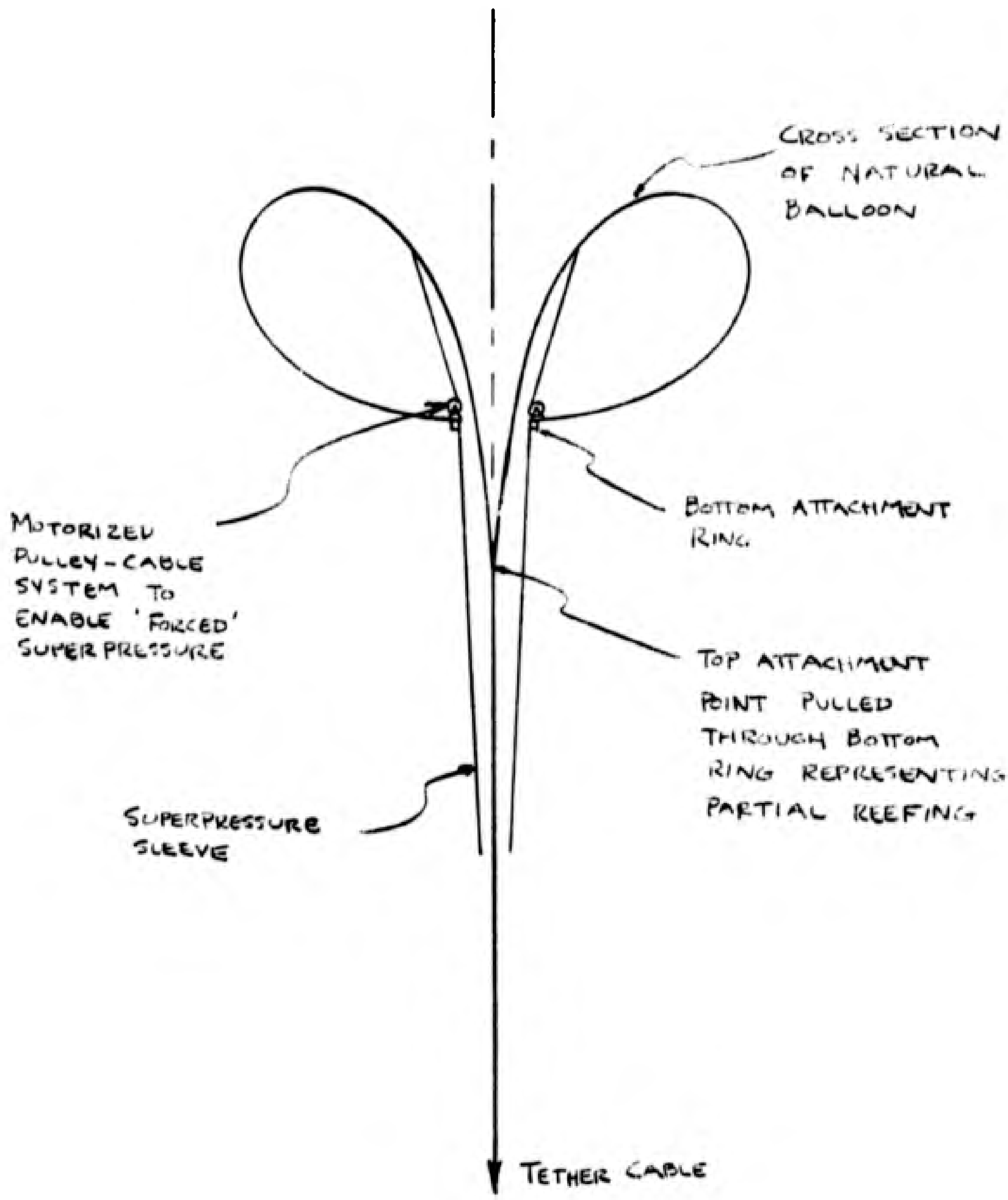
Natural balloons designed fortethering basically resist wind forces much greater than those balloons which are free . With this consideration in mind, development of the natural balloon to provide a more favorable shape and capability to maintain that shape was sought.

Theory, analysis, new developments, design procedure and a model test program are defined in detail in Appendix C. The appendix is written as a unit and should be examined in entirety to understand fully the subjects of the latter parts of the appendix.

Qualitatively, some of the more important items included in the appendix are presented below and depicted in Figure 8.

FIGURE 8

NATURAL SHAPE BALLOON WITH REEFING AND SUPERPRESSURE



Automatic reefing is provided by attaching the payload directly to the top of the balloon. (The cable passes through a ring at the bottom of the balloon.) As altitude changes, the balloon is automatically reefed by the use of gravitational forces and inherent geometry of the balloon. The resulting shape provides less frontal or drag area than does a bottom loaded natural balloon and eliminates problems caused by flagging and tearing of excess balloon material as wind passes over the surface.

Internal superpressure, desirable from the standpoint of retaining balloon shape under external wind loading, may be obtained naturally or automatically in magnitudes of certain limited values by use of the top loading concept as described above. Greater magnitudes may be obtained by a forced reefing system which requires an external power source and additional equipment.

Economy of construction may be realized for balloons designed under certain load conditions utilizing the cylinder balloon concept. Essentially these designs utilize the total strength of the material or results in a minimum weight design which may be simply and economically fabricated.

New design procedures for the natural balloon are established which eliminate the trial and error solutions previously necessary. These procedures may be utilized for cylinder, cylinder end, or fully tailored balloon designs and provide not only a minimum weight design for a desired factor of safety, but also inflated shape as well as gore design shape.

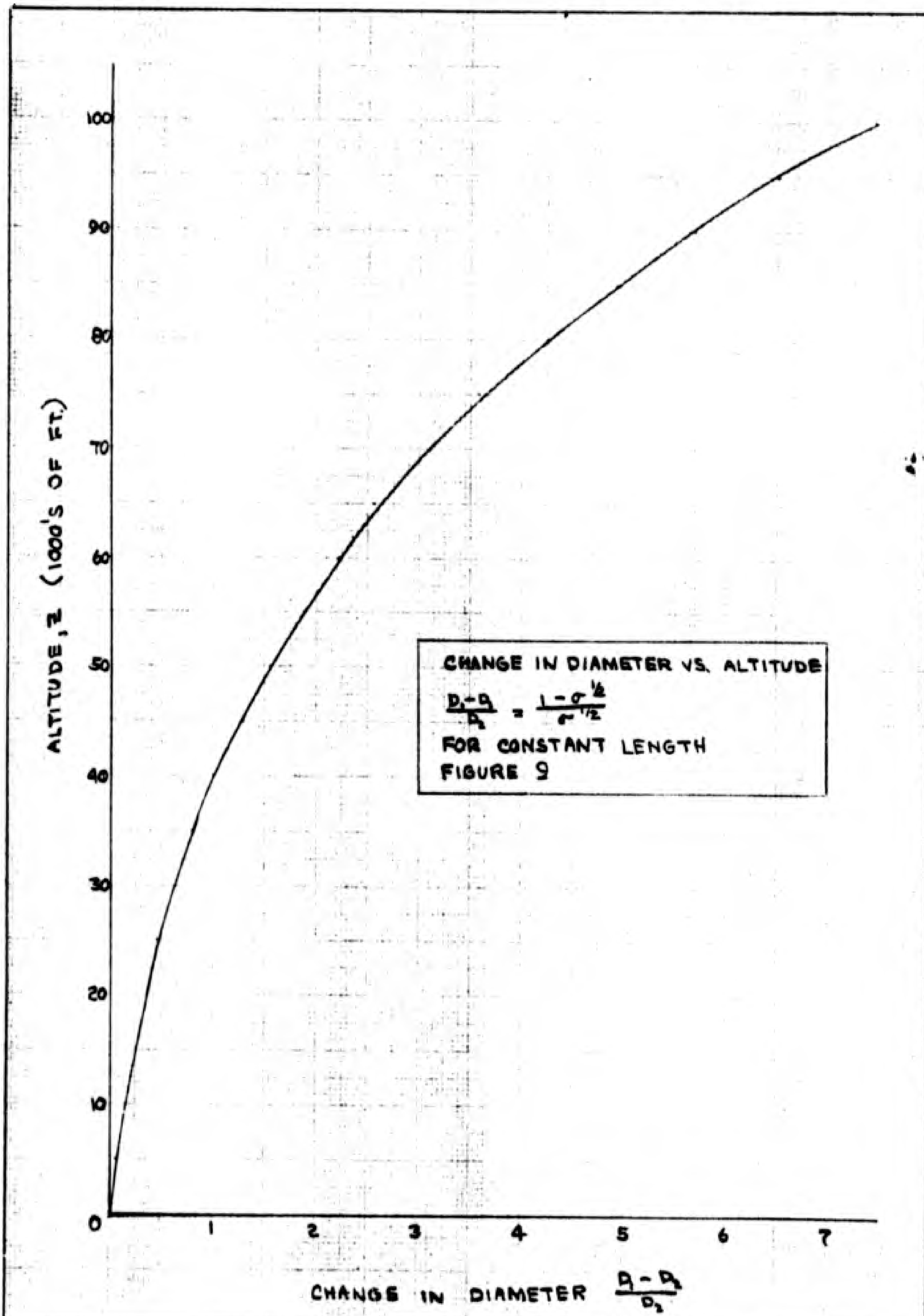
C. BALLOON PRESSURIZATION SYSTEMS

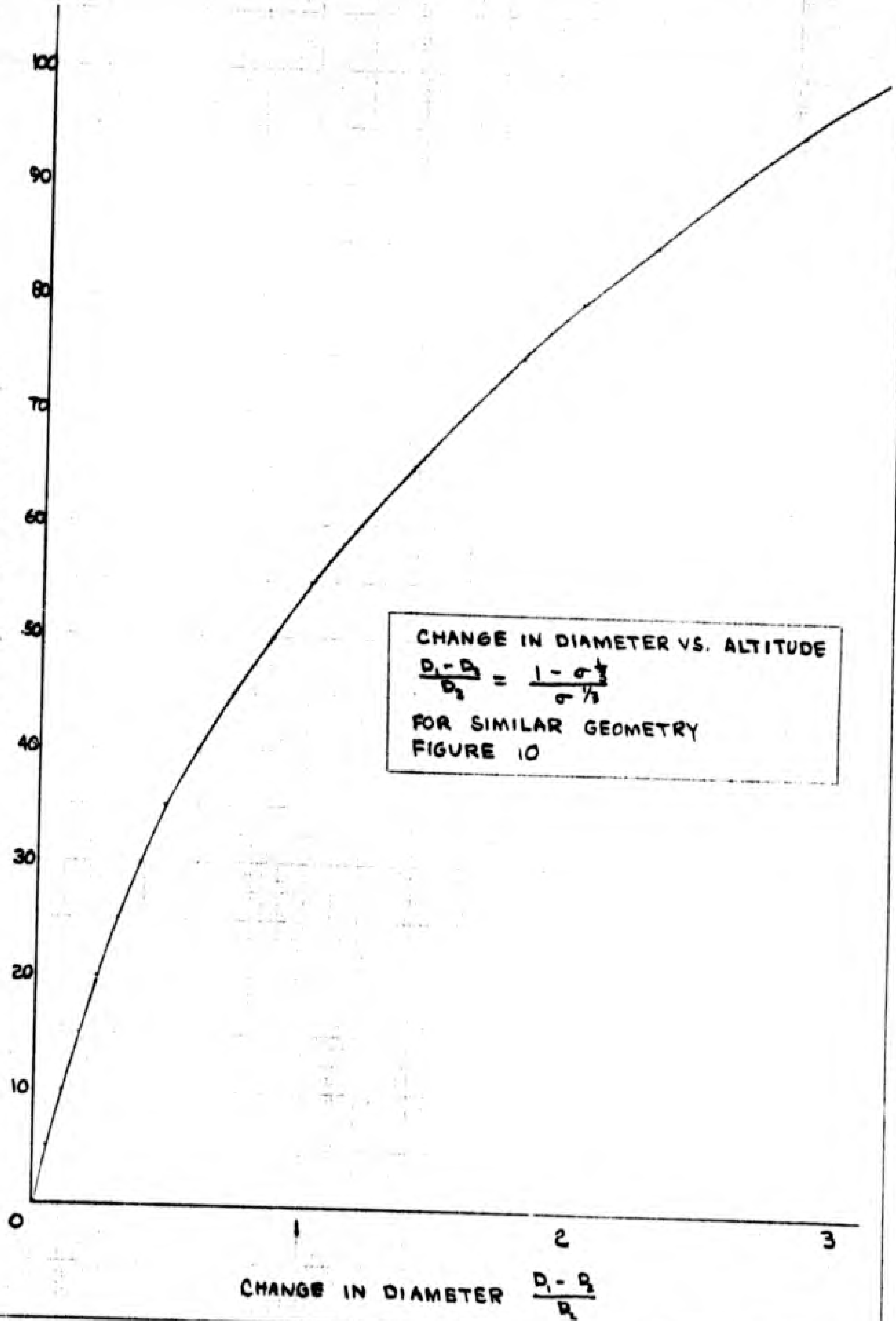
There are basically two methods of controlling balloon pressure of streamlined balloons during ascent and decent. The first is an active system utilizing fabric air cells, or ballonets, and a blower system. At launch, the ballonets are nearly full with air and, as the balloon ascends and the helium expands, this air is forced out through discharge valves which can be set to open at some previously determined setting. Upon descent, air is blown into the ballonets by the blower as the helium contracts, thus maintaining a constant internal pressure while descending. The second system is a passive system, or dilation system, utilizing a system of bungee cords which maintain structural integrity through the elastic energy of the cords. In this system the balloon cross sectional area and pressure are constantly increasing on ascent and decreasing on descent. Table III presents the advantages and disadvantages of these systems.

An additional dilation system is conceived wherein high stretch cloth materials might be used to provide dilation directly in the balloon envelope. The elongation characteristics required of streamlined balloon envelopes to accomplish volumetric change with altitude are defined in Figures 9 and 10 for two different balloon expansion geometries. Figure 9 defines the diameter increase for a streamlined balloon which maintains constant length with volume increase. Figure 10 defines the diameter increase for a streamlined balloon which maintains constant fineness ratio, i.e., with diameter and length increasing proportionally. It appears that a constant length variable diameter configuration offers the greater possibility of feasibility when considering attachment of fins and suspension systems to the hull. Figure 9 indicates that a material elongation of 35 per cent is required to achieve an altitude of 20,000 feet and an elongation of 155 per cent for 50,000 feet. Further investigation of this concept is required to establish feasibility including high stretch material load elongation characteristics.

TABLE III. COMPARISON OF PRESSURATION SYSTEMS

TYPE	ADVANTAGES	DISADVANTAGES
BALLONET BLOWER SYSTEM	1. Lighter weight system (for short flight time) 2. Constant pressure 3. Fixed suspension system geometry 4. Fixed fin orientation	1. Active system, therefore less reliable 2. Increased possibility of helium contamination from leaks in air system 3. Sensitive trim control problem
DILATION SYSTEM	1. High reliability of passive system 2. Helium less likely to become contaminated 3. Smaller volume on ground therefore easier ground handling 4. No operational time limit	1. Heavier weight system 2. Slightly larger volume required 3. Variable pressure 4. Difficult to maintain suspension system geometry 5. Variable fin orientation


ALTITUDE, Z (1000'S OF FT.)
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
CHANGE IN DIAMETER (D1 - D2)/D2
CHANGE IN DIAMETER VS. ALTITUDE
(D1-D2)/D2 = (1 - σ^1/2)/σ^1/2
FOR CONSTANT LENGTH
FIGURE 9



CHANGE IN DIAMETER VS. ALTITUDE

$$\frac{D_1 - D_2}{D_2} = \frac{1 - \sigma^{1/3}}{\sigma^{1/3}}$$

FOR SIMILAR GEOMETRY

FIGURE 10

D. CABLE - BALLOON SYSTEM EVALUATION

Section VII of Reference 1 presented a method for optimizing a particular balloon - cable combination at altitude while being subjected to a particular wind velocity profile.

As a continuation of this effort, a method for obtaining the zero wind characteristics of these optimum balloon systems was determined to insure that the system, after being designed for the selected wind condition and altitude, can lift the upper length of cable, which is equal to the float altitude selected in a zero wind condition.

The following curves are required in addition to the curves that are found in Reference 1.

1. Cable Weight (in zero wind) Vs Net Lift for Various Cable Angles at the Ground

   Two examples of this type curve are shown in Figures 11 and 12 for Missile Wire and Glastran Cable, Summer I Wind, 50,000 foot altitude $\Theta_B = 90^o$ and 70^o.

2. Zero Wind Net Lift Vs Net Lift for a Particular Balloon Operating in Design Winds

   Examples of the type curve are shown in Figures 13 through 16 for the Class C, Vee Balloon, Modified Mark II Balloon and the Ram Air C Configuration designed to fly at 50,000 feet altitude, Summer I Wind at various angles of attack.

   In order to show how these curves are used, the following example is given using the Class C balloon and tapered missile wire. The system is to fly at 50,000 feet altitude in a Summer I Wind.

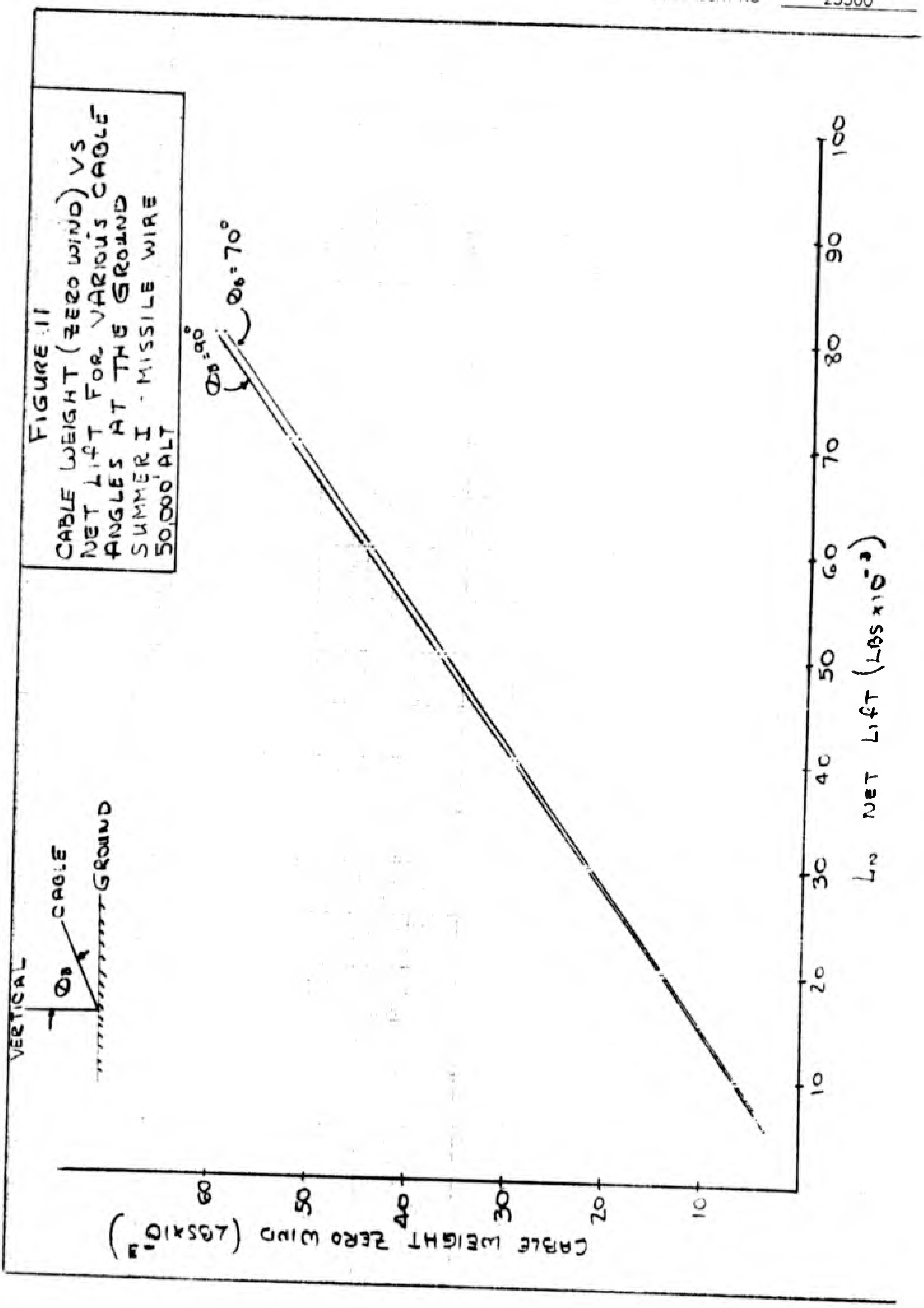


FIGURE 11
CABLE WEIGHT (ZERO WIND) VS NET LIFT FOR VARIOUS CABLE ANGLES AT THE GROUND
SUMMER I MISSILE WIRE
50,000' ALT

JR 220 (7-63)
REF: ENGRG PROCEDURE S-017

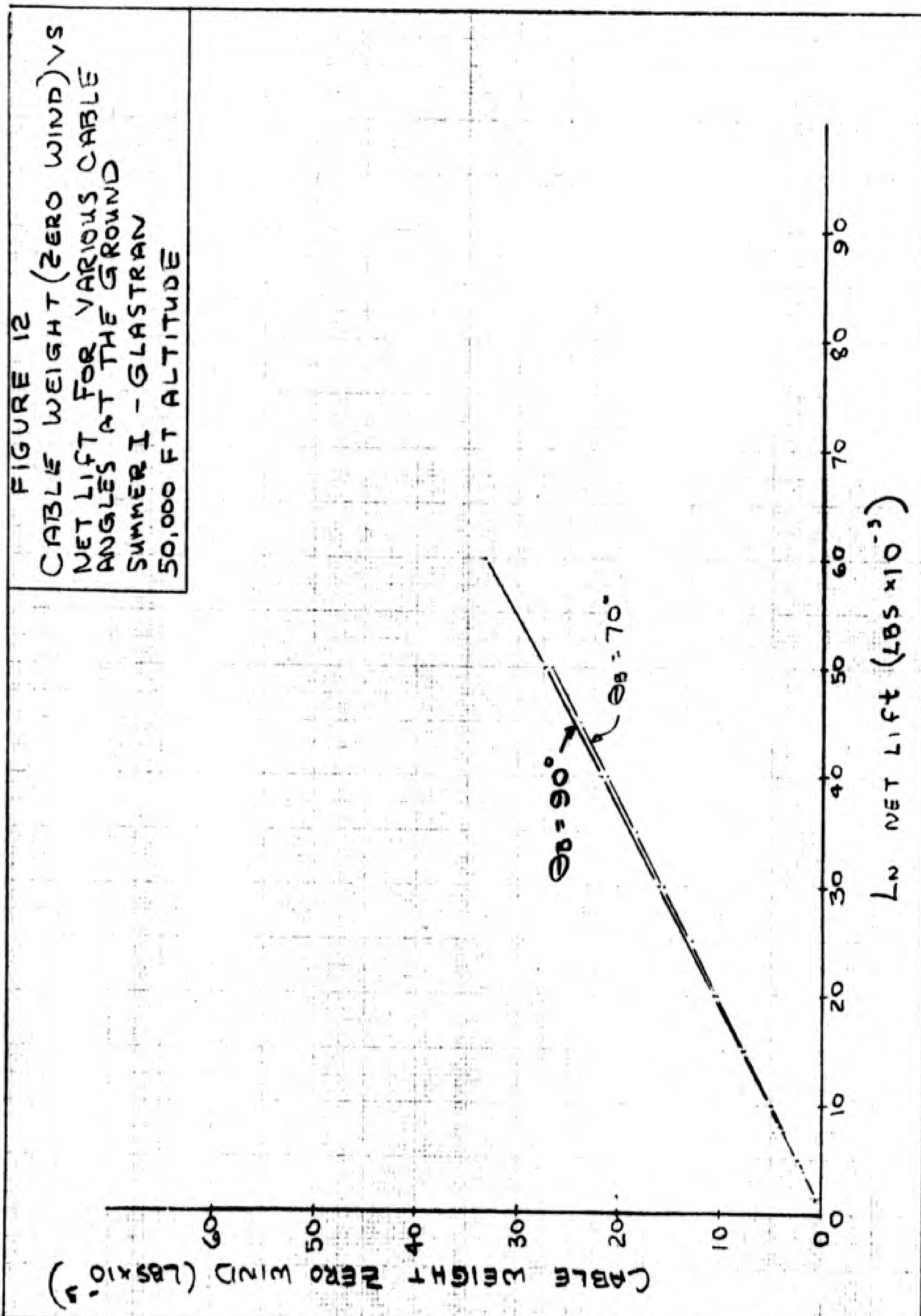


FIGURE 12
CABLE WEIGHT (ZERO WIND) VS NET LIFT FOR VARIOUS CABLE ANGLES AT THE GROUND
SUMMER I - GLASTRAN
50,000 FT ALTITUDE

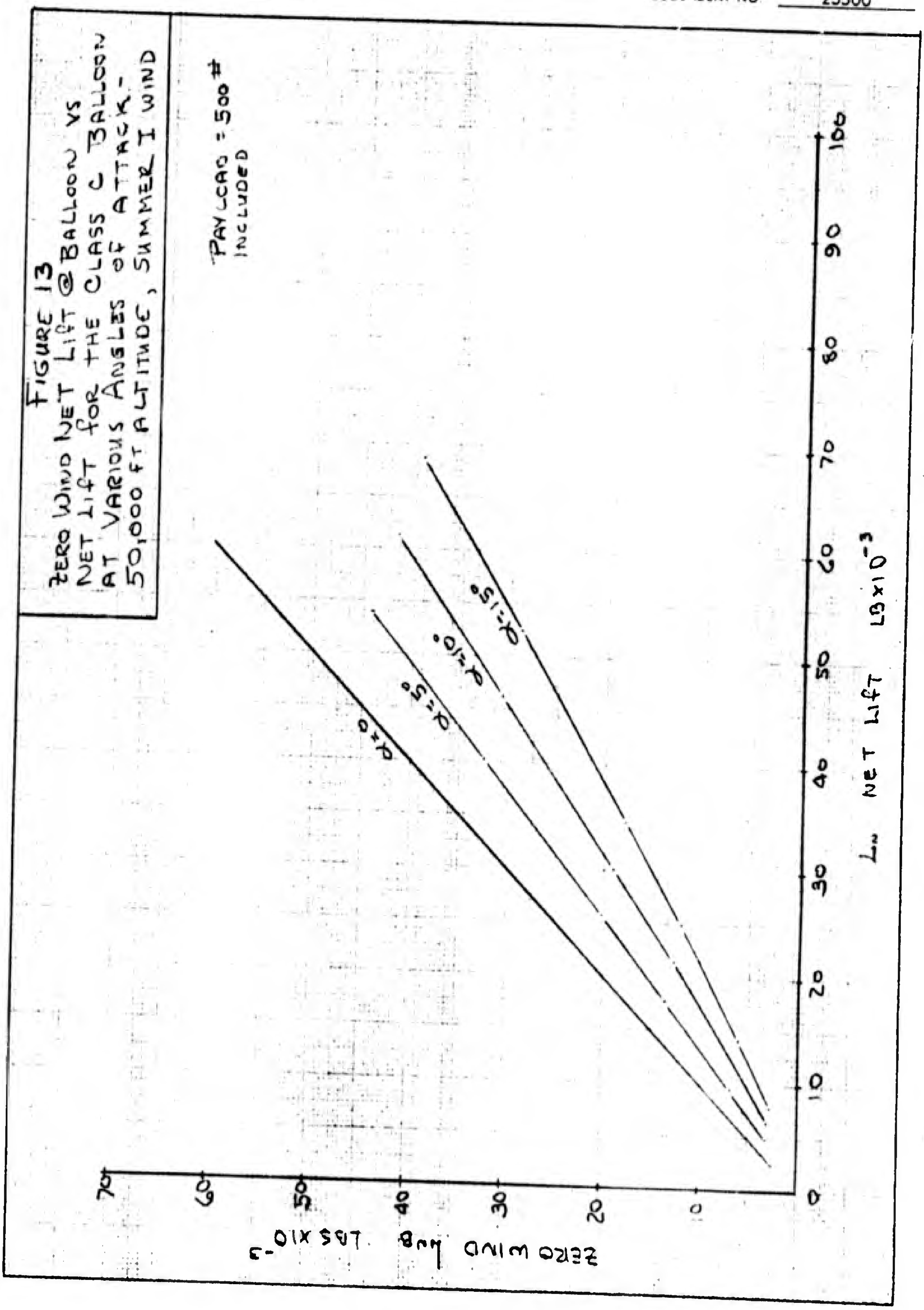


FIGURE 13
ZERO WIND NET LIFT @ BALLOON VS NET LIFT FOR THE CLASS C BALLOON AT VARIOUS ANGLES OF ATTACK - 50,000 FT ALTITUDE, SUMMER I WIND
PAYLOAD = 500 #
INCLUDED
α=0
α=-5°
α=-10°
α=-15°
0
10
20
30
40
50
60
70
80
90
100
L_N NET LIFT LB x 10^{-3}
0
10
20
30
40
50
60
70
ZERO WIND L_{NB} LBS x 10^{-3}

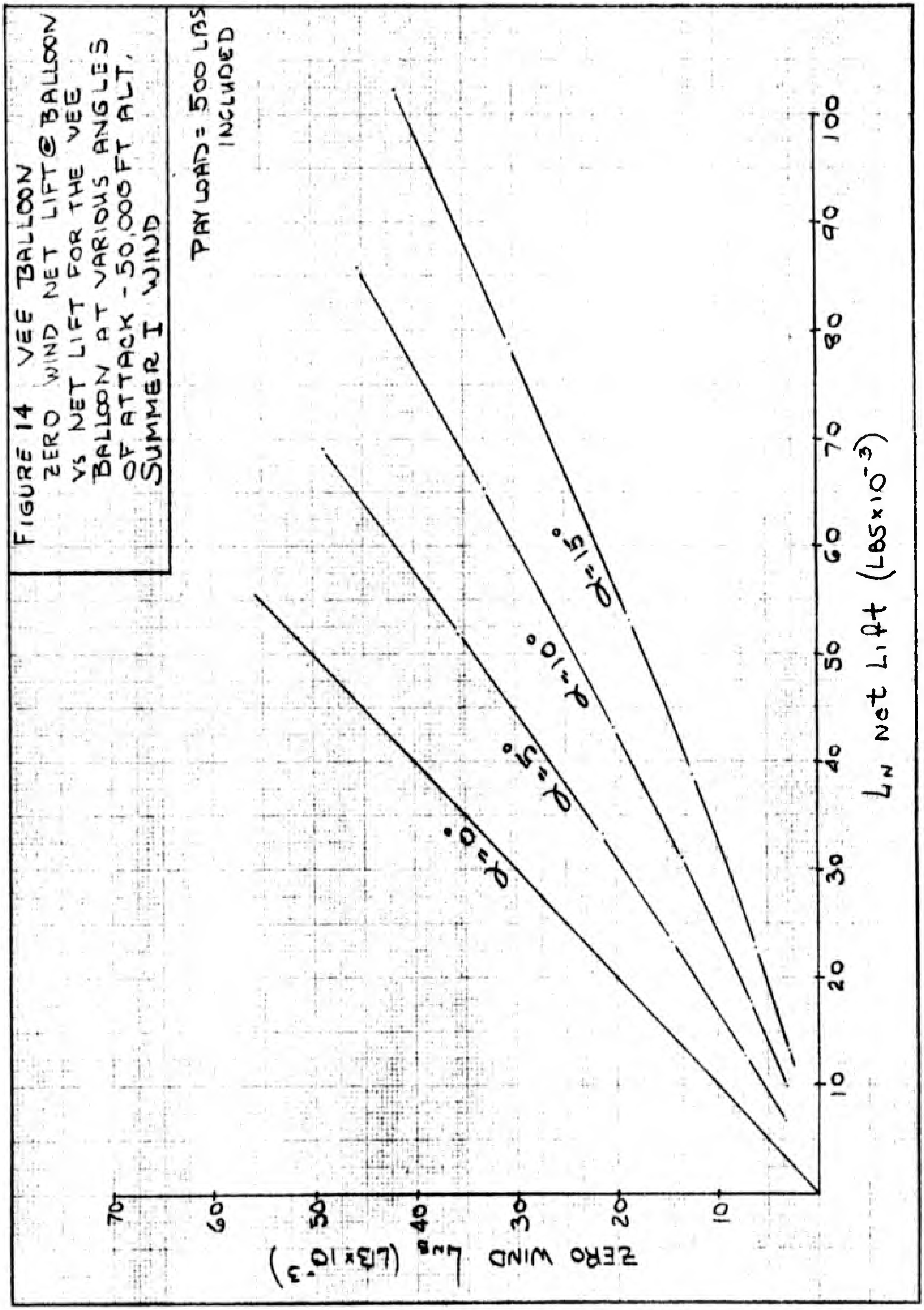


FIGURE 14 VEE BALLOON
ZERO WIND NET LIFT @ BALLOON
VS NET LIFT FOR THE VEE
BALLOON AT VARIOUS ANGLES
OF ATTACK - 50,000 FT ALT,
SUMMER I WIND

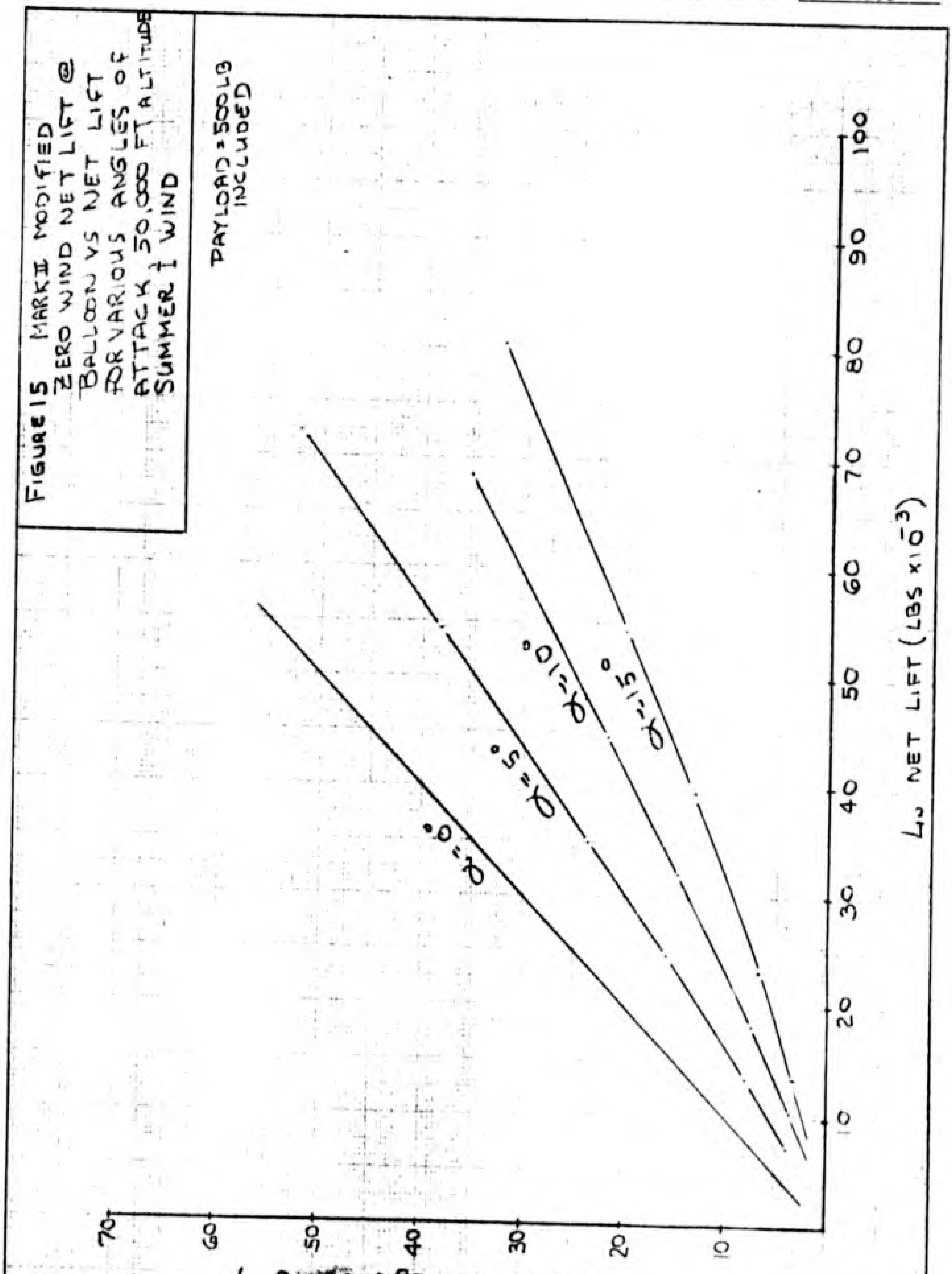


FIGURE 15 MARK II MODIFIED ZERO WIND NET LIFT @ BALLOON VS NET LIFT FOR VARIOUS ANGLES OF ATTACK 50,000 FT ALTITUDE SUMMER I WIND
PAYLOAD = 500 LB INCLUDED
α = 0°
α = 5°
α = 10°
α = 15°
0
10
20
30
40
50
60
70
80
90
100
L NET LIFT (LBS x10^-3)
ZERO WIND L (LBS x10^-3)

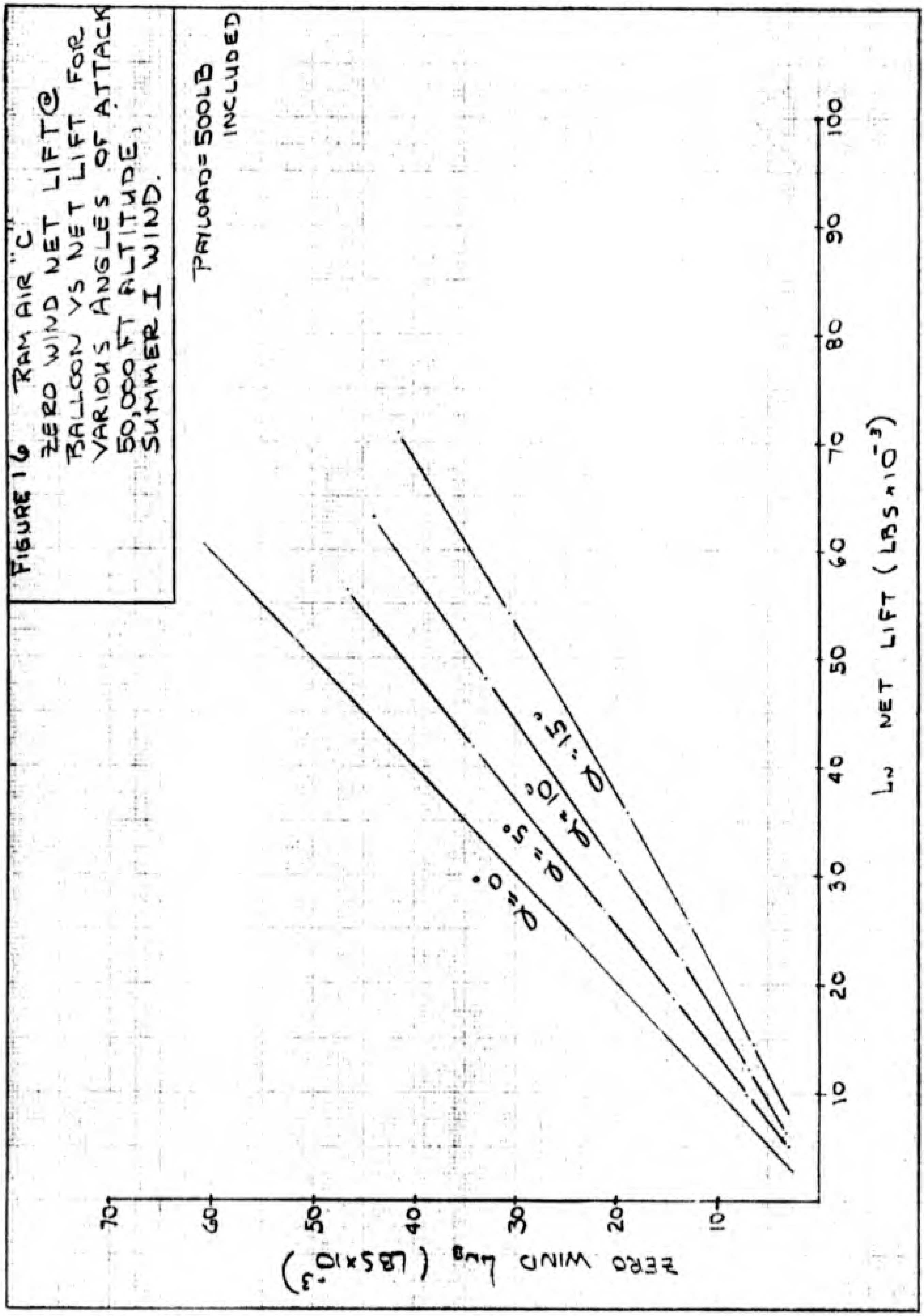


FIGURE 16 RAM AIR "C"
ZERO WIND NET LIFT @ BALLOON VS NET LIFT FOR VARIOUS ANGLES OF ATTACK 50,000 FT ALTITUDE, SUMMER I WIND.

From Figures 9 and 38 from Reference 1, partially reproduced in Figure 17 of this report, the crossover points of L_N/D_N and L_N give the following values of L_N for the balloon angle of attack selected.

for $\Theta_B = 90^o$; $h_1 = 0$

α (Degrees)	L_N (Lbs)
0	7,800
5	7,400
10	10,250
15	18,250

for $\Theta_B = 70^o$; $h_1 = 0$

α (Degrees)	L_N (Lbs)
0	12,900
5	12,600
10	17,800
15	29,250

By referring to Figure 13, the zero wind net lift of the Class C balloon can be determined and compared with the zero wind cable weight in Figure 11. See Figure 18 for this cross plot. The results show that if the Class C balloon is designed for an angle of attack greater than approximately 7 degrees in the selected wind condition, the balloon cannot lift the upper 50,000 feet of cable in a zero wind and thus remain on station. In this example, this occurs when the angle the cable makes with the vertical at ground level is 90^o and 70^o.

In order to select the optimum aerodynamic shaped balloon and cable for high altitude flight, a comparison was made of solutions of balloons cable combination each of which were designed for carrying a 500 pound payload to 50,000 feet. These balloon cable combinations used the Class C, Vee Balloon, Mark II Modified and the Ram Air C with both Glastran Cable and Missile Wire Cable in the Summer I Wind Condition and Glastran Cable in the Winter I Wind Condition.

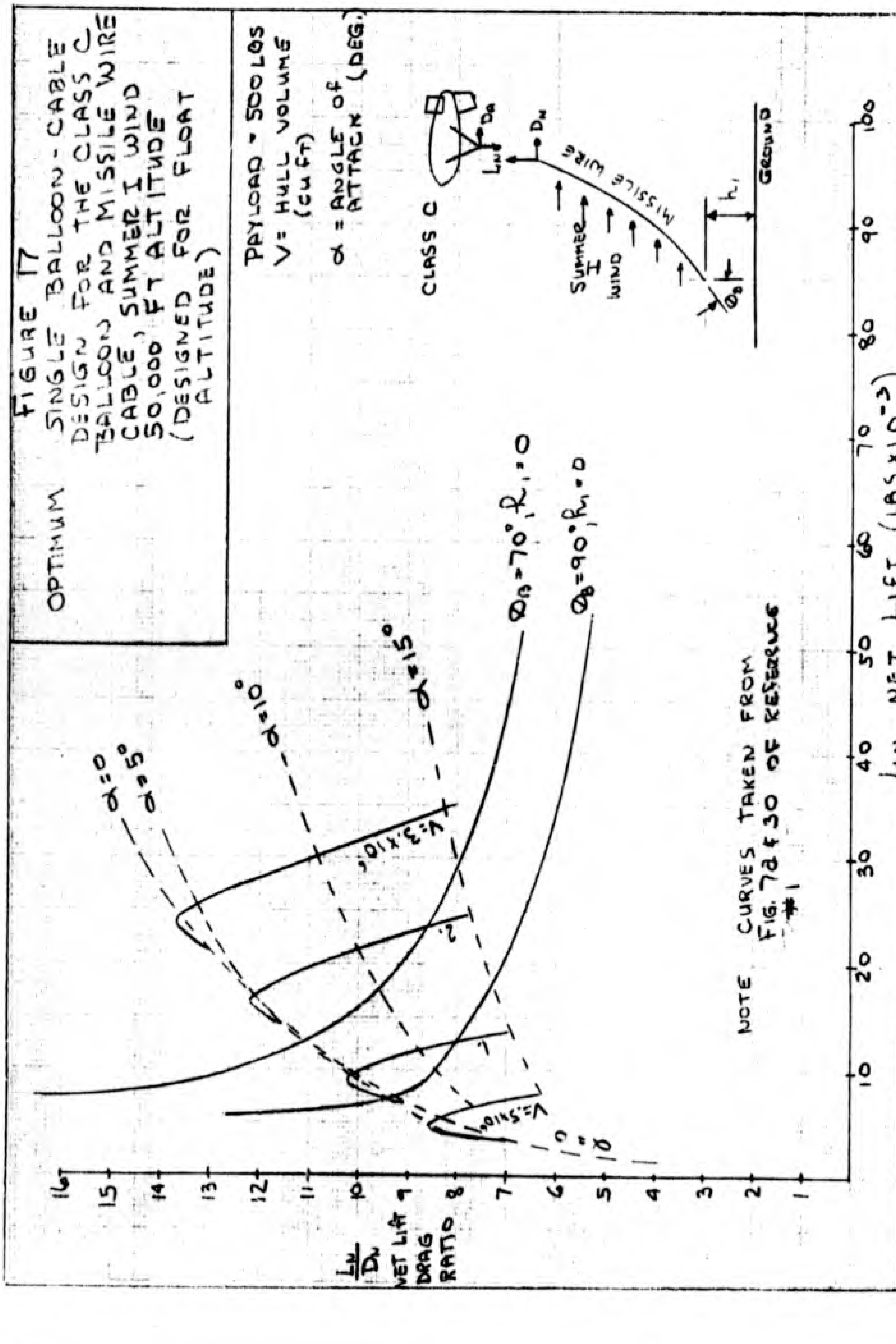


FIGURE 17
OPTIMUM SINGLE BALLOON - CABLE DESIGN FOR THE CLASS C BALLOON AND MISSILE WIRE CABLE, SUMMER I WIND 50,000 FT ALTITUDE (DESIGNED FOR FLOAT ALTITUDE)
PAYLOAD = 500 LBS
V = HULL VOLUME (CU FT)
α = ANGLE OF ATTACK (DEG)
CLASS C
MISSILE WIRE
SUMMER I WIND
GROUND
α = 0
α = 5°
α = 10°
α = 15°
V=3x10⁶
V=5x10⁵
NOTE CURVES TAKEN FROM FIG. 7a & 30 OF REFERENCE #1
NET LIFT (LBS x 10⁻³)
NET LIFT DRAG RATIO

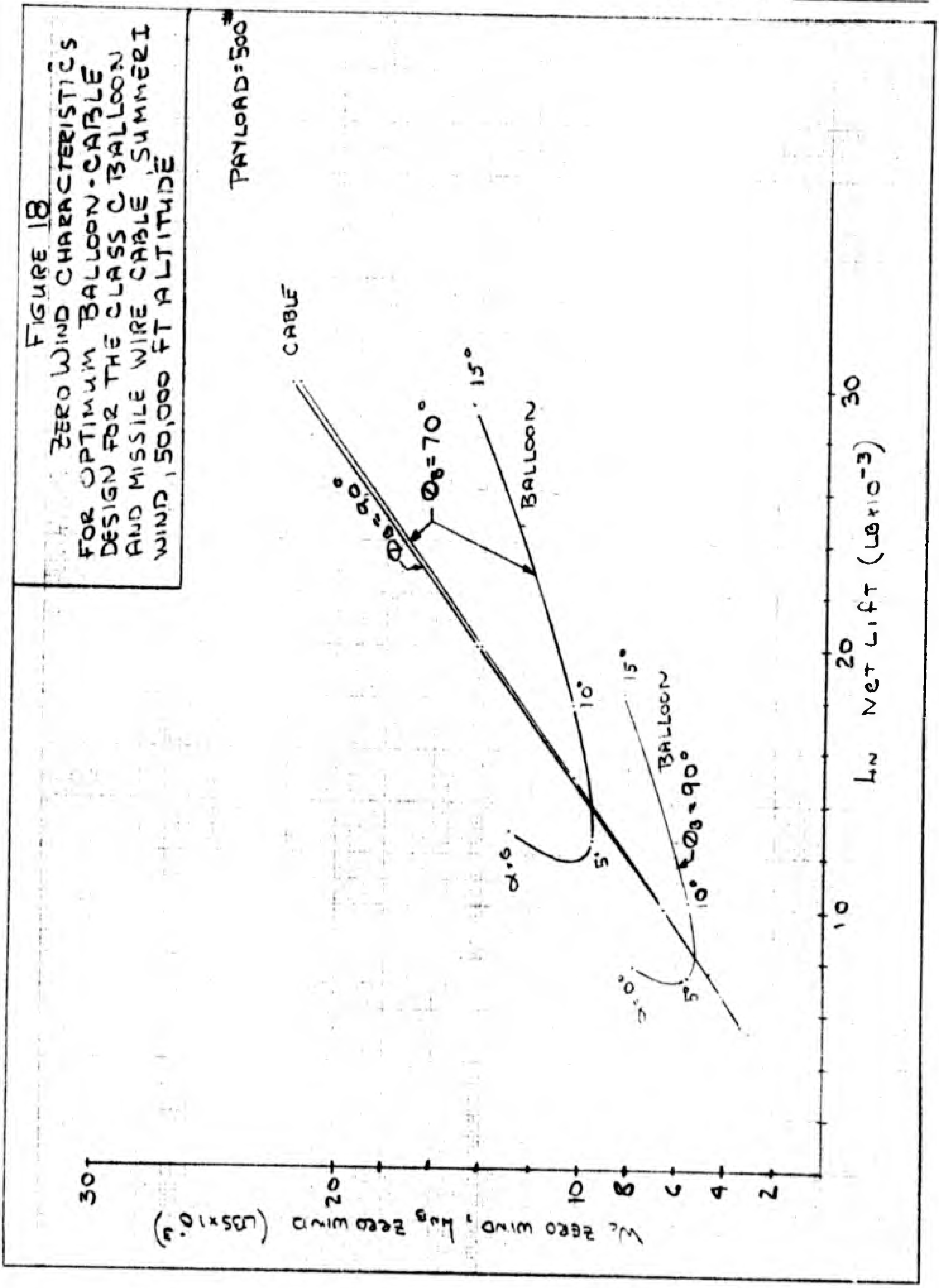


FIGURE 18
ZERO WIND CHARACTERISTICS FOR OPTIMUM BALLOON-CABLE DESIGN FOR THE CLASS C BALLOON AND MISSILE WIRE CABLE SUMMER I WIND, 50,000 FT ALTITUDE

JB 220 (7-63)
REF: ENGRG PROCEDURE 1-017

The characteristics of each system are given in Table IV, V and VI. These characteristics were obtained by using the procedures as outlined in Section VII of Reference 1 and the zero wind techniques described above.

A similar tabulation was compiled for Glastran Cable at 50,000 feet float altitude in Summer I Wind utilizing a constant angle of attack of five (5) degrees and is given in Table VII.

Also tabulated in Tables IV and V are the characteristics of a Superpressure Natural Shape Balloon as described in Reference 1.

With the data which has been presented in Tables IV through VII, it is desired to evaluate the different balloon systems and choose the one which has the best characteristics in all conditions listed. To do this, an evaluation system was set up which would rate the individual columns based upon the best value for that characteristic. The importance of the different characteristics was weighed by a point system. Those that were very important were given a base of 10, while those of less importance were assigned a base of 5. It may be that individual judgments for specific missions would result in greater emphasis on some factors than others.

The following items from Tables IV through VII were used for the evaluation.

ITEM	CHARACTERISTIC	BASE VALUE ASSIGNED	COMMENTS
1	Allowable Angle of Attack	10	Largest range
2	L_N	10	Smallest value
3	L_N (Zero Wind)	10	Smallest value
5	Total Balloon Volume	10	Smallest value

TABLE IV

BALLOON CABLE OPTIMIZATION FOR GLASTRAN CABLE

SUMMER I WIND, 50,000 FOOT ALTITUDE

ITEM	TYPE	$\theta_s = 90^o$, $h_1 = 0'$					$\theta_s = 70^o$, $h_1 = 0'$				
		CLASS C	RAM AIR C	MARK II MOD	VEE	NATURAL SHAPE	CLASS C	RAM AIR C	MARK II MOD	VEE	NATURAL SHAPE
1	Allowable Angle of Attack (Deg)	0 → 9.5	0 → 10	0 → 5	0 → 6	———	0 → 11	0 → 12	0 → 6.5	0 → 7	———
2	L_N (lbs)	7100	7200	7300	10,600	12,000	11,150	11,150	11,100	14,450	15,100
3	L_N Zero Wind (lbs)	3500	3500	3650	5400	12,000	5580	5580	5500	7300	15,100
4	Balloon Hull Volume (cu ft x 10^{-6})	.5	.52	.5	.8	1.5	.88	.80	.75	1.08	1.9
5	Total Balloon Volume (cu ft x 10^{-6})	.5259	.545	.604	.855	1.5	.924	.840	.905	1.152	1.9
6	Hull Length (ft)	208	210	280	238	144	251	243	321	263	144
7	Balloon Wt (lbs)	2000	1750	2000	2500	———	3000	2600	2800	3100	———
8	Balloon Drag (lbs)	900	920	900	2200	———	1400	1400	1350	2750	———
9	Blowdown Distance (ft)	63,000	63,000	63,000	60,000	60,000	40,000	40,000	40,000	45,000	45,000
10	Cable Tension (lbs)										
	Top	7000	7000	7000	10,500	12,125	11,125	11,125	11,125	15,000	15,500

9	Blowdown Distance (ft)	63,000	63,000	63,000	60,000	60,000	40,000	40,000	40,000	45,000	45,000
10	Cable Tension (lbs) Top	7000	7000	7000	10,500	12,125	11,125	11,125	11,125	15,000	15,500
	Bottom	4000	4000	4000	5750	6500	5750	5750	5750	7500	8000
11	Cable Dia (ft) Top	.0325	.0330	.0335	.0410	.0435	.0412	.0412	.0412	.0475	.0485
	Bottom	.0230	.0230	.0235	.0280	.0315	.0300	.0300	.0300	.0345	.0358
12	Cable Length (ft)	90,000	90,000	89,750	89,750	90,500	69,125	69,125	69,125	69,750	69,750
13	Total Cable Weight (lbs)	4750	4800	4800	8500	9000	7000	7000	7000	9500	15,100
14	Cable Weight In Zero Wind (lbs)	3500	3500	3650	5400	12,000	5580	5580	5500	7300	10,000

B

NOTES: 1. ITEMS 2 THRU 14 BASED ON MAXIMUM ALLOWABLE ANGLE OF ATTACK

2. SUPERPRESSURE NATURAL SHAPE INCLUDED FOR REFERENCE ONLY

D

TABLE V

BALLOON CABLE OPTIMIZATION FOR MISSILE WIRE

SUMMER I WIND, 50,000 FOOT ALTITUDE

ITEM	TYPE	$\theta_s = 90^o$, $h_1 = 0'$					$\theta_s = 70^o$, $h_1 = 0'$				
		CLASS C	RAM AIR C	MARK II MOD	VEE	NATURAL SHAPE	CLASS C	RAM AIR C	MARK II MOD	VEE	NATURAL SHAPE
1	Allowable Angle of Attack (Deg)	0→7	0→5	0→4	0→4.5	——	0→7	0→6	0→4.5	0→4.5	——
2	L_N (lbs)	8200	7200	9000	27,000	22,000	14,000	13,000	17,000	41,500	27,750
3	L_N Zero Wind (lbs)	5200	4500	6000	20,000	22,000	9500	8800	11,500	30,000	27,750
4	Balloon Hull Volume (cu ft x 10^{-6})	.75	.65	.75	2.7	2.75	1.4	1.25	1.4	4.1	3.4
5	Total Balloon Volume (cu ft x 10^{-6})	.79	.68	.905	2.88	2.75	1.475	1.31	1.69	4.38	3.4
6	Hull Length (ft)	238	227	320	356	173	310	282	418	408	187
7	Balloon Weight (lbs)	2750	2000	2500	7000		5000	4800	5250	13,500	
8	Balloon Drag (lbs)	1025	725	1200	4300		1350	1200	1900	6000	
9	Blowdown Distance (ft)	45,000	42,500	45,000	44,500	45,500	34,500	35,000	39,000	37,000	37,500
10	Cable Tension (lbs)										
	Top	8250	7300	9000	27,250	22,000	14,000	13,000	17,000	42,000	28,000

9	Blowdown Distance (ft)	45,000	42,500	45,000	44,500	45,500	34,500	35,000	39,000	37,000	37,500
10	Cable Tension (lbs)										
	Top	8250	7300	9000	27,250	22,000	14,000	13,000	17,000	42,000	28,000
	Bottom	3000	2750	3250	8500	7000	4750	4500	5500	13,000	8500
11	Cable Diameter (ft)										
	Top	.0250	.02325	.0265	.0500	.0450	.0345	.0330	.0385	.0620	0505
	Bottom	.0145	.01375	.0150	.0260	.0230	.01825	.01775	.0200	.0325	.0360
12	Cable Length (ft)	76,750	76,500	77,000	77,000	77,750	65,800	65,750	65,750	64,250	65,000
13	Total Cable Weight (lbs)	7500	7000	8000	25,000	19,000	11,500	10,000	12,000	36,000	27,750
14	Cable Weight In Zero Wind (lbs)	5200	4500	6000	20,000	22,000	9500	8800	11,500	30,000	24,000

B

NOTES: 1. ITEMS 2 THRU 14 BASED ON MAXIMUM ALLOWABLE ANGLE OF ATTACK

2. SUPERPRESSURE NATURAL SHAPE INCLUDED FOR REFERENCE ONLY

TABLE VI

BALLOON CABLE OPTIMIZATION FOR GLASTRAN CABLE

WINTER I WIND, 50,000 FOOT ALTITUDE

		$\theta_B = 90^o$, $h_1 = 20,000'$				$\theta_B = 90^o$, $h_1 = 15,000'$			
ITEM	TYPE	CLASS C	RAM AIR C	MARK II MOD	VEE	CLASS C	RAM AIR C	MARK II MOD	VEE
1	Allowable Angle of Attack (Deg)	0 → 2..25	0 → 2.75	0 → 1.5	No Solution	No Solution	0 → 3	No Solution	No Solution
2	L_N (lbs)	37,500	31,500	44,000	No Solution	No Solution	57,500	No Solution	No Solution
3	L_N Zero Wind (lbs)	20,500	17,000	24,000	No Solution	No Solution	30,000	No Solution	No Solution
4	Balloon Hull Volume (cu ft x 10^{-6})	6.8	4.2	5.25	No Solution	No Solution	7.4	No Solution	No Solution
5	Total Balloon Volume (cu ft x 10^{-6})	7.15	4.4	6.35	No Solution	No Solution	7.75	No Solution	No Solution
6	Hull Lengtn (ft)	496	423	632	No Solution	No Solution	510	No Solution	No Solution
7	Balloon Wt (lbs)	48,500	25,000	62,000	No Solution	No Solution	60,000	No Solution	No Solution
8	Balloon Drag (lbs)	10,000	7,500	20,000	No Solution	No Solution	16,000	No Solution	No Solution
9	Blowdown Distance (ft)	47,000	46,000	48,000	No Solution	No Solution	52,500	No Solution	No Solution
10	Cable Tension								

	(lbs)				Solution	Solution		Solution	Solution
8	Balloon Drag (lbs)	10,000	7,500	20,000	No Solution	No Solution	16,000	No Solution	No Solution
9	Blowdown Distance (ft)	47,000	46,000	48,000	No Solution	No Solution	52,500	No Solution	No Solution
10	Cable Tension (lbs)								
	Top	40,000	32,500	47,500	No Solution	No Solution	59,000	No Solution	No Solution
	Bottom	26,500	21,500	32,000	No Solution	No Solution	37,000	No Solution	No Solution
11	Cable Dia (ft)								
	Top	.0780	.0705	.0855	No Solution	No Solution	.0960	No Solution	No Solution
	Bottom	.0640	.0580	.0700	No Solution	No Solution	.0760	No Solution	No Solution
12	Cable Length (ft)	63,250	62,250	63,500	No Solution	No Solution	71,000	No Solution	No Solution
13	Total Cable Weight (lbs)	22,000	20,000	29,000	No Solution	No Solution	39,000	No Solution	No Solution
14	Cable Weight In Zero Wind (lbs)	20,500	17,000	24,000	No Solution	No Solution	30,000	No Solution	No Solution

NOTE: 1. ITEMS 2 THRU 14 BASED ON MAXIMUM ALLOWABLE ANGLE OF ATTACK

D

TABLE VII

BALLOON CABLE OPTIMIZATION FOR GLASTRAN CABLE

SUMMER I WIND, 50,000 FOOT ALTITUDE

		$\Theta_B = 90^o$, $h_1 = 0'$				$\Theta_B = 70^o$, $h_1 = 0'$			
ITEM	TYPE	CLASS C	RAM AIR C	MARK II MOD	VEE	CLASS C	RAM AIR C	MARK II MOD	VEE
1	L_N (lbs)	6000	6300	7300	10,700	9500	9400	10,800	14,500
2	L_N Zero Wind (lbs)	4200	4250	3800	6000	6800	6600	6200	8500
3	Balloon Hull Volume (cu ft x 10^{-6})	.52	.6	.5	.875	1.0	.9	.8	1.2
4	Total Balloon Volume (cu ft x 10^{-6})	.546	.629	.605	.935	1.05	.944	.965	1.28
5	Hull Length (ft)	211	221	280	245	262	253	327	272
6	Balloon Wt (lbs)	2000	1750	1800	2600	3250	2600	2800	3500
7	Balloon Drag (lbs)	750	630	900	2100	980	900	1250	2650
8	Blowdown Distance (ft)	70,000	65,000	63,000	60,000	38,000	38,000	40,000	45,000
9	Cable Tension (lbs)								
	Top	6000	6250	7000	10,700	5000	5000	5500	7500
	Bottom	3500	3500	4000	5750	9500	9500	11,000	15,000
10	Cable Diameter								

9	Cable Tension (lbs)									
		Top	6000	6250	7000	10,700	5000	5000	5500	7500
		Bottom	3500	3500	4000	5750	9500	9500	11,000	15,000
10	Cable Diameter (ft)									
		Top	.0325	.0375	.0335	.0425	.0380	.0380	.04075	.0475
		Bottom	.0210	.0215	.0235	.0295	.0275	.0275	.0295	.0345
11	Cable Length (ft)		94,000	93,500	91,000	89,750	69,500	69,500	69,125	69,750
12	Total Cable Weight (lbs)		1000	4000	5000	8000	6000	6000	6500	9500
13	Cable Weight In Zero Wind (lbs)		4200	4250	3800	6000	6800	6600	6200	8500

B

NOTE: BALLOON AND CABLE DESIGNED FOR ANGLE OF ATTACK OF 5 DEGREES

ITEM	CHARACTERISTIC	BASE VALUE ASSIGNED	COMMENTS
6	Hull Length	5	Smallest value
7	Balloon Weight	10	Smallest value
8	Balloon Drag	10	Smallest value
9	Blowdown Distance	10	Smallest value
12	Cable Length	10	Smallest value
13	Total Cable Weight	10	Smallest value
14	Cable Weight in Zero Wind	10	Smallest value

The evaluation system operates as follows:

a. The most favorable value for each column was chosen and this number was assigned the base number.

b. All the other values were related to this base value by the following relationship: Evaluation Number = $\frac{\text{Value}}{\text{Value}_{\text{best}}}$ X (base number)(e.g., the best value is 100, the next value is 150, and the base number is 10. The evaluation number is 150/100 x 10 = 15.)

See Tables VIII through XI for ratings of systems.

Inspection of the tables shows that for a single aerodynamically shaped balloon system, at a 50,000 foot altitude, under different wind conditions and with different cable materials, the balloon type exhibiting the best characteristics out of those evaluated, was of the C type design. Since the Ram Air C and the Class C were so close in several cases, it has been decided to narrow further investigation to the Class C balloon, keeping fully in mind the possibilities of switching to a ram air inflation system if research proves this to be more practical and economical. This qualitative evaluation is based on performance and does not consider such factors as stability and ground handling.

TABLE VIII

BALLOON CABLE EVALUATION FOR GLASTRAN CABLE

SUMMER I WIND, 50,000 FOOT ALTITUDE

		$\theta_8 = 90^o$, $h_1 = 0'$				$\theta_8 = 70^o$, $h_1 = 0'$			
BASE NO	TYPE	CLASS C	RAM AIR C	MARK II MOD	VEE	CLASS C	RAM AIR C	MARK II MOD	VEE
10	Allowable Angle of Attack	10.5	10	20	16.7	10.9	10	18.45	17.2
10	L_N	10	10.1	10.3	15	10.05	10.05	10	13
10	L_N Zero Wind	10	10	10.4	15.4	10.15	10.15	10	13.25
10	Total Balloon Volume	10	10.4	11.5	16.2	11	10	10.8	12.85
5	Hull Length	5	5.05	6.47	5.73	5.16	5	6.61	5.41
10	Balloon Weight	11.4	10	11.4	12.5	11.5	10	10.8	11.08
10	Balloon Drag	10	10.2	10	14.3	10.35	10.35	10	18.34
10	Blowdown Distance	10.5	10.5	10.5	10	10	10	10	11.25
10	Cable Length	10.05	10.05	10	10	10	10	10	10.09
10	Total Cable Weight	10	10.1	10.1	17.9	10	10	10	13.6
	Sum	97.45	96.4	110.94	133.73	99.11	95.55	106.66	126.07

NOTE: THIS EVALUATION IS FOR TABLE IV

TABLE IX

BALLOON CABLE EVALUATION FOR MISSILE WIRE

SUMMER I WIND, 50,000 FOOT ALTITUDE

		$\theta_B = 90^o$, $h_1 = 0'$				$\theta_B = 70^o$, $h_1 = 0'$			
BASE NO	TYPE	CLASS C	RAM AIR C	MARK II MOD	VEE	CLASS C	RAM AIR C	MARK II MOD	VEE
10	Allowable Angle of Attack	10	14	17.45	15.57	10	11.67	15.55	15.55
10	L_N	11.4	10	12.5	37.5	10.78	10	13.1	31.9
10	L_N Zero Wind	11.55	10	13.3	44.5	10.8	10	13.08	34.1
10	Total Balloon Volume	11.6	10	13.3	41.8	11.27	10	12.9	33.4
5	Hull Length	5.24	5	7.05	7.85	5.5	5	7.41	7.24
10	Balloon Weight	12.5	10	13.75	35	10.4	10	10.92	28.2
10	Balloon Drag	14.15	10	16.57	59.4	11.24	10	15.84	50
10	Blowdown Distance	10.6	10	10.6	10.48	10	10.16	10.72	11.3
10	Cable Length	10.2	10	10.7	10.7	10.24	10.22	10.22	10
10	Total Cable Weight	10.7	10	13.56	35.8	11.5	10	12	36
	Sum	107.94	99	128.78	263.95	101.73	97.05	121.74	257.69

NOTE: THIS EVALUATION IS FOR TABLE V

TABLE X

BALLOON CABLE EVALUATION FOR GLASTRAN CABLE

WINTER I WIND, 50,000 FOOT ALTITUDE

$\theta_a = 90^{\circ}$, $h_1 = 20{,}000'$				
BASE NO	TYPE	CLASS C	RAM AIR C	MARK II MOD
10	Allowable Angle of Attack	12.3	10	18.35
10	L_N	11.9	10	14
10	L_N Zero Wind	12.05	10	14.1
10	Total Balloon Vol	16.25	10	14.45
5	Hull Length	5.87	5	7.46
10	Balloon Weight	19.4	10	24.8
10	Balloon Drag	13.35	10	26.7
10	Blowdown Distance	10.2	10	10.43
10	Cable Length	10.15	10	10.2
10	Total Cable Weight	11	10	14.5
	Sum	112.57	95	154.99

NOTE: THIS EVALUATION IS FOR TABLE VI

TABLE XI

BALLOON CABLE EVALUATION FOR GLASTRAN CABLE

SUMMER I WIND, 50,000 FOOT ALTITUDE

		$\theta_s = 90^o$, $h_1 = 0'$				$\theta_s = 90^o$, $h_1 = 0'$			
BASE NO	TYPE	CLASS C	RAM AIR C	MARK II MOD	VEE	CLASS C	RAM AIR C	MARK II MOD	VEE
10	Allowable Angle of Attack	1C	10	10	10	10	10	10	10
10	L_N	10	10.5	12.15	17.85	10.1	10	11.5	15.42
10	L_N Zero Wind	11.05	11.19	10	15.8	11	10.65	10	13.7
10	Total Balloon Volume	10	11.09	11.5	17.1	11.15	10	10.25	13.58
5	Hull Length	5	5.24	6.55	5.8	5.17	5	6.49	5.39
10	Balloon Weight	11.42	10	10.3	14.85	12.5	10	10.76	13.48
10	Balloon Drag	11.9	10	14.3	32.4	10.88	10	13.9	29.4
10	Blowdown Distance	11.65	10.72	10.5	10	10	10	10.52	11.85
10	Cable Length	10.48	10.4	10.13	10	10.05	10.05	10	10.1
10	Total Cable Weight	10	10	12.5	20	10	10	10.82	14.6
	Sum	101.5	99.14	107.93	153.8	100.85	95.7	103.43	137.52

NOTES: 1. THIS EVALUATION IS FOR TABLE VII

2. THE ALLOWABLE ANGLE OF ATTACK IS 5 DEGREES IN ALL CASES

E. ADDITIONAL AERODYNAMIC DATA

Aerodynamic characteristics of some balloon configurations have been obtained by means of wind tunnel tests. Lift and drag characteristics for several streamlined balloons were presented in Reference 1. Wind tunnel tests of a natural shape balloon have been conducted on this program and are reported in Appendix B to this report.

Additional aerodynamic data for a Class C single hull balloon and a Vee balloon are presented here in Figures 19 and 20. Side force coefficient and yawing moment coefficient are plotted as a function of yaw angle.

Lateral aerodynamic data for the Navy Class C balloon have been modified from this basic wind tunnel data to use different dimensions. Hull volume to the two-thirds power is used as the reference area for side force coefficient. Hull volume is used as the reference area and length for yawing moment coefficient. Definition of the coefficients is noted in Figures 19 and 20. Yawing moment coefficients have also been transferred to the center of buoyancy for each balloon - 46 per cent of the length aft of the nose for the Class C balloon and 51.6 per cent of the length aft of the nose for the Vee balloon. Data has been shifted vertically to pass through the origin.

An inspection of the lateral aerodynamic characteristics data in Figures 19 and 20 show the effect of balloon configuration. Side forces generated with yaw angle are smaller for the Vee balloon than the Class C single hull. Directional stability as evidenced by the negative shape of the yawing moment coefficient versus yaw angle curve is comparable for both configurations below 10 degrees yaw angle. Above 10 degrees yaw the larger tail surfaces are required for the Vee balloon to insure restoring moments about the center of buoyancy.

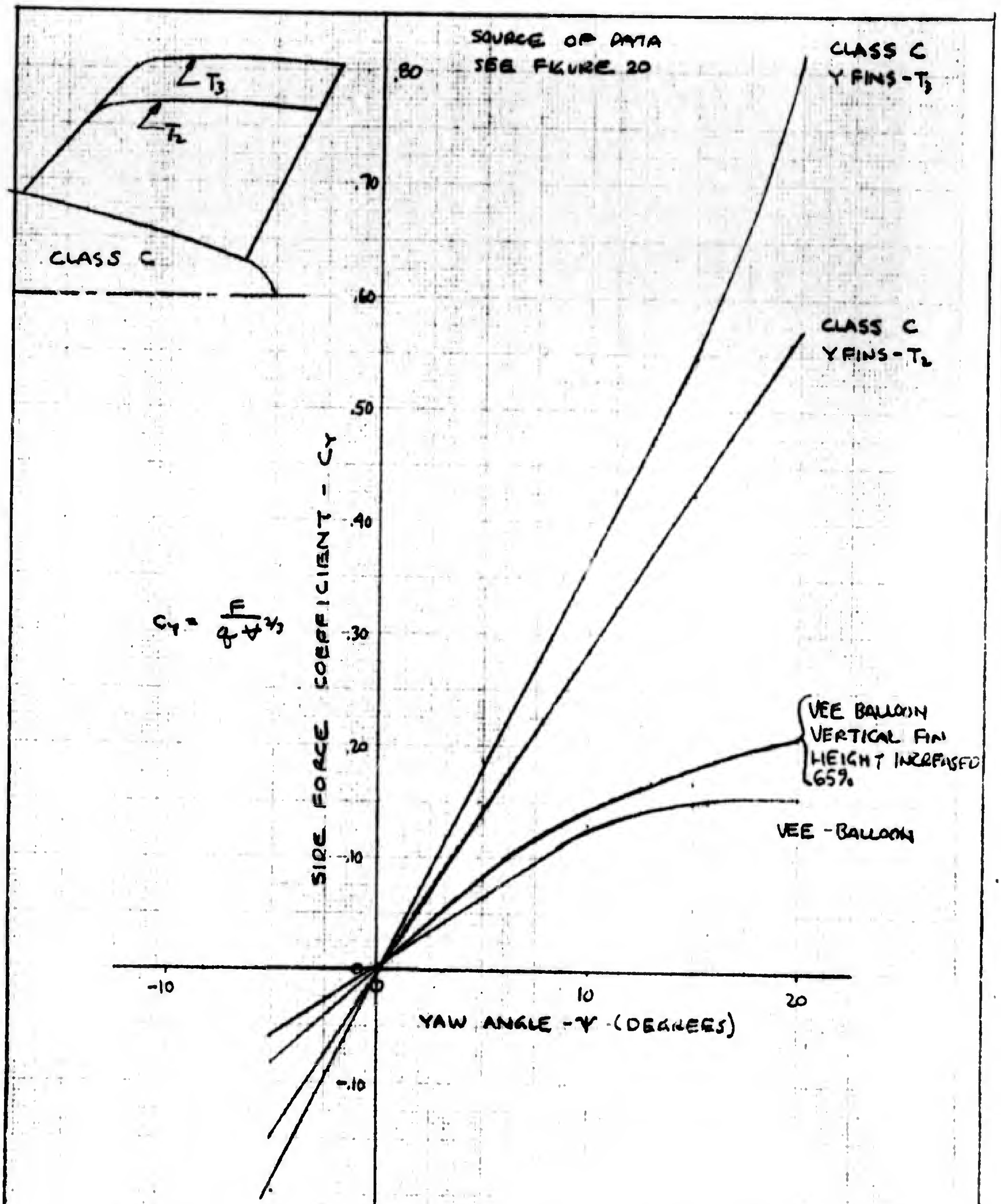


FIGURE 19 SIDE FORCE COEFFICIENT VERSUS YAW ANGLE FOR SEVERAL STREAMLINED BALLOON CONFIGURATIONS

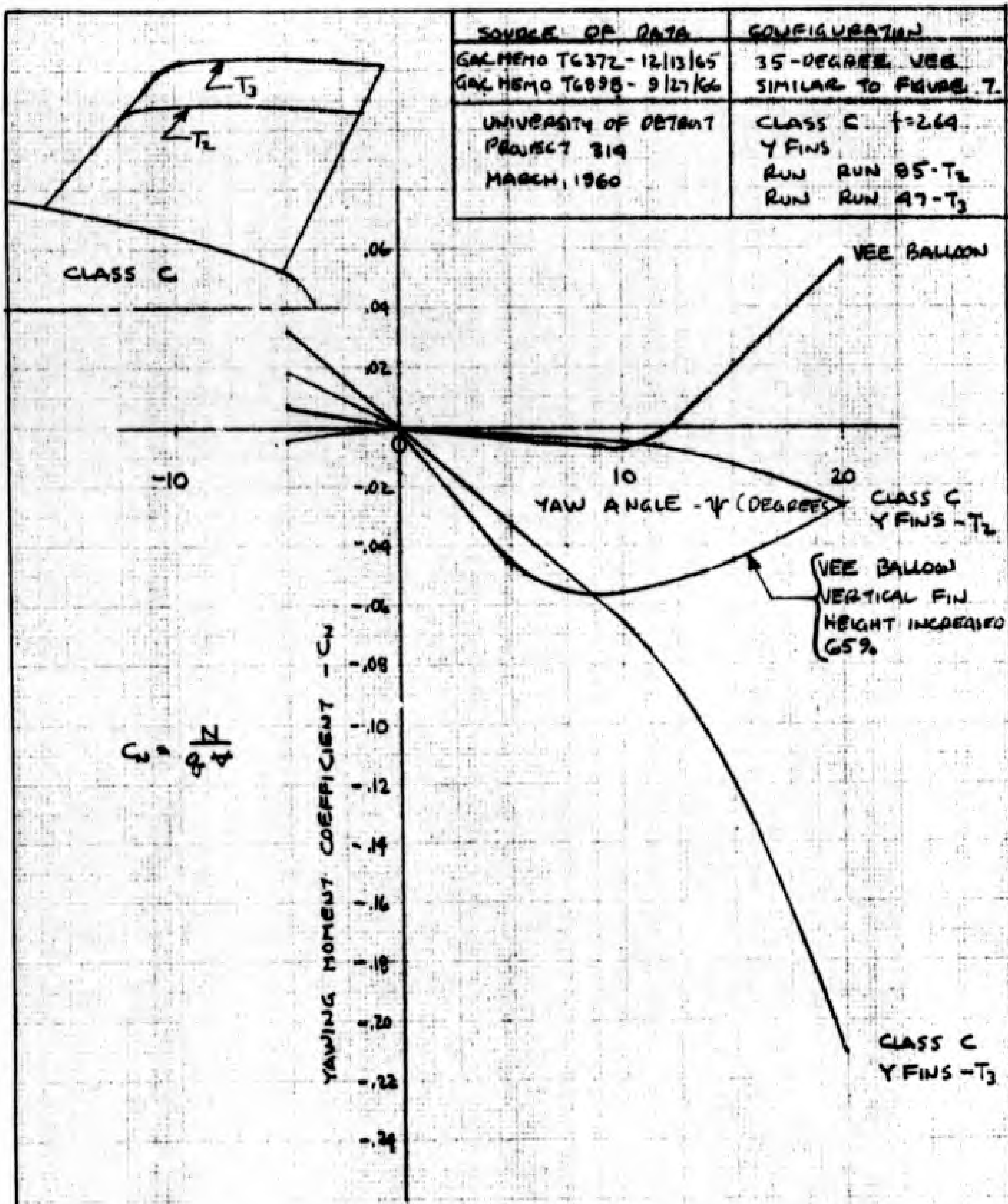


FIGURE 20 YAWING MOMENT COEFFICIENT VERSUS YAW ANGLE FOR SEVERAL STREAMLINED BALLOON CONFIGURATIONS

F. COMMENTS ON STABILITY OF TETHERED BALLOONS

The stability of tethered balloons will be generally interpreted to be a reflection on the degree of insensitivity the balloon-tether line system has to winds including gusts. A balloon which is totally insensitive to winds and gusts, i.e., it remains still relative to the ground tether point, is a very stable system. Displacement due to the drag forces as the wind changes in intensity and in direction will occur so that the ideal stability cannot be achieved. Relative stability is then the objective in the design which will minimize the displacement of the balloon. Giving a balloon a streamline form to reduce the drag for a given volume is meritorious; however, a concern over the weathercock (directional) stability must be introduced to align the balloon relative to the wind for minimum drag. The introduction of weathercock stability also introduces side forces on the balloon which will cause lateral displacements. Even spherical balloons experience side forces under the alternate shedding of vortices off the downwind side of a balloon with the intensity and frequency based on the air flow Reynolds number. Shapes of balloons additionally studied: the single hulled Class C shapes and the Vee balloon type are unique in their relationship of side force to weathercocking stability. The suspension harness below the balloon to which the tether line attaches is an important geometrical arrangement. Under a wind condition, the balloon will pitch up, the balloon aerodynamic lift is introduced and the weathercock stability is modified as well.

The damping of the balloon to angular velocity is an important consideration plus the side force due to angular velocity and the apparent mass of the balloon and its apparent moment of inertia are still other concerns in this appraisal of dynamic stability.

A method for the appraisal of the stability of a system may be experimental, utilizing dynamically scaled models and a towing facility such as the Princeton Dynamic Model Track. Reference 3 describes this technique. Analytically, one may relate the directional stability derivative (C_{n_ψ}) with the lateral stability derivative (C_{l_ψ}) referenced to the tethering point and all referenced to successful flight experience. An analysis may also be made of a short tether coupling situation where the tether line is essentially straight and an inverse pendulum exists by virtue of excess lift with the pivot point at the ground and then this pendulum being excited by the side forces on the balloon due to its weathercocking stability. Coupling of the pendulum frequency and the weathercock stability frequency may exist which may result in large motions. This possibility, of course, should be avoided.

The weathercock or directional stability is important in the design. It should not follow that a high degree of static directional stability is always desirable for this will produce a balloon which is very sensitive to wind direction changes. A stable balloon-tether line system must involve many aspects to achieve satisfactory stability.

SECTION IV - TETHER CABLE PROFILE AND BALLOON PERFORMANCE PARAMETERS

A. GENERAL

Sections IV and VI of Reference 1 describe how the cable profile and balloon performance curves were obtained. In Sections II and III of this report it was determined that Glastran cable and the Class C balloon were the tether cable material and intermediate altitude balloon which were going to be presented in curve form for further parametric study.

B. CABLE PROFILES AND BALLOON PARAMETERS

To continue the parametric study which was begun in Reference 1, cable profiles and balloon performance curves have been plotted for the intermediate altitudes of 10,000', 20,000', 30,000', 40,000', 50,000', and 60,000' for both Summer I and Winter I wind, also 70,000' for Winter I wind only. Using these curves in the manner described in Reference 1, it is possible to determine balloon and cable designs for any of the intermediate altitudes. If a multiple balloon system is required, the individual balloons and tether cables can be defined as was previously done with the 100,000' and 50,000' altitudes with the use of these curves.

Figures 21 through 27 are cable profiles for Glastran cable in Summer I winds at 10,000 feet to 60,000 feet in 10,000 foot increments and at 100,000 feet. Figures 28 through 35 are cable profiles for Glastran cable in Winter I at 10,000 feet to 70,000 feet in 10,000 foot increments and at 100,000 feet. Each unique cable is tapered such that breaking strength is equal to twice the tension at any point on the cable. All curves give the angle between the vertical and the bottom end of the cable, θ_B, and the distance between the end of the cable and the ground, h_1. See Figure 36 for complete description of the parameters used. The abscissa is net lift (L_N) or resultant of buoyancy, aerodynamic lift, payload, and balloon weight and the ordinate is net lift-to-drag ratio (L_N/D_N).

The balloon parameter curves presented in Figures 37 through 44 have axes identical to the cable curves. The parameters presented in these figures are angle of attack, α, and balloon volume, V. All cable profile and Class C balloon curves are based on the assumptions and conditions established in Reference 1. The assumptions underlying the natural shape balloon parameters Figure 44 are given in Appendix C to this report.

C. COMPATIBLE CABLE - BALLOON SYSTEMS (EXAMPLES)

Solutions for particular tethered balloon systems are obtained by selecting the proper set of curves consistent with user requirements.

As a first example, a single balloon system is designed for the following requirements:

General

Float altitude	= 100, 000 feet
Wind profile	= Summer I wind
System type	= Single balloon

Cable

Material type	= Glastran cable
Factor of safety	= 2.0
Cross-section variation	= Tapered
Selection criterion	= Angle at Base = 75 degrees

Balloon

Balloon type	= Natural
Component design	= As per Reference 1 and Appendix C
Angle of attack	= Not applicable

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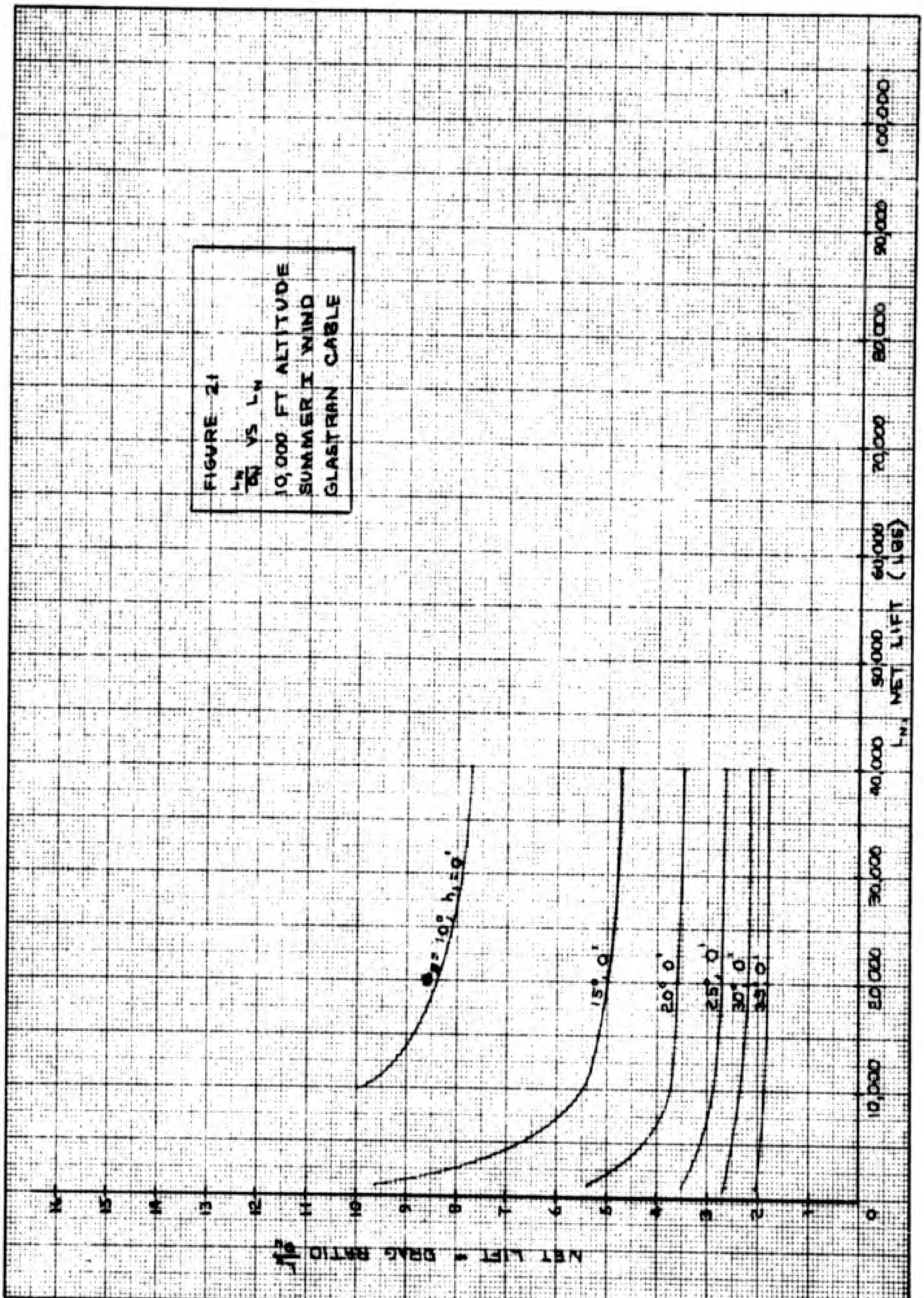

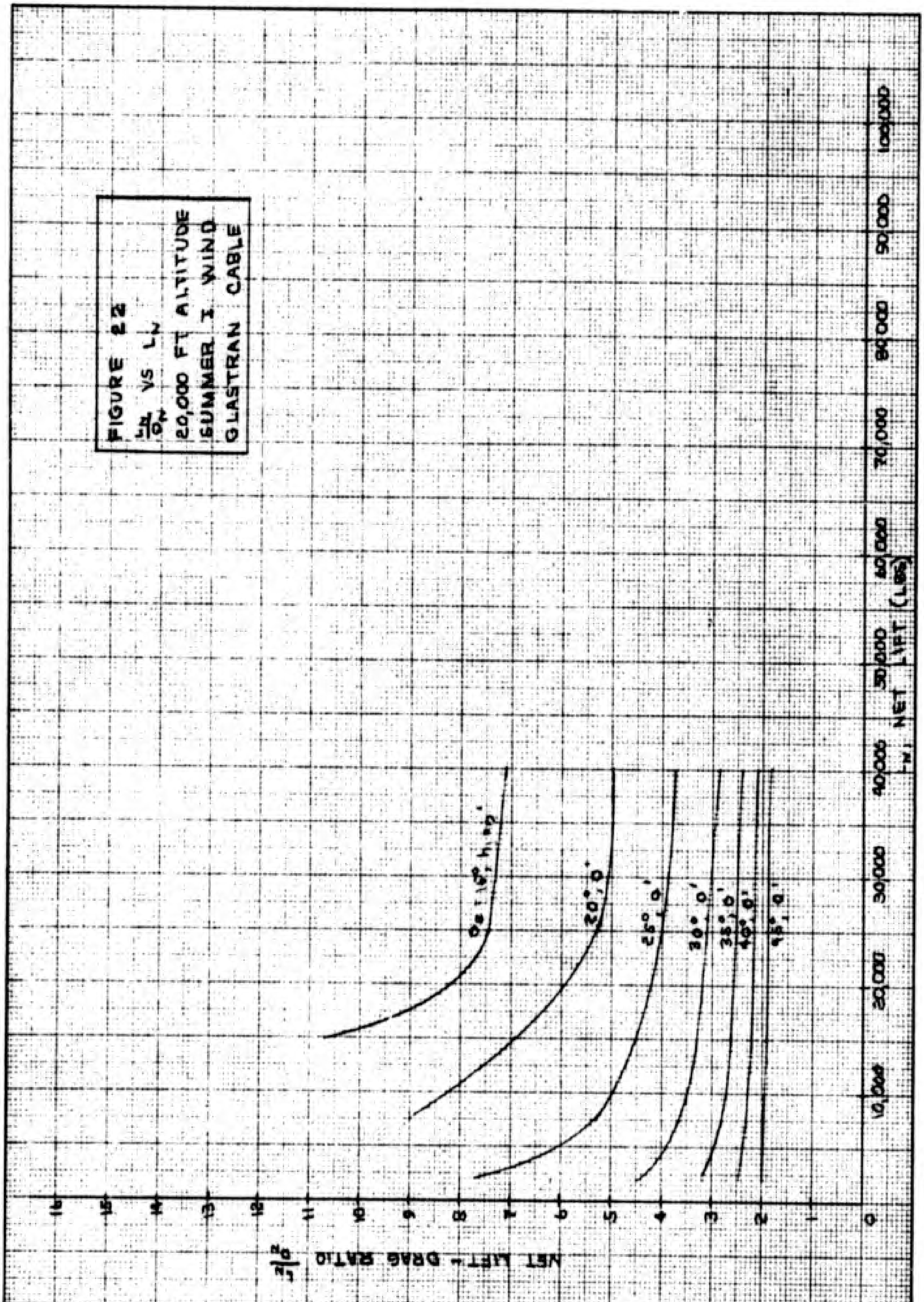
FIGURE 22
$\frac{L_N}{D_N}$ VS L_N
20,000 FT ALTITUDE
SUMMER I WIND
GLASTRAN CABLE
NET LIFT - DRAG RATIO $\frac{L_N}{D_N}$
L_N, NET LIFT (LBS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
20°, 0'
25°, 0'
30°, 0'
35°, 0'
40°, 0'
45°, 0'

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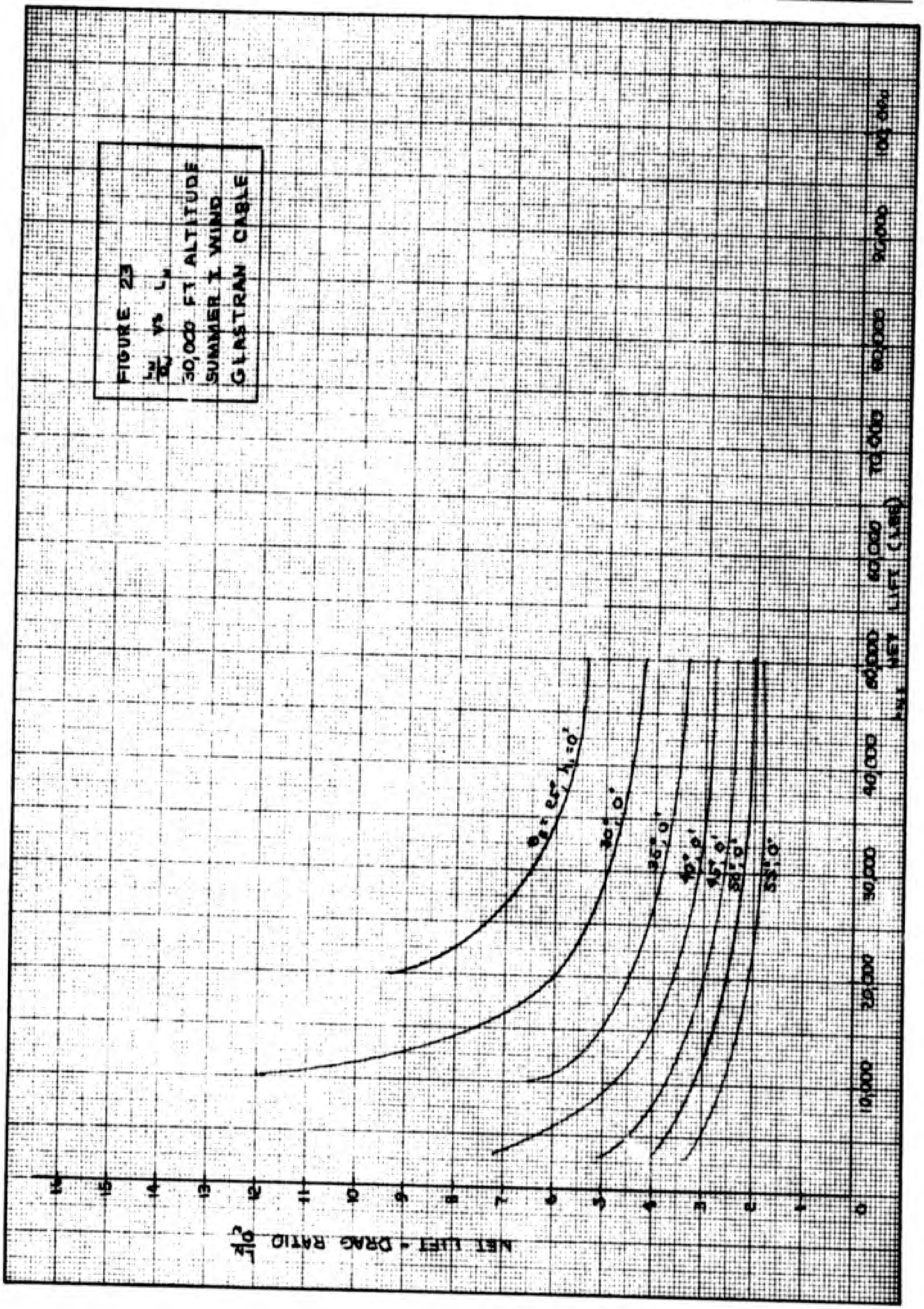

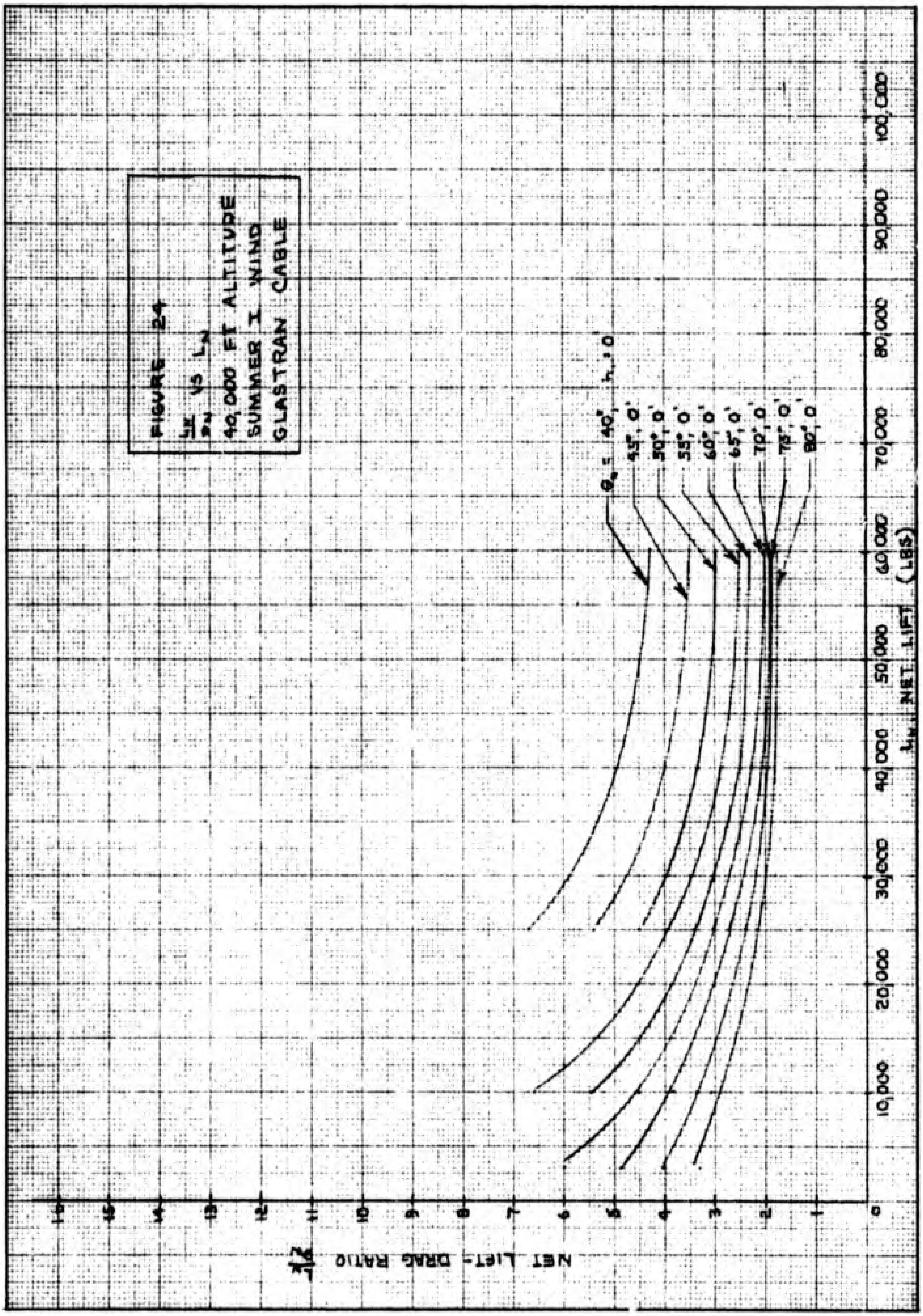
FIGURE 24
$\frac{L_N}{D_N}$ VS L_N
40,000 FT ALTITUDE
SUMMER I WIND
GLASTRAN CABLE
θ_s 40°, h, 0
45°, 0
50°, 0
55°, 0
60°, 0
65°, 0
70°, 0
75°, 0
80°, 0
$\frac{L_N}{D_N}$ NET LIFT - DRAG RATIO
L_N NET LIFT (LBS)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

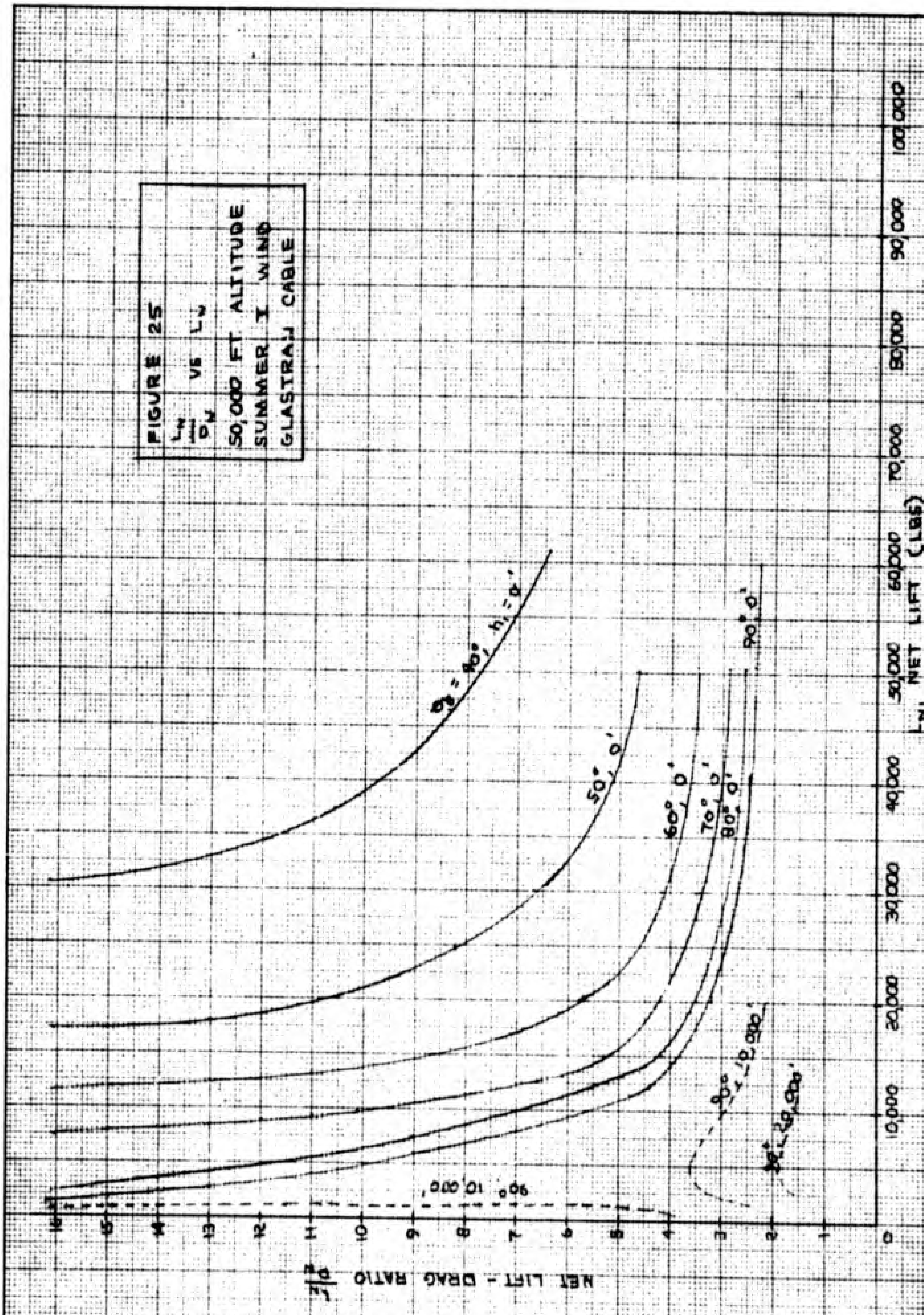
FIGURE 25
L_N/D_N VS L_N
50,000 FT. ALTITUDE
SUMMER I WIND
GLASTRAN CABLE
θ = 90°, h₁ = 0'
50°, 0'
60°, 0'
70°, 0'
80°, 0'
90°, 0'
90°, 10,000'
90°, 10,000'
90°, 20,000'
NET LIFT - DRAG RATIO L_N/D_N
L_N, NET LIFT (LBS)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

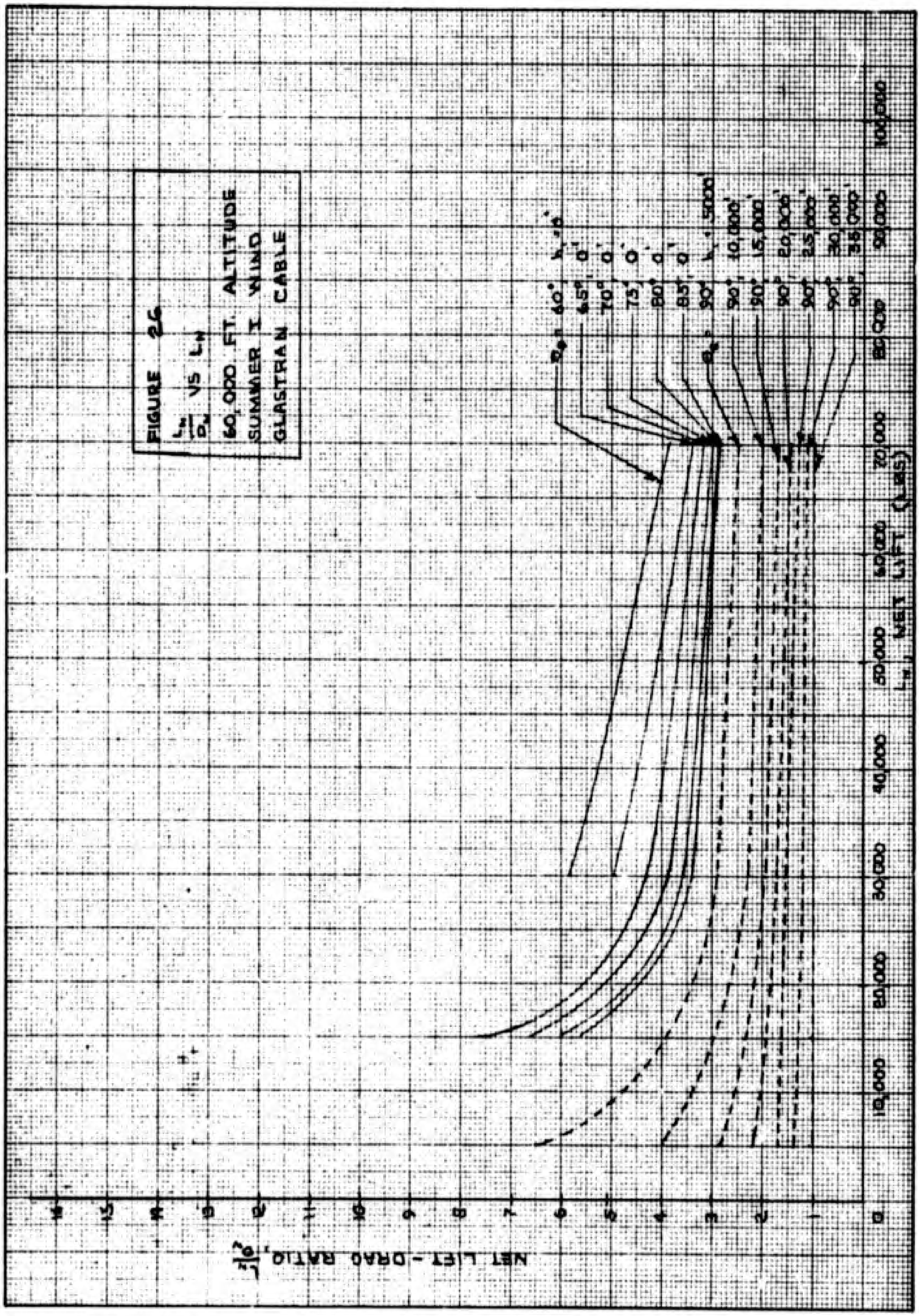
FIGURE 26
L_N/D_L VS L_N
60,000 FT. ALTITUDE
SUMMER I WIND
GLASTRAN CABLE
NET LIFT-DRAG RATIO, L/D
NET LIFT (LBS)

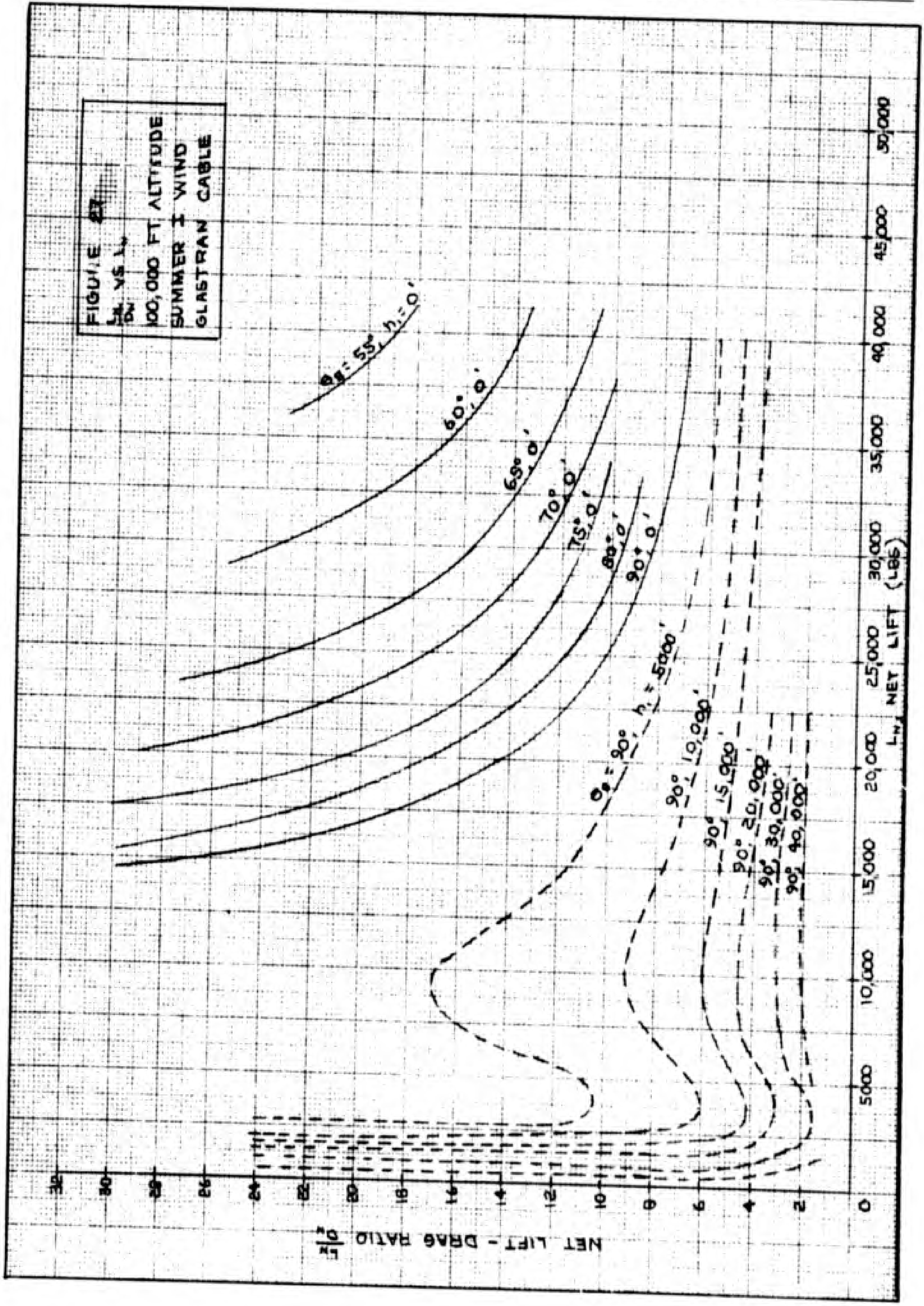
FIGURE
L_N/D_N VS L_N
100,000 FT. ALTITUDE
SUMMER I WIND
GLASTRAN CABLE
$\theta_s = 55°, h_i = 0'$
60°, 0'
65°, 0'
70°, 0'
75°, 0'
80°, 0'
90°, 0'
$\theta_s = 90°, h_i = 5000'$
90°, 10,000'
90°, 15,000'
90°, 20,000'
90°, 30,000'
90°, 40,000'
NET LIFT - DRAG RATIO L_N/D_N
L_N NET LIFT (LBS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
5000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000

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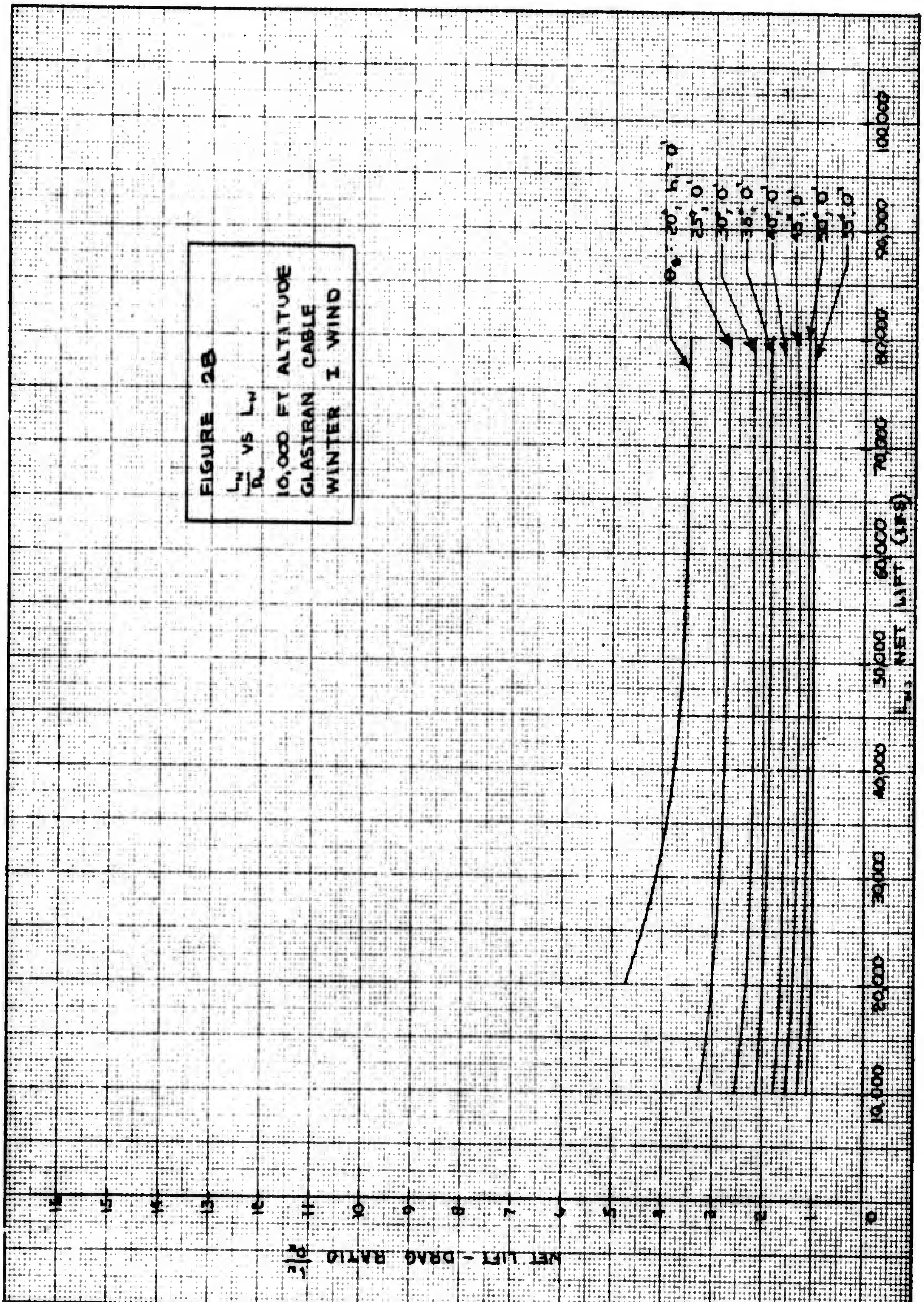


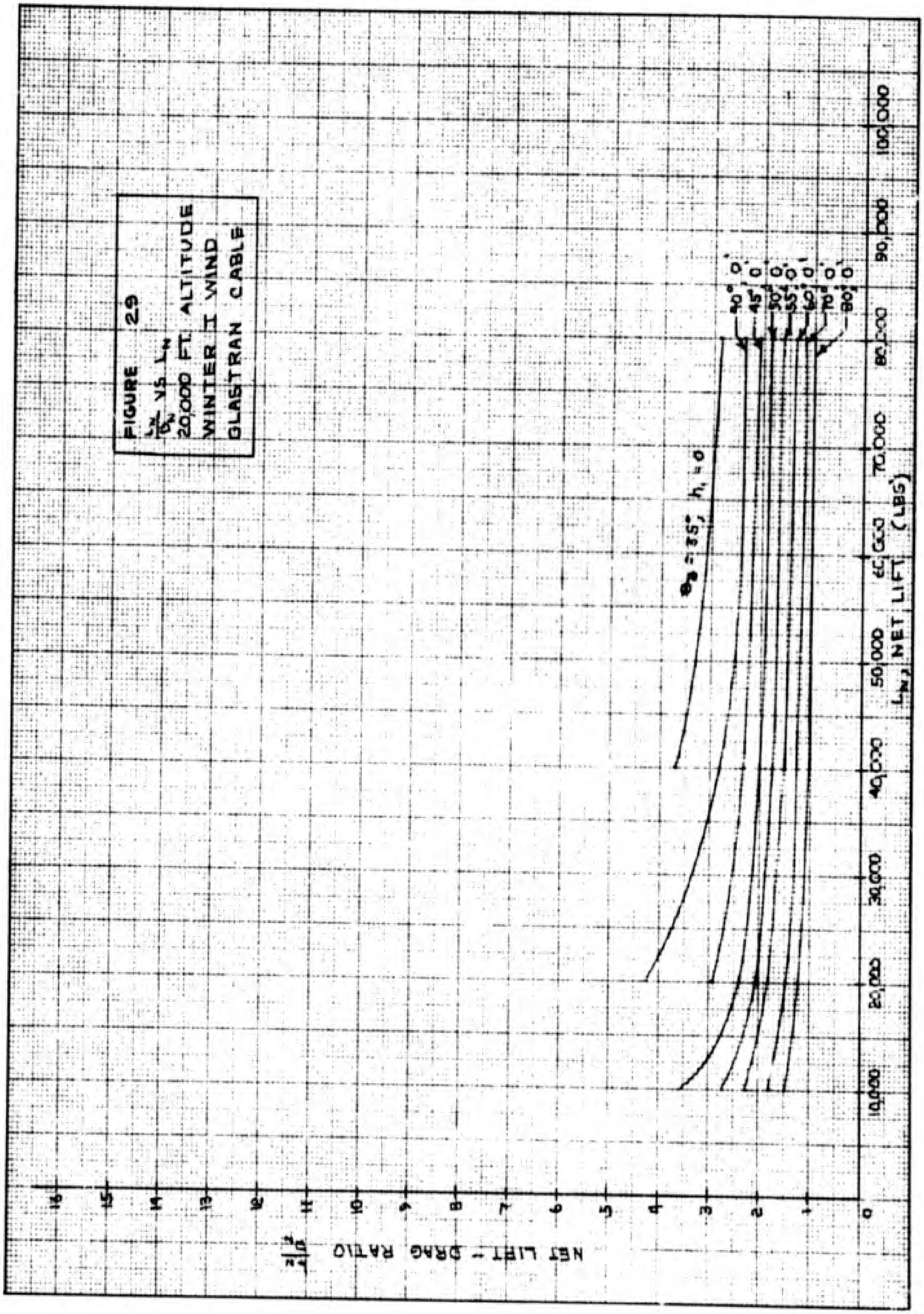


FIGURE 29
L/D vs L_N
20,000 FT. ALTITUDE
WINTER II WIND
GLASTRAN CABLE
θ_s = 35°, h, = 0
40°
45°
50°
55°
60°
70°
80°
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
L_N, NET LIFT (LBS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
NET LIFT - DRAG RATIO

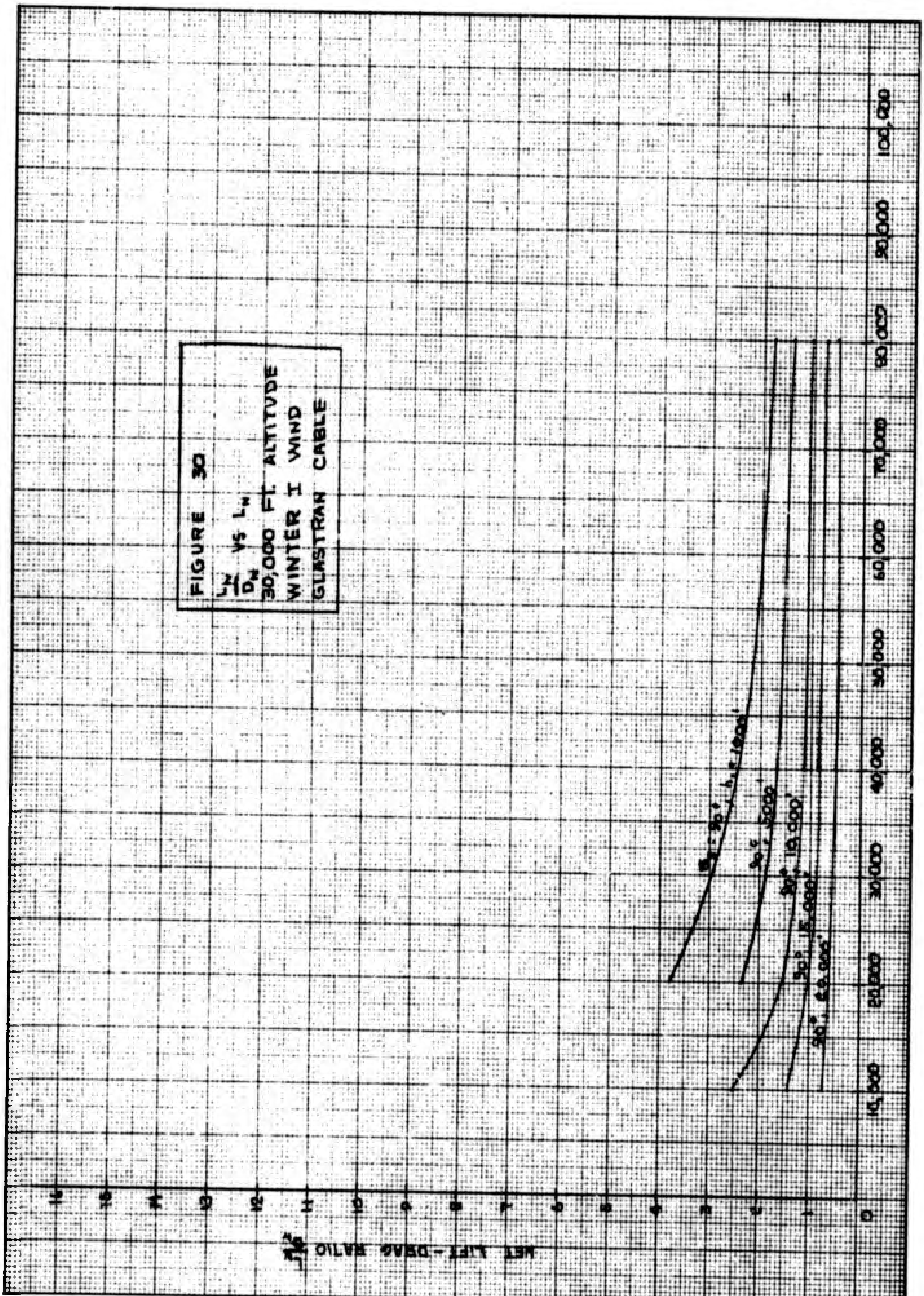


FIGURE 30
L_N/D_N VS L_N
30,000 FT. ALTITUDE
WINTER I WIND
GILSTRAN CABLE
NET LIFT - DRAG RATIO L_N/D_N
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000

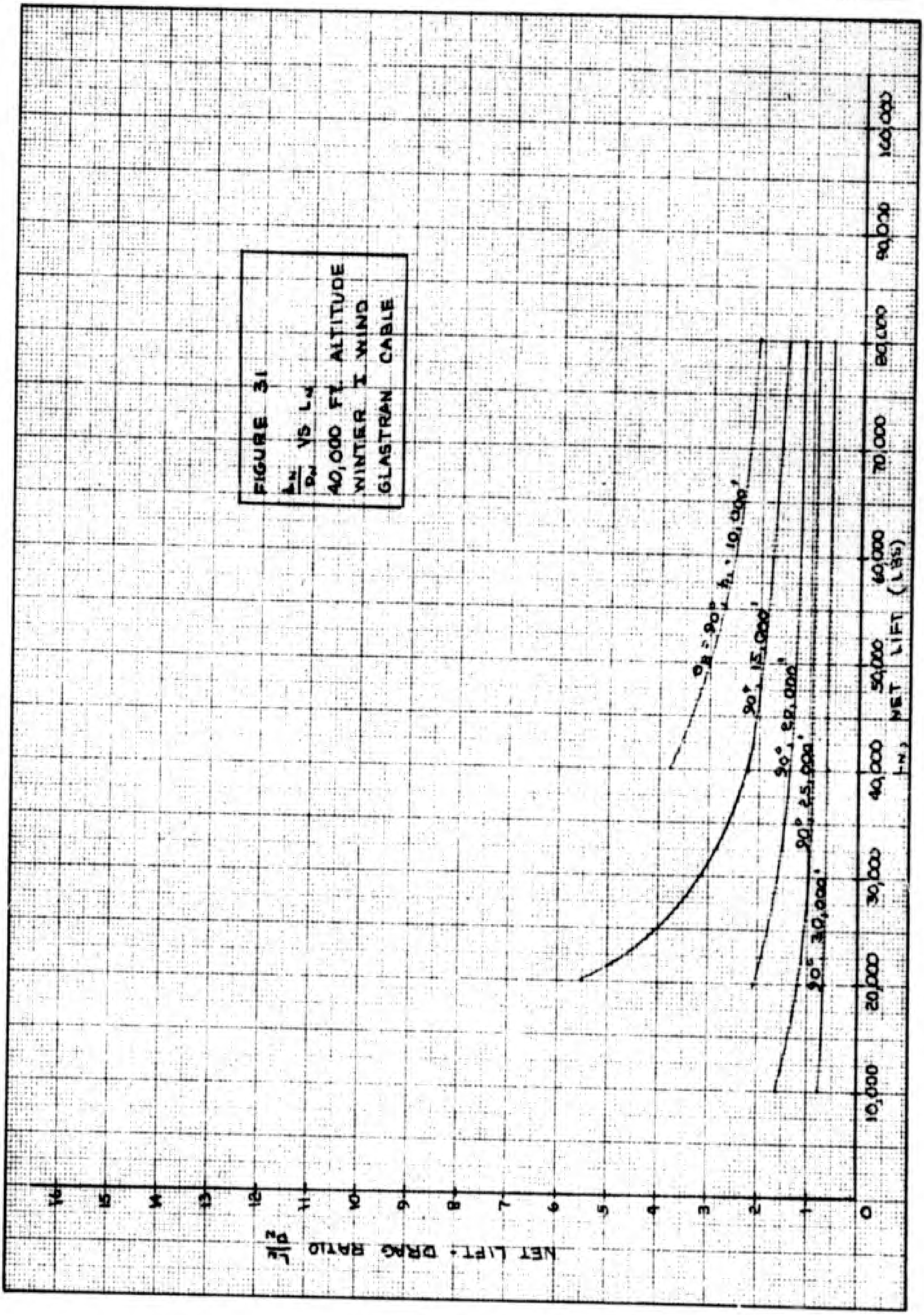


FIGURE 31
L_N/D_N VS L_N
40,000 FT. ALTITUDE
WINTER I WIND
GLASTRAN CABLE
θ_B = 90°, h_1 = 10,000'
90°, 15,000'
90°, 20,000'
90°, 25,000'
90°, 30,000'
NET LIFT ÷ DRAG RATIO L_N/D_N
NET LIFT (LBS) L_N
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000

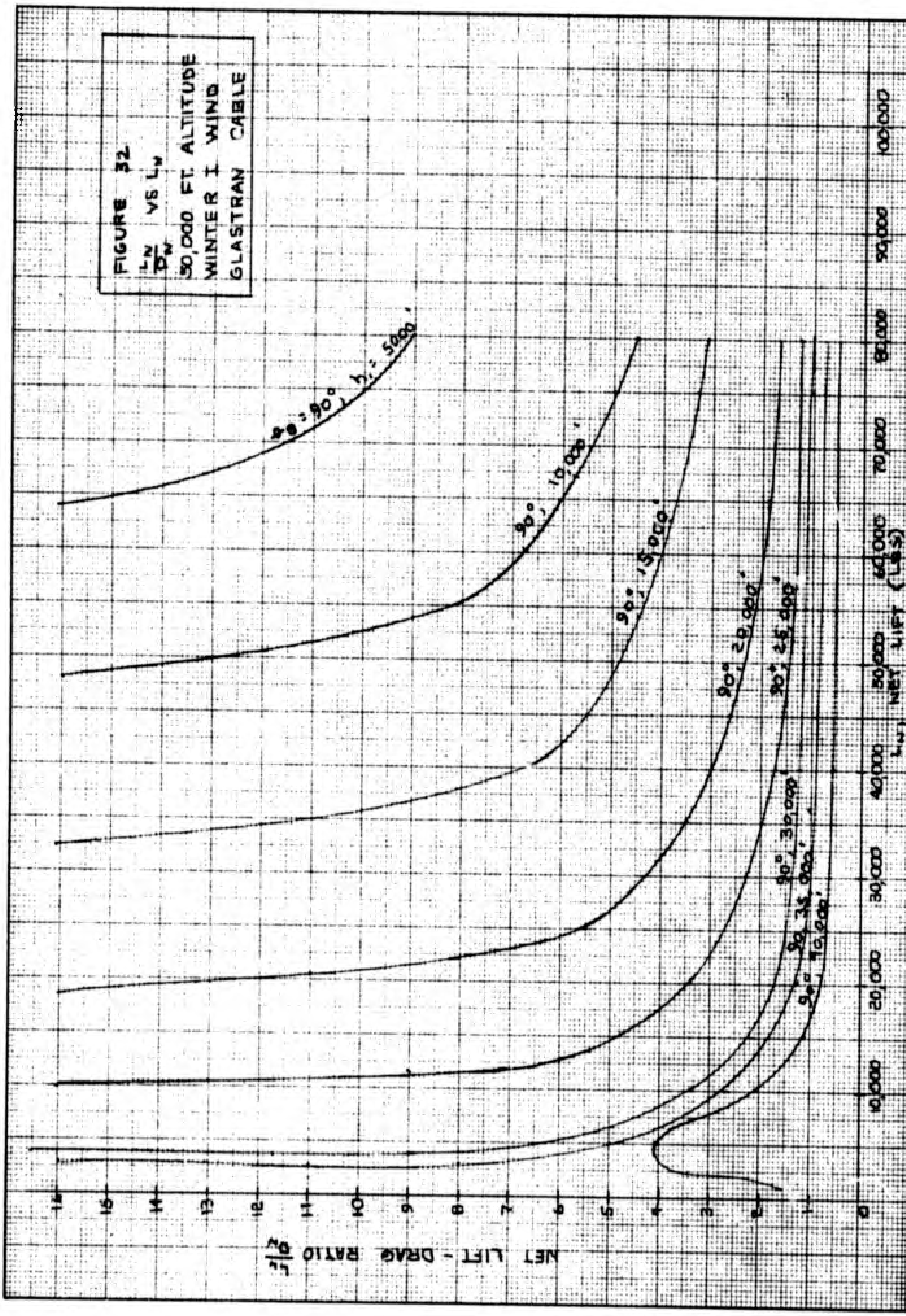


FIGURE 32
$\frac{L_N}{D_N}$ VS L_N
50,000 FT. ALTITUDE
WINTER I WIND
GLASTRAN CABLE
θ₀ = 90°, h₁ = 5000'
90°, 10,000'
90°, 15,000'
90°, 20,000'
90°, 25,000'
90°, 30,000'
90°, 35,000'
90°, 40,000'
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
NET LIFT (L_N) (LBS)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
NET LIFT - DRAG RATIO $\frac{L_N}{D_N}$

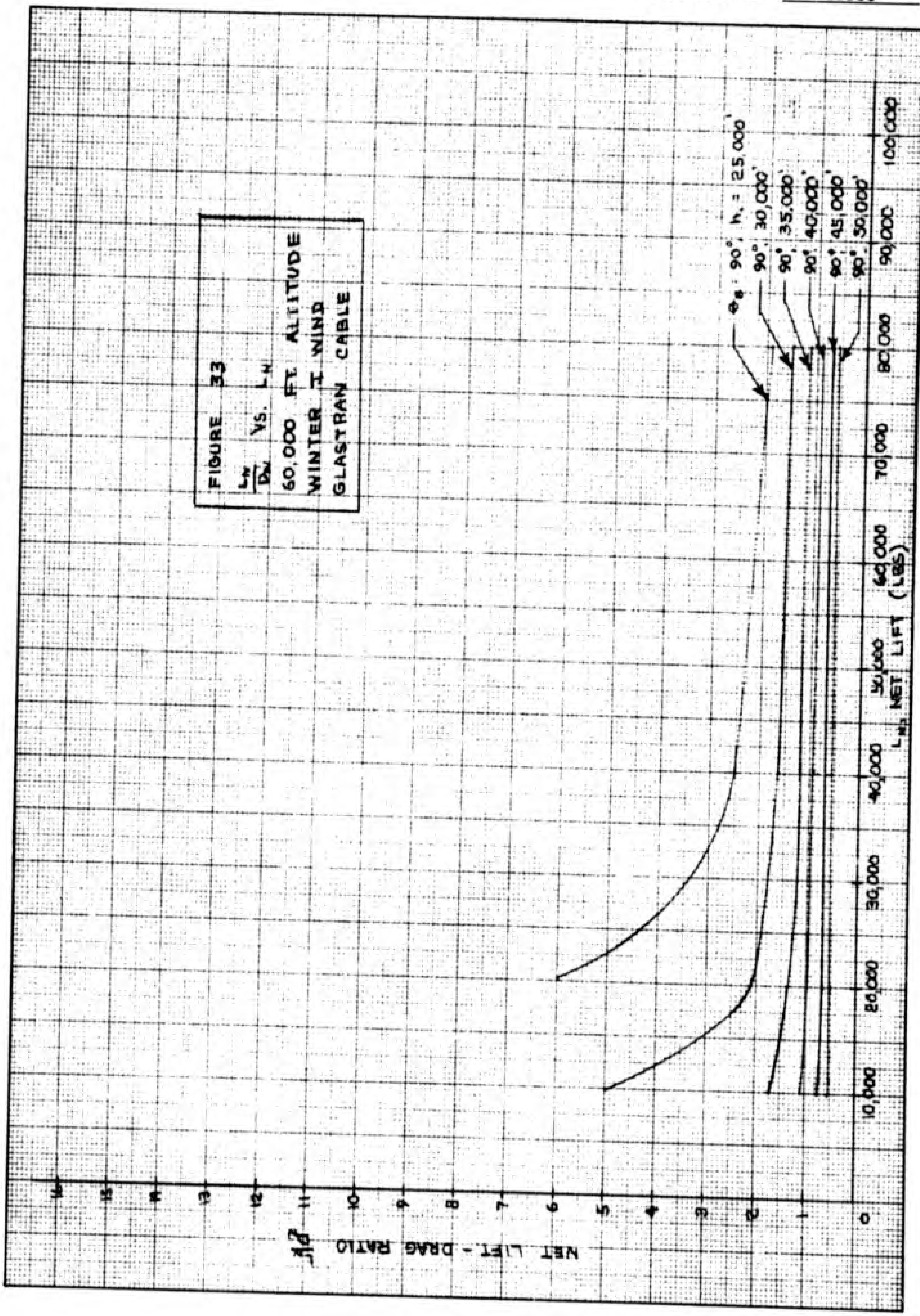


FIGURE 33
L_N/D_N VS. L_N
60,000 FT ALTITUDE
WINTER II WIND
GLASTRAN CABLE
θ_B: 90°, h_c = 25,000'
90°, 30,000'
90°, 35,000'
90°, 40,000'
90°, 45,000'
90°, 50,000'
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
L_N, NET LIFT (LBS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
NET LIFT - DRAG RATIO L_N/D_N

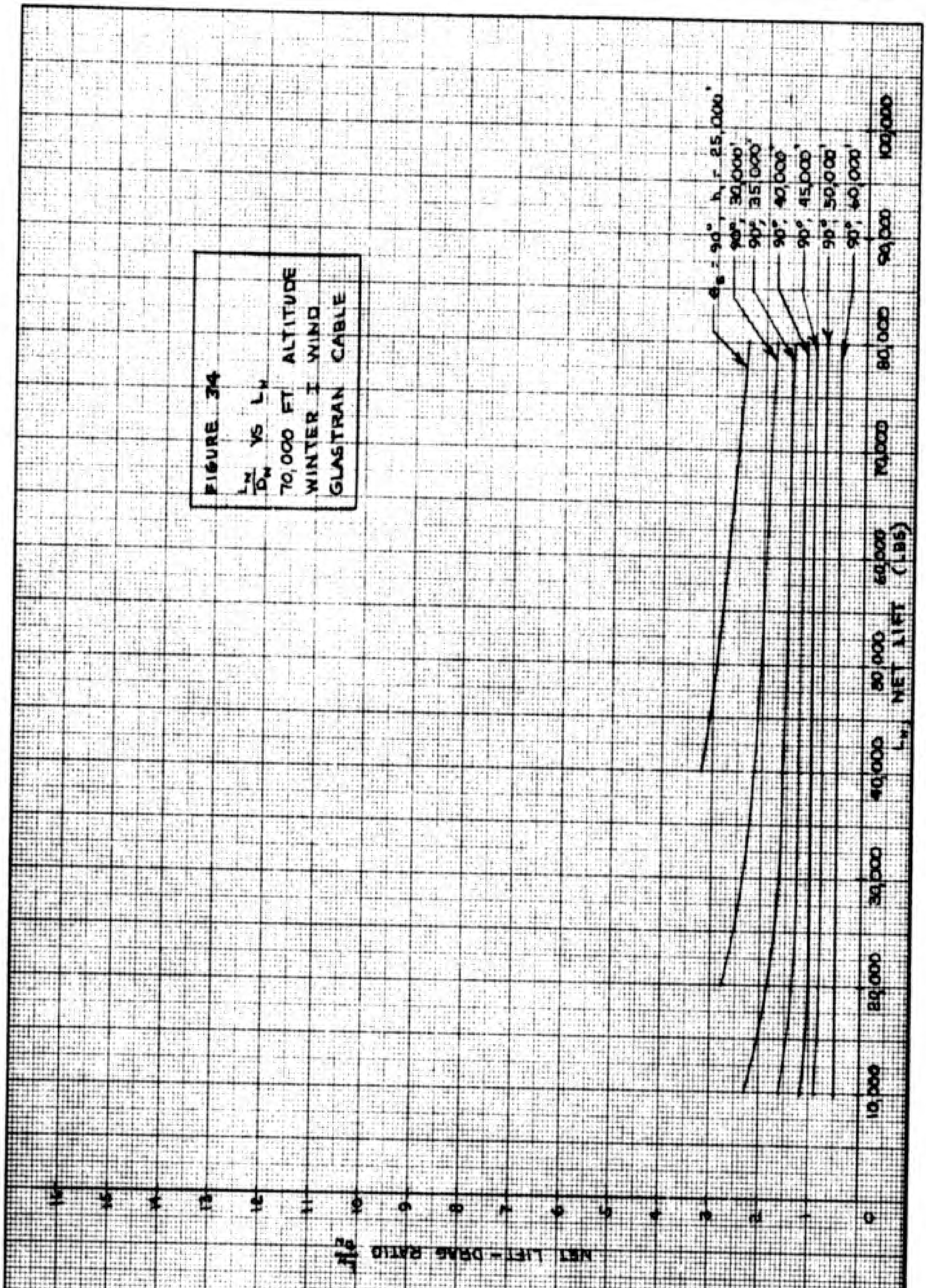


FIGURE 34
L_N/D_N VS L_N
70,000 FT ALTITUDE
WINTER I WIND
GLASTRAN CABLE
θ_s = 90°, h_c = 25,000'
90°, 30,000'
90°, 35,000'
90°, 40,000'
90°, 45,000'
90°, 50,000'
90°, 60,000'
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
L_N NET LIFT (LBS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
NET LIFT – DRAG RATIO L_N/D_N

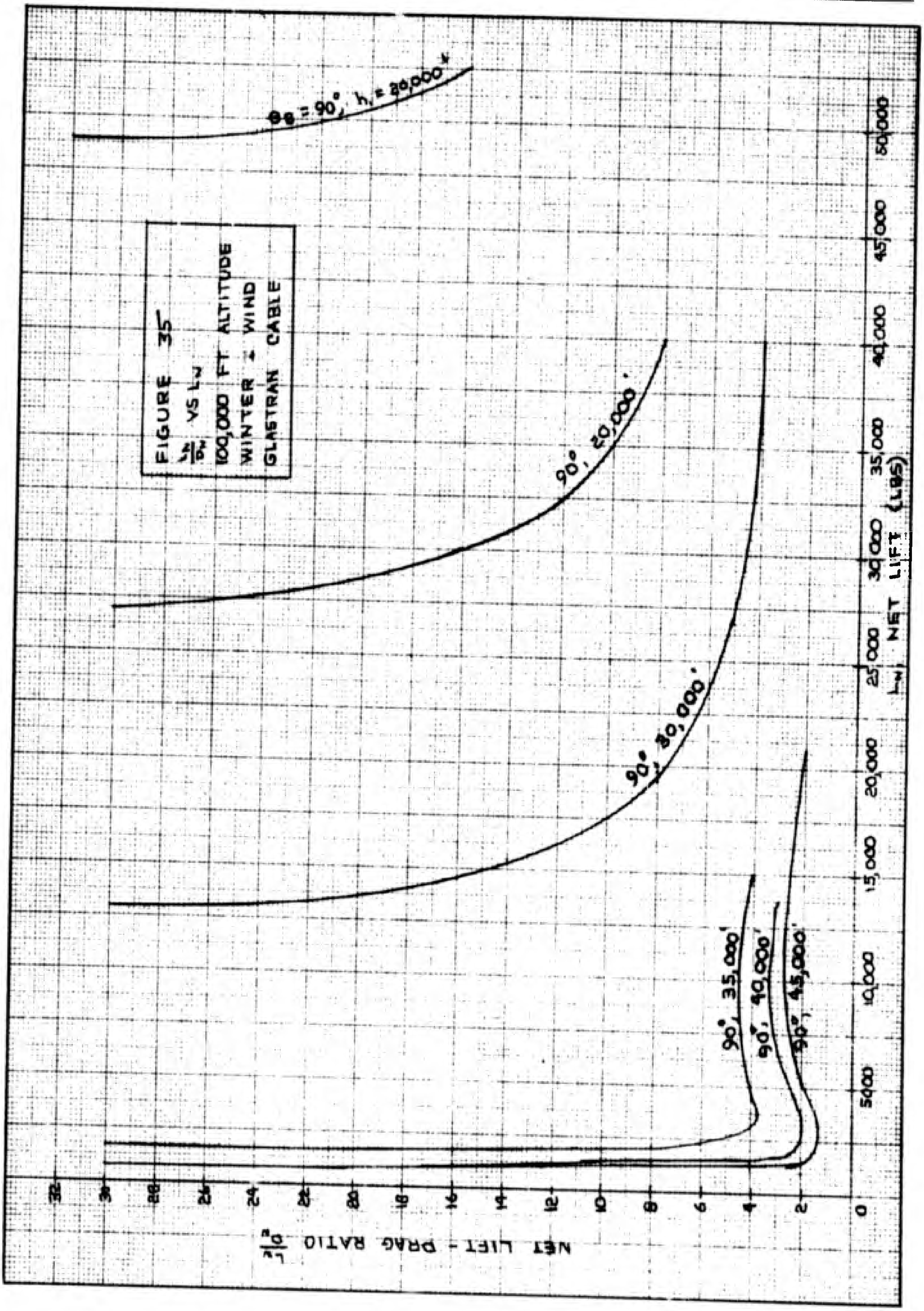
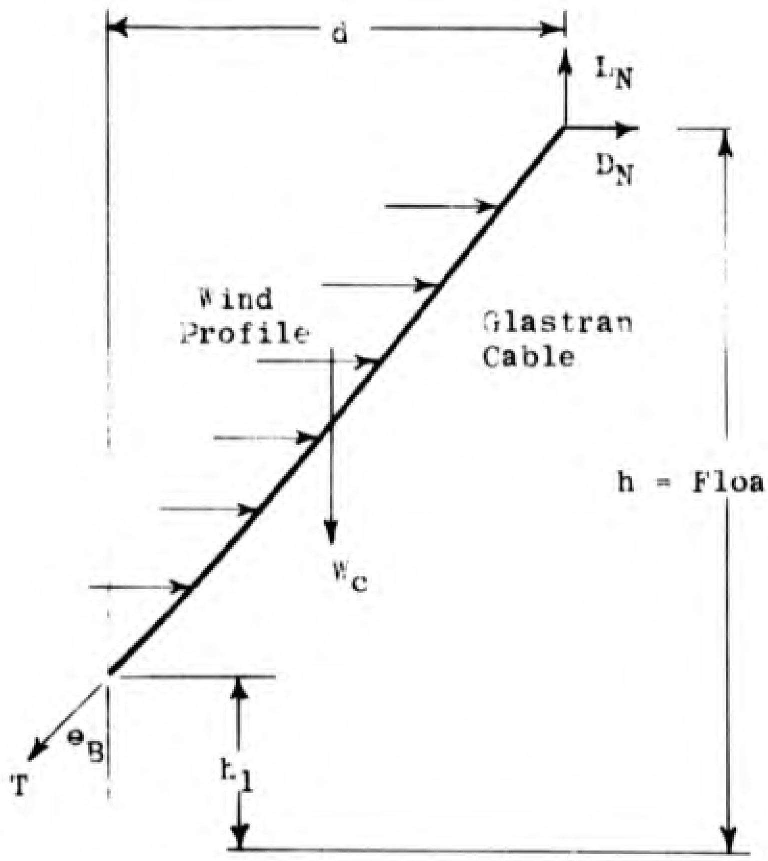


FIGURE 35
L_N/D_N VS L_N
100,000 FT ALTITUDE
WINTER WIND
GLASTRAN CABLE
θs = 90°, h1 = 20,000 ft
90°, 20,000'
90°, 30,000'
90°, 35,000'
90°, 40,000'
90°, 45,000'
NET LIFT - DRAG RATIO L/D
L_N, NET LIFT (LBS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
5000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000



d	blowdown distance or distance from top end of cable to bottom end measured parallel to earth plane
D_N	net drag, horizontal component of tension at top end of cable
L_N	net lift of balloon or vertical component of tension at the top end of the cable
h	float altitude above mean sea level
h_1	altitude above mean sea level at which cable is parallel to earth plane
W_c	total weight of cable
θ_B	angle between the cable and the vertical at the bottom end of the cable

FIGURE 36 - TETHER CABLE PROFILE PARAMETERS

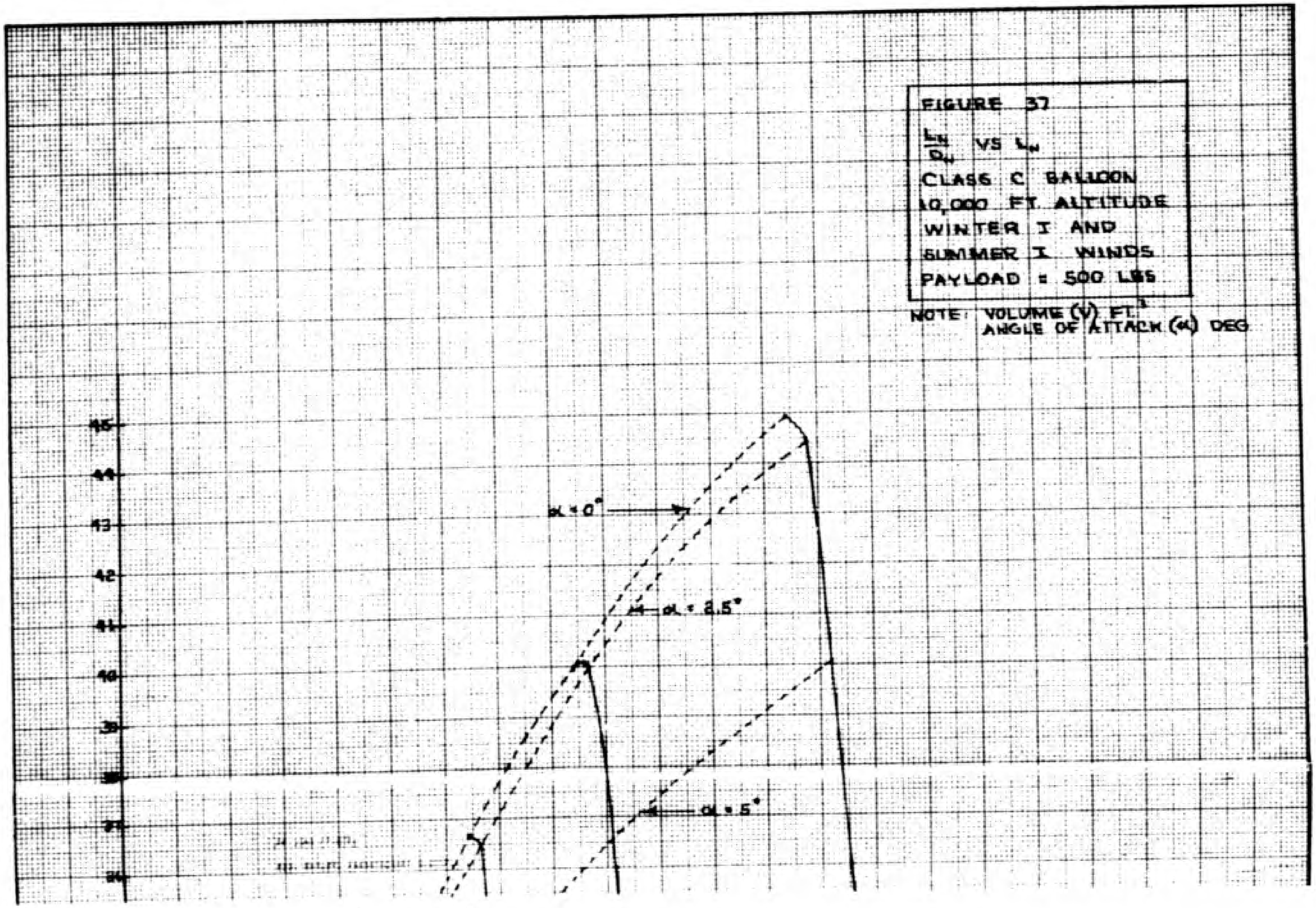
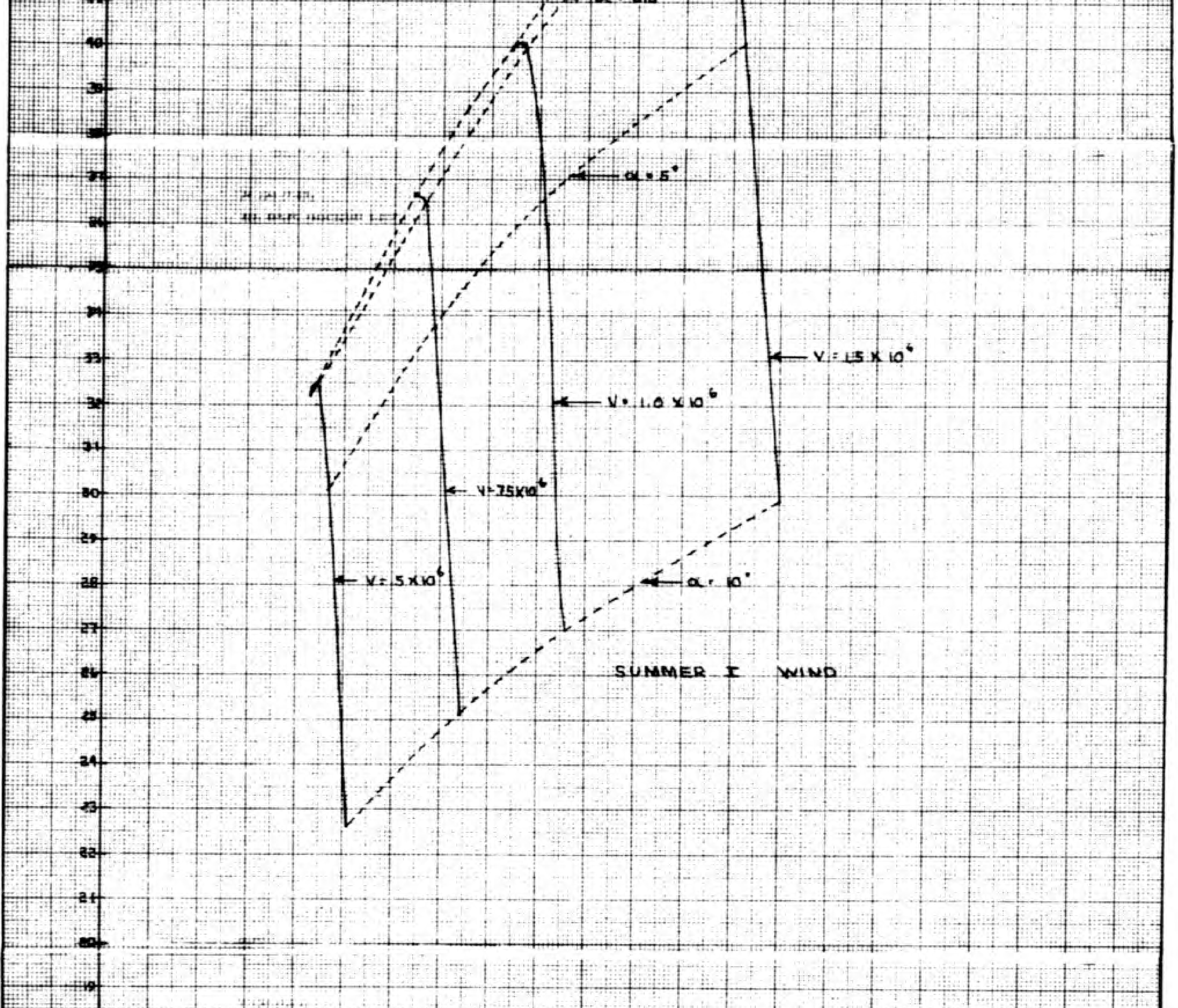
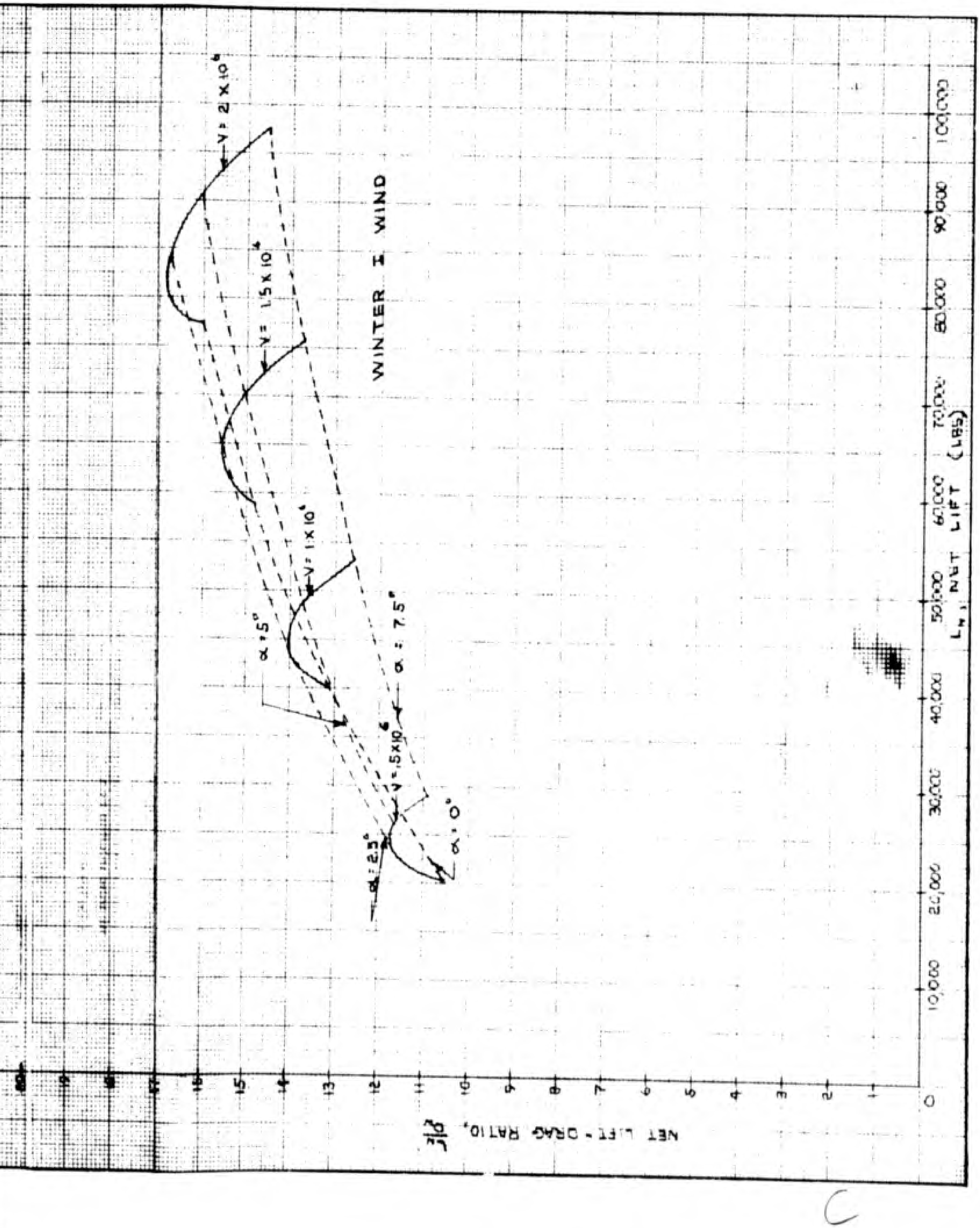


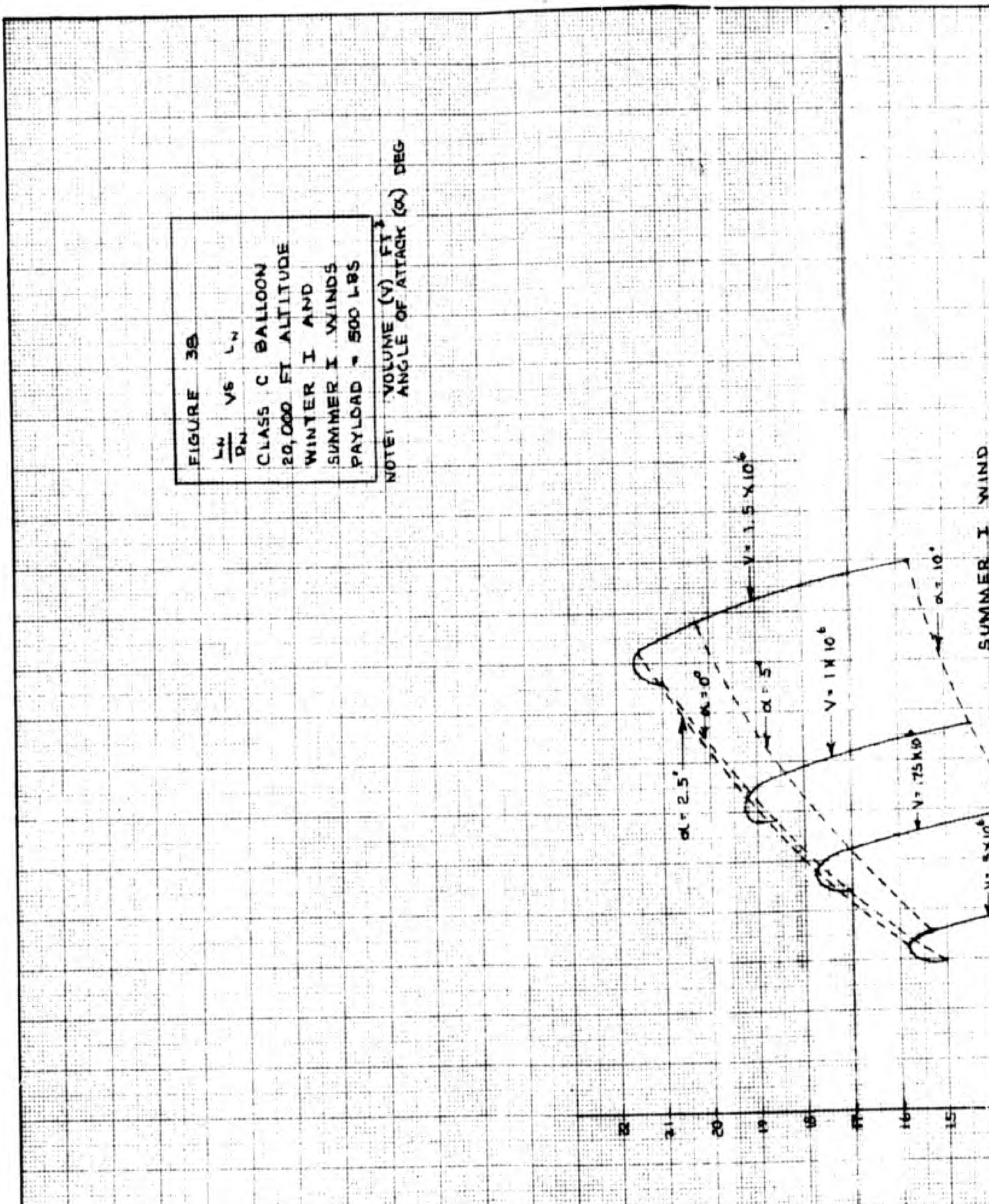
FIGURE 37
$\frac{L_H}{D_H}$ VS L_H
CLASS C BALLOON
10,000 FT. ALTITUDE
WINTER I AND
SUMMER I WINDS
PAYLOAD = 500 LBS
NOTE: VOLUME (V) FT.^{3}
ANGLE OF ATTACK (α) DEG
α = 0°
α = 2.5°
α = 5°
45
44
43
42
41
40
39
38
37
36



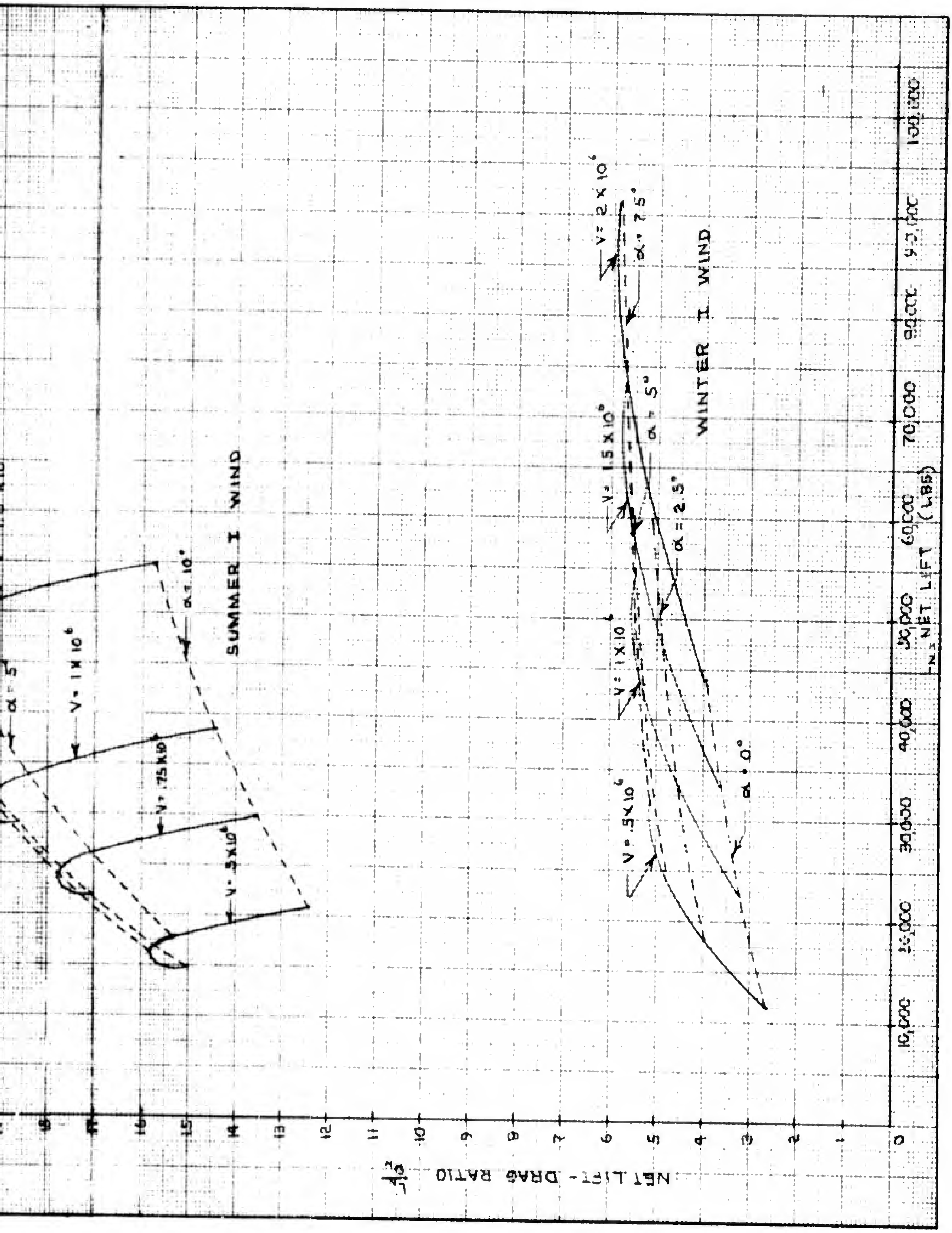
V = 1.5 X 10⁶
V = 1.0 X 10⁶
V = .75X10⁶
V = .5 X10⁶
α = 5°
α = 10°
SUMMER I WIND


WINTER I WIND
V = 2 X 10^6
V = 1.5 X 10^6
V = 1 X 10^6
V = .5 X 10^6
α = 0°
α = 2.5°
α = 5°
α = 7.5°
NET LIFT - DRAG RATIO, L/D
L_N, NET LIFT (LBS)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

DATE	**GOODYEAR AEROSPACE** CORPORATION	PAGE	DATE
REV DATE		GER.	REV DATE
REV DATE		CODE IDENT NO 25500	REV DATE



A



SUMMER I WIND
WINTER I WIND
V = 2 X 10^6
V = 1.5 X 10^6
V = 1 X 10^6
V = .5 X 10^6
V = .75 X 10^6
α = 10°
α = 7.5°
α = 5°
α = 2.5°
α = 0°
NET LIFT - DRAG RATIO
NET LIFT (LBS)
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000

B

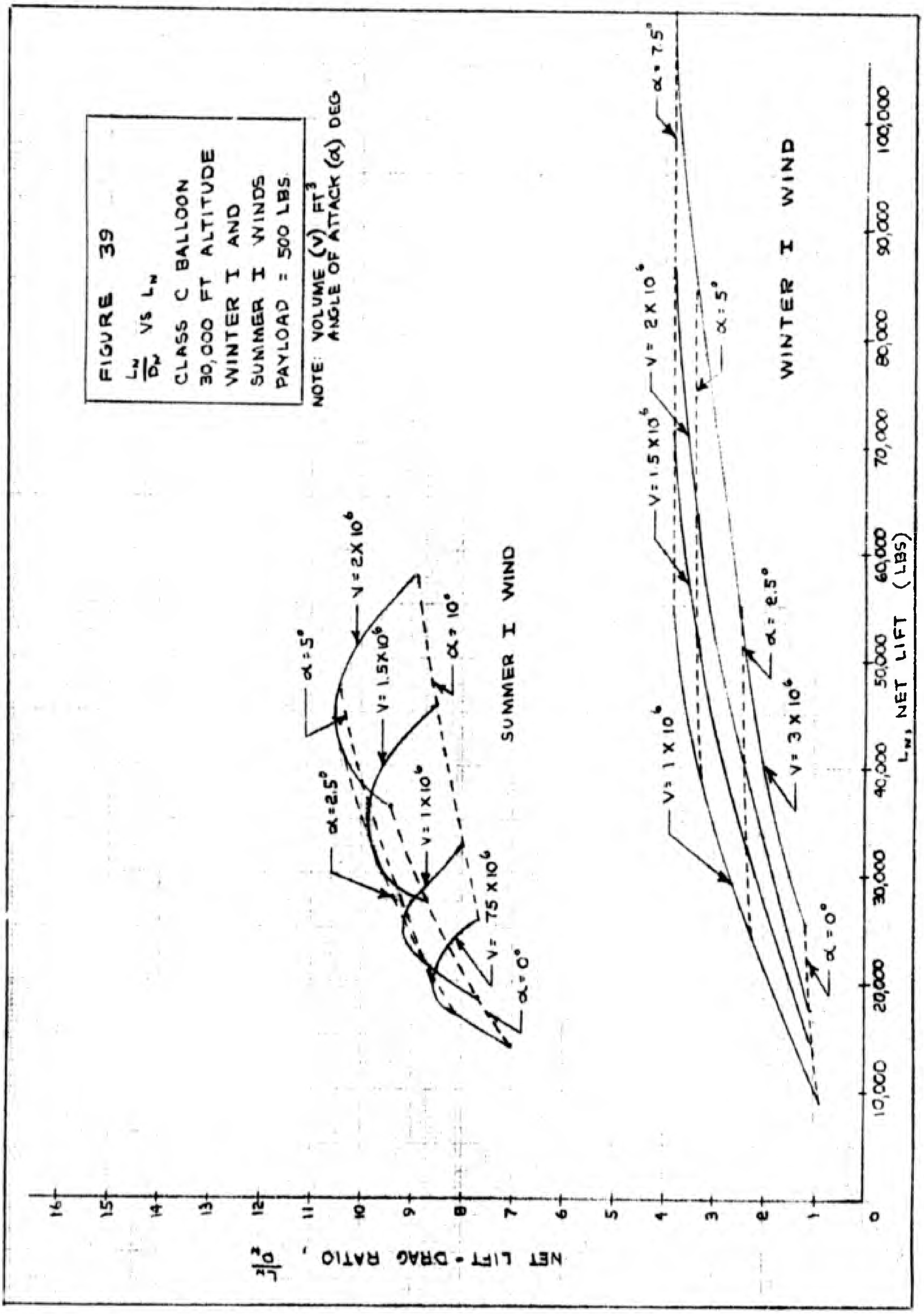


FIGURE 39
LN/DN VS LN
CLASS C BALLOON
30,000 FT ALTITUDE
WINTER I AND
SUMMER I WINDS
PAYLOAD = 500 LBS
NOTE: VOLUME (V) FT3
ANGLE OF ATTACK (α) DEG
SUMMER I WIND
WINTER I WIND
V = 2X10^6
V = 1.5X10^6
V = 1X10^6
V = .75X10^6
V = 3X10^6
α = 0°
α = 2.5°
α = 5°
α = 7.5°
α = 10°
NET LIFT - DRAG RATIO, LN/DN
LN, NET LIFT (LBS)
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000

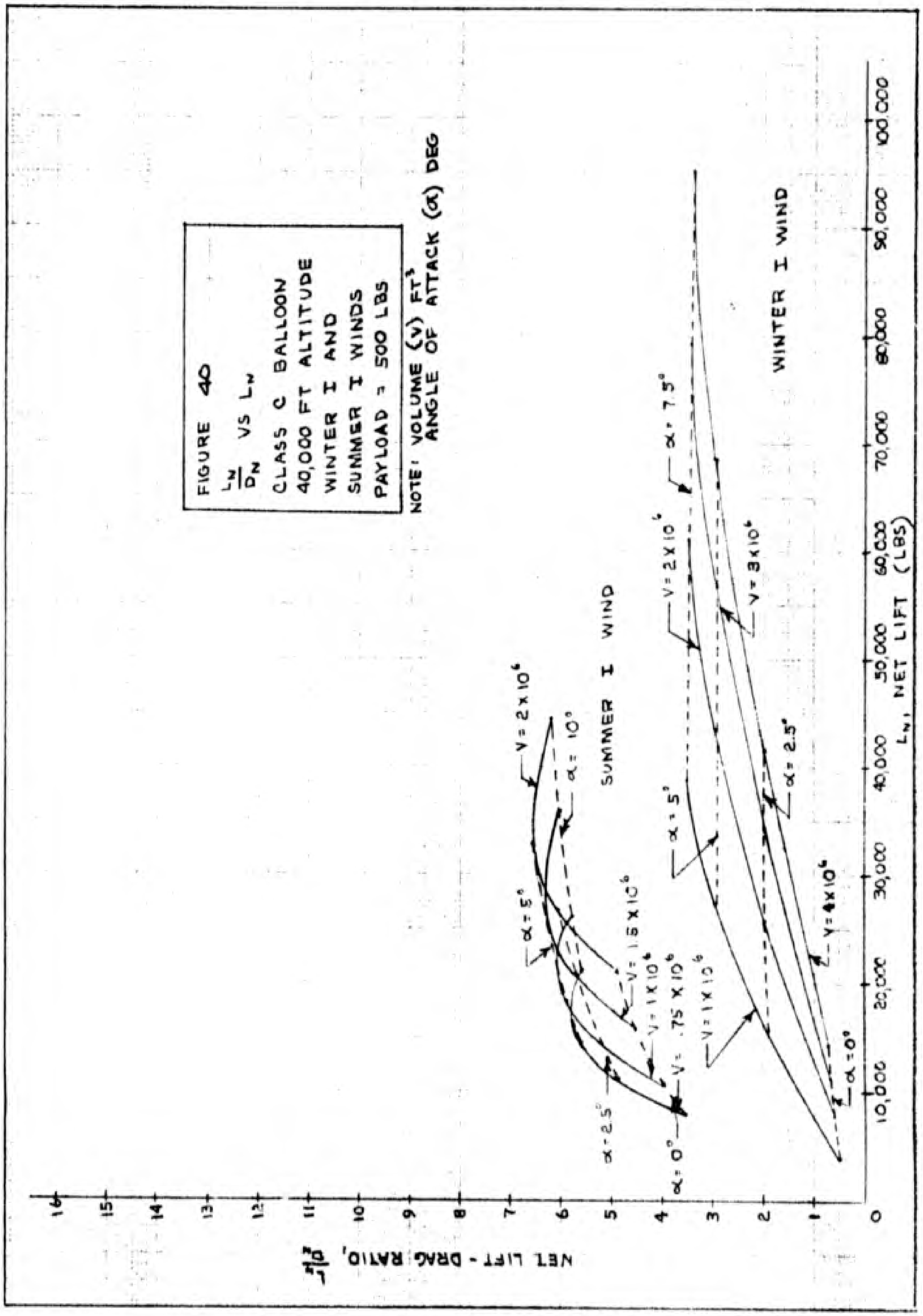


FIGURE 40
L_N/D_N VS L_N
CLASS C BALLOON
40,000 FT ALTITUDE
WINTER I AND
SUMMER I WINDS
PAYLOAD = 500 LBS

NOTE: VOLUME (V) FT^3
ANGLE OF ATTACK (α) DEG

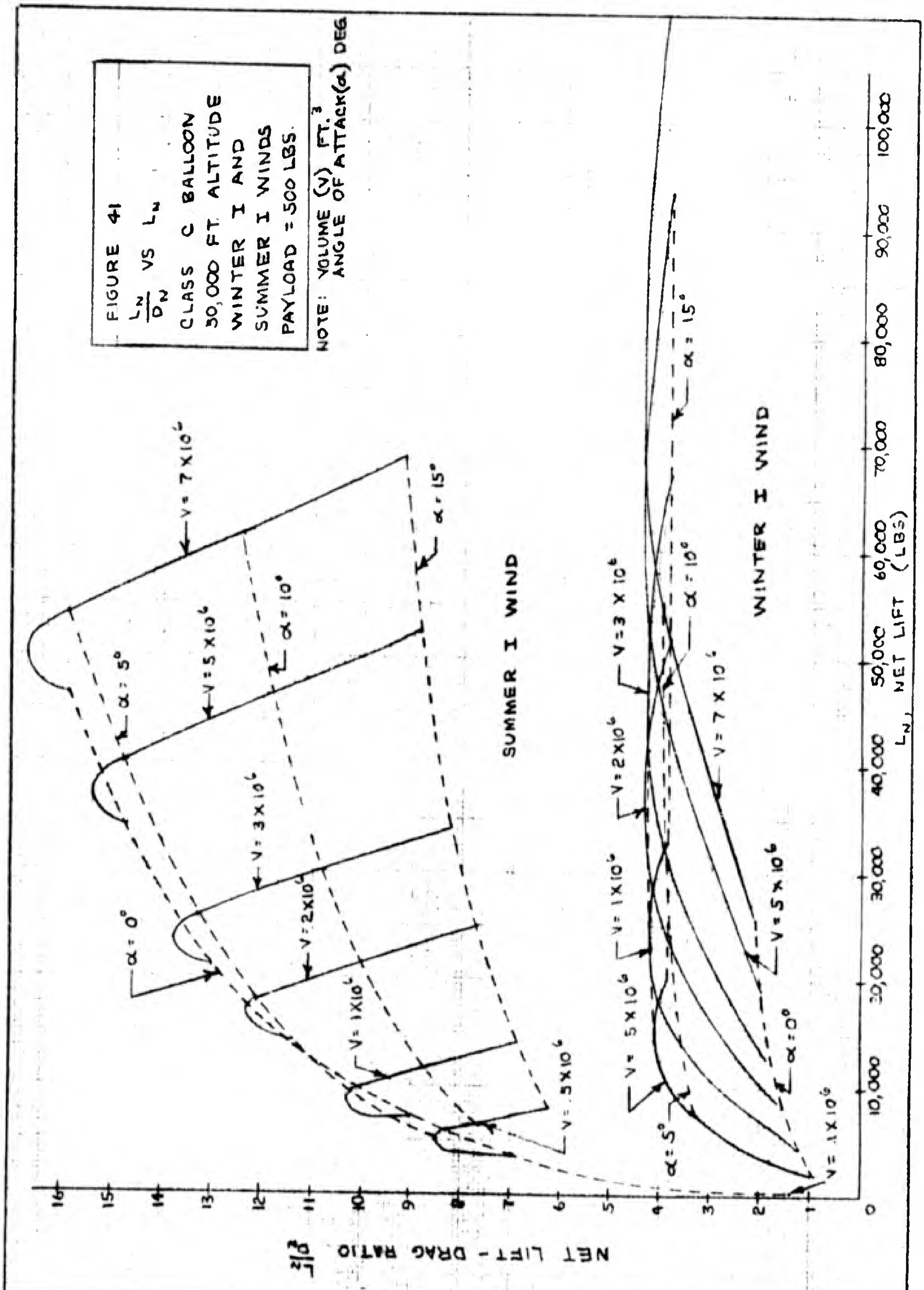


FIGURE 41
$\frac{L_N}{D_N}$ VS L_N
CLASS C BALLOON
30,000 FT. ALTITUDE
WINTER I AND
SUMMER I WINDS
PAYLOAD = 500 LBS.
NOTE: VOLUME (V) FT.³
ANGLE OF ATTACK(α) DEG
SUMMER I WIND
WINTER I WIND
V = 7X10⁶
V = 5X10⁶
V = 3X10⁶
V = 2X10⁶
V = 1X10⁶
V = .5X10⁶
V = .1X10⁶
V = 3 X 10⁶
V = 2X10⁶
V = 1X10⁶
V = 5X10⁶
V = 7 X 10⁶
V = 5 X 10⁶
α = 0°
α = 5°
α = 10°
α = 15°
NET LIFT - DRAG RATIO $\frac{L_N}{D_N}$
L_N, NET LIFT (LBS)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

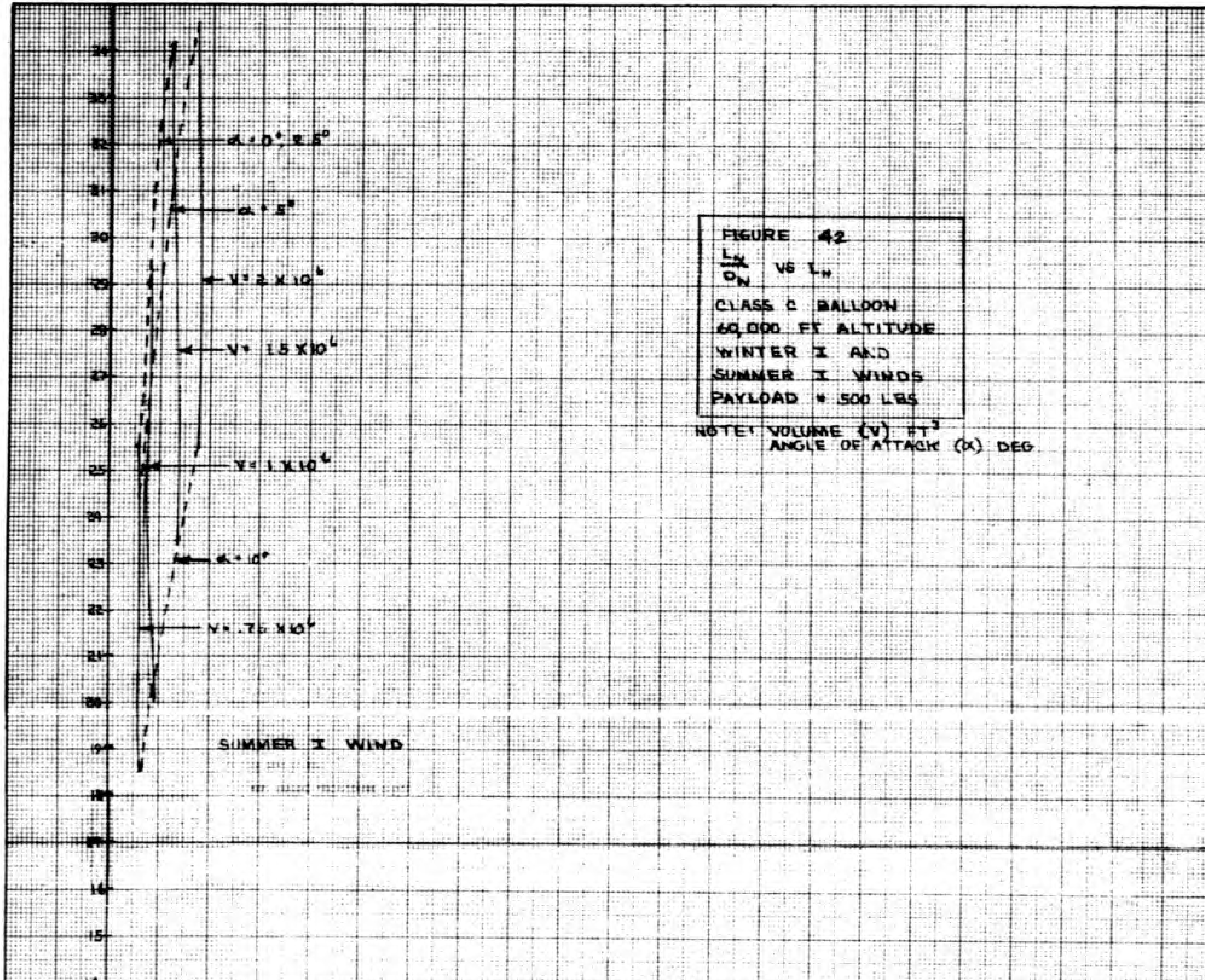
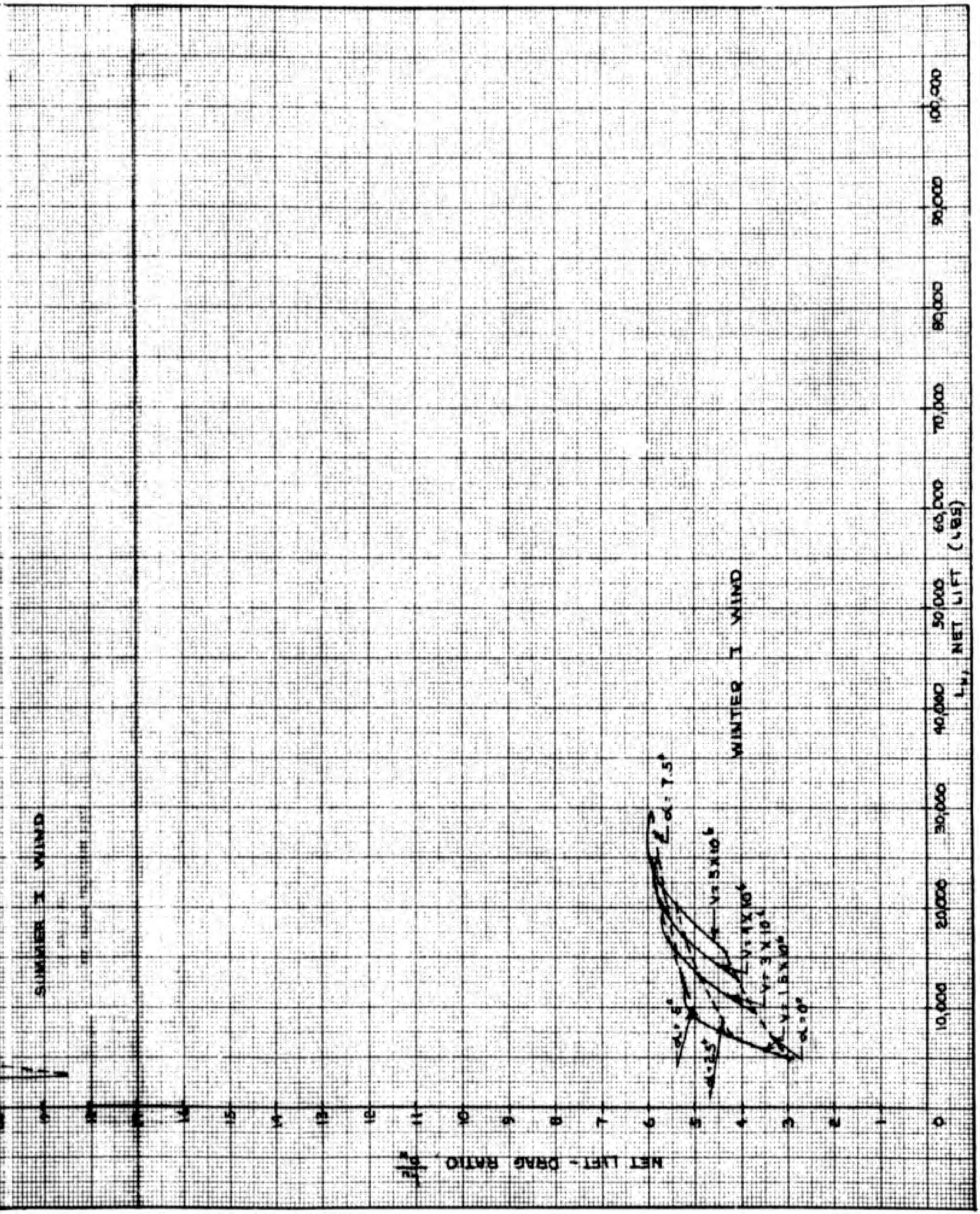


FIGURE 42
$\frac{L_N}{D_N}$ VS L_N
CLASS C BALLOON
60,000 FT ALTITUDE
WINTER I AND
SUMMER I WINDS
PAYLOAD = 500 LBS
NOTE: VOLUME (V) FT³
ANGLE OF ATTACK (α) DEG
α = 0°, 2.5°
α = 5°
V = 2 X 10⁶
V = 1.5 X 10⁶
V = 1 X 10⁶
α = 10°
V = .75 X 10⁶
SUMMER I WIND

A



WINTER I WIND
SUMMER I WIND
NET LIFT - DRAG RATIO
L_N, NET LIFT (LBS)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

B

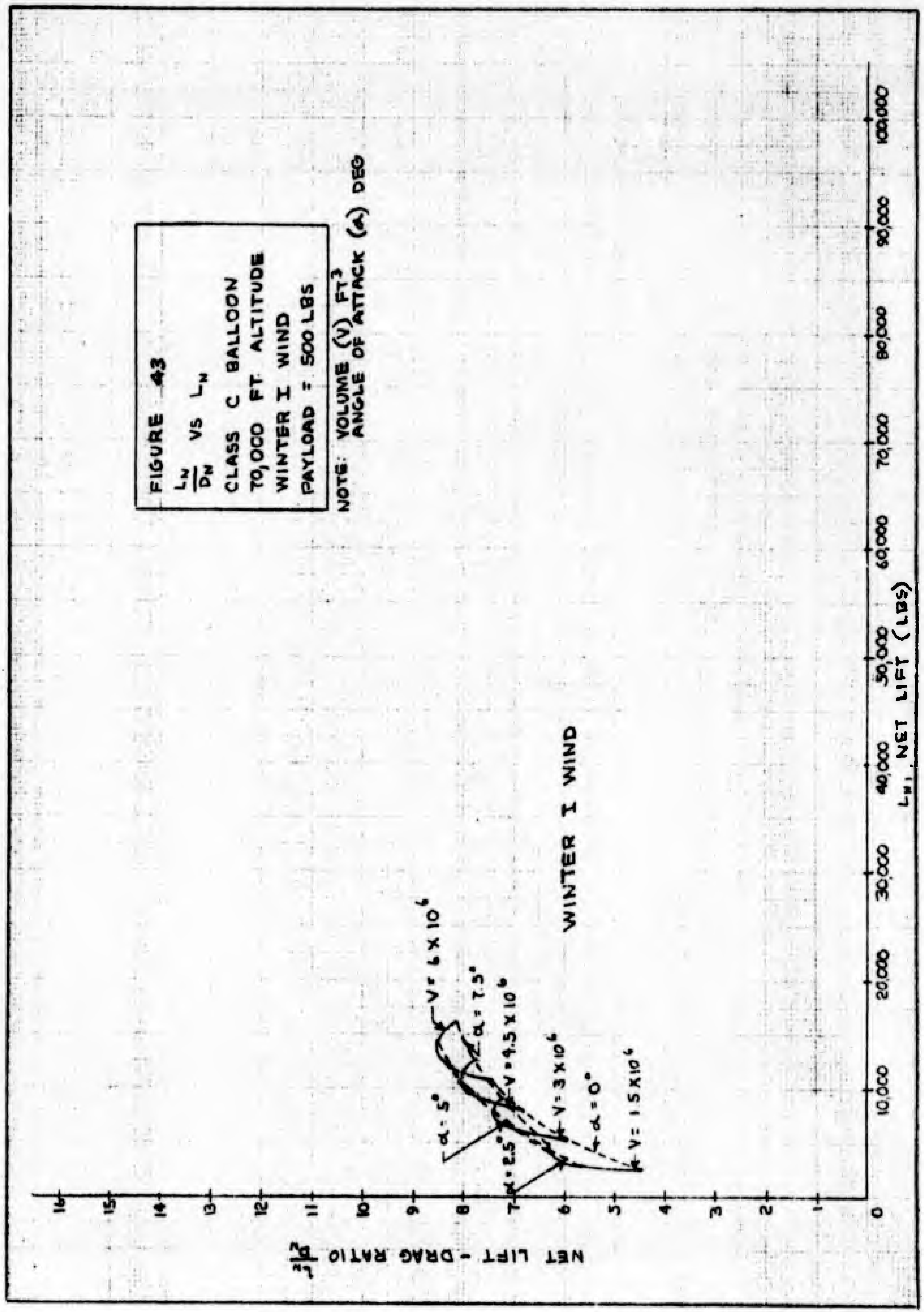


FIGURE 43
$\frac{L_N}{D_N}$ VS L_N
CLASS C BALLOON
70,000 FT. ALTITUDE
WINTER I WIND
PAYLOAD = 500 LBS
NOTE: VOLUME (V) FT³
ANGLE OF ATTACK (α) DEG
WINTER I WIND
V = 6 X 10⁶
α = 7.5°
V = 4.5 X 10⁶
V = 3 X 10⁶
α = 0°
V = 1.5 X 10⁶
α = 5°
α = 2.5°
NET LIFT - DRAG RATIO $\frac{L_N}{D_N}$
L_N, NET LIFT (LBS)

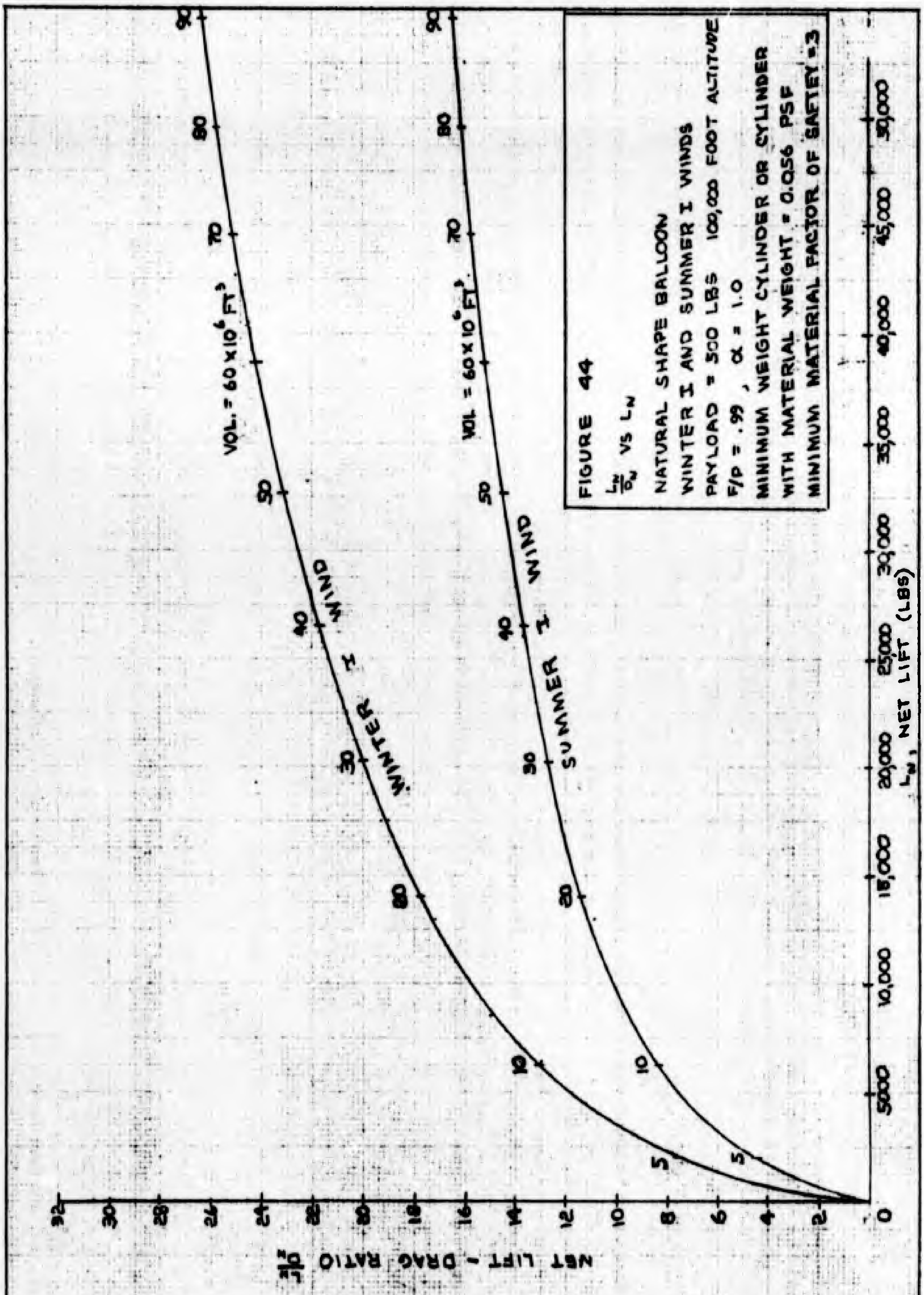


FIGURE 44
$\frac{L_N}{D_N}$ VS L_N
NATURAL SHAPE BALLOON
WINTER I AND SUMMER I WINDS
PAYLOAD = 500 LBS 100,000 FOOT ALTITUDE
F/P = .99 , α = 1.0
MINIMUM WEIGHT CYLINDER OR CYLINDER
WITH MATERIAL WEIGHT = 0.056 PSF
MINIMUM MATERIAL FACTOR OF SAFETY = 3
VOL. = 60 X 10^6 FT^3
WINTER I WIND
SUMMER I WIND
NET LIFT - DRAG RATIO $\frac{L_N}{D_N}$
L_N, NET LIFT (LBS)
0
5000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
5
10
20
30
40
50
70
80
90

An overlay of the proper curves as provided in Figures 27 and 44 indicate that a solution exists when a natural balloon of 39 x 10^6 cubic feet is provided.

A second example is provided to show the method for designing a multiple balloon system. The requirements here are:

General

Float altitude	= 100,000 feet
Wind profile	= Winter I wind
System type	= Minimum number of balloons

Cable

Material type	= Glastran cable
Factor of safety	= 2.0
Cross-section variation	= Tapered
Selection Criterion	= Not specified

Balloon

Balloon type	= Natural at float altitude
	= Class C at other altitudes
Component design	= As per Reference 1 and Appendix C
Angle of attack	= Natural balloon - not applicable
	Class C = 5 degrees

An overlay of Figures 35 and 44 will show that a 79 x 10^6 cubic foot natural balloon at float altitude provides a cable which becomes horizontal at an altitude of 20,000 feet. A single balloon this large may be considered undesirable, although its volume on the ground will be less than 1,000,000 cubic feet. Two balloons can be designed roughly 1/2 this size and placed in tandem at 90,000 and 100,000 feet if desired. A matching point obtained from Figure 45 indicates that the cable tension at this lower altitude of 20,000 feet is 17,500 pounds. Since the cable is horizontal at this point, the tension represents the total drag of the cable and balloon above. By placing another balloon at this

20,000 foot altitude, additional lift is provided. The combined drag of the upper cable and the upper balloon is then added vectorially to the lift of this lower balloon to provide a resultant vector enabling a segment of cable to reach the ground. Figures 46 and 47 (which can be obtained from Figures 29 and 38) are provided for the following factors:

General

Float altitude	=	20,000 feet
Wind profile	=	Winter I
System type	=	Second balloon of a multiple balloon system.

Cable

Material type	=	Glastran cable
Factor of safety	=	2.0
Cross-section variation	=	Tapered
Selection criterion	=	Angle at Base = 80degrees

Balloon

Balloon type	=	Class C
Component Design	=	As per Reference 1
Angle of attack	=	5 degrees

To provide a direct solution to this problem, the axes of Figures 46 and 47 are selected to be L_N and D_n. An overlay of the graphs with the cable curve shifted downward by a drag amount equal to the cable tension will provide an intersection indicating that a Class C balloon volume of 500,000 cubic feet will provide the desired solution.

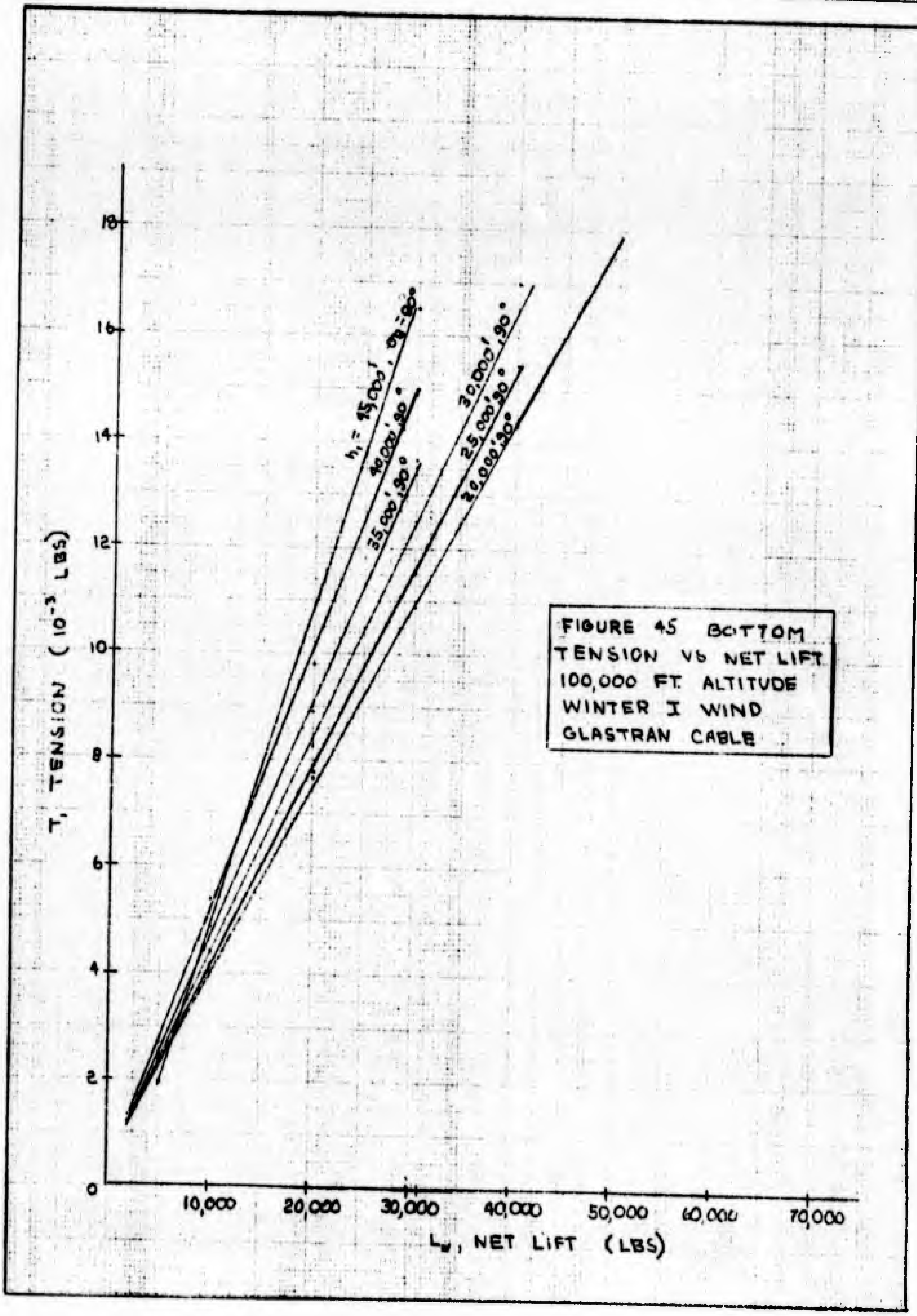


FIGURE 45 BOTTOM TENSION VS NET LIFT 100,000 FT. ALTITUDE WINTER I WIND GLASTRAN CABLE

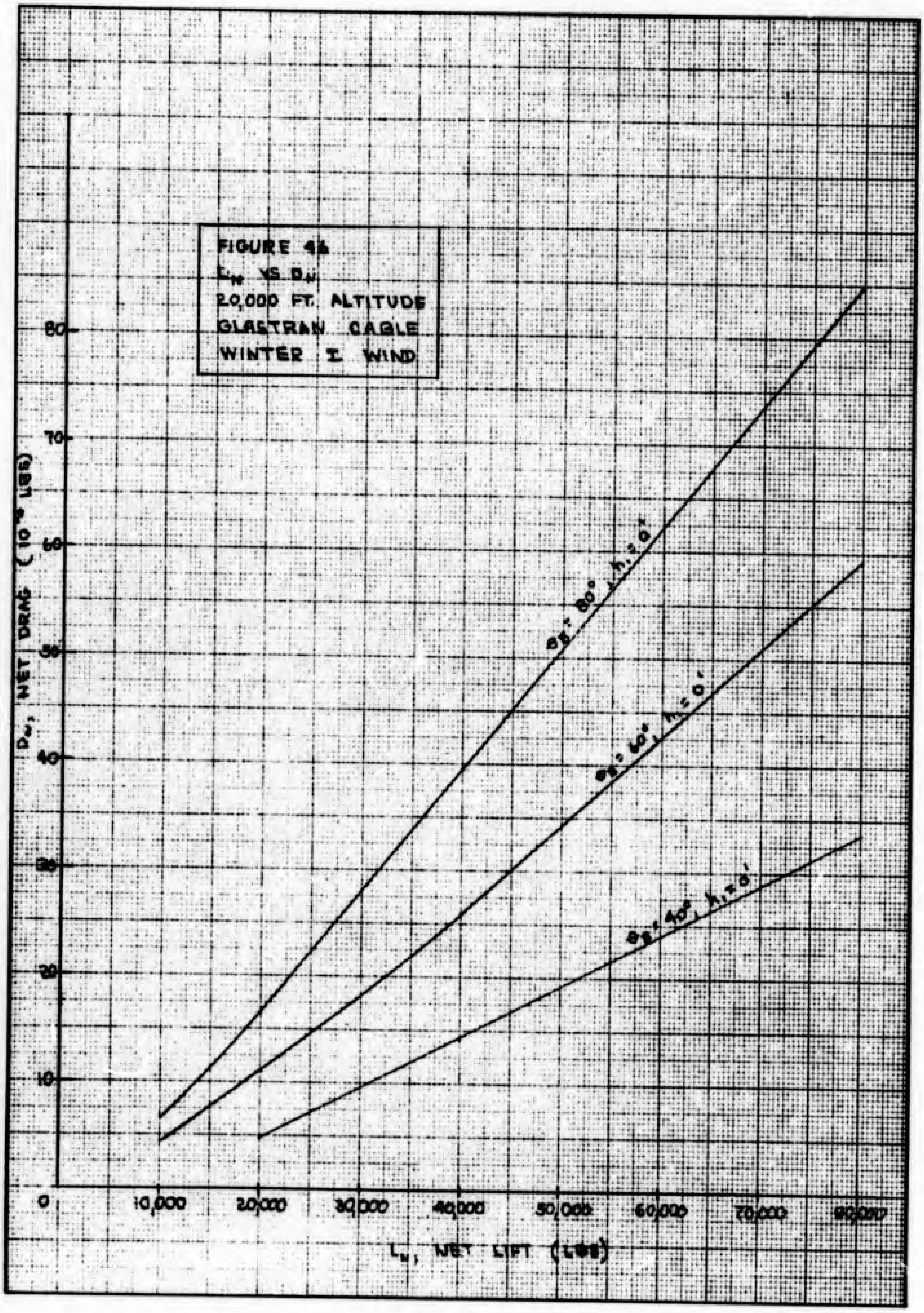


FIGURE 46
L_N VS D_N
20,000 FT. ALTITUDE
GLASTRAN CABLE
WINTER I WIND
D_N, NET DRAG (10^3 LBS)
L_N, NET LIFT (LBS)
0
10
20
30
40
50
60
70
80
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
$\theta_B = 80°$, $h_1 = 0'$
$\theta_B = 60°$, $h_1 = 0'$
$\theta_B = 40°$, $h_1 = 0'$

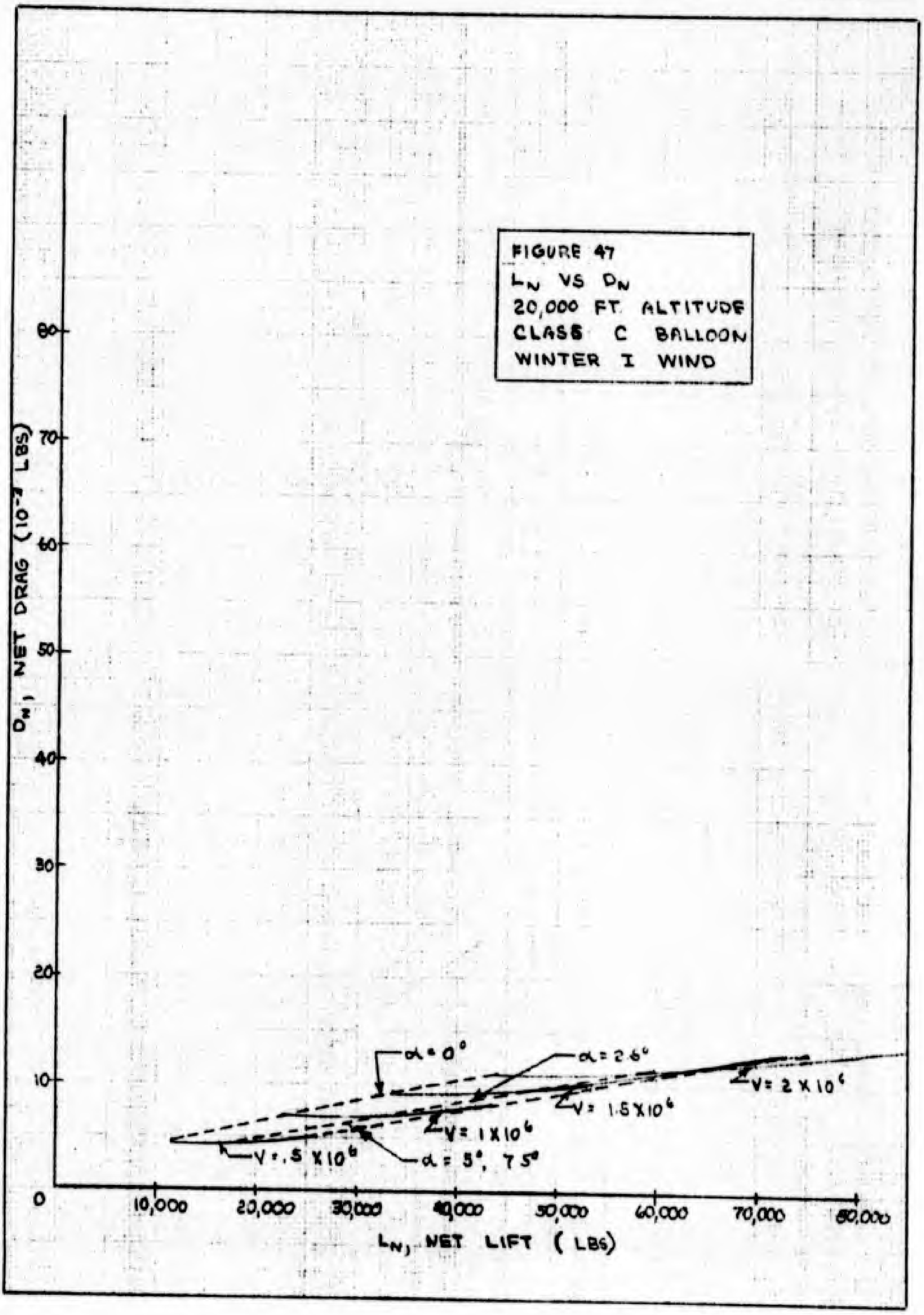


FIGURE 47
L_N VS D_N
20,000 FT. ALTITUDE
CLASS C BALLOON
WINTER I WIND
D_N, NET DRAG (10^{-3} LBS)
L_N, NET LIFT (LBS)
α = 0°
α = 2.6°
α = 5°, 7.5°
V = .5 X 10^6
V = 1 X 10^6
V = 1.5 X 10^6
V = 2 X 10^6

SECTION V - CONCLUSIONS AND RECOMMENDATIONS

Additional information has been compiled and generated which will be useful in establishing extremely high altitude tethered balloon system configurations.

Of the tether cables considered, Glastran cable has the most favorable strength to weight ratio. Limited test data indicate that it has static and dynamic fatigue characteristics comparable to or better than those for steel cables but has to be handled carefully. It is theoretically capable of being produced in tapered construction. Based on these considerations and neglecting cost factors, Glastran is suggested as the tether cable for this extremely high altitude tether application. Of the streamlined balloon configurations investigated, a single hull balloon of the Navy Class C type is the most desirable for the high altitude tether system based on the factors considered. Natural balloons are required at the extremely high altitude of 100,000 feet.

Typical tethered balloon configurations have been outlined as examples for Summer I and Winter I wind conditions (neglecting ascent and descent conditions). A single balloon system is possible for float at 100,000 feet in Summer I wind conditions but a smaller volume balloon can be used if a multiple balloon system is provided.

Winter I wind conditions require the use of multiple balloon systems for float at 100,000 feet as the only solution. In these multiple balloon systems it is very desirable to keep the lower streamlined balloon(s) below the regions of maximum wind velocity to minimize structural requirements. Volumetric change requirements are also minimized for lower altitude balloon designs.

Before feasible balloon system configurations can be suggested further work is required to investigate the ascent and descent problem analytically and to demonstrate the feasibility of the reefing technique for natural balloons by means of model tests. Dilation systems for high altitude streamlined balloons are worthy of further investigation to minimize size of balloons at sea level for ground handling.

SECTION VI - REFERENCES

1. High Altitude Tethered Balloon Systems Study. Technical Report 13260, Task Report Number 1. Goodyear Aerospace Corporation, Akron, Ohio, 10 May 1967.

2. Mechanical Testing of Glass-Epoxy and Steel Cables - Final Report. Technical Report Job No. (MRC): 2560-4 Monsanto Research Corporation, Dayton Laboratories, Dayton, Ohio, 1 October 1967.

3. Tethered Balloon Dynamic Model Testing. Technical Report GER-12969. Goodyear Aerospace Corporation, Akron, Ohio, December 1966.

APPENDIX A

CABLE PARAMETERS FOR

GLASTRAN AND ROCKET WIRE CABLES

WINTER I WIND - 100,000 FEET

A

CABLE PROFILE CHECK, GLASTRAN 11-16-67 EA623

X FEET	Y	Z FEET	THETA	PHI DEGREES	T POUNDS	LENGTH FEET	ALPHA	VELOCITY FPS	DIAMETER FEET	WEIGHT LB/FT
0.	0.	0.	180.0	177.3	49036.	0.	0.0	59.11	0.08752	0.64100
-38.	0.	-999.	180.0	177.3	48396.	1000.	-0.0	59.01	0.08694	0.63262
-77.	0.	-1998.	180.0	177.7	47764.	2000.	-0.0	58.91	0.08636	0.62436
-117.	0.	-2998.	180.0	177.7	47140.	3000.	-0.0	58.81	0.08578	0.61620
-158.	0.	-3997.	180.0	177.6	46524.	4000.	-0.0	58.71	0.08521	0.60816
-199.	0.	-4996.	180.0	177.6	45916.	5000.	-0.0	58.61	0.08465	0.60021
-240.	0.	-5995.	180.0	177.6	45317.	6000.	-0.0	58.88	0.08408	0.59237
-283.	0.	-6994.	180.0	177.5	44725.	7000.	-0.0	59.15	0.08352	0.58464
-328.	0.	-7993.	180.0	177.5	44141.	8000.	-0.0	59.42	0.08297	0.57700
-370.	0.	-8992.	180.0	177.4	43564.	9000.	-0.0	59.69	0.08242	0.56947
-414.	0.	-9991.	180.0	177.4	42995.	10000.	-0.0	59.96	0.08187	0.56203
-460.	0.	-10990.	180.0	177.4	42434.	11000.	-0.0	61.20	0.08132	0.55469
-506.	0.	-11989.	180.0	177.3	41880.	12000.	-0.0	62.44	0.08078	0.54745
-553.	0.	-12988.	180.0	177.3	41333.	13000.	-0.0	63.69	0.08024	0.54030
-601.	0.	-13987.	180.0	177.2	40793.	14000.	-0.0	64.94	0.07971	0.53325
-650.	0.	-14986.	180.0	177.1	40261.	15000.	-0.0	66.19	0.07918	0.52628
-699.	0.	-15985.	180.0	177.1	39735.	16000.	-0.0	69.40	0.07865	0.51941
-750.	0.	-16983.	180.0	177.0	39216.	17000.	-0.0	72.64	0.07813	0.51263
-802.	0.	-17982.	180.0	177.0	38705.	18000.	-0.0	75.88	0.07761	0.50594
-855.	0.	-18981.	180.0	176.9	38199.	19000.	-0.0	79.11	0.07709	0.49934
-909.	0.	-19979.	180.0	176.8	37701.	20000.	-0.0	82.35	0.07657	0.49282
-964.	0.	-20978.	180.0	176.7	37209.	21000.	-0.0	84.70	0.07606	0.48639
-1021.	0.	-21976.	180.0	176.7	36723.	22000.	-0.0	87.03	0.07556	0.48004
-1079.	0.	-22974.	180.0	176.6	36244.	23000.	-0.0	89.35	0.07505	0.47378
-1139.	0.	-23972.	180.0	176.5	35771.	24000.	-0.0	91.68	0.07455	0.46760
-1200.	0.	-24971.	180.0	176.4	35304.	25000.	-0.0	94.01	0.07405	0.46149
-1264.	0.	-25969.	180.0	176.3	34844.	26000.	-0.0	95.51	0.07356	0.45548
-1329.	0.	-26966.	180.0	176.1	34389.	27000.	-0.0	97.00	0.07307	0.44954
-1396.	0.	-27964.	180.0	176.0	33941.	28000.	-0.0	98.48	0.07258	0.44367
-1466.	0.	-28962.	180.0	175.9	33499.	29000.	-0.0	99.96	0.07210	0.43789
-1538.	0.	-29959.	180.0	175.7	33062.	30000.	-0.0	101.44	0.07162	0.43218
-1612.	0.	-30956.	180.0	175.6	32631.	31000.	-0.0	103.80	0.07114	0.42655
-1690.	0.	-31953.	180.0	175.4	32206.	32000.	-0.0	106.19	0.07066	0.42099
-1770.	0.	-32950.	180.0	175.2	31786.	33000.	-0.0	108.58	0.07019	0.41551
-1853.	0.	-33947.	180.0	175.0	31372.	34000.	-0.0	110.97	0.06972	0.41010
-1940.	0.	-34943.	180.0	174.8	30964.	35000.	-0.0	113.36	0.06926	0.40476
-2030.	0.	-35939.	180.0	174.6	30561.	36000.	-0.0	117.43	0.06879	0.39949
-2124.	0.	-36934.	180.0	174.3	30164.	37000.	-0.0	121.60	0.06833	0.39430
-2223.	0.	-37929.	180.0	174.1	29772.	38000.	-0.0	125.77	0.06788	0.38917
-2327.	0.	-38924.	180.0	173.7	29385.	39000.	-0.0	129.93	0.06743	0.38412
-2436.	0.	-39918.	180.0	173.4	29004.	40000.	-0.0	134.10	0.06698	0.37914
-2551.	0.	-40911.	180.0	173.0	28628.	41000.	-0.0	138.07	0.06653	0.37422
-2672.	0.	-41904.	180.0	172.6	28257.	42000.	-0.0	142.03	0.06609	0.36937
-2801.	0.	-42896.	180.0	172.1	27892.	43000.	-0.0	145.98	0.06565	0.36460
-2938.	0.	-43886.	180.0	171.6	27532.	44000.	-0.0	149.93	0.06521	0.35989
-3084.	0.	-44876.	180.0	171.1	27177.	45000.	-0.0	153.87	0.06478	0.35525
-3239.	0.	-45863.	180.0	170.4	26828.	46000.	-0.0	157.61	0.06435	0.35069
-3405.	0.	-46850.	180.0	169.8	26484.	47000.	-0.0	161.30	0.06393	0.34619
-3583.	0.	-47834.	180.0	169.0	26145.	48000.	-0.0	164.99	0.06351	0.34177
-3774.	0.	-48815.	180.0	168.2	25812.	49000.	-0.0	168.67	0.06309	0.33741

CABLE PROFILE CHECK, GLASTRAN 11-16-67 EA523

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
-3978.	0.	-49794.	180.0	167.3	25485.	50000.	-0.0	172.34	0.06269	0.33314
-4198.	0.	-50770.	180.0	166.4	25164.	51000.	-0.0	176.08	0.06227	0.32894
-4434.	0.	-51742.	180.0	165.3	24849.	52000.	-0.0	179.82	0.06187	0.32481
-4687.	0.	-52709.	180.0	164.2	24539.	53000.	-0.0	183.55	0.06147	0.32077
-4960.	0.	-53671.	180.0	162.9	24236.	54000.	-0.0	187.25	0.06108	0.31681
[illegible]	0.	-54627.	180.0	161.6	23960.	55000.	-0.0	[illegible]	[illegible]	[illegible]

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
[illegible]	[illegible]	-51742.	180.0	165.3	24848.	52000.	-0.0	179.82	0.06187	0.32481
-4667.	0.	-52709.	180.0	164.2	24539.	53000.	-0.0	183.55	0.06147	0.32077
-4960.	0.	-53671.	180.0	162.9	24236.	54000.	-0.0	187.25	0.06103	0.31681
-5254.	0.	-54627.	180.0	161.6	23949.	55000.	-0.0	190.93	0.06069	0.31294
-5570.	0.	-55575.	180.0	160.1	23659.	56000.	-0.0	194.61	0.06031	0.30915
-5910.	0.	-56516.	180.0	158.6	23368.	57000.	-0.0	198.26	0.05994	0.30546
-6275.	0.	-57447.	180.0	156.9	23093.	58000.	-0.0	201.88	0.05958	0.30187
-6667.	0.	-58367.	180.0	155.1	22827.	59000.	-0.0	205.45	0.05922	0.29839
-7087.	0.	-59274.	180.0	153.3	22568.	60000.	-0.0	208.97	0.05887	0.29501
-7537.	0.	-60167.	180.0	151.3	22318.	61000.	-0.0	211.78	0.05854	0.29174
-8018.	0.	-61044.	180.0	149.2	22076.	62000.	-0.0	211.69	0.05821	0.28858
-8530.	0.	-61903.	180.0	147.1	21843.	63000.	-0.0	211.60	0.05789	0.28553
-9073.	0.	-62743.	180.0	145.0	21618.	64000.	-0.0	211.52	0.05758	0.28259
-9646.	0.	-63562.	180.0	142.8	21402.	65000.	-0.0	211.43	0.05728	0.27976
-10250.	0.	-64359.	180.0	140.7	21194.	66000.	-0.0	211.35	0.05700	0.27704
-10884.	0.	-65133.	180.0	138.6	20994.	67000.	-0.0	210.87	0.05672	0.27443
-11545.	0.	-65883.	180.0	136.5	20802.	68000.	-0.0	208.54	0.05645	0.27192
-12234.	0.	-66608.	180.0	134.5	20617.	69000.	-0.0	206.29	0.05619	0.26951
-12948.	0.	-67308.	180.0	132.5	20441.	70000.	-0.0	204.11	0.05594	0.26720
-13685.	0.	-67984.	180.0	130.6	20271.	71000.	-0.0	202.01	0.05570	0.26498
-14444.	0.	-68635.	180.0	128.8	20109.	72000.	-0.0	199.99	0.05547	0.26286
-15224.	0.	-69261.	180.0	127.0	19953.	73000.	-0.0	198.05	0.05525	0.26083
-16022.	0.	-69863.	180.0	125.3	19805.	74000.	-0.0	196.17	0.05503	0.25889
-16838.	0.	-70442.	180.0	123.7	19663.	75000.	-0.0	193.23	0.05483	0.25703
-17665.	0.	-70997.	180.0	122.2	19528.	76000.	-0.0	190.06	0.05463	0.25526
-18516.	0.	-71529.	180.0	120.7	19398.	77000.	-0.0	187.02	0.05444	0.25357
-19376.	0.	-72040.	180.0	119.3	19274.	78000.	-0.0	184.10	0.05426	0.25195
-20248.	0.	-72529.	180.0	117.9	19157.	79000.	-0.0	181.31	0.05409	0.25041
-21131.	0.	-72997.	180.0	116.6	19044.	80000.	-0.0	178.64	0.05393	0.24894
-22025.	0.	-73446.	180.0	115.4	18937.	81000.	-0.0	176.08	0.05377	0.24754
-22929.	0.	-73874.	180.0	114.2	18835.	82000.	-0.0	173.63	0.05362	0.24621
-23841.	0.	-74284.	180.0	113.0	18738.	83000.	-0.0	171.29	0.05347	0.24494
-24761.	0.	-74675.	180.0	111.9	18645.	84000.	-0.0	169.06	0.05334	0.24373
-25685.	0.	-75049.	180.0	110.8	18558.	85000.	-0.0	166.90	0.05321	0.24259
-26623.	0.	-75405.	180.0	109.8	18475.	86000.	-0.0	164.63	0.05309	0.24150
-27564.	0.	-75743.	180.0	108.8	18396.	87000.	-0.0	162.56	0.05296	0.24047
-28511.	0.	-76065.	180.0	107.8	18321.	88000.	-0.0	160.55	0.05285	0.23949
-29463.	0.	-76371.	180.0	106.8	18250.	89000.	-0.0	158.64	0.05275	0.23856
-30420.	0.	-76661.	180.0	105.9	18184.	90000.	-0.0	156.83	0.05265	0.23769
-31382.	0.	-76935.	180.0	105.0	18121.	91000.	-0.0	155.11	0.05255	0.23687
-32348.	0.	-77193.	180.0	104.1	18062.	92000.	-0.0	153.50	0.05246	0.23610
-33318.	0.	-77437.	180.0	103.2	18006.	93000.	-0.0	151.98	0.05238	0.23538
-34291.	0.	-77666.	180.0	102.4	17954.	94000.	-0.0	150.55	0.05230	0.23470
-35268.	0.	-77880.	180.0	101.5	17906.	95000.	-0.0	149.21	0.05223	0.23407
-36248.	0.	-78079.	180.0	100.7	17861.	96000.	-0.0	147.96	0.05216	0.23348
-37230.	0.	-78265.	180.0	99.9	17820.	97000.	-0.0	146.80	0.05210	0.23294
-38216.	0.	-78436.	180.0	99.1	17782.	98000.	-0.0	145.73	0.05204	0.23244
-39203.	0.	-78593.	180.0	98.3	17747.	99000.	-0.0	144.75	0.05199	0.23198

B

CABLE PROFILE CHECK,GLASTRAN 11-16-67 EA623

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
-40193.	0.	-78737.	180.0	97.5	17715.	100000.	-0.0	143.85	0.05194	0.23157
-41184.	0.	-78867.	180.0	96.7	17687.	101000.	-0.0	143.04	0.05189	0.23120
-42178.	0.	-78983.	180.0	95.9	17662.	102000.	-0.0	142.31	0.05186	0.23087
-43172.	0.	-79086.	180.0	95.1	17639.	103000.	-0.0	141.67	0.05182	0.23058
-44168.	0.	-79175.	180.0	94.4	17620.	104000.	-0.0	141.11	0.05179	0.23033
-45165.	0.	-79252.	180.0	93.6	17604.	105000.	-0.0	140.64	0.05177	0.23012
-46163.	0.	-79314.	180.0	92.9	17591.	106000.	-0.0	140.24	0.05175	0.22995
-47162.	0.	-79364.	180.0	92.1	17581.	107000.	-0.0	139.93	0.05173	0.22982
-48161.	0.	-79401.	180.0	91.3	17575.	108000.	-0.0	139.70	0.05172	0.22973
-49161.	0.	-79424.	180.0	90.5	17572.	109000.	-0.0	139.56	0.05172	0.22970
-50161.	0.	-79435.	180.0	89.5	17575.	110000.	-0.0	139.49	0.05172	0.22974

CABLE IS TOO CLOSE TO HORIZONTAL

TOTAL CABLE WEIGHT = 39286.42575

TABLE A-1 GLASTRAN CABLE - WINTER I WIND - 100,000 FEET

A

CABLE PROFILE CHECK,ROCKET WIRE EA623

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
0.	0.	0.	180.0	177.8	49036.	0.	0.0	59.11	0.06073	1.00261
-38.	0.	-999.	180.0	177.7	48034.	1000.	-0.0	59.01	0.06008	0.98141
-78.	0.	-1998.	180.0	177.7	47054.	2000.	-0.0	58.91	0.05944	0.96066
-118.	0.	-2998.	180.0	177.6	46094.	3000.	-0.0	58.81	0.05881	0.94035
-159.	0.	-3997.	180.0	177.6	45154.	4000.	-0.0	58.71	0.05819	0.92047
-201.	0.	-4996.	180.0	177.5	44235.	5000.	-0.0	58.61	0.05757	0.90101
-244.	0.	-5995.	180.0	177.5	43335.	6000.	-0.0	58.88	0.05696	0.88196
-288.	0.	-6994.	180.0	177.4	42453.	7000.	-0.0	59.15	0.05635	0.86332
-333.	0.	-7993.	180.0	177.4	41591.	8000.	-0.0	59.42	0.05575	0.84507
-380.	0.	-8992.	180.0	177.3	40747.	9000.	-0.0	59.69	0.05516	0.82720
-427.	0.	-9991.	180.0	177.2	39921.	10000.	-0.0	59.96	0.05457	0.80972
-475.	0.	-10990.	180.0	177.2	39112.	11000.	-0.0	61.19	0.05399	0.79261
-525.	0.	-11989.	180.0	177.1	38320.	12000.	-0.0	62.44	0.05342	0.77586
-575.	0.	-12987.	180.0	177.0	37545.	13000.	-0.0	63.69	0.05285	0.75946
-627.	0.	-13986.	180.0	177.0	36787.	14000.	-0.0	64.94	0.05229	0.74341
-680.	0.	-14984.	180.0	176.9	36045.	15000.	-0.0	66.19	0.05174	0.72771
-735.	0.	-15983.	180.0	176.8	35318.	16000.	-0.0	69.39	0.05119	0.71233
-791.	0.	-16981.	180.0	176.7	34607.	17000.	-0.0	72.63	0.05064	0.69728
-848.	0.	-17980.	180.0	176.6	33911.	18000.	-0.0	75.87	0.05011	0.68255
-907.	0.	-18978.	180.0	176.5	33229.	19000.	-0.0	79.11	0.04957	0.66813
-967.	0.	-19976.	180.0	176.4	32563.	20000.	-0.0	82.34	0.04905	0.65402
-1029.	0.	-20974.	180.0	176.3	31910.	21000.	-0.0	84.69	0.04853	0.64021
-1093.	0.	-21972.	180.0	176.2	31271.	22000.	-0.0	87.02	0.04801	0.62669
-1159.	0.	-22970.	180.0	176.1	30646.	23000.	-0.0	89.34	0.04750	0.61346
-1226.	0.	-23968.	180.0	176.0	30034.	24000.	-0.0	91.67	0.04700	0.60051
-1296.	0.	-24965.	180.0	175.9	29435.	25000.	-0.0	93.99	0.04650	0.58784
-1367.	0.	-25963.	180.0	175.8	28848.	26000.	-0.0	95.50	0.04601	0.57543
-1442.	0.	-26960.	180.0	175.6	28275.	27000.	-0.0	96.99	0.04552	0.56329
-1518.	0.	-27957.	180.0	175.5	27713.	28000.	-0.0	98.47	0.04504	0.55141
-1597.	0.	-28954.	180.0	175.3	27164.	29000.	-0.0	99.95	0.04456	0.53978
-1679.	0.	-29951.	180.0	175.1	26626.	30000.	-0.0	101.43	0.04409	0.52840
-1764.	0.	-30947.	180.0	175.0	26099.	31000.	-0.0	103.78	0.04362	0.51726
-1851.	0.	-31943.	180.0	174.8	25584.	32000.	-0.0	106.17	0.04316	0.50636
-1942.	0.	-32939.	180.0	174.6	25080.	33000.	-0.0	108.55	0.04270	0.49569
-2036.	0.	-33935.	180.0	174.4	24587.	34000.	-0.0	110.94	0.04225	0.48525
-2134.	0.	-34930.	180.0	174.1	24104.	35000.	-0.0	113.33	0.04180	0.47504
-2236.	0.	-35924.	180.0	173.9	23632.	36000.	-0.0	117.37	0.04136	0.[illegible]504
-2343.	0.	-36919.	180.0	173.6	23169.	37000.	-0.0	121.53	0.04092	0.[illegible]527
-2453.	0.	-37913.	180.0	173.4	22717.	38000.	-0.0	125.70	0.04049	0.44570
-2569.	0.	-38906.	180.0	173.0	22275.	39000.	-0.0	129.86	0.04006	0.43634
-2690.	0.	-39899.	180.0	172.7	21842.	40000.	-0.0	134.02	0.03964	0.42718
-2817.	0.	-40890.	180.0	172.3	21419.	41000.	-0.0	137.99	0.03922	0.41822
-2951.	0.	-41881.	180.0	171.9	21005.	42000.	-0.0	141.94	0.03881	0.40947
-3092.	0.	-42872.	180.0	171.5	20600.	43000.	-0.0	145.89	0.03840	0.40090
-3240.	0.	-43860.	180.0	171.0	20204.	44000.	-0.0	149.83	0.03800	0.39253
-3397.	0.	-44843.	180.0	170.4	19818.	45000.	-0.0	153.76	0.03760	0.38434
-3564.	0.	-45834.	180.0	169.8	19440.	46000.	-0.0	157.50	0.03721	0.37634
-3740.	0.	-46818.	180.0	169.2	19070.	47000.	-0.0	161.19	0.03682	0.36853
-3927.	0.	-47801.	180.0	168.5	18710.	48000.	-0.0	164.87	0.03643	0.36090
-4127.	0.	-48781.	180.0	167.7	18358.	49000.	-0.0	168.54	0.03606	0.35345

CABLE PROFILE CHECK,ROCKET WIRE EA623

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
-4339.	0.	-49758.	180.0	166.9	18014.	50000.	-0.0	172.21	0.03568	0.34618
-4565.	0.	-50732.	180.0	166.0	17679.	51000.	-0.0	175.93	0.03532	0.33909
-4807.	0.	-51702.	180.0	165.0	17353.	52000.	-0.0	179.67	0.03495	0.33218
-5065.	0.	-52668.	180.0	164.0	17035.	53000.	-0.0	183.39	0.03460	0.32545
-5341.	0.	-53630.	180.0	162.9	16725.	54000.	-0.0	187.09	0.03425	0.31890
-5636.	0.	-54585.	180.0	161.6	16424.	55000.	-0.0	190.77	0.03391	0.31254
-5951.	0.	-55534.	180.0	160.3	16132.	56000.	-0.0	194.45	0.03357	0.30635
-6289.	0.	-56475.	180.0	158.8	15849.	57000.	-0.0	198.10	0.03324	0.30036
-6650.	0.	-57408.	180.0	157.3	15574.	58000.	-0.0	201.72	0.03292	0.29455
-7036.	0.	-58330.	180.0	155.7	15309.	59000.	-0.0	205.31	0.03260	0.28893
-7448.	0.	-59241.	180.0	153.9	15052.	60000.	-0.0	208.85	0.03229	0.28351
-7883.	0.	-60140.	180.0	152.1	14806.	61000.	-0.0	211.78	0.03199	0.27829
-8357.	0.	-61023.	180.0	150.1	14568.	62000.	-0.0	211.69	0.03170	0.27326
-8855.	0.	-61890.	180.0	148.1	14340.	63000.	-0.0	211.60	0.03142	0.26843
-9383.	0.	-62739.	180.0	146.1	14121.	64000.	-0.0	211.52	0.03115	0.26380
[illegible]	0.	-63565.	180.0	144.0	13911.	65000.	-0.0	211.43	0.03089	0.25935

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
[illegible]	0.	[illegible]	180.0	157.3	15574.	58000.	-0.0	201.72	0.03292	0.29455
-7036.	0.	-58330.	180.0	155.7	15309.	59000.	-0.0	205.31	0.03260	0.28893
-7446.	0.	-59241.	180.0	153.9	15052.	60000.	-0.0	208.85	0.03229	0.28351
-7883.	0.	-60140.	180.0	152.1	14806.	61000.	-0.0	211.78	0.03199	0.27829
-8357.	0.	-61023.	180.0	150.1	14569.	62000.	-0.0	211.69	0.03170	0.27326
-8855.	0.	-61890.	180.0	148.1	14340.	63000.	-0.0	211.60	0.03142	0.26843
-9383.	0.	-62739.	180.0	146.1	14121.	64000.	-0.0	211.52	0.03115	0.26380
-9941.	0.	-63569.	180.0	144.0	13911.	65000.	-0.0	211.43	0.03089	0.25935
-10525.	0.	-64378.	180.0	141.9	13710.	66000.	-0.0	211.35	0.03063	0.25511
-11145.	0.	-65166.	180.0	139.5	13518.	67000.	-0.0	210.77	0.03039	0.25105
-11790.	0.	-65940.	180.0	137.6	13335.	68000.	-0.0	208.40	0.03015	0.24717
-12462.	0.	-66670.	180.0	135.7	13160.	69000.	-0.0	206.10	0.02993	0.24347
-13160.	0.	-67386.	180.0	133.7	12994.	70000.	-0.0	203.87	0.02971	0.23995
-13883.	0.	-68077.	180.0	131.8	12835.	71000.	-0.0	201.72	0.02950	0.23660
-14628.	0.	-68744.	180.0	129.9	12685.	72000.	-0.0	199.65	0.02930	0.23341
-15395.	0.	-69385.	180.0	128.0	12542.	73000.	-0.0	197.66	0.02911	0.23039
-16183.	0.	-70001.	180.0	126.3	12406.	74000.	-0.0	195.74	0.02893	0.22750
-16989.	0.	-70593.	180.0	124.5	12277.	75000.	-0.0	192.36	0.02875	0.22478
-17813.	0.	-71159.	180.0	122.9	12155.	76000.	-0.0	189.13	0.02859	0.22219
-18654.	0.	-71702.	180.0	121.2	12039.	77000.	-0.0	186.03	0.02843	0.21974
-19509.	0.	-72220.	180.0	119.6	11930.	78000.	-0.0	183.09	0.02829	0.21743
-20378.	0.	-72714.	180.0	118.1	11826.	79000.	-0.0	180.25	0.02816	0.21524
-21260.	0.	-73186.	180.0	116.7	11728.	80000.	-0.0	177.56	0.02800	0.21317
-22153.	0.	-73635.	180.0	115.3	11636.	81000.	-0.0	175.00	0.02787	0.21122
-23058.	0.	-74061.	180.0	113.9	11559.	82000.	-0.0	172.56	0.02775	0.20939
-23972.	0.	-74466.	180.0	112.5	11468.	83000.	-0.0	170.25	0.02764	0.20766
-24896.	0.	-74849.	180.0	111.2	11391.	84000.	-0.0	168.07	0.02753	0.20604
-25828.	0.	-75211.	180.0	110.0	11319.	85000.	-0.0	165.89	0.02743	0.20452
-26766.	0.	-75553.	180.0	108.7	11252.	86000.	-0.0	163.75	0.02733	0.20310
-27715.	0.	-75873.	180.0	107.5	11190.	87000.	-0.0	161.75	0.02724	0.20177
-28669.	0.	-76174.	180.0	106.3	11131.	88000.	-0.0	159.[illegible]7	0.02716	0.20054
-29623.	0.	-76455.	180.0	105.1	11077.	89000.	-0.0	158.12	0.02708	0.19940
-30594.	0.	-76716.	180.0	104.0	11028.	90000.	-0.0	156.48	0.02701	0.19834
-31564.	0.	-76957.	180.0	102.9	10982.	91000.	-0.0	154.97	0.02694	0.19737
-32539.	0.	-77180.	180.0	101.7	10940.	92000.	-0.0	153.58	0.02689	0.19649
-33518.	0.	-77383.	180.0	100.6	10902.	93000.	-0.0	152.31	0.02683	0.19569
-34501.	0.	-77568.	180.0	99.6	10869.	94000.	-0.0	151.16	0.02678	0.19496
-35487.	0.	-77734.	180.0	98.5	10837.	95000.	-0.0	150.12	0.02673	0.19432
-36476.	0.	-77882.	180.0	97.4	10810.	96000.	-0.0	149.26	0.02670	0.19375
-37468.	0.	-78011.	180.0	96.4	10787.	97000.	-0.0	148.39	0.02666	0.19326
-38462.	0.	-78122.	180.0	95.3	10768.	98000.	-0.0	147.70	0.02663	0.19284
-39457.	0.	-78214.	180.0	94.3	10752.	99000.	-0.0	147.12	0.02661	0.19250

CABLE PROFILE CHECK,ROCKET - [illegible]

EA623

X	Y	Z	THETA	PHI	T	LENGTH	ALPHA	VELOCITY	DIAMETER	WEIGHT
-40455.	0.	-78289.	180.0	93.2	10739.	100000.	-0.0	146.65	0.02659	0.19223
-41453.	0.	-78345.	180.0	92.2	10730.	101000.	-0.0	146.30	0.02658	0.19205
-42452.	0.	-78384.	180.0	91.2	10724.	102000.	-0.0	146.06	0.02657	0.19192
-43452.	0.	-78405.	180.0	90.2	10721.	103000.	-0.0	145.93	0.02655	0.19186
-44452.	0.	-78403.	180.0	89.1	10722.	104000.	-0.0	145.91	0.02657	0.19189

CABLE IS TOO CLOSE TO HORIZONTAL

TOTAL CABLE WEIGHT = 43477.36719

CABLE DIAM	NO. OF FEET	UNIT WEIGHT/1000'	TOTAL WEIGHT
.0625' (3/4")	5000	1068	5340
.0573' (11/16")	9,000	894	8050
.0520' (5/8")	10,000	741	7410
.0468' (9/16")	11,000	598	6570
.0416' (1/2")	13,000	476	6200
.0364' (7/16")	15,000	363	5450
.0312 (3/8")	41,000	267	10,950
			49,970

TABLE A-2 ROCKET WIRE - WINTER I WIND - 100,000 FEET

APPENDIX B

WIND TUNNEL TESTS OF NATURAL SHAPED BALLOON MODEL

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION B-I - INTRODUCTION

Wind tunnel testing of a model of the natural-shaped balloon was performed during the week of 18 September 1967, at NASA Ames, in fulfillment of the High Altitude Tethered Balloon Systems Study with the Air Force Cambridge Research Laboratory (Contract F19628-67-C-0145). Lift, pitching moment, drag and surface pressure data were obtained for a Reynolds number range of 450,000 to 12 million. The data is presented and discussed in the following sections.

SECTION B-II - APPARATUS AND TEST PROCEDURE

A. WIND TUNNEL AND EQUIPMENT

The experimental data were obtained in the Ames 12 foot pressure tunnel which is a closed circuit, variable density wind tunnel that operates at subsonic speeds. The internal stagnation pressure can be varied from 2.5 to 75 pounds per square inch absolute. A maximum Reynolds number of 9.5 million per foot can be obtained. A more detailed description of the facility can be found in Reference B1.

The model was sting mounted and the forces and moments were measured with an internal six component balance. A dangleometer mounted internally was used to measure the model angle of attack. Recording of the pressure data was facilitated through the use of a 48 port scanning valve. Figure B0 is a rear view of the model mounted on the sting.

B. MODEL DESCRIPTION

The wind tunnel model (Figure B1) consisted of a 1/8 inch thick shell with an internal platform and balance housing for sting attachment and equipment mounting. The natural balloon model represents a shape with top loading F/p = 0, superpressure parameter α = .9315 and Σ = .0315. The shell was spun from 6061-T6 aluminum in two sections to permit access to the interior. During the test, the two halves were bolted together as shown in Figure B2. The screw heads were filled in with model wax to maintain a smooth surface. Pertinent details and dimensions of the model surface are presented in Table B1. Measured coordinates were found to be within ±0.03 inch of the computer, or theoretical coordinates.

Forty-three pressure taps were positioned on the model surface as shown in Figure B3 to obtain the surface pressure distribution. Note in Figure B3 that the taps are located on one side of the model only. Since the flow is symmetrical in the horizontal plane, the pressure distribution on both sides of the model is the same. Hence, the pressures on one side only need be measured. Table BII presents the angular coordinates of the model orifices.

Photographs of the model are reproduced as Figures B4 and B5. The pressure taps and 2 inch diameter hole for sting mounting are clearly shown in the model assembled view of Figure B4. Figure B5 presents an interior view of the model. The balance housing and adapter kit for the small balance have been removed from the interior platform and placed in front of the model. Note the plastic tubing used for pressure measurements.

C. TESTS AND PROCEDURE

Lift, drag, pitching moment and pressure data were obtained at Reynolds numbers, based on the maximum model diameter (1.5 feet), of 0.45, 0.53, 0.78, 1.05, 5.00 and 12.00 million at a constant Mach number of 0.29. A six degree nose up bent sting was used so that the angle of attack scan was from -4 to +24 degrees. Inverting the model thus permitted an angle of attack range from -24 to +24 degrees.

A 1.5 inch diameter balance was used to measure the forces and moments at Reynolds numbers from 1 to 12 million. A smaller, 0.75 inch diameter balance was used for Reynolds numbers of and below 1 million. This was necessary since the larger balance, which allows drag measurements to 300 pounds, is inaccurate in the lower Reynolds number regime; i.e., at lower drag levels. The smaller balance, which has a capacity of 50 pounds, was limited to Reynolds numbers below 1 million.

D. REDUCTION OF DATA

Force and moment data presented herein have been reduced to standard coefficient form, or

$$C_D' = \frac{\text{Drag}}{q\,\forall^{2/3}} \quad (1)$$

$$C_L' = \frac{\text{Lift}}{q\,\forall^{2/3}} \quad (2)$$

$$C_m = \frac{\text{Pitching Moment}}{q\,\forall} \quad (3)$$

In the equations, q is the free stream dynamic pressure in pounds per square foot, $\forall$ is the model volume (1.275 ft^3) and $\forall^{2/3}$ is the reference area (1.176 ft^2). The reference axes are wind (stability) axes and the moment center is the balloon tether point. Figure B6 illustrates the sign convention employed and locates the model moment center.

Since a portion of the model surface was removed to allow attachment to the sting, it was necessary to apply a base pressure and internal pressure correction to the lift and drag. The axial force coefficient may be written as

$$C_x = C_x' + C_{p_{internal}}\left[\frac{\pi d^2_{hole}}{4\,\forall^{2/3}}\right] - C_{p_{local}}\left[\frac{\pi d^2_{hole}}{4\,\forall^{2/3}}\right]$$

$$= C_x' + (C_{p_{internal}} - C_{p_{local}})\frac{\pi d^2_{hole}}{4}\left(\frac{1}{\forall^{2/3}}\right) \quad (4)$$

With this pressure correction, equations (1) and (2) may be written as

$$C_D = C_D' + (C_{p_{internal}} - C_{p_{local}})\frac{\pi d^2_{hole}}{4}\left(\frac{1}{\forall^{2/3}}\right)\cos\alpha_{model} \quad (5)$$

$$C_L = C_L' - (C_{p_{internal}} - C_{p_{local}}) \frac{\pi d^2_{hole}}{4} \left(\frac{1}{V^{2/3}}\right) \sin \alpha_{model} \quad (6)$$

Pressure coefficients were reduced to standard coefficient form as

$$C_p = \frac{p_{port} - p_{static}}{q} \quad (7)$$

SECTION B-III - RESULTS AND DISCUSSION

Lift, moment, and drag data are plotted in coefficient form against angle of attack in Figures B7 through B22. A sample pressure distribution for a Reynolds number of 0.45 million is shown in Figure B23. The force and pressure data are tabulated in coefficient form (Tables BIV and BV) at the end of this report. For brevity, repeat runs are not included. The complete set of data can be found in Reference B2.

A. LIFT

In general, at all Reynolds numbers, the lift curves (Figures B7 - B11) exhibit a common trend with angle of attack. Zero lift occurs at some negative angle of attack while positive lift exists at zero angle of attack for Reynolds numbers to 1 million. For a Reynolds number of 12 million (Figure B11), the model exhibits negative lift at zero angle of attack; however, the slope through zero angle of attack is still positive. The model generally stalled at some angle of attack. An exception to each of these trends occurs at a Reynolds number of 5 million (Figure B10). In this case, the data points are quite scattered, not showing any continuous pattern. It is thought that this scatter is the result of unsteady flow at this condition. The fact that severe buffeting of the model was observed at a Reynolds number of 5 million lends support to this conclusion.

B. PITCHING MOMENT

Aerodynamic pitching moment data about the model tether point are plotted in Figures B12 - B16. At each Reynolds number, the model exhibits a negative pitching moment at zero angle of attack. Zero pitching moment occurs at some positive angle of attack, generally between 5 and 15 degrees; however, this trim condition is an unstable one since the slope of the moment curve is positive.

Again, there is some scatter of data at a Reynolds number of 5 million (Figure B15), although not so severe as the lift data at the same condition. The slope of the moment curve at negative angles of attack for the 5 million Reynolds number condition is definitely negative; whereas, the moment curves for the other Reynolds numbers flatten out or become slightly positive in slope at negative angles of attack.

C. DRAG

The drag data are plotted in coefficient form against angle of attack in Figures B17 - B21. The model generally exhibits increasing drag below zero degrees angle of attack. Between 0 and 10 degrees angle of attack, the drag decreases suddenly, then slowly increases with increasing angle of attack.

Figure B22 is a plot of drag coefficient at zero degrees angle of attack as a function of Reynolds number. Also plotted in Figure 22 is an average drag curve for a sphere[B3] in still air (zero turbulence). A direct comparison between the sphere and balloon drag can be made since the turbulence level in the 12 foot pressure wind tunnel is considered zero by the tunnel operators. Examination of the experimental data reveals that the drag of the natural shaped balloon is somewhat higher than that of the sphere. In particular, the drag of the balloon model increases in the supercritical region (Reynolds number greater than 1 million); whereas, the sphere drag curve flattens out. At the higher Reynolds numbers, however, the sphere drag curve is an extrapolation recommended by Hoerner[B4] and not based on experimental data. A comparison of the two curves in this region is therefore meaningless.

The critical Reynolds number region, defined as that region of Reynolds numbers where a radical decrease in drag coefficient occurs, is apparently larger than the corresponding region for a sphere. No data was obtained for Reynolds numbers below 440,000 hence the beginning of the critical region is not defined for the balloon.

D. PRESSURE DISTRIBUTION

The computer printout of the pressure data is presented in Table BV at the end of the report. The output format is defined in Table BIII. Figure B23 is a sample pressure distribution in the $\phi = 0$ plane of the model at zero degrees angle of attack. Note that the surface pressure is less than that of the tunnel static pressure except for a small area at the front of the model.

SECTION B-IV - CONCLUDING REMARKS

Results of a wind tunnel investigation to determine the effects of Reynolds number and angle of attack on the lift, pitching moment, drag, and surface pressure distribution of the natural shaped balloon indicate the following:

1. Positive lift exists at zero degrees angle of attack for Reynolds numbers to 1 million; negative lift exists at higher Reynolds numbers.
2. A form of stall occurs at a positive angle of attack generally less than 10 degrees.
3. An unstable trim point occurs between 5 and 15 degrees angle of attack.
4. The drag at zero degrees angle of attack is greater than that of a sphere at the same Reynolds number.

SECTION B-V - LIST OF SYMBOLS

C_D	drag coefficient	$\frac{\text{drag}}{q\,\mathcal{V}^{2/3}}$
C_L	lift coefficient	$\frac{\text{lift}}{q\,\mathcal{V}^{2/3}}$
C_m	pitching moment coefficient about tether point	$\frac{\text{moment}}{q\,\mathcal{V}}$
C_p	pressure coefficient	$\frac{p_{port} - p_{static}}{q}$
$C_{p_{internal}}$	pressure coefficient measured inside the balloon shell	
$C_{p_{local}}$	pressure coefficient measured in the area of the sting opening	
C_x	axial force coefficient	$\frac{\text{axial force}}{q\,\mathcal{V}^{2/3}}$
M	free stream Mach number	
p_{port}	static pressure at a particular orifice	lb/ft^2
p_{static}	free stream static pressure	lb/ft^2
q	dynamic pressure	$1/2\,\rho U^2 (lb/ft^2)$
R	Reynolds number based on maximum model diameter of 1.5 ft	
U	free stream velocity	ft/sec
$\mathcal{V}$	model volume	ft^3
$\mathcal{V}^{2/3}$	reference area	ft^2
ρ	free stream density	$slugs/ft^3$
α	model angle of attack	degrees

SECTION B-VI - LIST OF REFERENCES

B1. NACA: Characteristics of Six Research Wind Tunnels of the Ames Aeronautical Laboratory, 1957.

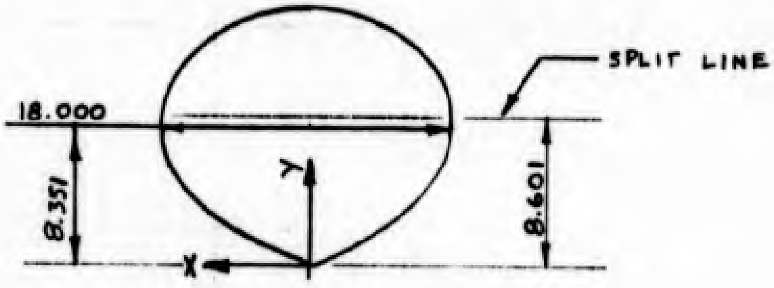
B2. Magnetic Tape, Reel No. 12-310-R1 (560)(CYF). Preliminary Results of a Wind Tunnel Test of the Natural Shaped Balloon. (Test No. 12-310)(AF-AM-805). Received: November 17, 1967.

B3. D'allura, J. D.: Aerodynamic Characteristics of Spheres and Hemispheres at Subsonic Speeds for Radome Application, GAC GER-8159, April 1957.

B4. Hoerner, S. F.: Aerodynamic Drag, the Otterbein Press, May 1951.

TABLE B I. - MODEL COORDINATES

(ALL DIMENSIONS ARE INCHES)



X	Y	X	Y	X	Y
0.000	0.000	4.990	2.285	8.687	6.554
0.244	0.093	5.210	2.426	8.766	6.803
0.489	0.188	5.428	2.572	8.834	7.056
0.733	0.282	5.642	2.722	8.891	7.311
0.977	0.377	5.853	2.877	8.937	7.569
1.220	0.473	6.061	3.037	8.970	7.829
1.464	0.570	6.264	3.202	8.991	8.090
1.706	0.668	6.463	3.372	9,000	8.351
1.948	0.768	6.658	3.547	8.996	8.613
2.190	0.869	6.847	3.728	8.980	8.874
2.431	0.972	7.031	3.914	8.951	9.134
2.670	1.077	7.210	4.105	8.909	9.393
2.909	1.184	7.382	4.304	8.854	9.649
3.147	1.294	7.708	4.712	8.786	9.902
3.383	1.406	7.860	4.925	8.706	10.151
3.618	1.521	8.004	5.143	8.614	10.396
3.852	1.640	8.141	5.367	8.509	10.636
4.084	1.761	8.269	5.595	8.392	10.870
4.313	1.887	8.388	5.828	8.264	11.098
4.541	2.016	8.497	6.066	8.125	11.320
4.767	2.148	8.597	6.308	7.975	11.535

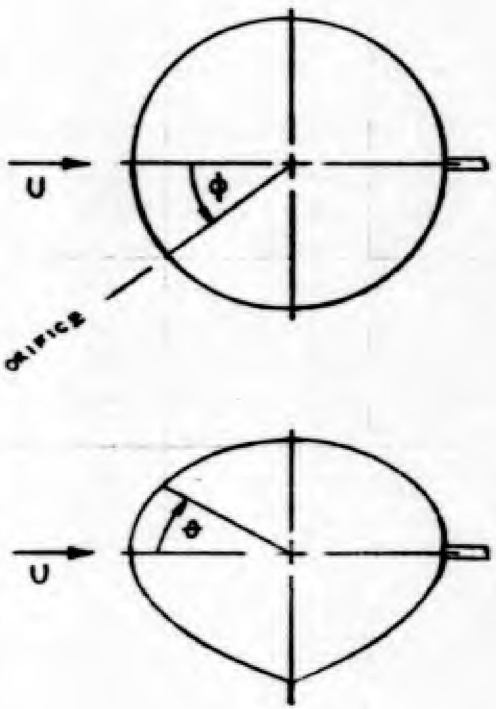
TABLE BI CONTINUED . . .

X	Y
7.815	11.742
7.645	11.941
7.466	12.132
7.278	12.314
7.082	12.488
6.879	12.652
6.668	12.808
6.451	12.954
6.229	13.092
6.000	13.220
5.768	13.339

X	Y
5.530	13.450
5.289	13.551
5.045	13.645
4.797	13.730
4.547	13.807
4.295	13.877
4.040	13.939
3.785	13.995
3.527	14.044
3.269	14.087
3.010	14.124

X	Y
2.750	14.157
2.490	14.184
2.229	14.207
1.968	14.226
1.707	14.241
1.445	14.254
1.184	14.264
0.922	14.272
0.660	14.278
0.399	14.283
0.137	14.288

TABLE BII. - POLAR COORDINATES OF PRESSURE TAPS



θ / ϕ	-88°	-66.4°	-60°	-40°	-30.8°	-19.6°	-6.6°	0°	19.6°	40°	51.5°	57.3°	90°
0°	2	3		4		5		6	7	8		9	10
30°		16		17		18		19	20	21		22	10
60°		23		26		27		28	29	30		31	10
90°			32		33			34	35		36		10
120°			37		38			39	40		41		10
150°			42		43			44	45		46		10
180°			15		14		13		12		11		10

TABLE B III. - PRESSURE DATA OUTPUT FORMAT

HEADER

ITEM	LISTING	TUNNEL-TEST IDENTIFICATION	RUN	ORIENTATION*	q	M	α	R
DIGITS	X	XXXXXX	X	XXXX	XXX.X	X.XXX	XX.XX	XX.XX
LINE	1	1	1	1	1	1	1	1

BODY

PRINTED TITLE	ORIFICE NO.	DIGITS	LINE
C_p	2 - 12	X.XXX	2
	12 - 23	X.XXX	3
	26 - 35	X.XXX	4
	36 - 47	X.XXX	5

* ORIENTATION CODE - 0001 : NORMAL
0002 : INVERTED

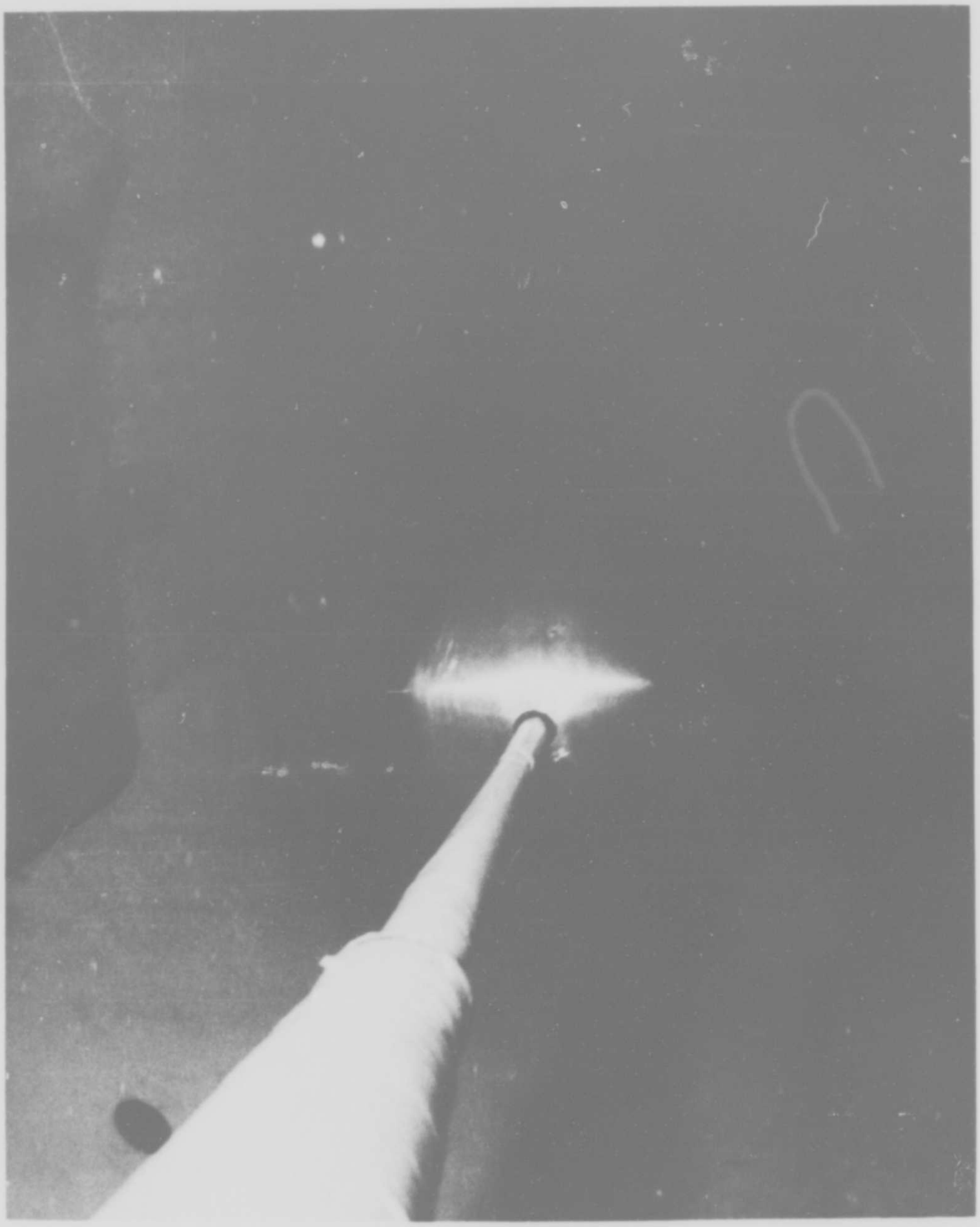
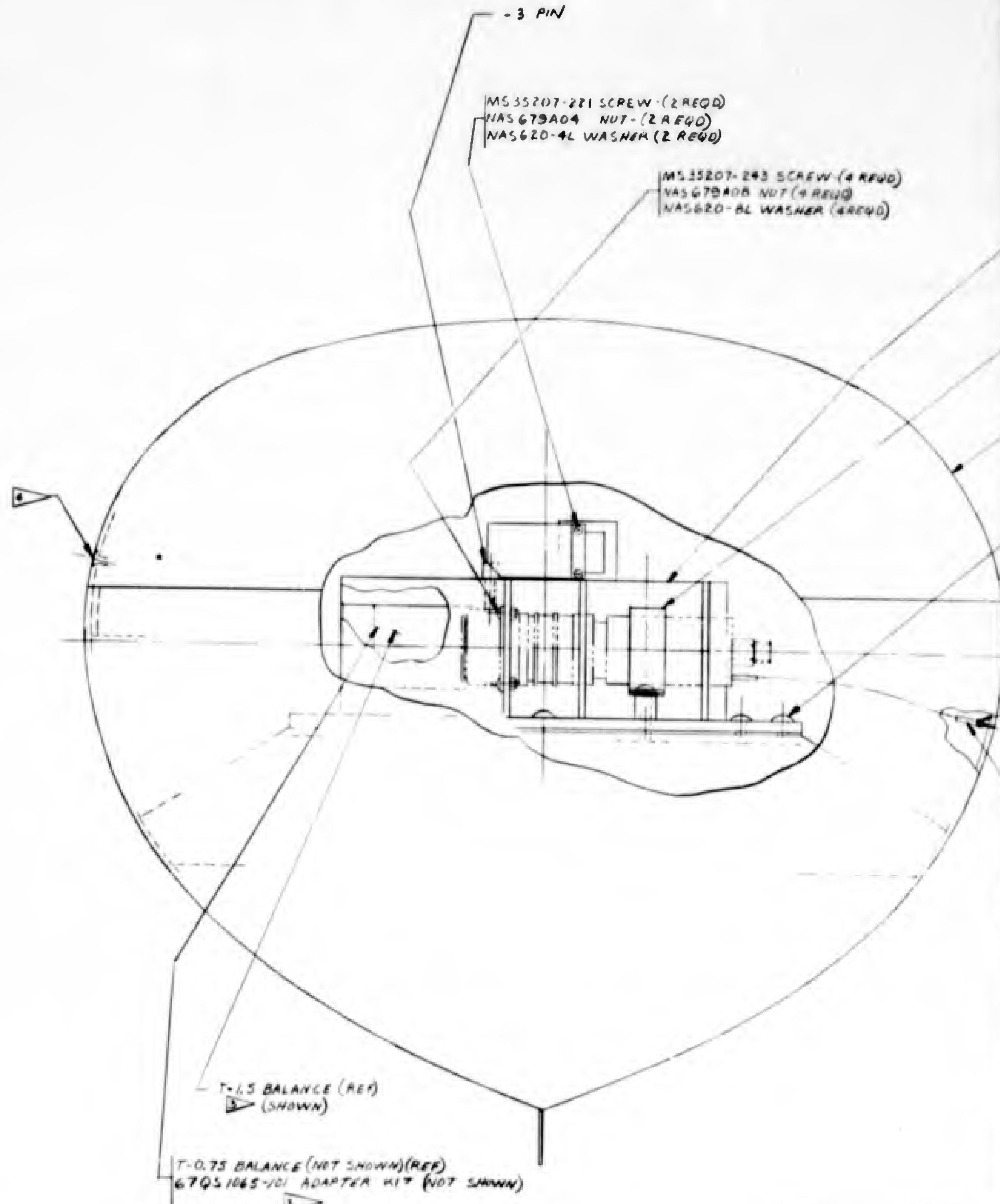


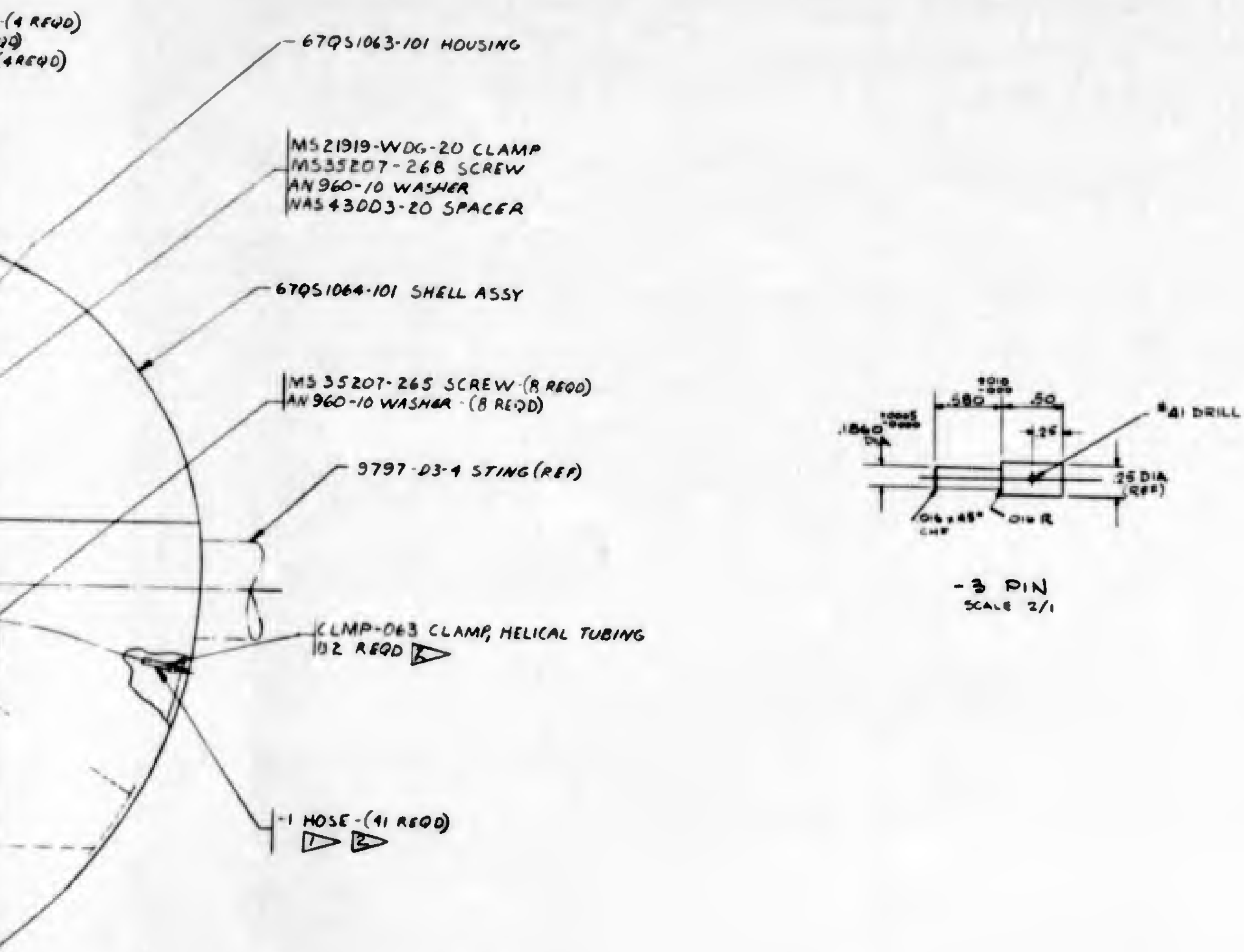
FIGURE B0 - REAR VIEW OF MODEL, LOOKING UPSTREAM



NOTES: UNLESS OTHERWISE S

1. IDENTIFY HOSES WITH
2. SCANIVALVE CO. 631 30
3. THE T 1.5 BALANCE IS
T-0.75 BALANCE & 670S
-103 ASSEMBLY WHIC
4. AFTER ASSEMBLY THE
COVERED WITH A FILLE

A



NLESS OTHERWISE SPECIFIED
ENTIFY HOSES WITH IDENTIFYING NUMBER ON SHELL.
ANIVALVE CO, 631 30TH STREET, SAN DIEGO, CALIF. 92102
E T-25 BALANCE IS USED WITH -101. ASSY AS SHOWN, THE
275 BALANCE & 67QS1065-101 ADAPTER KIT IS USED WITH
03 ASSEMBLY WHICH IS NOT SHOWN
TER ASSEMBLY, THE HEADS OF ALL SCREWS ARE TO BE
VERED WITH A FILLER AND BLENDED WITH THE SURFACE.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES ON: DECIMALS .X ± .1, .XX ± .04, .XXX ± .010; ANGLES ± 1°
MATERIAL:
SEE GR60-3-60 FOR DRAWING INTERPRETATION STANDARDS.
CONTR / WTS / STRESS / ENGR / CHECK / DRAWN / GAC APPROVAL / CUSTOMER APPROVAL

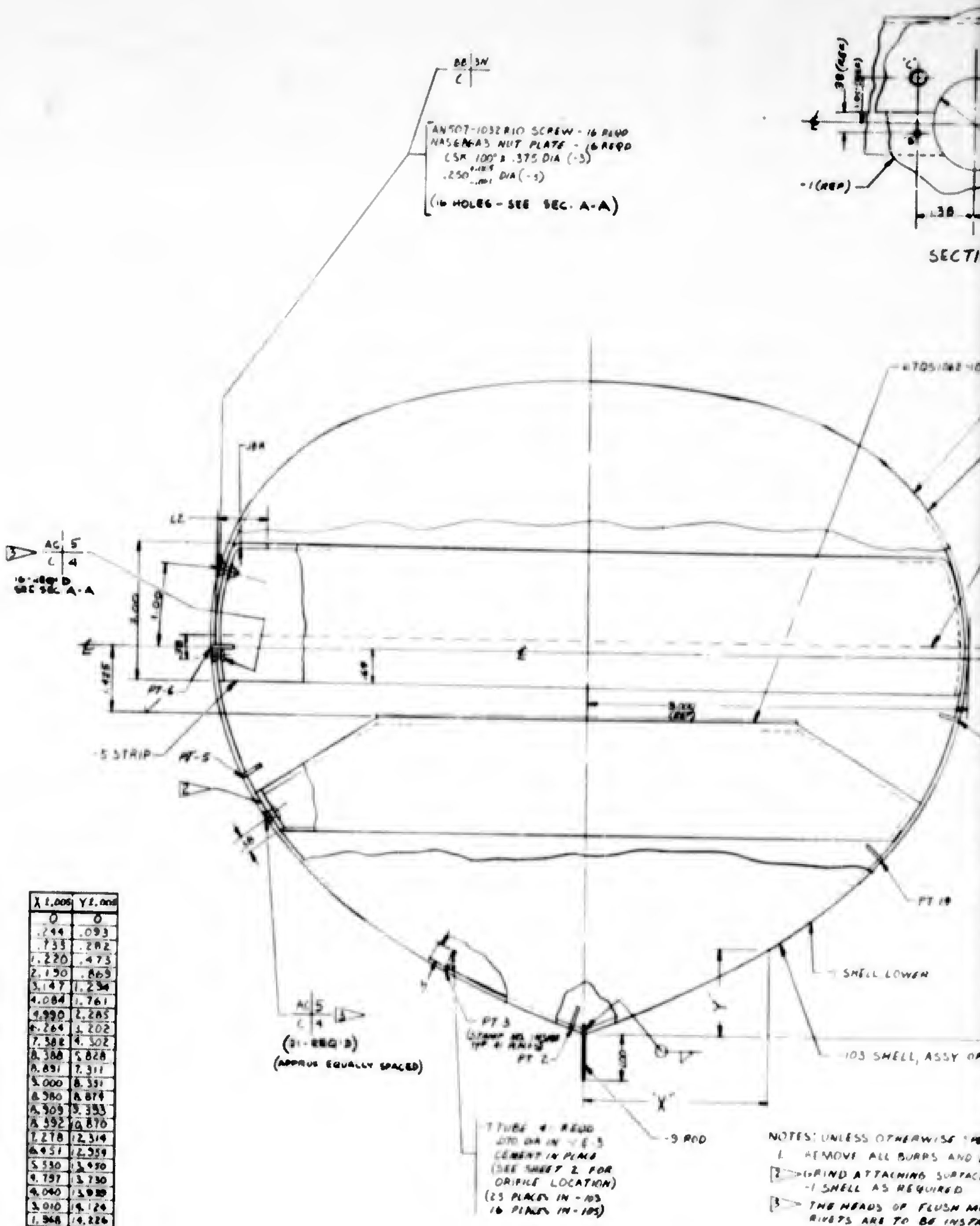
GOODYEAR AEROSPACE CORP
AKRON, OHIO

MODEL, BALLOON
WIND TUNNEL

SIZE E | CODE IDENT NO. 25500 | DRAWING NO. 67QS1066
SCALE 1/1 | SHEET 1 OF 1

FIGURE BI - WIND TUNNEL MODEL

B



X ±.005	Y ±.005
0	0
.244	.093
.735	.282
1.220	.473
2.190	.869
3.147	1.234
4.084	1.761
4.990	2.285
6.264	3.202
7.388	4.302
8.388	5.828
8.891	7.311
9.000	8.351
8.980	8.874
8.909	9.353
8.592	10.870
7.278	12.314
6.451	12.959
5.530	13.450
4.797	13.730
4.040	13.920
3.010	14.126
1.968	14.226
.922	14.272
.137	14.283

A

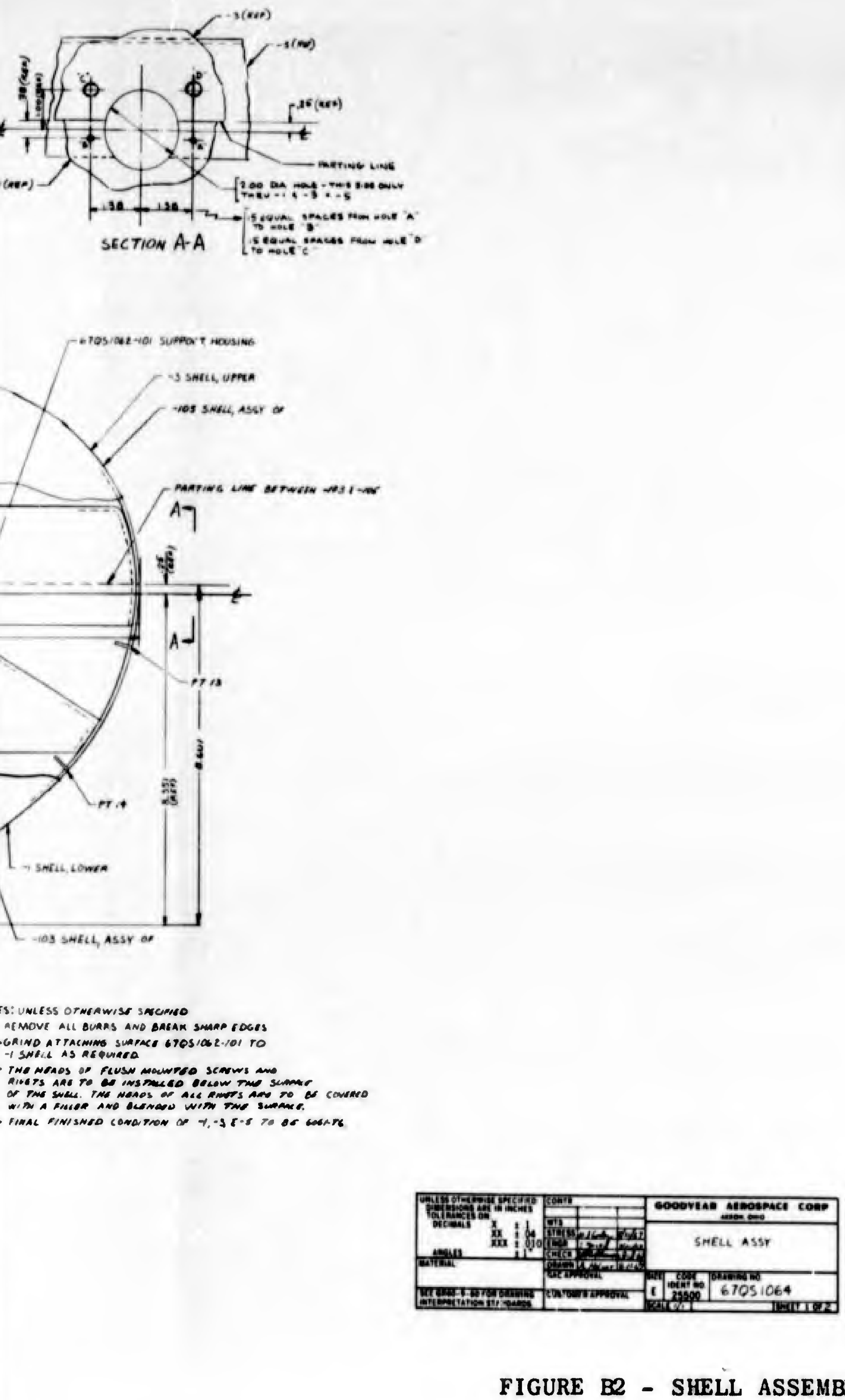
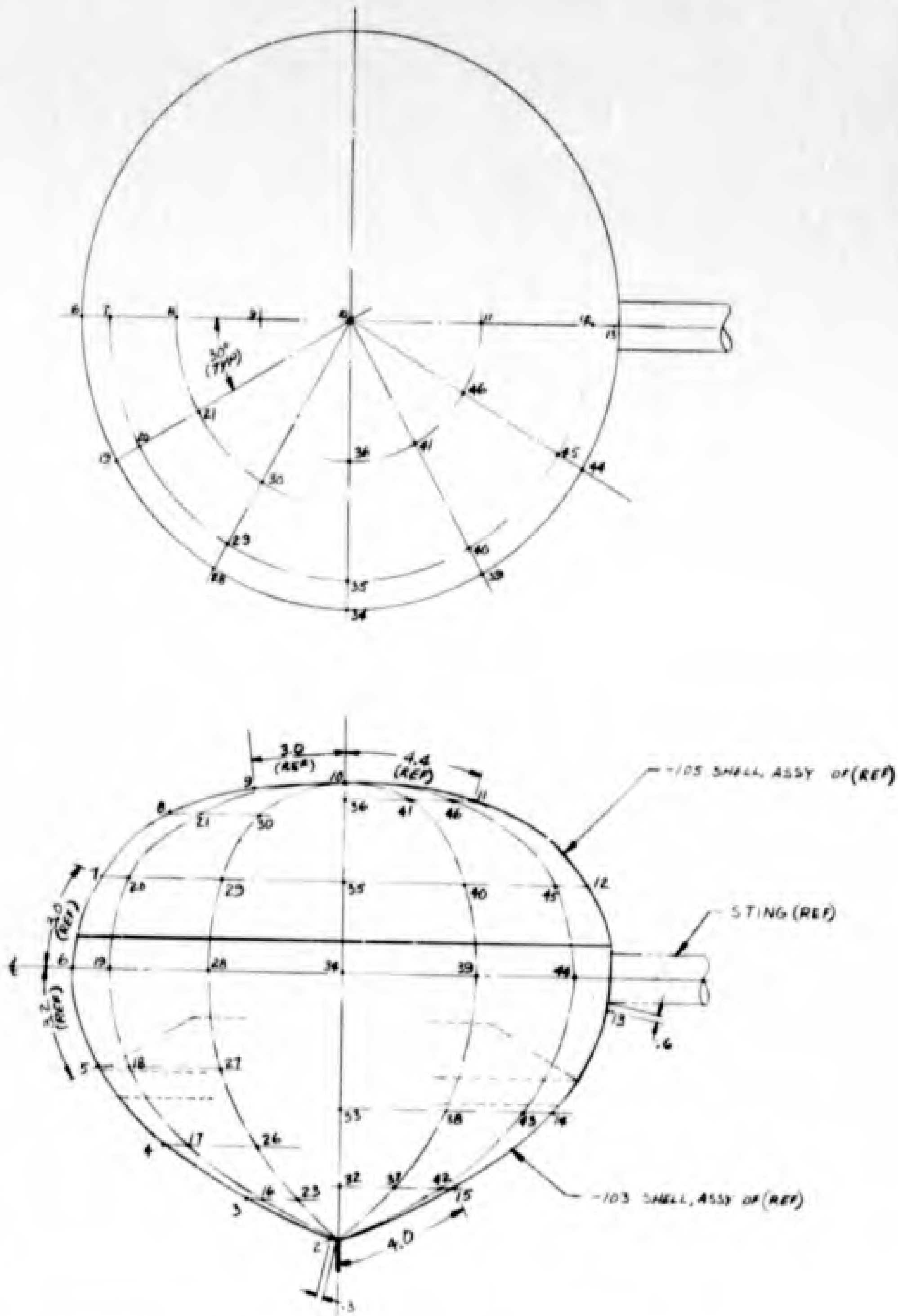


FIGURE B2 - SHELL ASSEMBLY

B



POINTS	DISTANCE BETWEEN POINTS
10-9	3.0
9-8	3.0
8-7	3.0
6-5	3.2
5-4	3.2
4-3	3.2
10-11	4.4
11-12	4.4
15-14	4.0
10-21	6.0
21-20	3.0
19-18	3.2
18-17	3.2
17-16	3.2
10-46	4.4
46-45	4.4
42-43	4.0
10-30	6.0
30-29	3.0
28-27	3.2
27-26	3.2
26-25	3.2
10-41	4.4
41-40	4.4
37-38	4.0
10-36	4.4
36-35	4.4
32-33	4.0

LOCATION OF EXTERNAL PRESSURE ORIFICES
SCALE 1/2

SIZE	CODE IDENT NO	DRAWING NO
E	25500	670S1064
SCALE 1/1		SHEET 2 OF 2

FIGURE B3 - LOCATION OF EXTERNAL PRESSURE ORIFICES

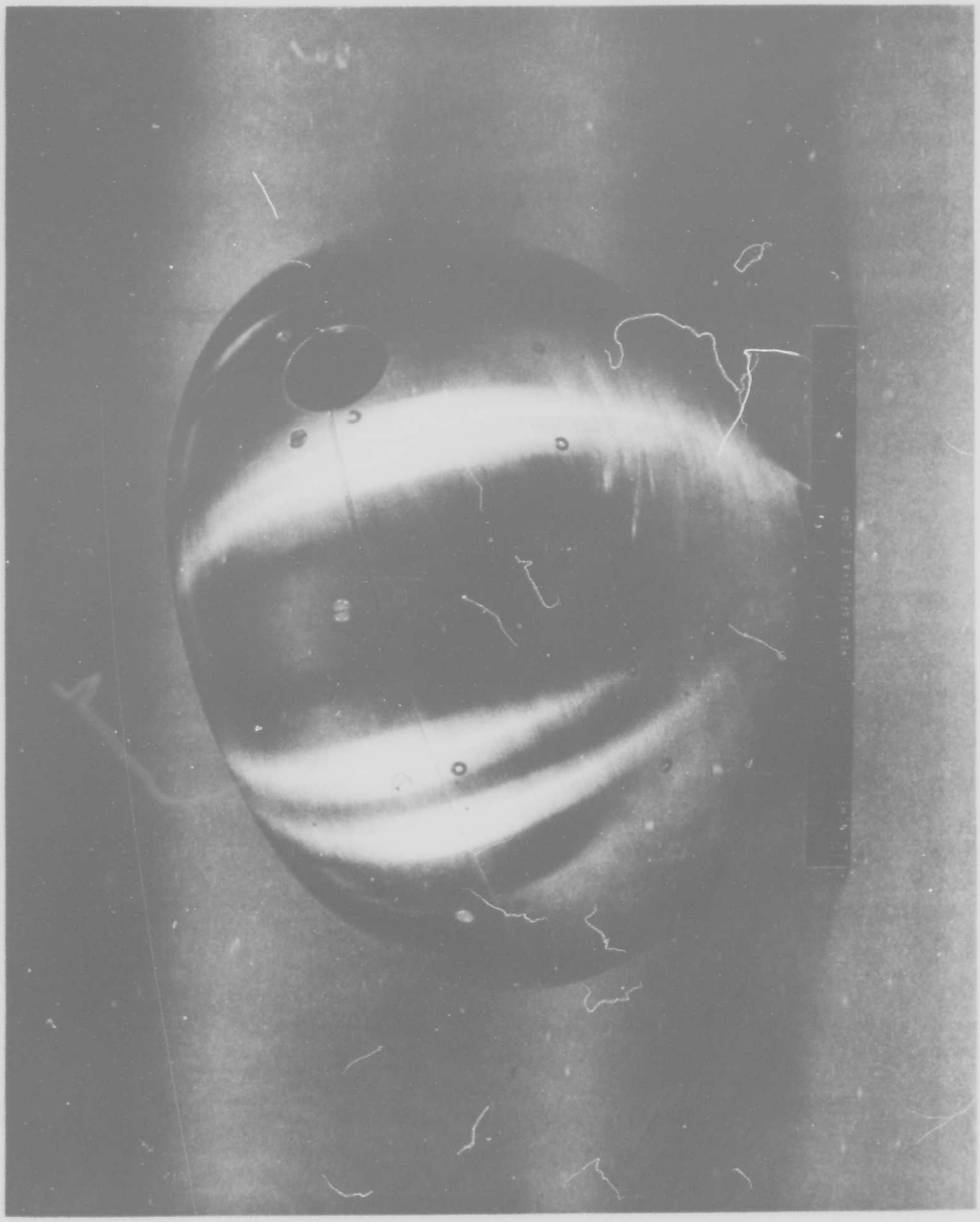


FIGURE B4 - PHOTOGRAPH OF MODEL - ASSEMBLED VIEW

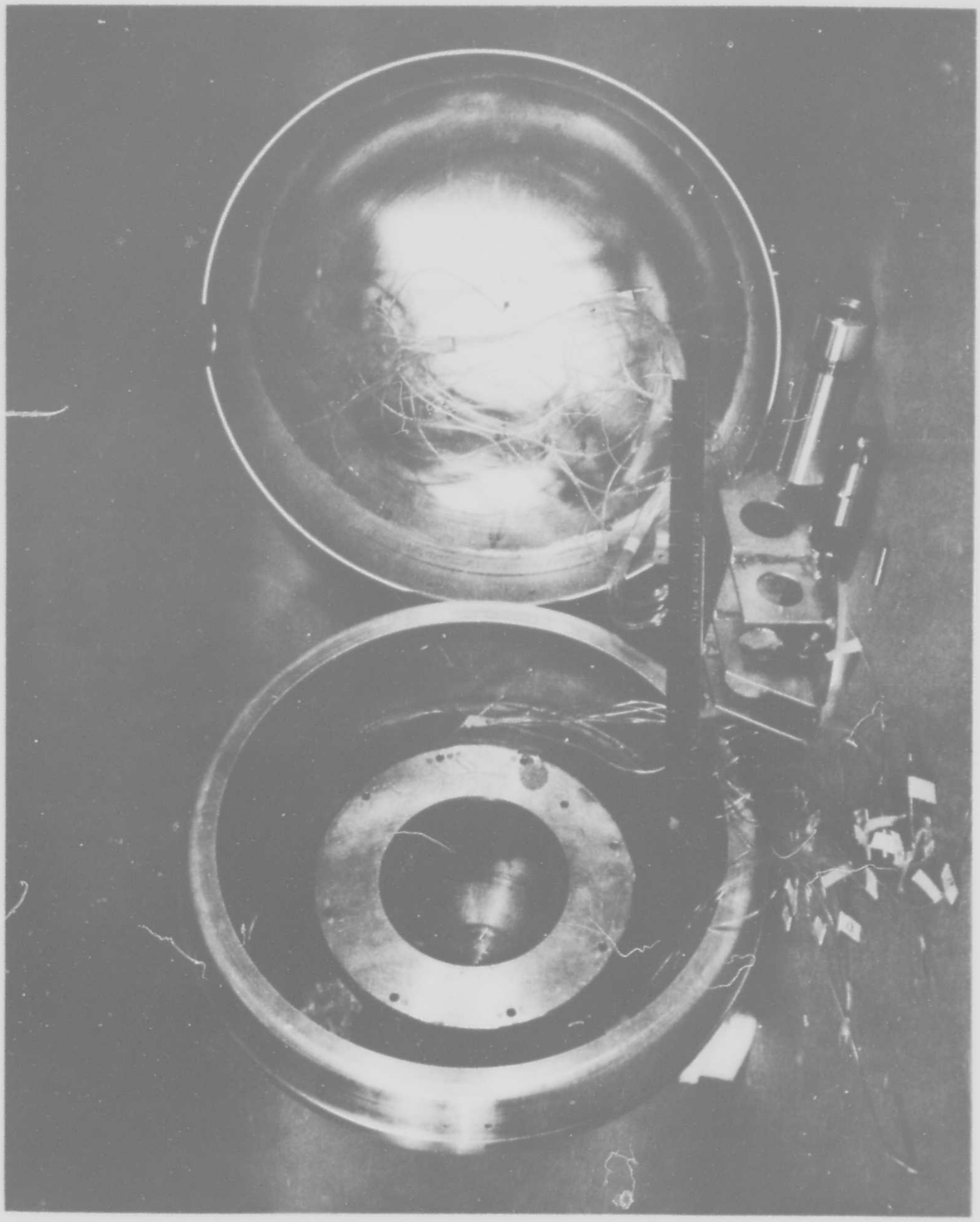


FIGURE B5 - PHOTOGRAPH OF MODEL - DISASSEMBLED VIEW

FIGURE B6.

AERODYNAMIC SIGN CONVENTION FOR BALLOON

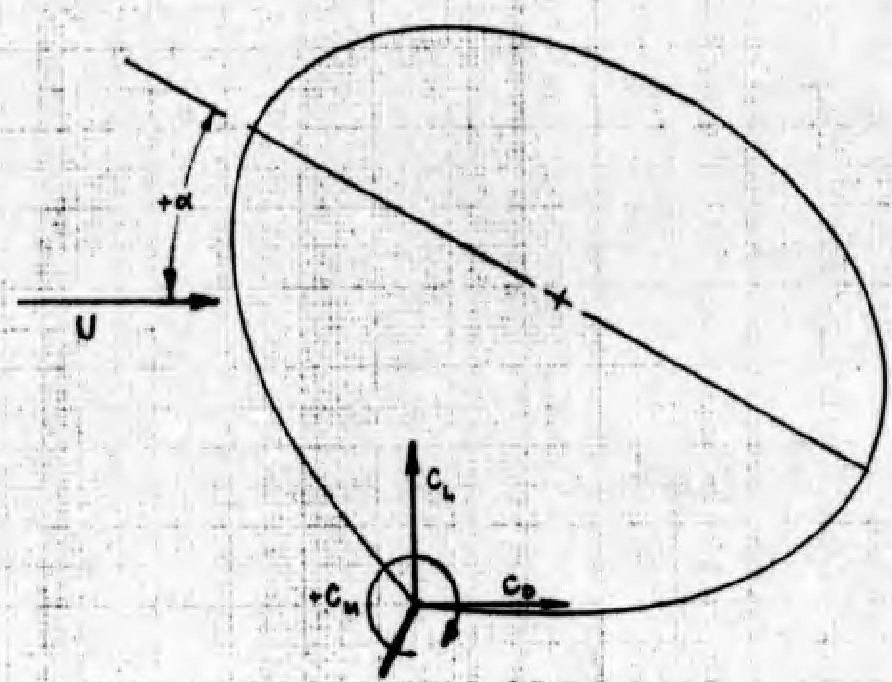
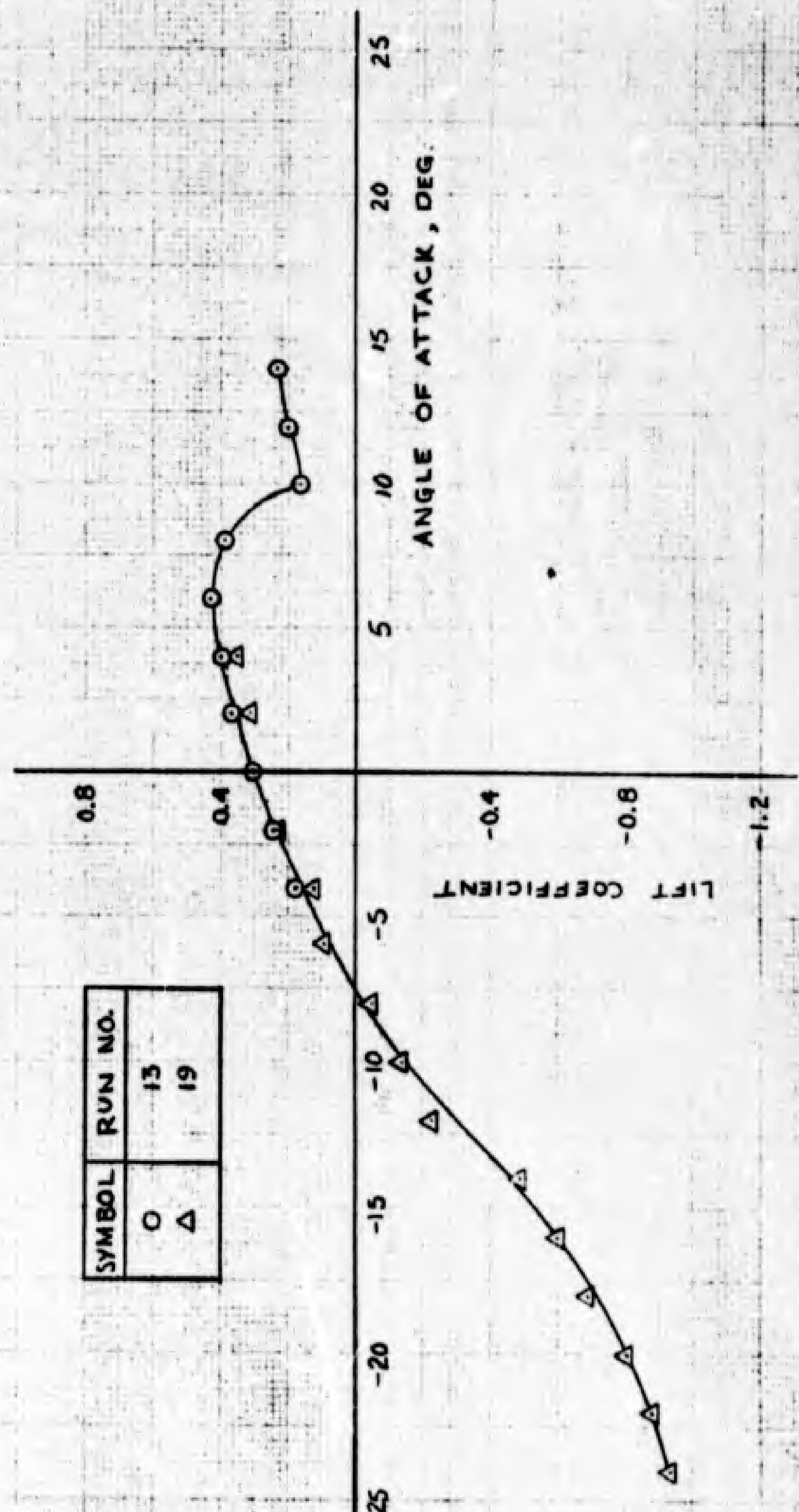


FIGURE B 7. - BALLOON LIFT COEFFICIENT VS. ANGLE OF ATTACK

REYNOLDS NUMBER = 0.45 MILLION



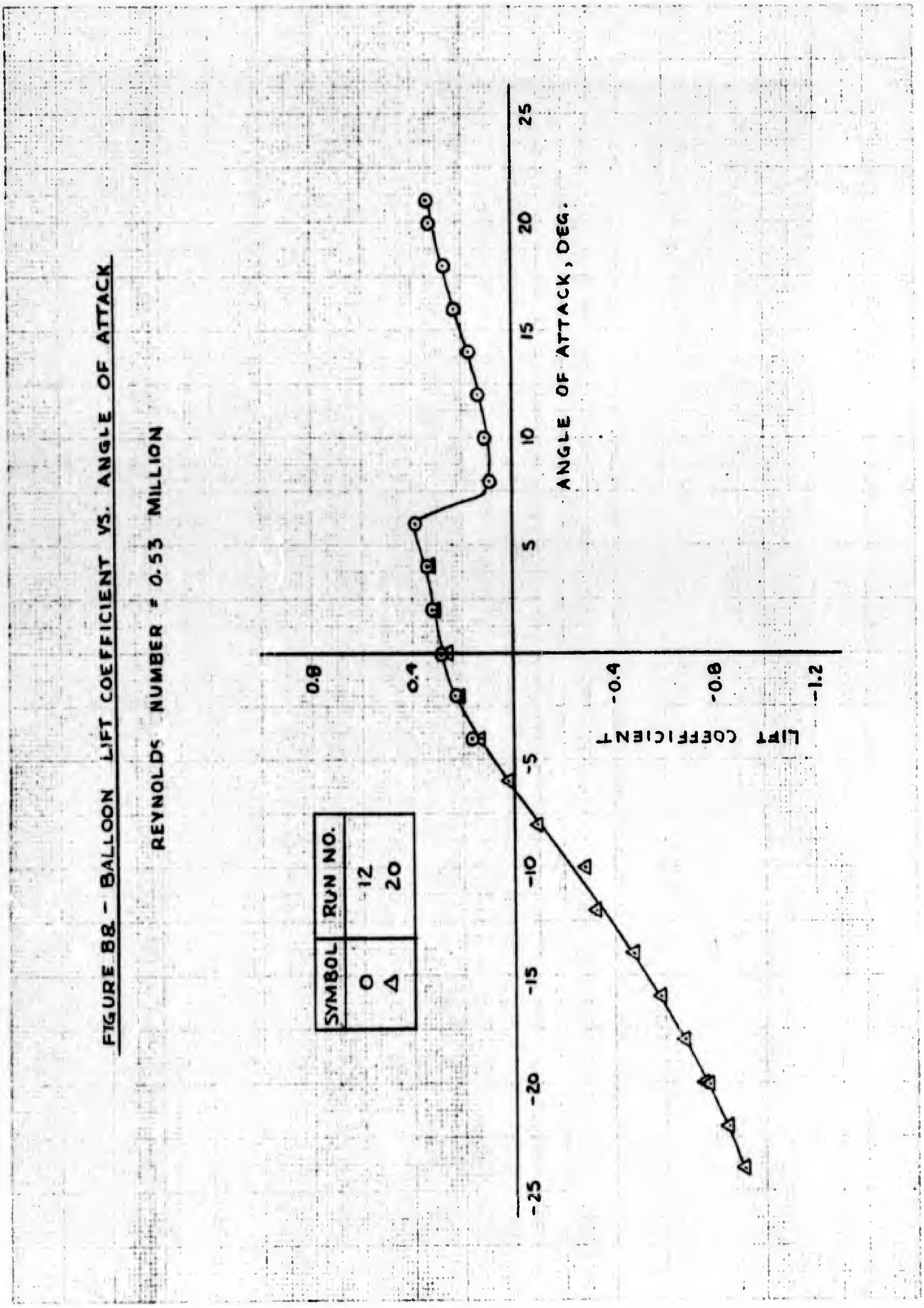
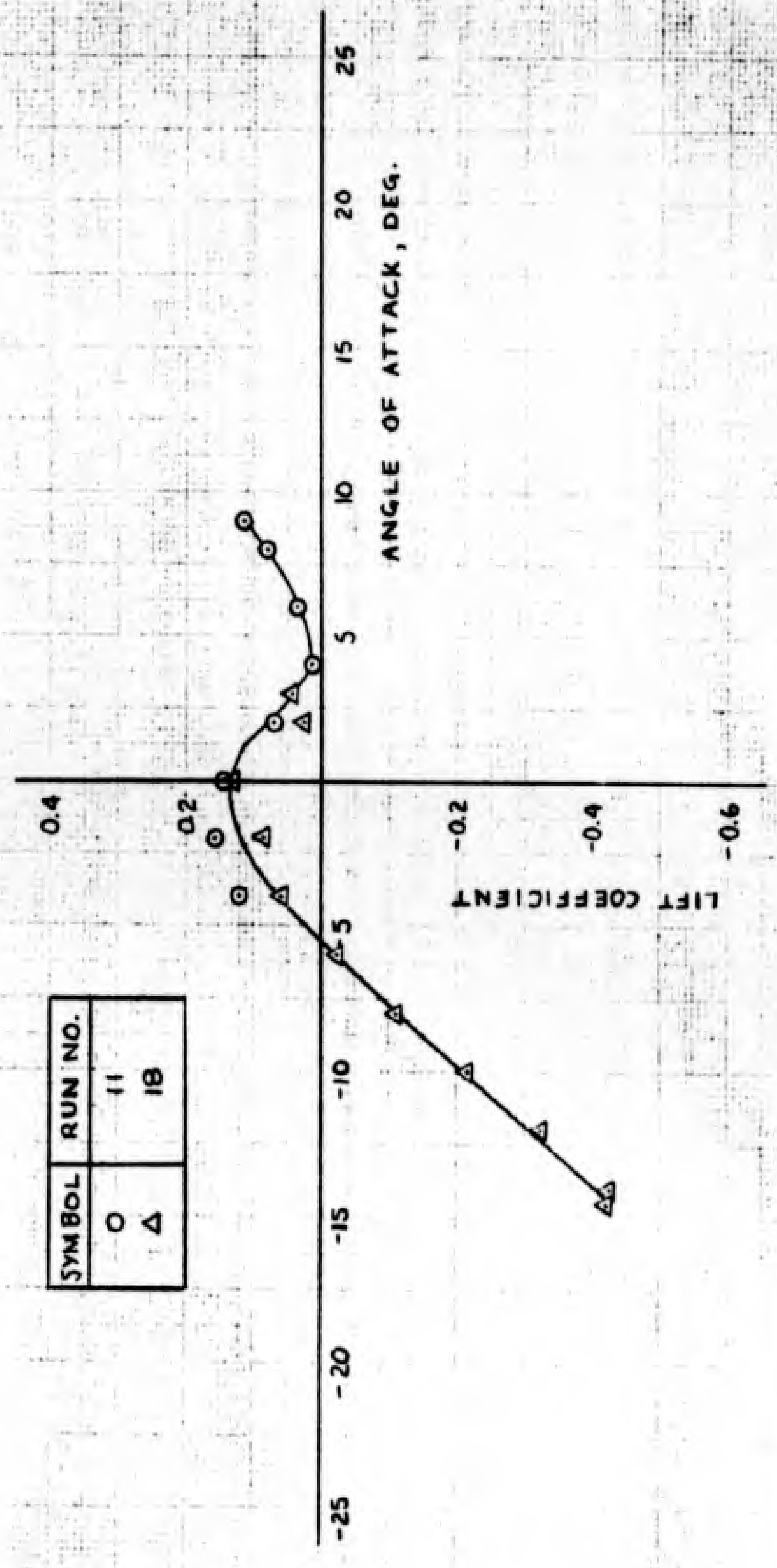


FIGURE B8 - BALLOON LIFT COEFFICIENT VS. ANGLE OF ATTACK

JR 220 (7-63)
REF: ENGRG PROCEDURE S-017

FIGURE B9. - BALLOON LIFT COEFFICIENT VS ANGLE OF ATTACK

REYNOLDS NUMBER = 1.05 MILLION



DATE		PAGE	B-29
REV DATE	**GOODYEAR AEROSPACE** CORPORATION AKRON 15, OHIO	GER.	13552
REV DATE		CODE IDENT NO.	25500

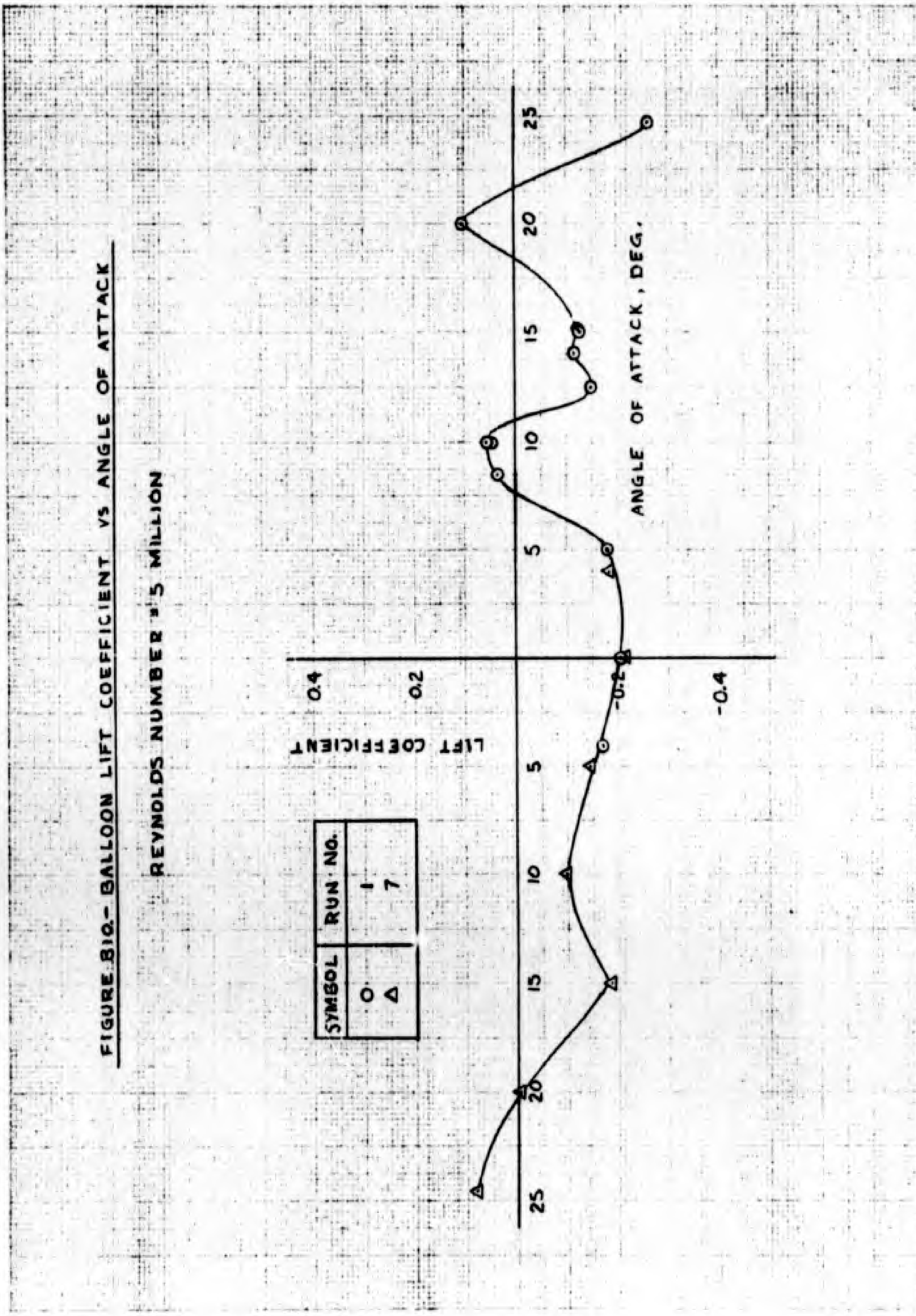


FIGURE B10.- BALLOON LIFT COEFFICIENT VS ANGLE OF ATTACK
REYNOLDS NUMBER = 5 MILLION

FIGURE B11. - BALLOON LIFT COEFFICIENT VS. ANGLE OF ATTACK

REYNOLDS NUMBER = 12 MILLION

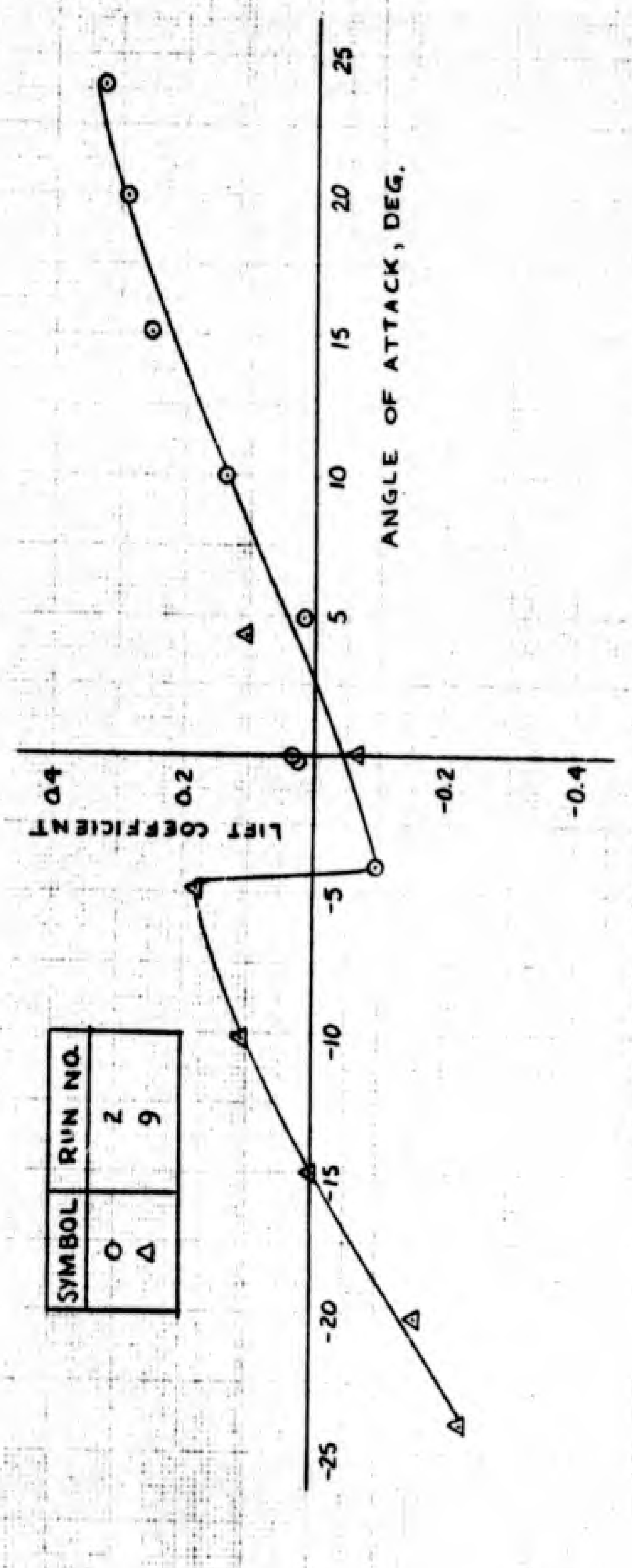
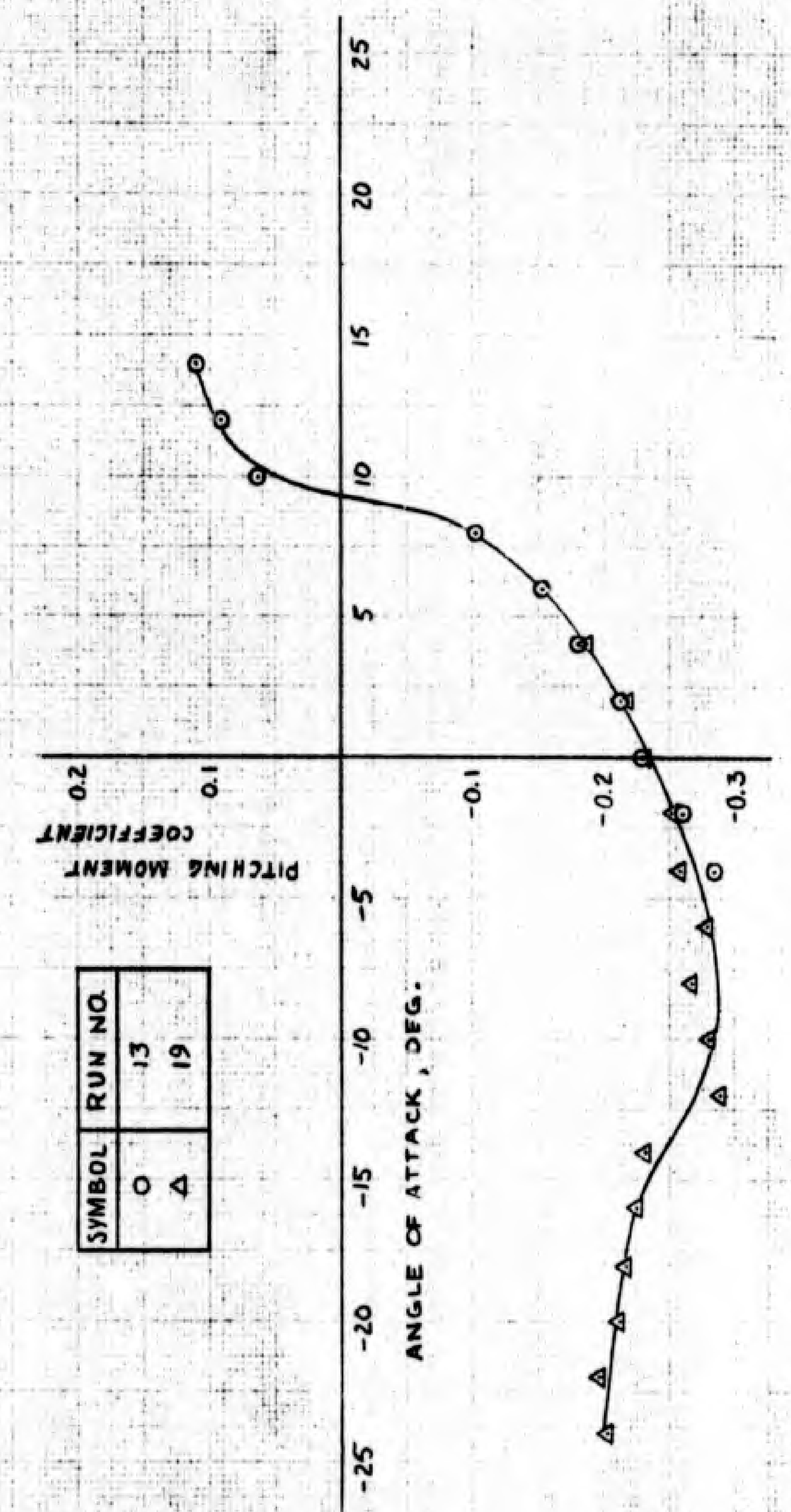


FIGURE B12. - BALLOON PITCHING MOMENT COEFFICIENT VS. ANGLE OF ATTACK

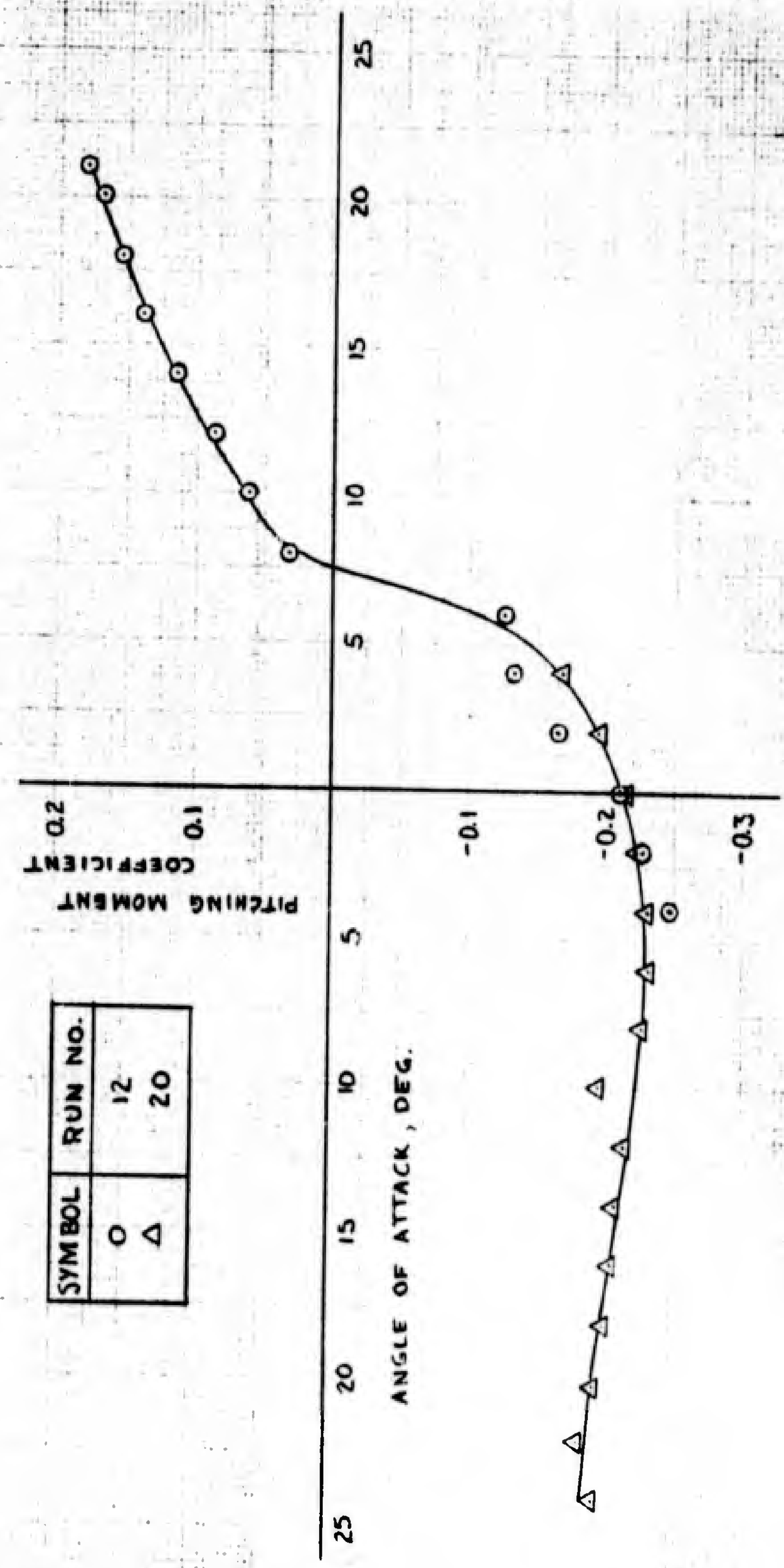
REYNOLDS NUMBER = 0.45 MILLION



JR 220 (7-63)
REF. ENGRG PROCEDURE 5-017

FIGURE B 13. - BALLOON PITCHING MOMENT COEFFICIENT VS ANGLE OF ATTACK

REYNOLDS NUMBER = 0.53 MILLION



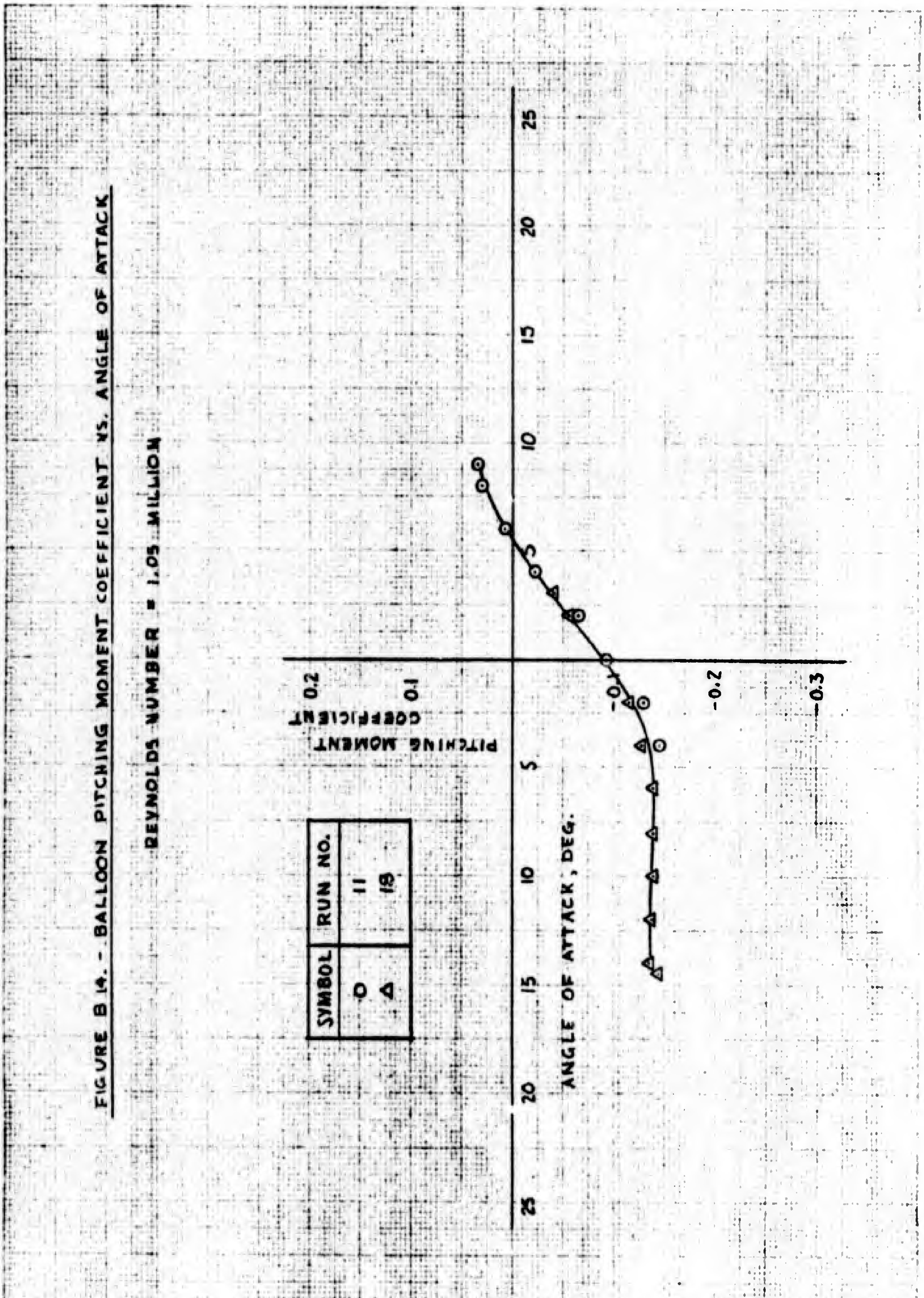


FIGURE B 14. - BALLOON PITCHING MOMENT COEFFICIENT VS. ANGLE OF ATTACK

DATE
REV DATE
REV DATE

GOODYEAR AEROSPACE
CORPORATION
AKRON 15, OHIO

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GER. 13552
CODE IDENT NO. 25500

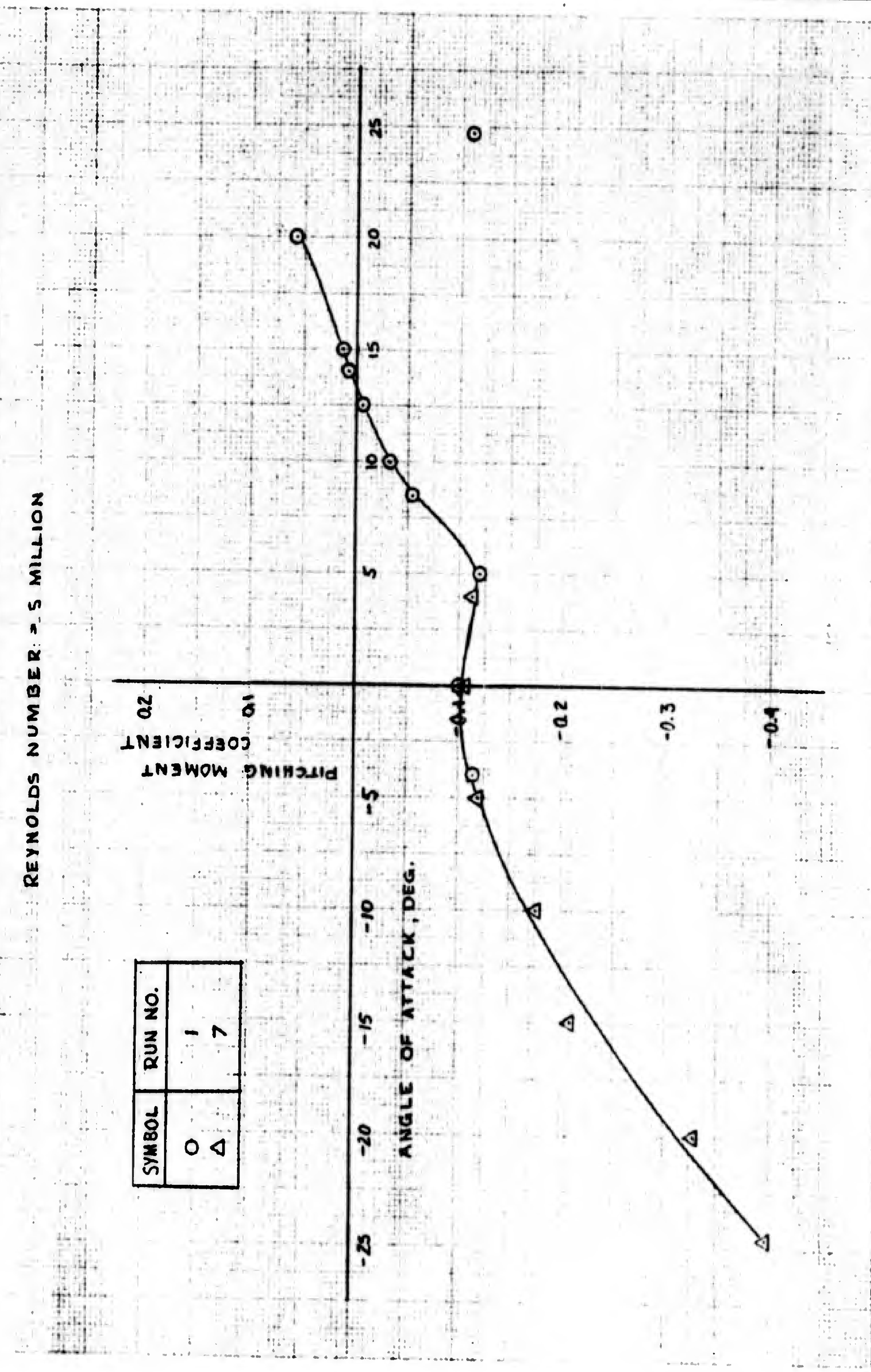


FIGURE B15.- BALLOON PITCHING MOMENT COEFFICIENT VS ANGLE OF ATTACK

JR 220 (7-63)
REF: ENG'G PROCEDURE 1-017

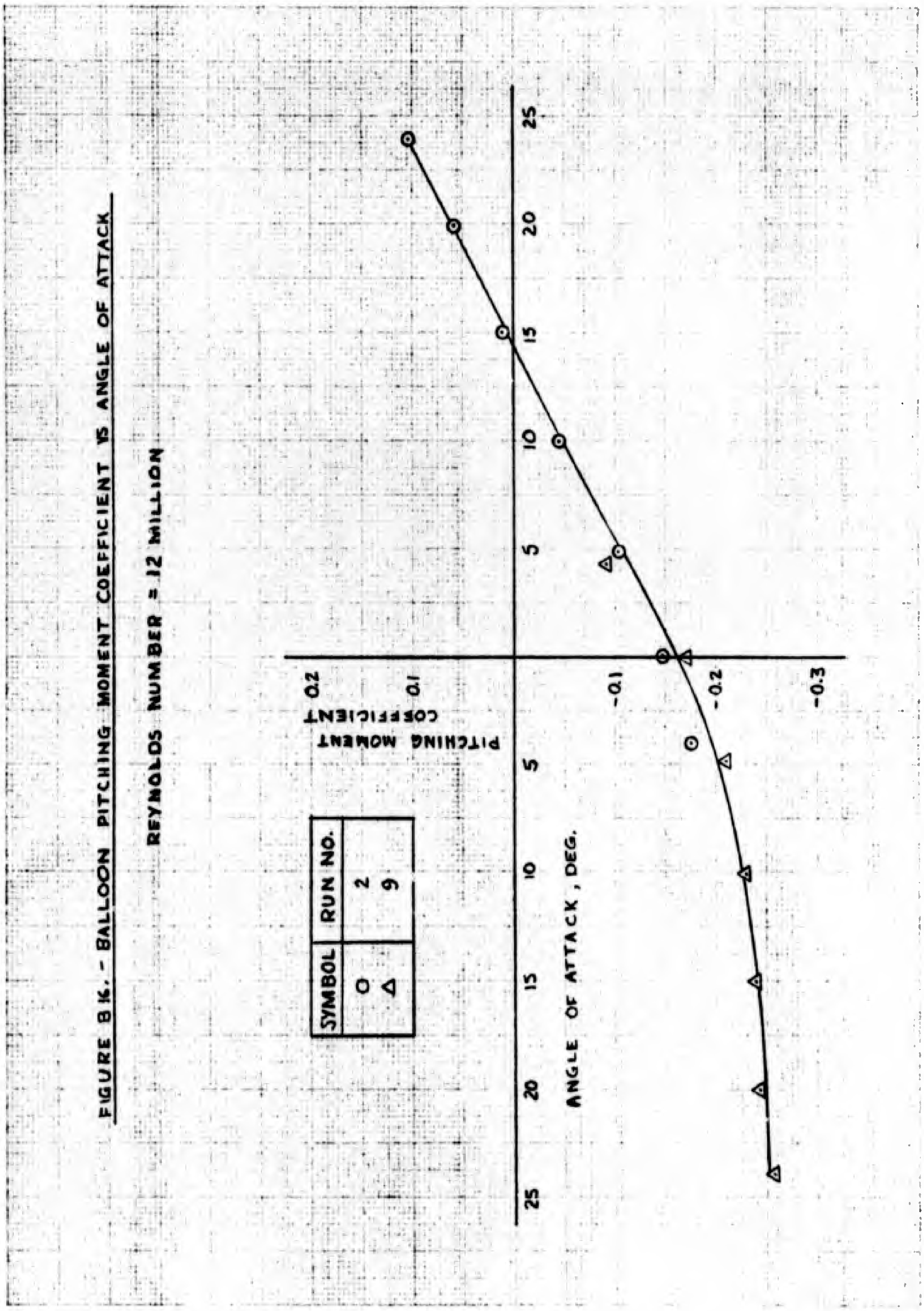
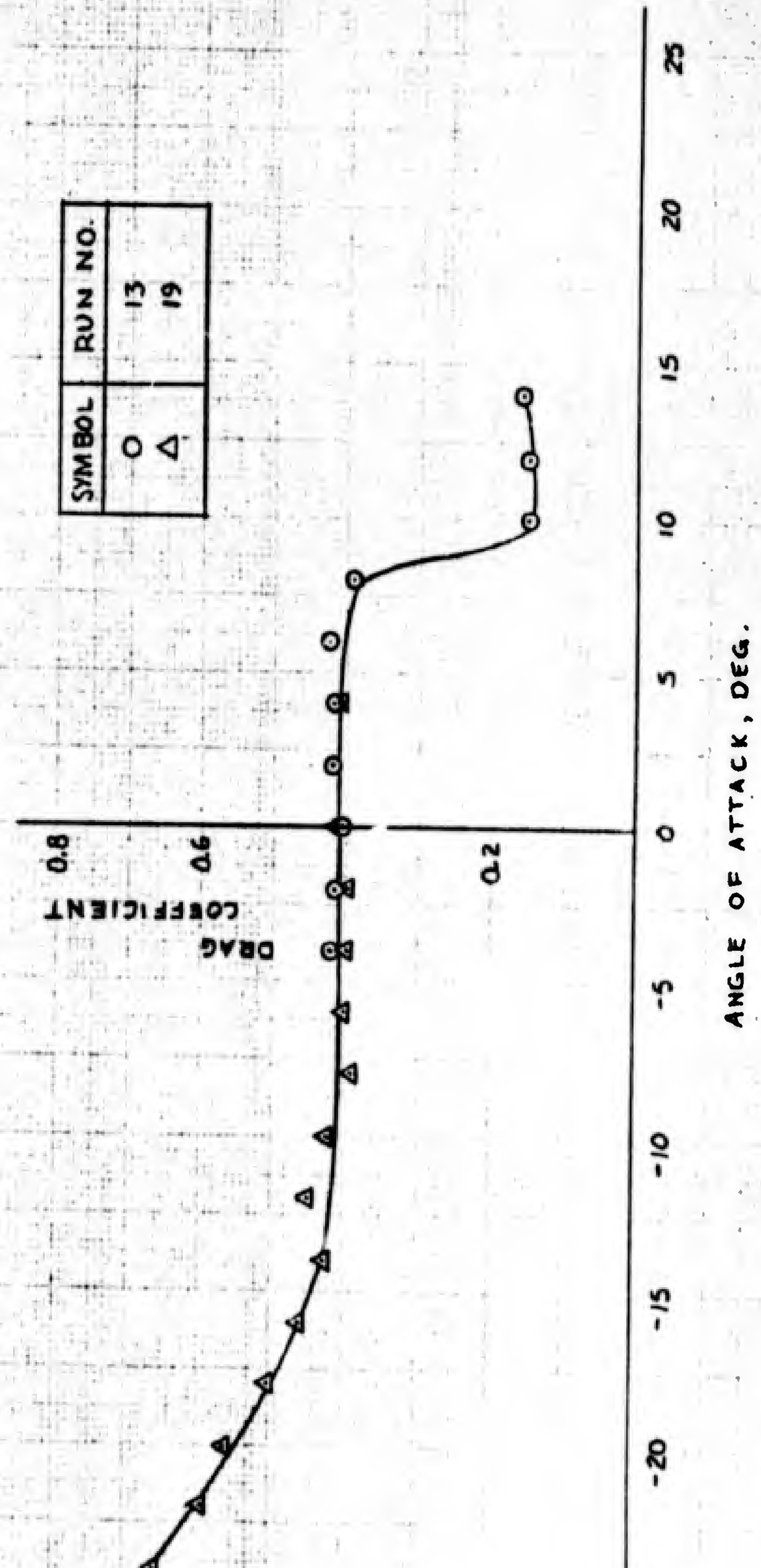


FIGURE B16. - BALLOON PITCHING MOMENT COEFFICIENT VS ANGLE OF ATTACK

FIGURE B 17. - BALLOON DRAG COEFFICIENT VS ANGLE OF ATTACK

REYNOLDS NUMBER = 0.45 MILLION



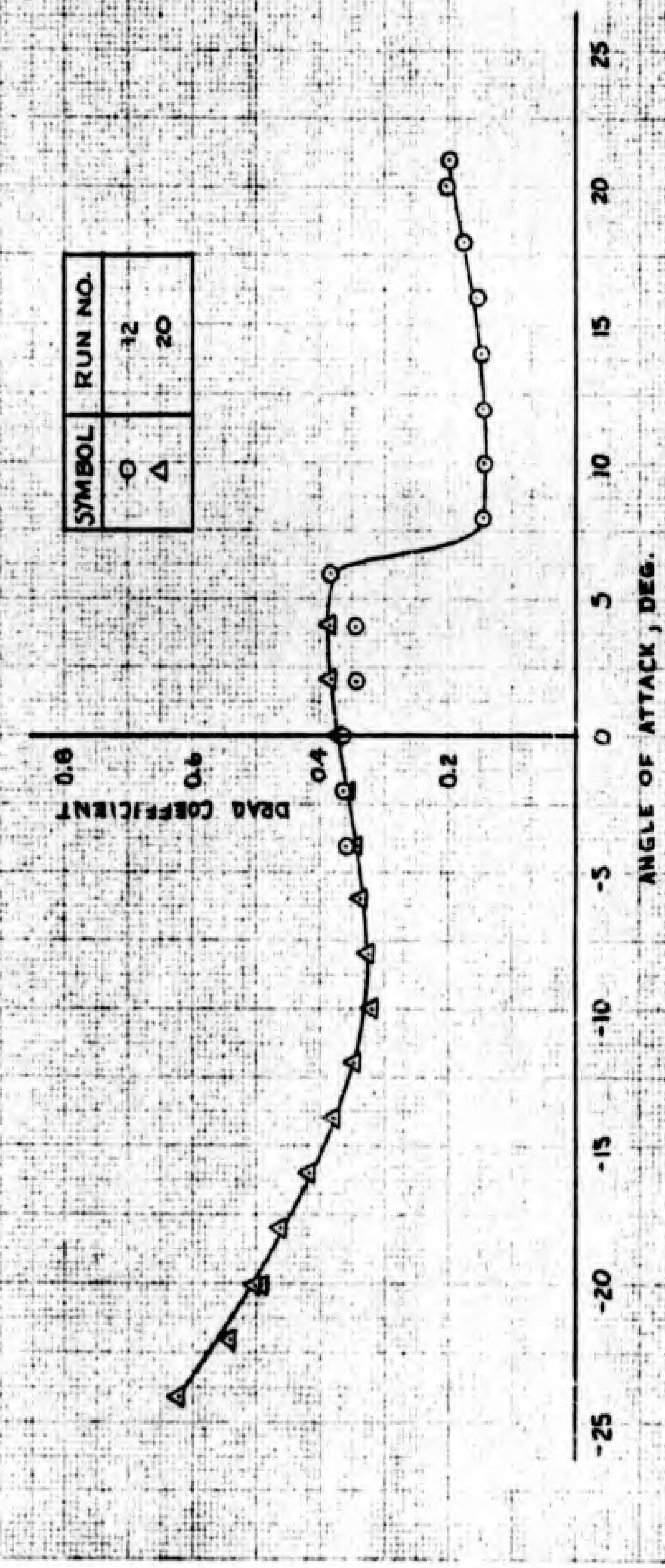


FIGURE B18.- BALLOON DRAG COEFFICIENT VS ANGLE OF ATTACK

DATE

REV DATE

REV DATE

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AKRON 15, OHIO

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GER. 13552
CODE IDENT NO. 25500

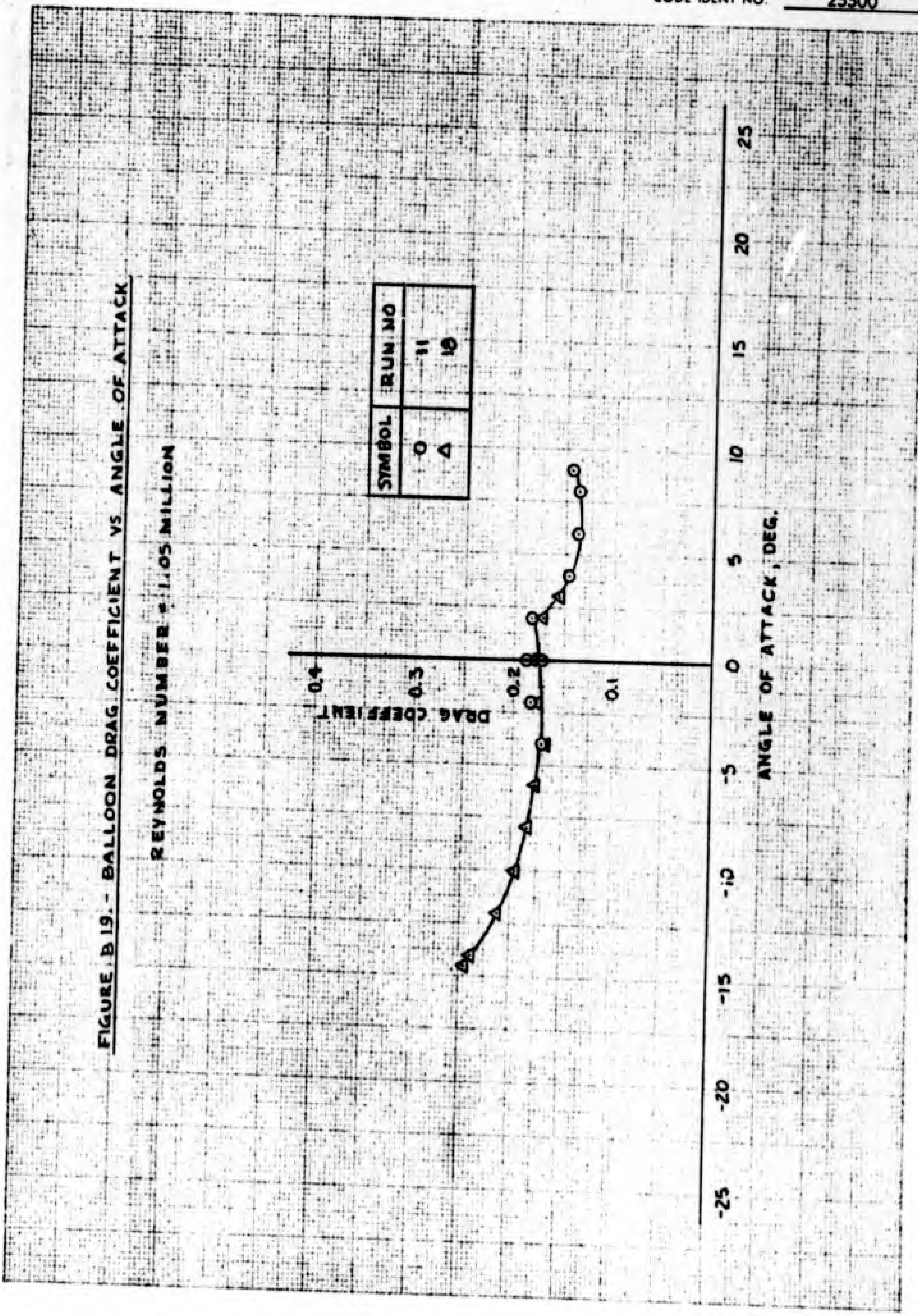


FIGURE B 19. - BALLOON DRAG COEFFICIENT VS ANGLE OF ATTACK

JR 220 (7-63)
REF: ENGRG PROCEDURE 5-017

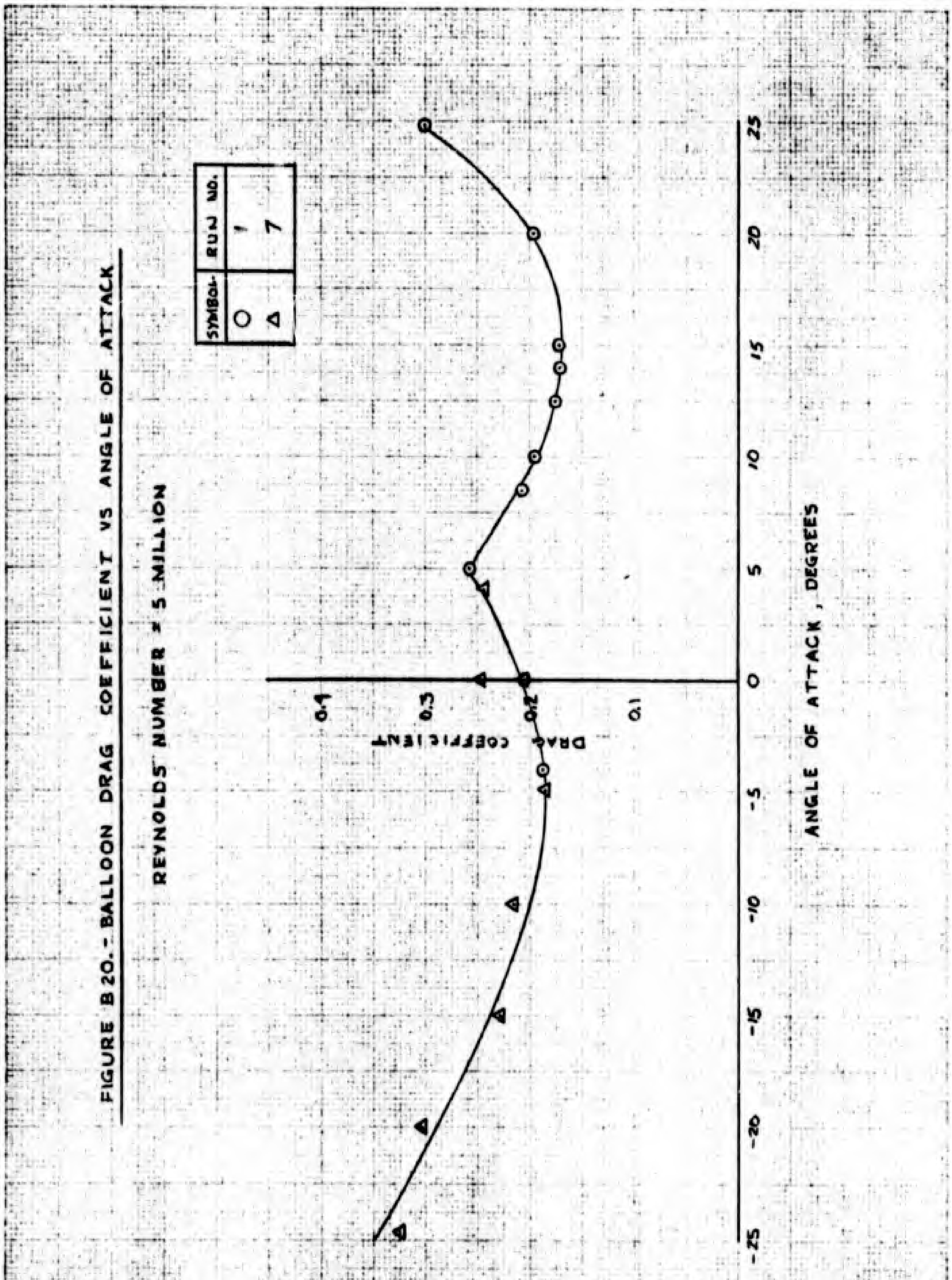
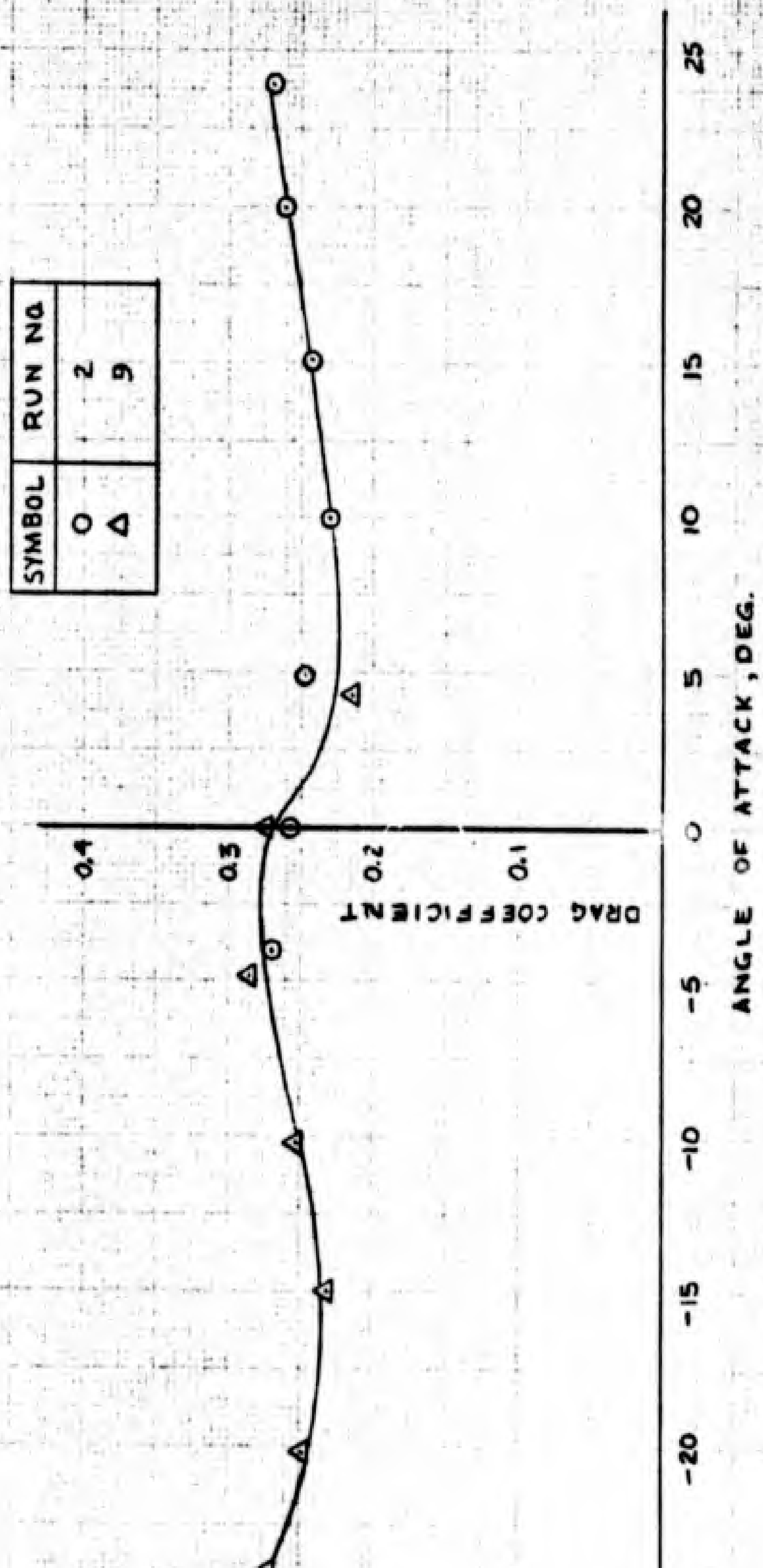


FIGURE B20.- BALLOON DRAG COEFFICIENT VS ANGLE OF ATTACK

FIGURE B21. - BALLOON DRAG COEFFICIENT VS. ANGLE OF ATTACK

REYNOLDS NUMBER = 12 MILLION



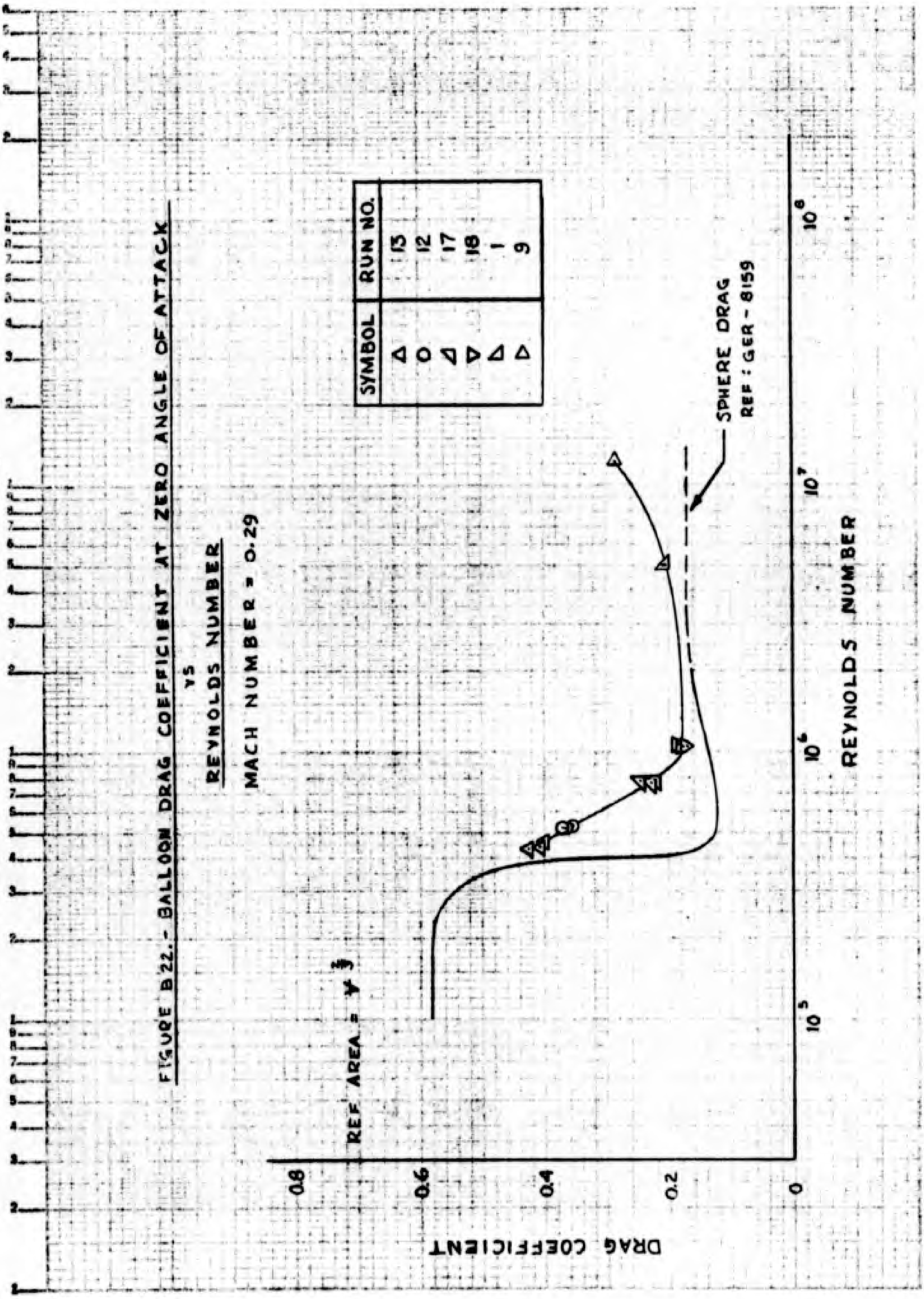


FIGURE B22.- BALLOON DRAG COEFFICIENT AT ZERO ANGLE OF ATTACK VS REYNOLDS NUMBER

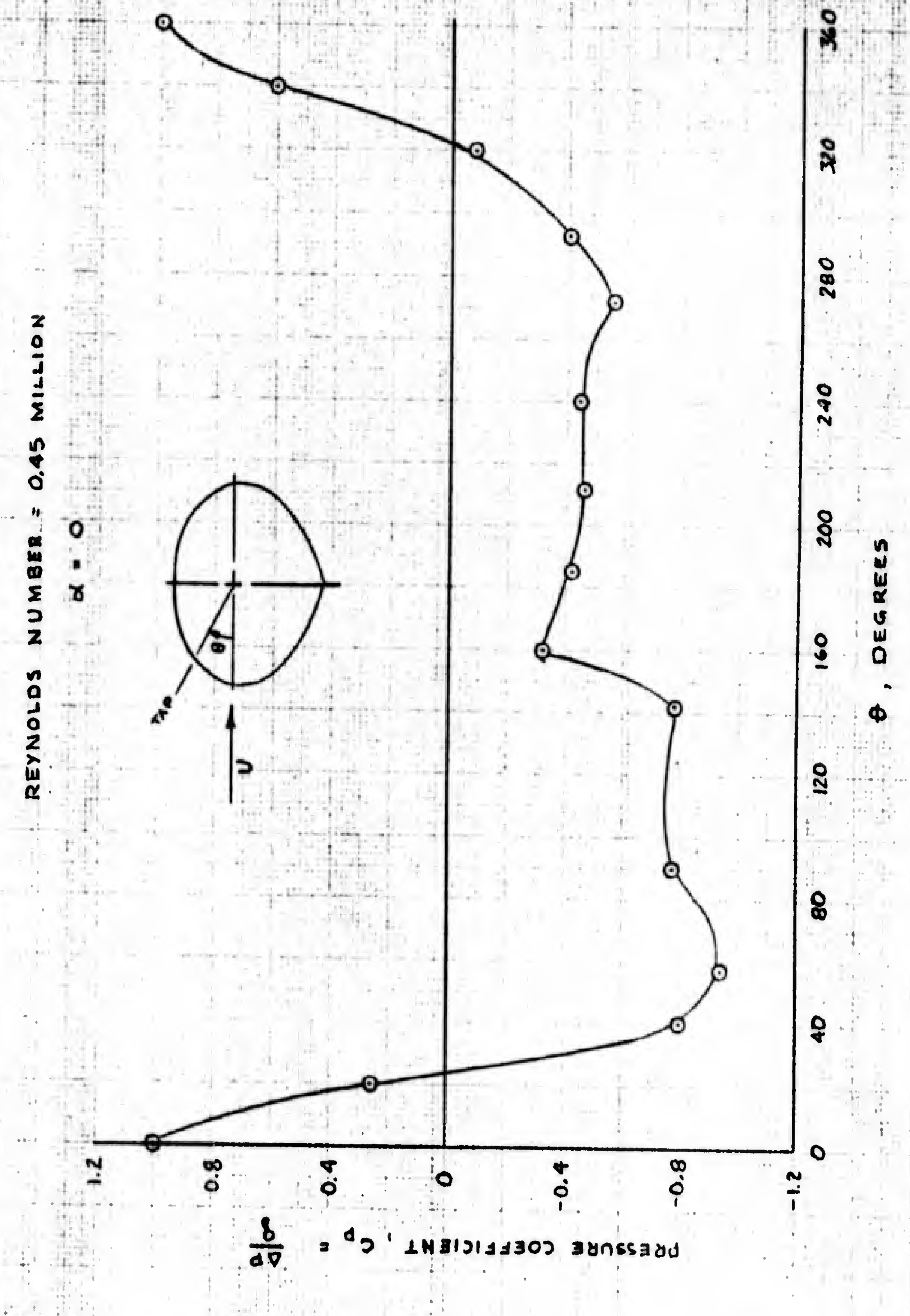


FIGURE B23. - SURFACE PRESSURE DISTRIBUTION IN φ = 0° PLANE

Table BIV - Tabulated Force Data

RUN	CONFIG	Q
1	1	212.9

M	ALPHA	R	CL	CD	CM
0.290	-3.95	5.06	-0.170	0.189	-0.115
0.289	0.04	5.05	-0.207	0.205	-0.103
0.290	5.02	5.05	-0.180	0.257	-0.119
0.290	10.05	5.05	0.047	0.194	-0.031
0.289	15.08	5.03	-0.128	0.168	0.013
0.288	8.52	5.01	0.036	0.209	-0.055
0.289	10.03	5.02	0.058	0.194	-0.027
0.289	12.54	5.02	-0.148	0.175	-0.006
0.289	13.96	5.02	-0.117	0.173	0.008
0.289	15.15	5.02	-0.121	0.172	0.014
0.290	20.06	5.02	0.104	0.196	0.058
0.288	24.75	5.00	-0.260	0.302	-0.110
0.290	0.04	5.02	-0.202	0.203	-0.100

RUN	CONFIG	Q
2	1	526.2

M	ALPHA	R	CL	CD	CM
0.283	0.14	12.03	0.030	0.256	-0.142
0.283	-4.06	12.01	-0.095	0.270	-0.176
0.283	-0.08	12.00	0.033	0.259	-0.147
0.282	4.90	11.97	0.017	0.248	-0.103
0.282	10.06	11.97	0.138	0.230	-0.044
0.282	15.11	11.96	0.252	0.243	0.012
0.281	19.95	11.91	0.290	0.261	0.058
0.281	23.92	11.91	0.327	0.269	0.104
0.281	-0.22	11.90	0.025	0.269	-0.151

RUN	CONFIG	Q
7	2	215.7

M	ALPHA	R	CL	CD	CM
0.291	0.02	5.04	-0.209	0.246	-0.136
0.290	4.02	5.03	-0.182	0.242	-0.112
0.290	-0.01	5.03	-0.198	0.242	-0.133
0.290	-4.99	5.03	-0.142	0.185	-0.120
0.291	-10.01	5.01	-0.099	0.217	-0.176
0.290	-15.06	5.00	-0.184	0.230	-0.209
0.290	-19.99	5.00	-0.005	0.306	-0.329
0.290	-24.63	5.00	0.082	0.326	-0.397
0.290	0.0	4.99	-0.179	0.203	-0.104

RUN	CONFIG	Q
9	2	524.2

M	ALPHA	R	CL	CD	CM
0.283	0.03	12.14	-0.095	0.284	-0.173
0.283	4.29	12.11	0.105	0.214	-0.091
0.282	0.04	12.06	-0.048	0.284	-0.173
0.282	-4.85	12.05	0.178	0.285	-0.210
0.282	-10.18	12.05	0.106	0.252	-0.229
0.282	-15.00	12.04	-0.001	0.231	-0.238
0.282	-20.20	12.04	-0.162	0.243	-0.243
0.282	-23.89	12.02	-0.231	0.272	-0.257
0.282	-0.04	12.01	-0.069	0.285	-0.174

RUN	CONFIG	Q
11	1	44.7

M	ALPHA	R	CL	CD	CM
0.296	0.01	1.05	0.163	0.188	-0.102
0.297	-3.98	1.06	0.120	0.172	-0.146
0.297	-2.00	1.06	0.157	0.183	-0.130
0.296	0.0	1.05	0.145	0.172	-0.090
0.296	2.03	1.05	0.070	0.183	-0.065
0.295	4.02	1.05	0.015	0.146	-0.022
0.296	6.03	1.06	0.036	0.138	0.007
0.296	8.05	1.06	0.080	0.138	0.030
0.295	9.04	1.06	0.112	0.144	0.034
0.294	0.02	1.05	0.120	0.180	-0.092

RUN	CONFIG	Q
12	1	21.6

M	ALPHA	R	CL	CD	CM
0.293	0.03	0.52	0.287	0.367	-0.208
0.294	-4.00	0.52	0.164	0.359	-0.247
0.295	-1.98	0.52	0.233	0.361	-0.227
0.294	0.03	0.52	0.290	0.371	-0.211
0.294	2.03	0.52	0.319	0.342	-0.164
0.294	4.03	0.52	0.340	0.345	-0.133
0.294	6.03	0.53	0.388	0.384	-0.125
0.292	8.03	0.53	0.089	0.147	0.033
0.292	10.06	0.53	0.108	0.144	0.062
0.293	12.04	0.53	0.137	0.147	0.087
0.289	14.06	0.53	0.177	0.149	0.114
0.290	16.07	0.53	0.233	0.156	0.139
0.288	18.07	0.53	0.272	0.175	0.155
0.289	20.09	0.53	0.325	0.205	0.167
0.289	21.07	0.54	0.314	0.198	0.180
0.284	0.0	0.53	0.273	0.356	-0.201

RUN	CONFIG	Q
13	1	17.8

M	ALPHA	R	CL	CD	CM
0.291	0.01	0.43	0.325	0.427	-0.246
0.292	-3.99	0.43	0.182	0.420	-0.285
0.293	-2.00	0.43	0.245	0.415	-0.261
0.294	0.01	0.44	0.304	0.404	-0.230
0.293	2.03	0.44	0.368	0.420	-0.213
0.294	4.04	0.45	0.399	0.419	-0.181
0.294	6.03	0.45	0.434	0.427	-0.153
0.295	8.05	0.45	0.392	0.391	-0.102
0.295	10.04	0.45	0.168	0.151	0.063
0.295	12.06	0.45	0.201	0.149	0.092
0.295	14.07	0.46	0.235	0.158	0.115
0.293	0.02	0.46	0.290	0.402	-0.229

RUN	CONFIG	Q
17	2	34.3

M	ALPHA	R	CL	CD	CM
0.305	0.01	0.77	0.193	0.229	-0.128
0.305	4.02	0.77	0.170	0.240	-0.071
0.305	2.00	0.78	0.163	0.239	-0.100
0.305	0.0	0.78	0.143	0.245	-0.128
0.304	-2.00	0.78	0.118	0.234	-0.146
0.304	-4.00	0.78	0.041	0.215	-0.146
0.301	-6.01	0.78	-0.051	0.226	-0.160
0.299	0.01	0.78	0.141	0.221	-0.119

RUN	CONFIG	Q
18	2	46.7

M	ALPHA	R	CL	CD	CM
0.304	-0.01	1.05	0.129	0.172	-0.093
0.304	3.07	1.05	0.044	0.156	-0.041
0.303	2.01	1.05	0.026	0.173	-0.055
0.302	0.01	1.05	0.098	0.176	-0.085
0.302	-1.99	1.06	0.085	0.177	-0.115
0.302	-4.00	1.06	0.059	0.168	-0.128
0.300	-6.01	1.06	-0.023	0.177	-0.139
0.300	-8.03	1.06	-0.110	0.184	-0.140
0.300	-10.01	1.07	-0.215	0.196	-0.139
0.300	-12.02	1.07	-0.322	0.213	-0.137
0.299	-14.04	1.07	-0.425	0.239	-0.136
0.298	-14.53	1.07	-0.420	0.245	-0.145
0.297	0.0	1.08	0.130	0.183	-0.100

RUN	CONFIG	Q
19	2	18.5

M	ALPHA	R	CL	CD	CM
0.299	-0.01	0.44	0.293	0.412	-0.240
0.299	4.04	0.44	0.353	0.411	-0.187
0.297	1.99	0.44	0.313	0.421	-0.219
0.298	0.0	0.44	0.275	0.399	-0.231
0.299	-1.98	0.45	0.234	0.399	-0.252
0.299	-4.00	0.45	0.122	0.398	-0.258
0.298	-6.00	0.45	0.088	0.401	-0.279
0.299	-8.03	0.45	-0.052	0.390	-0.267
0.299	-10.01	0.45	-0.140	0.424	-0.280
0.294	-12.03	0.45	-0.226	0.448	-0.289
0.295	-14.03	0.45	-0.487	0.427	-0.231
0.294	-16.03	0.45	-0.596	0.459	-0.225
0.294	-18.05	0.45	-0.687	0.501	-0.217
0.294	-20.09	0.45	-0.803	0.561	-0.213
0.293	-22.05	0.45	-0.879	0.592	-0.197
0.292	-24.05	0.46	-0.937	0.659	-0.203
0.289	0.01	0.46	0.281	0.391	-0.227

RUN	CONFIG	Q
20	2	22.4

M	ALPHA	R	CL	CD	CM
0.304	0.02	0.52	0.267	0.374	-0.215
0.305	4.04	0.52	0.331	0.386	-0.167
0.304	2.01	0.52	0.303	0.382	-0.195
0.302	0.0	0.52	0.260	0.372	-0.213
0.301	-1.99	0.52	0.217	0.351	-0.223
0.302	-3.98	0.53	0.126	0.342	-0.230
0.300	-6.01	0.53	0.020	0.338	-0.232
0.300	-6.02	0.53	0.014	0.338	-0.227
0.301	-8.02	0.53	-0.090	0.323	-0.228
0.299	-10.00	0.53	-0.281	0.319	-0.197
0.299	-12.02	0.53	-0.325	0.348	-0.216
0.299	-14.03	0.53	-0.475	0.380	-0.209
0.298	-16.04	0.53	-0.581	0.418	-0.207
0.297	-18.04	0.53	-0.675	0.461	-0.202
0.297	-20.15	0.54	-0.773	0.501	-0.194
0.295	-20.06	0.54	-0.754	0.493	-0.196
0.295	-22.06	0.54	-0.853	0.541	-0.183
0.294	-24.05	0.54	-0.914	0.621	-0.195
0.294	0.0	0.54	0.226	0.330	-0.189

Table BV - Tabulated Pressure Data

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1   29  123101    1  0001 2129 0289 0004 0505

   CP 2-11-1693-0723-0267 0514 1008 0256-0809-0947-0731-0304
     12-23-0224-0146-0134-0561-0949-0542 0056 0443-0114-0866-0935-1375
     26-35-1097-0841-0687-0809-0978-0889-1525-1312-1184-1132
     36-47-0912-1223-0839-0393-0650-0852-0785-0148-0173-0239-0668 0003

1   30  123101    1  0001 2137 0290 0502 0505

   CP 2-11-1645-0567-0061 0683 0977 0027-0997-0976-0693-0312
     12-23-0479-0228-0173-0696-0798-0345 0231 0444-0275-0980-0934-1258
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1   31  123101    1  0001 2143 0290 1005 0505

   CP 2-11-1503-0387 0151 0824 0893-0250-1231-1088-0711-0432
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     26-35-0852-0669-0747-1052-1159-0972-1420-1280-1265-1134
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1   32  123101    1  0001 2129 0289 1508 0503


   CP 2-11-1450-0233 0328 0920 0773-0523-1396-1066-0584-0030
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     26-35-0722-0577-0775-1114-1177-0880-1371-1232-1157-0887
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1   33  123101    1  0001 2129 0288 0852 0501


   CP 2-11-1547-0451 0082 0782 0923-0184-1193-1095-0746-0455
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1   34  123101    1  0001 2143 0289 1003 0502


   CP 2-11-1511-0392 0148 0819 0894-0258-1254-1104-0722-0395
     12-23-0278-0128-0130-0616-0628-0153 0353 0375-0513-1200-1029-1108
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APPENDIX C

NATURAL SHAPE BALLOONS

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SECTION C-I - INTRODUCTION

Considerable work has been completed to extend existing concepts of natural balloon shape, reefing capability, superpressure control and construction. It will be shown in the following how certain load distribution schemes on the balloon will "automatically" or naturally provide for volumetric expansion or contraction while maintaining a superpressure on all material not reefed. It will also be shown how additional superpressure of any desired amount may be obtained by the use of auxiliary equipment. Economy of design as suggested by cylinder balloon construction is another product of the work shown herein.

Before the above concepts can be developed, the basic language of natural balloons must be understood along with terms introduced for newly developed design methods. For this reason sections on development of the differential equations are included.

SECTION C-II - BASIC NATURAL BALLOON PARAMETERS (A) AND EQUATIONS (B)

A. PARAMETERS

The term "natural" is used here to indicate a balloon in which the load is transferred from the lifting gas to the tether line by means of meridional stress only. That is, circumferential stress is zero. In this study, only those balloons which have cables attached to the bottom and/or through the bottom to the top are considered.

Terminology as used here is generally that specified by Smalley in Reference C.1. Some of the items of major importance are presented here for clarity of this report.

F - Load or force applied to the top attachment of the balloon. (lbs.)

L - Load or force applied to the bottom attachment of the balloon (lbs.)

P = F + L Total load applied to the balloon via the loading cable and ring (lbs) (1)

a - Superpressure within the balloon as measured at the base of the balloon in feet of helium. (feet)
Superpressure is computed as follows:

$$a = \frac{p_i}{b} \qquad (2)$$

p_i - The internal pressure desired at the base of the balloon. (psf)

b - The unit lift of the buoyant gas at the altitude of consideration. (pcf)

Table C.1 provides values of density, absolute pressure, and buoyancy for 100, 95 and 90 percent pure helium for various altitudes. Density and absolute pressure are obtained from the 1962 Standard Atmosphere as written

TABLE C.1

ATMOSPHERIC DENSITY, DENSITY RATIO, PRESSURE AND BUOYANCY OF HELIUM VERSUS ALTITUDE

ALT FT	DENS SLUG/CUFT	DENS RATIO ALT/ZERO	PRES PSF	BUOY-100 PCF	BUOY-95 PCF	BUOY-90 PCF
0.	0.0023769	1.0000000	2116.2170410	0.0659059	0.0626106	0.0593153
1000.	0.0023081	0.9710660	2040.8571777	0.0639989	0.0607990	0.0575990
2000.	0.0022409	0.9427790	1967.6914062	0.0621347	0.0590280	0.0559212
3000.	0.0021751	0.9151295	1896.6716309	0.0603124	0.0572968	0.0542812
4000.	0.0021109	0.8881069	1827.7478027	0.0585315	0.0556049	0.0526783
5000.	0.0020482	0.8617023	1760.8730469	0.0567913	0.0539517	0.0511121
6000.	0.0019868	0.8359040	1695.9997559	0.0550910	0.0523364	0.0495819
7000.	0.0019269	0.8107038	1633.0812988	0.0534302	0.0507587	0.0480871
8000.	0.0018684	0.7860914	1572.0712891	0.0518081	0.0492177	0.0466272
9000.	0.0018113	0.7620566	1512.9265137	0.0502240	0.0477128	0.0452016
10000.	0.0017555	0.7385901	1455.6020508	0.0486774	0.0462436	0.0438097
11000.	0.0017011	0.7156832	1400.0544434	0.0471677	0.0448094	0.0424510
12000.	0.0016479	0.6933257	1346.2407227	0.0456943	0.0434095	0.0411248
13000.	0.0015961	0.6715091	1294.1193848	0.0442564	0.0420436	0.0398308
14000.	0.0015455	0.6502230	1243.6489258	0.0428535	0.0407108	0.0385682
15000.	0.0014961	0.6294589	1194.7880859	0.0414851	0.0394108	0.0373365
16000.	0.0014480	0.6092079	1147.4982910	0.0401504	0.0381429	0.0361353
17000.	0.0014011	0.5894610	1101.7407227	0.0388490	0.0369065	0.0349641
18000.	0.0013553	0.5702096	1057.4758301	0.0375802	0.0357012	0.0338221
19000.	0.0013107	0.5514442	1014.6652832	0.0363434	0.0345262	0.0327091
20000.	0.0012672	0.5331573	973.2741699	0.0351382	0.0333813	0.0316244
21000.	0.0012249	0.5153396	933.2644043	0.0339639	0.0322657	0.0305675
22000.	0.0011836	0.4979826	894.6005859	0.0328200	0.0311790	0.0295380
23000.	0.0011435	0.4810780	857.2475586	0.0317059	0.0301206	0.0285353
24000.	0.0011043	0.4646176	821.1711426	0.0306210	0.0290900	0.0275589
25000.	0.0010662	0.4485928	786.3369141	0.0295649	0.0280867	0.0266084
26000.	0.0010292	0.4329959	752.7124023	0.0285370	0.0271101	0.0256833
27000.	0.0009931	0.4178191	720.2653809	0.0275367	0.0261599	0.0247831
28000.	0.0009580	0.4030532	688.9619141	0.0265636	0.0252354	0.0239072
29000.	0.0009239	0.3886521	658.7734375	0.0256171	0.0243362	0.0230554
30000.	0.0008907	0.3747267	629.6672363	0.0246967	0.0234619	0.0222270
31000.	0.0008584	0.3611497	601.6137695	0.0238019	0.0226118	0.0214217
32000.	0.0008270	0.3479538	574.5842285	0.0229322	0.0217856	0.0206390
33000.	0.0007966	0.3351310	548.5485840	0.0220871	0.0209827	0.0198784
34000.	0.0007670	0.3226740	523.4787598	0.0212661	0.0202028	0.0191395
35000.	0.0007382	0.3105754	499.3469238	0.0204687	0.0194453	0.0184219
36000.	0.0007103	0.2988280	476.1262207	0.0196945	0.0187098	0.0177251
37000.	0.0006780	0.2852482	453.8615723	0.0187995	0.0178596	0.0169196
38000.	0.0006463	0.2719093	432.6379395	0.0179204	0.0170244	0.0161284
39000.	0.0006161	0.2591956	412.4089355	0.0170825	0.0162284	0.0153743
40000.	0.0005873	0.2470773	393.1274414	0.0162838	0.0154697	0.0146555
41000.	0.0005598	0.2355266	374.7490234	0.0155226	0.0147465	0.0139703
42000.	0.0005336	0.2245171	357.2316895	0.0147970	0.0140571	0.0133173
43000.	0.0005087	0.2140231	340.5344238	0.0141054	0.0134001	0.0126948
44000.	0.0004849	0.2040206	324.6193848	0.0134462	0.0127738	0.0121015
45000.	0.0004623	0.1944863	309.4494629	0.0128178	0.0121769	0.0115360
46000.	0.0004407	0.1853986	294.9897461	0.0122189	0.0116079	0.0109970
47000.	0.0004201	0.1767363	281.2070312	0.0116480	0.0110656	0.0104833

41000.	C.0005558	0.2355266	374.7490234	0.0155226	0.0147465	0.0139703
42000.	C.0005336	0.2245171	357.2316895	0.0147970	0.0140571	0.0133173
43000.	0.0005087	0.2140231	340.5344238	0.0141054	0.0134001	0.0126948
44000.	C.0004849	0.2040206	324.6193848	C.0134462	0.0127738	0.0121015
45CCC.	C.0004623	0.1944863	309.4494629	0.0128178	0.0121769	C.0115360
46CCC.	0.0004407	0.1853986	294.9397461	0.0122189	0.0116079	0.0109970
47000.	0.0004201	0.1767363	281.2070312	0.0116480	0.0110656	0.0104832
48000.	C.0004005	0.1684793	268.0693359	0.0111038	0.0105486	0.0099934
49CCC.	C.0003817	C.1606091	255.5469666	0.0105851	0.0100558	0.0095266
50000.	0.0003639	0.1531070	243.6104279	C.0100907	0.0095861	0.0090816
510CC.	C.0003469	0.1459562	232.2325439	0.0096194	0.0091384	0.0086574
52CCC.	C.0003307	C.1391399	221.3870392	0.0091701	0.0087116	0.0082531
530CC.	0.0003153	0.1326425	211.0490265	0.0087419	0.0083048	0.0078677
54000.	0.0003006	0.1264491	201.1947174	0.0083337	C.0079171	0.0075004
55000.	C.0002865	C.1205454	191.8013458	0.0079447	0.0075474	0.0071502
560CC.	C.0002731	0.1149181	182.8473969	0.0075738	0.0071951	C.0068164
57000.	0.0002604	0.1095537	174.3122406	0.0072202	0.0068592	0.0064982
580CC.	C.0002482	C.1044404	166.1763611	0.0068532	0.0065391	0.0061949
59CCC.	C.0002367	0.0995662	158.4208832	0.0065620	0.0062339	0.0059058
60CCC.	C.0002256	0.0949198	151.0279388	C.0062558	0.0059430	0.0056302
61000.	0.0002151	C.0904906	143.9806671	0.0059639	0.0056657	0.0053675
62000.	C.0002050	0.0862685	137.2628937	0.0056856	0.0054013	0.0051170
630C0.	C.0001955	0.0822439	130.8591919	0.0054204	0.0051493	0.0048783
64000.	0.0001864	0.0784073	124.7548218	0.0051675	0.0049091	0.0046508
650C0.	C.0001777	0.0747501	118.9357910	0.0049265	0.0046801	0.0044338
66CCC.	C.0001693	0.0712459	113.3880157	0.0046955	0.0044607	0.0042260
67CC0.	0.0001612	0.0678335	108.1079407	0.0044706	0.0042471	0.0040236
68000.	0.0001535	0.0645868	103.0772552	0.0042566	0.0040438	0.0038310
690C0.	C.0001462	0.0614957	98.2871857	0.0040532	0.0038505	0.0036479
700CC.	C.0001392	0.0585660	93.7239276	0.0038598	0.0036669	0.0034739
710C0.	0.0001326	0.0557761	89.3879852	C.0036760	0.0034922	0.0033084
72000.	0.0001263	0.0531210	85.2509308	C.0035010	0.0033259	0.0031509
73000.	C.0001203	0.0505973	81.3133087	0.0033347	0.0031679	0.0030012
74CCC.	0.0001146	C.0481984	77.5651398	0.0031766	0.0030177	0.0028589
750C0.	0.0001091	0.0459147	73.9921417	0.0030261	0.0028747	0.0027234
76000.	0.0001040	0.0437422	70.5883636	0.0028829	0.0027387	0.0025946
77C00.	C.0000991	0.0416767	67.3476715	0.0027467	0.0026094	0.0024721
780C0.	C.0000944	0.0397100	64.2578583	0.0026171	0.0024863	0.0023554
79000.	0.0000899	0.0378398	61.3157043	0.0024939	0.0023692	0.0022445
800CC.	C.0000857	0.0360602	58.5120239	0.0023766	0.0022577	C.0021389
810CC.	C.0000817	0.0343664	55.8401184	0.0022650	0.0021517	0.0020385
820CC.	C.0000779	0.0327555	53.2953186	0.0021588	0.0020508	0.0019429
83000.	0.0000742	C.0312211	50.8681030	C.0020577	0.0019548	0.0018519
84000.	C.0000707	0.0297605	48.5545349	0.0019614	0.0018633	0.0017653
85CCC.	C.0000674	0.0283711	46.3505859	0.0018698	0.0017763	0.0016828
860CC.	0.0000643	0.0270482	44.2494659	0.0017826	0.0016935	0.0016044
87000.	C.0000613	0.0257887	42.2462616	0.0016996	0.0016146	0.0015297
88000.	C.0000584	0.0245895	40.3362732	0.0016206	0.0015396	0.0014585
890CC.	C.0000557	0.0234475	38.5150299	0.0015453	0.0014681	0.0013908
900CC.	0.0000531	0.0223607	36.7794800	0.0014737	0.0014000	0.0013263
91000.	0.0000507	0.0213250	35.1232147	C.0014054	0.0013352	0.0012649
92000.	0.0000483	0.0203392	33.5446777	0.0013405	0.0012734	0.0012064
930C0.	C.0000461	0.0193996	32.0380554	0.0012785	0.0012146	0.0011507
94000.	0.0000440	0.0185051	30.6019592	0.0012196	0.0011586	0.0010976
950C0.	0.0000420	0.0176530	29.2320251	0.0011634	0.0011053	C.0010471
96CCC.	C.0000400	0.0168418	27.9259949	0.0011100	0.0010545	0.0009990
970CC.	0.0000382	0.0160683	26.6791077	0.0010590	0.0010060	0.0009531
98000.	C.0000364	0.0153313	25.4894714	C.0010104	0.0009599	0.0009094
990C0.	C.0000348	C.0146295	24.3550873	C.0009642	0.0009160	0.0008678
00000.	C.0000332	0.0139607	23.2726440	0.0009201	0.0008741	0.0008281

B

for computer usage for Goodyear Aerospace Corporation. Buoyancy is then computed using the following relation:

$$b_{100} = \gamma_{az} - \gamma_{hz}$$

but $\dfrac{\gamma_{ho}}{\gamma_{ao}} = \dfrac{\gamma_{hz}}{\gamma_{az}}$

therefore $b_{100} = \gamma_{az}\left(1 - \dfrac{\gamma_{ho}}{\gamma_{ao}}\right)$

$$= (\rho_{az})g\left(1 - \frac{\gamma_{ho}}{\gamma_{ao}}\right)$$

$$b_{100} = 27.728\,\rho_{az} \qquad (3)$$

$$b_{95} = .95\, b_{100}$$

$$b_{90} = .90\, b_{100}$$

where γ is density (pcf)

ρ is mass density (slugs/cu.ft.)

g is the acceleration of gravity (ft./sec.^{2})

(assumed constant = 32.17426)

Subscripts

100, 95, 90 - Purity of helium as a percentage

a - air

h - helium

z - altitude at point of consideration

o - altitude of sea level

Continuing with the definition of symbols we have,

w - Unit balloon material weight. (psf)

W - Total balloon material weight. (lbs.)

s - Arc length along meridian measured from the bottom of the balloon to the point of interest. (ft.)

r - Radius coordinate as measured from the balloon axis to the point of interest. (ft.)

z - Height coordinate as measured from the base of the balloon parallel to the central axis to the point of interest.

t_m - Meridional stress. (lbs./ft.)

T - $2\pi r t_m$ - Total film load carried in the meridional direction by entire circumference of the film at any gore station (length along the gore). (Note that this term is a scalar quantity.) (lbs.)

A - Surface area of inflated shape from the base to the height of interest. ($ft.^2$)

$\forall$ - Volume enclosed by the inflated shape as measured from the base to the height of interest. ($ft.^3$)

The above factors describe balloon parameters for specific conditions. A powerful extension in use and scope of these parameters can be made by non-dimensionalizing the parameters as shown below.

Units of length and force are the essential factors which describe the balloon parameters. Choice of non-dimensionalizing terms should be those that represent factors of basic and general importance. The total load P is a term of such nature and will be used to non-dimensional force terms. A length term of general importance might be a number such that when it is cubed will result in the volume of the balloon. The volume of a weightless balloon can be computed as:

$$\forall = \frac{P}{b} \qquad (4)$$

The length factor may thus be called lambda (λ) and would be the cube root of $\forall$ or

$$\lambda = (\forall)^{1/3}$$

$$\lambda = \left(\frac{P}{b}\right)^{1/3} \qquad (5)$$

Lambda may thus be thought of as number which when cubed will result in the volume of a weightless balloon large enough to lift the payload.

The terms P and λ will be used to non-dimensionalize the parameters presented earlier. Note that for ease of conversion, the term b may be directly used as a non-dimensionalizing factor since

$$b = \frac{P}{\lambda^3}$$

The factors presented below are correctly termed non-dimensional superpressure, non-dimensional arc length, etc., however, for brevity, they will simply be called superpressure, arc length, etc.

$\frac{F}{P}$ - Amount of top load factor, (a convenient misnomer is percent top load)

$\alpha = \frac{a}{\lambda}$ - Superpressure factor.

(6)

$\Sigma = \frac{w}{b\lambda}(2\pi)^{1/3}$ Sigma factor or material weight factor. (Note that the units of w are (psf) and are non-dimensionalized by the product $b\lambda$ which also has units of psf. The power of 2π factor is simply for convenience.)

$\frac{W}{P}$ = Balloon weight factor.

$\sigma = \frac{S}{\lambda}$ Arc length factor.

$\rho = \frac{r}{\lambda}$ Radius coordinate factor.

$\zeta = \frac{z}{\lambda}$ Height coordinate factor.

$\tau_m = \frac{t_m}{b\lambda^2}$ Meridional stress factor.

$\frac{T}{P}$ = Total film load factor.

$\frac{A}{\lambda^2}$ = Inflated surface area accumulated to the point of interest.

$\frac{V}{\lambda^3}$ = Inflated volume accumulated to the point of interest.

B. EQUATIONS OF SHAPE AND STRESS

Basic differential equations may be developed by considering the static equilibrium of a sector of the balloon. Kerr and Alexander in Ref. C.2, develop these equations in a concise manner. Their equations are shown below after modification by use of different notation and elimination of circumferential stress.

Equation of Stress

$$\frac{d(rt_m)}{ds} = wr \cos \theta \qquad (7)$$

Equation of Shape

$$\frac{d\theta}{ds} = \frac{w \sin\theta - b(z + a)}{t_m} \qquad (8)$$

These equations may be solved by an iterative procedure as follows:

Select the following initial conditions:

$$\theta(0) = \theta_o$$

$$(rt_m)_o = \frac{P-F}{2 \cos\theta_o} \qquad (9)$$

$$r(0) = 0$$

$$z(0) = 0$$

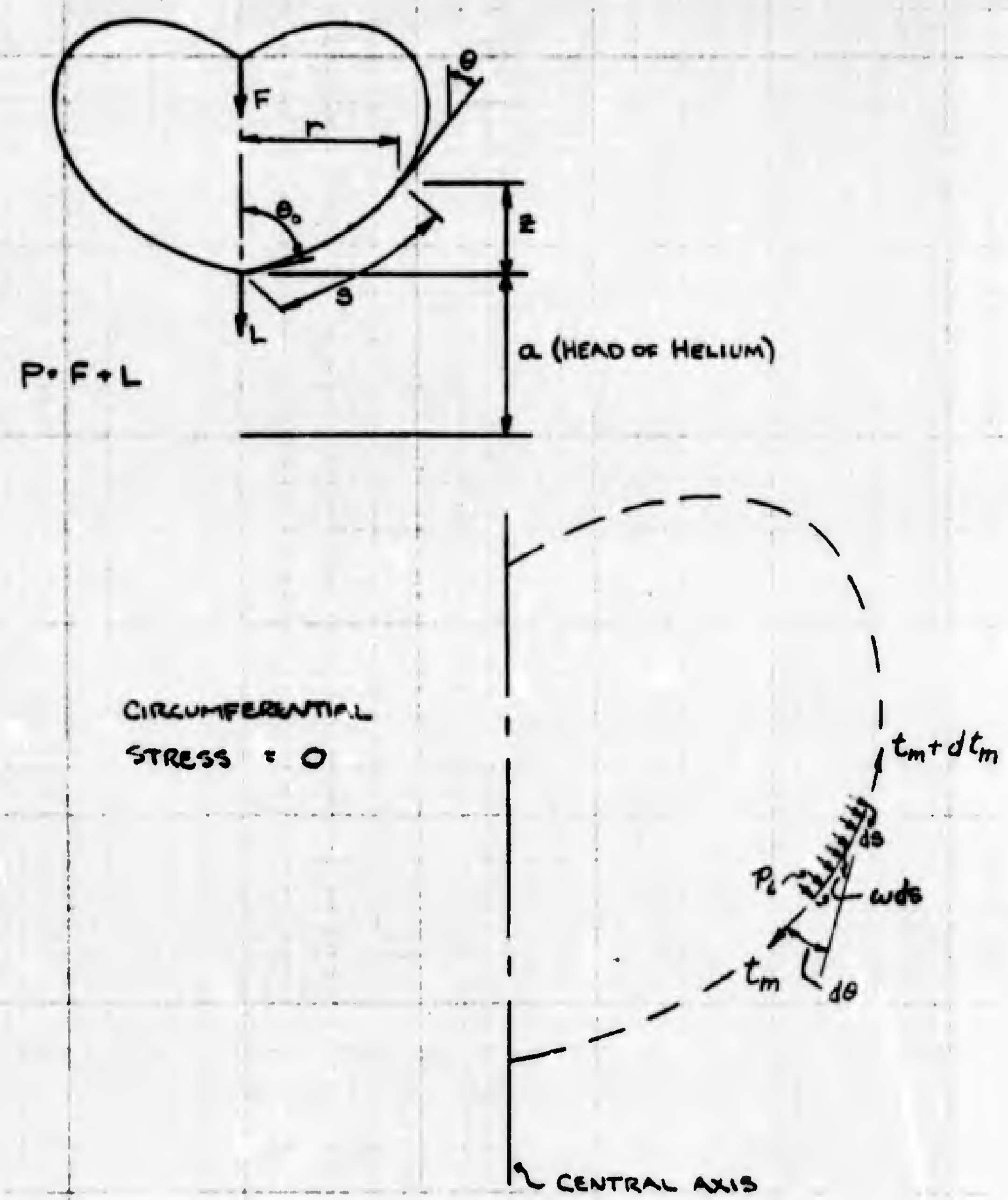
Notation is as shown in Figure C.1.

The solution is continued by numerically integrating from the bottom of the balloon to the top by selecting a certain incremental arc length as shown in Figure C.1.

FIGURE C.1

BALLOON ELEMENT SHOWING

NOMENCLATURE AND EQUILIBRIUM



That is, find a change in stress $\Delta(rt_m)$ and a corresponding change in angle $\Delta\theta$ for each increment. The last increment will occur when r returns to zero. At this point, the equilibrium force F (amount of top load) may be computed from statics from the stress and angle of the final increment.

Generally F will not be the desired value and thus a new initial angle must be chosen for the second iteration. Continue iterating until the desired accuracy is obtained.

In non-dimensional form the differential equations become:

$$\frac{d(\rho\tau_m)}{d\sigma} = K\Sigma\rho\zeta' \qquad (10)$$

$$\frac{d\theta}{d\sigma} = \frac{-K\Sigma\rho - (\zeta + \alpha)}{\tau_m} \qquad (11)$$

Where $K = 2\pi^{-(1/3)}$

The solution of these equations is performed in the same manner as prescribed previously, note that Smalley's computer solution utilizes the Runge-Kutta method when numerically integrating. The solution utilized during this program is similar to that utilized in Ref. C.1.

It is pointed out here that three parameters completely define a particular balloon shape. They are:

$\frac{F}{P}$ = Percent of top loading.

α = Non-dimensional superpressure.

Σ = Non-dimensional unit weight.

That is, these parameters define the forces and loads which act on the balloon, and correspondingly establish equilibrium and shape definition. Tables such as Smalley's "Sigma" tables provide non-dimensional solutions which incorporate all balloons of a common shape. Specific balloon design data are then obtained after multiplication by the proper power of λ.

Other quantities as desired may be obtained during the numerical integration which are useful in the analysis such as surface area, volume, film stress, etc.

SECTION C-III - DEVELOPMENT OF THE MATERIAL WEIGHT FACTOR β

After the data generated by computer solutions is understood and carefully analyzed, it may be observed that balloons designed by such tables may be inefficient. That is, it may be observed that for balloons of common interest (low W/P ratios) the total load to be carried at one horizontal cross-section does not vary greatly from that carried at any other cross-section. (See Balloon Solution Table C.2, or any of the tables in Ref. C.1 for $W/P \doteq .5$, observe that T/P is nearly constant from bottom to top of balloon.) The amount of material to resist this load, as measured by the product of circumference and thickness, however, varies greatly. The effects of this mismatch of load and material may result in either a heavy material that is very inefficient or understressed over a major portion of the balloon, or in a light material that is over-stressed throughout a major portion of the balloon. Of course, reinforcements and modifications to thickness can be made, but then the shape predicted by the design table is no longer accurate.

It was suggested by Mr. James Dwyer of Air Force Cambridge Research Laboratories that a design be accomplished for eliminating this mismatch of strength and material weight.

This modification can be accomplished by changing Σ or w (material weight) at every level in the balloon such that the load per unit area of the material is a constant. The modification can most easily be conceived as that of a balloon design of "variable" or "tapered" skin thickness. However, a more practical design would be one in which excess fullness was allowed at every level such that the ratio of layout or gore circumference to inflated circumference is equal to the ratio of the so called "tapered" thickness to the constant thickness established for the entire balloon.

To accomplish this modification, a factor C is defined as the ratio of material weight to corresponding strength.

$$C = \frac{w}{t_m} \quad \text{(1/ft.)} \quad \text{(reciprocal of breaking length)} \qquad (12)$$

therefore $w = C\, t_m$

In non-dimensional form the relation becomes,

$$\frac{1}{K}\,\frac{w}{b\lambda} = \frac{C\lambda t_m}{Kb\lambda^2}$$

with $\Sigma = \frac{1}{K}\,\frac{w}{b\lambda}$

and setting $\beta = C\lambda$ (13)

the following equation may be obtained

$$\Sigma = \frac{1}{K}\,\beta\,\Upsilon_m \qquad (14)$$

A new parameter β has been introduced which is related to quantities generally known at the beginning of a problem by the relation

$$\beta = C\lambda = C\sqrt[3]{\frac{P}{b}}$$

It is noted that the weight-strength factor C can easily be obtained from plots similar to that given on Page 35 of Ref. C.3.

Values of C are shown on a reproduction of this curve in Figure C.2. Note that many of the practical values of balloon materials tend to fall near a particular weight-strength value, namely C = .000043. If a safety factor is desired, it may be handled as follows:

$$C_{SF} = S.F.\ (C_{QB}) \qquad (15)$$

For example, if the strength weight ratio at the quick break failure point is C_{QB} = .000043, and a safety factor of 3 is desired, then

$$C_{SF} = 3(.000043)$$

$$C_{SF} = .000129$$

Determination of a specific balloon design table or shape now involves the input of these parameters,

$\frac{F}{P}$ = Percent of top loading

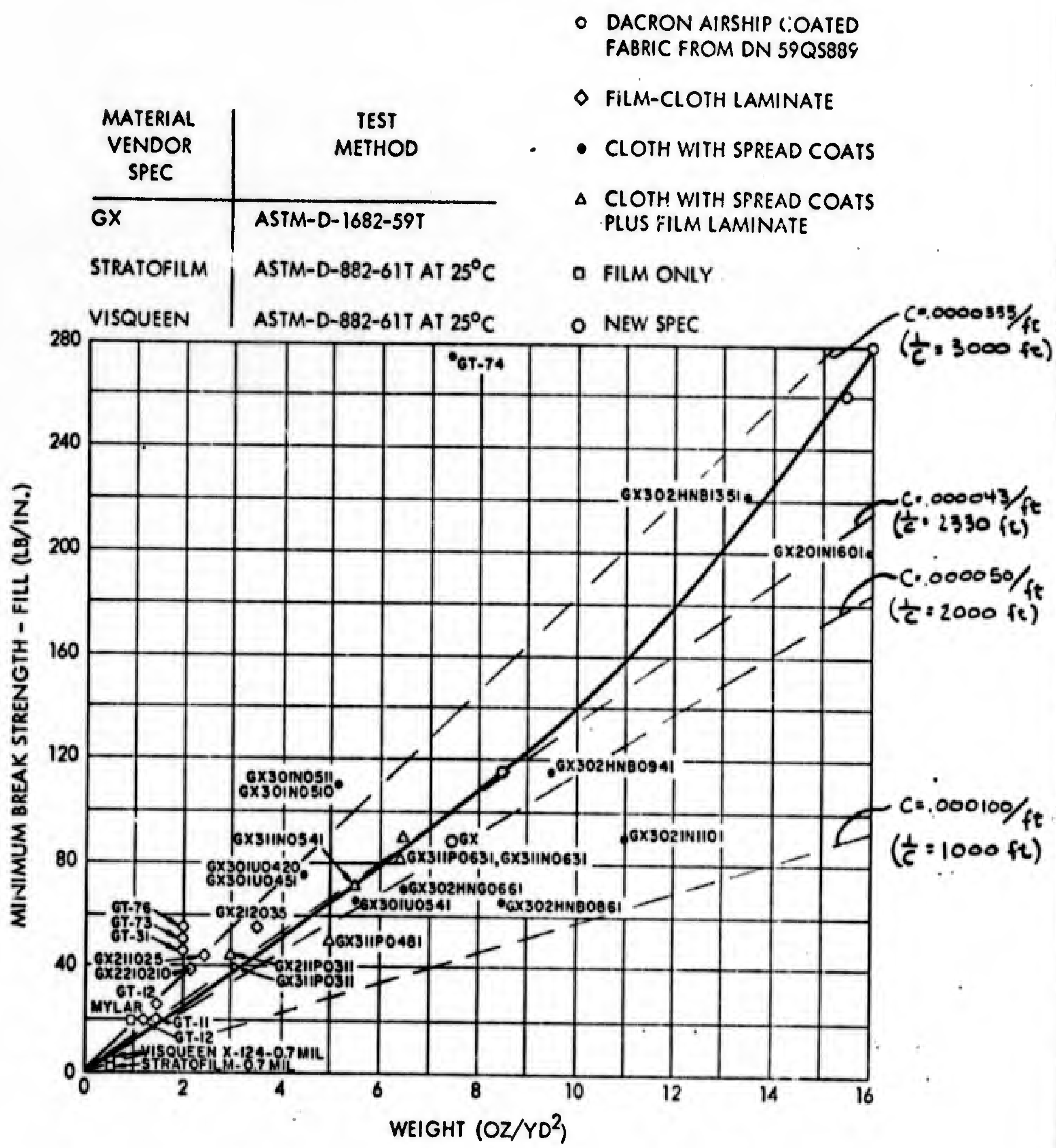
α = Superpressure factor

β = Material weight factor

FIGURE C.2

Breaking Strength versus Unit Weight for Various Balloon Materials

MATERIAL VENDOR SPEC	TEST METHOD
GX	ASTM-D-1682-59T
STRATOFILM	ASTM-D-882-61T AT 25°C
VISQUEEN	ASTM-D-882-61T AT 25°C



A computer solution utilizing the above concept is included with a description of the data presented in Table C.2.

Values selected for presentation were:

$\frac{F}{p} = .25$

$\alpha = 7.0008$

$\beta = 0.0103602$

An incremental arc length of .04 was chosen to provide a compact presentation. Generally .02 is chosen. An initial value of θ_o = 87 degrees was selected.

At this point, the computer begins the numerical integration as previously suggested. The value of $\frac{F}{p}$ is computed as the top of the balloon is reached. In this case, it is $\frac{F}{p}$ = .24386. With this error in $\frac{F}{p}$, the command is to try a new value of θ_o that varies from the previous value by 1/2 degree. θ_o is increased if $\frac{F}{p}$ is to decrease. The new value of θ_o selected is 87.5 degrees, the computed $\frac{F}{p}$ for this case is .557, much too large. Interpolation or extrapolation is performed at this point to provide a new value. This is continued until the value of θ_o is within .1 degree or the value of $\frac{F}{p}$ is accurate to 3 significant figures. Once this accuracy is obtained, a final print-out run is presented on the next computer page. The columns of data provided here are as follows: Non-dimensional coordinates of arc length, radius and height from base are presented. Each is divided by L or lambda.

A

TABLE C.2

TYPICAL COMPUTER PRINTOUT OF NATURAL BALLOON SOLUTION

EA652 VARIABLE WEIGHT TEST EA652

THE INPUTS ARE:

F/P = 0.25000

ALPHA = 7.0008

[redacted] = 0.0103602

THETAO = 87.000

COMPUTED F/P = 0.24386

THETAO = 87.500

COMPUTED F/P = 0.55723

THETAO = 87.000

COMPUTED F/P = 0.24386

THETAO = 87.000

EA652 VARIABLE WEIGHT TEST EA652

S/L	R/L	Z/L	THETA	TAUM	T/P	A/L2	V/L3	SIGMA	RATIO	A'/L2
0.0	0.0	0.0	87.000	0.0	14.32995	0.0	0.0	0.0	0.0	0.0
0.0400	0.03994	0.00213	86.840	57.099	14.33022	0.00502	0.00000	1.09159	19.30318	0.19378
0.0800	0.07987	0.00448	86.394	28.555	14.33057	0.02008	0.00003	0.54589	9.65327	0.38756
0.1200	0.11978	0.00723	85.668	19.042	14.33097	0.04517	0.00012	0.36403	6.43742	0.58135
0.1600	0.15964	0.01058	84.660	14.288	14.33147	0.08028	0.00033	0.27315	4.83030	0.77514
C.2000	0.19942	0.01474	83.371	11.438	14.33208	0.12540	0.00075	0.21867	3.86695	0.96894
0.2400	0.23909	0.01988	81.801	9.541	14.33284	0.18051	0.00154	0.18240	3.22549	1.16275
0.2800	0.27858	0.02621	79.951	8.189	14.33378	0.24557	0.00288	0.15655	2.76838	1.35658
0.3200	0.31783	0.03390	77.822	7.178	14.33492	0.32052	0.00504	0.13723	2.42669	1.55041
0.3600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

S/L	R/L	Z/L	THETA	TAUM	T/P	A/L2	V/L3	SIGMA	RATIO	A*/L2
0.0	0.0	0.0	87.000	0.0	14.32995	0.0	0.0	0.0	0.0	0.0
0.0400	0.03994	0.00213	86.840	57.099	14.33022	0.00502	0.00000	1.09159	19.30318	0.19378
0.0800	0.07987	0.00448	86.394	28.555	14.33057	0.02008	0.00003	0.54589	9.65327	0.38756
0.1200	0.11978	0.00723	85.668	19.042	14.33097	0.04517	0.00012	0.36403	6.43762	0.58135
0.1600	0.15964	0.01058	84.660	14.288	14.33147	0.08028	0.00033	0.27315	4.83030	0.77514
0.2000	0.19942	0.01474	83.371	11.438	14.33208	0.12540	0.00075	0.21867	3.86695	0.96894
0.2400	0.23909	0.01988	81.801	9.541	14.33284	0.18051	0.00154	0.18240	3.22549	1.16275
0.2800	0.27858	0.02621	79.951	8.189	14.33378	0.24557	0.00288	0.15655	2.76838	1.35659
0.3200	0.31783	0.03390	77.822	7.178	14.33492	0.32052	0.00504	0.13723	2.42669	1.55041
0.3600	0.35675	0.04314	75.413	6.396	14.33629	0.40530	0.00836	0.12227	2.14219	1.74427
0.4000	0.39521	0.05411	72.728	5.774	14.33791	0.49980	0.01325	0.11038	1.95197	1.93814
0.4400	0.43309	0.06695	69.768	5.270	14.33982	0.60390	0.02019	0.10074	1.78149	2.13203
0.4800	0.47022	0.08182	66.537	4.854	14.34202	0.71743	0.02975	0.09280	1.64109	2.32596
0.5200	0.50641	0.09884	63.039	4.508	14.34455	0.84018	0.04253	0.08619	1.52407	2.51991
0.5600	0.54145	0.11812	59.278	4.217	14.34741	0.97169	0.05919	0.08062	1.42577	2.71391
0.6000	0.57510	0.13973	55.263	3.971	14.35063	1.11223	0.08039	0.07592	1.34260	2.90794
0.6400	0.60710	0.16371	51.001	3.763	14.35419	1.26082	0.10675	0.07194	1.27215	3.10202
0.6800	0.63717	0.19007	46.503	3.586	14.35811	1.41722	0.13885	0.06856	1.21243	3.29615
0.7200	0.66503	0.21875	41.781	3.437	14.36238	1.58091	0.17711	0.06571	1.16199	3.49033
0.7600	0.69038	0.24968	36.849	3.312	14.36698	1.75130	0.22179	0.06332	1.11969	3.68458
0.8000	0.71291	0.28272	31.724	3.208	14.37189	1.92770	0.27294	0.06134	1.08466	3.87889
0.8400	0.73235	0.31766	26.425	3.124	14.37709	2.10938	0.33032	0.05973	1.05626	4.07327
0.8800	0.74843	0.35427	20.974	3.058	14.38255	2.29554	0.39343	0.05847	1.03396	4.26772
0.9200	0.76092	0.39225	15.394	3.009	14.38820	2.48528	0.46145	0.05753	1.01739	4.46224
0.9600	0.76961	0.43128	9.710	2.977	14.39402	2.67770	0.53332	0.05691	1.00639	4.65684
1.0000	0.77437	0.47098	3.951	2.960	14.39994	2.87180	0.60771	0.05658	1.00053	4.85153
1.0400	0.77510	0.51096	-1.855	2.958	14.40590	3.06660	0.68316	0.05655	1.00000	5.04629
1.0800	0.77178	0.55080	-7.677	2.972	14.41185	3.26107	0.75811	0.05682	1.00472	5.24113
1.1200	0.76444	0.59010	-13.485	3.002	14.41771	3.45420	0.83102	0.05739	1.01478	5.43606
1.1600	0.75317	0.62846	-19.247	3.048	14.42344	3.64498	0.90048	0.05827	1.03038	5.63106
1.2000	0.73812	0.66551	-24.933	3.111	14.42898	3.83246	0.96525	0.05948	1.05178	5.82614
1.2400	0.71952	0.70090	-30.512	3.193	14.43427	4.01571	1.02437	0.06104	1.07937	6.02129
1.2800	0.69760	0.73434	-35.956	3.294	14.43927	4.19385	1.07717	0.06298	1.11368	6.21651
1.3200	0.67264	0.76559	-41.238	3.418	14.44394	4.36610	1.12331	0.06534	1.15536	6.41180
1.3600	0.64497	0.79445	-46.333	3.565	14.44926	4.53173	1.16271	0.06816	1.20530	6.60714
1.4000	0.61488	0.82079	-51.218	3.741	14.45220	4.69009	1.19560	0.07151	1.26462	6.80254
1.4400	0.58271	0.84454	-55.874	3.948	14.45575	4.84063	1.22240	0.07548	1.33477	6.99800
1.4800	0.54876	0.86567	-60.281	4.193	14.45892	4.98284	1.24369	0.08017	1.41766	7.19350
1.5200	0.51333	0.88421	-64.426	4.484	14.46169	5.11634	1.26015	0.08572	1.51581	7.38904
1.5600	0.47668	0.90024	-68.295	4.829	14.46409	5.24077	1.27252	0.09232	1.63260	7.58461
1.6000	0.43907	0.91384	-71.878	5.244	14.46612	5.35586	1.28151	0.10024	1.77269	7.78021
1.6400	0.40072	0.92517	-75.166	5.746	14.46782	5.46140	1.28781	0.10985	1.94260	7.97584
1.6800	0.36180	0.93438	-78.152	6.365	14.46920	5.55723	1.29204	0.12168	2.15178	8.17149
1.7200	0.32247	0.94166	-80.832	7.142	14.47029	5.64323	1.29473	0.13653	2.41439	8.36716
1.7600	0.28286	0.94719	-83.202	8.142	14.47112	5.71930	1.29633	0.15566	2.75267	8.56284
1.8000	0.24306	0.95120	-85.259	9.476	14.47171	5.78535	1.29721	0.18116	3.20351	8.75853
1.8400	0.20315	0.95388	-87.001	11.338	14.47212	5.84146	1.29764	0.21675	3.83294	8.95422
1.8800	0.16318	0.95546	-88.427	14.115	14.47235	5.88750	1.29781	0.26984	4.77180	9.14992
1.9250	0.12319	0.95615	-89.537	18.698	14.47245	5.92348	1.29785	0.35745	6.32101	9.34563
1.9600	0.08319	0.95618	-90.330	27.688	14.47245	5.94942	1.29786	0.52932	9.36030	9.54133

EA652 VARIABLE WEIGHT TEST EA552

S/L	R/L	Z/L	THETA	TAUM	T/P	A/L2	V/L3	SIGMA	RATIO	A*/L2
2.0000	0.04319	0.95576	-90.806	53.328	14.47239	5.96530	1.29785	1.01949	18.02826	9.73703
2.0400	0.00320	0.95512	-90.966	720.427	14.47229	5.97113	1.29785	13.77263	243.54985	9.93273
2.0432	0.00000	0.95507	-90.965	1440.449	14.47228	5.97116	1.29785	27.54132	487.03027	9.94937

COMPUTED F/P = 0.24386

VOL = 1.29785 1.+W/P = 1.30487

SIGMA-MIN = 0.056550

K * SIGMA-MIN = 0.030646

B

Note that arc length S/λ is provided in increments of .04 except for the last increment which is .0032 for this case. This value was selected for the last increment because it was desired to have the radius return exactly to 0 or to the centerline of the balloon. Theta, or the angle of each increment as measured from the positive vertical (up) axis to the increment, is provided in the fourth column. The next four columns include non-dimensional stress, total film load, and accumulated area and volume. Note that L2 and L3 are used to indicate λ^2 and λ^3. The value of Σ compatible with τ_m, R/λ, and material strength is provided in the next column. The column signified by RATIO is simply a ratio of the particular value of τ_m to the minimum value of τ_m shown in a previous column. The ratio $\frac{\tau_m}{\tau_{m}\text{min.}}$ is the same as $\frac{\Sigma}{\Sigma\text{min.}}$ except when $\Sigma = 0$, the case of a weightless balloon. The last column is accumulated non-dimensional area of the gore layout if the material as specified by $\Sigma_{min.}$ is utilized throughout the entire surface. More useful than this, it provides a check on the total weight of material necessary at any point in the balloon simply by utilizing the minimum weight material as a multiplier times this A'/λ^2 column. Although this column is produced under a separate integral, it is essentially the accumulated product of A/λ^2 and RATIO for each increment.

To eliminate confusion about the trivial points where $\tau_m = \infty$ at the location where R = 0, the term has arbitrarily been set equal to 0. The factors sigma and ratio have also been set equal to 0 when R = 0.

Final values for check purposes are included at the bottom of the page. The term VOL is actually V/λ^3 which should be equal to 1 + W/P for the exact solution. The values of $\Sigma_{min.}$ and $K\Sigma_{min.}$ are included. Note that $K\Sigma_{min.} = \frac{W}{b\lambda}$.

Accuracy of the program can be changed at any time simply by specifying different check limits for $\frac{F}{P}$ and θ_o. For the present purpose, however, the accuracy provided is adequate.

USE OF DESIGN TABLE

As a demonstration of the use of the Balloon Design Table, the following example is given:

GIVEN:

1. Payload = 10,000 lbs.
2. Altitude = 50,000 ft.
3. Wind Velocity = 197.0 ft./sec.

General Material Properties

4. C_{QB} = .000043/ft. (Weight/Strength)
5. SF = 3 (Safety Factor)

REQUIRED:

1. Balloon Shape
2. Balloon Area and Volume
3. Balloon Material and Weight

Solution

1. Determine Input Parameters

   a. Tentatively choose $\frac{F}{P} = .25$.

   (This is an arbitrary choice at this point)

   b. $\lambda = \frac{P}{b}^{1/3} = \frac{10,000}{.01}^{1/3} = 100.0$

   $b = .01$ for Alt $= 50,000$ ft.

   c. $\alpha = \frac{a}{\lambda}$, $a = \frac{q}{b}$

   $q = 1/2 \rho v^2$

   $\rho = .0003639$

   $$\alpha = \frac{1/2(.0003639)(197.0)^2}{.01(100)}$$

   $\alpha = 7.00$

   d. $\beta = C_{SF}\lambda = SF(C_{qB})\lambda$

   $\beta = 3(.0000345)(100)$

   $\beta = .01036$

2. Select Proper Design Table for

   $\frac{F}{P} = .25$

   $\alpha = 7.00$

   $\beta = .01036$

   Table C.2 presents values closely approximating these.

3. Inflated shape may be determined from the first three columns of the design table by multiplying the non-dimensional factors by λ. e.g.

Total arc length = 2.0432(100) = 204.32'

Max radius = .77510(100) = 77.51'

Max height = .95618(100) = 95.62'

4. Balloon area and volume are:

Surface area of inflated shape = $5.9653(100)^2$ = 59,653 $ft.^2$

Volume of balloon = $1.29785(100)^3$ = 1,297,850 $ft.^3$

5. Balloon material

Several gore layout schemes are available including tapered and stepped skin thicknesses. The use of uniform thickness material, however, is most practical from the standpoint of construction and will be considered here. For this solution, fullness is required at every gore station after inflation except at the max radius of the shape. The uniform thickness material to be used must be determined from the minimum value of Σ as:

w = K (sigma-min) (b λ)

= .030646 (.01 x 100)

w = .0306 psf.

Gore design here would be obtained by determining the total gore layout circumference at every station.

Circ = $2\pi(R/\lambda)$ (Ratio) λ

for example at $S/\lambda = .20$.

Circ = $2\pi(.19942)$ (3.867) (100)

= 485 ft.

It may be noted that the gore layout circumferences at every station is nearly constant. This may be expected by observing that the total film load ($\frac{T}{P}$) is nearly constant. Thus the amount of material required at every station is nearly constant. It may be seen that this design will result in a gore layout nearly that of a cylinder.

The total area of the balloon material is

$$A_m = \left(\frac{A'}{\lambda^2}\right)\lambda^2$$

$$= 9.948(100^2) = 99{,}480 \text{ ft.}^2$$

Total material weight is:

$$W = A_m\,(w)$$

$$= 994{,}800(.0306)$$

$$= 3{,}040 \text{ lb.}$$

The above design has the advantages of easy production and minimum weight, however, excess fullness occurs over the entire balloon even at float altitude. Further study into the effects of wrinkles on balloon drag should be conducted. The other methods of production suggested above would eliminate the excess fullness and resulting wrinkles at float altitude.

SECTION C-IV - GRAPHICAL PRESENTATION OF BALLOON PARAMETERS

To establish trends and visual relations between the various parameters, the following graphs were drawn. Some of the relations shown are determined from previously established relations while others are determined from a series of computer runs.

A. PAYLOAD VS. β

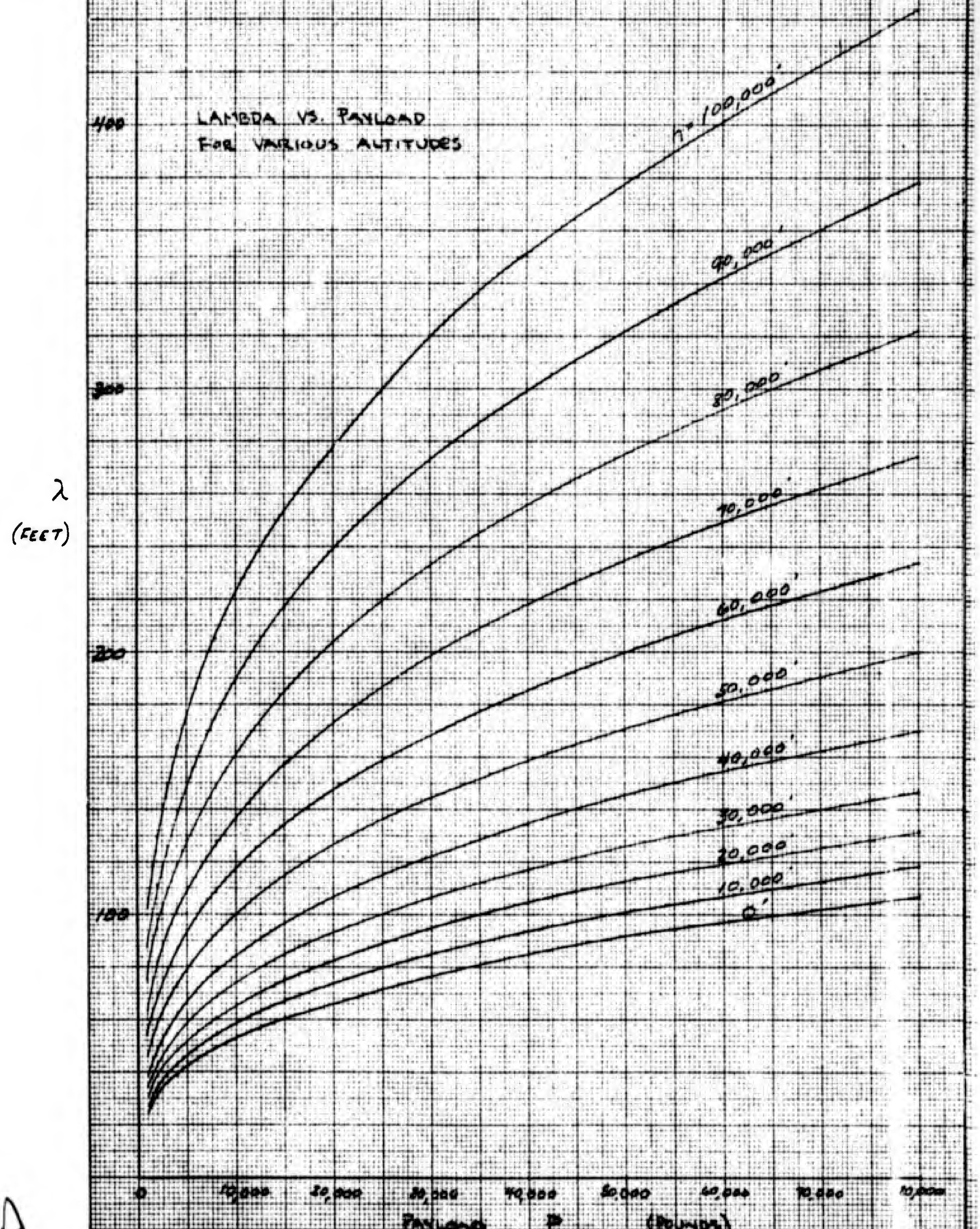
Figure C.3 provides a relation between payload P and material weight β. As an intermediate step, curves of λ versus P for various values of altitude h are shown. At each h, the amount lift b is determined such that the curves are plotted based on the equation

$$\lambda = (P/b)^{1/3}$$

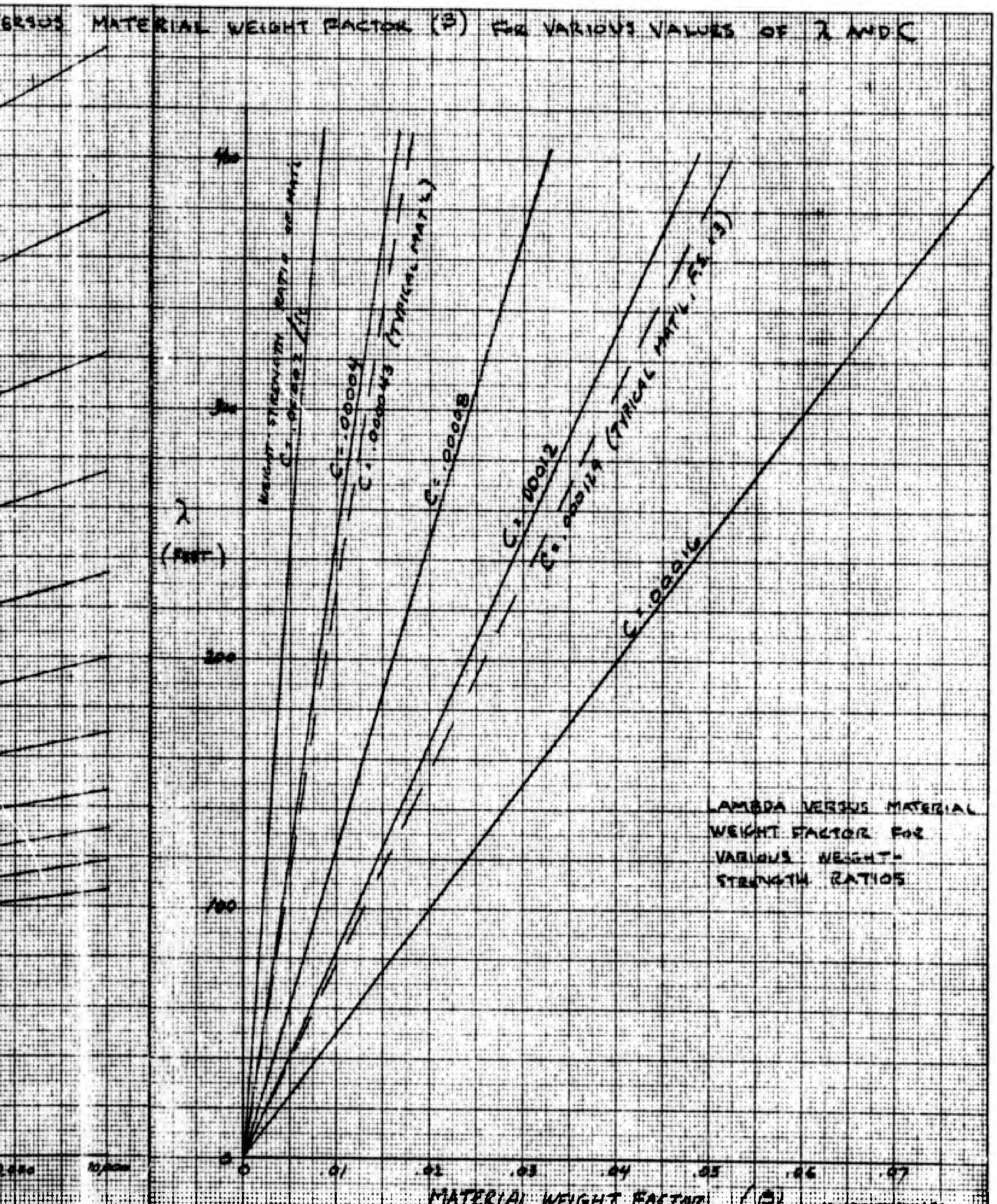
With this value of λ, the material weight factor β may be obtained for various weight-strength values (C) from the relation.

$$\beta = C\lambda$$

FIGURE C.3 PAYLOAD (P) VERSUS MATE



A


ERSUS MATERIAL WEIGHT FACTOR (β) FOR VARIOUS VALUES OF λ AND C
WEIGHT STRENGTH RATIO OF MAT'L
C = .00004
C = .000043 (TYPICAL MAT'L)
C = .00008
C = .00012
C = .000129 (TYPICAL MAT'L
C = .00016
λ (FEET)
400
300
200
100
0
0
.01
.02
.03
.04
.05
.06
.07
MATERIAL WEIGHT FACTOR (β) NONDIMENSIONAL
LAMBDA VERSUS MATERIAL WEIGHT FACTOR FOR VARIOUS WEIGHT-STRENGTH RATIOS

B

B. BALLOON WEIGHT VS. α

Balloon weight may be obtained from Figure C.4. Here values of $\frac{W}{P}$ versus α for various values of β and F/P are shown. These curves were obtained from computer runs. Balloon weight may be easily obtained from the product of the $\frac{W}{P}$ value and P.

$$W = \left(\frac{W}{P}\right) P$$

Balloon volume may also be easily obtained using the value of $\left(\frac{W}{P}\right)$ and a relation developed as shown below. The volume of gas must lift the payload P and the weight W, therefore:

$$\forall = \frac{(P + W)}{b}$$

$$= \frac{(P + W)\ P}{P\ (b)}$$

$$= \left(1 + \frac{W}{P}\right) \left(\frac{P}{b}\right)$$

$$\forall = \left(1 + \frac{W}{P}\right) \lambda^3$$

C. BALLOON PROFILE

Balloon geometry, as obtained from the computer runs, is shown in the following figures. Figures C.5, C.6 and C.7 show the variation in shape of the meridian in a non-dimensional form by plotting Z/λ versus R/λ for:

a.	$\beta = 0$	$\alpha \approx .400$	F/P varies	(Fig. C.5)
b.	$\beta = 0$	α varies	F/P = .99	(Fig. C.6)
c.	β varies	$\alpha = .500$	F/P = .99	(Fig. C.7)

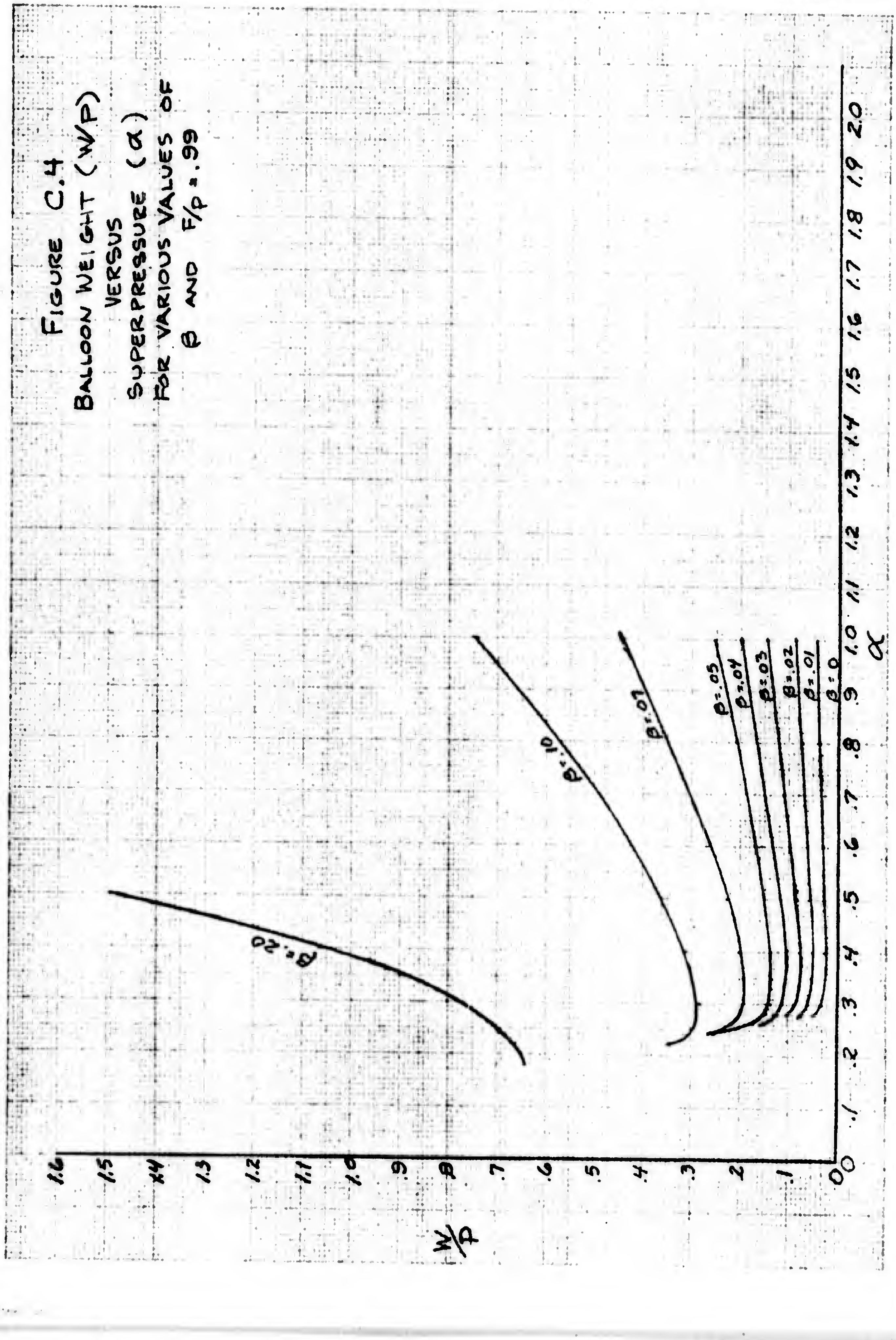


FIGURE C.4
BALLOON WEIGHT (W/P) VERSUS SUPERPRESSURE (α) FOR VARIOUS VALUES OF β AND F/ρ = .99

FIGURE C.5
BALLOON SHAPE
AS
F/p VARIES

ZERO N_θ BALLOON SHAPE
FOR
VARIABLE F/p
≈ CONSTANT α (.364 & .400)
CONSTANT β = 0

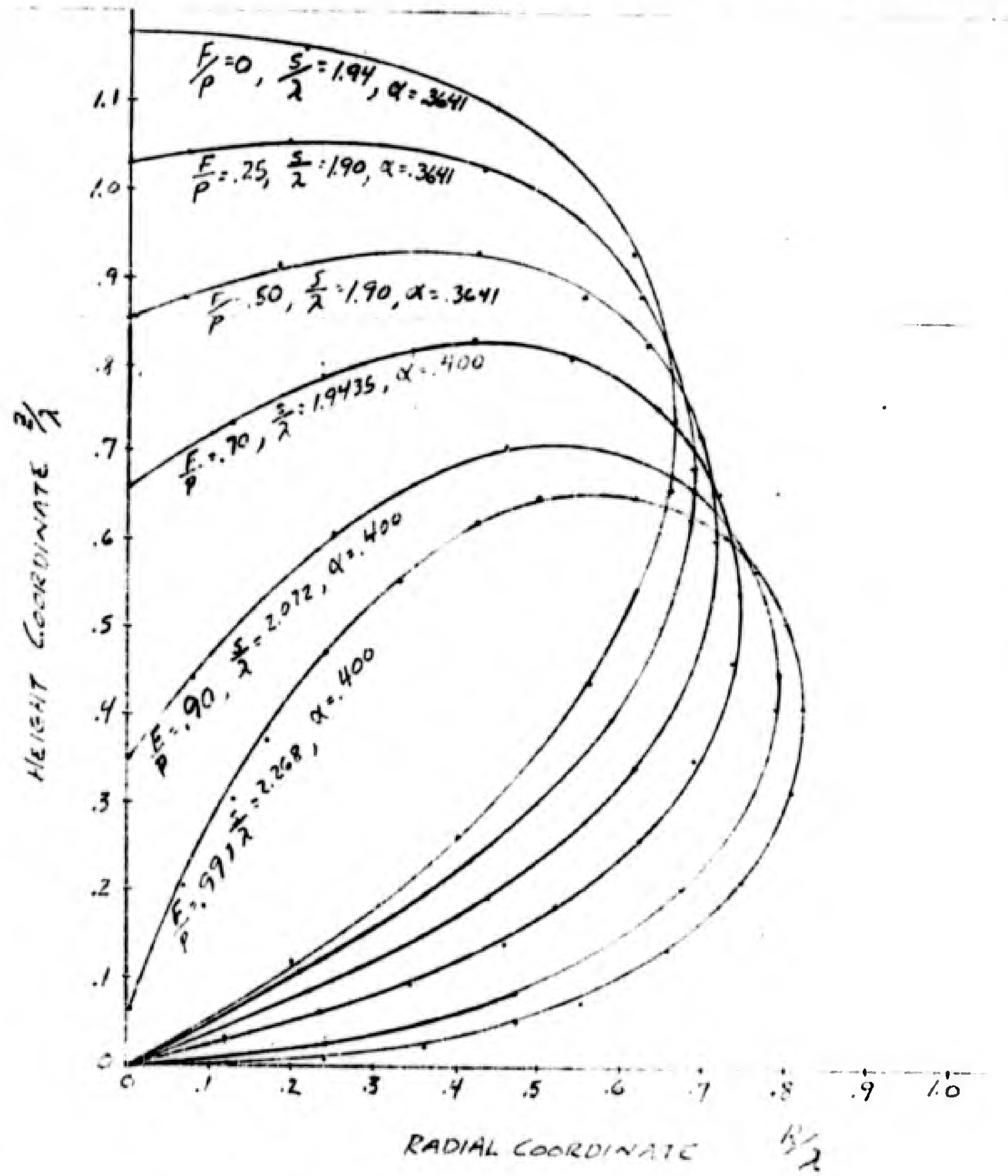
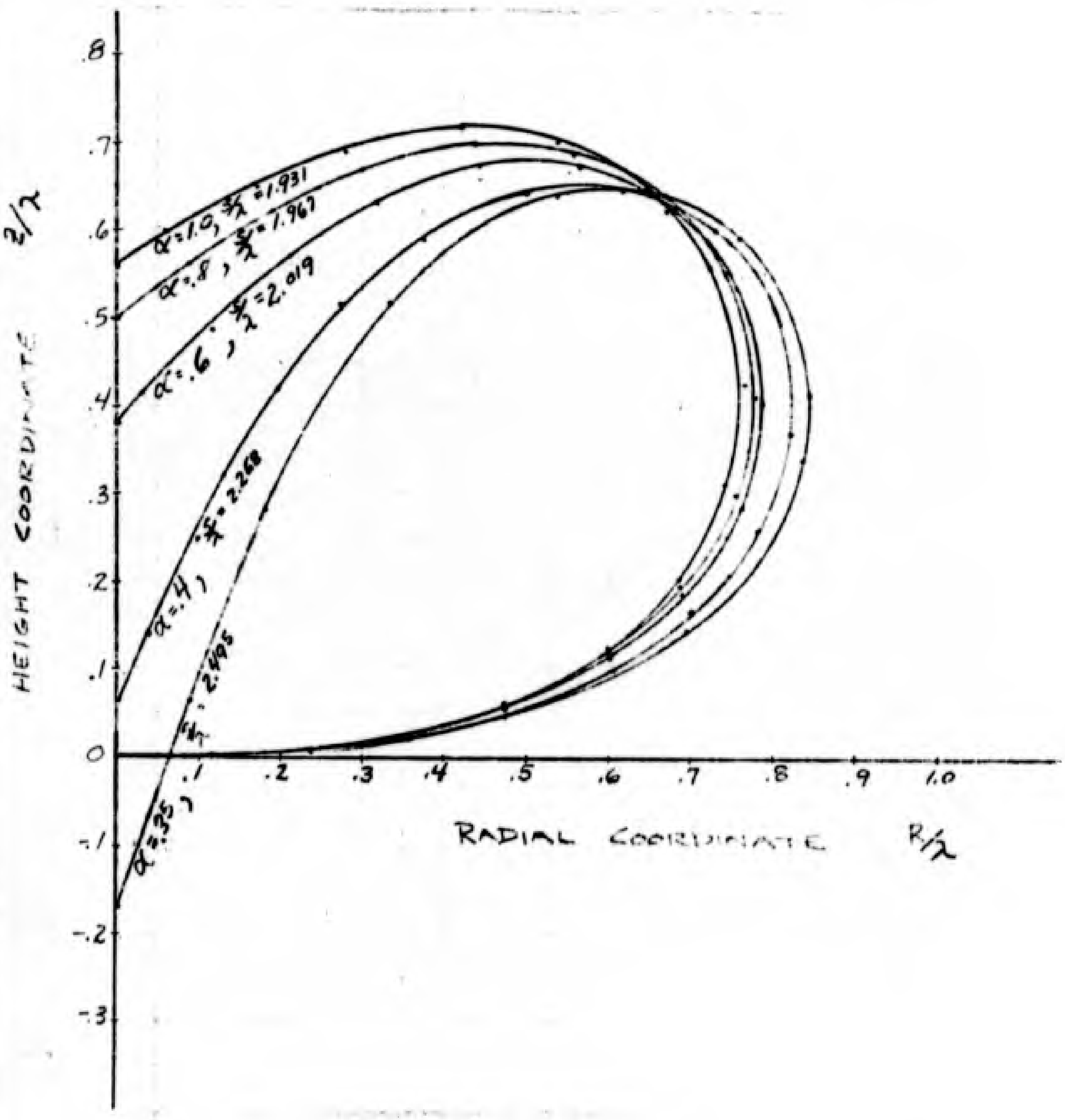


FIGURE C.6
BALLOON SHAPE
AS
α VARIES

ZERO No BALLOON SHAPE
FOR
VARIABLE α
CONSTANT F/p = .99
CONSTANT β = 0



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CORPORATION

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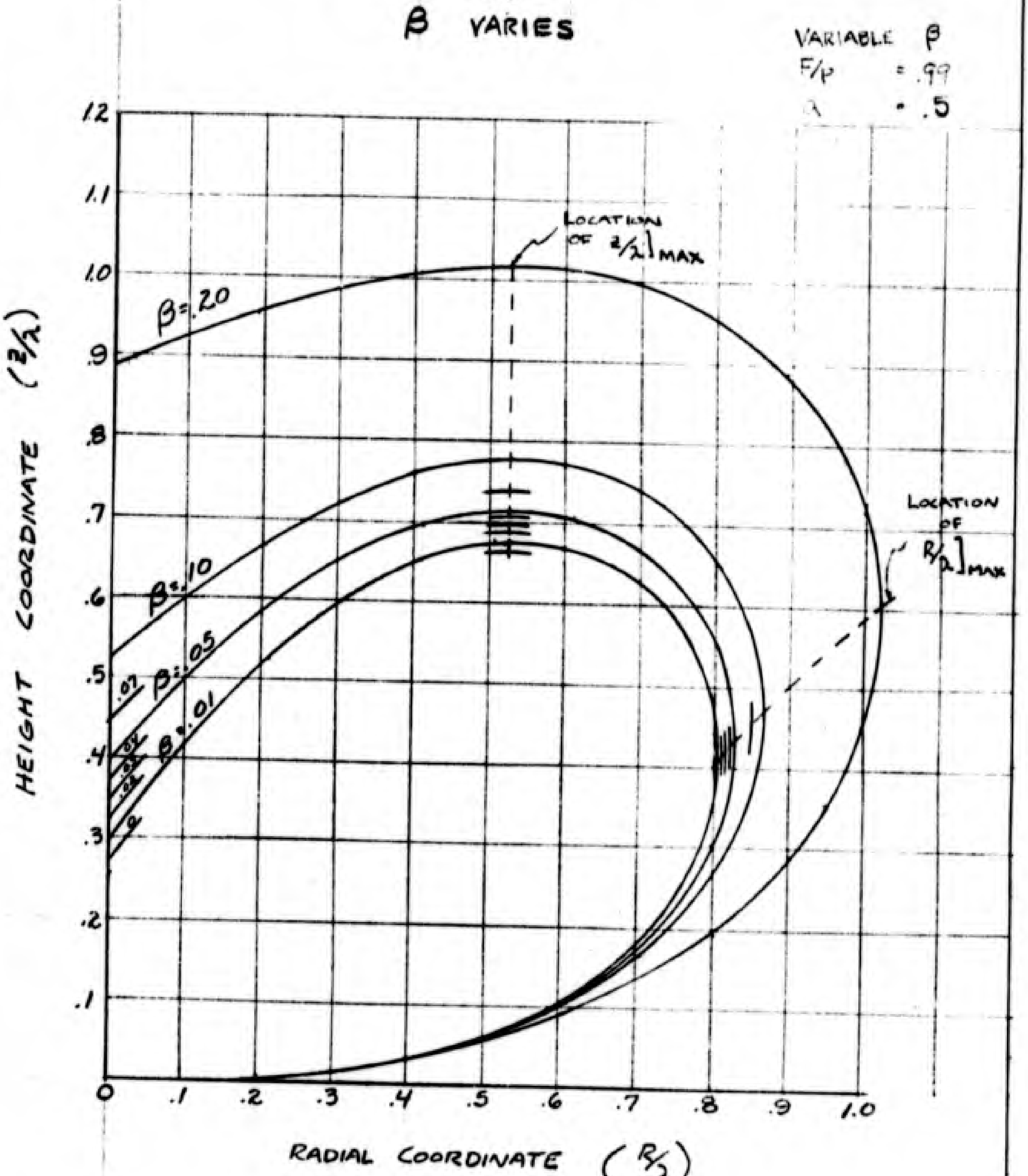
FIGURE C.7
BALLOON SHAPE
AS
β VARIES



REF: ENGRG PROCEDURE S-017
Z-ID-37(7-3-64)(213-83)

D. OTHER GEOMETRIC FACTORS

Curves of $S/\lambda]_{final}$ versus α for various β and F/P values are shown in Figures C.8, C.9 and C.10. Note that $S/\lambda]_f$ tends to become very large in the vicinity of $\alpha = .30$ for F/P = .99. As may be seen from Figure C.6, the top end of the balloon pulls through the bottom at values of α in this range such that the arc length required becomes large.

Figures C.11, C.12, C.13 respectively plot $R/\lambda]_{max.}$, $Z/\lambda]_{max.}$ and $Z/\lambda]_{final}$ versus α for $\beta = 0$ and F/P = .99.

SECTION C-V - CYLINDER BALLOON CONCEPT ... THEORY AND ECONOMY

ECONOMY

As was noted in the computer example of Section C-III, the total film load $\frac{T}{P}$ is nearly constant throughout the arc length S/λ. Figure C.14 plots $\frac{T}{P}$ versus S/λ for different values of α, β and F/P as shown. For the cases where the film load is nearly constant, a cylinder balloon (or slightly tailored cyl) of constant material thickness would provide the minimum weight design. This is true provided that the stresses occurring in the balloon are sufficiently large enough to require material equal to or greater than the minimum gage available. The minimum weight solution, when a gage less than the minimum occurs, is presented in Section C-VII.

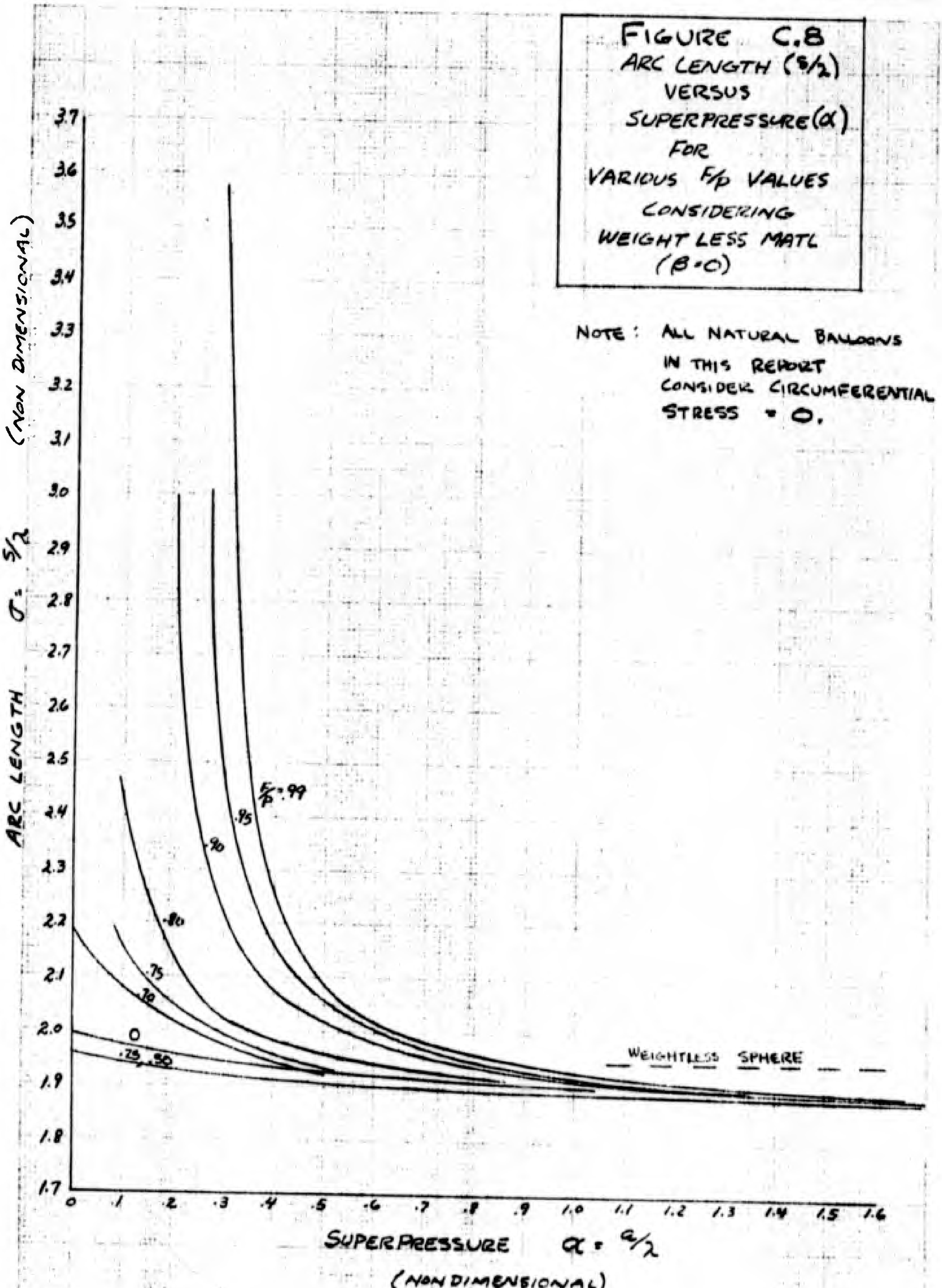


FIGURE C.8
ARC LENGTH (S/2) VERSUS SUPERPRESSURE (α) FOR VARIOUS F/p VALUES CONSIDERING WEIGHT LESS MATL (β = 0)
NOTE: ALL NATURAL BALLOONS IN THIS REPORT CONSIDER CIRCUMFERENTIAL STRESS = 0.
ARC LENGTH σ = S/2 (NON DIMENSIONAL)
SUPERPRESSURE α = a/λ (NON DIMENSIONAL)
WEIGHTLESS SPHERE
F/p = .99
.95
.90
.80
.75
.70
0
.25
.50
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6

FIGURE C.9
MAGNIFIED FIGURE OF ARC LENGTH (s/λ) VERSUS SUPERPRESSURE (α) AS β VARRIES

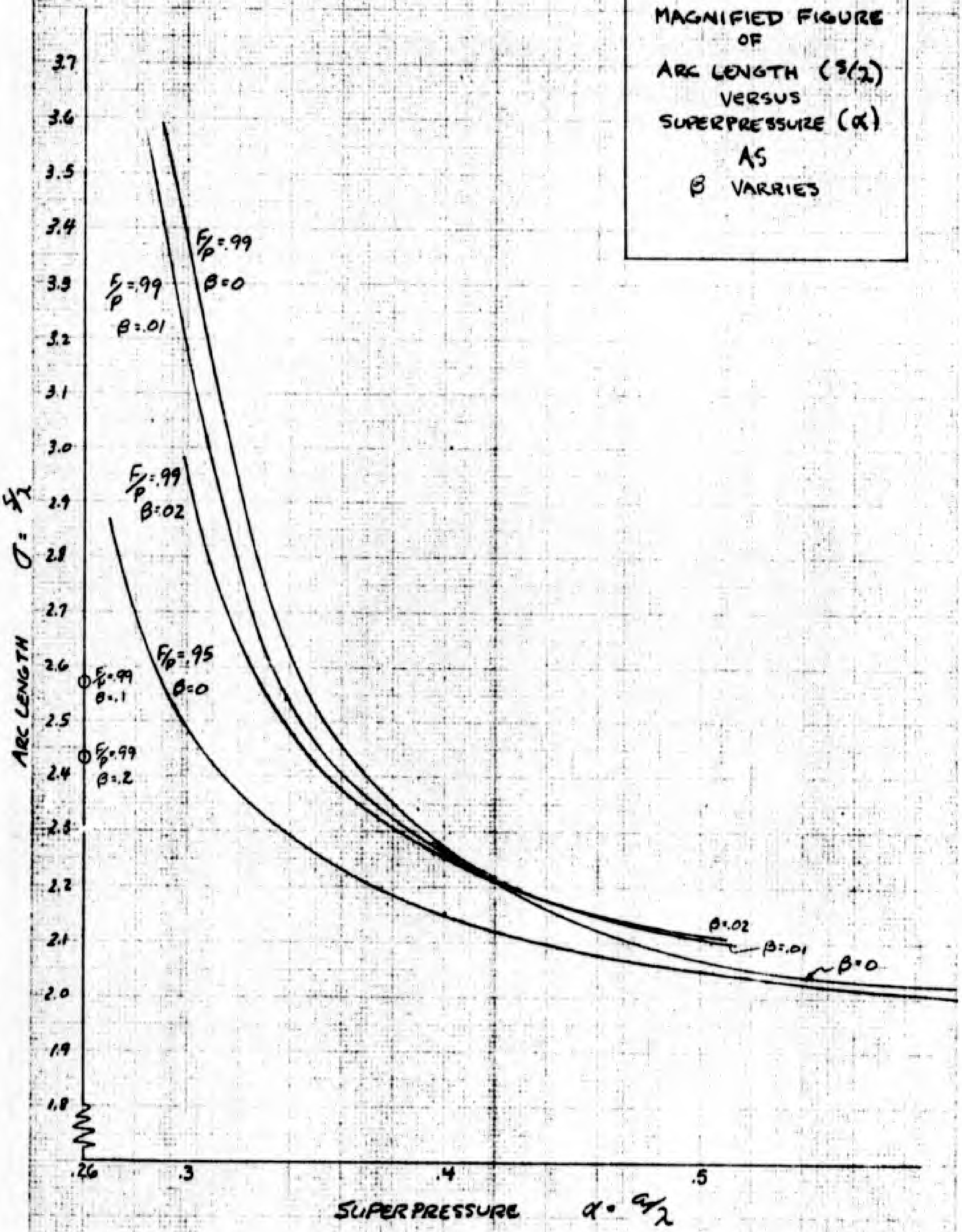
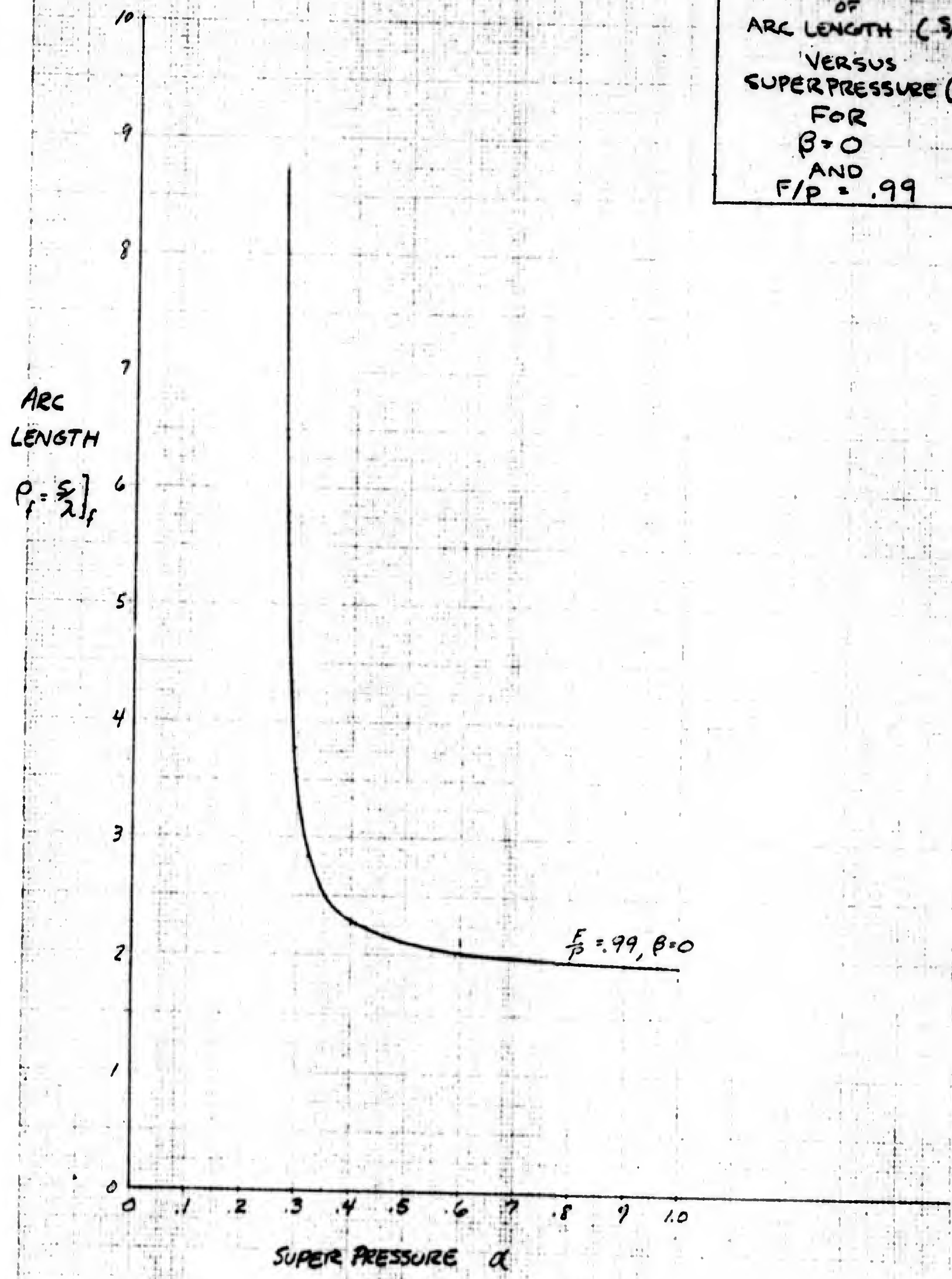


FIGURE C.10
EXTENDED CURVES OF ARC LENGTH (S/λ) VERSUS SUPERPRESSURE (α) FOR β = 0 AND F/p = .99



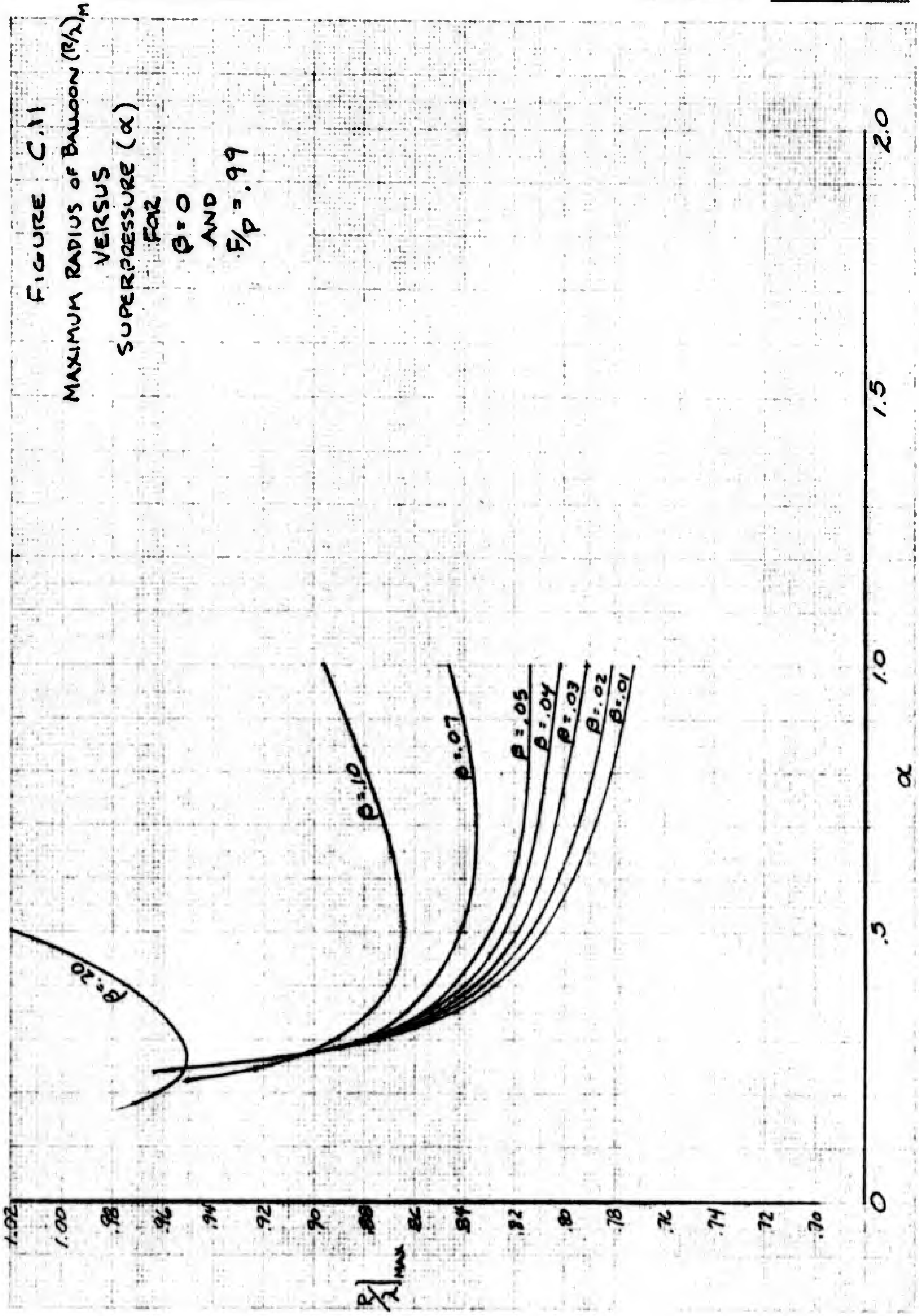


FIGURE C.11
MAXIMUM RADIUS of BALLOON $(R/\lambda)_M$
VERSUS
SUPERPRESSURE (α)
FOR
$\beta = 0$
AND
$F/P = .99$
$\beta = .20$
$\beta = .10$
$\beta = .07$
$\beta = .05$
$\beta = .04$
$\beta = .03$
$\beta = .02$
$\beta = .01$
$R/\lambda|_{MAX}$
1.02
1.00
.98
.96
.94
.92
.90
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
0
.5
1.0
1.5
2.0
α

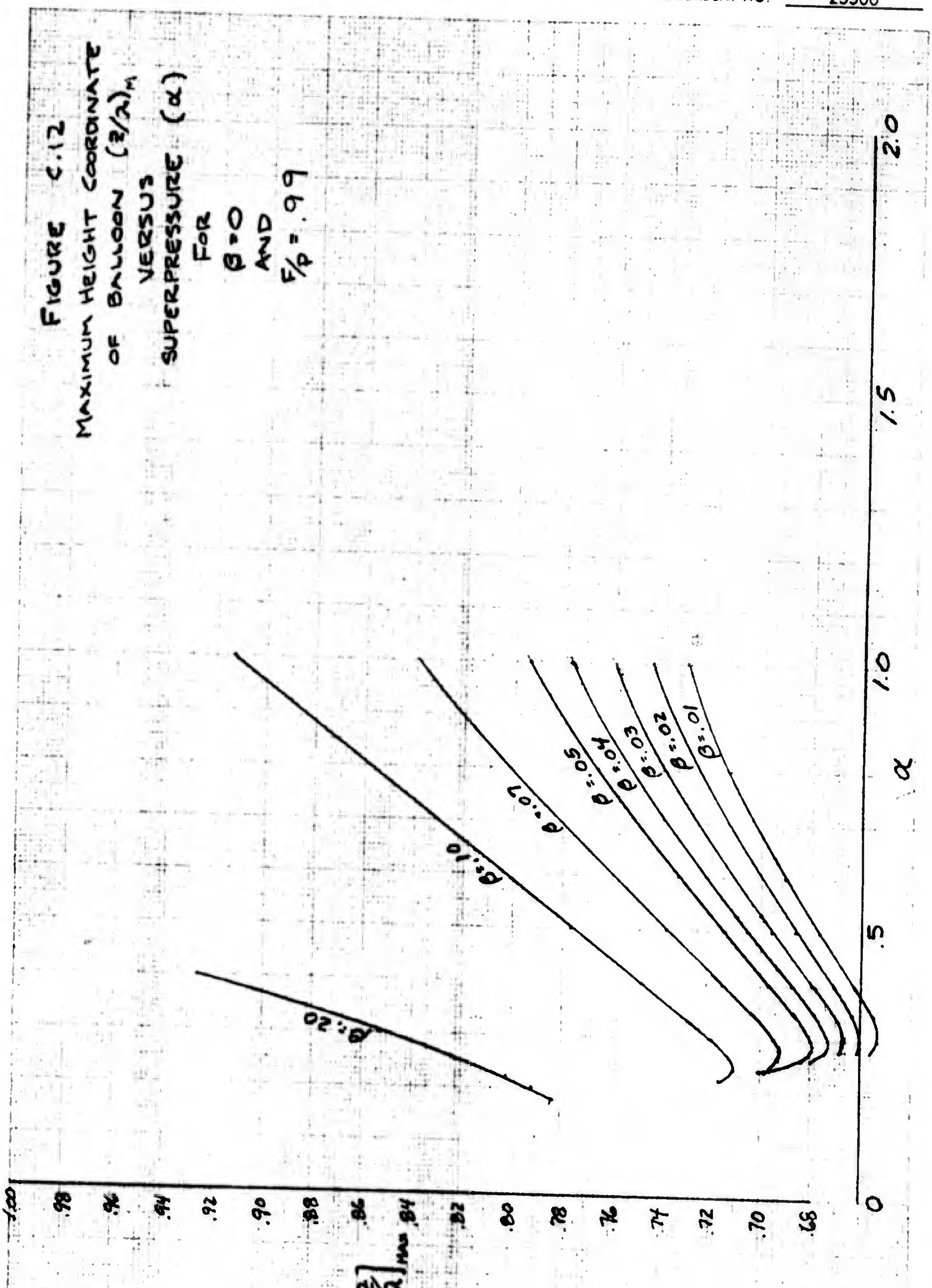


FIGURE C.12
MAXIMUM HEIGHT COORDINATE OF BALLOON $(z/\lambda)_M$ VERSUS SUPERPRESSURE (α) FOR $\beta = 0$ AND $F/P = .99$
$\beta = .20$
$\beta = .10$
$\beta = .07$
$\beta = .05$
$\beta = .04$
$\beta = .03$
$\beta = .02$
$\beta = .01$
$(z/\lambda)_{MAX}$
1.00
.98
.96
.94
.92
.90
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
.68
α
0
.5
1.0
1.5
2.0

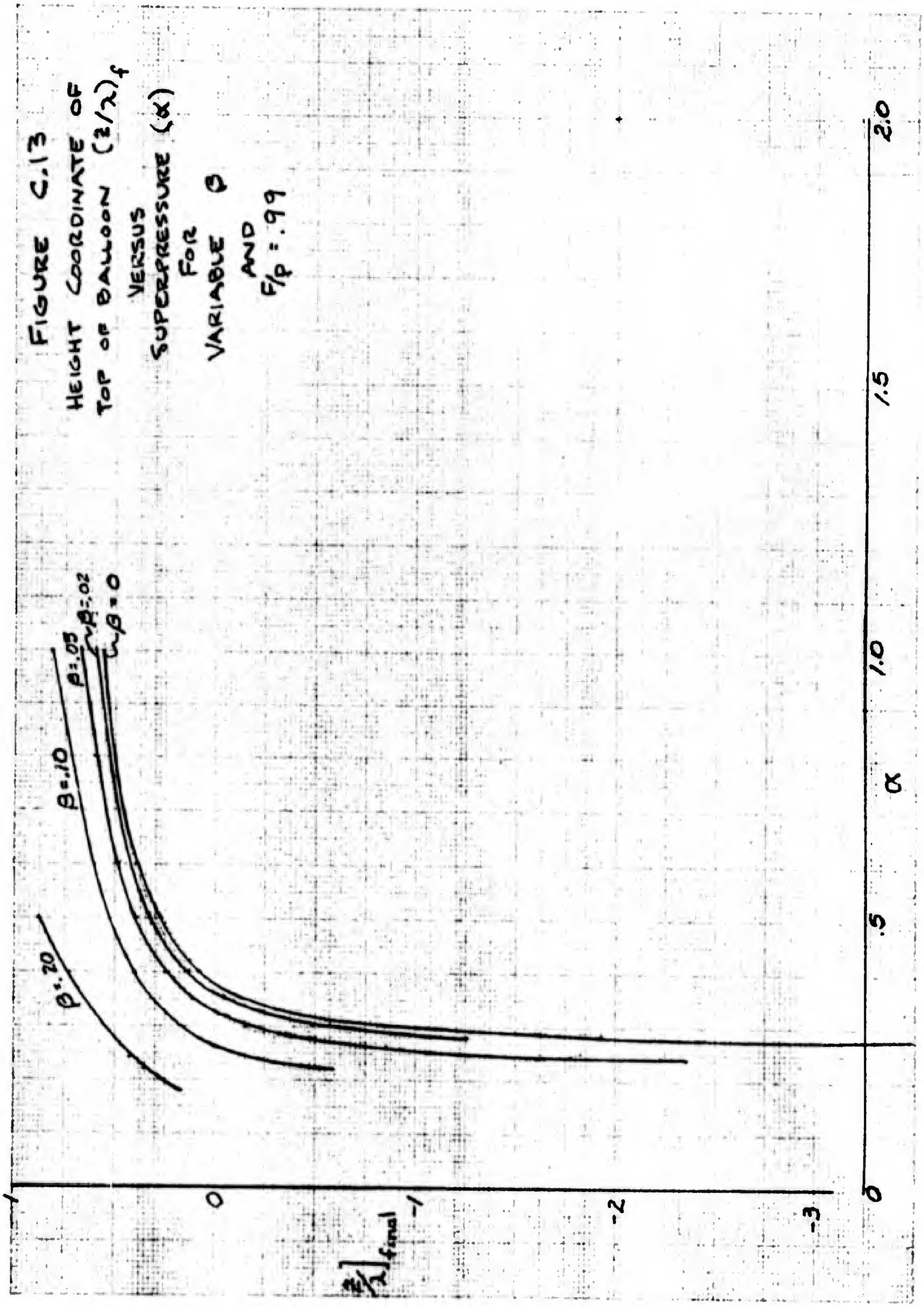


FIGURE C.13
HEIGHT COORDINATE OF
TOP OF BALLOON $(z/\lambda)_f$
VERSUS
SUPERPRESSURE (α)
FOR
VARIABLE β
AND
F/P = .99
β=.20
β=.10
β=.05
β=.02
β=0
$z/\lambda]_{final}$
1
0
-1
-2
-3
0
.5
1.0
1.5
2.0
α

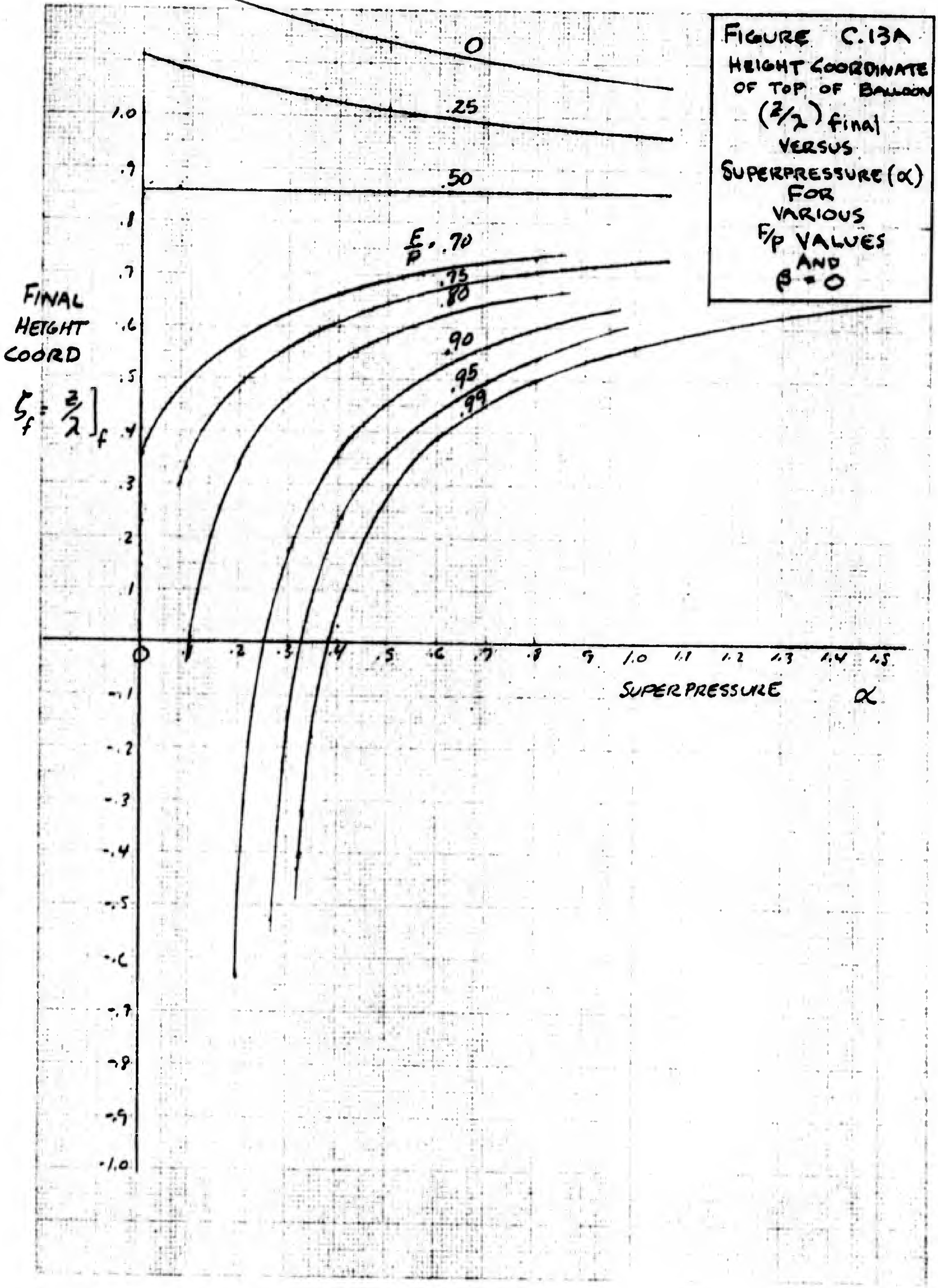


FIGURE C.13A
HEIGHT COORDINATE OF TOP OF BALLOON
(z/λ) final
VERSUS
SUPERPRESSURE (α)
FOR
VARIOUS
F/P VALUES
AND
β = 0
FINAL HEIGHT COORD
ζf = z/λ]f
SUPERPRESSURE α
E/P = .70
.75
.80
.90
.95
.99
0
.25
.50

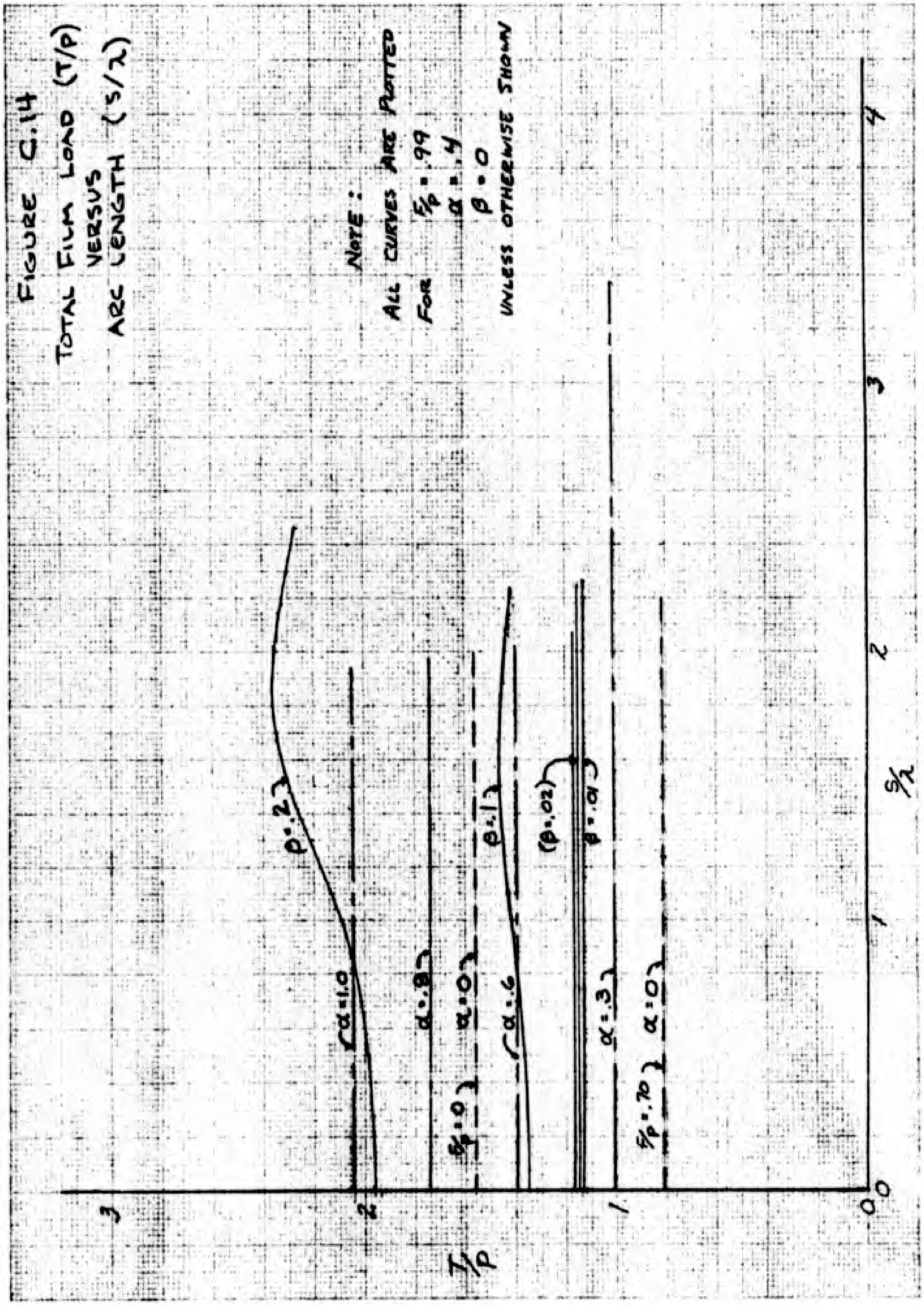


FIGURE C.14
TOTAL FILM LOAD (T/p) VERSUS ARC LENGTH (s/λ)
NOTE:
ALL CURVES ARE PLOTTED
FOR f/p = .99
α = .4
β = 0
UNLESS OTHERWISE SHOWN
β = .2
α = 1.0
α = .8
f/p = 0
α = 0
β = .1
α = .6
(β = .02)
β = .01
α = .3
f/p = .70
α = 0
T/p
s/λ
0
1
2
3
4

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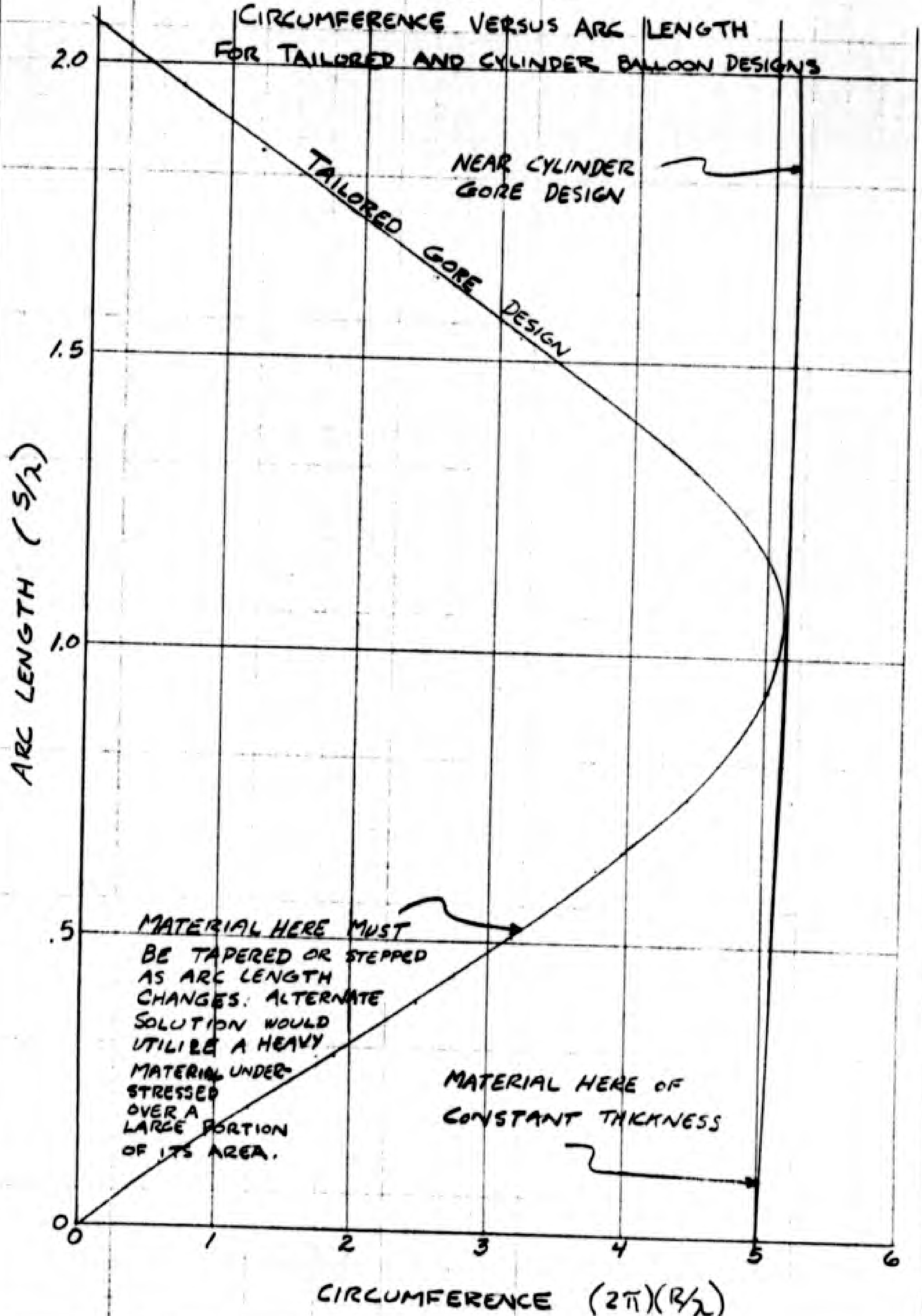
This near cylinder (hereafter called cylinder) shape, of course, must be tied together at its ends to fittings as desired. As the balloon is inflated, the typical natural shape will occur. The excess material present at every station (except possibly at max. radius) will allow fullness to exist. Upon full inflation of the tailored balloon, generally no fullness or excess material is present at any location. Figure C.15 depicts the cylinder and tailored balloon layout pattern.

Cylinder construction thus is the minimum weight configuration possible for cases requiring material gages equal to or greater than minimum gage material. Minimum weight also results in minimum material cost. Construction cost is also minimal since a fully tailored gore pattern is replaced by the rectangular or very slightly tailiored gore. Aerodynamically, both balloons have excess fullness and correspondingly higher drag at altitudes below float. At float altitude, the cylinder design still retains considerable fullness over a large portion of its area; however, for high altitude applications dynamic pressure is generally orders of magnitude below the maximum dynamic pressure encountered on ascent or descent, thus the importance of excess fullness is reduced.

FIGURE C.15

CIRCUMFERENCE VERSUS ARC LENGTH FOR TAILORED AND CYLINDER BALLOON DESIGNS



SECTION C-VI - REEFING ACCOMPLISHED BY TOP LOADING SCHEME

Reefing of the natural balloon is desired to maintain excess material (needed for expansion) in a compact manner. Being compact will eliminate unnecessary drag caused by loose material spread over a large area and will prevent overstressing, tearing or flagging of loose material as the balloon is subjected to high dynamic pressure. Many systems of reefing have been suggested, but in general they can be utilized only during expansion and not during contraction. In addition, these systems usually require extra and/or elaborate equipment and power sources to operate the reefing mechanism.

A system utilizing a high percentage of top loading requires little and inexpensive excess equipment, provides for reefing during ascent or descent (expansion or contraction), and requires no excess power. The geometry of the system is such that gravity is utilized in a manner that automatically forces reefing while it maintains the volume in a compact form. In addition to reefing the material, this loading system also provides a bonus, superpressure. That is, a superpressure is automatically induced on the gas volume due to the geometry of the system. This superpressure, although not great, provides an insight into the problem of attaining much higher superpressures as covered in Section VIII.

The items necessary to permit this reefing concept include a bottom ring*, a top cable attachment and a superpressure sleeve as shown in Figure C.16.

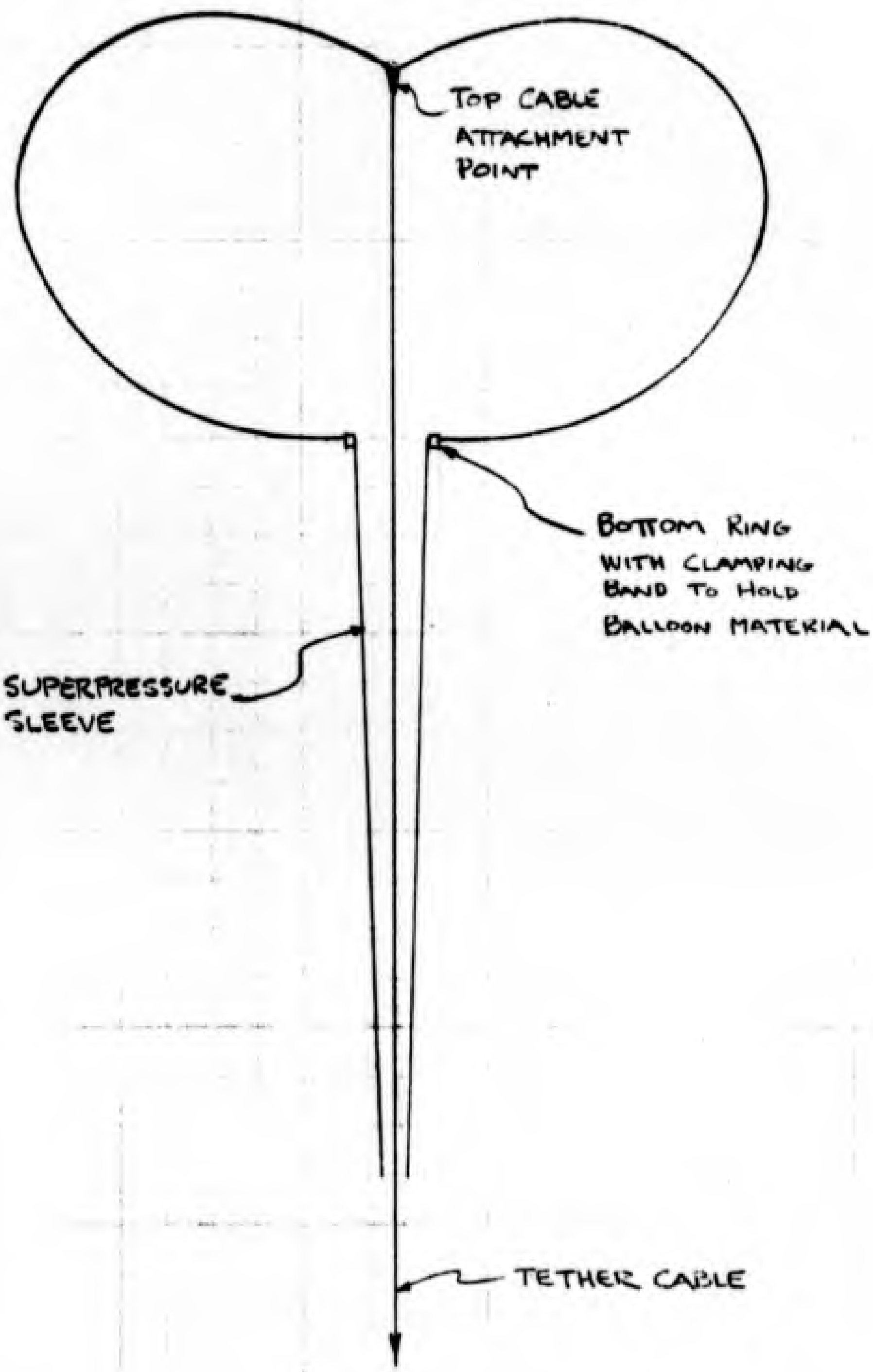
Examples of the shapes occurring with this scheme are provided in Figure C.6. Note that F/P = .99 and ß = 0. F/P = .99 was chosen for representation since the entire tether load would be applied to the top of the balloon while only a small load, that of the bottom end ring, would be applied at the bottom. It was estimated that this bottom ring would represent approximately 1% of the total applied load. Figures C.8, C.9 and C.10 show that the curves represented by ß = 0 are not far different than those representing small values of ß (0 to .1).

It might be noted that the conventional bottom loaded balloon (F/P = 0) provides for volumetric expansion but in doing so allows the excess or expansion material to form in a conical shape which extends from the payload to a point tangent to the gas bubble.

* It is noted here that the diameter of the bottom ring is dependent on the maximum diameter of the material which pulls through this ring. This maximum diameter can be determined from computer runs, and would occur when the gas volume is smallest, that is the lowest altitude position of the balloon. As may be seen from the design of the model as shown in Section IX, the bottom ring may become respectively quite large. For full scale models it is felt that the size of this ring could be reduced considerably if desired. This reduction would, of course, cause the balloon material to come in contact with the ring. Frictional resistance could be minimized by providing rollers around the perimeter of the ring.

FIGURE C.16

REEFING SYSTEM COMPONENTS



Here a large drag area is subjected to wind forces which may cause serious problems. If the balloon were top loaded, essentially this conical shaped element of material is replaced by a densely reefed meridian located nearly coincident with the vertical axis of symmetry of the balloon.

To determine the shape, superpressure, stresses, etc., of the balloon at altitudes below float, a new consideration of the basic parameters must be made. Previously the parameters selected were $\frac{F}{P}$, α, and β. For a first pass at design and for float altitude consideration these factors remain the necessary items. Once the size parameter (λ) has been established, an additional item, arc length (s_{total}), has also been established. For reefing methods as suggested in this section, the arc length established at float altitude will, of course, be the arc length necessary at all altitudes. This suggests a new set of factors necessary to examine the balloon at other altitudes, namely F/P, s/λ, and β. Here the value of α compatible with the above factors can be determined. Hence, α is dependent and may not be selected at random.

An example is shown below to indicate the computation necessary to establish a shape and superpressure for a balloon at an altitude below float.

1. Select the balloon to be used at float altitude.
   a. $\frac{F}{P} = .99$

b. $\alpha = 1.00$

c. $\beta = 0$

$\alpha = 1.00$ was selected because it provides for a low value of arc length without a large value of superpressure as is evident from Figure C.10. (High superpressure would create high stresses.)

$\beta = 0$ is selected as representative of the shapes of lightweight balloons necessary for high altitude application.

Figure C.10 indicates that $s/\lambda = 1.93$ for this case.

If this balloon were to be designed to carry a payload P = 20,000 lbs. at a float altitude of h = 100,000 feet, the value of λ from Figure C.3 would be

$\lambda = 279$ feet.

The corresponding arc length is

$$s = (\frac{s}{\lambda})\lambda$$

$$= 1.93\ (279)$$

$$s = 539 \text{ ft.}$$

At altitude zero for the same payload, Figure C.3 yields

$\lambda = 67.1$

therefore, $\left.\frac{s}{\lambda}\right]_{h=0} = \frac{539}{67.1} = 8.03$

Returning to Figure C.10 with F/P = .99, $s/\lambda = 8.03$, and $\beta = 0$, the corresponding value of α is

$\alpha = .271$

or $a = \alpha\lambda$

$= .271\ (67.1) = 18.2$ ft. of helium.

this corresponds to an internal pressure of

$p_i = ab = 18.2\ (.0659) = 1.198$ psf

A practical understanding of curve C.8, C.9 and C.10 for S/λ versus α is realized by observing that during expansion, large changes in volume may occur which simply move the top fitting up or down along the centerline. The balloon material, however, is free to move without restriction, thus little change in superpressure occurs as represented by the near vertical line on the graphs. As the balloon moves to altitudes where the top end fitting approaches its highest point or what is equivalent as s/λ is approaching its lower limit near 1.9, the balloon material near the top attachment begins to form an angle of considerable size with the axis of symmetry. With this increasing angle comes increasing restriction to volume change, thus superpressure begins to increase rapidly. This portion of the curve is represented by the near horizontal line of Figure C.10.

It is noted that a change in balloon shape at float altitude may be accomplished by shifting from a top loaded to a bottom loaded balloon system. Aerodynamically one shape may be more desirable than another. Examples of these shapes are provided in Figure C.5.

The system required to accomplish this would consist of an internal cable system connecting the top and bottom of the balloon. These vertical cables would utilize a pulley and brake systems to control the distance between the top and bottom. Upon command the proper set of brakes could be released such that the tether load is applied to the top and/or bottom as desired, with the corresponding shape resulting as shown in Figure C5. It is noted that the force of gravity supplies the power required to change shape; the brake simply holds a particular position once it is attained.

SECTION C-VII - BALLOON DESIGN TABLES, GRAPHS, AND EXAMPLES

As was noted in Section CII and re-emphasized in Section CVI, three parameters must be specified to determine the shape of a natural balloon. Whether these parameters be F/P, α and Σ or F/P, s/λ and β or some other combination is immaterial. To completely define the balloon a fourth parameter, size (λ) must also be specified which will yield the volume, area, and dimensions of the balloon in a dimensional form.

The size parameter (λ) is generally defined at the onset of a problem when the payload (P) and float altitude buoyancy (b) are specified. The three shape parameters, however, may appear at this point to be arbitrary choices. Subtly the preceding sections have specified or related these parameters in such a manner that they are now no longer arbitrary. The top load parameter F/P must be large in order to accomplish reefing as presented in Section CVI. Although the exact or final value of F/P is not known, it may be approximated as:

$$\frac{F}{P} = .99$$

Superpressure (a) existant at float altitude is generally related to the maximum external dynamic pressure (q) that may occur as shown in Section CVIII. With a and

λ defined, α or the second shape parameter is thus also set as:

$$\alpha = \frac{a}{\lambda}$$

β is also defined by λ as shown before.

$$\beta = C\lambda \geq \beta_{min} \qquad (17)$$

Previous experience has shown that for the lighter payloads a minimum gage material governs the design. Noting this fact a new relation is established to provide the proper β factor for the balloon in these cases. Equation 14 provides the following relation

$$\Sigma = \frac{1}{K} \beta \Upsilon m$$

But,

$$\Sigma = \frac{1}{K} \frac{w}{b\lambda}$$

therefore,

$$\frac{w}{b\lambda} = \beta \Upsilon m$$

If the above parameters consider a constant thickness material, then the unit material weight (w) of the cylinder balloon may be computed utilizing Σ_{min} and Υm min for a particular computer run.

Therefore

$$\beta \Upsilon m]_{min} = \frac{w}{b\lambda}$$

The value of $\beta \Upsilon m]_{min}$ may now be computed with the knowledge of material weight (w) in addition to b and λ. β is then obtained from Figure C17 which provides a plot of β versus $\beta \Upsilon m]_{min}$ for various values of α and for F/P = .99. These curves are obtained from computer data of the natural balloon.

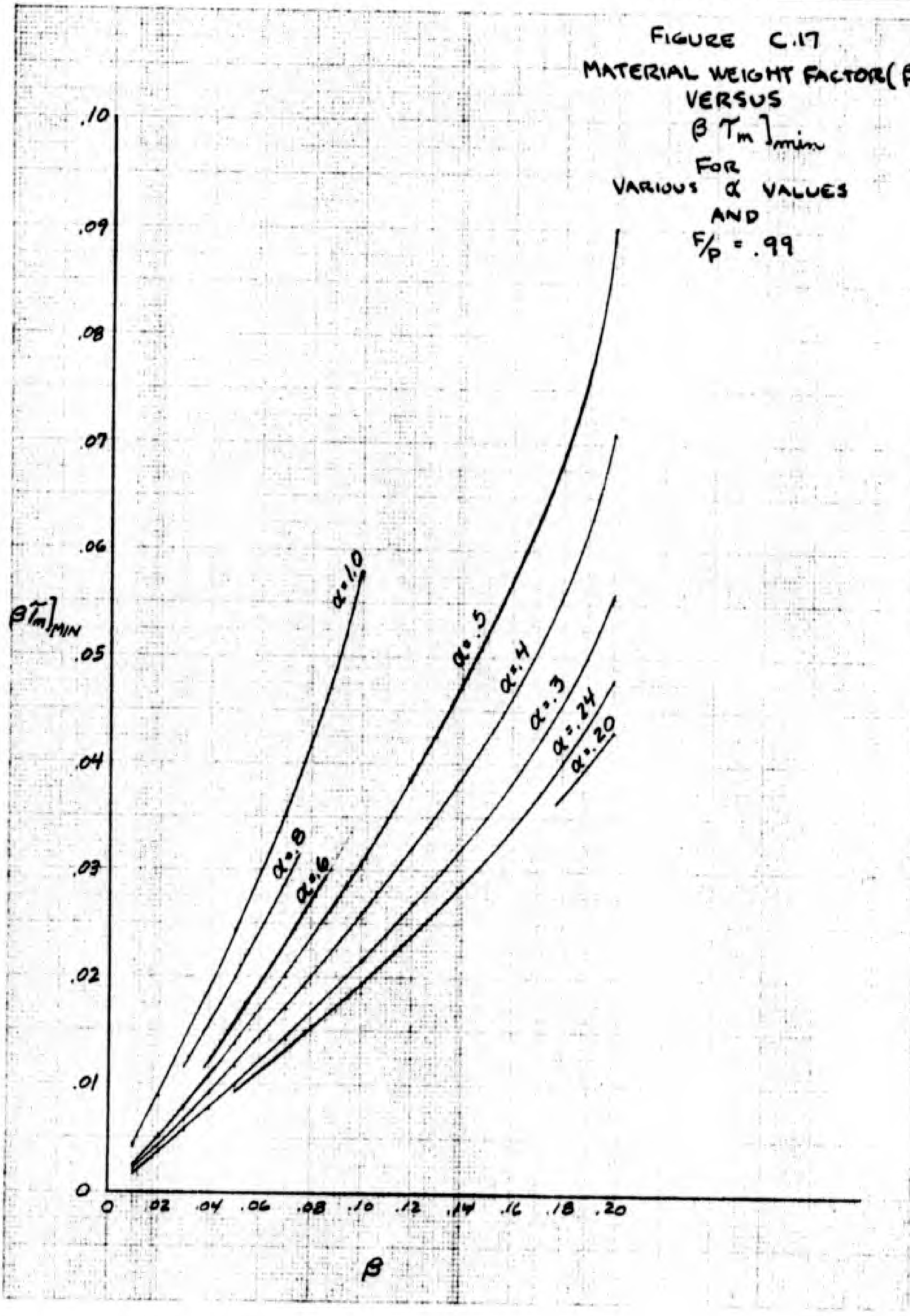


FIGURE C.17
MATERIAL WEIGHT FACTOR (β) VERSUS β Tm]min FOR VARIOUS α VALUES AND F/P = .99
β Tm]MIN
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
α=1.0
α=.8
α=.6
α=.5
α=.4
α=.3
α=.24
α=.20
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
β

If w is a minimum gage material, β will be a minimum possible value (β_{min}). Hence a lower limit or check value is provided for Equation 17.

Thus, if the four defining parameters wind condition (a), payload (P), buoyancy at altitude (b), and reefing system are defined, the shape (F/P, α, β) and size (λ) of the natural balloon are defined explicitly. This method is an improvement over the previous method of defining Σ since a trial and error solution is eliminated.

A demonstration of the method of solution is provided below in which values necessary to establish the balloon design curves of Figure 44 is obtained. Table C3 summarizes the data and is referred to for explanation of the design method.

GIVEN:

1. Float Altitude h = 100,000 ft
2. Design wind Winter I and Summer I
3. Natural Balloon designed for top load

REQ'D:

Establish a balloon design curve for net lift values ranging from 0 to 80,000 lbs.

SOLUTION:

1. Unit lift at 100,000' for 100 percent pure helium is

   b = .0009201

2. Eight values of payload (P) are selected as shown in Column 1 to adequately cover the range of interest.
3. Lambda (λ) is computed in Column 2 as

$$\lambda = \left(\frac{P}{b}\right)^{1/3}$$

TABLE C

BALLOON DESIGN TA

AT AN ALTITUDE

$F/_p = .99$, $\alpha = 1.0$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PAYLOAD P	λ	λ^3 $\cdot 10^6$	$b\lambda$	ω_{min}	$\beta T_m]_{min}$	β_{min}	$\beta]_{FS=3}$	$\omega]_{FS=3}$	$(W/P)_P$	R_{oo}	$A'/\lambda^2]_{ba}$	$A/\lambda^2]_{ba}$	$A'/\lambda^2]_{ca}$	A/λ^2
1000	102.7	1.093×10^6	.0945	.0056	.0594	.1019	.01322	.000893	.771	7.70	.49	.04	8.94	5.4
5000	176	5.45	.1620	.0056	.0346	.0678	.0227	.001718	.382	2.98	1.23	.24	8.10	5.2
10,000	222	10.94	.204	.0056	.0274	.0550	.0286	.00274	.290	1.92	1.94	.52	7.92	4.9
15,000	253	16.2	.233	.0056	.0240	.0490	.0326	.00356	.250	1.50	2.43	.78	6.70	4.7
20,000	279	21.7	.256	.0056	.0219	.0448	.0360	.00417	.226	1.20	2.95	1.15	6.15	4.4
30,000	319.5	32.5	.294	.0056	.01905	.0397	.0411	.00686	.203	1.00				
50,000	377.5	53.2	.348	.0056	.01610	.0340	.0486	.01621	.247	1.00				
80,000	443	86.9	.408	.0056	.01372	.0298	.0571	.0233	.303	1.00				

A

TABLE C.3

ESIGN TABLE FOR BALLOONS

ALTITUDE OF 100,000 FEET

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
$A'/\lambda^*]_{ta}$	$A/\lambda^*]_{ta}$	$A'/\lambda^*]_i$	$A/\lambda^*]_f$	R_A	$(W/P)_f$	W	V	$V^{2/3}$	$C_D]_{V^{2/3}}$	D_A Summer I	D_A Winter I	L_N	L_N/D_A Summer I	L_N/D_A Winter I
							×10⁶							
8.94	5.46	9.48	5.55	.586	.451	451	1.588×10⁶	13600	.1811	224	142.1	252	1.125	1.771
8.10	5.24	9.48	5.88	.620	.236	1180	6.74	35600	"	586	372	3851	6.56	10.36
7.92	4.98	9.48	5.54	.586	.1697	1697	12.80	54800	"	901	572	8567	9.50	14.98
6.70	4.70	9.48	7.40	.781	.1952	2930	19.35	72000	"	1187	752	12,900	10.88	17.11
6.15	4.45	9.48	7.56	.798	.1802	3604	25.6	87000	"	1432	909	17,520	12.22	19.29
						6090	39.2	116000	"	1910	1212	26,160	13.68	21.6
						12,350	66.3	164000	"	2700	1712	42,700	15.82	25.0
						24,240	113.2	234000	"	3860	2440	66,200	17.15	27.2

B

4. λ^3 is shown in Column 3.
5. Columns 4, 5, and 6 respectively express the quantities $b\lambda$, minimum gage material w_{min} and $\beta \Upsilon m]_{min}$ which are necessary to establish the lower limit of β. The minimum gage w_{min} = .0056 psf was selected to represent 2 layers of .25 mil mylar bonded together to provide a relatively gas tight seal.
6. The lower limit of β (β_{min}) is shown in Column 7 as obtained from Figure C.17.
7. The actual value of β necessary to provide a safety factor of 3 is shown in Column 8 as obtained from Figure C.3.
8. The greater of the two values of β shown in Columns 7 and 8 should be circled as it represents the value necessary for the particular balloon of interest.
9. The unit material weight ($w]_{F.S.\ =\ 3}$) corresponding value representing a factor of safety of 3 is shown in Column 9. (Fig C-17)
10. The greater of the two values of w shown in Columns 5 and 9 should be circled for reason specified in Step 8.
11. A preliminary value of W/P, $(W/P)_p$ is provided in Column 10 after entering Figure C4 with F/P, α, and β.
12. The amount of overdesign may be measured comparing the actual thickness of the material to the thickness necessary to give a factor of safety of three. This ratio of overdesign is symbolized as R_{OD} shown in Column 11, and obtained as shown below:

$$R_{OD} = \frac{w\ actual}{w]_{FS\ =\ 3}}$$

w actual is the value used in the design which is circled. The overdesign ratio strictly is the ratio at the gore length where $\beta \Upsilon m]_{min}$ would occur; however, if T/P is nearly constant as is the case for most practical designs, this ratio then is not greatly in error at any gore station.

13. At this point it is observed that some of the balloons may be grossly overdesigned by the fact that a minimum gage material was specified. In these cases a complete cylinder gore design is not efficient because it requires the amount of overdesign necessary at the maximum radius* to be maintained throughout the balloon. For these cases then, tailoring of the gore from this maximum radius point to the gore station where the overdesign factor becomes 1.00 (which is equivalent to the point where the factor becomes 3) would result in the minimum weight balloon. This design is similar to those previously termed cylinder end balloons. The radius at which the tailoring would stop and continue on as a cylinder is easily determined by dividing the maximum radius ($R/\lambda]_{max}$) by the overdesign ratio as shown below:

$$R/\lambda]_{cyl\ end} = \frac{R/\lambda]_{max}}{R_{OD}}$$

This point represents the place where the circumference or radius has reduced sufficiently to allow the remaining material to act fully efficient. At points on the tailored portion, the safety factor varies from its maximum value down to a value of 3. Points of the cylinder portion all have a safety factor closely approximated by 3.0. It was noted earlier that one of the columns of data available from the computer run of the natural balloon is termed RATIO. RATIO it may be recalled is the ratio of the radius of the cylinder design pattern to the actual radius of the inflated balloon. In a natural balloon this RATIO increases from

*The maximum radius of the balloon coincides with the point where $\Upsilon_m]_{min}$ or Σ_{min} would occur.

a value of 1.0 at the maximum radius to larger values as the top or bottom of the balloon are approached. Rather than make the computation as shown above, the point at which the cylinder end should be started is the gore station noted in the computer run where RATIO is equal to R_{OD}.

For purposes of estimating weight in balloon designs utilizing a minimum gage material, the weight factor W/P will be modified in a manner shown below to account for a reduction in weight provided by tailoring as is indicated above. The resulting weight will be a very close approximation of the minimum weight design. It is noted here that the changes made in the weight distribution of the balloon also change the shape of the balloon. Thus a particular computer run does not exactly represent the true shape. Comparison of computer runs, however, indicates that for lightweight materials as utilized in this program, the error in shape is small. With this in mind, the new weight estimates provided by the procedure below are realistic.

A modification of the weight of a cylinder balloon to a value representative of a minimum weight cylinder end balloon can be accomplished as follows. It was concluded above that a tailored shape would be utilized throughout the center portion of the balloon in which case the thickness of the material would be that of the minimum gage while the area of the material would be that of the tailored shape rather than the cylinder shape included in the preliminary value of W/P. The cylinder ends of the balloon would then be made up of material of minimum gage thickness of over a cylindrical surface area $1/R_{OD}$ times the area of the original cylindrical surface.

A graph of accumulated surface areas at various arc lengths along the balloon would provide the information necessary to determine the modified weight as suggested above. Such a graph is presented in Figure C18, which plots accumulated surface area versus the term RATIO for F/P = .99, $\alpha = 1.0$, and $\beta = .01$. The above plot is obtained from a computer run in such a manner that a given accumulated area and RATIO are selected at a particular arc length. Both inflated surface area (A/λ^2) and cylindrical surface area (A'/λ^2) are plotted. When a particular value of RATIO = R_{OD} is selected, the curve may be consulted to obtain the various values of area necessary to compute the minimum weight. These areas are shown in Columns 12 through 16.

The areas shown are respectively:

$A'/\lambda^2]_{ba}$ - The accumulated area of the cylinder for the bottom portion (below the point RATIO in the lower sector).

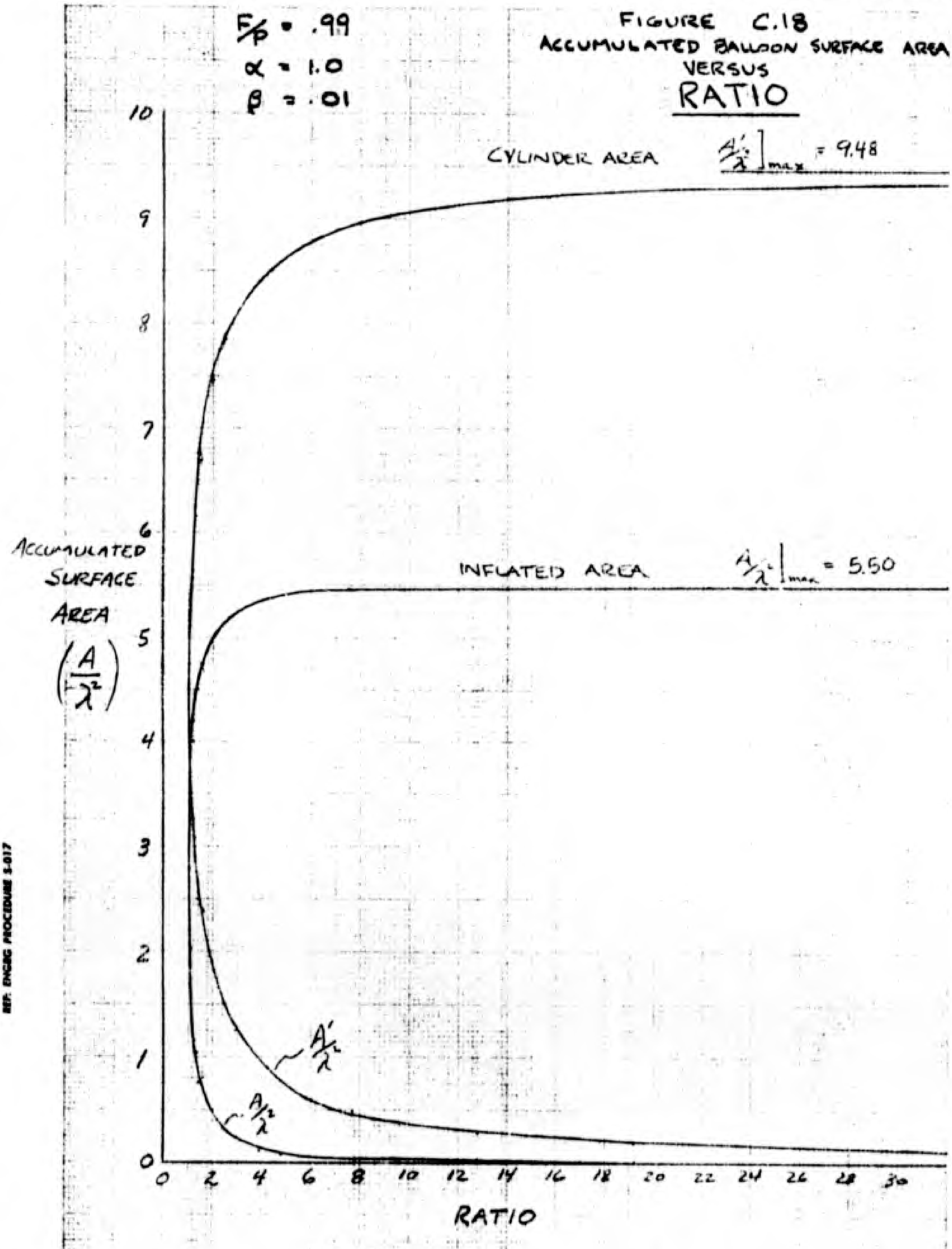
$A/\lambda^2]_{ba}$ - The accumulated area of the inflated shape for the bottom portion

$A'/\lambda^2]_{ta}$ - The accumulated area of the cylinder for the top portion (from the base to the point RATIO on the upper sector)

$A/\lambda^2]_{ta}$ - The accumulated area of the inflated shape for the top portion

$A'/\lambda^2]_{i}$ - The total accumulated area of the cylinder shape, termed here initial.

FIGURE C.18
ACCUMULATED BALLOON SURFACE AREA
VERSUS
RATIO



14. Column 17 combines these areas in a manner to obtain a final or minimum area estimate $A/\lambda^2]_f$ for the cylinder end balloon. This area is:

$$\frac{A}{\lambda^2}\Big]_f = \left\{\frac{A'}{\lambda^2}\Big]_{ba} + \frac{A'}{\lambda^2}\Big]_i - \frac{A'}{\lambda^2}\Big]_{ta}\right\} \frac{1}{R_{OD}} + \frac{A}{\lambda^2}\Big]_{ta} - \frac{A}{\lambda^2}\Big]_{ba}$$

The value of area as shown above is relatively accurate only for the values of F/P, α, and β for which it was plotted. If, however, the ratio of this area to the initial cylinder area

$$R_A = \frac{\frac{A}{\lambda^2}\Big]_f}{\frac{A'}{\lambda^2}\Big]_i}$$

is obtained, it is reasoned that this ratio will be approximately the same regardless of the value of F/P, α, and β for which it is plotted. Practically, the values of F/P, α, and β should remain within the scope of this program for the statement above to hold true.

15. A final estimate of weight, $(W/P)_f$, is provided in Column 19 and is obtained by multiplying the preliminary value W/P_p by the ratio of areas R_A.

$$\frac{W}{P}\Big]_f = R_A\left(\frac{W}{P}\Big]_p\right)$$

16. An estimate of total film weight is given in Column 20 obtained as:

$$W = \left(\frac{W}{P}\right]_f \Big) P$$

17. Total balloon volume is shown in Column 21.

$$\forall = 1 + \frac{W}{P}\Big]_f \lambda^3$$

18. Columns 22 through 25 simply compute drag on balloon for the Summer I and Winter I wind conditions. This computation is similar to that provided in Reference C.3. Note here that a constant value is assumed for the drag coefficient (C_D = .1811). This maximum value of drag occurring on a sphere in the post critical range of Reynolds numbers was chosen rather than computing separated values based on Reynolds numbers for each balloon.

19. Net lift L_N is provided in Column 26. Its value is computed from the value of the payload P. P represents the total external load applied to the balloon excluding balloon fabric. From this the net lift may be computed by subtracting any actual payload (P') and equipment weight (W). For this program P' = 500 lbs and W' = .55W.

Therefore,

$$L_N = P - P' - W'$$

$$L_N = P - 500 - .55W$$

20. Finally values of L_N/D_A are provided in Columns 27 and 28 for Summer I and Winter I winds.

SECTION C-VIII - SUPERPRESSURE OCCURRING NATURALLY AND BY THE USE OF AUXILIARY SYSTEMS

Superpressure at float altitude of any desired magnitude may be obtained with any percentage of top loading simply be designing the natural balloon to reach its fully expanded form a few feet below float altitude. When float altitude is reached the resistance to volume expansion will result in a pressure increase.

Some percentages of top loading, however, will provide superpressure at altitudes below float while other percentages will not. Graphically this is depicted in Figure C.8. As was shown in the examples of Section C VI, the factor S/λ is one of the primary parameters for investigating a balloon at altitudes below float. Since λ changes with altitude and total arc length (S) remains the same, it is evident that S/λ will change with altitude. Figure C.8 shows that for a weightless material ($\beta = 0$), the arc length factor (S/λ) may increase considerably for some percentage of top loading and a superpressure will continue to be maintained. Instances where F/P is .50 or less, however, reduce to zero superpressure with very little decrease in altitude. It may be seen that $F/P \geq .90$ will result in values of $\alpha \geq .20$ regardless of what altitude reduction is made. It also is shown in Figure C.9 that curves of α versus S/λ for low values of β ($< .1$) are not grossly different than those for $\beta = 0$.

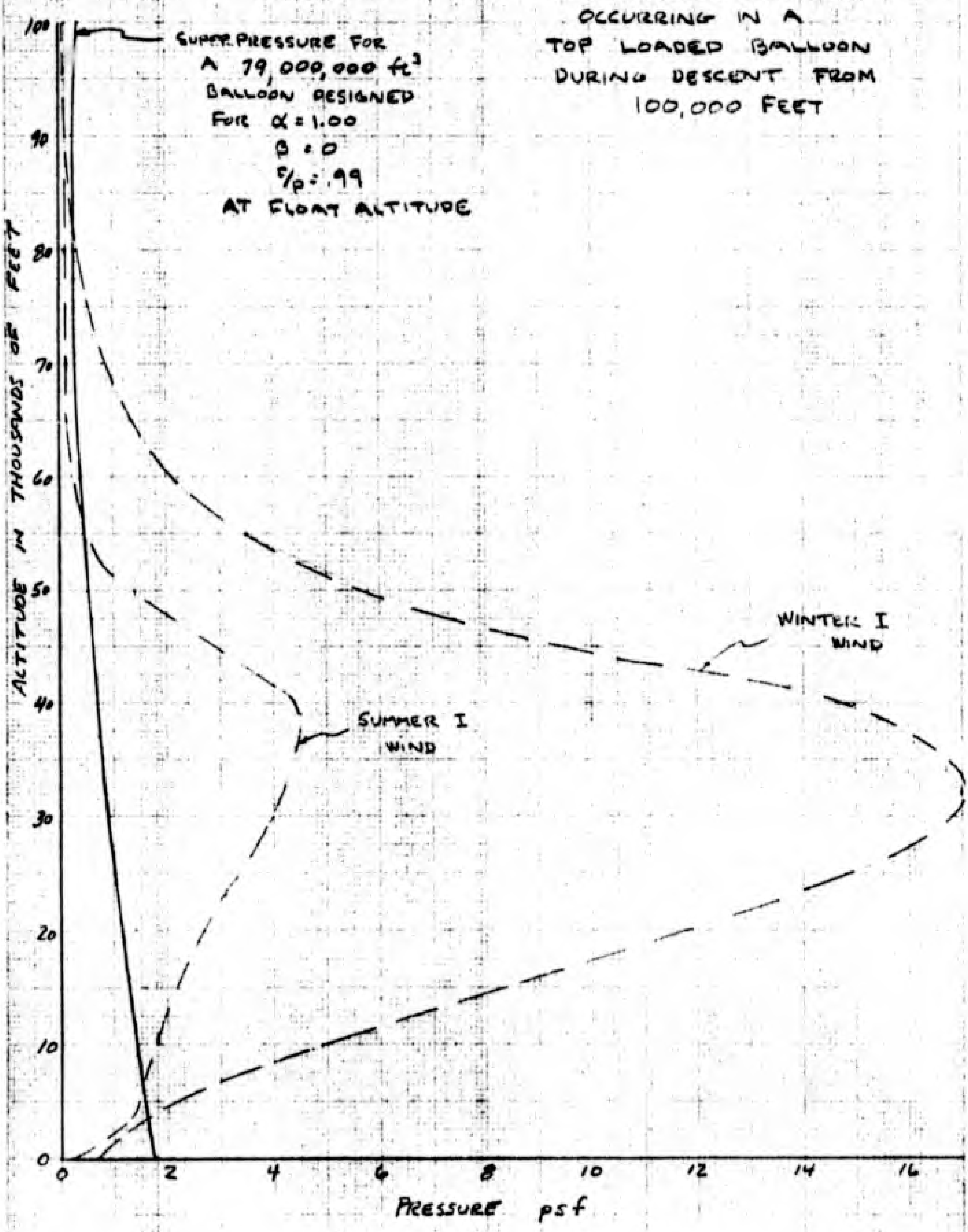
A plot of the superpressure that occurs naturally for a 79×10^6 cu ft natural balloon placed at a float altitude of 100,000 ft with a superpressure $\alpha = 1.0$ and then brought to altitude zero is shown in Figure C.19. (This volume is the size selected for one of the examples of Section IV.) An $F/P = .99$ and a weightless material is assumed with points depicting practical values of β.

Also shown in Figure C.19 are curves for the external dynamic pressure that may occur at various altitudes for Summer I and Winter I winds.

If it is desired to maintain an internal pressure equal to a possible external pressure at all altitudes, an auxiliary system for obtaining internal pressures over and above those occurring naturally will have to be utilized.

FIGURE C.19

SUPERPRESSURE NATURALLY OCCURRING IN A TOP LOADED BALLOON DURING DESCENT FROM 100,000 FEET



A conventional system of blowers and ballonets does not appear feasible with the evidence available at this time. Such systems rather than increasing the pressure, would cause the shape to change according to Figure C.8 with a corresponding increase in volume. The shape and volume change that would occur would be similar to that occurring if the altitude were increased. With this observation it is realized that a pressure increase of any significance would occur only if the volume and shape were increased back to that occurring, at float altitude. This of course is an unrealistic solution.

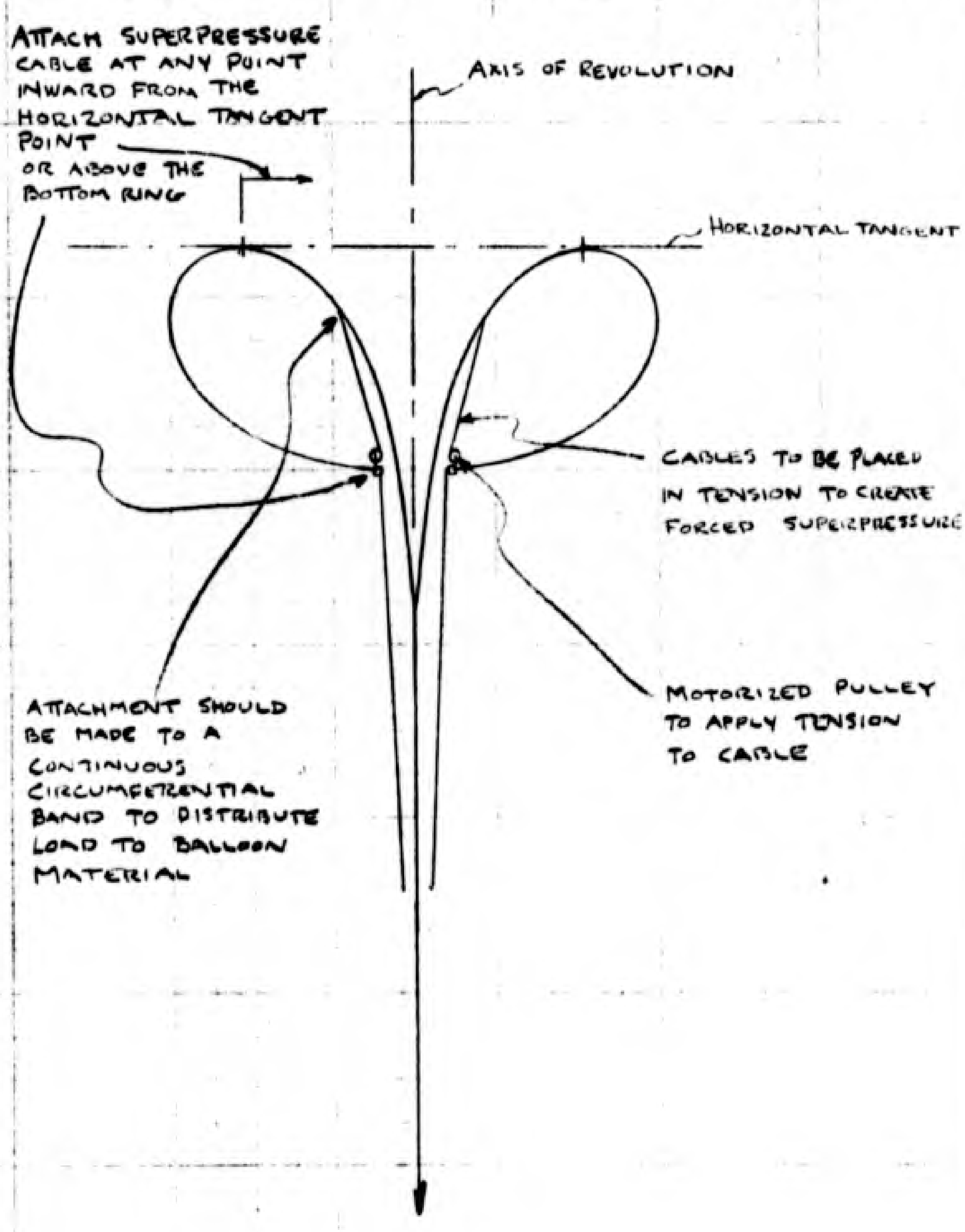
A system which will reduce the volume slightly and in turn increase the pressure to the desired value is proposed below. Essentially this system might consist of the cables attached to the upper portion of the balloon's surface and extending to the bottom ring of the balloon where they are attached to a motorized wind-up pulley. When increased internal pressure is desired, the cable is shortened, the volume decreased, and the pressure correspondingly increased. This system may be termed "forced reefing" for convenience.

It is noted that the cable must be attached to the upper balloon surface at a point located toward the axis of revolution from the upper horizontal tangent of the balloon. This requirement is depicted in Figure C.20. If the cable were attached at a point located outward from this horizontal tangent, the upper attachment point of the balloon would simply move upward as the cable was shortened rather than reducing the volume as is desired.

Another requirement placed on the location of the attachment points is that its position must be at a point above the motorized pulley. If the point of attachment were to pass through the bottom ring, a shortening of the cable would tend to increase the volume rather than decrease it.

Superpressure requirements as dictated by wind velocity may require that several attachment points be utilized during ascent or descent. The cables to these points being programmed to apply tension only when they attain a favorable position as specified above.

FIGURE C.20
SYSTEM NECESSARY TO ATTAIN FORCED SUPERPRESSURE



This superpressure requirement will obviously increase the weight of the balloon and components as power sources, cables, pulleys, motors, and increased fabric strength will be necessary.

Two notes are presented at this point. If excess superpressure were desired only during ascent, it could be obtained by retarding the expansion of the balloon material as it pulls through the bottom ring. This retardation if properly programmed would provide the desired superpressure utilizing no power supply other than that occurring naturally. A second note is provided to indicate that any superpressure to be attained requires the use of a retention or superpressure sleeve extending below the bottom of the balloon. Without this sleeve, the helium would simply spill over as the pressure is increased. The length of the sleeve is equal to the superpressure head (a) as measured in feet of helium.

A demonstration of some of the computation necessary to provide a superpressure equal to the dynamic pressure at the location of peak dynamic pressure is provided in the example below. Fabric weight requirements are of primary interest here.

The balloon chosen for this example is the same as previously used, a 79×10^6 cu ft balloon at float altitude 100,000 feet in a Winter I Wind. Identifying parameters of the balloon are

FLOAT ALTITUDE

$h = 100,000$ ft

$V = 79 \times 10^6$ cu ft

$L_N = 49,200$ lbs

assume

$P = 1.17\ L_N = 57,500$ lbs

$\lambda = 398$ ft

$F/P = .99$

$\alpha = 1.00$

β = .0514

S/λ = 1.92

S_{cyl} = 763 ft

R_{cyl} = .814 (398) = 324 ft

HIGH q ALTITUDE (FOR WINTER I WIND)

q = 17.0 psf

h = 32,000 ft

P = 57,500 lbs

λ = 136.3 ft

S/λ = 5.60

F/P = .99

α = .238

β = .0176

a = 32.4 ft

P_{δ} = .742 psf

R_{max} = .964 (136.3) = 131.3 ft

Z_{final} = 350 ft

The internal pressure (p_i) is much smaller than the dynamic pressure (q) at 32,000 ft. If the internal pressure is to be increased to equal q, the fabric stresses may be estimated as follows. Assume that the material located at the maximum radius resists the entire increase in pressure necessary ($q - p_i$).

Let

$$p_i' = q - p_i = 17.00 - .742$$

$$= 16.26 \text{ psf}$$

The meridional stress becomes

$$t_m' = \frac{p_i' R_{MAX}}{2}$$

$$= \frac{16.26\ (131.3)}{2} = 1068 \text{ lbs/ft}$$

The actual stress in the film may be obtained from the figures above after reduction by the ratio of the inflated radius to the radius of the full cylinder of material

$$t_m\Big]_{actual} = \frac{R_{MAX}}{R_{CYL}}\ (t_m')$$

$$= \frac{131.3}{324} = 434 \text{ lbs/ft}$$

Unit material weight may be computed as:

$$w' = C\, t_m$$

$$= .000129\ (434)$$

$$= .0559 \text{ psf}$$

The total weight of the additional material required to provide superpressure may be computed as the product of unit material weight, radius of the cylinder, and arc length from the bottom ring to the point of attachment of the superpressure cable.

$$W' = w'\ (R_{cyl})\ (S')$$

let

$$S' = S_{cyl} - Z_{final}$$

$$W' = .0559\ (324)\ \ (763 - 350)$$

$$= 7460 \text{ lbs}$$

When this weight is compared to that weight required when no superpressure is applied (W = 11,920), it is easily seen that the superpressure requirement overshadows any other requirement.

Additional factors to be considered include the power required to apply the required tension.

$$T = 2\pi R_{MAX}\, t_m'$$
$$= 2\pi\,(131.3)\;(1068)$$
$$= 884,000 \text{ lbs}$$

A note is added here to indicate that with the increased weight necessitated by the above additions, the balloon no longer can provide the lift necessary to hold the cable in the proper configuration at 100,000 feet for which it was selected.

As may be seen from the example above, the penalty that must be paid in material weight to attain the desired superpressure makes the solution of the problem impractical. Perhaps the solution to the problem would be to require lower superpressures within the balloon and thus, launch and retrieve only during more favorable wind conditions than utilized in the analysis above.

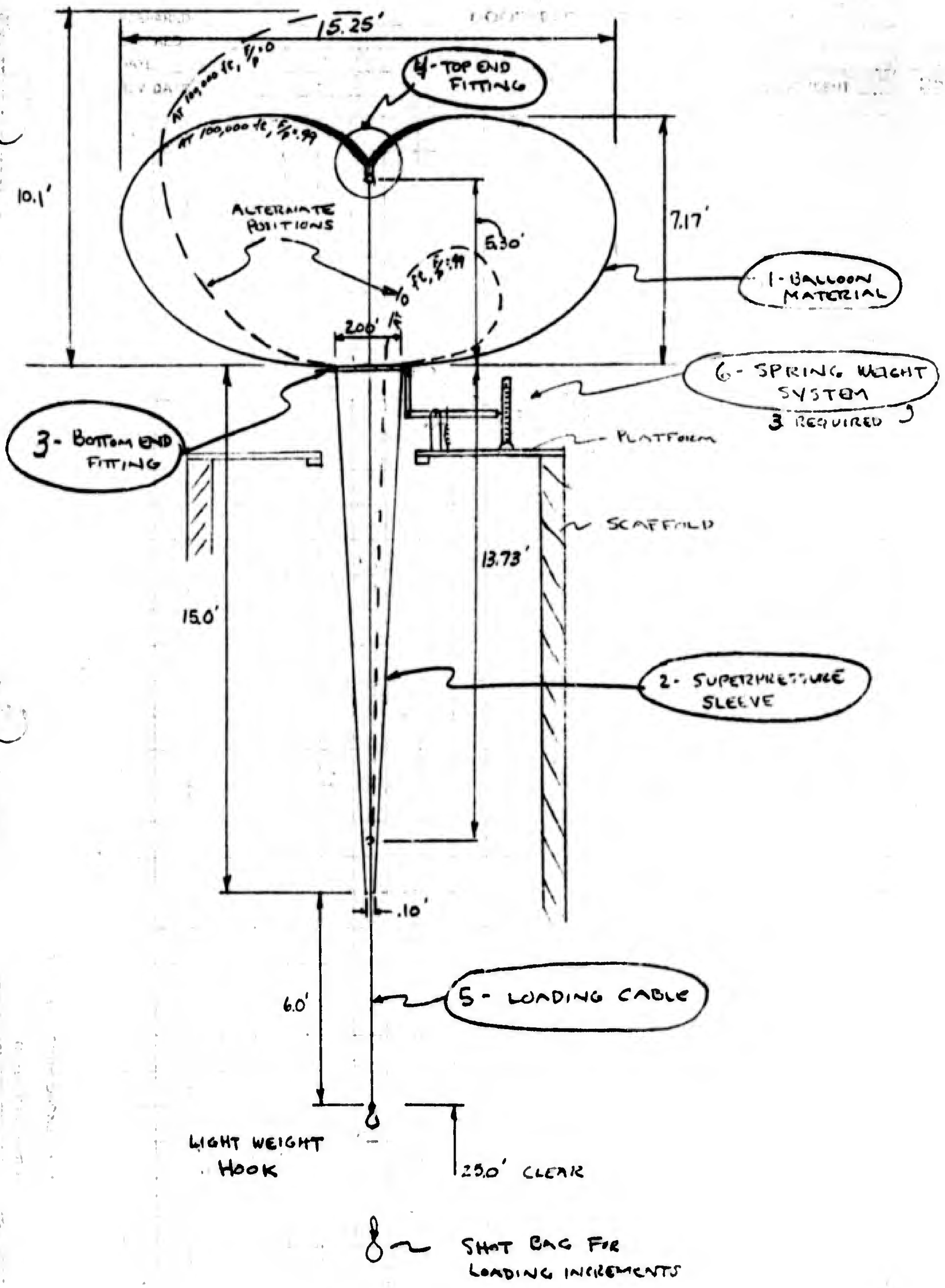
SECTION C-IX - DESIGN OF A NATURAL BALLOON MODEL TO DEMONSTRATE CONCEPTS PRESENTED ABOVE

A model of the natural balloon has been constructed to demonstrate the reefing system presented above. Shape and volume change as would occur in a balloon for altitude changes from 0 to 100,000 feet are demonstrated.

The balloon is constructed of the lightest film fiber available (1/4 mil Mylar) to a maximum volume of 1000 cubic feet. Details of construction and nomenclature are provided in Figure C.21.

FIGURE C.21

DETAILS OF MODEL CONSTRUCTION



Testing is to be performed at existing atmospheric conditions in our test building. Examination of the nondimensional parameters of the model will indicate that three shape factors ($F/P = .99$, $w = 2.5\ oz/yd^2$, $S/\lambda = 1.932$) are defined. The size factor (λ) is the only quantity remaining to be defined. In a normal balloon flight the unit lift term (b) changes thereby changing λ. Correspondingly similar changes can result by variation in the load term (P). This equivalence thus enables testing to take place at ground level while load and volume changes demonstrate shapes that would occur during ascent.

The test will be performed according to the schedule provided in table C.4. Increments of load and corresponding volume of the balloon representative of altitude increment of 10,000 feet are provided. The test will be conducted by placing the proper load increment on a cable which is attached to the top end of the balloon and inflating the balloon until the equilibrium is reached.

Measurements to be made include:

a. Load applied to the tether cable.
b. Total weight of helium used to fill the balloon.
c. Equilibrium load applied at the bottom end ring of the balloon.
d. Photographs of the balloon shape superposed on a grid background.

The test set up is depicted in Figure C.22.

An additional item of testing will involve a demonstration of an increase in superpressure possible by the use of forced reefing. With the resulting data, information will be collected to establish practicality of the proposed free and forced reefing technique and determine validity of the theoretical equations used in the derivation.

TABLE C.4

TEST SCHEDULE FOR BALLOON MODEL

TEST Nº	REPRESENTATIVE ALTITUDE	TOTAL LOAD (P)	TOP LOAD (F)	BOTTOM LOAD (L)	VOLUME (ft³)
1	0	.875 #	.866	.009 #	14.0
2	10,000'	1.185	1.173	.012	18.9
3	20,000	1.578	1.562	.016	26.2
4	30,000	2.33	2.10	.023	37.[illegible]
5	40,000	3.54	3.51	.035	56.5
6	50,000	5.71	5.65	.057	91.2
7	60,000	9.21	9.12	.092	147
8	70,000	14.89	14.74	.149	238
9	80,000	23.2	23.0	.232	372
10	90,000	39.1	38.7	.391	625
11	100,000	62.6	62.0	.626	1000

OTHER TESTS INVOLVE RANDOM TRIAL TO ATTAIN FORCED SUPERPRESSURE.

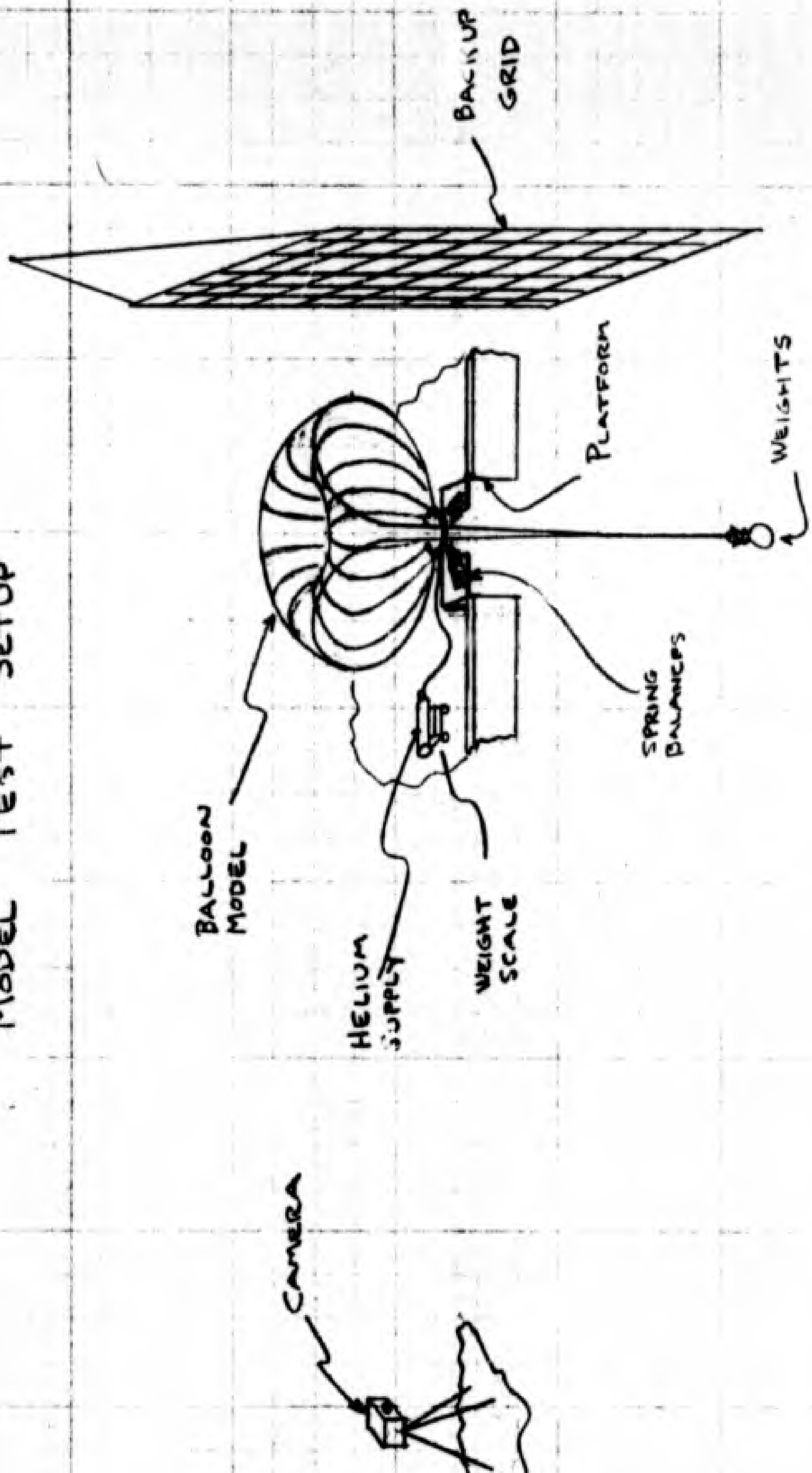


FIGURE C.22
MODEL TEST SETUP

SECTION C-X - REFERENCES

C.1 "Determination of the Shape of a Free Balloon" by J.H. Smalley, Applied Science Division, Litton Systems, Inc., Report No. 2713, Contract No. AF 19(628)-2783, Project No. 6665, Task No. 666501, Final Report, February 5, 1965.

C.2 "Shape and Stress Analysis of Rotationally Symmetric Balloons" by A.D. Kerr and H. Alexander, New York University, NYU-AA-65-11, Contract AF19(628)-4990, September 1965.

C.3 "High Altitude Tethered Balloon Systems Study," Task Report No. 1 (Schedule Sub-Line Item IAA), Goodyear Aerospace Corporation, GER 13260, May 10, 1967.