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COLD WEATHER AEROSTAT STUDY

Robert L. Ashford

TCOM Corporation
Subsidiary of Westinghouse Electric Corporation
Columbia, MD 21044

October 1982

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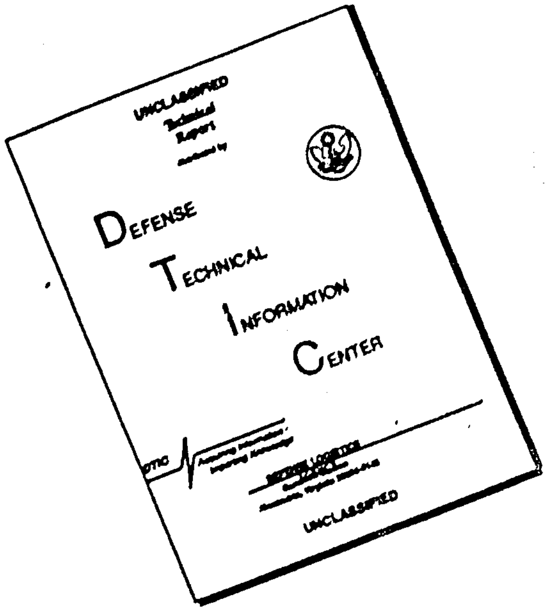

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Aerostats are being considered for application in cold weather regions. A review of aerostat flight experience to date was made to determine the limitations of the current technology. Areas for improvements and modifications to extend the aerostat system cold weather survivability/operability were also made.

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I. INTRODUCTION

TCOM Corporation, a wholly owned subsidiary of the Westinghouse Electric Corporation, for more than 11 years has been involved in the manufacture of complete aerostat systems to carry an assortment of electronic payloads to altitudes between 3,000 and 18,000 feet above the ground and maintain them there to take advantage of the performance gains that can be achieved at higher altitudes. During this period of time TCOM has had several experiences operating in regions where the winter weather caused considerable difficultly in maintaining a consistent and safe aerostat operation. During these cold weather operating periods techniques have been developed to offset most of the problems that have been encountered.

This study is performed to review the past experiences of TCOM in cold weather operations, to anticipate the more severe cold weather problems that may be encountered in winter arctic operations and especially to anticipate the severe weather problems that will be encountered during operations in northern Vermont during the months of January and February 1983. Previous operational problems have been examined in the light of past experiences and in anticipation of the events that might occur in Vermont in simulated arctic operation. Particular emphasis has been placed on the improvement of components and techniques to permit aerostat operations to be conducted safely and successfully over a wide range of cold weather conditions that up until now have prevented aerostat operations.

Methods of snow and ice removal from the aerostat while it is moored were reviewed and improved techniques identified wherever possible. New techniques for the prevention of ice accretion and for the removal of snow and ice during aerostat flight have been investigated. Techniques that have been used in the past were reviewed, tested and improved wherever possible. The results of this study are contained in this report, which documents our findings and reviews the relevant past experience.

II. COLD WEATHER AEROSTAT FLIGHT EXPERIENCE

A. REPUBLIC OF KOREA

The first TCOM contract, which began in 1972, was for installing a dual-aerostat station and for training Ministry of Education, Republic of Korea, personnel to operate the aerostat system to broadcast educational TV and FM radio programs over a large area of the country.

The two aerostat sites were located by the Korean Government in a mountainous area where the turbulence of the wind made aerostat operations difficult in light winds and virtually impossible in moderate wind conditions. In addition, the sites were located in the northern part of the country in the middle of the winter snow belt. Although there were long periods of very cold weather during December, January and February, there were also many typical weather sequences with warm front and cold front passages accompanied by heavy wet snow storms that often dumped four to six inches (and occasionally as much as 18 inches) of snow on the sites at temperatures hovering right at 0° C. The cold front passages that cleared away the snow clouds were attended by cold air masses, high winds and bitter cold temperatures. Table 1 portrays a climatological summary for the days when aerostats were operated by TCOM during the winters of 1975/6 and 1976/7.

In addition to the severe weather which was hostile to both airborne and moored operation of the aerostats, the cold weather and moist air combined to provide ideal carburetor icing conditions for the airborne engine-generator power system. Although the unreliable generator operation could not be proven to be due entirely to carburetor icing, partial or complete airborne power failures compounded the operational problem already made difficult by the foul weather and turbulence.

The TCOM Korean operational experience emphatically confirmed an already-perceived need for power-up-the-tether to ensure acceptable and viable performance of aerostat systems, and provided the development incentive which has led to that fundamentally important, and in many applications operationally critical, TCOM capability.

The Korean experience also dramatically demonstrated that the weight of four to six inches of snow overcomes the lift of a moored 250,000 cubic foot displacement aerostat and forces it to settle against the ground. If the snow is "wet" and heavy, such settling may indeed cause damage to the payload in the windscreen, to other equipment mounted on the underside of the hull, or to the aerostat itself. However, after experiencing this sort of difficulty in conjunction with two heavy snowstorms, a simple, straightforward, and successful manual method for removing snow, (as it accumulated) from the upper surfaces of a moored aerostat solved the problem.

Two "snow wipers," each made up of a 36-inch-long, 4-inch-high, ½-inch-thick piece of Teflon, connected to two 150-foot-long light Dacron lines by suitable bridles (see Figure 1), were placed atop the aerostat. These snow wipers were lashed in place during aerostat flights, but the lashings could be quickly loosened when the aerostat was moored. When heavy snowfalls began, the lashings were loosened and four people moved the two wipers over the upper hull surface by walking back and forth on the ground, pulling the ends of the 150-foot lines. Very little pulling force was required, and a person could easily perform this task for several hours without tiring.

The horizontal fins of the aerostat were deflated at the same time the snow wipers were activated after installing quick disconnect devices to enable separating the upper fin guy lines. This prevented snow accumulation on the upper surfaces of the horizontal fins, so that there was essentially no loss of lift from snow accumulation on either the aerostat hull or fin surfaces. Snow scraped from the hull, and snow that fell directly to the surrounding ground was removed by conventional means. This method worked so well that other. more sophisticated (and more difficult and expensive) approaches to removal or prevention of snow accumulation on moored aerostats were never implemented.

TABLE 1. WEATHER SUMMARY — REPUBLIC OF KOREA
OCTOBER 1, 1975 — FEBRUARY 15, 1977

Day	Max Temp °F	Min Temp °F	Max Wind (Knots)	Wind Direction (Degrees)
10/1/75	76	42	16	N/A
10/6	74	46	26	N/A
10/8	60	24	40	N/A
10/20	68	32	8	N/A
10/21	58	32	24	N/A
10/22	58	38	16	N/A
10/23	58	30	32	N/A
10/25	58	28	18	N/A
10/27	58	30	16	N/A
10/28	62	32	30	N/A
10/29	54	24	50	N/A
11/18	56	20	46	N/A
11/20	46	8	32	N/A
11/28	50	12	36	N/A
11/29	38	14	58	N/A
12/1	42	14	22	N/A
12/3	52	24	36	N/A
12/4	48	28	32	N/A
12/5	52	22	26	N/A
12/8	32	12	20	N/A
12/9	46	20	16	N/A
12/10	38	14	58	N/A
12/11	26	0	38	N/A
12/12	32	0	32	N/A
12/15	40	14	34	N/A
12/16	36	2	26	N/A
12/17	34	12	18	N/A
12/18	42	16	40	N/A

TABLE 1 (CONT)

Day	Max Temp °F	Min Temp °F	Max Wind (Knots)	Wind Direction (Degrees)
11/19/76	54	40	0	75
11/30	28	22	10	N/A
12/1	42	26	4	176
12/4	46	38	0	N/A
12/6	46	22	12	45
12/9	24	12	44	149
12/11	44	16	44	N/A
12/16	44	40	34	N/A
12/17	36	30	12	N/A
12/21	48	20	50	N/A
12/31	22	-2	56	N/A
1/7/77	32	4	58	N/A
1/10	30	6	46	N/A
1/12	30	-8	48	N/A
1/14	16	0	58	N/A
1/17	28	4	62	N/A
1/18	28	10	34	N/A
1/19	26	6	46	N/A
1/20	24	2	62	122
1/24	26	10	52	75
1/25	34	22	70	N/A
1/26	38	30	26	225
2/3	16	-4	46	145
2/5	4	-2	0	40
2/7	28	1	38	105
2/8	26	10	50	85
2/9	32	6	40	185
2/10	34	8	62	55
2/11	36	12	52	180
2/14	24	-4	36	210
2/15	12	-16	66	N/A

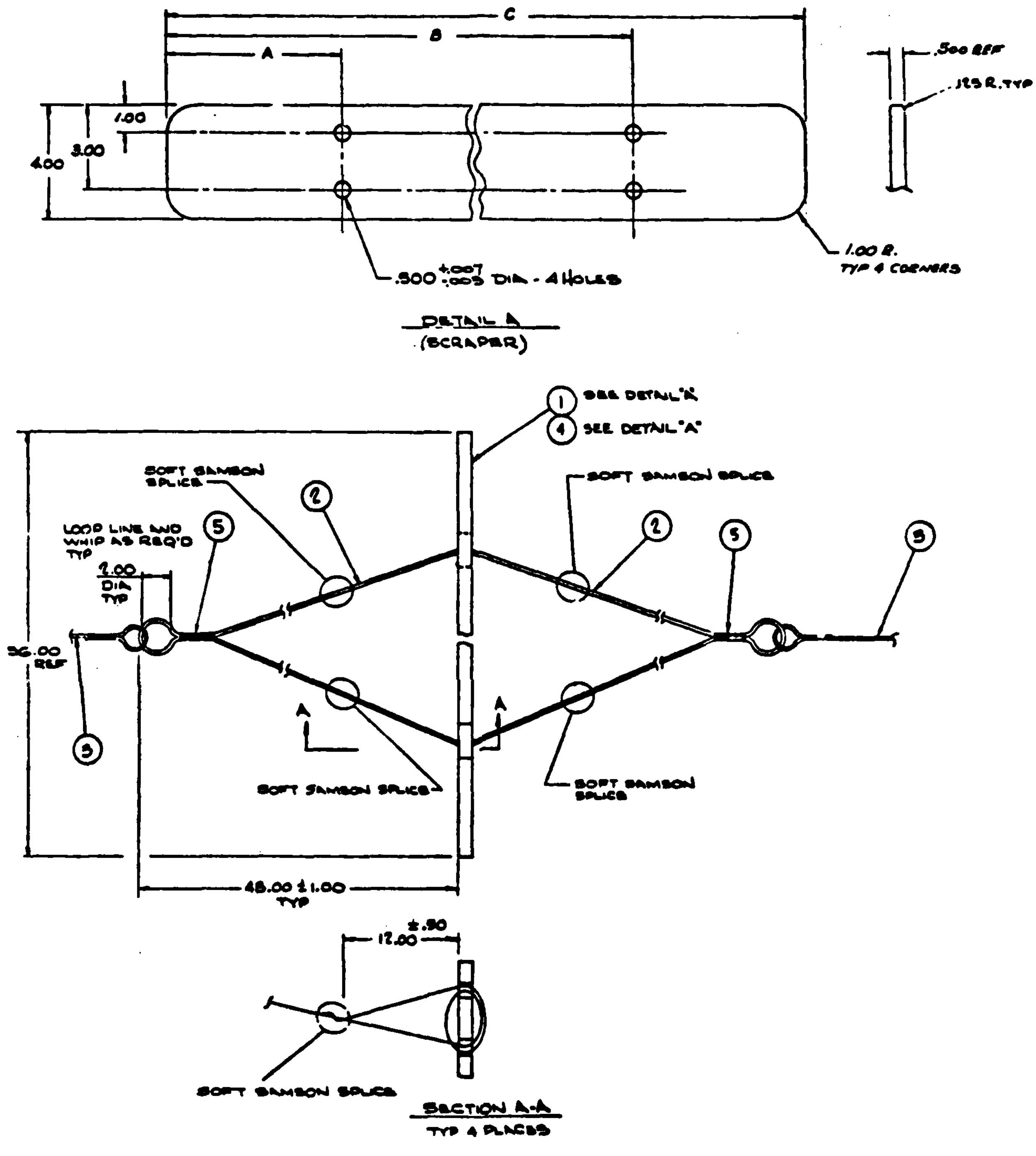


Figure 1. Snow Scraper

No difficulty was encountered with aerostat icing during the three winters of TCOM operations in Korea, except for the freezing of a helium pressure indicator early in the program and the (suspected but never proven) chronic carburetor icing of the gasoline engine that drove the airborne electric power generator. The helium pressure indicator problem was corrected by a simple redesign, and the airborne engine problem has, of course, been corrected by the incorporation of the powered tether.

B. SUMMARY OF BEAUFORT SEA EXPERIENCE

During this operation, under contract to Dome Petroleum, Ltd., a modified STARS system provided a platform for radar ice surveillance in the Beaufort Sea between the northern coast of Canada and the polar pack ice.

These tests were conducted between September 12, 1981, and October 19, 1981. During that time frame four separate flights were performed totaling over 415 flight hours. The tests were terminated when the presence of sea ice began to inhibit vessel operation at which point the vessel returned to its base at Tuktoyaktuk.

Flight limitations as a function of arctic climatology were encountered on our second flight,which originated in Tuktoyaktuk Harbor and terminated in McKinley Bay. During this test the weather conditions encountered were high winds with two-to three-meter waves on September 19, then icing conditions the next day with subfreezing temperatures. Ice accumulation on the aerostat was gradual and resulted in loss of tether tension and a change in aerostat pitch. Eventually the aerostat pitch went to 36 degrees positive and tether tension was about 100 pounds. Hull pressure was pulsated in an attempt to flex the hull enough to break the ice. However, as determined later visually, this method was marginal. The aerostat pressure pulse cycle caused the hull pressure to rise slowly to 3.0 IWG and then decrease slowly to 2.0 IWG; a greater pressure range may have been of more value. Changes in altitude were initiated in an attempt to find a more favorable temp/humidity condition. As our wet bulb temperature was inoperative, the success of this activity was limited and could only be determined through resultant pitch and tether tension readings. By increasing the support vessel's speed through the water, the aerostat maintained altitude, the ice eventually sublimated and aerostat pitch and tether tension returned to normal.

A significant part of the aerostat icing problem stemmed from the fact that the aerostat flight operations were conducted entirely from a small ship; the ship was 134 feet long — the STARS aerostat is 82.5 feet long. During periods of any significant wave action, the ship's motion became so violent that it was impossible to launch or recover the aerostat. Furthermore, if the aerostat had been moored during rough weather, it would have been torn apart by the violent ship and mooring system motion. Therefore, it was impossible in most instances to gain access to the aerostat to help reduce the ice load when it accumulated.

The arctic cold and constant wind do not in themselves present a condition that precludes arctic aerostat operations. However, as experienced during these tests, ice accumulation is the problem that must be overcome prior to long term successful arctic aerostat operations. During the operating period from mid-September to mid-October the average daily temperature was making the annual excursion from above 0° C to below 0° C. Characteristical the diurnal variation in temperature was only a few degrees above or below the average. Therefore, during the entire operating period the temperature hovered in the range where the most severe icing conditions can occur. Table 2 is a summary of the climatological data recorded during the Beaufort Sea operating period.

Figure 2 is a photograph of the aerostat just above the mooring system, showing the heavy coating of ice on the entire set of aerostat rigging including the handling lines, mooring lines, suspension lines and the nose line. Figure 3 is a photograph taken at the flying sheave end of the mooring system showing the type of ice that was broken from the tether cable during recovery. Figure 4 is a photograph of the aerostat at a high angle of attack (approximately 35°) showing the tether cable at the right hand edge of the picture leading out to the aerostat. The high angle of attack and the very low altitude of the aerostat are due to the heavy ice load that was being carried by the aerostat at the time of the photograph.

III. ANTICIPATED ARCTIC ENVIRONMENT

The arctic environment that is recorded as a matter of statistical data shows that the temperature in the arctic region varies considerably less on a diurnal basis than most areas in a more temperate zone. The average temperature follows a sine wave curve through the year with the average rising above 0° C for a few of the summer months (June, July, August and early September). By mid-September the average daily temperature drops below freezing and plunges rapidly to a low average temperature during the winter months. The average variation from day to night in the arctic region is on the order of 6° C. Arctic weather is also characterized by periods of heavy snow fall accompanied by gale force winds (25 to 40 knots). The particular problems that we would expect to encounter in a true arctic environment are involved with the collection of snow and/or freezing rain and/or heavy frost on the aerostat during the temperature transition period in the late spring or early fall when the average temperature is in the vicinity of 0° C. During that period of time we would be most likely to encounter the types of ice accretion and snow fall that would create heavy buildups on the surface of a moored or flying aerostat. During the colder winter months the precipitation is too cold and too dry to stick readily to the aerostat surface. Furthermore, the winds are high enough in velocity that very little snow would be able to accumulate on the surface of the aerostat.

The weather that we expect to encounter in northern Vermont in January and February of 1983 will subject us to many of the weather extremes that we can expect to encounter in the arctic regions as well as the very dangerous weather that can occur during the temperature transition period (0° C). During the month of January in Vermont the average temperature will be in the region of -10° C. However, there will be many periods when the daily maximum temperature will rise above freezing and on each day it can be expected that the minimum temperature will drop well below freezing.

TABLE 2. WEATHER SUMMARY - BEAUFORT SEA SEPTEMBER 10 — OCTOBER 20, 1982

Day	Max Temp °C	Min Temp °C	Precipitation	Max Surface Wind (Knots)	Wind Direction (Degrees)
9/10	1.9	0.8	F	17	80
11	1.6	0.0	F	11	30
12	4.0	1.1	F	16	130
13	5.2	2.0	F	20	110
14	6.0	2.5	RF	18	110
15	5.4	2.4	RF	26	90
16	3.6	0.6	RFL	30	280
17	1.6	-1.4	SL	26	300
18	2.6	-0.6	RSF	32	90
19	3.0	-0.6	RFL	30	300
20	-0.1	-3.0	S	22	320
21	2.0	-1.7	X	18	70
22	2.0	0.4	S	16	90
23	1.3	-1.4	F	22	150
24	2.1	0.5	X	17	110
25	1.4	-0.5	F	18	70
26	0.8	-0.4	X	20	60
27	0.6	-1.0	RSF	32	40
28	0.5	-1.0	RSF	34	10
29	1.6	-1.4	SFL	29	360
30	2.4	-0.3	F	14	80
10/1	2.0	-0.7	SFL	15	30
2	1.8	0.0	SF	12	350
3	0.0	-3.0	F	25	350
4	-2.0	-4.0	S	30	330
5	-1.7	-4.0	X	30	300
6	0.0	-4.0	S	22	170
7	-0.3	-2.7	F	25	10
8	0.0	-0.8	F	21	120
9	1.0	-1.2	F	21	120
10	0.0	-1.5	F	20	120
11	0.0	-0.8	X	20	120
12	0.0	-1.0	SF	23	130
13	0.0	-1.0	X	22	100
14	-1.0	-1.3	S	21	100
15	-1.0	-3.7	S	22	50
16	-3.8	-6.4	S	20	30
17	-5.8	-7.0	S	8	300
18	-3.5	-5.7	S	16	60
19	-3.8	-6.6	S	22	30
20	-6.7	-10.5	S	12	330

Key to Precipitation: X = No precip, R = Rain, S = Snow, F = Fog, L = Drizzle

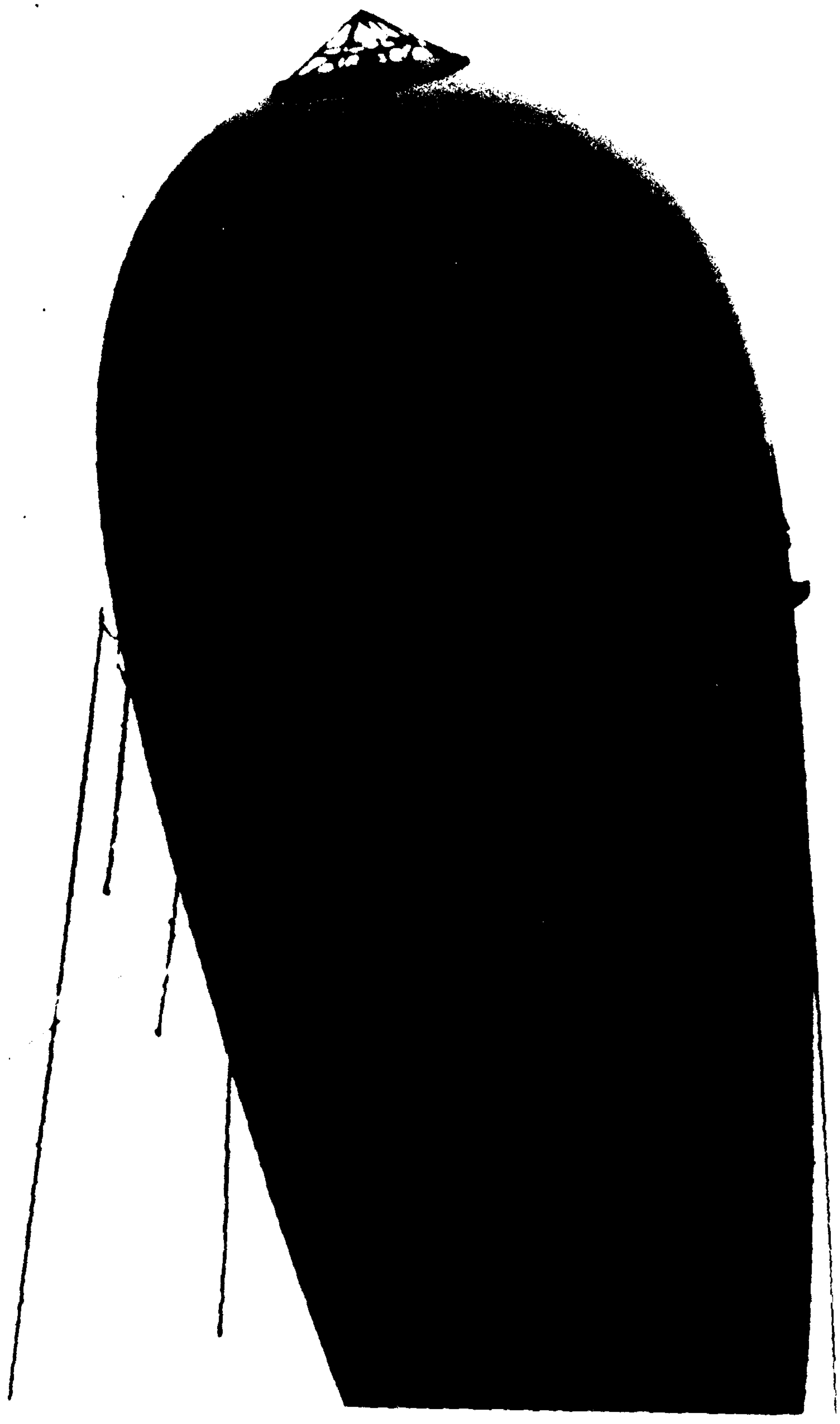


Figure 2. Ice on Aerostat Rigging

Figure 3. Ice on Aerostat Flying Sheave

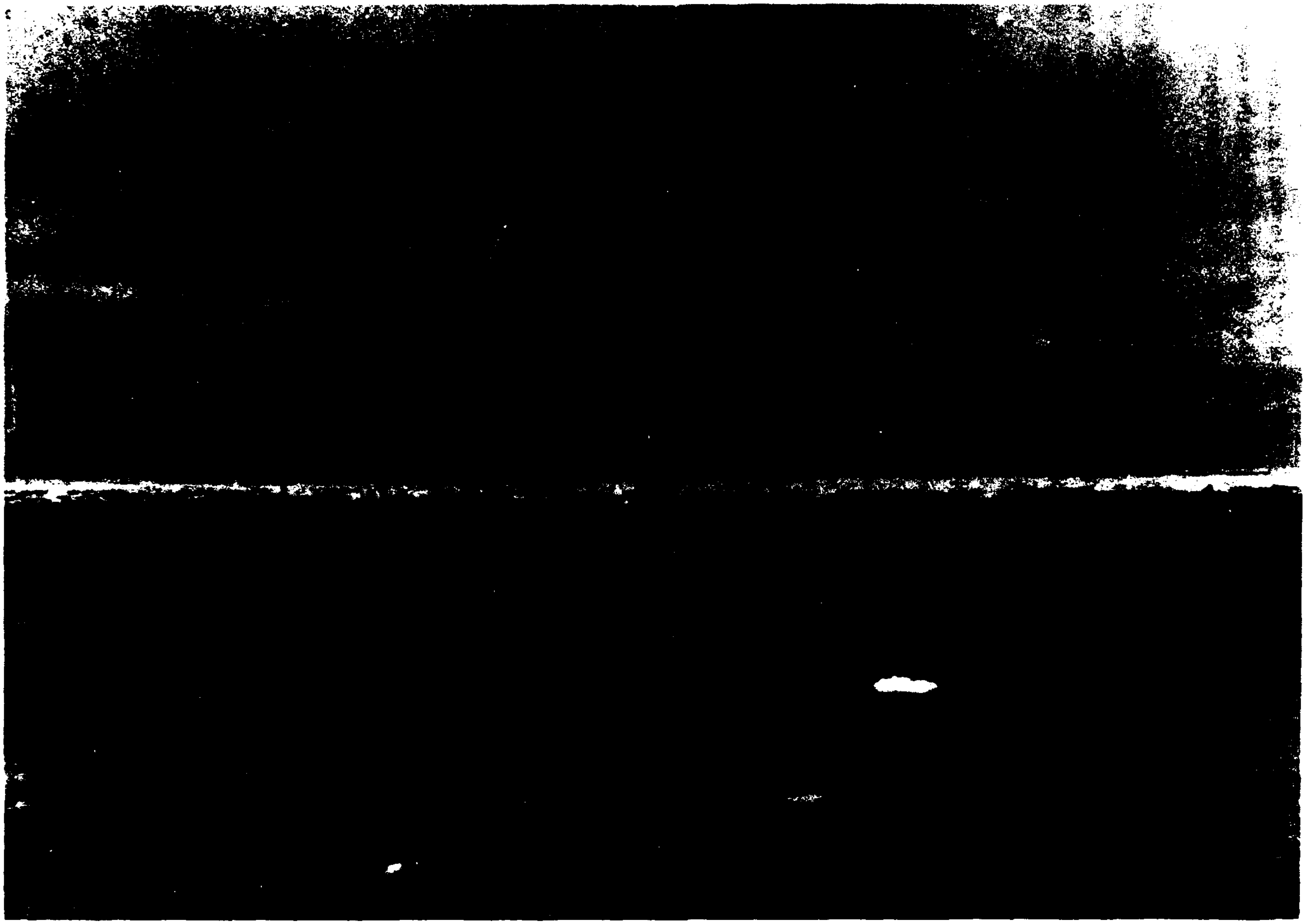


Figure 4. High Angle of Attack Caused by Heavy Ice Load

During these periods of thawing and freezing, precipitation in almost any form will stick readily to the surface of the aerostat while it is moored or while it is flying. We anticipate that the severest problem we will encounter will result from these periods in the transition temperature region.

Other weather data from the proposed operating area in Vermont show that the maximum sustained surface winds that we can expect to encounter will be in the region of 45 to 50 knots. Except for infrequent periods of high gusty winds, we should be able to recover the aerostat at almost any time during the winter months. It is our belief that during periods of high winds the aerostat will be relatively unaffected either while it is flying or while it is moored.

The AFGL provided a weather summary for Fort Ethan Allen, Vermont, to TCOM which was obtained by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) during the months of January and February 1982. These weather data are repeated in Tables 3 through 6. Our postulation of the simulated arctic environment is based on the data furnished for this project.

In summary, TCOM has attempted to anticipate the cold weather problems that will be encountered in Vermont and relate them to the types of cold weather experience that we can expect in an arctic region.

IV — CURRENT SYSTEM DESCRIPTION (STARS)

INTRODUCTION

TCOM Corporation's Small Tethered Aerostat Relocatable System (STARS) provides a versatile, transportable airborne platform for a broad spectrum of surveillance and communications applications. Small initial investment requirements and low operating costs make the system ideally suited for many military and commercial uses such as:

Surveillance

- Coastal (small ship detection)
- Airspace (low-flying aircraft)
- Border/ground (vehicle/personnel detection)
- Passive EW (detection of emitters)
- Acoustical
- Electro-optical

TABLE 3. WEATHER SUMMARY — FORT ETHAN ALLEN, VERMONT — JANUARY 1982

DAY	MAX TEMP (F)	MIN TEMP (F)	SNOWFALL (IN.)	MAX SURFACE WIND (KNOTS)	WIND DIRECTION (DEG)
1	36	28	.4	32	182
2	32	-4	T	15	23
3	34	-8		8	190
4	32	28	.1+.7 RAIN	35	166
5	32	9	T	20	291
6	34	3	1.2	20	160
7	34	10	1	12	280
8	10	-2	T	18	65
9	25	-6	.2	14	202
10	0	-13	.2	20	193
11	3	-11	.6	24	213
12	3	-22	.4	10	315
13	9	-17	.8	8	264
14	18	9	2.75	8	288
15	18	-6	2.3	14	286
16	25	-9	.6	19	210
17	3	-11	T	20	23
18	9	-18	T	8	272
19	14	-4	.4	10	42
20	23	-4	2	14	313
21	1	-20		14	331
22	3	-24		18	18
23	34	-18	5	48	179
24	28	9	.8	19	282
25	10	-13		16	327
26	3	-15		11	35
27	16	-18		10	243
28	30	5	T	21	296
29	30	0	T	22	175
30	36	1	1.2	27	172
31	36	14	4	37	

ABS. MAX (F) 36°
ABS. MIN -22
MEAN MAX 20
MEAN MIN -4

MEAN NO DAYS T => 90F 0
MEAN NO DAYS T =< 32°F 31
MEAN NO DAYS T =< 0°F 21
TOTAL SNOW FALL = 24 In.

Long Term Averages - January - Burlington, VT

ABS. MAX (F) 63
ABS. MIN -30
MEAN MAX 28
MEAN MIN 10
PERCENT FREQ WIND =>17 Knots 6.8
PERCENT FREQ WIND =>28 Knots .1
PREVAILING WIND DIRECTION SOUTH

MEAN NO DAYS T =>90 0
MEAN NO DAYS T =<32 30
MEAN NO DAYS T =<0 9
MEAN SNOW FALL (In) 18.5

TABLE 4. WEATHER SUMMARY — FORT ETHAN ALLEN, VERMONT — FEBRUARY 1982

DAY	MAX TEMP (F)	MIN TEMP (F)	SNOWFALL (IN.)	MAX SURFACE WIND (KNOTS)	WIND DIRECTION (DEG)
1	34	3	.8	44	140
2	36	0	.5	21	161
3	45	32	T	13	201
4	46	9	.4	16	194
5	27	0	.5	12	165
6	30	14	1.5	15	209
7	25	9	.2	20	203
8	28	10	.1	13	263
9	34	14	2.9	8	232
10	21	1	.7	17	247
11	23	5		17	214
12	25	10	T	10	237
13	30	9	.2	9	31
14	27	1	.2	11	296
15	45	1	.3	32	177
16	41	12		17	320
17	21	3		11	246
18	41	7		12	207
19	36	23	1.5	16	174
20	36	23	T	9	6
21	43	18	T	10	264

ABS. MAX(F)	46	MEAN NO DAYS T =>90	0
ABS. MIN	0	MEAN NO DAYS T =<32	28
MEAN MAX	33	MEAN NO DAYS T =<0	3
MEAN MIN	10	TOTAL SNOWFALL = 13 In.	

Long Term Averages - February - Burlington, VT

ABS. MAX(F)	60	MEAN NO DAYS T =>90	0
ABS. MIN	-26	MEAN NO DAYS T =<32	27
MEAN MAX	30	MEAN NO DAYS T =<0	6
MEAN MIN	11	MEAN SNOWFALL (IN.)	19

PERCENT FREQ WIND =>17 Knots 5.2
PERCENT FREQ WIND =>28 Knots 0.0
PREVAILING WIND DIRECTION SOUTH

TABLE 5. UPPER AIR DATA — FORT ETHAN ALLEN, VERMONT — JANUARY 1982

Altitude 3500 ft MSL (2800 ft AGL)
All data recorded at 0430 hours unless otherwise noted

Mean Wind (Knots) 23
Max Wind (23 Jan-0945) 59

Mean Temperature (F) 2
Min Temp (10 Jan-0700) 18

Day-Time	Wind Speed (Knots)	Temperature(F)
5-900	33	1
6	31	23
7	19	16
8	21	-11
9	17	1
10	20	-20
11	20	-17
12-0630	25	-13
13	7	1
14	1	16
15	26	-2
16-0550	34	12
17-		
18	20	-17
19-1000	13	3
20	23	10
21	20	-8
22-1600	9	0
23-0745	59	9
24-		
25-		
26	22	-15
27-		
28	33	23
29-0600	37	9
30-0800	41	21
31-1105	6	10

TABLE 6. EXAMPLES OF SHORT DURATION WEATHER EXTREMES — FORT ETHAN ALLEN, VERMONT — JANUARY 1982 — FEBRUARY 1982

<u>Temperature (°F)</u>

10 Jan - 24 Hour Avg		≈ -6
12 Jan - 24 Hour Avg		≈ -9
21 Jan - 24 Hour Avg		≈ -9
22 Jan - 24 Hour Avg		≈ -11
12 Jan - 8 Hour Avg	(2-9 AM)	≈ -18
22 Jan - 8 Hour Avg	(2-9 AM)	≈ -19

<u>Winds</u> (Knots) - At 8 Meter (26 Ft) Tower

1 Jan - 6 Hour Avg	(7-12 AM)	26
4 Jan - 3 Hour Avg	(9-11 AM)	24
23 Jan - 7 Hour Avg	(10AM-4PM)	28
28 Jan - 12 Hour Avg	(8AM-7PM)	15

<u>Notes</u>

1. All winds at 22M (73 ft) tower are approximately double those at 8M.
2. All data tabulated from SNOW-ONE A meteorological reports by Cold Regions Research and Engineering Laboratory, C of E.

Communications

Military
Over-the-horizon relays for remotely piloted vehicles (RPVs) and missiles
Rural telephone
Very low frequency communications (VLF)
Emergency broadcast and telephone

Completely self-contained, a STARS system can be quickly transported to an unimproved site and be operational within hours after arrival. Besides providing a rapid deployment capability, STARS is the most economical airborne platform to acquire, operate and maintain. Compared to any other means, STARS costs less in terms of both materials and manpower to provide service over large areas for extended periods of operation.

APPLICATIONS

STARS is an airborne platform that improves the performance of many electronic payloads by extending their range and overcoming terrain obstructions. The system uses unmanned, helium-filled tethered aerostats to support payloads weighing as much as 125 kilograms at operating altitudes up to 750 meters above terrain where the sea level temperature is 30° C. Nominal line-of-sight (LOS) coverage is provided out to 110 kilometers. For omnidirectional services, the resultant ground coverage area is 38,000 km^2.

Many operational scenarios can be built around these parameters. The following applications typify system versatility.

SURVEILLANCE

Coastal

Since ground-based radars located on the seashore have a relatively limited range (on the order of 25 km) against ship targets, the requirement for continuous coastal surveillance at ranges of 100 km is unsolved. The use of airplanes and ships for this mission is very expensive and is becoming ever more costly with sharply rising fuel costs. As a result, there is a demand for a much more economical solution. The transportable small aerostat system provides an effective solution to this requirement. It can support lightweight radars at an altitude of about 750 meters above sea level to provide sufficient LOS coverage. Available radars can detect 100-m^2 targets in conditions up to sea state 4 at maximum LOS range.

Air

The detection of slow, low-flying aircraft crossing borders and entering countries with illegal cargo is a very likely application for STARS. Solutions based on the use of airplanes equipped with radars prove to be extremely costly and, as a result, the surveillance activities have to be limited in both time and space.

Lightweight, down-looking radars carried aloft by small aerostats can provide economical coverage of large areas on a continuous basis within the weather constraints specified for the aerostat operations.

Ground

Ground surveillance radars are in great demand for border protection as well as for military applications in the battlefield. Useful as they are, their inherent limitation is their ground-level position. A radar operated from ground level to detect ground targets may have more than 50 percent of the area within its range shadowed and obscured by hills and mountains. Elevating the radar to a sufficient altitude decreases the obscured area to acceptable proportions and makes the radar coverage more useful.

Radar border surveillance conducted from aerostats can provide 360 degree coverage and improve the effectiveness of border protection units. The extended radar range permits infiltrators to be detected at significant distances from the border. Mobile units can be directed to intercept the infiltrators at the right place with great savings in manpower and with a high probability of success.

Small lightweight radars suitable for mounting on STARS can provide early warning and perimeter surveillance for division-size units in the mobile mode of the modern battlefield.

COMMUNICATIONS

Military

For tactical military operations, an aerostat platform is well suited for voice and data relay functions. Anti-insurgence operations may be one typical situation; battlefield communications another. A small mobile aerostat will answer this requirement by providing communication ranges out to a 100-km radius. The mobility of the system is particularly important in this application as the zone of operations changes frequently.

Relays for Remotely Piloted Vehicles (RPVs)

RPV missions often require that the vehicle be operated at ranges that are over the horizon for ground-based command and control stations. To accommodate these ranges, a small aerostat platform can be used as a communication relay between ground control stations and the RPVs. In comparison with aircraft serving as relay stations, STARS offers a much more economical approach and can fulfill this mission in a less conspicuous manner. Deployment of an aerostatborne communications relay can practically free the RPV from limits of operational altitude and range within which communication line-of-sight can be maintained.

Rural Telephone

In thinly populated rural areas where telecommunications requirements are limited and potential subscribers are considerably spread out, telephone service is often not available. Terrestrial system costs are normally too high to justify these services. For such areas, which exist in many countries, a small aerostat system could make rural telephone service possible.

Carrying a TCOM rural telephone transponder, one small aerostat operating at an altitude of 750 meters could provide telephone service via low-cost radio units to subscribers as far as 110 km from the aerostat. By strategically locating the operational site to serve a large fringe area adjacent to an area where a telephone network exists, it would be possible to connect subscribers in the fringe area into the existing network. Similarly, the small aerostat system can be located in such a manner as to work into an existing satellite terminal. Because it is an add-on at the periphery of other equipment, the aerostat could be taken out of operation because of adverse weather conditions without interrupting other services.

THE STARS SYSTEM

The STARS system consists of five subsystems; the aerostat, a suitable payload, a powered tether, a mooring system trailer, and a support system trailer (if required). When these subsystems are linked together, the STARS system is capable of carrying a payload to an altitude up to 750 meters operating for extended periods of time (up to 7 days) before recovery. Although the aerostat system is not designed for operations in thunderstorms or other severe weather conditions, it is capable of operations at flight altitude in steady-state winds up to 70 knots. The aerodynamic design provides a high degree of stability in flight. The payloads are usually three-axis stabilized by means of gimbals and azimuth drive. The strong, lightweight hull material is tear-resistant, has excellent weather and abrasion resistance properties and minimizes helium gas leakage.

The aerostat maintains its position above the launch point by means of a single cable called the "tether." The tether not only anchors the aerostat in flight but also provides electrical power to the airborne components via electrical conductors embedded in the tether.

The mooring system is used to store the tether when the aerostat is on the ground, to maintain the tether at the desired length in flight, and to inhaul and outhaul the tether when the aerostat is launched or retrieved. The system makes maximum use of conventional equipment. For example an entire STARS system, including diesel fuel (for generation of electricity), is mounted on two flatbed trailers. These trailers are drawn by trucks, which are required only when the system is moved.

STARS AEROSTAT SYSTEM

The STARS aerostat consists of a flexible hull structure that has a design volume for helium of 708 cubic meters. Three stabilizing fins are mounted at the aft end of the hull. An air inflatable windscreen is attached to the underside of the hull structure to house and protect the payload. The aerostat is rigged with appropriate suspension lines, fin guys, handling lines, and mooring lines. A lightweight metallic cone structure is laced to the nose of the aerostat and is used to attach the aerostat to the mooring system. There is a small balloon within the helium compartment called a ballonet; the ballonet is inflated with air and is used to maintain and adjust the internal aerostat hull pressure. A pressure system which consists of a control unit, pressure sensors, blowers, valves and emergency batteries governs the flow of air into and out of the ballonet.

STARS AEROSTAT SYSTEM DESCRIPTION

The STARS aerostat hull is built from a laminate fabric consisting of an outer layer of Tedlar bonded to a substrate of Dacron fabric, which is the strength member of the hull structure. The bonding resin used in this structure is a hydrolytically stable polyester resin called Hytrel. The hull, when inflated, is 25 meters in length and 8 meters in diameter at its largest point. There are three fins; an upper vertical fin and two lower fins at an anhedral angle of 45 °. The fins are all the same size and are air inflated. Approximately the last 3 meters of the aerostat hull is air inflated and is separated from the main hull with a diaphragm. The fins connect directly with the air inflated tail cone. The ballonet consists of a flexible fabric membrane attached to the interior lower surface of the hull which has an inflated volume of approximately 170 cubic meters. Two blowers are mounted on the hull so that they blow air into the ballonet when directed. A pressure control unit containing two pressure switches senses the internal hull pressure of the aerostat and commands first one blower and then the second blower into operation when the hull pressure drops to the predetermined pressure switch values. The pressure control unit also contains two pressure transducers which sense the ballonet air pressure and the helium hull internal pressure, and convert these pressure signals to electrical signals for transmission to the ground via the telemetry system. Three poppet valves are used in the pressure system. Two of these valves are mounted in the ballonet and act as pressure relief valves for ballonet air. The third poppet valve is mounted between the ballonet and the windscreen and allows air to flow from the ballonet into the windscreen at a slightly reduced pressure. Thus the windscreen is pressurized with air at a slightly lower pressure than the ballonet. A fabric tube connects the ballonet to the after hull cone and allows air to flow freely into or out of the tail cone as required to maintain the proper pressure in the tail cone and fins.

STARS AEROSTAT PERFORMANCE

The STARS aerostat is designed to carry a 125-kg payload to an altitude of 750 meters on a hot day (30 ° C). There is a safety factor called "free lift" which is calculated to be 15% of the gross lift of the aerostat which is maintained to insure that the aerostat remains at its design altitude in turbulent conditions. Much heavier payloads can be carried by STARS, but with a corresponding penalty in altitude. The STARS must also pay a penalty for operation on hotter days than a 30° C day but gains a distinct advantage in payload capability on cooler days. The following aerostat performance chart shows various payloads from 100 kg to 180 kg operating at sea level temperatures from 0° C to 40° C. (See Figure 5.)

The performance characteristics of STARS are summarized as follows:

- Operating altitude - up to 900 meters above ground (see performance curves)
- Ground coverage: Typical range - 110 km; area - 38,000 km^2
- Payload lift capacity - up to 180 kg
- Continuous time on station - up to 7 days
- Operating environments - operations in steady or horizontal winds up to 70 knots.
- Manning: With the aerostat aloft, one person to operate the aerostat system and one or more to operate and monitor the various payloads. Setup, launch, retrieval and dismantling require up to five persons.
- Ground installation: No civil works are required. In some forested or rocky environments, limited clearing may be necessary.
- Deployment: By two suitable vehicles such as flatbed trailers, or by suitable aircraft or helicopters.

STARS MOORING SYSTEM

The mooring system consists of two main separate components. One is the structural component, which physically controls the aerostat during the mooring phase, the inhaul and outhaul phase and the flying phase. This component consists of a boom and tower, used mainly in the mooring phase; the hydraulic winch system, which controls inhaul and outhaul; and the tether itself, which links the aerostat to the mooring system, and also provides the means for conducting electricity to power the payload and on-board equipment.

The second component is the power source which provides the electrical needs of the mooring system. Electrical power is needed to power the motor drive for the main winch and closehaul winch hydraulic systems, to operate airborne electrical equipment including the payload through copper wires in the tether core and to operate ground support equipment such as lights and utility outlets for heating or cooling space occupied by operating personnel.

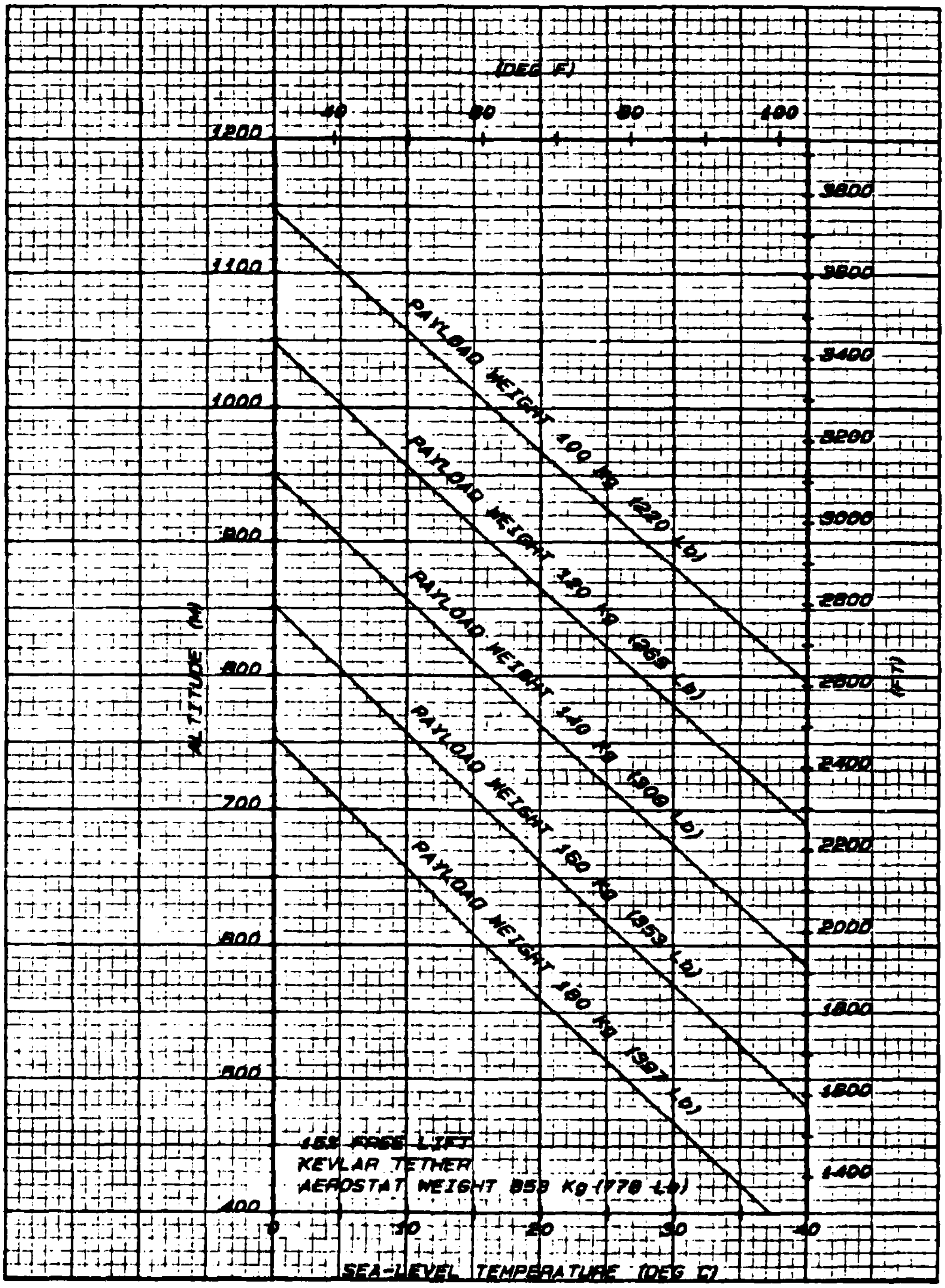


Figure 5. Operating Altitude of the STARS Aerostat as a Function of Sea-Level Temperature for Various Payload Weights

MOORING SYSTEM DESCRIPTION

The typical configuration of the STARS mooring system is as shown in the following sketches. The system is trailer-mounted and weather resistant. The mooring system serves a dual purpose. One purpose is to secure the aerostat when it is not being operated, the other is to control aerostat altitude during flight via the tether winching system. Since it is difficult to separate these functions, they are integrated into a single system. (See Figures 6 and 7.)

The primary structural elements of the mooring system are a tower and cantilevered boom which are joined together at the base of the tower and mounted to a turntable bearing located below this juncture. The structure is rotated by forces applied to it by the aerostat, either through the mooring lines or the tether cable. The structure may also be rotated by activating the rotary drive device from the control console. This feature is used to align the boom & tower with the aerostat when inhauling and docking. The turntable bearing is mounted on a base structure which is anchored to the ground. When being moored, the nose line from the aerostat is routed through the latch at the top of the tower to the nose line winch and closehaul lines attached to the sides of the aerostat are coupled to the closehaul winches on the boom outriggers.

Several subsystems are mounted on the mooring system structure. These are:

- Control console
- Tether winch
- Closehaul winches

The control console is mounted on the boom near the base of the tower. The location of the console is such as to provide the operator with an unobstructed view of activities related to all phases of the aerostat operation. Power is supplied to the mooring system through cabling running from a 50-kW diesel electric generator through a slipring located on the axis of the turntable bearing to the control console. From there it is distributed to the electric motors in the hydraulic power supply via the motor starter units. Hydraulic motor speed and direction controls are provided at the console to operate the winch systems.

The tether winch is located on a cantilevered appendage that counter-balances the boom. The tether cable is routed through the boom and over the flying sheave on the outboard end of the boom to the aerostat. The sheave pivots with the movement of the aerostat so that the sheave and tether are always in the same plane.

The tether winch has the capability of storing 1066 meters of .91-cm-diameter steel cable or 1.16-cm-diameter Kevlar cable on 76-cm-diameter drum. The drum is driven by a direct drive, high torque, low-speed hydraulic motor. Cable can be inhauled at 55m/min. with 815 kg of line tension. Fail-safe hydraulically operated disc brakes are provided on the winch drum. They are capable of holding against a peak line load of 4,535 kg. A slipring is provided on the drum shaft to pass electrical power and signals to the tether cable.

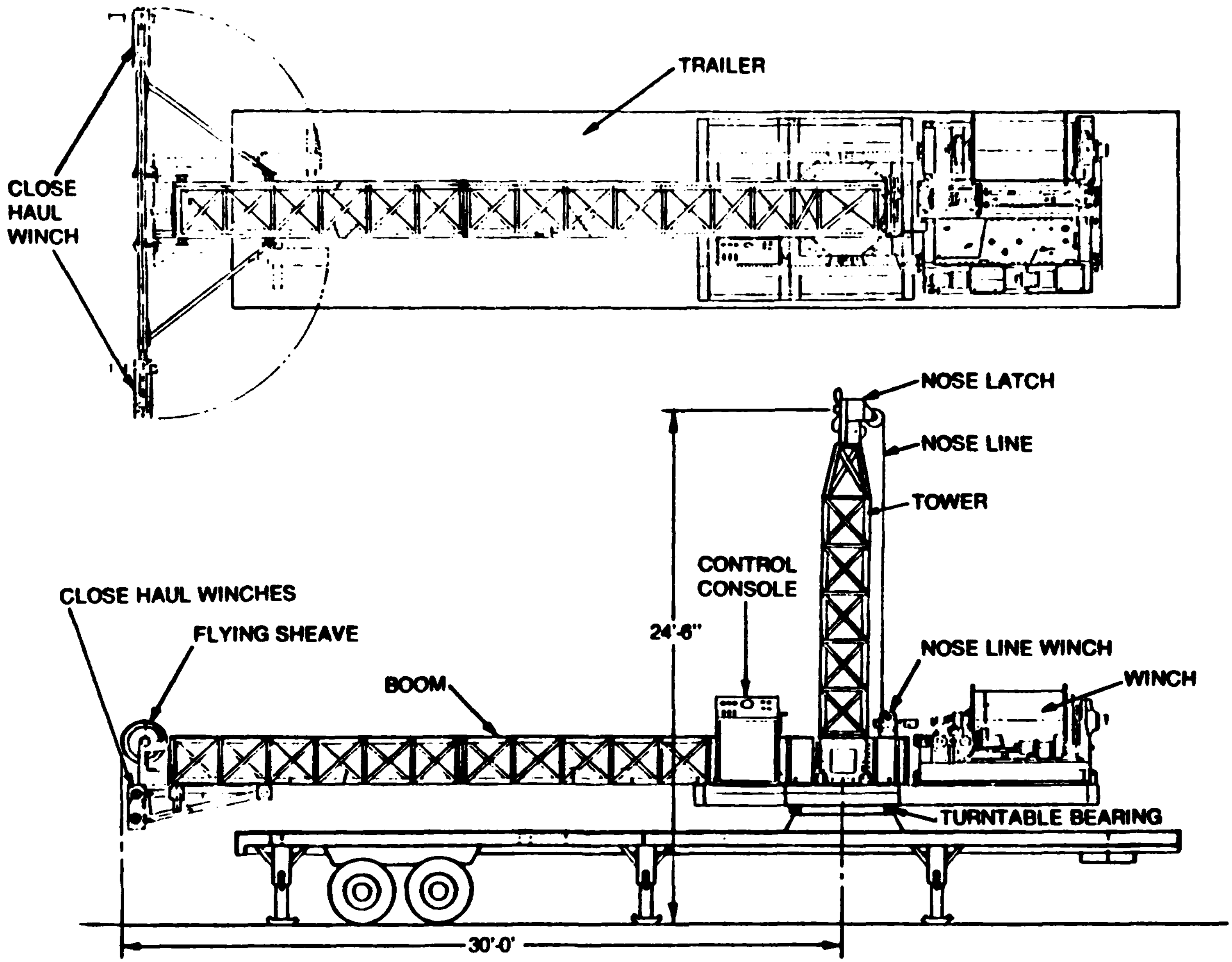


Figure 6. Mooring System Deployed Configuration

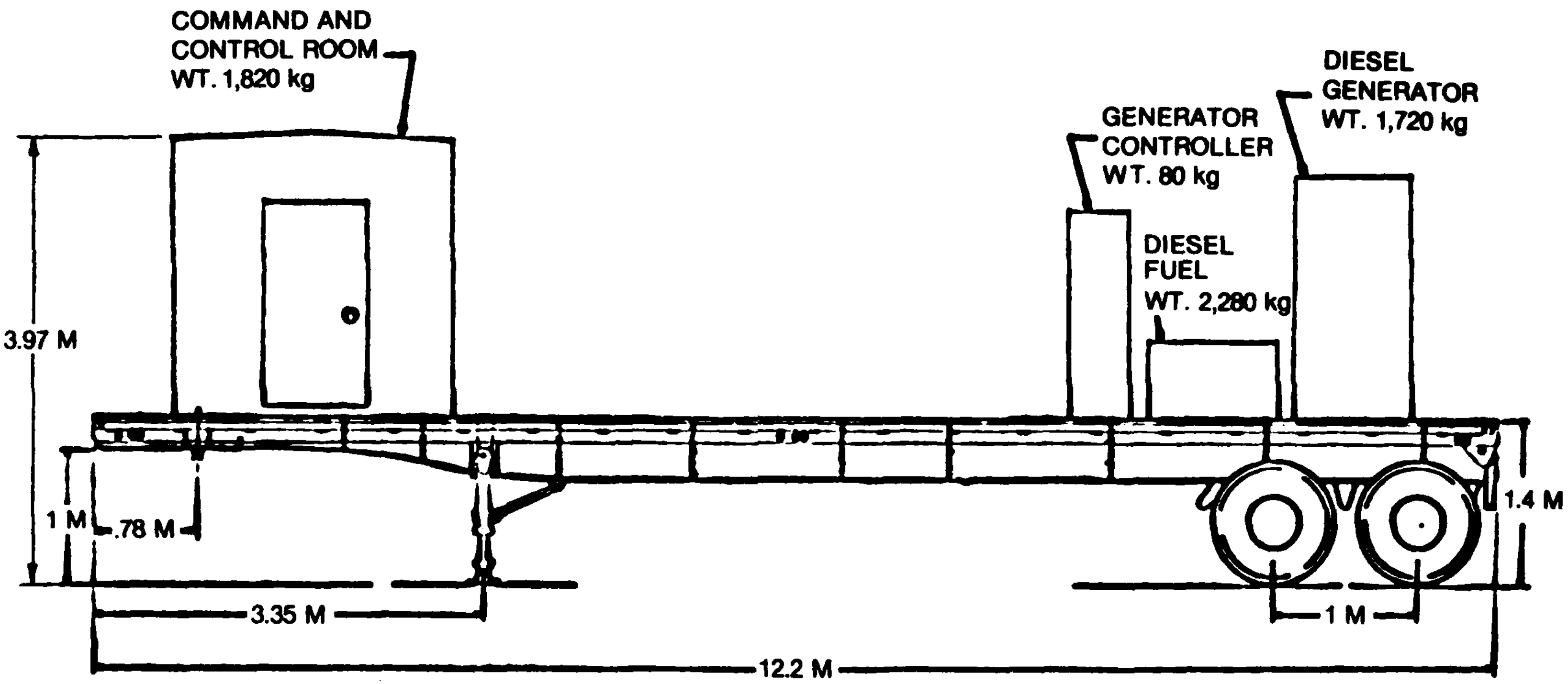


Figure 7. Support Trailer

Laying of cable on the drum is controlled by a level wind device with an automatic adjustment feature which permits the use of a range of cable diameters without major equipment change. The level wind mechanism is driven by a separate fixed displacement hydraulic motor whose activation and direction is controlled by a fleet angle sensor.

There are three small winches, one nose winch and two closehaul winches. One closehaul winch is located on each side of the outboard end of the boom and has inhaul capability of approximately 12 meters per minute at a line tension of 450 kg. These winches pay out or inhaul the closehaul lines during launch and recovery of the aerostat. The nose line winch is mounted at the base of the tower and has the same capacity as the closehaul winches. The nose line to the aerostat, routed through the nose latch, is controlled by this winch during launch and recovery.

The tether is an electromechanical cable with either a steel or Kevlar strength member which serves several functions in the aerostat system. This cable provides a mechanical tether which anchors the aerostat to the mooring system and a link for transmission of electrical power to the aerostat. The tether also functions as part of the lightning protection system.

Provisions can be made to protect the system against lightning strikes to the aerostat and tether. Typically, a single lightning ground wire is suspended above the aerostat on insulated standoff poles, running from the top of the upper vertical fin to the upper nose and to the metal nose mooring ring. A lightning ground wire runs from the nose ring to a lower standoff pole and from there to the confluence point, where it is attached electrically to the tether, which will act to carry lightning discharge to the mooring system.

ARCTIC MODIFICATION

A number of modifications were made to the basic STARS mooring system to form a Penguin mooring system capable of accommodating the Beaufort Sea environment. Figure 8 shows this Penguin system in its transit configuration. Figure 9 shows it in operation, deployed on the aft end of a support ship. The mooring system modifications required for the Penguin program included:

1. Addition of a control cab, tether winch enclosure and closehaul winch enclosures.
2. Addition of heating system to raise the ambient temperatures of the flying sheave, turntable drive, slipring, closehaul winches, nose latch, control cab, and tether winch enclosure to an acceptable level.
3. Addition of an intercom system.
4. Addition of a transformer on the mooring system to accommodate 208-volt heaters.
5. Addition of a mooring system ground power supply and battery backup.
6. Addition of a bumper bag and inflation blower.
7. Change to Mil-Spec 5606-H hydraulic fluid.
8. Change to Aeroshell arctic grease in nose winch, close haul winches, flying sheave bearings, turntable bearing, and nose latch bearings.

Figure 8. Penguin Mooring System Configured for Transit

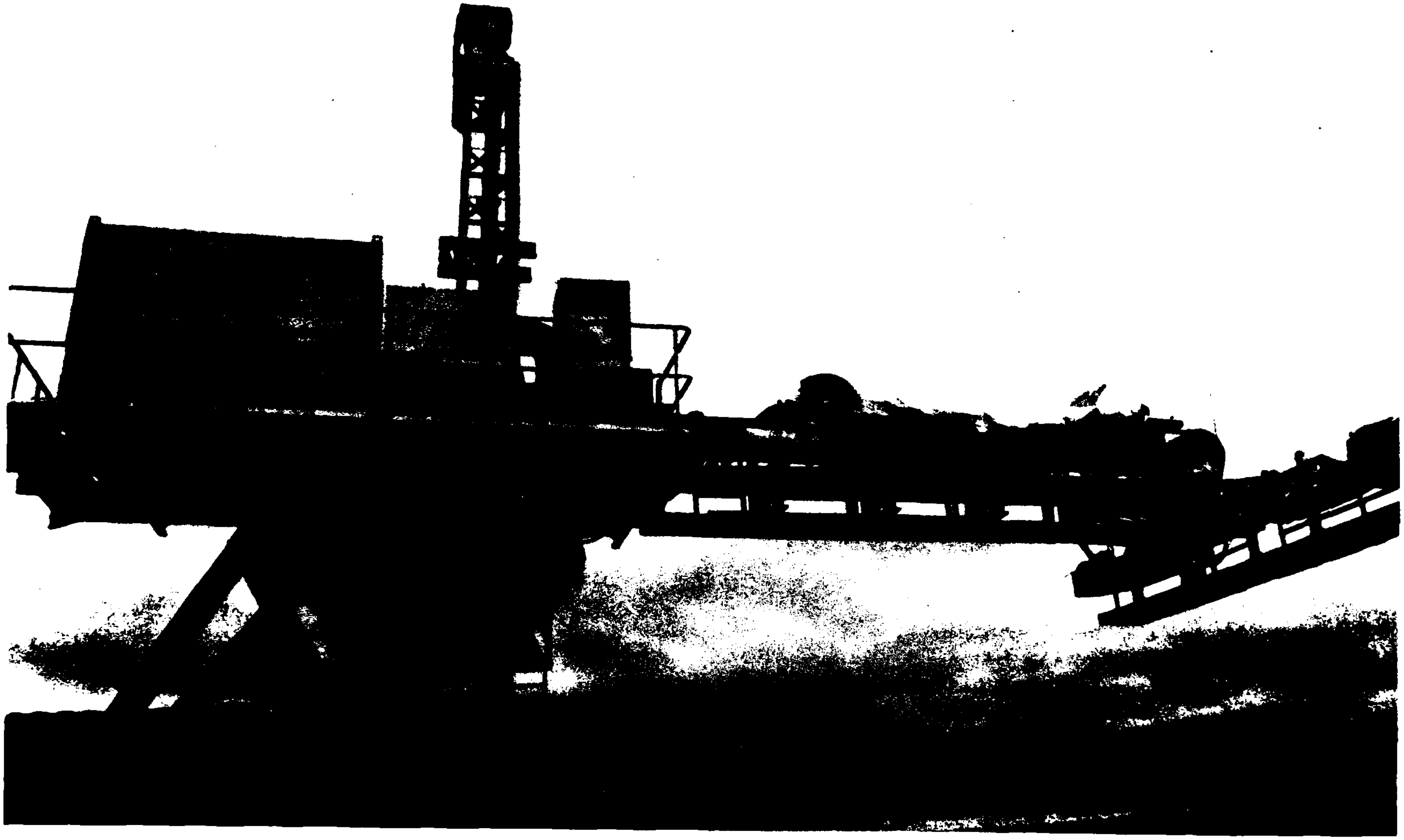


Figure 9. Mooring System Deployed on Support Ship

SUPPORT TRAILER

If the STARS system is deployed to a remote area, a transportable power source must accompany it. A flatbed trailer outfitted with a 50-kW diesel generator, diesel fuel tank and a generator controller can be furnished for this purpose. The support trailer also carries a heated/air-conditioned fiberglass shelter for use as a command and control room.

SYSTEM PERFORMANCE

The set up of a STARS system can be accomplished in a few hours after arrival on site by a small crew of trained personnel. After removing the aerostat container from the mooring trailer, the mooring tower is erected and secured. Winches are unfolded and locked into position. Ground anchors are driven to stabilize the trailer and power cables are connected. The aerostat is then inflated and attached to the anchored mooring system. The transport configuration of the mooring system is shown in Figure 10.

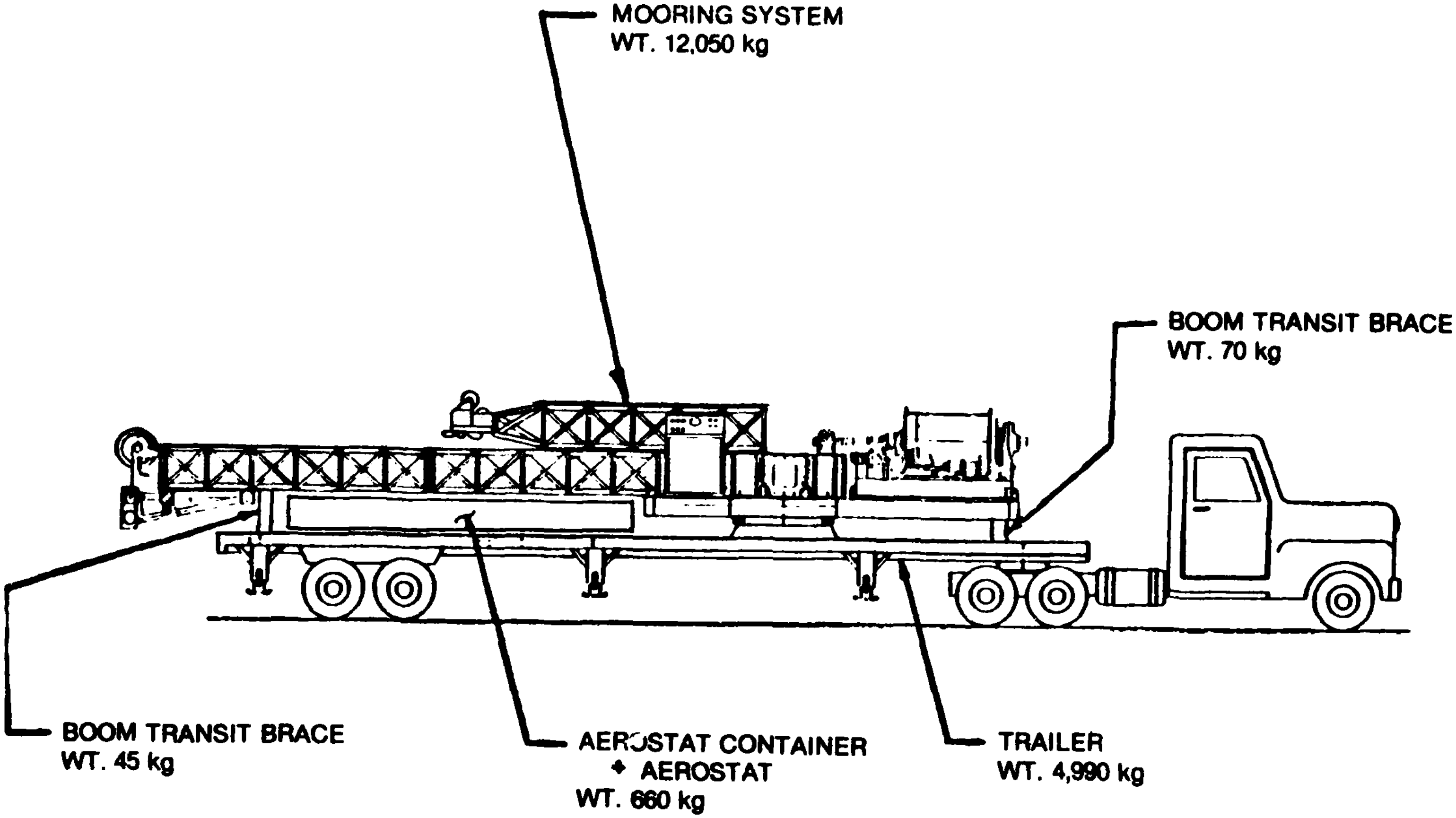
While moored, the aerostat is secured to the mooring system through a nose latch at the top of the tower. The aerostat is free to weathervane 360° around the tower to minimize wind resistance.

For most applications, a transportable system such as the trailer-mounted configuration will be suitable. When lighter payloads are involved and the system must be more frequently relocated, a mobile system could be provided. The mobile system would perform similarly except that the aerostat volume would be approximately half, the payload capacity would be on the order of 50 kg and the system would offer a limited cross-country mobility for relocation over short distances with the aerostat aloft.

SITING REQUIREMENTS

The mooring system trailer should be located in an area that is clear of trees and other obstructions taller than about 1 meter for a minimum radial distance of 50 meters. The support trailer should be placed approximately 45 meters away from the mooring trailer. This allows space for launch and recovery as well as aerostat weathervaning when moored.

When the mooring system trailer is deployed, all six landing gears should be used to level the trailer and lift the system slightly to relieve the weight from the tires. When the aerostat is inflated and moored or flying, overturning forces are introduced to the trailer. Therefore, a firm foundation for the six landing gears is required. Along with the landing gear being in contact with the ground, cable tiedowns are required. This is accomplished through the use of earth anchors or, where the soil has insufficient character to hold an earth anchor, concrete anchoring devices. Earth anchors consist of a single 25.4-cm helix on a 3-meter anchor rod screwed into the ground much like an auger. Eight of these are normally used. The soil types that will permit the anchors to develop their holding power are classes 4, 5 and 6. Class 4 soil is a medium dense sandy gravel or very stiff to hard silts and clays. Class 5 soil is medium dense coarse sand and sandy gravel or stiff to very stiff



MOORING SYSTEM *(with braces & aerostat)*

- WITH TRAILER - 17,815 kg
- WITHOUT TRAILER - 12,825 kg

Figure 10. Mooring System Transport Configuration

silts and clays and Class 6 soil is loose to medium dense, fine to coarse sand or firm to stiff silts and clays. Where soil classes are unknown, the use of a soil test probe will yield acceptable data to determine the classification.

In areas where the ground surface is soft due to moisture or loose sand or gravel, additional bearing surface for the landing gear pads may be necessary. Ten-cm-thick timbers or 60-cm-square heavy metal plates may be placed under the landing gear pads to increase the bearing area.

Both the mooring trailer and support trailer should be grounded. The mooring trailer will be protected from lightning strikes and the support trailer will be grounded for personnel safety. Grounding of both trailers will be accomplished by the use of ground rods with copper wire leads off the trailer frame.

V. SYSTEM ENVIRONMENTAL LIMITATIONS

TCOM has been operating the STARS aerostat system for approximately 15 months. When we first began our operations we established conservative environmental limits for the operation of the system. We originally anticipated that we would operate the system in maximum winds of 50 knots at flight altitude and that we would launch and recover the aerostat in winds no greater than 15 knots with gusts of ± 3 knots. As we gained experience with the system, we increased our flight limitations until we now routinely launch and recover the aerostat with 25 knots of wind with gusts of ± 5 knots about the average. Although no specific written limitation has presently been placed on the STARS, system we believe that a practical safe limitation for the launch and recovery of the system depends upon the experience of the operating crew, the degree of turbulence and the average wind conditions. With an experienced crew it is safe to launch or recover the aerostat in winds up to 35 knots, provided there is little or no turbulence. Launches and recoveries in this wind region have been conducted. We also have raised our restriction on the maximum wind at flight altitude to at least 70 knots and have no fear of flying in steady winds of even greater velocity at flight altitude. To date, we have experienced maximum wind velocity at flight altitude of about 45 knots. On the basis of our present STARS environmental limitations and the available weather information, we do not believe that there will be any wind conditions encountered in Vermont which will preclude flying at operating altitude. However, there may be periods when it will not be possible to launch or recover the aerostat due to high gusty surface wind conditions.

The STARS system that will be employed in Vermont will be equipped as described in subsequent sections of this report to survive in the snow and ice environment which we anticipate. We do know that a large accumulation of snow or ice on the surface of the aerostat will exceed the free lift of the aerostat and cause it to descend from operational altitude or will crush it to the ground while it is on the mooring system. As described below, steps will be taken with this system to provide the maximum amount of free lift to combat snow loads while flying. In addition, an air-inflated bumper bag will be provided on the mooring system to assist the aerostat in surviving excessive snow loads while moored. The environmental limitation on snow and ice that must be observed is the amount of accumulation that might cause catastrophic damage to the aerostat. Steps must be taken during large accumulations to remove the snow and/or ice as rapidly as possible.

In summary, we do not believe from the information on hand that there will be any limitations placed on the operation of the STARS system by the winds that can be expected at the operating altitude of the aerostat. We believe that the winds at all times will be within the capability of the STARS aerostat, tether and mooring system. There may be some periods of time when there are windy, gusty ground conditions that would make it unsafe or inadvisable to attempt to launch or recover the STARS system. Except in periods of emergency when the aerostat must be recovered or when it appears that the risk would warrant launching the aerostat to avoid a greater risk on the ground, the aerostat will not be recovered or launched.

The real environmental limitation that we would expect to encounter is the amount of ice and/or snow that might accumulate on the surface of the aerostat either while flying or while moored and not be removable using the precautionary means that will be installed on this aerostat. These heavy weight snow/ice accumulations can cause damage to the aerostat on the ground or cause it to descend rapidly from operational altitude and crash into the ground. These extreme operational conditions will be avoided in every way possible during the tests in Vermont.

VI. SYSTEM EVALUATION FOR COLD WEATHER OPERATION

The tethered aerostat study for operation of the STARS system in a simulated arctic environment has been conducted by making a series of ministudies of several aerostat related subjects. The studies which have been performed are those tasks that were listed in the work breakdown structure and included in the investigation: Valve/Blower Heating, Aerostat Ice Accretion, Pressure Cycling Subsystem, Aerostat Snow Accumulation, Mooring Lines, Battery, Aerostat Performance Analysis, Helium Consideration, Pressure Control System, Tether Test, Tether, Sliprings, Aerostat Cabling, Mooring System and Non-Flexible Aerostat Structures, Diesels and Low Temperature Repair Techniques.

A. VALVE/BLOWER HEATING TESTS

PURPOSE

Evaluate effectiveness of blanket heaters used on the blowers and valves for Penguin Project. Determine suitability of system for deicing and propose changes if any that would appear necessary for arctic environment operation.

DESCRIPTION OF TESTS

Install blowers and valves on aerostat in an operational configuration and measure the temperature rise above ambient.

a. For the valve, this should be done in still air and the temperature of the mounting ring, valve duct, and valve should be measured at equilibrium.
b. For the blower, these measurements should be conducted in still air with and without the blower running. The temperature of the blower housing and adapter ring and mounting ring should be recorded.
c. Determine operational limits of built-in "cutoff" switches and recycling time.
d. To the extent possible, repeat the test for the valve at a lower ambient temperature (in freezer) to determine repeatability.

MATERIALS AND INSTRUMENTATION

- Penguin blower and valve
- Variable voltage power supply, min 10 A @ 28 V
- Temperature indicators — multiple thermocouples and readout device. Model 175 digital readout and thermocouple switch
- Either 25M001 or 25M002 STARS aerostat, whichever is available for suitable period of time
- Freezer — in lab at Elizabeth City

RESULTS

Figure 11 is a plot of the temperature at selected points on a valve/duct assembly. These data were taken at an ambient temperature of approximately -18° F. The temperature cycling is due to an internal temperature limit switch to prevent overheating. The plot of power vs. time indicates a heater duty cycle of about 66%. Since the valve seat will be at approximately 32° F while ice is being melted, only about 1/3 of the power will be required to maintain this temperature, leaving about 2/3 of the power to melt ice. This corresponds to about 800 gm/hr. Figure 12 is a plot of temperature at selected points for the blower/duct/check-valve assembly. Again the ambient temperature was about -18° F. It is noted that apparently only one heater "over-temperature" switch was functional, as indicated by the high temperature at the blower mounting clamp. The duty cycle for these heaters is also about 67%. By reasoning similar to that for the valve/duct assembly, we should be able to melt approximately 800 gm/hr.

These tests seem to confirm the Penguin experience of not having any icing problem. A cycling system would seem to be necessary in order to have enough reserve power to melt ice.

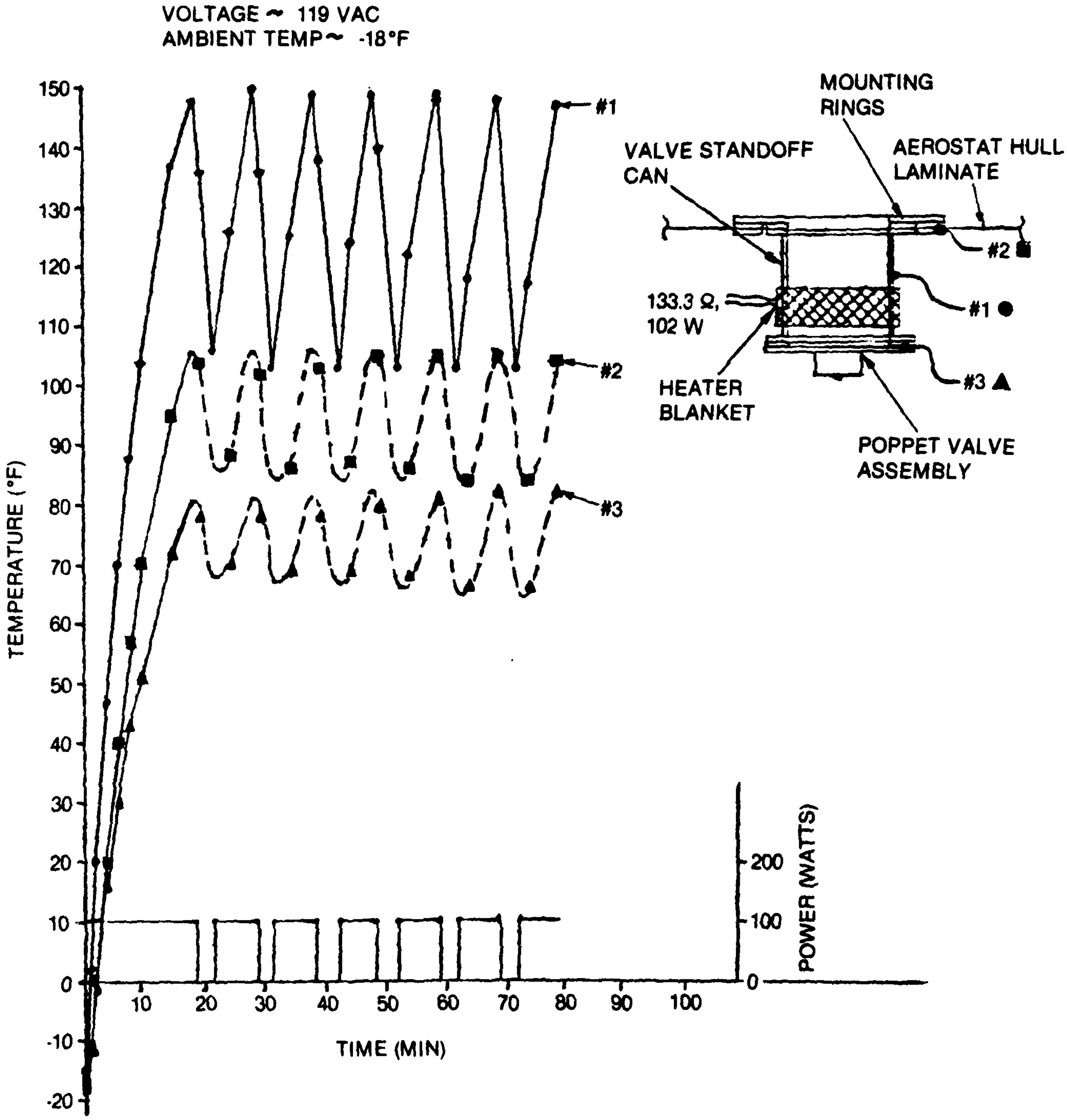


Figure 11. Valve Heater Operation

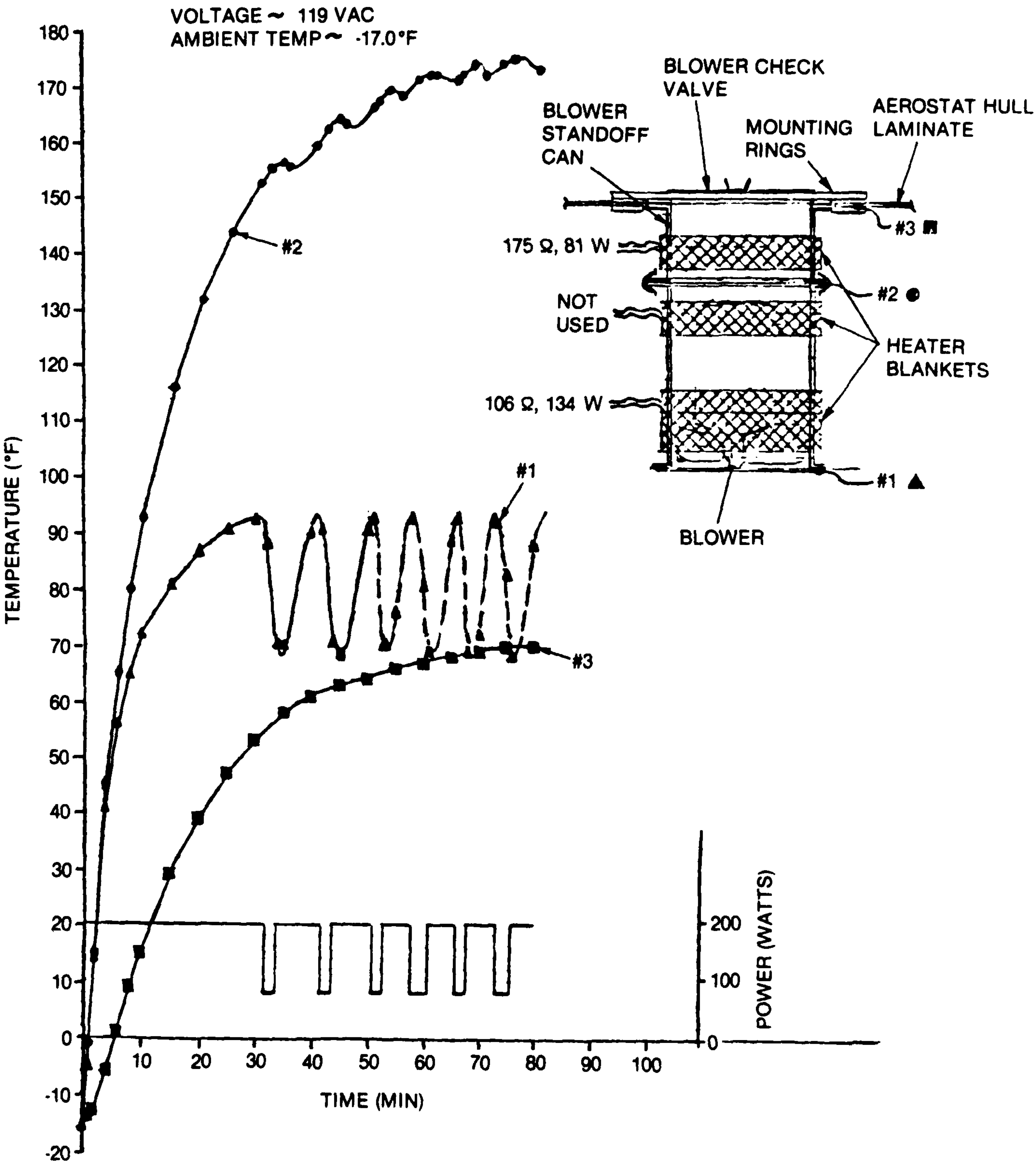


Figure 12. Blower Heater Operation

B. AEROSTAT ICE ACCRETION

At the outset of this study it was our intention to sign a contract with a commercial polymer research laboratory to develop a substance which could be chemically grafted to the surface of the aerostat hull and which would act as an ice or water repellent. However, a preliminary investigation established that the desired results might not be achieved. This fact and budgetary constraints eliminated TCOM's plans to develop an aerostat coating commercially for this program. The AFGL, meanwhile, has entered into an agreement with the Cold Region Research and Engineering Laboratory of the Army Corps of Engineers to identify possible coatings under development or already developed that can be used in this program. (The actual application of a hydrophobic coating will be part of Phase 2 of this study program.)

C. PRESSURE CYCLING SUBSYSTEM

During the Penguin program a pressure cycling scheme was used in which the normal aerostat pressurization blower and valve were utilized. The air relief valve was set to open at 3.0 IWG and to close at or below 1.8 IWG. This provided only a mild pressure cycling to the aerostat hull and was probably only marginally effective.

This study has developed a pressure pulse system which will work in combination with the normal aerostat pressurization system but which will cause the pressure of the aerostat to pulsate between 1.5 IWG and 4.0 IWG.

The system requires an all-new aerostat pressure control unit, an ac high power blower, and an electric ballonet relief valve. New poppet valves are also required due to deficiencies in the current design.

Blowers

The concept developed in this study calls for three blowers, the two existing Penguin/STARS heater dc blowers and a "new" ac blower taken from inventory. The ac blower selected is an M5171B-1B1, which has been used as a sustainer blower on a large aerostat program. The reason for using this blower is that it pumps about twice as much air as the standard STARS dc blower and it has a significantly higher stalling pressure making it ideal for "pressure pulsing" the aerostat.

The ac blower, which will be located on the ballonet forward of the windscreen, had been selected because it is readily available and meets the performance criteria for the pressure pulsing concept. It should work well in pulsing to 4.0 IWG as currently planned.

The two dc emergency descent blowers will be mounted on the aft air compartment adjacent to (just forward of) the emergency blower control unit (EBCU).

Valves

Valves include poppet valves for windscreen fill and relief and a check valve to the ballonet to prevent windscreen overpressure relative to the hull. Two overpressure relief poppet valves will be provided, one in the ballonet and one in the aft air compartment. Both valves will be set to open at 4.3 IWG. An electric relief valve, a Sheldahl 100943-001 modified, is provided for the pressure pulse as well as the normal modes of operation. Controls in the APCU enable the electric valve to change from a normal 2.7/2.4 (open/close) cycle to a 4.5/1.5 (open/close) cycle for pressure pulsing.

All valves require new heating arrangements since the poppets are to be a new design intended to correct deficiencies in the present 1097D34 design and, of course, the Sheldahl valve never has been heated.

Aerostat Pressure Control Unit

A new design APCU is required for the added ac blower and electric valve with provision for a controlled pressure pulse. Penguin relied on commanding both blowers on and having the valves preset permanently to higher than normal values. This required the operator to watch the pressure build-up then stop the blowers and let the valves and normal leakage bleed off the pressure. The necessarily modest valve hysteresis made this a slow process. The new concept provides a large aerostat, 15-inch, electric valve adjusted to open about 25% of its normal travel which has a flow rate of about 800 cfm at 4 IWG (about twice the flow rate of the ac blower). Control logic will be provided with a pair of pressure switches to cycle pressure up to 4.5 IWG with the ac blower, then open the valve until a pressure of 1.5 IWG is reached, at which time the logic reverts to the normal pressure control levels. The normal pressure operating mode will hold the pressure at a nominal 2.0 IWG (1.8 IWG blower ON, 2.1 IWG blower OFF with valving between 2.7 and 2.4 IWG).

The present concept does not include lightning protection for the aerostat. However, transorbs will be added to the APCU in the off chance of their being needed in the winter and potential future operation in the summer.

At the moment there is doubt that a modular approach (using plug-in boards for each control module) is appropriate for this program. Most likely the STARS APCU will be implemented on a single electric control plate. Existing modules were designed for remote power contactors. This is not needed for STARS so there would be redundant relays for the blower, or the modules would have to be redesigned with the power contactors on the modules.

PRESSURIZATION SYSTEM SUMMARY

Blowers

Proposed blower* complement is:

1 ea.	M5171B-1B1	ac blower. Same as 365H (large, high altitude aerostat) sustainer. Requires heaters.
2 ea.	M4641J-1A	dc blower. Present heater Penguin/STARS blower.

*Each blower is equipped with a check valve, adapter ring, and V-retainer.

Valves

2 ea.	TCOM	Pneumatic poppet valve. New design to replace 1097D34
1 ea.	100943-003	Electric valve modifed to shorten stroke to 25% or less and possibly increase motor speed as well as add heaters.

APCU

1 ea.	TCOM	New design about ½ complexity of PIP-APCU to provide control for electric valve, blowers, and pressure plumbing.

Battery Box and Emergency Blower Control Unit

1 ea.	TCOM	New design heated battery assy with 3 ea. $LiSo_4$ battery strings and discharge indicators.

Outputs:	APCU, 2 batteries T&C, 1 battery
Input:	ac main; heater power
Monitor:	Battery temp.

D. MOORING LINES

During the aerostat operations in the Beaufort Sea there was considerable accumulation of ice on the mooring lines, the suspension lines and the handling lines of the Penguin aerostat. Furthermore, these lines which are made of either 3/8 inch or 1/2 inch Samson braid, soak up considerable amounts of water which then freeze in the lines, making them heavy, stiff and hard to handle. The mini-study in this area has consisted of developing a coating which encases the mooring line in a jacket of urethane, preventing water from getting inside the line and making it difficult for ice and snow to adhere to the line itself. Samples of these jacketed lines were obtained for tests in this study and were included in the cold chamber tests that were conducted and are reported below.

E. BATTERY HEATING

The Penguin aerostat had a thermostat and heater blanket which maintained the lithium emergency descent batteries at the recommended operational temperature. This thermostat/heater blanket arrangement had never been tested to determine its efficiency, particularly since it was included inside a box with other electronic components which provided additional heating to the batteries.

In order to eliminate the long lead time associated with purchasing $LiSo_2$ batteries, TCOM will use batteries of identical electrical characteristics but different form factor which are on hand for another program. New battery heaters are on order and will be tested in a cold chamber as part of Phase 2 of this program.

F. AEROSTAT SNOW ACCUMULATION

An integral part of this study has been the computation of the weight of snow that can accumulate on the STARS aerostat under varying conditions. It is interesting t; note that as the snow accumulates on the aerostat, it causes an appreciable nose up attitude which in itself tends to discourage further accumulation of snow on the upper surface of the aerostat.

The weight of snow which would accumulate on the STARS for a 1-inch snowfall, in the absence of wind, has been calculated for both wet and dry snow. These calculations were based on experimental measurements made by Sheldahl, Inc., under contract to TCOM during the winter of 1974*. The experimental test apparatus consisted of 6 x 6 inch plates inclined at angles from 0° to 90° to the horizontal. The plates were covered with aerostat hull material, Tedlar side up, and enclosed in an open-topped plywood box. The depth of snow accumulated was determined for each angle of inclination.

For dry snow up to inclined angles of $<50°$ the results closely followed a cosine law were the no-dimensional depth, $\hat{h}$, is defined as:

$$\hat{h} = \frac{h}{h_o} = \cos\phi \tag{1}$$

where h = depth of snow measured normal to the surface on a plate inclined at the angle, Φ.

h_o = depth on a horizontal surface

Φ = angle of inclination of the surface

*Witherow, R.G., "Snow Accumulation and Removal, Tethered Aerostats," Sheldahl, Inc. Report No. SAR-56-014, Northfield, Minnesota, 14 February, 1975.

At angles greater than 75° no snow accumulated. Between 50° and 75° the relationship of depth to angle was approximately linear.

$$50° < \Phi < 75°$$
$$\hat{h} = .6428\,(75 - \Phi°)/25 \tag{2}$$

Experiments on wet snow gave an approximately linear relationship between depth and angle with no snow accumulating at angles greater than 65°. For wet snow

$$\hat{h} = 1 - \Phi°/65 \tag{3}$$

These results were applied to the STARS aerostat at various angles of attack in order to estimate the snow load which would accumulate and its center of gravity. This requires the determination of the angle of inclination from the horizontal, Φ, of every element of the surface and integration of the functions, Equations 1 and 2 or Equation 3, over the surface.

The angle of inclination of a surface element is the angle, Φ, made by a vector normal to the surface with respect to a vertical axis (perpendicular to the earth's surface). This angle is easy to see if the aerostat is at zero pitch angle and the surface element lies along a meridian cut by a vertical plane passing through the aerostat's center line. It is identical to the angle, θ, in Figure 13A.

$$\phi = \theta = \tan^{-1} \frac{dR}{dx} \tag{4}$$

where R = radius of the aerostat

In a coordinate system with the x-axis parallel to the aerostat center line and the z-axis perpendicular to the centerline, the vector $\vec{V}$ of unit length has the components

$$\vec{V} = \begin{Bmatrix} \sin\theta \\ 0 \\ \cos\theta \end{Bmatrix} \tag{5}$$

Now consider a surface element located on the side of the aerostat at the polar angle, ψ (Figure 13B). In a coordinate system such as just described with its z-axis passing through the centerline, the vector normal to the surface has the components given by (5). The angle of inclination of the surface, however, is given by the angle between $\vec{V}$ and the vertical axis, z′. This is found by transforming the vector to a coordinate system (x′, y′, z′) alinged with the earth. Such a coordinate system is obtained by rotating (x, y, z) about its x-axis through the angle ψ. This transformation is given by

$$\vec{V}' = [r(\psi)]\,\vec{V}$$

where

$$[r(\psi)] = \begin{bmatrix} 1, & 0, & 0 \\ 0, & \cos\psi, & \sin\psi \\ 0, & -\sin\psi, & \cos\psi \end{bmatrix} \tag{6}$$

$$\vec{V}' = \begin{Bmatrix} \sin\theta \\ \cos\theta \sin\psi \\ \cos\theta \cos\psi \end{Bmatrix}$$

The angle of inclination of the surface, Φ, is then given by

$$\cos\phi = \frac{V_z}{|V|} = \cos\theta \cos\psi \tag{7}$$

In the general case where the aerostat is also pitched at the angle, α, the (x, y, z) aerostat-aligned coordinate system must be rotated by ψ about its x-axis and then rotated by α about its y-axis in order to obtain the earth-aligned system (x′, y′, z′) as shown in Figure 13C.

$$\vec{V}' = [p(\alpha)]\ [r(\psi)]\ V \tag{8}$$

$$[p(\alpha)] = \begin{bmatrix} \cos\alpha, & 0, & -\sin\alpha \\ 0 & 1, & 0 \\ \sin\alpha, & 0, & \cos\alpha \end{bmatrix} \tag{9}$$

$$\vec{V}' = \begin{Bmatrix} \cos\alpha \sin\theta - \sin\alpha \cos\theta \cos\psi \\ \cos\theta \sin\psi \\ \sin\alpha \sin\theta + \cos\alpha \cos\theta \cos\psi \end{Bmatrix} \tag{10}$$

Thus, according to Equation (7),

$$\cos\phi = \sin\alpha \sin\theta + \cos\alpha \cos\theta \cos\psi \tag{11}$$

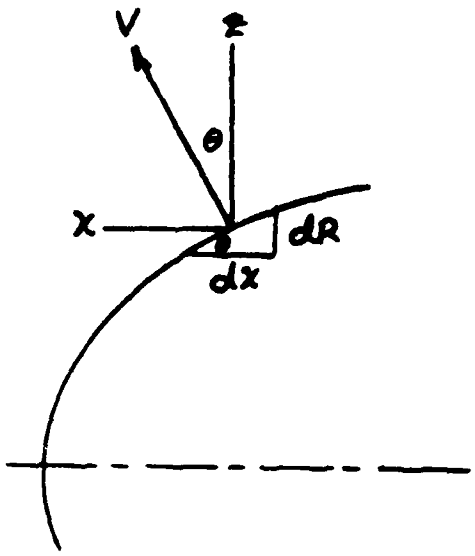


Figure 13A.

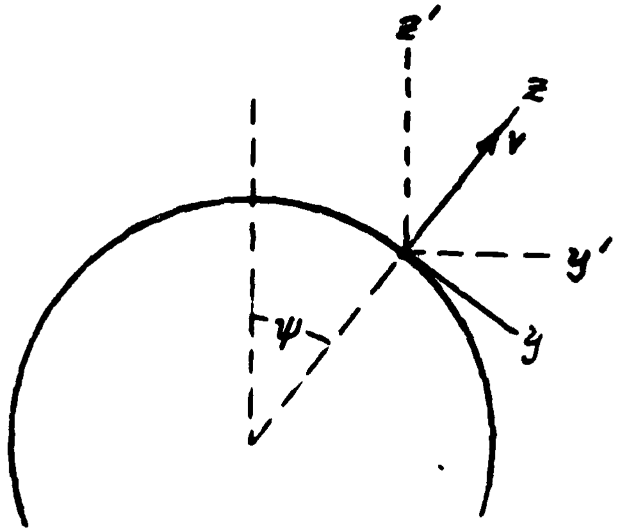


Figure 13B.

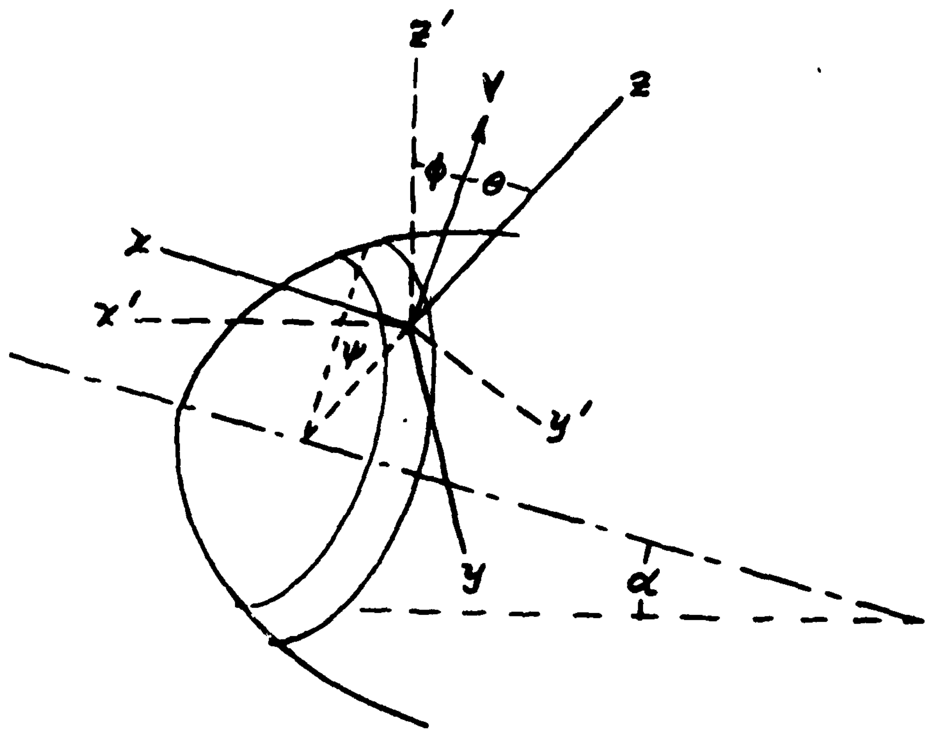


Figure 13C.

Figure 13 Aerostat Coordinate System

These transformations are given in numerous references including Jones and Krausman*.

To find the weight of snow on the aerostat, the depth, which is a function of ϕ, was integrated over the top surface of the aerostat

$$W = 2\rho h_o \int_0^{\bar{c}} \int_0^{\frac{\pi}{2}} \frac{\hat{h}(\phi)R}{\cos\theta} d\psi dx \tag{12}$$

where ρ = snow density
h_o = snow depth on a horizontal surface
$\bar{c}$ = hull length

The moments about the nose were found by the following relations

$$M_z = 2\rho h_o \int_0^{\bar{c}} \int_0^{\frac{\pi}{2}} \frac{\hat{h}(\phi)\cos\psi R^2}{\cos\theta} \tag{13}$$

$$M_x = 2\rho h_o \int_0^{\bar{c}} \int_0^{\frac{\pi}{2}} \frac{\hat{h}(\phi)Rx}{\cos\theta} d\psi dx \tag{14}$$

The center of gravity is therefore

$$x = \frac{M_x}{W} \tag{15}$$

$$z = \frac{M_z}{W} \tag{16}$$

*Jones, S.P. and Krausman, J.A., "Non-Linear Dynamic Simulation of a Tethered Aerostat," AIAA Lighter than Air Systems Technology Conference, AIAA-1340-CP, Annapolis, Maryland, July 1981.

For the fins, the angle with the horizontal is given by,

$$\cos \phi = \cos \psi$$

$$\psi = 45^{o} \tag{17}$$

The weight of snow on the fins is then,

$$W_f = \rho \hat{h}_o A_f \hat{h}(\phi) \tag{18}$$

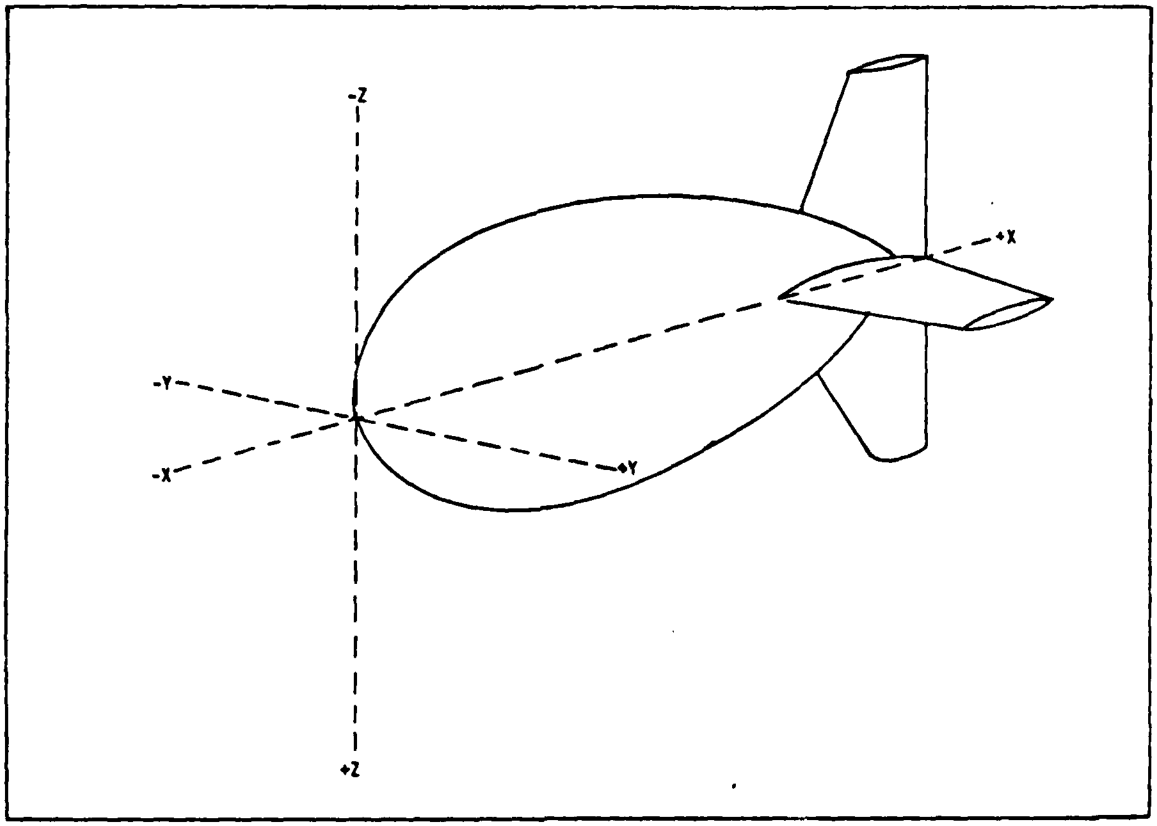
$$A_f = \text{fin area} \tag{19}$$

The results of these calculations are shown in Figures 14, 15 and 16 for a 1-inch snowfall using the densities given in the referenced report for wet and dry snow.

G. AEROSTAT PERFORMANCE ANALYSIS

A mini-study of the STARS aerostat performance in cold weather such as that expected to be encountered in Burlington, Vermont, has been conducted. As a first step in this analysis the weight and balance of the aerostat has been entered and updated in the computer. Tables 7 through 12 are computer printouts of the STARS aerostat weight and balance as configured for the site at Fort Ethan Allen. Table 7 lists the "A" items of the aerostat which are the mechanical components including the flexible aerostat structure. The "B" list given in Table 8 is the rigging including the handling lines, suspension lines and other softgoods. Table 9 is the list of "C" items which includes the various electrical components on the aerostat. Table 10 lists the "D" aerostat control rack which contains the power distribution unit, the aerostat pressure control unit, the radio box, the telemetry control system and the heater control unit. Table 11 accounts for the battery rack which includes the emergency descent batteries and the controls necessary to operate the emergency descent system. This box is generally called the emergency blower control unit (EBCU). Table 12 is the weight and balance summary sheet which shows the total weight given in each of the previous tables with the moment arms in the x, y and z direction for each of the lists. The total weight of the entire aerostat system is shown in both metric and English units in this table. The sketch below shows the coordinate system used in the weight and balance analysis. Note that in this convention z is positive downward.

The weight and balance conducted in this study is, of necessity, preliminary in nature and probably will change somewhat as the aerostat is prepared for the tests at Fort Ethan Allen. However, this preliminary analysis is well within the accuracy required to make predictions on the performance of the aerostat system.



Sketch — Aerostat Coordinate System for Weight and Balance

The next nine tables, 13 through 21, are reproductions of computer printouts generated by the computer "FLIGHT" program.

AFGL FLIGHT PROGRAM

The FLIGHT printout is a computer-generated analysis of aerostat response to steady-state or static wind conditions. The wind is assumed to be traveling horizontally at a given velocity at the altitude specified. A constant dynamic pressure model is used to compute the windspeed at various altitudes in order to calculate aerodynamic forces along the tether. The tether model is mathematically represented by a set of linear springs. During FLIGHT, the aerostat is assumed to face into the wind.

The computer printout reproduced in the tables is divided into three main sections: physical and environmental conditions, parameters as a function of windspeed, and optimum conditions.

In the first main section of the printout which shows physical and environmental conditions, the aerostat weight is the total weight of all hardware including the flexible structure, rigging, electrical equipment, heaters, etc. The center of gravity is specified by x and z, as measured longitudinally back from the nose and down from the centerline, respectively. Shown under payload weight is the ballast necessary to properly trim the aerostat to an acceptable pitch angle above the horizontal. The ballast is located between the lower fins on the underside of the aerostat. The ballast could also represent additional equipment, such as vibrators for snow removal. Shown next is fuel weight and location, which is not used on this aerostat. When snow is assumed to be present, the calculated weight, x and z are printed in this section. The next items are system weight, x and z, which are computed by summation of the moments of the above items.

The next item is internal hull pressure above ambient in units of inches of water. The program automatically maintains this delta pressure above the dynamic pressure created by the wind. Shown next is helium relative humidity. Zero is entered, since it is assumed that the helium in this case does not contain water vapor. The next item is tether modulus of elasticity multiplied by tether cross sectional area. This contant is used in calculating stretch of the tether.

The first item in the right column is flight altitude. This item can be entered or left free to vary. In one series of the runs, the flight altitude at zero wind is set at 3,700 ft above sea level, or 3,000 ft above the pad. According to the note at the top of the printout, the aerostat is flown at constant tether length, i.e., the winch is "locked" with the aerostat at 3,700 ft above sea level in zero wind. As the wind increases, the aerostat travels downwind to a lower altitude, as shown in a later section. In another series of runs, "Max" is specified for flight altitude. In this mode, the aerostat increases in altitude until one of the following constraints is reached:

1. Ballonet air volume decreases to zero
2. Winch tension decreases to the value specified as "free lift" shown at the bottom of the printout
3. Winch angle increases to 90°
4. Tether length increases to the available tether length specified at the top of the printout

The next item shown is the pad altitude above sea level. Shown below that is standard gross lift corresponding to the amount of pure helium in the aerostat at standard conditions. The standard lift is calculated for these runs by filling the aerostat with helium, i.e., zero ballonet air volume, at the altitude shown with zero superheat. Shown next is helium purity in percent. It is assumed that the helium has 2% contamination.

The next four items specify tether parameters. Tether weight per foot, diameter, and location of the confluence point are specified.

Shown next is the total longitudinal length of the hull. Below that is the available helium volume. This represents the main hull compartment volume with ballonet air completely evacuated.

The next items are the temperature and pressure at sea level and at pad altitude. Standard pressure of 29.291 inches of mercury is specified for sea level. The pad pressure is then calculated using a standard lapse rate.* The pad temperatures in the various runs are given as -40° F, 0° F and 32° F. The sea level temperatures are then calculated from these using a standard lapse rate.* Given next is the lapse rate showing change in ambient temperature for each foot change in altitude.

The second section of the printout shows varous parameters as a function of windspeed. There are two rows of data for each wind to avoid overcrowding in one row. For each wind, the first row shows dynamic pressure (i.e., 1/2 ρu^2), aerostat pitch angle above horizontal, internal superheat, ballonet air volume, aerodynamic lift, and aerodynamic drag. The superheat can be specified as zero, plus for day, or minus for night. The program calculates superheat based on radiation and convection as a function of windspeed. The second group of data shows confluence point tension, confluence point angle from vertical, winch tension, winch angle from vertical as measured at the flying sheave, blowdown (horizontal) length from winch to aerostat, and altitude (vertical) above sea level.

The third main section of the printout shows the optimum altitude and lift. This is the theoretical point where the altitude is maximum based on the given conditions. The day and night superheats and free lift are specified. For these runs, 25° F day and 0° F night superheat are used. The free lift is 30% of the optimum lift. From these inputs and the physical conditions listed in the first section of the printout, the optimum altitude and lift are calculated. The optimum conditions are shown in this case for information purposes only. The actual runs are made using maximum helium fill at zero superheat.

The description presented above shows the aerostat in a given situation in Vermont. However, the program has additional options and modes to tailor it to virtually any environmental or flight condition.

In the following tables a ballast weight and center of gravity are shown listed as payload and are used to trim the aerostat to approximately 3° nose up at ground level with zero wind. Tables 13, 14 and 15 show the performance of the aerostat at -40° F assuming zero superheat. Table 13 is constructed using no snow load; Table 14 uses a dry snow load of 0.1 inch and Table 15 is constructed using 0.5 inch. Note that with ½ inch of snow the pitch angle increases to about 29°. Note also that the winch tension which represents the free lift of the aerostat — that margin of lift which will keep it airborne — decreases from 645 lb with no snow to only 250 lb with ½-inch snow load. Tables 16, 17 and 18 demonstrate the same three conditions of performance of the aerostat except that the temperature used is 0° F instead of -40° F. In the 0° case less helium must be used in the hull and consequently slightly less ballast (70 versus 100 lbs) is used to properly trim the

*List, Robert J., Smithsonian Meteorological Tables, Smithsonian Institution, Washington, D.C. (1951) p. 274.

aerostat. Note that the pitch increases to almost 32° with a ½-inch snow load and that the cable tension decreases from 530 lbs to 144 lbs with a full snow load. Tables 19, 20 and 21 again repeat the same three flight conditions except that a temperature of 32° F is used with the snow in a wet condition. In this case, the standard lift is further reduced and the ballast weight is dropped from 70 lbs to 50 lbs. Note that the cable tension decreases from 450 lbs without a snow load to 110 lbs with a ½-inch snow load. There is an error in this program in that the pitch reading with the snow load is shown as 26.92°. We know that this is in error since the pitch has increased beyond a point where the ballonet program will properly handle the trim angle. It is estimated that the trim in this case approached 38°. The next three tables 22, 23 and 24 describe the operation of the aerostat using the maximum altitude routine of the FLIGHT program. In this routine the lift is adjusted to give the maximum overall altitude under all conditions while maintaining the specified value of free lift for conditions of zero superheat, positive superheat and negative superheat. The aerostat is filled with 1781 lb of lift at standard conditions in order to reach pressure height of 3,000 feet above the ground with zero superheat. Table 22 shows the predicted performance of the aerostat on a bright sunny day where maximum superheat would be acquired under zero wind conditions. This maximum positive superheat causes the aerostat to reach pressure height at 2371 ft above sea level at zero wind. At 30 knots and above, the ballonet volume is no longer zero, but tether length becomes the limiting factor for attainable altitude. Table 23 is the performance prediction for the same aerostat loading but assumes a cloudly day with zero superheat. Table 24 is the "worst" case set of conditions wherein the aerostat operates with the same standard lift but on a clear starlit night where the maximum negative superheat is achieved. Note that the minimum cable tension of 515 lb is achieved with zero wind conditions and maximum negative superheat at an altitude of 3,185 feet above sea level.

Figures 17, 18, 19 and 20 are plots made from the information contained in the last three tables (22, 23 and 24). Figure 17 shows the variation of altitude with wind velocity for the three conditions of no superheat, daylight maximum superheat, and nighttime negative superheat. Figure 18 shows the amount of down wind displacement (called blowdown) that will occur as a function of wind velocity under the three superheat conditions. Figure 19 is a plot of the expected variation in the winch tension (tether tension) at the ground as a function of wind velocity for the three conditions of superheat. Note that by the time the wind velocity reaches 25 knots at altitude there is no difference in the winch tension curves and the maximum tension achieved will be 3,270 lb at 70 knots. This tension is well within the working limits of the Kevlar tether system.

Figure 20 is a plot of the aerostat pitch angle as a function of wind velocity for the three conditions of superheat. Note that as the wind velocity increases the aerostat approaches what is know as the infinite wind velocity pitch angle. For the STARS aerostat this angle is computed to be approximately 9° nose-up.

Finally, as part of the aerostat performance analysis we exercised the STARS aerostat as configured for the Fort Ethan Allen tests in the Non-Linear Dynamic Simulation (NLDS) in order to observe the aerostat motions. The aerostat is configured with a 70-lb ballast and a 275-lb snow load at

0° F ground temperature, resulting in a zero wind pitch angle of 24° at an altitude of 3,300 ft above sea level. It has been assumed for this computer simulation that a worst-case condition would obtain if the aerostat was subjected to mild turbulence and a relatively severe downdraft while under the influence of a heavy snow load. The conditions used in this simulation were mild turbulence of 5 feet per second rms value and 20 knot downdraft. The average headwind used during the simulation was 5 knots. Figures 21 and 22 show the plots of the aerostat parameters. Figure 21 shows its motion in the x and z coordinates as well as the pitch angle and tether tension. Figure 22 shows the motion in the y coordinate as well as the heading and roll angles. Figure 23 is a pictorial plot of the motion of the aerostat from a top view (the xy plane) and shows the typical excursions that a tethered aerostat will make when subjected to a prolonged downdraft much in ex ess of the average wind velocity. Figure 24 shows the first 5 minutes of the simulation flight shown in Figure 23. Figure 25 is a pictorial display of the aerostat motion from a side view (the xz plane) for the first 5 minutes of flight. It shows that the aerostat does not descend radically from altitude under the influence of the 20 knot downdraft even though the free lift of the system is reduced by the snow load.

Although this performance analysis is preliminary, it is exhaustive in nature in that it examines many of the conditions that could be hazardous to the safety of the aerostat while in flight in the Fort Ethan Allen tests. One of the objectives of the tests will be to subjectively examine the behavior of the aerostat, particularly in terms of pitch, cable tension and aerostat motions with respect to the predictions that we will be able to make using the NLDS.

H. HELIUM CONSIDERATION

A short study was made of the handling problems of helium in extreme cold weather conditions. It has been determined that the helium supplied by suppliers and by the U.S. Bureau of Mines has a dew point of -80° F. This means that we would not expect to have any problems with the manifold of helium tube banks in cold weather since the moisture content is low enough that ice cannot form in the manifold.

Aside from the possible moisture problems in helium, none of the suppliers know of any problems that have ever been experienced in cold weather handling of helium. We would anticipate that the helium supplied for this project by the U.S. Bureau of Mines would be of sufficiently low moisture content that there will be no handling problems.

I. COLD CHAMBER TESTS

A series of tests utilizing the cold chamber facilities of the Westinghouse Defense and Electronics Center were conducted as part of this study to verify information previously gathered or to extend our knowledge in specific areas. The tests were conducted as individual engineering tests; a test plan was prepared and followed; results were recorded. Each test was documented as an Engineering Division Technical Memorandum (EDTM). Except for the title page the several EDTM's are repeated here in their entirety and accurately describe the tests results.

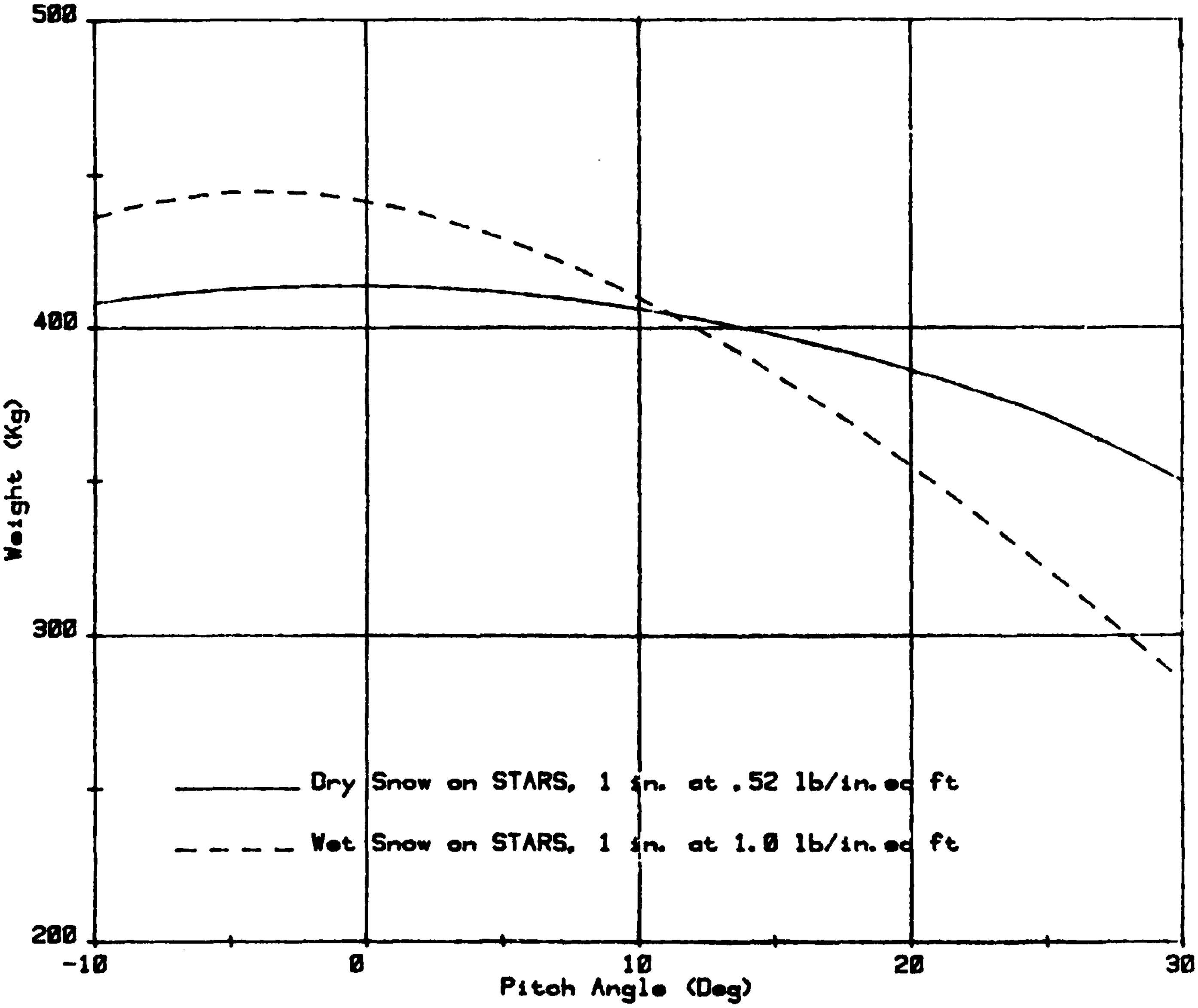


Figure 14. Snow Load Weight as a Function of Pitch Angle

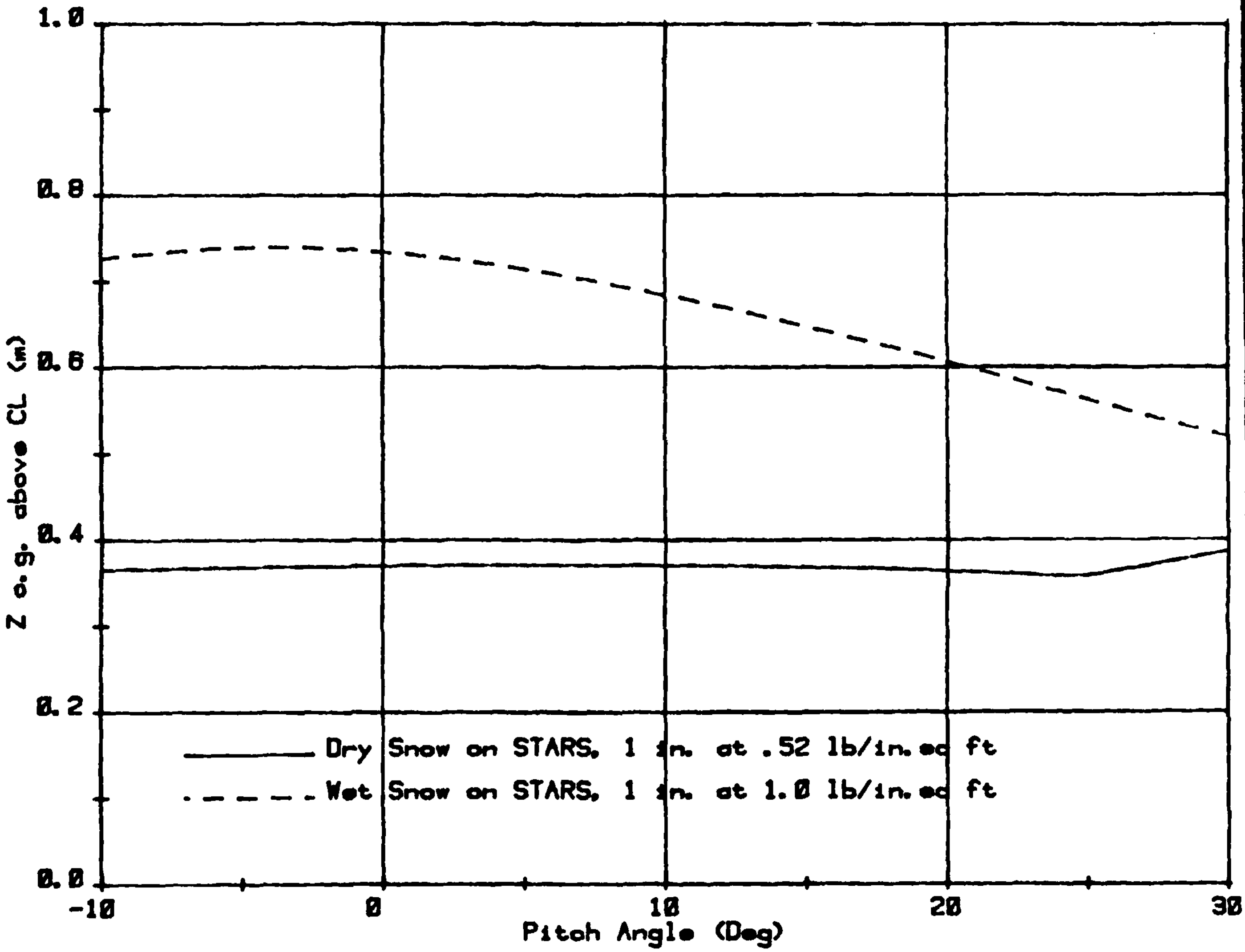


Figure 15. Vertical Center of Gravity of Snow Load

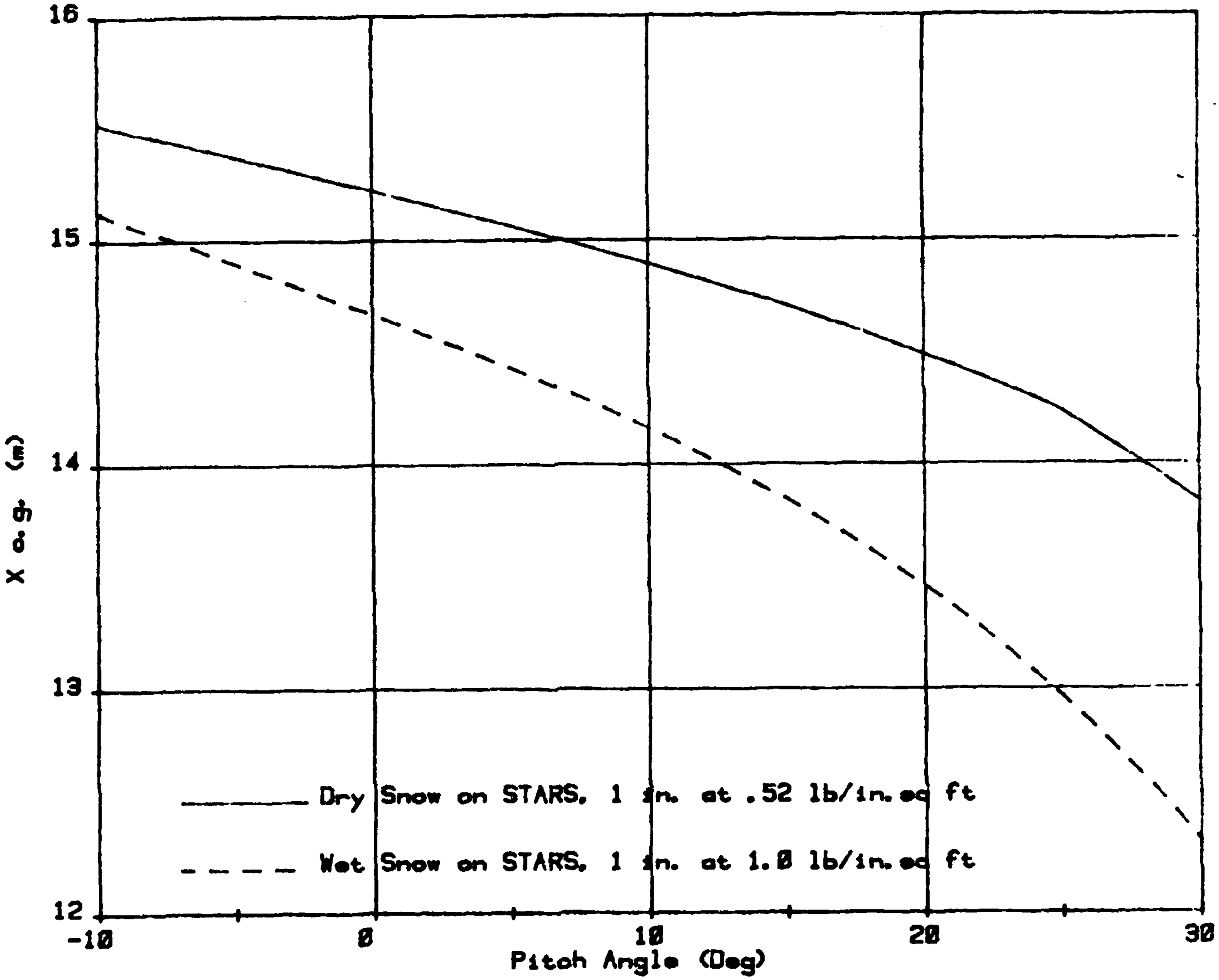


Figure 16. Horizontal Center of Gravity of Snow Load

TABLE 7. AEROSTAT WEIGHT AND BALANCE — MECHANICAL INSTALLATIONS

WEIGHT BALANCE CHART A   TYPE 25M   FILE AFGL 8/16/82

MODEL 25M   SERIAL NUMBER   SITE JERICHO PAD

Item no.	Description part number	Weight (kg)	(ACTUAL X (m)	DIMENSIONS) Y (m)	Z (m)
A	MECHANICAL INST (A.4 8/12/82)	-	0.00	-	0.00
A- 1	AEROSTAT	184.000	13.818	0.000	1.128
A- 2	NOSE CONE	27.000	-0.203	0.000	0.000
A- 3	INFLATION PORT	0.955	3.018	-0.102	3.773
A- 6	DUCT TERMINATION-FWD	1.660	14.118	-0.103	3.366
A- 7	DUCT TERMINATION-AFT	1.660	21.315	0.000	1.735
A- 8	PRESSURE TAP-HELIUM	0.222	20.652	0.596	1.842
A- 9	PRESSURE TAP-AIR	0.222	22.529	0.361	1.269
A-10	ACCESS PORT-HELIUM	3.900	21.093	0.000	1.017
A-12	DRAIN,WATER-FWD	0.012	5.162	-0.102	4.086
A-13	DRAIN,WATER-AFT	0.012	14.460	-0.102	3.103
A-14	SCAVENGE SYSTEM	5.300	17.733	-0.051	2.554
A-16	DRIP STRIPS-4 ROLLS	1.960	10.007	0.000	3.884
A-17	WINDSCREEN FILL VALVE	0.430	14.118	-0.103	3.366
A-18	WINDSCREEN RELIEF VALVE	0.430	9.222	0.000	4.163
A-19	WINDSCREEN CHECK VALVE	0.600	15.021	0.102	4.097
A-20	BALNT VALVE MOUNT RING & DUCT	6.170	8.507	2.056	3.084
A-21	DESTRUCT WIRE	0.100	0.375	0.000	0.000
A	SUB TOTAL	234.633	12.257	0.053	1.152

TABLE 8. AEROSTAT WEIGHT AND BALANCE — RIGGING

WEIGHT BALANCE CHART A   TYPE 25M   FILE AFGL 8/16/82

MODEL 25M   SERIAL NUMBER   SITE JERICHO PAD

Item no.	Description part number	Weight (kg)	(ACTUAL X (m)	DIMENSIONS) Y (m)	Z (m)
B	RIGGING (B.4 8/9/82)	-	0.00	-	0.00
B- 1	NOSE LINE	1.900	-0.610	0.000	0.000
B- 2	SUSPENSION LINE-PORT	4.189	6.451	3.606	1.958
B- 3	SUSPENSION LINE-STBD	4.189	6.451	-3.606	1.958
B- 4	CLOSE HAUL LINE-PORT	1.814	5.509	4.111	0.000
B- 5	CLOSE HAUL LINE-STBD	1.814	5.509	-4.111	0.000
B- 6	SNUBBER LINE-PORT	1.000	17.662	2.243	1.499
B- 7	SNUBBER LINE-STBD	1.000	17.662	-2.243	1.499
B- 8	WINDSCREEN FURLING SYSTEM	0.879	13.015	0.000	4.001
B- 9	FIN GUY LINES	0.597	22.277	0.000	0.000
B	SUB TOTAL	17.382	7.648	0.000	1.319

TABLE 9. AEROSTAT WEIGHT AND BALANCE — ELECTRICAL INSTALLATIONS

WEIGHT BALANCE CHART A   TYPE 25M   FILE AFGL 8/16/82

MODEL 25M   SERIAL NUMBER   SITE JERICHO PAD

Item no.	Description part number	Weight (kg)	(ACTUAL X (m)	DIMENSIONS) Y (m)	Z (m)
C	ELECTRICAL (C.4 8/16/82)	-	0.00	-	0.00
C- 1	NAV LIGHT-FWD	1.150	1.262	-0.101	2.876
C- 2	NAV LIGHT-PORT	1.150	22.473	4.767	5.071
C- 3	NAV LIGHT-STBD	1.150	22.473	-4.767	5.071
C- 6	HELIUM TEMP PROBE INST	0.200	21.093	0.000	0.102
C- 7	PITOT - STATIC TUBE	1.040	20.800	3.865	3.865
C- 8	AEROSTAT HARNESS	9.650	14.019	0.000	3.075
C- 9	POWER SLIP RING CABLE	3.750	6.514	-2.057	6.170
C-10	TETHER TERMINATION	6.478	6.514	0.000	8.227
C-17	AMBIENT TEMP PROBE INST	0.140	16.023	0.000	2.865
C-18	AC BLOWER	5.000	8.507	-2.056	3.084
C-19	DC BLOWER	4.330	21.294	-0.338	1.701
C-20	DC BLOWER	4.330	21.294	0.338	1.701
C-21	ELECTRO-MECH VALVE, BALNT	5.850	8.507	2.056	3.084
C-22	ICE DETECTOR	1.413	5.855	1.216	3.927
C-23	DESTRUCT WIRE CONTROL BOX	11.000	3.057	0.000	3.765
C	SUB TOTAL	56.631	10.626	-0.006	3.897

TABLE 10. AEROSTAT WEIGHT AND BALANCE — CONTROL RACK

WEIGHT BALANCE CHART A   TYPE 25M   FILE AFGL 8/16/82

MODEL 25M   SERIAL NUMBER   SITE JERICHO PAD

Item no.	Description part number	Weight (kg)	(ACTUAL X (m)	DIMENSIONS) Y (m)	Z (m)
D	AEROSTAT CONROL RACK (D.5 8/9/82)	-	8.43	-	3.90
D- 1	RACK/LACING	9.710	8.437	0.000	4.121
D- 2	POWER DIST UNIT (PDU)	23.090	8.437	0.000	4.429
D- 3	AERO PRESS CONTROL UNIT (APCU)	18.460	8.437	0.000	4.429
D- 4	RADIO BOX	10.390	8.437	0.000	4.429
D- 5	T & C	11.750	8.437	0.000	4.429
D- 6	HEATER CONTROL UNIT	1.500	8.437	0.000	4.429
D	SUB TOTAL	74.900	8.437	0.000	4.389

TABLE 11. AEROSTAT WEIGHT AND BALANCE — BATTERY RACK

WEIGHT BALANCE CHART A TYPE 25M FILE AFGL 8/16/82

MODEL 25M SERIAL NUMBER SITE JERICHO PAD

Item no.	Description part number	Weight (kg)	(ACTUAL X (m)	DIMENSIONS) Y (m)	Z (m)
E	BATTERY RACK (E.4 8/9/82)	-	22.80	-	1.21
E- 1	RACK	4.350	22.767	0.000	1.736
E- 2	BATTERY ASSY	10.000	22.767	0.000	1.939
E	SUB TOTAL	14.350	22.767	0.000	1.877

TABLE 12. AEROSTAT WEIGHT AND BALANCE — SUMMARY CHART

METRIC UNITS

WEIGHT BALANCE CHART B TYPE 25M FILE AFGL 8/16/82

MODEL 25M SERIAL NUMBER SITE JERICHO PAD

Item no.	Description part number	Weight (kg)	(ACTUAL X (m)	DIMENSIONS) Y (m)	Z (m)
A	MECHANICAL INST	234.633	12.257	0.053	1.152
B	RIGGING	17.382	7.648	0.000	1.319
C	ELECTRICAL	56.631	10.626	-0.006	3.897
D	AEROSTAT CONROL RACK	74.900	8.437	0.000	4.389
E	BATTERY RACK	14.350	22.767	0.000	1.877
	TOTAL	397.896	11.484	0.030	2.185
	INERTIA: Ixx,Iyy,Izz (N-m-sec2)		150.00	1288.62	1207.77
	Ixy,Iyz,Izx (N-m-sec2)		2.57	-0.88	-70.97

ENGLISH UNITS

WEIGHT BALANCE CHART B TYPE 25M FILE AFGL 8/16/82

MODEL 25M SERIAL NUMBER SITE JERICHO PAD

Item no.	Description part number	Weight (lb)	(ACTUAL X (ft)	DIMENSIONS) Y (ft)	Z (ft)
A	MECHANICAL INST	517.272	40.214	0.173	3.778
B	RIGGING	38.320	25.091	0.000	4.326
C	ELECTRICAL	124.849	34.861	-0.020	12.785
D	AEROSTAT CONROL RACK	165.125	27.681	0.000	14.401
E	BATTERY RACK	31.636	74.694	0.000	6.159
	TOTAL	877.202	37.676	0.099	7.169

TABLE 13. AEROSTAT FLIGHT ON CONSTANT LENGTH TETHER (3,000 FEET) WITH ZERO SUPERHEAT, -40° F

FLIGHT ver 46.820811 Aerostat 25A Date: 08 24 82

Time: 11:05

AFGL AT JERICHO, VERMONT

Flight at constant tether length

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1927.00 lb
Payload wt =	100.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Fuel wt =	0.00 lb	Tether x =	21.33 ft
Fuel x =	0.00 ft	Tether z =	26.25 ft
Fuel z =	0.00 ft	Hull length =	82.13 ft
System wt =	977.20 lb	Avail He Vol =	27628.90 cu ft
System x =	41.46 ft	Sea level T =	-37.50 deg F
System z =	6.84 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	-40.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.00 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	3.28	0.00	-3	0	0
5	0.091	3.48	0.00	-2	5	5
10	0.364	4.07	0.00	7	22	21
15	0.819	4.91	0.00	33	62	47
20	1.459	5.82	0.00	84	132	87
25	2.285	6.62	0.00	156	239	141
30	3.299	7.25	0.00	238	382	209
35	4.501	7.73	0.00	319	560	292
40	5.892	8.08	0.00	395	772	388
45	7.470	8.34	0.00	463	1015	499

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	935	0.0	645	0.0	0	3700
5	940	0.3	650	1.5	44	3700
10	958	1.2	668	5.9	171	3695
15	997	2.7	710	12.4	367	3675
20	1070	4.7	787	19.8	600	3632
25	1180	6.9	904	26.6	829	3571
30	1330	9.0	1062	32.1	1026	3502
35	1519	11.1	1259	36.3	1190	3435
40	1744	12.9	1493	39.3	1318	3376
45	2005	14.4	1761	41.6	1418	3326

Note: For Superheat=+25.00 ± 0.00 deg F and Free lift=546 lb:
Optimum alt = 3625.91 ft
Optimum lift = 1820.84 lb

TABLE 14. AEROSTAT AT 3,700 FEET AMSL, ZERO SUPERHEAT, 0.1 INCH SNOW LOAD, -40° F

FLIGHT ver 48.820811 Aerostat 25A Date: 08 2? 82

Time: 11:00

AFGL AT JERICHO, VERMONT

Flight at constant tether length

Dry snowfall = 0.100 inches

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1927.00 lb
Payload wt =	100.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Snow wt =	90.06 lb	Tether x =	21.33 ft
Snow x =	49.09 ft	Tether z =	26.25 ft
Snow z =	-1.21 ft	Hull length =	82.13 ft
System wt =	1067.27 lb	Avail He Vol =	27628.90 cu ft
System x =	42.11 ft	Sea level T =	-37.50 deg F
System z =	6.16 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	-40.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.00 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	8.48	0.00	-3	0	0

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt (ASL) (ft)
0	845	0.0	555	0.0	0	3700

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=559 lb:
Optimum alt = 3004.08 ft
Optimum lift = 1863.48 lb

TABLE 15. AEROSTAT AT 3,700 FEET AMSL, ZERO SUPERHEAT, 0.5 INCH SNOW LOAD, -40° F

FLIGHT ver 48.820811 Aerostat 25A Date: 08 23 82

Time: 11:02

AFGL AT JERICHO, VERMONT

Flight at constant tether length
Dry snowfall = 0.500 inches

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1927.00 lb
Payload wt =	100.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Snow wt =	390.68 lb	Tether x =	21.33 ft
Snow x =	45.65 ft	Tether z =	26.25 ft
Snow z =	-1.25 ft	Hull length =	82.13 ft
System wt =	1367.88 lb	Avail He Vol =	27626.90 cu ft
System x =	42.66 ft	Sea level T =	-37.50 deg F
System z =	4.53 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	-40.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.00 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	26.84	0.00	-3	0	0

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	545	0.0	254	0.0	0	3700

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=603 lb:
Optimum alt = 955.33 ft
Optimum lift = 2009.44 lb

TABLE 16. AEROSTAT FLIGHT ON CONSTANT LENGTH TETHER (3,000 FEET), ZERO SUPERHEAT, 0° F

FLIGHT ver 48.820811 Aerostat 25A Date: 08 24 82

Time: 11:17

AFGL AT JERICHO, VERMONT

Flight at constant tether length

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1781.00 lb
Payload wt =	70.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Fuel wt =	0.00 lb	Tether x =	21.33 ft
Fuel x =	0.00 ft	Tether z =	26.25 ft
Fuel z =	0.00 ft	Hull length =	82.13 ft
System wt =	947.20 lb	Avail He Vol =	27628.90 cu ft
System x =	40.41 ft	Sea level T =	2.50 deg F
System z =	6.93 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	0.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.08 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F ft

Wind (kt)	Dynamic P (lb sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	3.14	0.00	-1	0	0
5	0.084	3.35	0.00	-0	4	5
10	0.336	3.96	0.00	9	20	19
15	0.757	4.83	0.00	36	56	44
20	1.349	5.77	0.00	88	121	80
25	2.112	6.59	0.00	159	220	130
30	3.049	7.24	0.00	238	352	193
35	4.160	7.72	0.00	314	517	269
40	5.444	8.07	0.00	383	712	359
45	6.902	8.33	0.00	444	937	461

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt (ASL) (ft)
0	821	0.0	531	0.0	0	3700
5	825	0.3	535	1.7	47	3700
10	841	1.3	551	6.6	186	3693
15	877	2.9	590	13.8	398	3670
20	944	4.9	662	21.7	643	3621
25	1046	7.1	772	28.7	878	3553
30	1176	9.4	920	34.1	1077	3480
35	1360	11.4	1103	38.0	1236	3411
40	1569	13.2	1319	40.8	1358	3352
45	1811	14.8	1568	42.9	1453	3303

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=515 lb:
Optimum alt = 3192.45 ft
Optimum lift = 1716.26 lb

TABLE 17. AEROSTAT AT 3,700 FEET AMSL, ZERO SUPERHEAT, 0.1 INCH SNOW LOAD, 0° F

FLIGHT ver 48.820811 Aerostat 25A Date: 08/23/82

Time: 11:08

AFGL AT JERICHO, VERMONT

Flight at constant tether length
Dry snowfall = 0.100 inches

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1781.00 lb
Payload wt =	70.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Snow wt =	89.80 lb	Tether x =	21.33 ft
Snow x =	48.98 ft	Tether z =	26.25 ft
Snow z =	-1.21 ft	Hull length =	82.13 ft
System wt =	1037.00 lb	Avail He Vol =	27626.90 cu ft
System x =	41.15 ft	Sea level T =	2.50 deg F
System z =	6.23 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	0.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.08 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	6.91	0.00	-1	0	0

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	731	0.0	441	0.0	0	3700

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=526 lb:
Optimum alt = 2541.05 ft
Optimum lift = 1754.43 lb

TABLE 18. AEROSTAT AT 3,700 FEET AMSL, ZERO SUPERHEAT, 0.5 INCH SNOW LOAD, 0° F

FLIGHT ver 48.820811 Aerostat 25A Date: 08/23/82

Time: 11:08

AFGL AT JERICHO, VERMONT

Flight at constant tether length
Dry snowfall = 0.500 inches

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1781.00 lb
Payload wt =	70.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Snow wt =	385.69 lb	Tether x =	21.33 ft
Snow x =	45.36 ft	Tether z =	26.25 ft
Snow z =	-1.27 ft	Hull length =	82.13 ft
System wt =	1332.89 lb	Avail He Vol =	27628.90 cu ft
System x =	41.84 ft	Sea level T =	2.50 deg F
System z =	4.56 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	0.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.08 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	31.70	0.00	-1	0	0

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	435	0.0	144	0.0	0	3700

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=565 lb:
Optimum alt = 416.22 ft
Optimum lift = 1883.38 lb

TABLE 19. AEROSTAT FLIGHT ON CONSTANT LENGTH TETHER (3,000 FEET), ZERO SUPERHEAT, 32° F

FLIGHT ver 46.820811 Aerostat 25A Date: 08 24 82

Time: 11:10

AFGL AT JERICHO, VERMONT

Flight at constant tether length

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1679.00 lb
Payload wt =	50.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Fuel wt =	0.00 lb	Tether x =	21.33 ft
Fuel x =	0.00 ft	Tether z =	26.25 ft
Fuel z =	0.00 ft	Hull length =	82.13 ft
System wt =	927.20 lb	Avail He Vol =	27628.90 cu ft
System x =	39.67 ft	Sea level T =	34.50 deg F
System z =	7.00 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	32.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.14 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	3.13	0.00	0	0	0
5	0.079	3.35	0.00	1	4	4
10	0.317	3.97	0.00	11	19	18
15	0.714	4.86	0.00	39	53	41
20	1.272	5.80	0.00	93	115	76
25	1.992	6.63	0.00	165	209	123
30	2.875	7.27	0.00	241	334	182
35	3.922	7.75	0.00	312	490	254
40	5.133	8.09	0.00	376	674	339
45	6.506	8.35	0.00	432	886	435

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	740	0.0	449	0.0	0	3700
5	744	0.3	453	1.9	51	3700
10	759	1.3	469	7.3	201	3692
15	793	3.0	507	15.1	426	3665
20	857	5.1	576	23.4	683	3610
25	954	7.4	681	30.5	922	3536
30	1086	9.7	822	35.7	1120	3460
35	1252	11.7	996	39.5	1274	3390
40	1449	13.5	1200	42.1	1392	3332
45	1677	15.0	1435	43.9	1482	3285

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=492 lb:
Optimum alt = 2852.08 ft
Optimum lift = 1639.41 lb

TABLE 20. AEROSTAT AT 3,700 FEET AMSL, ZERO SUPERHEAT, 0.1 INCH SNOW LOAD, 32° F

FLIGHT ver 48.820811 Aerostat 256 Date: 09 01 82

Time: 09:31

AFGL AT JERICHO, VERMONT

Flight at constant tether length
Wet snowfall = 0.100 inches

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1679.00 lb
Payload wt =	50.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Snow wt =	91.28 lb	Tether x =	21.33 ft
Snow x =	46.64 ft	Tether z =	26.25 ft
Snow z =	-2.26 ft	Hull length =	82.13 ft
System wt =	1018.48 lb	Avail He Vol =	27628.90 cu ft
System x =	40.30 ft	Sea level T =	34.50 deg F
System z =	6.17 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	32.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.14 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	9.09	0.00	0	0	0

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	648	0.0	356	0.0	0	3700

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=503 lb:
Optimum alt = 2167.29 ft
Optimum lift = 1675.08 lb

TABLE 21. AEROSTAT AT 3,700 FEET AMSL, ZERO SUPERHEAT, 0.5 INCH SNOW LOAD, 32° F

FLIGHT ver 48.820811 Aerostat 25A Date: 09 01 82

Time: 09:56

AFGL AT JERICHO, VERMONT

Flight at constant tether length
Wet snowfall = 0.500 inches

Aerostat wt =	877.20 lb	Flight alt =	3700.00 ft
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1679.00 lb
Payload wt =	50.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Snow wt =	338.57 lb	Tether x =	21.33 ft
Snow x =	41.76 ft	Tether z =	26.25 ft
Snow z =	-1.79 ft	Hull length =	82.13 ft
System wt =	1265.77 lb	Avail He Vol =	27628.90 cu ft
System x =	40.23 ft	Sea level T =	34.50 deg F
System z =	4.65 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	32.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.14 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	26.92	0.00	0	0	0

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	401	0.0	110	0.0	0	3700

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=532 lb:
Optimum alt = 328.18 ft
Optimum lift = 1773.84 lb

TABLE 22. AEROSTAT FLIGHT AT MAXIMUM ALTITUDE, DAY SUPERHEAT, 0° F PAD TEMPERATURE

FLIGHT ver 48.820811 Aerostat 25A Date: 09 02 82

Time: 16:10

AFGL AT JERICHO, VERMONT

Flight at max altitude
Available tether length = 3000 ft

Aerostat wt =	877.20 lb	Flight alt =	Ma
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1781.00 lb
Payload wt =	70.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Fuel wt =	0.00 lb	Tether x =	21.33 ft
Fuel x =	0.00 ft	Tether z =	26.25 ft
Fuel z =	0.00 ft	Hull length =	82.13 ft
System wt =	947.20 lb	Avail He Vol =	27628.90 cu ft
System x =	40.41 ft	Sea level T =	2.50 deg F
System z =	6.93 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	0.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.08 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F ft

Wind (kt)	Dynamic P (lb sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	0.36	20.56	0	0	0
5	0.087	1.37	14.38	0	2	5
10	0.342	2.95	7.30	0	15	19
15	0.765	4.21	4.89	0	49	43
20	1.356	5.37	3.68	0	112	80
25	2.114	6.32	2.95	0	210	129
30	3.047	7.06	2.46	65	342	191
35	4.159	7.60	2.10	178	508	268
40	5.442	7.99	1.83	260	704	357
45	6.899	8.27	1.63	332	929	459
50	8.532	8.49	1.46	409	1163	574
55	10.335	8.65	1.33	467	1466	702
60	12.310	8.78	1.22	520	1775	842
65	14.457	8.88	1.12	569	2113	994
70	16.776	8.96	1.04	615	2478	1158

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt (ASL) (ft)
0	925	0.0	763	0.0	0	2371
5	896	0.3	696	1.0	23	2764
10	873	1.2	629	5.2	131	3223
15	895	2.8	635	12.0	324	3386
20	954	4.8	687	20.2	577	3473
25	1052	7.0	779	28.2	857	3531
30	1188	9.3	920	34.1	1086	3505
35	1362	11.3	1103	38.0	1236	3419
40	1570	13.2	1318	40.9	1364	3363
45	1810	14.7	1566	43.0	1462	3316
50	2084	16.0	1847	44.3	1525	3264
55	2388	17.1	2158	45.5	1584	3232
60	2724	18.0	2499	46.4	1632	3206
65	3089	18.8	2870	47.1	1671	3186
70	3485	19.4	3271	47.6	1704	3169

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=515 lb:
Optimum alt = 3192.45 ft
Optimum lift = 1716.26 lb

TABLE 23. AEROSTAT FLIGHT AT MAXIMUM ALTITUDE, ZERO SUPERHEAT, 0° F PAD TEMPERATURE

FLIGHT ver 48.820811 Aerostat 25A Date: 09/02/82

Time: 15:56

AFGL AT JERICHO, VERMONT

Flight at max altitude
Available tether length = 3000 ft

Aerostat wt =	877.20 lb	Flight alt =	Max
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1781.00 lb
Payload wt =	70.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Fuel wt =	0.00 lb	Tether x =	21.33 ft
Fuel x =	0.00 ft	Tether z =	26.25 ft
Fuel z =	0.00 ft	Hull length =	82.13 ft
System wt =	947.20 lb	Avail He Vol =	27628.90 cu ft
System x =	40.41 ft	Sea level T =	2.50 deg F
System z =	6.93 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	0.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.08 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	3.14	0.00	0	0	0
5	0.084	3.35	0.00	-0	4	5
10	0.336	3.96	0.00	9	20	19
15	0.757	4.83	0.00	36	56	44
20	1.349	5.77	0.00	88	121	80
25	2.112	6.59	0.00	159	220	130
30	3.049	7.24	0.00	237	352	193
35	4.160	7.72	0.00	312	517	269
40	5.444	8.07	0.00	381	712	359
45	6.901	8.33	0.00	442	937	461
50	8.532	8.53	0.00	497	1190	576
55	10.334	8.68	0.00	546	1472	703
60	12.309	8.80	0.00	592	1781	843
65	14.457	8.90	0.00	635	2119	995
70	16.775	8.97	0.00	677	2483	1159

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	821	0.0	531	0.0	0	3698
5	825	0.3	535	1.7	47	3699
10	841	1.3	551	6.6	186	3693
15	877	2.9	590	13.8	398	3670
20	944	4.9	662	21.7	643	3621
25	1046	7.1	772	28.7	878	3553
30	1186	9.4	920	34.1	1077	3480
35	1360	11.4	1103	38.0	1236	3411
40	1569	13.2	1319	40.8	1358	3352
45	1811	14.8	1568	42.9	1453	3303
50	2084	16.0	1847	44.4	1528	3264
55	2388	17.1	2158	45.5	1586	3232
60	2724	18.0	2499	46.4	1634	3206
65	3089	18.8	2870	47.1	1673	3186
70	3485	19.4	3271	47.6	1705	3170

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=515 lb:
Optimum alt = 3192.46 ft
Optimum lift = 1716.26 lb

TABLE 24. AEROSTAT FLIGHT AT MAXIMUM ALTITUDE, NIGHT SUPERCOOL, 0° F PAD TEMPERATURE

FLIGHT ver 48.820811 Aerostat 25A Date: 09 02 82

Time: 16:30

AFGL AT JERICHO, VERMONT

Flight at max altitude
Available tether length = 3000 ft

Aerostat wt =	877.20 lb	Flight alt =	Ma
Aerostat x =	37.68 ft	Pad alt =	700.00 ft
Aerostat z =	7.17 ft	Std lift =	1761.00 lb
Payload wt =	70.00 lb	He purity =	98.00 %
Payload x =	74.69 ft	Tether wt =	0.097 lb/ft
Payload z =	4.00 ft	Tether dia =	0.470 in
Fuel wt =	0.00 lb	Tether x =	21.33 ft
Fuel x =	0.00 ft	Tether z =	26.25 ft
Fuel z =	0.00 ft	Hull length =	82.13 ft
System wt =	947.20 lb	Avail He Vol =	27628.90 cu ft
System x =	40.41 ft	Sea level T =	2.50 deg F
System z =	6.93 ft	Sea level P =	29.92 in Hg
Hull press =	2.00 in water	Pad T =	0.00 deg F
He Rel Hum =	0.00 %	Pad P =	29.09 in Hg
Tet Mod*Area =	2.50E 05 lb	Lapse rate =	0.0035662 deg F/ft

Wind (kt)	Dynamic P (lb/sq ft)	Pitch (deg)	S-heat (deg F)	Balnt Vol (cu ft)	Aero lift (lb)	Aero drag (lb)
0	0.000	5.22	-12.32	1214	0	0
5	0.085	4.53	-7.52	631	6	5
10	0.336	4.51	-3.78	241	23	19
15	0.757	5.16	-2.52	191	60	44
20	1.349	5.98	-1.89	204	126	81
25	2.112	6.73	-1.51	251	225	131
30	3.049	7.33	-1.25	313	357	194
35	4.160	7.78	-1.07	377	522	270
40	5.444	8.11	-0.93	437	717	360
45	6.901	8.36	-0.83	492	941	462
50	8.532	8.55	-0.75	541	1194	576
55	10.334	8.70	-0.68	587	1475	704
60	12.309	8.82	-0.62	629	1785	843
65	14.456	8.91	-0.57	669	2121	995
70	16.775	8.98	-0.53	708	2486	1160

Wind (kt)	Cp Tens (lb)	Cp Angle (deg)	W Tens (lb)	W Angle (deg)	Blow Down (ft)	Alt(ASL) (ft)
0	755	0.0	515	0.0	0	3185
5	787	0.4	515	1.7	46	3513
10	824	1.3	535	6.8	192	3694
15	868	2.9	581	14.0	405	3669
20	939	4.9	657	21.9	649	3620
25	1044	7.2	770	28.8	883	3552
30	1184	9.4	918	34.1	1081	3479
35	1360	11.5	1102	38.1	1238	3411
40	1569	13.3	1319	40.9	1360	3352
45	1810	14.8	1567	42.9	1455	3303
50	2084	16.1	1847	44.4	1529	3264
55	2388	17.1	2158	45.5	1586	3232
60	2724	18.0	2499	46.4	1635	3207
65	3089	18.8	2870	47.1	1674	3186
70	3485	19.4	3271	47.6	1706	3170

Note: For Superheat=+25.00 & 0.00 deg F and Free lift=515 lb:
Optimum alt = 3192.45 ft
Optimum lift = 1716.26 lb

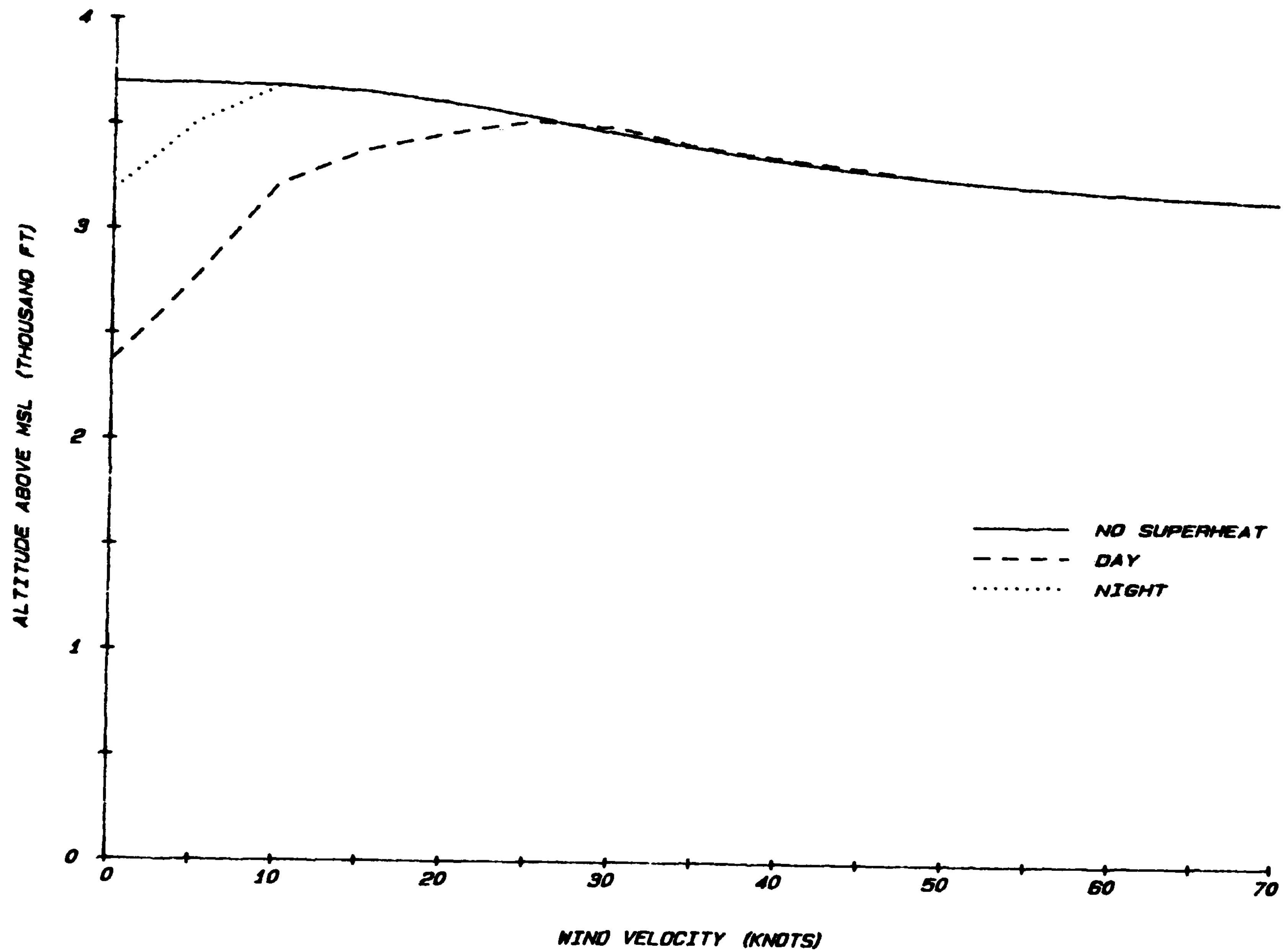


Figure 17. Altitude vs Wind Velocity

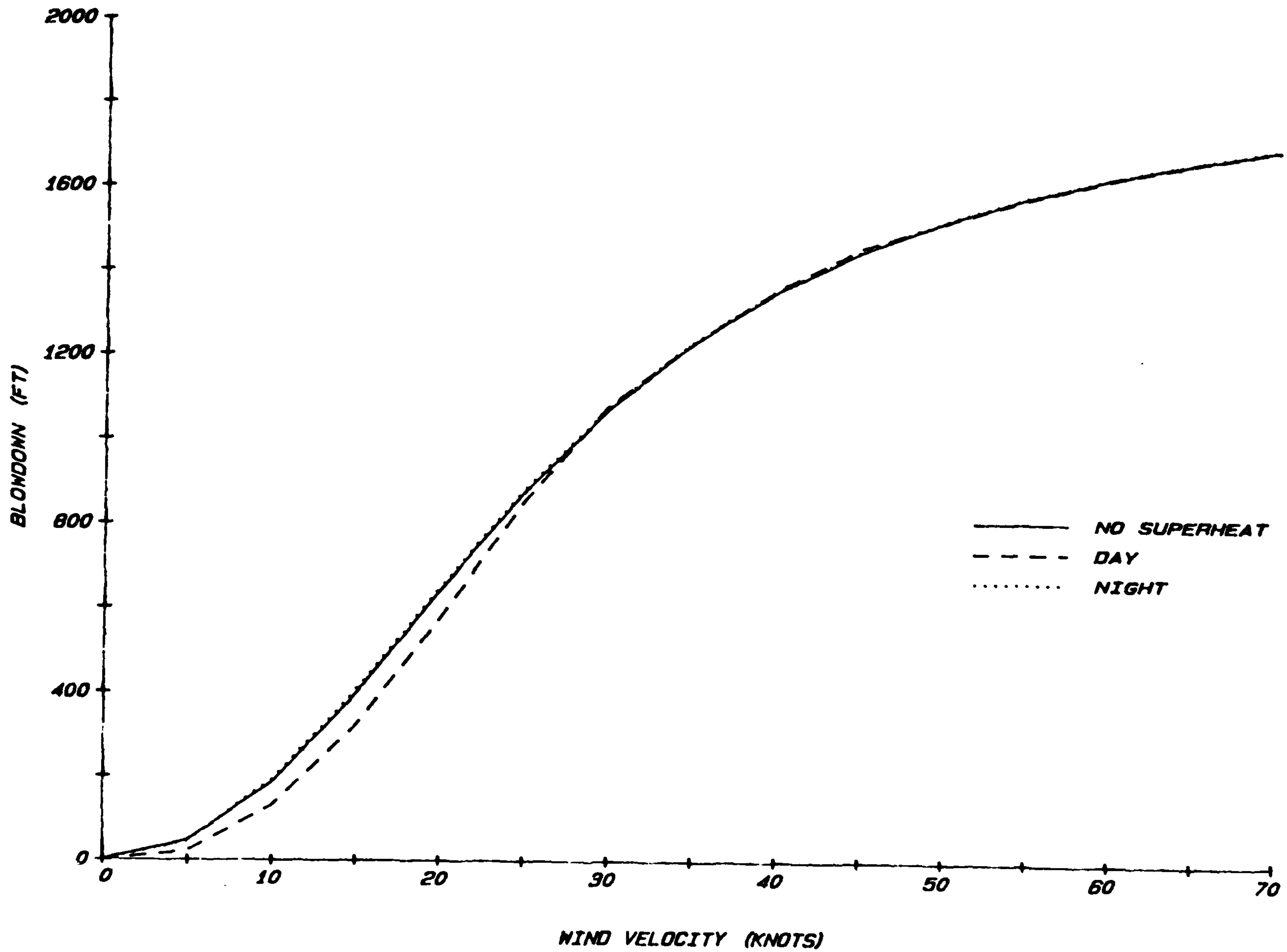


Figure 18. Blowdown vs Wind Velocity

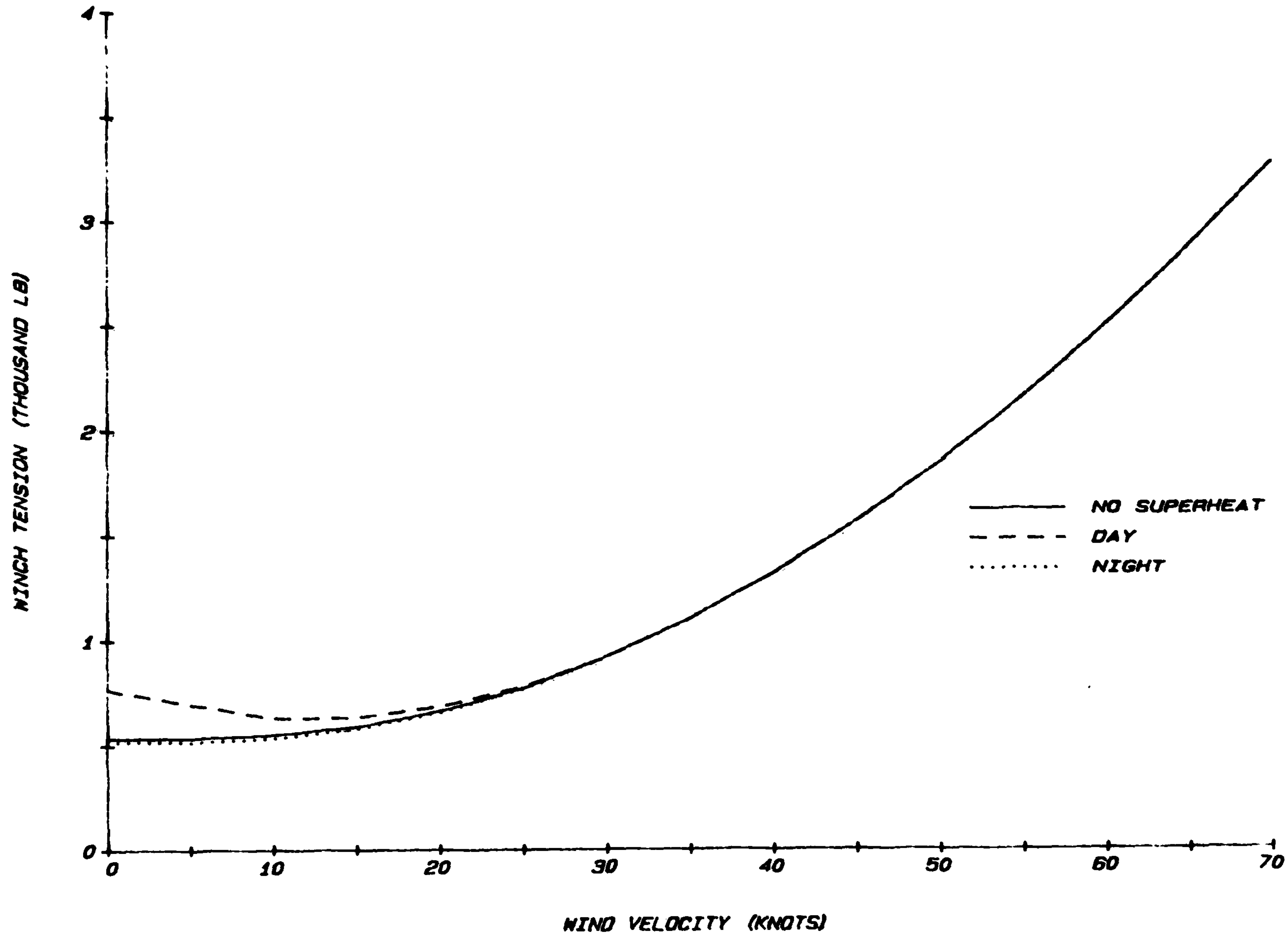


Figure 19. Tether Tension vs Wind Velocity

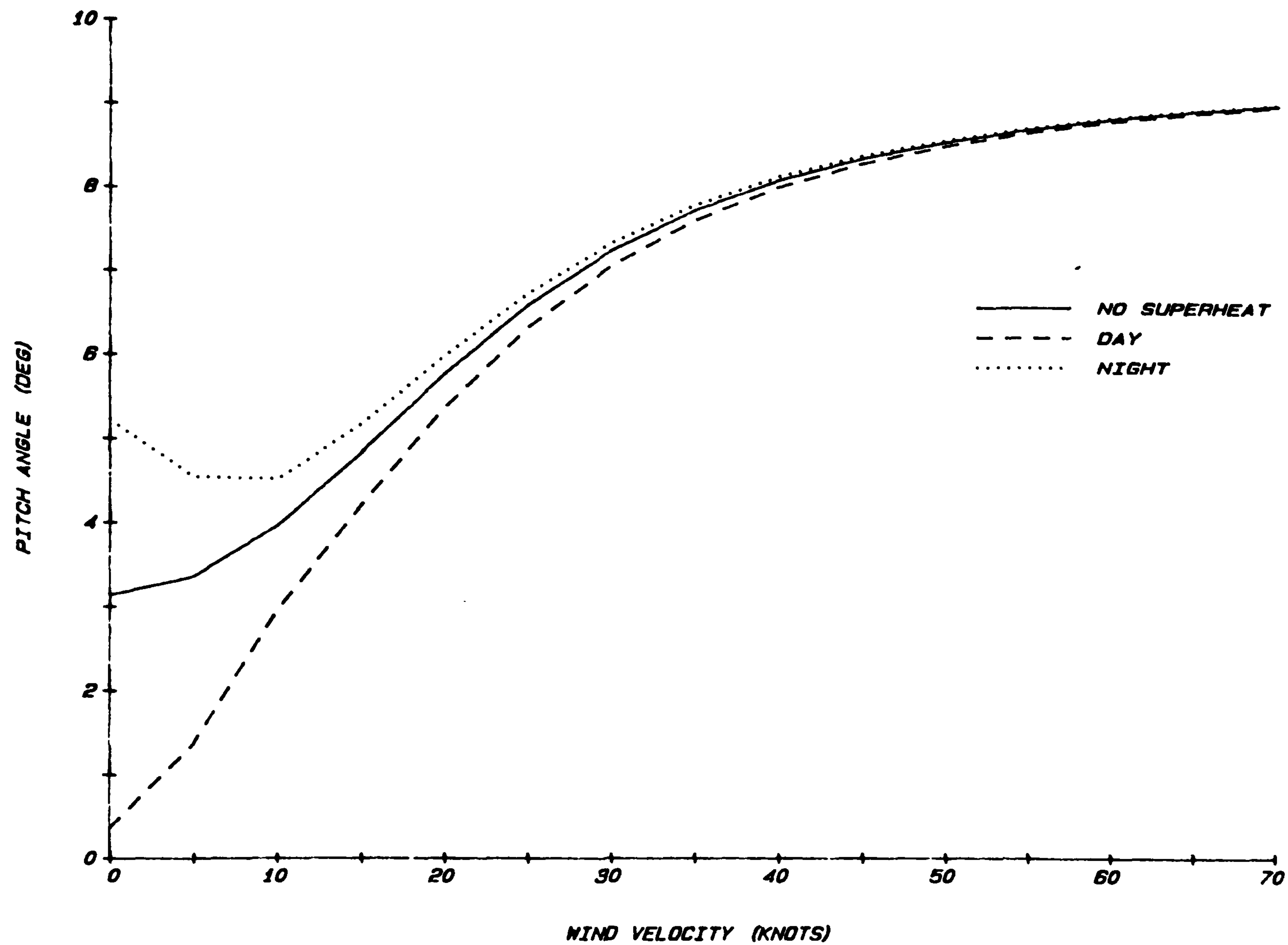


Figure 20. Aerostat Pitch Angle vs Wind Velocity

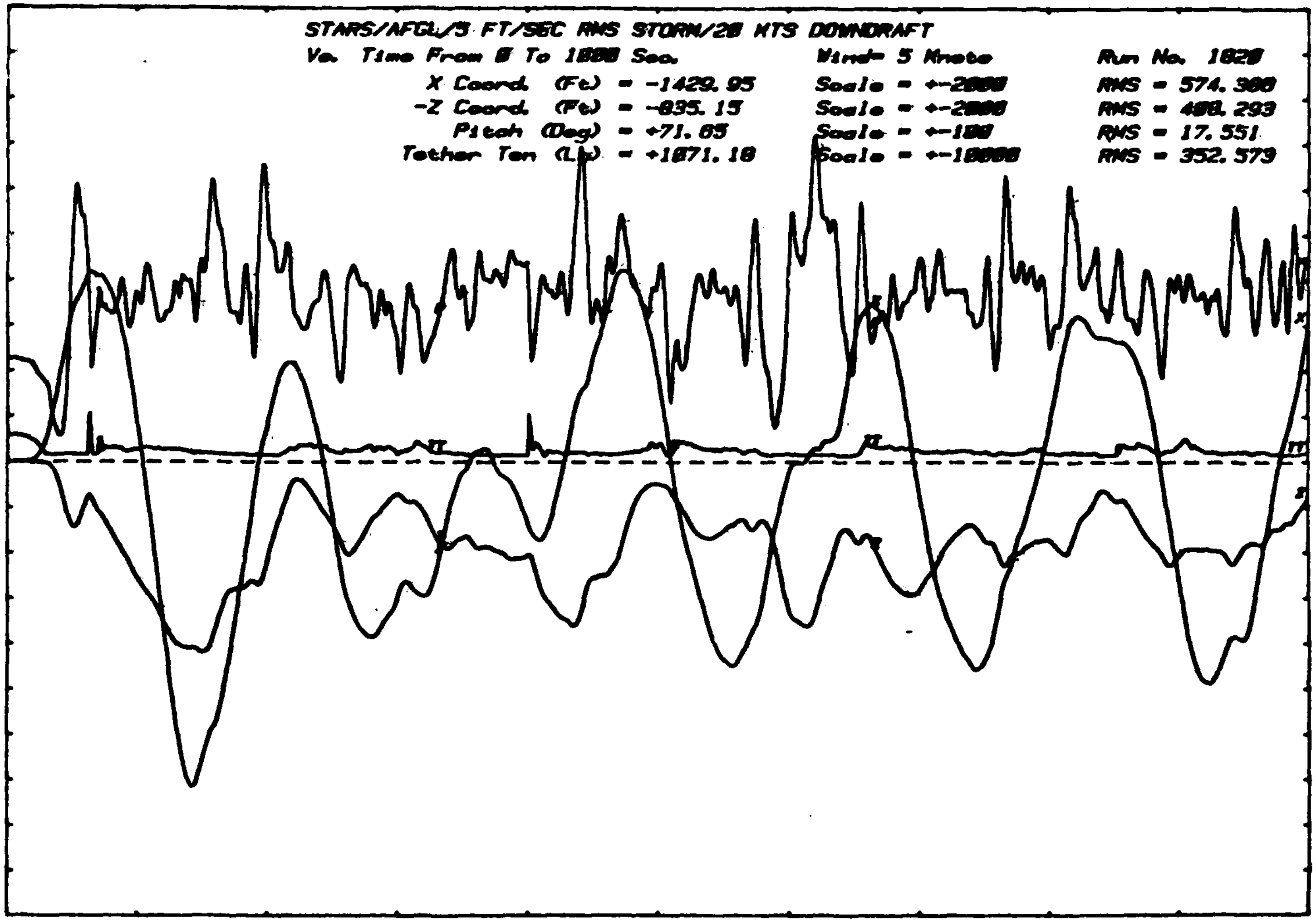


Figure 21. Aerostat Flight Simulation in Downdraft — Panel A

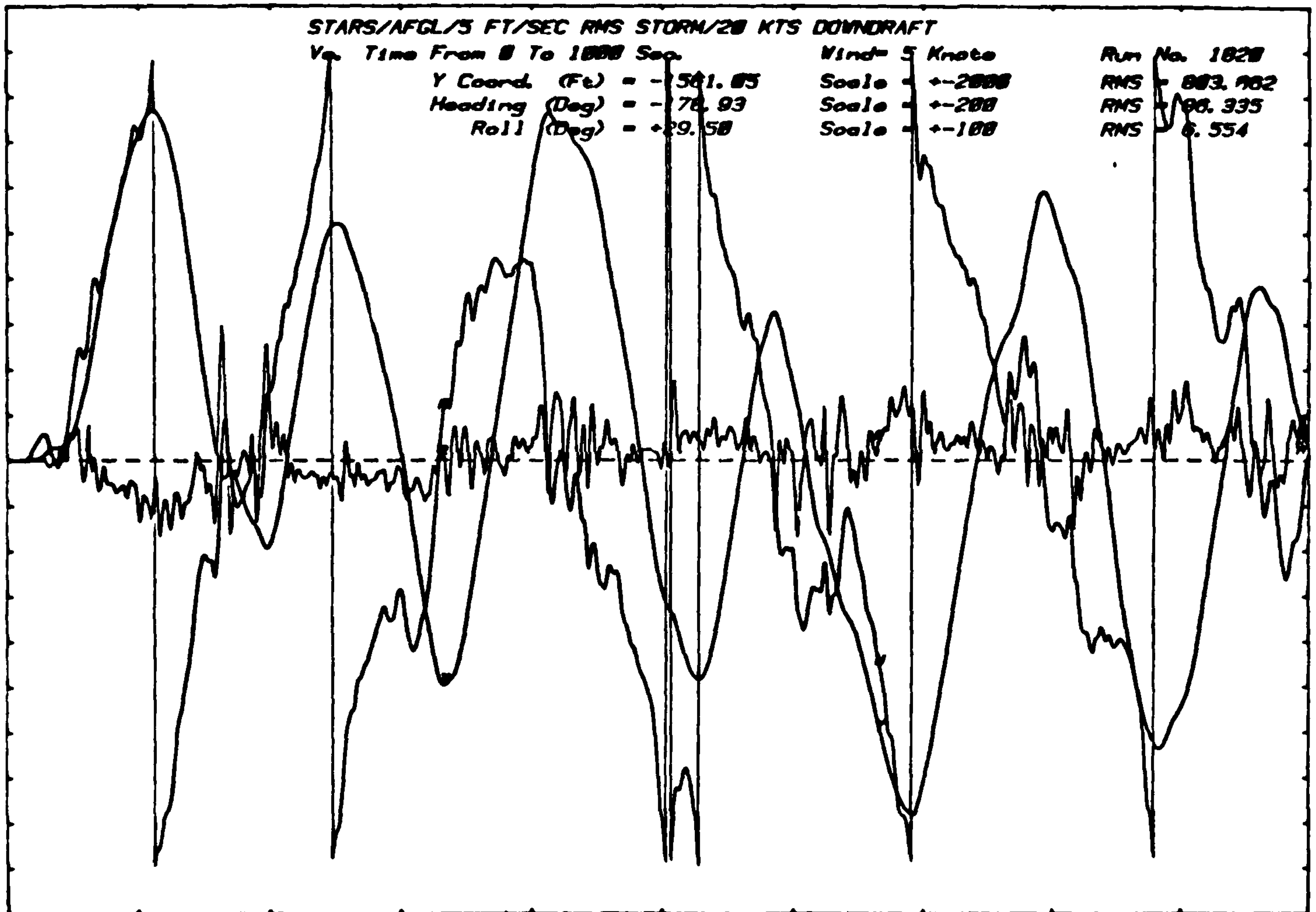


Figure 22. Aerostat Flight Simulation in Downdraft — Panel B

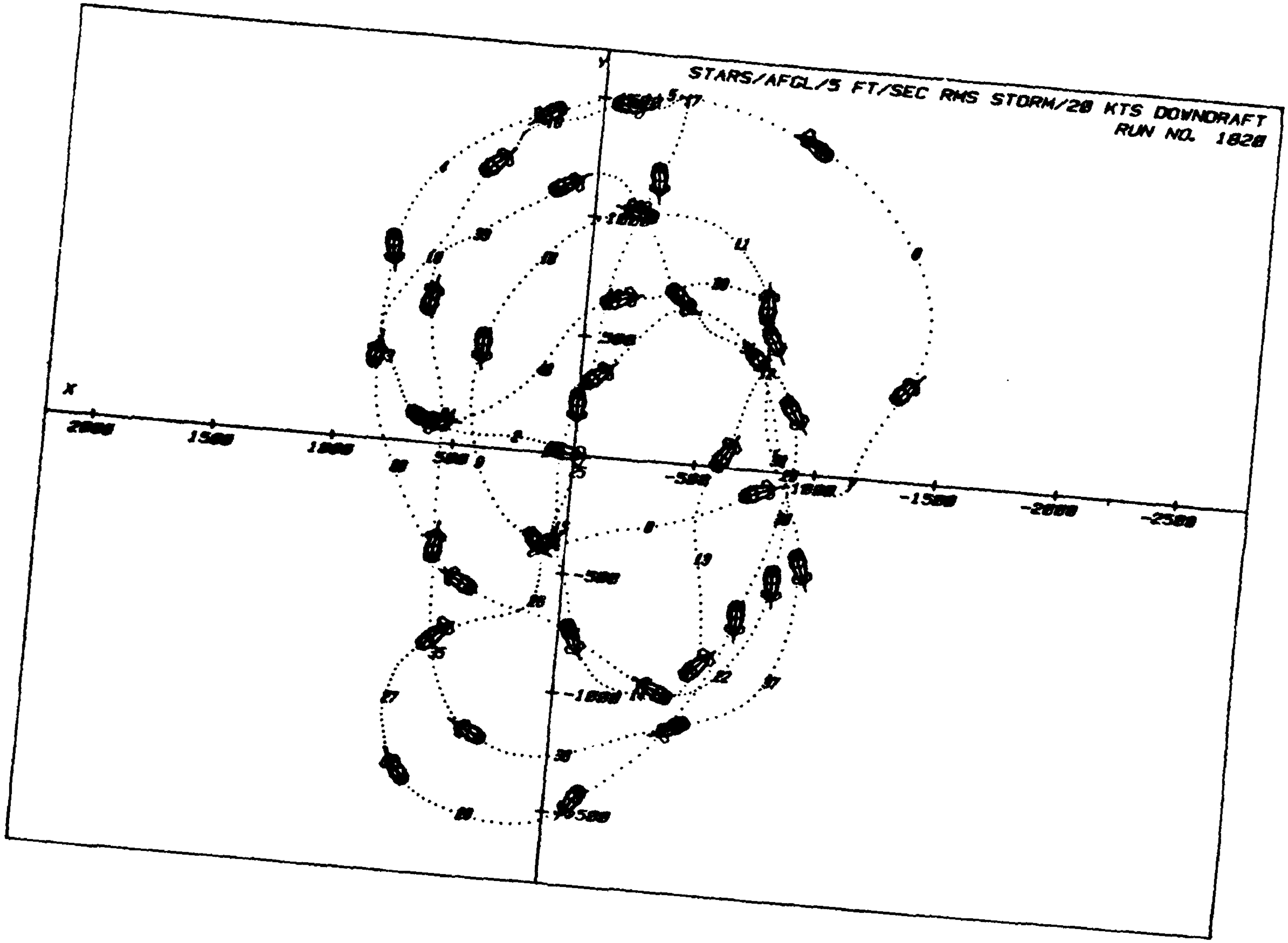


Figure 23. Aerostat Simulation — Motion in the XY Plane

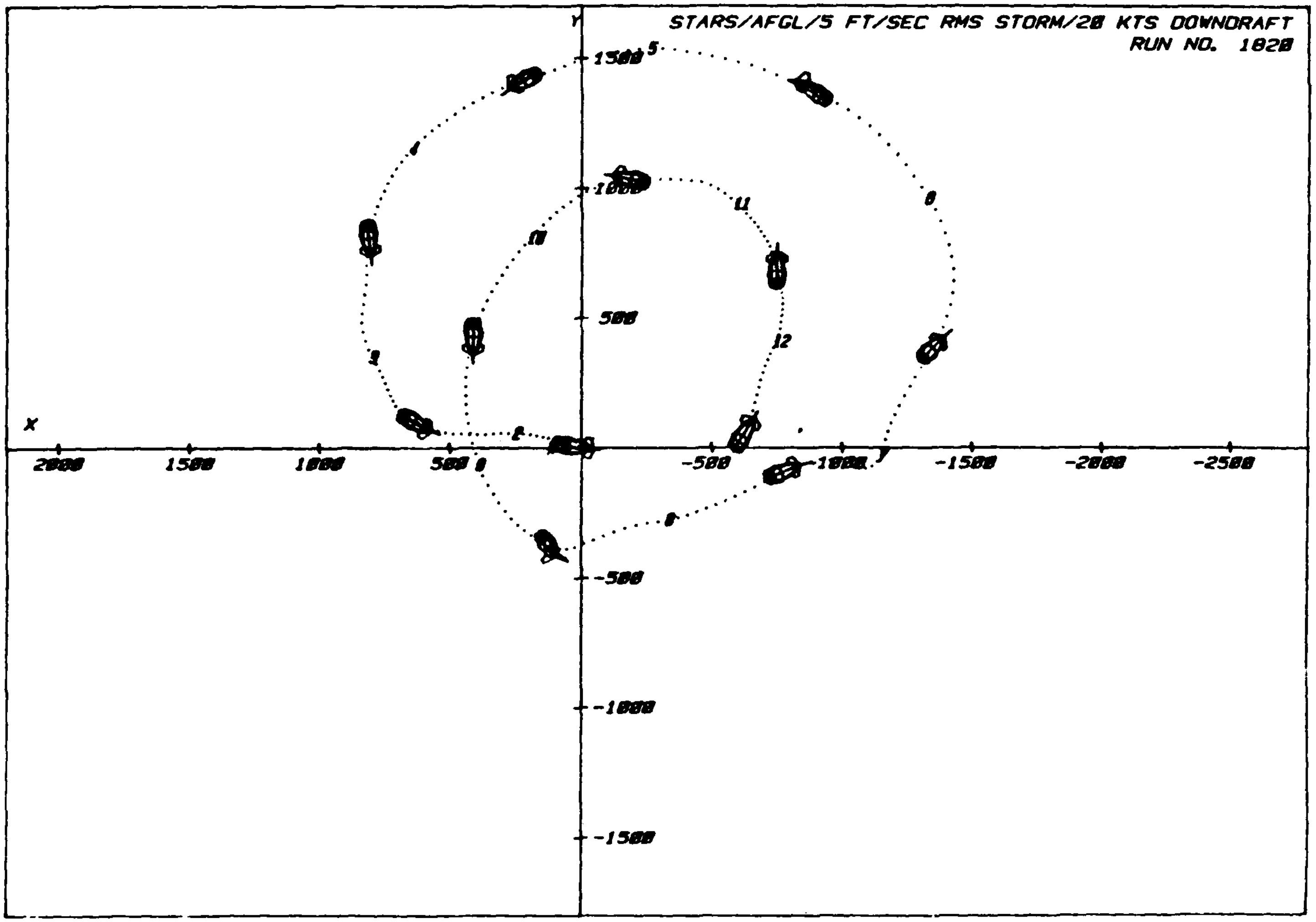


Figure 24. Aerostat Simulation — Motion in the XY Plane (5 Minutes Only)

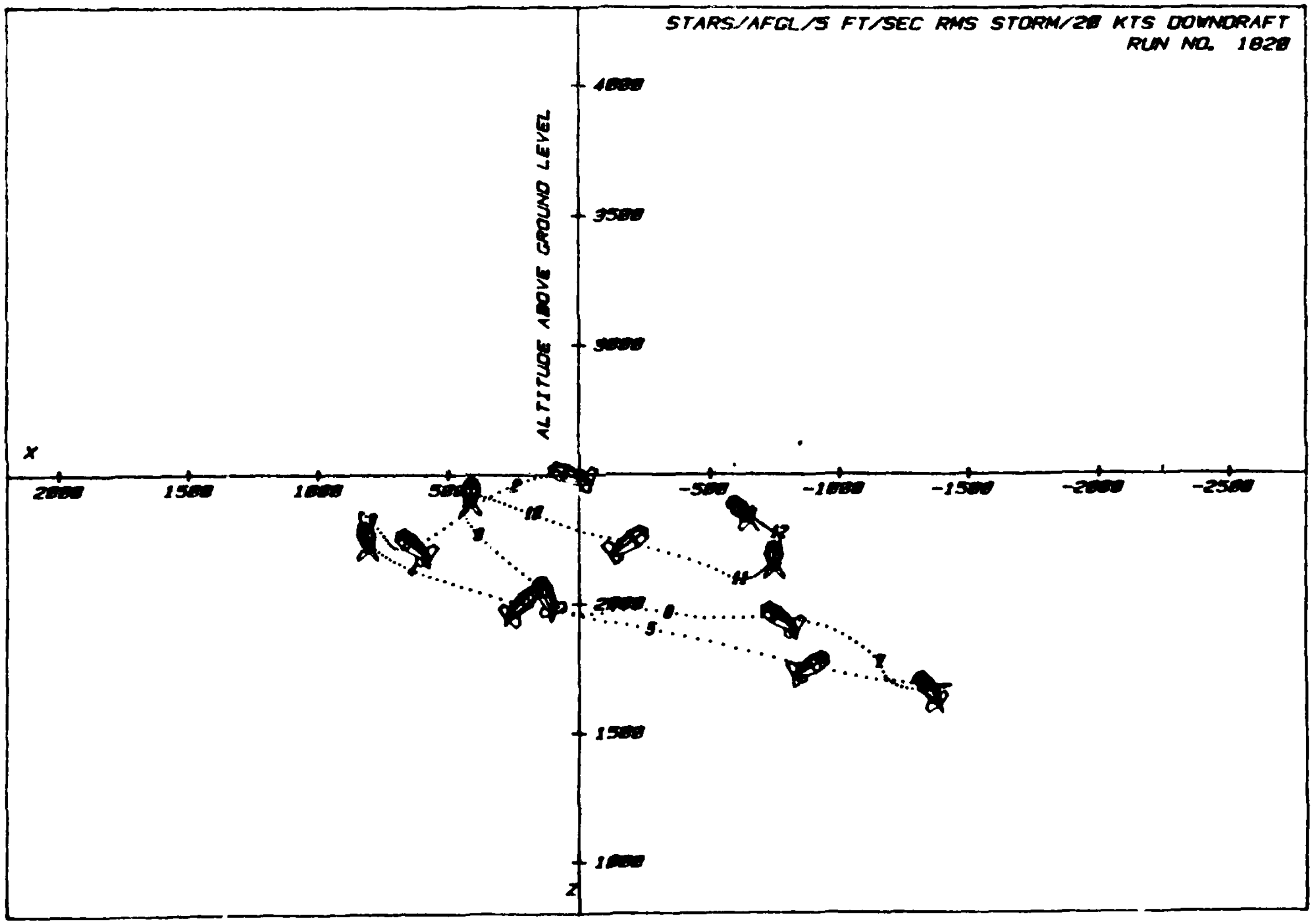


Figure 25. Aerostat Simulation — Motion in the XZ Plane

All of the tests described in this section were performed during the month of September 1982.

ICE ACCRETION/REMOVAL TEST

Abstract

Tests were conducted during September 1982 on an inflated air bag to evaluate the effectiveness of some ice removal techniques. The techniques tested were a copolymer release coating and mechanical vibration of the bag fabric. The test did not show either of the techniques to be beneficial in ice removal.

Background

An earlier test was performed in July 1981 in conjunction with a cold weather flight project to determine ways in which ice and snow form on an aerostat and to test procedures that might cause ice, snow, and frost to fall free from the aerostat surface. Several commercially available release agents were tried, but none of these were effective. The most effective means of cracking glazed ice was pressure cycling of the aerostat. It was recommended that a vibrator be mounted on the surface of the aerostat and used in conjunction with pressure cycling.

Objective

The purpose of these tests was to evaluate the feasibility of some additional ice removal techniques. Specifically, a new (to TCOM) release agent, a copolymer coating, was applied to a section of the fabric. A vibrator was mounted on the bag. The effectiveness of the release agent and vibration for ice removal were tested.

Test Description (Air Bag)

An air bag constructed of STARS aerostat material was used for the tests. This bag is a cylinder 4 feet in diameter, with spherical end caps, and a total length of 9 feet. A mounting ring with a quick disconnect air hose fitting was installed in one end of the bag. A quarter section of the opposite end cap was coated with a release agent. This coating is a block copolymer of polycarbonate and dimethylsiloxane with 10% silicone oil added. This material was developed by Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers, to reduce ice adhesion. Three coats were applied. The vibrator was laced to the top of the bag. See Figure 26.

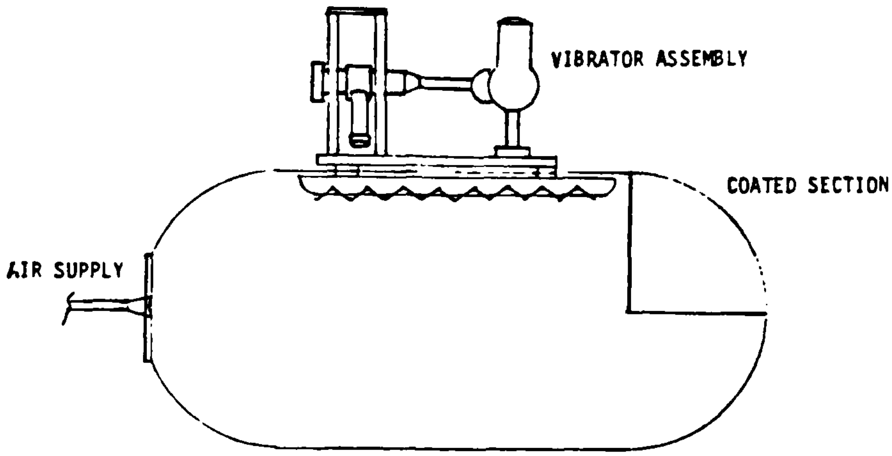


Figure 26.

(Vibrator)

The vibrator mechanism works on the rotating eccentric weight principle. The force of vibration is given by $F = 2.84 \times 10^{-5} WRN^2$, where W is the eccentric weight in lb, R is the radius of gyration in inches, and N is speed of rotation in rpm. The mechanism was constructed from 2-inch lumber and ¾-inch pipe fittings. This is driven with a variable speed drill through a 1:2 ratio geared right angle drive. Speeds of up to 2,000 rpm can be obtained. See Figure 27. By installing various length (2" to 6") nipples in the branch of the tee, the WR can be varied from 0.1 to 2.8.

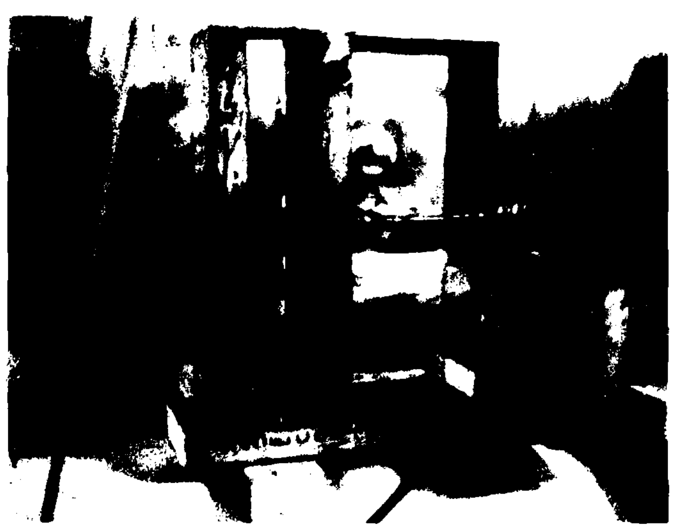


Figure 27.

Previously, the vibrator was installed and operated on the 25-meter aerostat. Forces up to 30 lb at 600 rpm were used. This force was scaled down to about 10 lb for the test bag to achieve a comparable level of vibration.

(Pressurization System)

The pressure in the bag is controlled by a regulator and valve assembly as shown in Figure 28. The pressure can be varied from 5 to 35 inches of water. The aerostat has a radius 6.6 times that of the bag. To achieve a stress in the bag equivalent to that in the aerostat, the pressure in the bag must be 6.6 times the pressure in the aerostat. The pressure can be increased from 6 to 20 inches of water in 20 seconds, or reduced from 20 to 6 inches in 4 minutes.

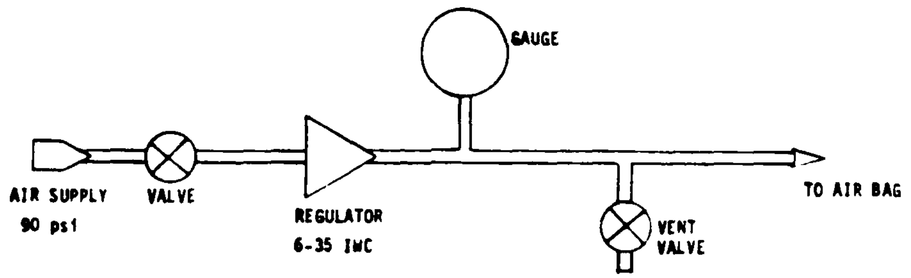


Figure 28. Air Bag Pressure Regulation — Schematic

(Environmental Chamber)

The air bag assembly was placed in a temperature-altitude-humidity chamber 8.5 ft x 14 ft x 8 ft. Figure 29 shows the assembly in the chamber. This chamber is capable of temperatures of -100° F to +500° F. Humidity can be increased to cause frost formation. The altitude feature of the chamber was not used.

A garden sprayer was used to direct a fine spray of water on the test bag at low temperatures. This will cause a build up of ice and frost on the bag.

Results

The chamber was cooled to 0° F and the bag was pressurized to 6 inches of water. Water was sprayed onto the bag from the sprayer. A layer of ice froze on the untreated area of the bag. The bag was sprayed several times to build up a layer of ice about 1/16 inch.

In the coated area, the surface could not be wetted, and the ice formed as small droplets instead of a sheet of ice. Some of the water ran off of the bag before freezing.

Figure 29. Air Bag Under Test in Cold Chamber

Beyond the ice areas (in the overspray) were areas of frost formation (rime ice). This frost was very thin, and the copolymer coating did not appear to make any difference in frost formation.

Attempts were then made to remove the ice. The vibrator was turned on and run at various forces and frequencies. This had no effect on the ice. The internal pressure of the bag was cycled from 6 to 20 inches of water, causing the bag to expand and contract. This caused cracks in the ice layer; some chunks of ice were lying free on the surface of the air bag. These could be locally removed by striking the bag or by scraping; however, vibration seemed to have little or no effect.

The coated area of the bag had small drops of ice which were unaffected by either pressure cycling or vibration. The rime ice could be removed only by scraping.

The test was repeated at a temperature of + 25° F. The only significant difference noted was that it took longer for the water to freeze. Again, the pressure cycling caused the ice on the uncoated area to crack. The vibration again had no effect.

The test was repeated with the vibrator running to see if it affected the formation of ice. There was no detectable difference in ice formation in the uncoated area. In the coated area, the water was more likely to fall off before freezing.

The chamber temperature was lowered to + 10° F and steam was introduced. This was an attempt to form frost on the bag. This was done both with and without the vibrator running.

Very little frost formed probably due to the addition of too much steam and superheat in the bag.

Conclusion

From the results obtained it can be concluded that:

1. Vibration at the level and frequency used has little or no effect in removing ice or preventing ice formation on the test bag.
2. The release agent changes the characteristics of the ice formation from continuous sheets of ice to ice droplets. Used in conjunction with vibrators, water is more likely to run off before freezing. However, the ice cannot be cracked by pressure cycling.

Recommendations

Additional testing should be done. There is probably a scale effect between the test bag and the actual aerostat. Ice would be heavier and more likely to slide off of the aerostat. Also the curvature is less on the aerostat. Vibration should be tried at higher frequencies — manufacturers of vibrators recommend high frequencies for moving wet, sticky material, and low frequencies for dry, fluffy materials. Vibration may be more effective on the fins than on the hull.

LOW TEMPERATURE REPAIR TECHNIQUES

Abstract

Tests were conducted to evaluate aerostat repair techniques and adhesive systems under simulated arctic conditions. The results indicate that none of the tested systems was adequate. The thermoplastic hot melt glue adhesive seems to have the best chance of being incorporated into a workable field repair system.

Background

Successful operation of an aerostat system under arctic conditions requires that a practical field repair technique be available to make a structured repair that is both helium and air tight. Our opérational experience has shown that hull punctures, although infrequent, do occur and the suvival of the aerostat depends on being able to effect adequate repairs. For example, if a tear in the helium compartment were to occur, the helium would escape and the ballonet would expand to make up for the lost helium and try to maintain overall hull shape and pressure. The ballonet would quickly fill up and pressurize and shut off the blowers. Since the helium would continue to escape, the helium compartment would lose pressure and shape thus allowing the aerostat to deflate with almost certain damage to hull and payload. If the tear were to occur in the ballonet or fins, the blowers would come on to supply the lost air and try to maintain pressure. If the blower capacity is greater than the air loss then the blowers would simply run more often until the leak was fixed, however, if the blower were not able to keep up with the loss the aerostat would lose its shape, which contributes to the aerodynamic response. In any significant wind, the aerostat could destroy itself and the payload.

Under more favorable environmental conditions, a typical tear in the hull would be temporarily taped closed. Then the tear would be stitched and an overall patch applied using a urethane base adhesive. During previous cold region operations it was realized that an adequate field repair technique did not exist. Although no critical problems occured, it was necessary to make repairs to the hull. Several adhesives were tried with varying degrees of success. Given this firsthand experience and a generally held belief that adhesives are drastically degraded at low temperature, it was clear that this was an area that required further investigation and development.

Objectives

This experiment had as its primary objective the identification of a suitable low temperature field repair system. Should this objective not be met then, as a secondary objective, it is important to identify promising candidates for further development. In addition, this was an opportunity to develop application techniques suitable for low temperatures. Of the present or promising repair candidates none except the "hot melt glue" are recommended for low temperature use. It was hoped that by using the selected adhesive systems at low temperature we would gain some insight into the problems and could develop application techniques that would allow their successful use outside their normal temperature range.

Test Description

These tests were conducted at the Product Qualification Laboratory (PQL) of the Westinghouse Defense and Electronics Center located in Linthicum Maryland. Arrangements were made at PQL to use their Temperature-Altitude-Humidity Chamber. This is a large insulated vessel (8 ft x 14 ft x 8 ft) capable of maintaining a temperature of -100° F to +500° F, a pressure altitude from sea level to 100,000 ft, and a relative humidity of +10% to 90% at +35° F to +180° F. A cylindrical balloon, one and one-quarter meters in diameter with spherical end caps and two and three-quarter meters long was fabricated to provide a suitable work surface to make the test seals on the samples. The balloon was inflated to approximately 6 IWG (inches water gauge) to simulate the soft spongy surface of an aerostat at about 1 IWG hull pressure.

The sample material was TCOM L01 hull laminate (TCOM specification 950532). This material consists of a 1-mil-thick Tedlar (polyvinyl fluoride) film, laminated to a woven polyester cloth with a rectangular 16 x 16 yarns per inch plain weave using a Hytrel polyester elastomeric resin adhesive. A rectangular patch of L01 fabric was taped to the test balloon and one and one-half inch wide strip of L01 fabric was then sealed to the test patch front (Tedlar side) to back (cloth side). The test was to consist of two sample seals of each adhesive at each temperature. Figure 30 shows the nominal test set up in the chamber with two patches taped to the balloon. The structure attached to the top of the balloon was part of an ice shedding test being run simultaneously in the chamber.

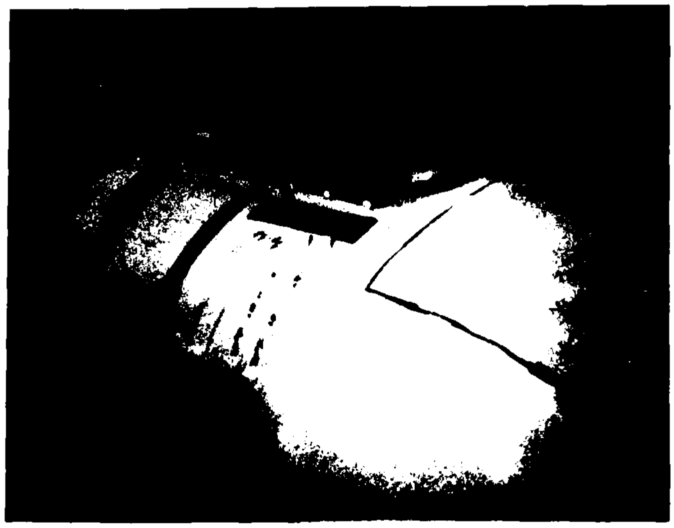


Figure 30. Test Balloon with Sample Patches

In the case of the solvent-thinned adhesives it was necessary to flash-off (evaporate) the solvent prior to making the seal. Localized heating in the form of two 250W, infrared lamps were used to warm the seal area and speed flash off. Infrared lamps were chosen because they heat by radiation and would be less affected by inclement weather such as wind, snow, etc. They also have the added advantage of providing a light source.

Test Results

In general, the tests results were disappointing from the point of view that none of the adhesive systems is suitable without modification. Those samples of the test matrix not tested were due to difficulties either with the equipment or adhesive which were directly related to the low temperature. On the other hand, with some modification of equipment the 1975 Hot Melt adhesive seems to be the most promising. The two solvent-thinned adhesives might be made to work at least down to -20° F with some additional equipment and modification of application technique. The 1440 polysulfide rubber base adhesive seems to be all but useless as was the #390 tape which lost its inital "grab" and tear strength. Table 25 shows the test matrix.

Specifically, for the UR1087 adhesive, two sample seals were made at room temperature as a control. At 30° F the solvents were very slow to flash off and the IR heat lamps were used to speed the evaporation. This technique was very successful and was used throughout the test. Methyl ethyl keytone (MEK) is used as an adhesive activator after the coated surfaces have dried. The initial "grab" was satisfactory. At 0° F the heat lamps were again used to dry the adhesive but it was also necessary to warm the adhesive in the container because it became too thick to brush on. This was the case at all lower temperatures and probably existed to some extent at 30° F. The MEK was totally ineffective at 0° F in activating the adhesive surface and we were unable to stick

TABLE 25. ACTUAL SEAL SAMPLE TEST MATRIX

Adhesive	Number of Samples at Each Temperature				
	75° F	30° F	0° F	-20° F	-40° F
UR-1087	2	2	2	2	—
0271	2	2	2	2	—
1975 Hot Melt	2	2	1	3	—
1440	2	2	1	—	—
Tape, 390	*	*	*	*	*

*No T-peel tests done

the strip to the sample patch. Heat did not seem to make any difference in the initial "grab". Since the adhesive is thinned with MEK we decided to try to activate the seal surface with a wet coat of adhesive. This did increase the "grab" and we were able to seal the strip in this manner. The sample seals at -20° F were made using local heating from the IR lamps with an additional wet coat of adhesive as a activator. It was necessary to heat the adhesive cup continuously in order to keep it liquid. However, at -40° F we were not able to heat the adhesive cup sufficiently to be able to spread the adhesive on the sample. It is not clear if it would be possible to spread the adhesive on the sample even if it had been heated. It seems obvious that if this system is to be made workable the application technique needs to be developed along with some new equipment.

The 0271 solvent thinned neoprene rubber-based adhesive behaved about the same as the UR1087. It tended to become thick and increasingly difficult to spread at low temperatures until at -40° F the adhesive became too thick to spread. Unlike the UR1087 adhesive, our experience with the 0271 adhesive is very limited but two advantages were readily apparent: 1) being a 1-part adhesive, no mixing was required; 2) no activator was required prior to effecting the seal.

When the solvent-thinned adhesive samples were removed from the test chamber each was examined for peel strength subjectively by hand. All samples exhibited very low peel strength and it is estimated at less than 1 lb/in. Table 26 is a tabulation of the maximum and minimum T-peel values in pounds per inch achieved by each sample after being allowed to cure at room temperature for 6 days. It is included primarily for completeness and care should be exercised in drawing any conclusions from it in that the cure and peel tests were both done at room temperature and not at the test temperature. Table 26 lists T-peel values for each sample because the strips were peeled first at one end and then the other.

TABLE 26. T-PEEL VALUES FOR ADHESIVE SAMPLES

Sample No.	Adhesive System	Temp. °F	1st Peel min/max value	2nd Peel min/max value	Comments
1	1440	30	19/23	14/20	
2	1440	30	19/21	19/21	
3	1440	0	25/30	25/30	
4	1975	30	40/48	15/20	Greater glue line thickness on 1# peel
5	1975	30	34/42	19/44	
6	1975	0	18/29	27/41	
7	1975	-20	27/35	21/35	
8	1975	-20	15/35	30/34	
9	1975	-20	17/27	25/30	
10	0271	75	3.5/5	4.5/5	
11	0271	75	5/6	5/6	
12	0271	30	1/2	3/5	
13	0271	30	1/3	1/5	
14	0271	0	2.5/4.5	3/5	
15	0271	0	1/3	3/4	
16	0271	-20	3.5/3.5	3/4	
17	0271	-20	2/4	3/4	
18	UR1087	75	4/5	—	2nd peel delaminated
19	UR1087	75	—	4/8.5	1st peel delaminated
20	UR1087	30	5/8	5/5	
21	UR1087	30	3/5	5/5	
22	UR1087	0	5/7	4/7	
23	UR1087	0	—	1/3	1st peel delaminated
24	UR1087	-20	2.5/4.5	1.5/2.5	
25	UR1087	-20	1.5/1.5	2/2	
26	1975	22/25	37/40		
27	1975	75	11/15	—	2nd peel delaminated
28	1440	75	—	—	Sample damaged
29	1440	75	—	—	Sample damaged

The type 1975 Hot Melt adhesive is applied with an electrically heated/compressed air driven gun. This system requires the most support equipment and thus would require the longest preparation time prior to making a repair. It is difficult to make a repair that looks good cosmetically due to the poor flow control of the gun and nozzle design. The nature of the adhesive in general, the fact that it is hot makes it difficult to trowel, it sets up rapidly, etc., all contribute to the poor appearance. However, from a structural point of view, this system exhibits the best initial "grab" and quickly develops full strength about as fast as it is applied. The main drawback in using this system is the gun applicator. At 0° F and below the nozzle would cool allowing the adhesive to solidify during periods when adhesive was not actually being applied. The power switch also malfunctioned and allowed the gun to cool. Both of these problems seemed to be related to the very low ambient temperature.

The 1440 polysulfide rubber-base adhesive seem to be the least satisfactory. At 30° F where its viscosity was low enough for it to be applied, its initial shear strength was so low that the strip would slide around. At 0° F and below the viscosity was so high that it was impossible to operate the hand-powered applicator gun. Additionally, the cure time at low ambient temperatures is estimated in terms of weeks. This adhesive, even though it is the only one that has been used previously, does not seem to be a good choice.

The 3-M Company ordnance tape #390 was very poor in initial "grab" at 30° F and below; in addition, its tear strength was so poor that it was torn as easily as a sheet of paper. It should be noted that if warm and applied to a warm surface it appeared to be satisfactory. Some sample patches were taped to the test balloon using the IR heat lamp and remained in place throughout the test. No peel values are available for the tape.

Conclusions and Recommendations

Of the four adhesive systems tested it can be concluded that:

1. As is, none is suitable for low temperature use,
2. The 1975 Hot Melt adhesive seems to have the best potential of being developed for this application.
3. The 1975 Hot Melt adhesive system is the most complicated.
4. The use of the IR heat lamp was effective and easy to control for local skin heating; in addition, the light output was significant.
5. When using a solvent-thinned adhesive, a heated container must be used as an adhesive reservoir.
6. The initial "grab" and tear strength of tape at low temperature is very low and of no practical use.
7. The use of the IR heat lamp to warm the tape and surface was necessary to achieve a useful bond.

In view of the stated results and conclusions it is recommended that the 1975 Hot Melt adhesive system be selected for additional testing and development. The application gun in particular must be modified by changing the nozzle design and by adding some insulation over the heater and tip to reduce cooling in this area. Availability of a more suitable gun should be examined. A typical repair might consist of the following steps:

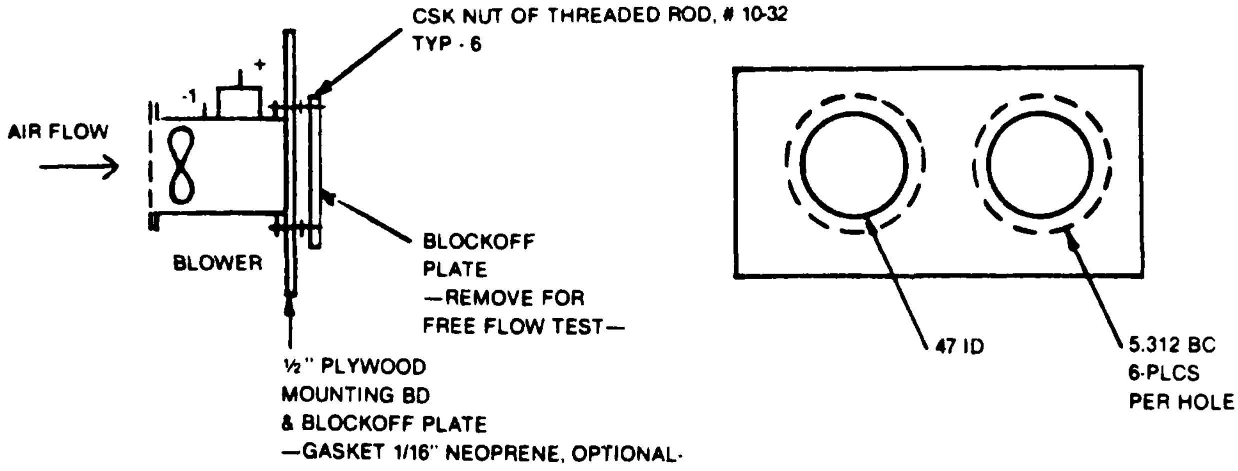
1. Close the cut by hand stitching, if practical, otherwise close the cut using the Hot Melt glue and many short narrow strips across the opening.
2. Use a strip of hull material about 1 to 1½ inches wide to seal the opening from one end to the other.
3. Seal the edges of the strip applied in Step 2 above to prevent helium or air loss.
4. After the situation is stabilized, apply a larger patch of hull material using hot glue adhesive so as to extend at least 2 inches on all sides of the cut. Seal edges using hot glue as required.
5. When weather permits, cover entire area with 6-inch-wide white Tedlar tape.

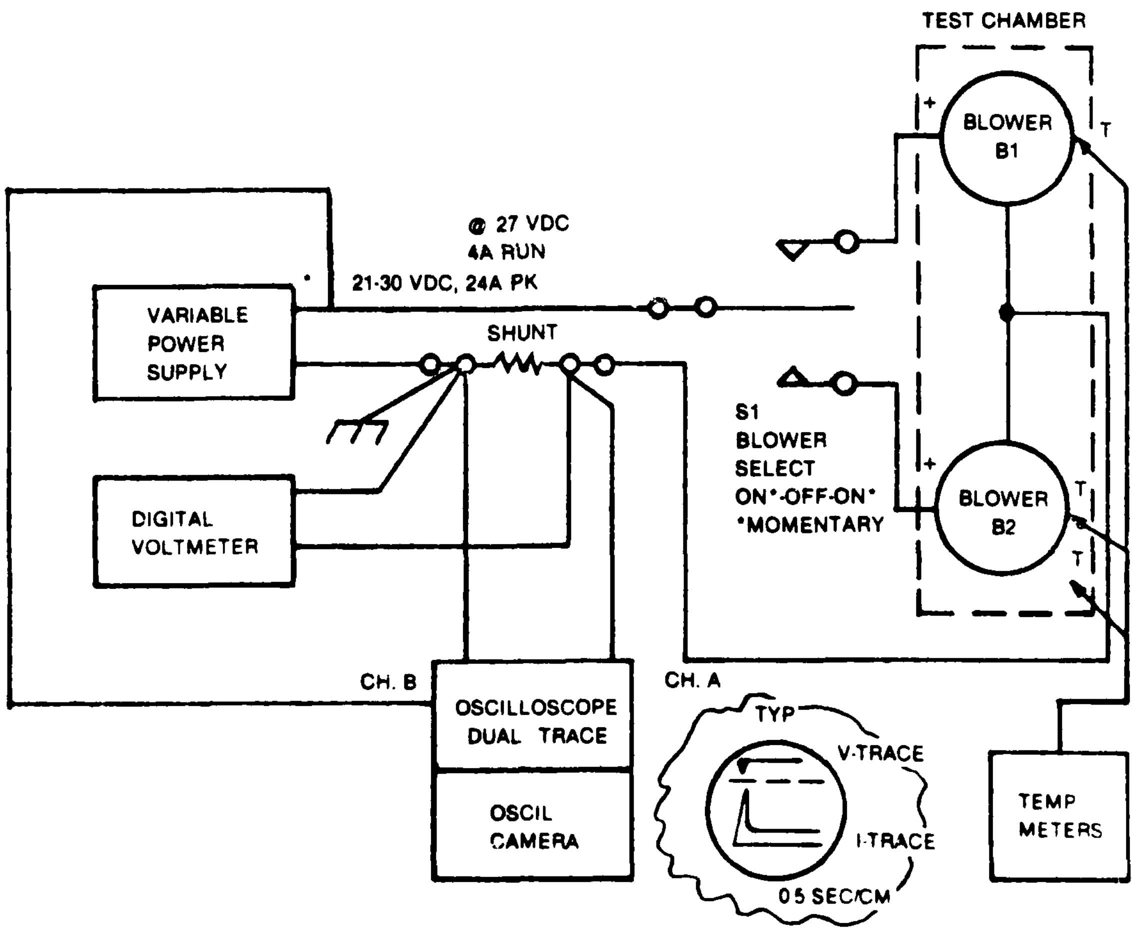
It is further recommended that an alternate adhesive system similar to the UR1087 or 0271 be developed as a backup. The problems associated with the support equipment necessary for the Hot Melt system; i.e., air compressor, air line, power cords, etc., should not be minimized. The compressed air hoses were like steel rods as were the electric power extension cords. The compressed air lines froze during the test thus incapacitating the gun applicator. These are very real problems that will occur sooner or later and point toward the desirability of developing a simpler system such as the one-part adhesive.

DC BLOWER TEST PLAN

PURPOSE: Measure starting surge at various temperatures and voltages at blockoff and free flow to establish required circuit protection. (See Figure 31.)

TEST EQUIP: Oscilloscope, dual trace
Camera, oscilloscope
Current shunt
Power supply, 50 A variable voltage 21-30 V
Mounting plate, blower
Blockoff plate
Temperature meter & probes
Multimeter, digital 3½ digit, peak and avg reading





*NOTE PS MAY LIMIT VALIDITY OF TEST

Figure 31 DC Blower Test Setup

UNIT UNDER
TEST: 2 ea. M4671J-1A Blowers

TESTS:

1. Room Temp, 24, 27 Vdc
   - 1.1 Free flow
   - 1.2 Blockoff
2. Cold 0° F ± 5° F; 27, 30 Vdc
   - 2.1 Free flow
   - 2.2 Blockoff
3. Colder -20° F ± 5° F; 27, 30 Vdc
   - 3.1 Free flow
4. Coldest -40° F ± 5° F; 27, 30 Vdc
   - 4.1 Free flow

DATA: Current/voltage pulse on start, photographs; Motor T (Monitor only to assure correct starting pt.); Chamber (AMB T).

AC BLOWER TEST PLAN

PURPOSE: Measure starting surge at various temperatures. (Test Setup shown in Figure 32.)

TEST EQUIP:
Oscilloscope
Camera, oscilloscope
Current shunt
Current transformer
Temperature meter and probe
Multimeter digital [illegible] digit peak and avg rms cal reading

UNIT UNDER
TEST: [illegible]

[illegible]

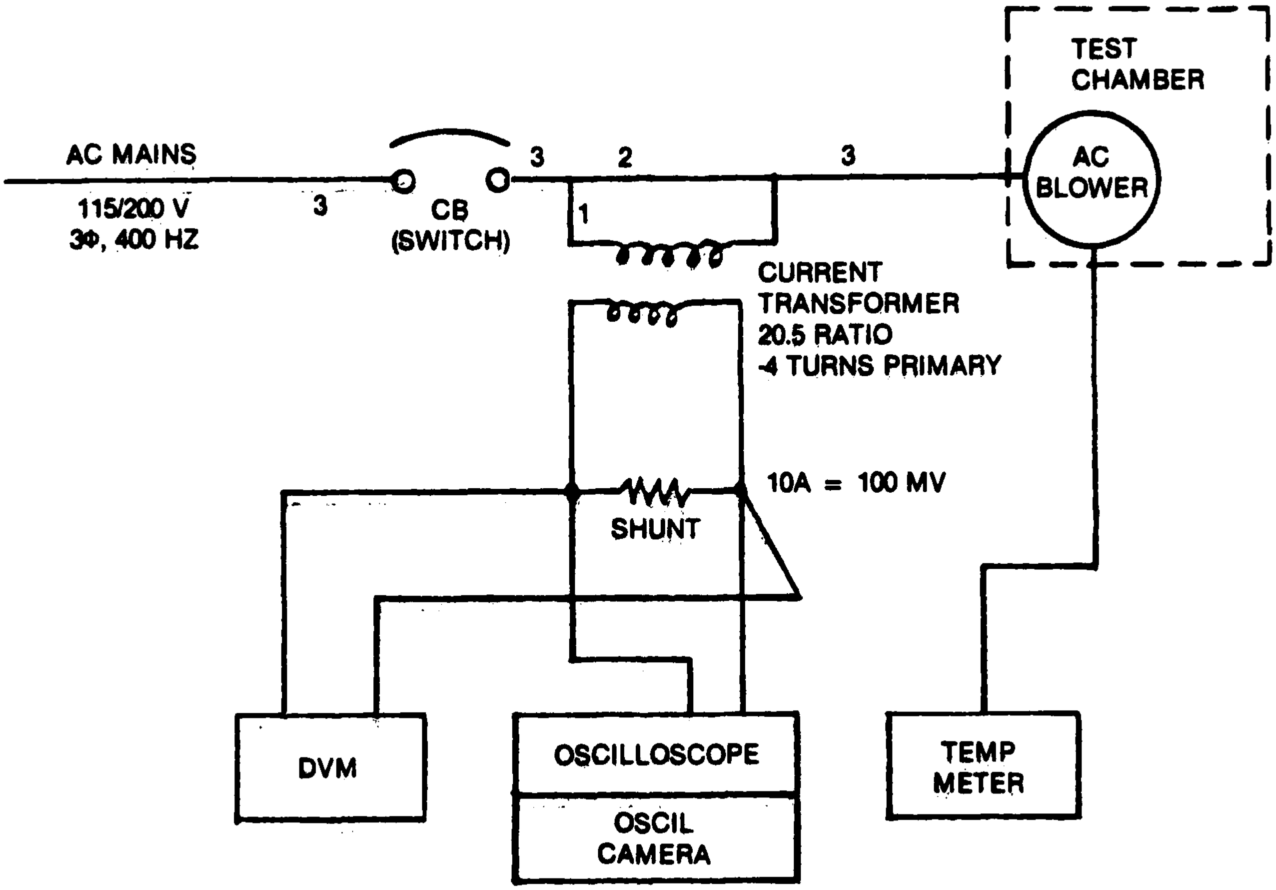


Figure 32. AC Blower Test Setup

AC/DC BLOWER TEST -

Abstract

The purpose of the blower tests was to determine the start surge along with run current for various temperatures down to -40° F to determine the required circuit protection and verify power source size.

DC blowers, M4641J-1A, were remarkably consistent. The start pulse was a step with exponential decay of a 0.1 second half width and a surge peak of up to 50 ± 7 A at -40° F and 39 ± 6 A at +85° F at 28 Vdc. Run current under nominal backpressure of 2.0 IWG may be expected to be 5.7 ± 0.9 A at -40° F and 4.5 ± 0.5 A at +85° F. Blocked flow slightly reduced the initial surge.

AC blower, M5171B-1B1, tests were run at unrestricted flow and showed a higher surge than factory data. The àc starting surge was a step function to a nearly level wine glass shape which finally decayed at about 0.9 second from a peak of 10.6 ± 1 A (RMS) at -40° F and in about 0.7 second with a peak of 9.8 ± 1A (RMS) at +85° F. Run current was 2.2 ± 0.2 A and 1.6 ± 0.14 A at -40° F and +85° F, respectively, under free flow conditions. Factory data showed a starting surge of 6.8 ± 0.6 A (rms).

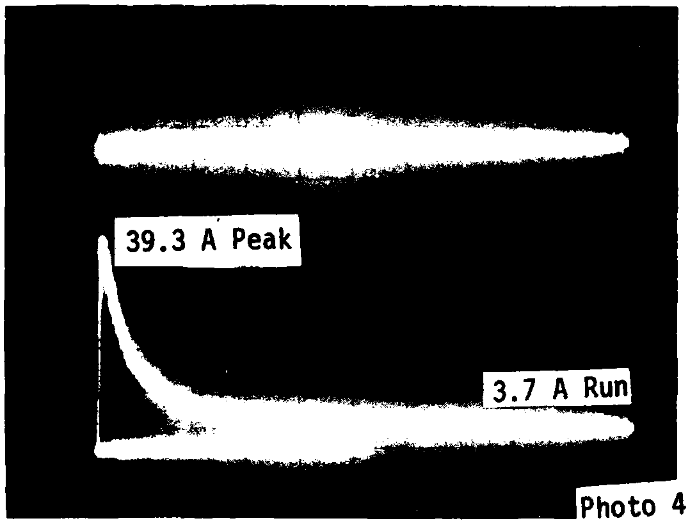
DC Blower Test Results — Open and Blocked Flow

Both dc blowers were tested at open (unrestricted) and blocked flow at room temperature and a nominal 0° F. An additional pair of runs was also made for reduced voltage starting (+24 Vdc). See Figures 33, 34, 35, 36 and 37 as well as Table 27.

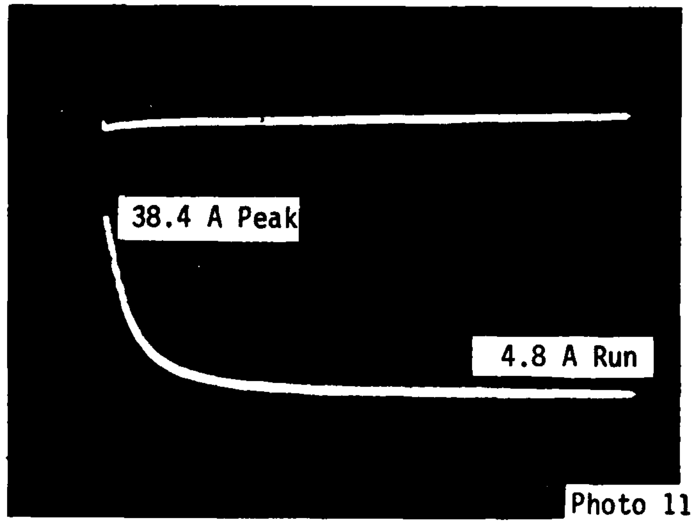
Peak currents were not significantly affected by blocked flow conditions although in several cases the measured peak actually decreased (photo 6 vs 9 and 16 vs 14).

Run currents under blocked flow were somewhat less than expected from the manufacturer,s data (see Figure 38) which, for 27 V, was at least 1 amp higher than measured in these tests. This could be caused by a combination of operating at a high temperature (small effect), leakage (unlikely) and sample variations. After completing these runs, it was concluded that the effect on starting surge was minimal and all further tests were run only on open flow. The two blowers were tested to observe sample variations. The test was run with 28-volt input and open air flow.

At -40° F nominal one blower (see Figure 35) had a surge of 3.3 amps peak higher than the other (49.4 vs 56.1 amps) which decreased at room temp, +85° F, to 2.2 amps difference (41.5 vs 39.3 amps) (see Figure 33 and Table 27 photos 4 and 5). Run current compares similarly; at -40° F nominal the difference was 0.6 amp (4.6 vs 4.0 amps) and at room temperature, 85° F nominal, the difference was 0.3 amp (4.0 vs 3.7 amps). Figures 36 and 37 show the open and blocked flow cases for the two dc blowers near 0° F.

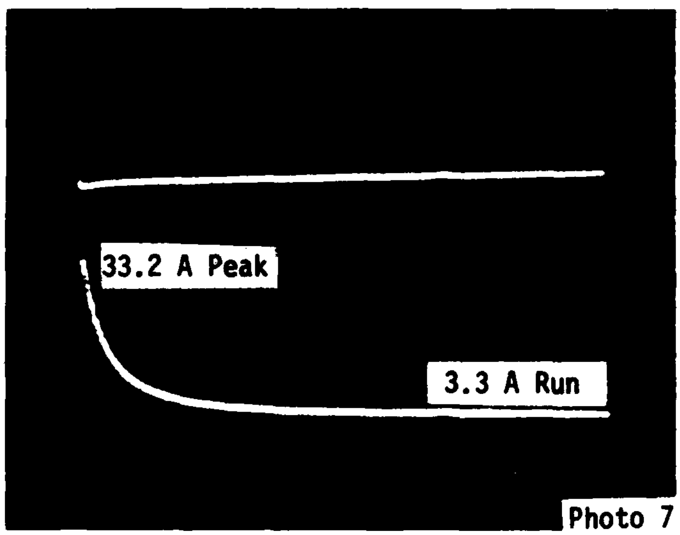


#1 DC Blower, 84^{0} F, 28 Vdc
Open Flow

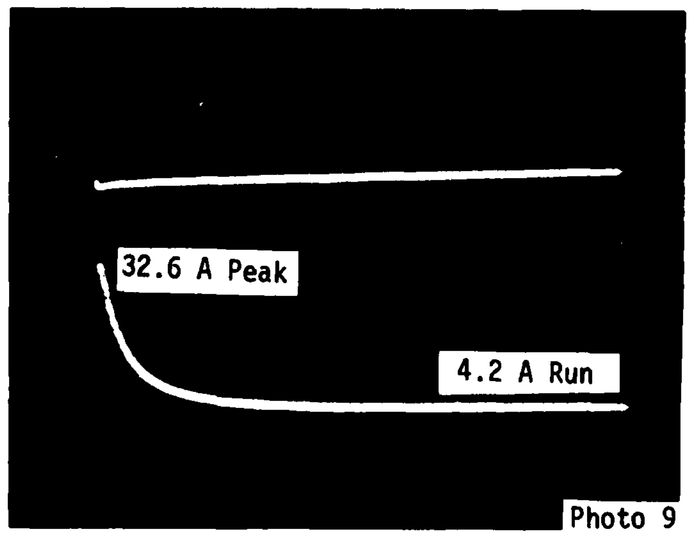


#1 DC Blower, 85.6^{0} F, 28 Vdc
Blocked Flow

Figure 33. DC Blower Start for Open and Blocked Flow, 85° F

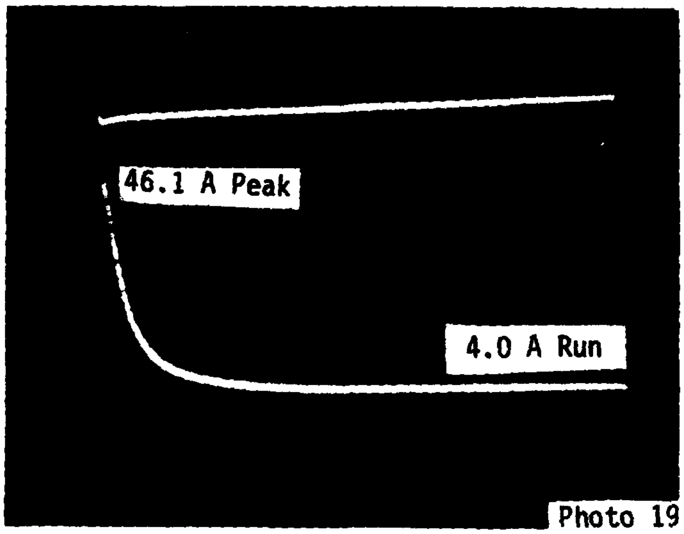


#1 DC Blower, 84^{0} F, 24 Vdc
Open Flow

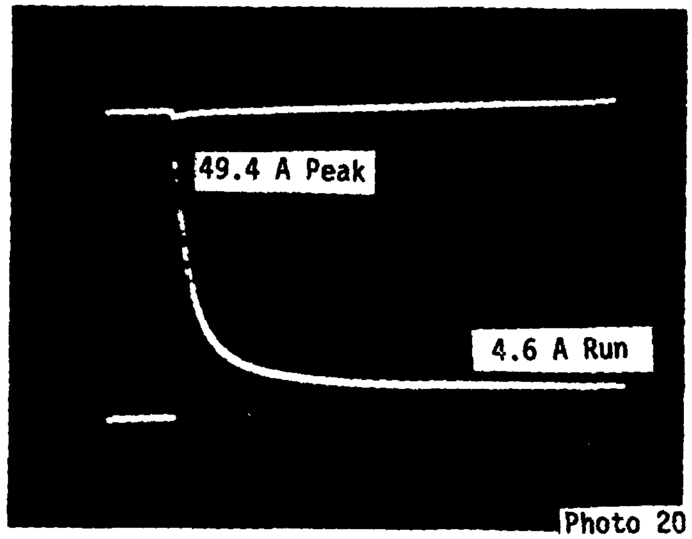


#1 DC Blower, 84^{0} F, 24 Vdc
Blocked Flow

Figure 34. Low Voltage DC Blower Start, Open and Blocked Flow

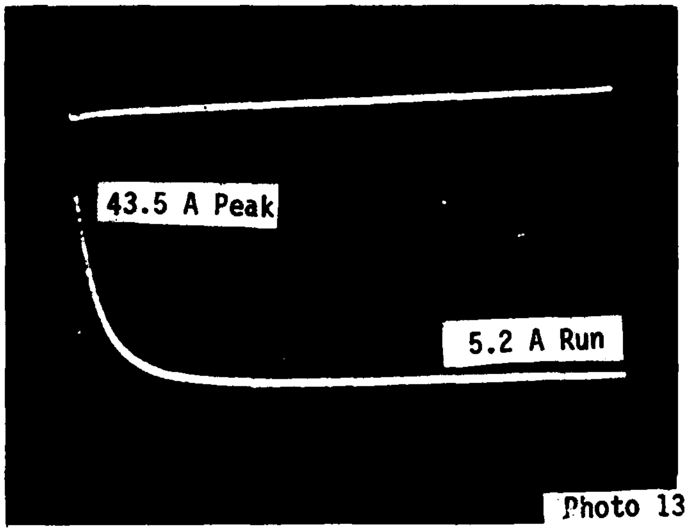


#1 DC Blower, -38.2^{0} F, 28 Vdc
Open Flow

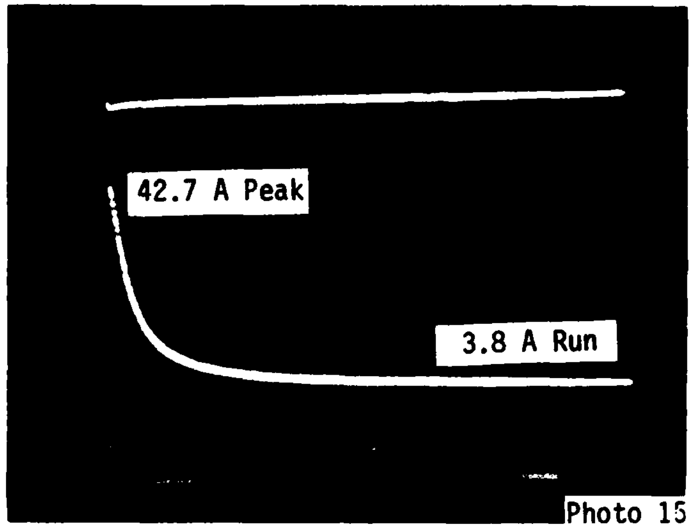


#2 DC Blower, 41.8^{0} F, 28 Vdc
Open Flow

Figure 35. DC Blower Start, Open Flow -40° F

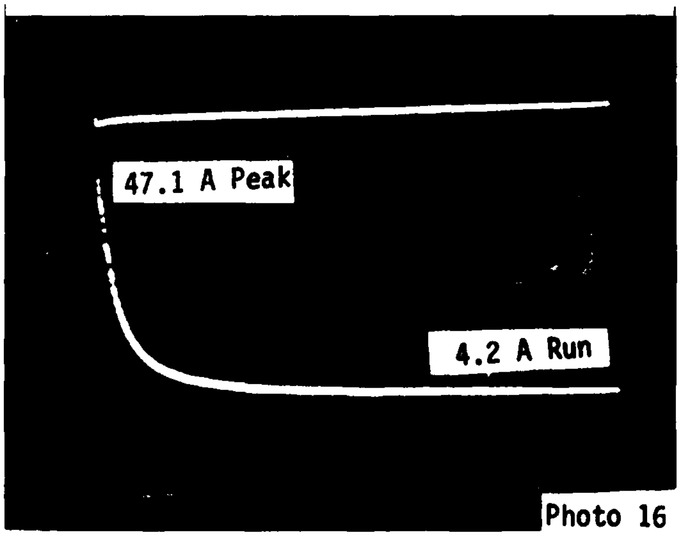


#1 DC Blower, -0.6^{0} F, 28 Vdc
Open Flow

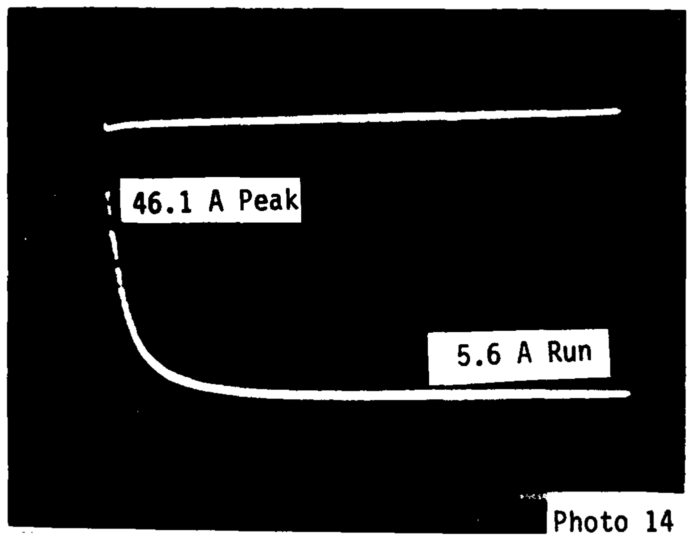


#1 DC Blower, 3.2^{0} F, 28 Vdc
Blocked Flow

Figure 36. DC Blower Start for Open and Blocked Flow, 0° F



#2 DC Blower, - 2.2^{0} F, 28 Vdc
Open Flow



#2 DC Blower, 0.8^{0} F, 28 Vdc
Blocked Flow

Figure 37. Alternate DC Blower, Open and Blocked Flow. 0° F

TABLE 27. BLOWER START/RUN TEST DATA

Photo No.	Blower	Open/ Blocked	Power In	Current (A) Peak	Run	Temp (Deg F)	Photo Quality
1	1-dc	Open	28 Vdc	39.7	3.8		Missed start
2	1-dc	Open	28 Vdc	38.1	3.7		Underexposed
3	1-dc	Open	28 Vdc	38.6	3.8		Power supply transient
4	1-dc	Open	28 Vdc	39.3	3.7	85	OK/over exposed
5	2-dc	Open	28 Vdc	41.5	4.0	82.6	OK
6	1-dc	Open	24 Vdc	33.3	3.3	84.4	Missed start
7	1-dc	Open	24 Vdc	33.2	3.3		OK
8	2-dc	Open	24 Vdc	34.8	3.5	83.2	OK
9	1-dc	Blocked	24 Vdc	32.6	4.2	84.5	OK
10	1-dc	Blocked	28 Vdc	39.6	4.9	85	Grid double exposed
11	1-dc	Blocked	28 Vdc	38.4	4.8	85.6	OK
12	1-dc	Blocked	28 Vdc	44.0	5.2	3.6	Just missed startup
13	1-dc	Blocked	28 Vdc	43.5	5.2	3.2	OK
14	2-dc	Blocked	28 Vdc	46.1	5.6	0.8	OK
15	1-dc	Open	28 Vdc	42.7	3.8	- 0.6	OK/corner smudged
16	2-dc	Open	28 Vdc	47.1	4.2	- 2.2	OK
17	1-dc	Open	28 Vdc	44.8	3.9	-19.3	OK
18	2-dc	Open	28 Vdc	47.8	4.4	-19.3	OK
19	1-dc	Open	28 Vdc	46.1	4.0	-38.2	OK
20	2-dc	Open	28 Vdc	49.4	4.6	-41.8	OK
21	ac	Open	115/200 V, 400 Hz	18.3 mv = 10.6 A	3.8 mv = 2.2 A	-41.6	Retraced
22	ac	Open		18.3 mv = 10.6 A	3.8 mv = 2.2 A	-42.2	Print chemical smeared
23	ac	Open		18.4 mv = 10.7 A	3.8 mv = 2.2 A	-43.2	OK
24	ac	Open		16.9 mv = 9.8 A	2.8 mv = 1.6	86	Missed start
25	ac	Open		19.6 mv = 11.3	2.8 mv = 1.6	85.4	Unusual transient
26	ac	Open		16.9 mv = 9.8	2.8 mv = 1.6		OK
—	ac	Open	115/200 V, 400 Hz	96.2 mv = 9.6 A	21 mv ≈ 2.1A	-26	No photo, meter only
—	ac	Open	115/200 V, 400 Hz	96.9 mv = 9.7 A	21.8 mv = 2.2 A	-42	No photo, meter only

These variations of the two samples are consistent with the vendor's quoted 12% tolerance on specified power consumption. The relative difference increased at lower temperatures.

A few runs were made at low voltage (photos 6 through 9, Figure 34). Start surge and run current decreased in rough proportion to the voltage. The voltage decreased by 4 volts (28 to 24 Vdc) while starting surge decreased by about 6A (39 to 33.3 A) for the first blower and 41.5 to 34.8 A for the second blower. A blocked off run with the first blower at reduced voltage also showed a slight decrease in starting surge to 32.6 A as compared to the open flow case.

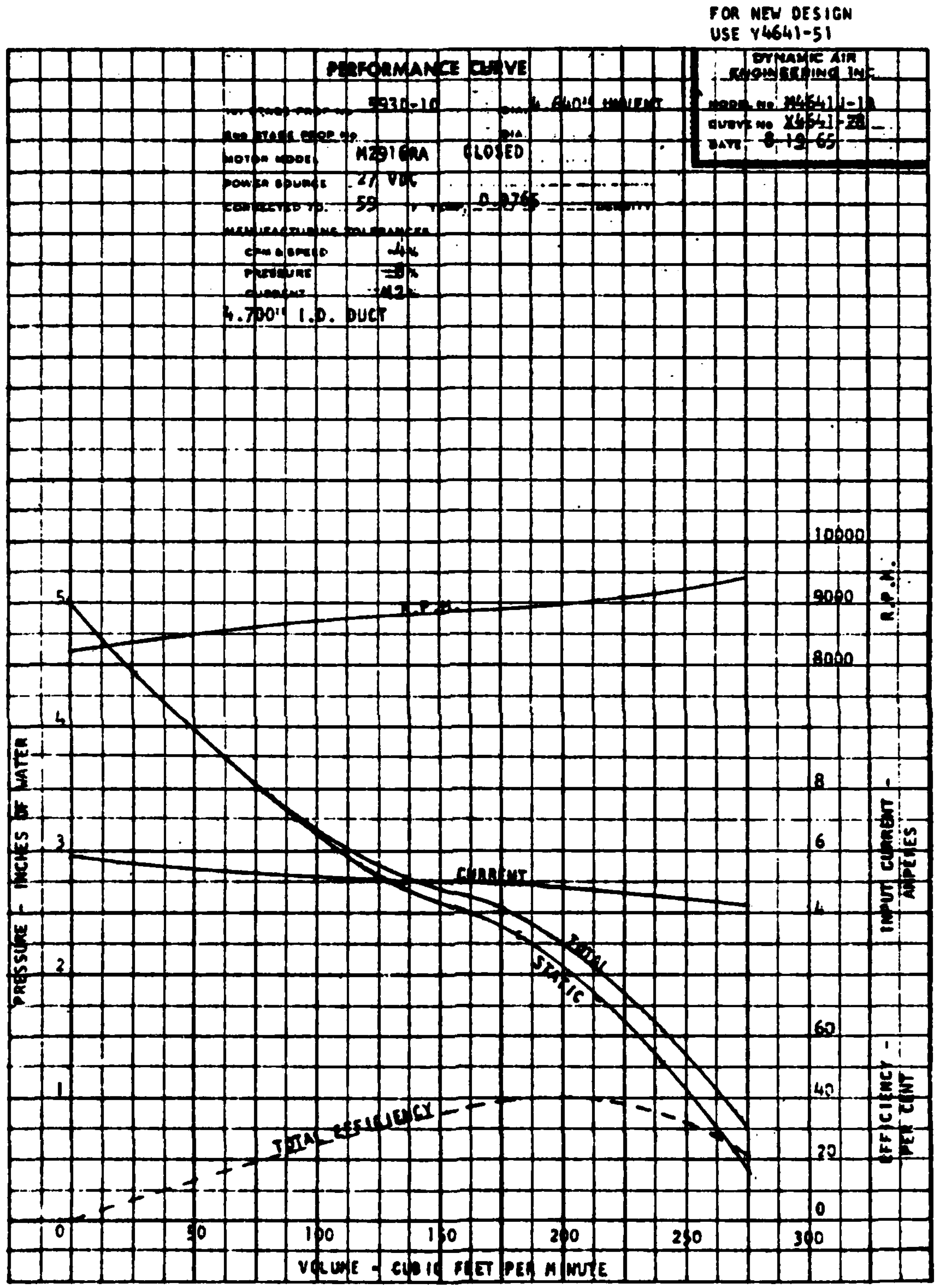


Figure 38. DC Blower Performance, M4641J-1A

The two dc blowers were tested at several temperatures from room temperature to a nominal -40° F at free flow conditions. Peak surge increased by about 15% between these extremes and run current increased a similar percentage. Air density variations between the temperature extremes could account for a 15% increase in run power while the starting surge increase would have to be accounted for by increased bearing friction.

Run current increased from 3.75 to 4.0 A from +85° to -42° F for the first blower and from 4.0 to 4.6 A for the second blower over the same temperature range.

The maximum observed starting surge of 49.4 A was with the second blower at -42° F and the minimum at room temperature, +85° F, with the first blower was 28.1 A, all run at 28 Vdc at the power supply.

AC Blower Tests

The ac blower test was restricted to start/run measurements at room temperature and -40° F. Photographs were made of the start current pulse (Figure 39).

Additional measurements using a precision shunt with the peak (rms) reading ammeter at -26° F and -42° F were made before the photographs. The results were virtually identical. Max surge and run current at the two temperatures were 9.6 A and 2.1 A at 26° F and 9.7 A and 2.2A at -42° F.

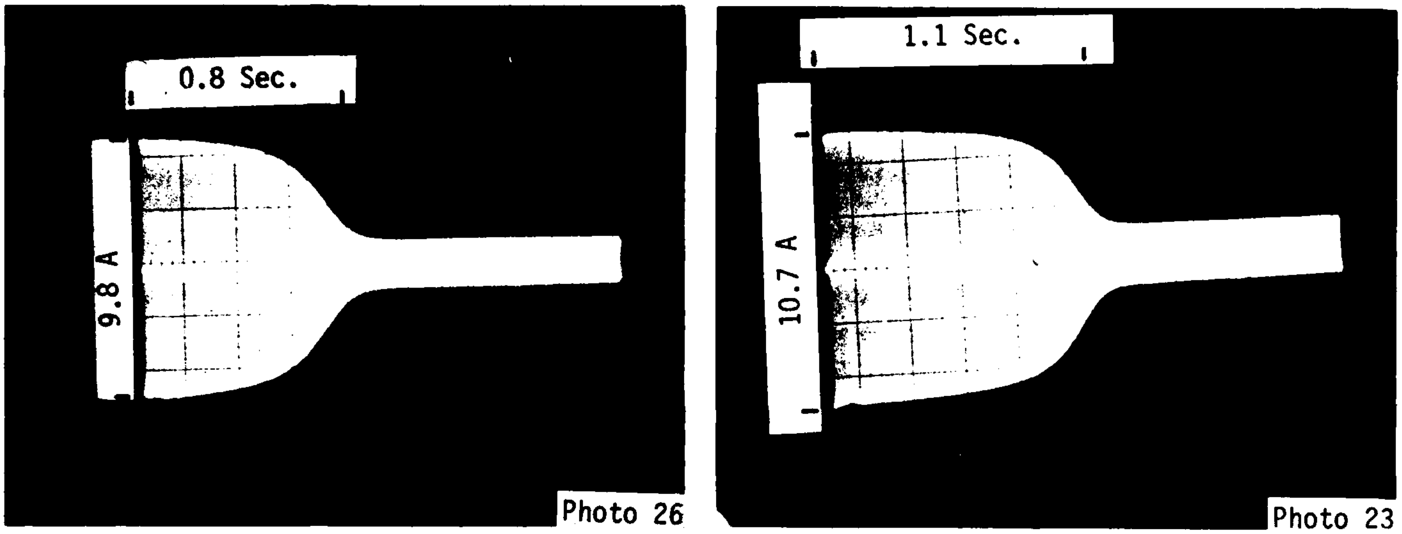
The results show a modest 8% increase in the maximum surge current with a 38% increase in run current as the temperature changed from +85° F to -40° F. The surge to run current ratio at room temperature was 6 to 1 and at -40° F it was 4.75 to 1. Factory supplied oscilloscope data (Figure 40) from several years ago indicates a 4.75 to 1 ratio with a somewhat lower 6.8 A surge, 1.48 A run. The total surge duration of the -40° F measurement and the factory photo show about 1.0 and 0.9 sec, respectively, while the new data shows a duration of under 0.8 sec at +85° F.

Conclusions

From the results of the tests it is concluded that:

1. The 10-amp slo-blow fuse (MDL-10) used to protect the battery is sufficient for dc blower protection. The fuse provides a nominal delay of about 1 second at 50 amps, more than enough to break the blower free if necessary and provide the 0.2-second start surge.

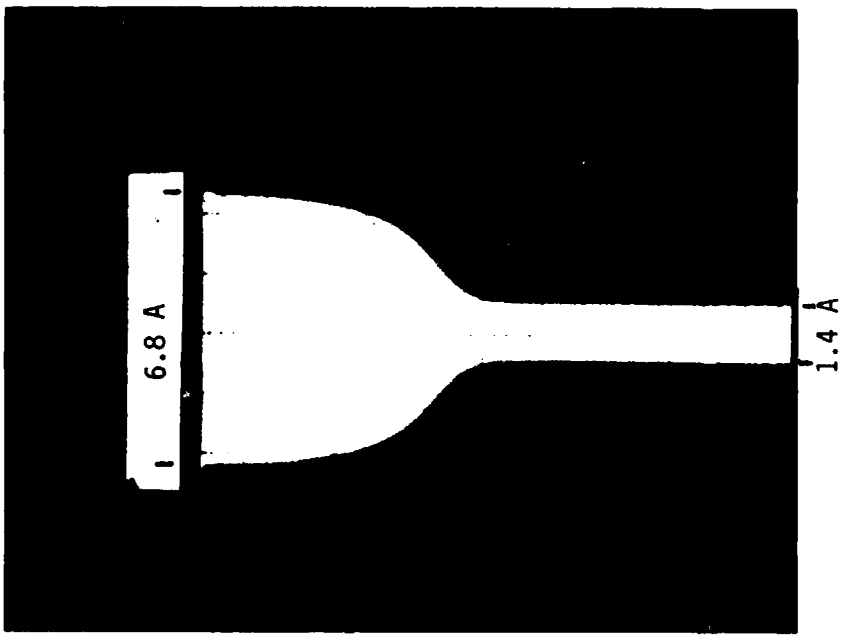
2. AC blower performance was unusual as compared with the factory data; however, even the somewhat greater start level and duration can be handled by circuit breakers of reasonable size. A 5-amp breaker may help avoid nuisance trips and should be considered for the arctic application since the specified minimum trip time at 200% load (10 A) is 0.9 second, which is the nominal duration of the start surge under extreme cold conditions.



85° F, 115/200 V, 400 Hz, Open Flow

-42° F, 115/200 V, 400 Hz, Open Flow

Figure 39. AC Blower Start



0.9 Sec.
(0.2 Sec./div.)

Figure 40. AC Blower Start Factory Test

3. If the larger unsealed APGN, delay 400, type breaker is used, a 5-amp rating could be used for system/wire protection which would trip within 10 to 70 seconds under locked rotor conditions.

4. There was no real question of blower operability under cold conditions since the blowers are routinely exposed to airborne environment under both private and commercial aviation conditions and are also used in military applications.

J. STRUCTURE — MOORING SYSTEM DESIGN LOADS

The basic design requirements and resulting mooring system loads of the critical operating modes are noted below.

1. Moored (see Figure 41) — withstand forces developed by the aerostat from a steady wind of 50 knots with gusts reaching 70 knots.
2. Flight (see Figure 42) — withstand forces developed by the aerostat and transmitted through the tether cable from a steady wind of 50 knots with gusts reaching 70 knots.
3. Launch and recovery (see Figure 43) — withstand forces developed by the aerostat from winds up to 40 knots.

Based on these requirements, the design of the boom, tower, and base is governed by the mooring mode loads. Maximum stress levels in these components are .208 σ_y*, .48 σ_y, and .43 σ_y,respectively. The outrigger design is governed by the launch and recovery mode loads and the maximum stress level is .40 σ_y. The relatively low stress levels in the boom and base are the result of the fact that the breaking strength of the tether cable was imposed on the original design as the governing structural load. Subsequent aerodynamic analyses have shown the maximum tether tension to be 3195 pounds at the flying sheave.

The STARS mooring system was evaluated previously in 1981 for Beaufort Sea operation in the September-October time frame. An extreme low temperature of -10° F was predicted with mean temperatures in the +5° F to +25° F range anticipated. Since these temperatures did not vary dramatically from those experienced during winter operations at the Elizabeth City, N.C., test site, and the structural materials used were commonly used in these temperatures, the STARS structure was judged to be an acceptable risk for the Penguin tests. Modifications made to the system were intended primarily to protect personnel from the elements, prevent icing of critical equipment, and protect the hydraulic system from damage due to subzero temperature effects.

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*σ_y = material yield stress

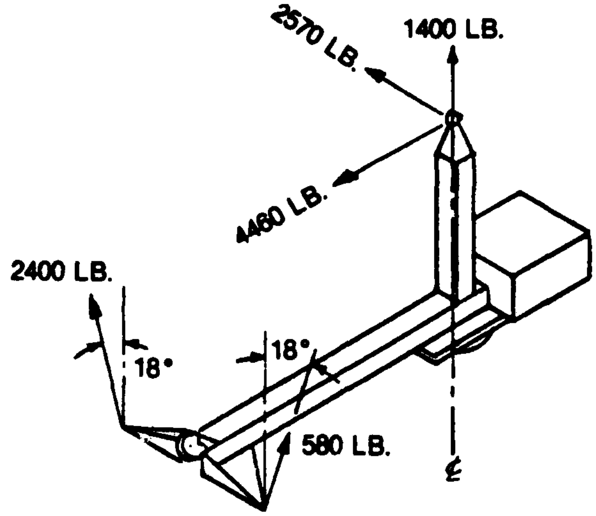

Figure 41. Mooring System Loads — Moored

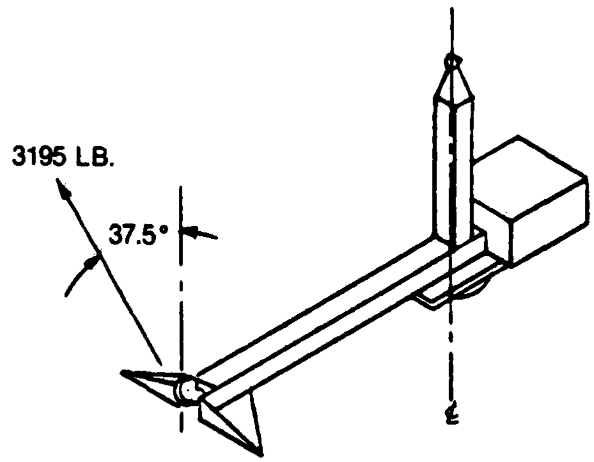

Figure 42. Mooring System Loads — Flight

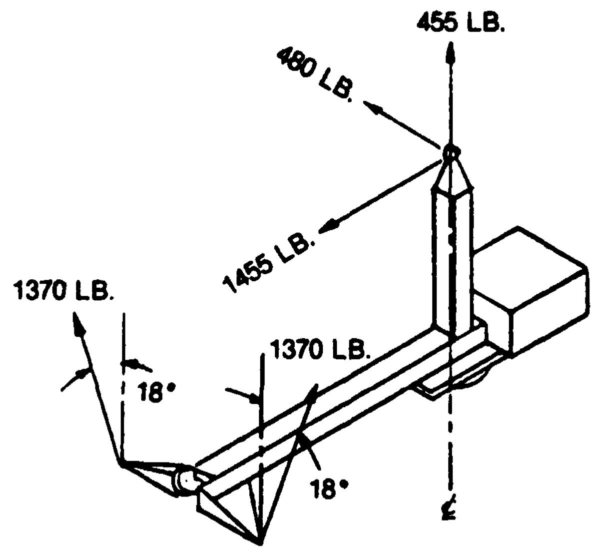

Figure 43. Mooring System Loads — Launch and Recovery

The Penguin mooring system performed satisfactorily during the Beaufort Sea tests. However, since the lowest temperature experienced during operation was +20° F, it was not possible to confirm the adequacy of the structure for very cold temperature use.

Temperature data available from the Burlington, Vermont, area indicates a maximum low of -30° F and a mean minimum of 10° F. The maximum low at the Dew Line is -70° F. The ensuing analysis will address these conditions.

All of the primary structural elements in the mooring system are fabricated from medium-carbon steel (0.3%-0.5% C). This type of steel experiences a transition in properties from being a ductile material at room temperature to being a brittle material at somewhat lower temperatures. As the temperature is reduced, the strength of the steel actually increases. However, its loss of ductility makes a crack propagation likely at relatively low stress levels, especially under impact loading. If a crack continues to propagate, a catastrophic failure will eventually occur. Flaws, which can precipitate cracks, exist in all materials as a result of the fabrication process. This is particularly true if there has been no heat treatment to relieve residual stresses after fabrication. Therefore, the mechanism for brittle or catastrophic failure is always present. Whether this mechanism is triggered or not depends on the size and shape of the flaw, the temperature and the loading that the material experienced.

To help designers evaluate these various parameters, NRL has developed a fracture analysis diagram (see Figure 44). Although this diagram was developed for pressure vessels, it is useful in visualizing the interaction of the various parameters. Use of it requires a knowledge of the Nil Ductility Temperature (NDT) of the material in question. This is the temperature at which the transition from ductile to brittle material properties is complete. Typical NDT values for medium-carbon steels are in the 0° F to 40° F temperature range. Thus the mean low temperatures in Burlington will be at the NDT for most of the materials. Temperatures at the Dew Line will be well below the NDT and the structural materials will have brittle material characteristics.

The Crack Arrest Temperature (CAT) curve on the fracture analysis diagram defines the boundary below and/or to the right of which fractures will not propagate. This zone is therefore "safe" for any application. Since the low Dew Line temperatures are well below the NDT of the main mooring system materials, the stresses would have to be kept below the 5 to 8 ksi range (.138σ_y to .222σ_y) to be in the "safe zone." If the stresses above the CAT curve are expected, the allowable flaw size must be considered.

The critical flaw depth for brittle fracture can be estimated from the equation:

$$a_{cr} = \frac{K_{IC}^2 \, Q}{1.21 \pi \sigma^2} \tag{20}$$

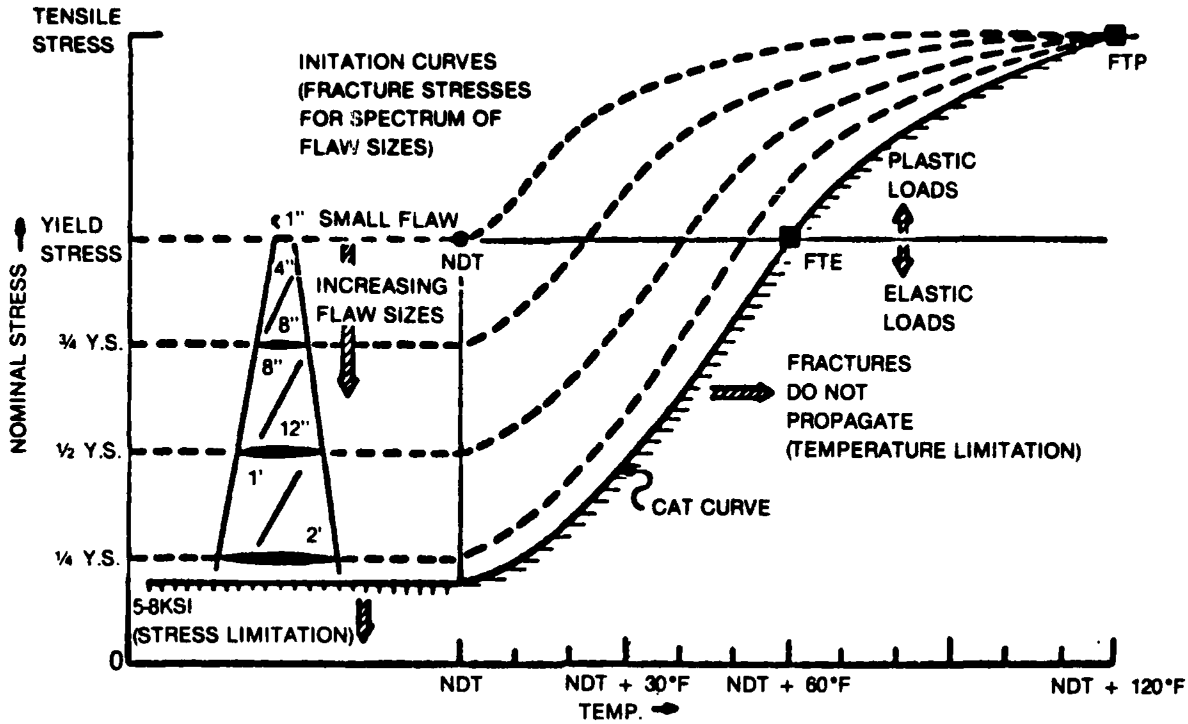

Figure 44. Fracture Analysis Diagram

where: K_{IC} = critical stress intensity factor
Q = flaw shape factor
σ = applied stress

For medium carbon steels, the stress intensity factory (K_{IC}) is relatively insensitive to temperatures below the NDT and in the extreme low temperature case for a value of 30 ksi$\sqrt{in}$.

From previous discussions, it was noted that the maximum stresses occurred in the base of the mooring tower where maximum stress levels are about 17,000 psi. Assuming a flaw shape factor (Q) of .9, the critical flaw depth is .71 inch, which is deeper than the thickness of any of the structural members. Therefore, a case can be made for concluding that brittle fracture is not a concern. However, there is one unknown that cannot be evaluated — the magnitude of the residual stresses induced during the fabrication process. If there are tensile residual stresses that are additive to the maximum applied stress, the critical flaw size could be reduced considerably to where it could be a significant concern. In general, though, it is probably safe to conclude that the present Penguin mooring system would survive the expected mean low temperatures in Burlington. However, it would probably be wise to assume a brittle fracture condition would exist at the Dew Line.

To insure against a brittle fracture failure, either the material would have to be changed to one with a higher NDT or the structure heated to above the NDT of the present material. It is estimated it would take a 12-kW heater to heat the critical areas of the structure. An inspection of the welds in the most highly stressed ends of the tower, boom, and outriggers should also be made to provide an extra measure of assurance against structural failure.

Machinery System

A tacit assumption made in the course of this analysis was that the basic machinery must be capable of withstanding the operational loads imposed at the lowest ambient temperature without any benefits which might be derived from heating other than the heat generated by the machinery itself during operation. Heat is supplied to machinery and hydraulic components used in the flight and launch and recovery modes of operation. However, in the event of failure of the heating system during either of these modes, the aerostat could be returned to the moored mode in a short period of time before temperature-related damage could occur. The moored mode then is of some concern relative to the adequacy of the machinery items which must not fail in the event of heating system failure.

During passive weathervaning of the mooring system, the turntable gear back drives the hydraulic motor, causing it to act as a pump. A relief valve is provided to permit local circulation of fluid. In essence, this provides a damping action on oscillations of the mooring system. During unheated, low temperature operations, the fluid viscosity could become high enough to generate high loads in the motor and/or gear teeth. To minimize this effect, a bypass circuit for the relief valve will be provided which may be activated by opening a hand valve.

The pinion gear is fabricated from A1S1 4140 steel. As seen from Figure 45, this material has excellent low temperature characteristics if heat treated to produce a quenched structure containing 90% or more martensite at the center. It is not clear that the heat treatment presently specified for this gear meets this criterion. An evaluation to determine the proper heat treatment is required for this item.

The turntable bearing races are fabricated from medium carbon steel (A1S1 1050) and are susceptible to the same problem of ductile to brittle transition noted for the mooring system structure. However, the bearing is being loaded to only about 0.21 x rated capacity, and therefore should be well below the acceptable stress level noted previously. In addition, the races are normalized at about 900° C. This process lowers the NDT as much as 30° F (see Figure 46). The balls in the bearing are fabricated from a chrome alloy steel (52100). This material should exhibit good properties at low temperatures (similar to the pinion gear described above). Consultation with the Rotek design engineerng department confirmed the conclusion that, because of the light loading on the turntable bearing, it should be adequate for the low temperature environments proposed.

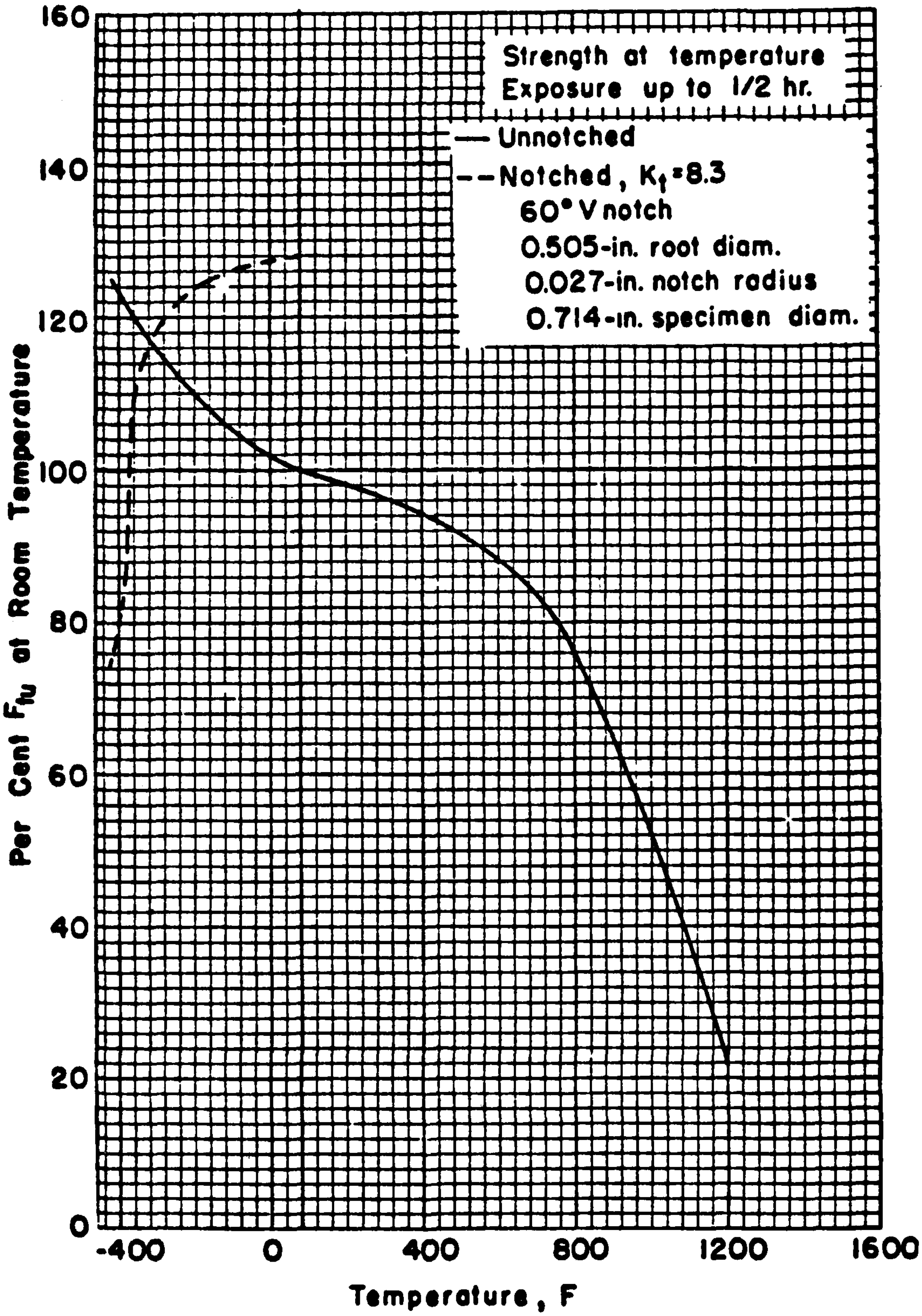

Figure 45. Effect of Temperature on the Ultimate Tensile Strength (F_{tu}) of AISI Alloy Steels

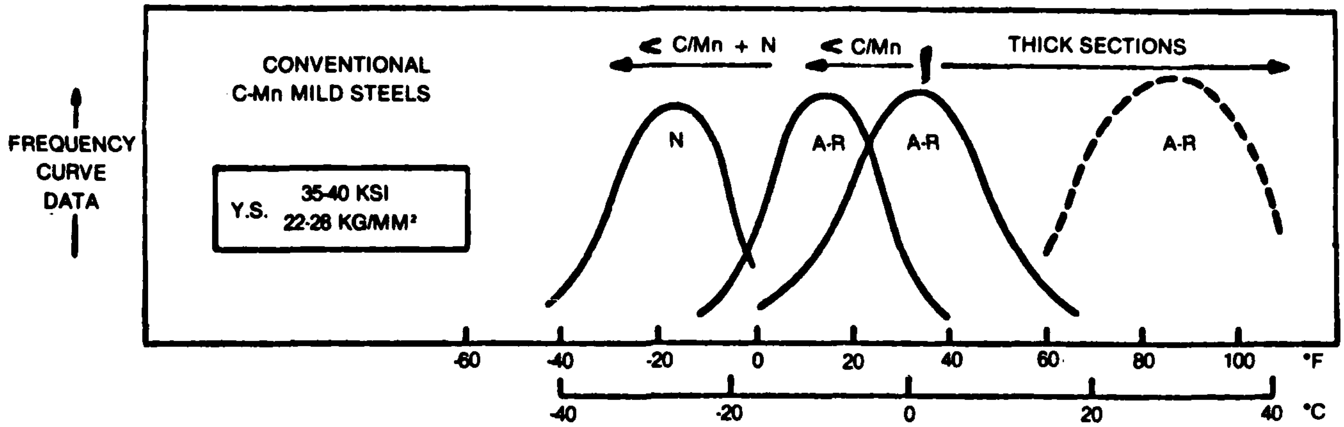

Figure 46. NDT Range

Concerns also exist in machinery areas where materials with large differences in their coefficients of thermal expansion are assembled in such a fashion as to induce stresses as a result of temperature change. This is the case in two areas, the nose latch and the flying sheave assemblies.

The nose latch mechanism is mounted to the top of the tower via an aluminum pillow block containing a steel, spherical, self-aligning bearing. The bearing is initially pressed into the pillow block with a maximum interference fit of .0056 inch on a 7.75-inch diameter. The differential contraction due to a temperature drop from + 70° F to -70° F leads to an additional interference of .0084 inch or a total of .014 inch. This interference will result in a hoop stress in the pillow block far in excess of the ultimate strength of the material. A failure of this part could possibly result in loss of the nose mooring of the aerostat and therefore must be prevented by a redesign of the part. One solution would be to change the bearing fit to provide an initial clearance of .005 inch minimum on the diameter. If this is not an acceptable approach, a heavier wall could be used on the pillow block to reduce the stress level. Another possibility would be to change the material to steel and avoid the problem altogether.

The flying sheave housing and sheave fairleads are fabricated from aluminum. All other components are steel. Interference fits between the aluminum fairlead and steel sheave and between the aluminum housing and steel sheave shaft will occur at low temperatures. Stress levels in the housing appear to be acceptable. The fairlead stresses could exceed the yield strength of the material. An increase in diametrical clearance of .010 inch between the fairleads and sheave should eliminate any problem in this area.

Heating System

Enclosures and a heating system were added to the Penguin mooring system for the comfort of the winch operator and to ensure the proper operation of the machinery. This equipment worked very well in the Beaufort Sea and should be adequate for use in Burlington, Vermont. Also, with the addition of some insulation or packing material to fill in the voids around hydraulic plumbing, the heating system for the operator's cab and winch enclosure should also be sufficient for the Dew Line operation.

The heating system for the flying sheave, turntable drive, slipring, closehaul winches and nose latch also worked well in the Beaufort Sea. However, the adequacy of the system was not really tested because the temperature was never extremely low during operation. However, the system should be adequate for the Burlington, Vermont, cperation. While it is felt that additional heating capacity for this system will almost surely be required for the Dew Line operation, a further evaluation should be postponed until after it has been obseved in Burlington, Vermont.

Operation and Servicing

While the critical factor affecting the structure and machinery elements is the low temperature at the designated sites, other factors impact the operation and servicing of the mooring system (i.e., freezing rain, snow, wind, operator exposure).

Freezing rain does not have an impact on the major machinery elements since they are housed and heated. However, the tether cable is exposed and susceptible to icing and consequent disruption of the winching function. Fortunately, freezing rain only occurs at relatively moderate temperatures when it is practical for the operators to manually remove the ice as the tether is inhauled. Ice accummulation on the structure can be kept within reasonable limits by similar treatment.

Snow presents a problem in that it must not be allowed to accummulate or drift to depths above 2 ft or it inhibits weathervaning of the moored aerostat. An 85-ft-radius circle must be kept clear at all times. This might present a problem in a Dew Line installation. Assuming that snow removal machinery could not be used in close proximity to the aerostat for fear of damaging it, some hand shoveling might be required. The exertion required in low temperature conditions would probably be beyond an acceptable level. One solution might be to discard the trailer as a mounting platform and place the mooring system on a pedestal which was high enough to permit normal snow accumulation without interfering with weathervaning of the aerostat.

Wind and low temperature combined result in the most severe operator exposure situation. Even without significant wind velocity, personnel cannot work for extended periods at very low temperatures. During the flight mode, the operator is protected by a heated enclosure. During launch and retrieval of the aerostat the assistance of three people to tend mooring lines is required. While these assistants are exposed to the elements to perform their functions, the time involved is short (10 to 15 minutes), and appears to be acceptable for most normal operating conditions. However, as the wind chill chart in Figure 47 shows, there is increasing danger of frostbite as the wind increases. Extreme cold such as -40° C and a calm wind is dangerous for even a properly clothed person to be outside. If the wind velocity increases to about 13 knots, the equivalent

Wind Chill Chart

Estimated Wind Speed km/h	Actual Thermometer Reading °C											
	10	4.5	−1	−6.6	−12	−17.7	−23	−28	−34	−40	−45	−51
	Equivalent Temperature °C											
Calm	10	4.5	−1.	−6.6	−12	−17.7	−23.	−28.	−34.	−40.	−45.	−51.
4.3	8.8	2.7	−2.7	−8.8	−14.4	−20.5	−26.	−32.2	−37.7	−43.8	−43.4	−56.5
8.6	4.4	−2.2	−8.8	−15.5	−22.7	−29.4	−36.	−43.3	−50.	−55.6	−63.8	−70.5
12.9	2.2	−5.5	−12.7	−20.5	−27.7	−37.7	−42.7	−50.	−57.7	−65.	−72.7	−60.
17.3	0	−7.7	−15.5	−23.3	−31.6	−39.4	−47.2	−55.	−63.3	−71.1	−78.8	−86.6
21.5	−1.1	−8.8	−17.7	−26.1	−33.8	−42.2	−50.5	−58.8	−66.6	−75.5	−83.3	−91.6
25.9	−2.2	−10.5	−18.8	−27.7	−36.1	−44.4	−52.7	−61.6	−70	−78.3	−87.2	−95.5
30.2	−2.7	−11.6	−20.	−28.8	−37.2	−45.	−55.	−63.3	−72.2	−80.5	−89.4	−98.3
34.5	−3.3	−12.2	−21.1	−29.4	−38.3	−47.2	−56.1	−65.	−73.3	−82.2	−91.1	−100.
Wind speeds greater than 64 km/h have little additional effect.	Little danger for properly clothed person				Increasing danger			Great danger				
								Danger from freezing of exposed flesh.				

Figure 47. Wind Chill Chart

temperature is about -65° C due to the wind chill. For this reason not much outside work is done. Servicing of the aerostat equipment is a potentially time-consuming operation and is the area of most concern relative to exposure of personnel. Fortunately, the areas where equipment exists which needs servicing are in close proximity; in the windscreen and just forward of it. It appears that a tent-like enclosure could be provided that would provide an enclosed working area for equipment servicing (see Figure 48). Bellows sections, extended from the tent and zipper connected to the aerostat, would provide a flexible coupling and permit limited relative motion of the aerostat. Heat would be provided via the duct that carries heated air to the flying sheave. Such an enclosure might not be needed for the Burlington, Vermont, test site since average minimum temperatures only reach +10° F but would be mandatory for the Dew Line location where mean minimum temperatures reach -70° F.

The enclosure would have to be collapsed and stowed prior to flight of the aerostat. A folding skeletal frame concept is shown in Figure 49.

K. STARS/PENGUIN CABLES

The STARS aerostat cabling is basically a point-to-point wiring system. The cables are run from one unit to another with very few branches to third units.

The cables are made using the following types of components:

- Connectors

  1. PT06CE — Bendix proprietary version of MIL-C-26482 (-65° C to +150° C)
  2. PT06SE/MS3126F — MIL-C-26482 style connectors
  3. MS3106F — MIL-C-5015, environmental, used mainly for power circuits (-55° C to +127° C)

- Wire

  1. MIL-W-16878/4 Type E — (-65° C to 500° C)
  2. RG-581A — Coax, polyethylene jacket (-55° C to +71° C)
  3. Braid — Tinned copper

- Jacket Material — RT-102 (Polyolefin) Raychem (-75° C to +135° C)

All of these components were used in Penguin system with no failures. The only problem was that the strobe light connectors were found to be too brittle, too small and too hard to disconnect. These connectors were simple molded rubber connectors and will be replaced by MIL-type twist lock connectors such as PT015E8-4P.

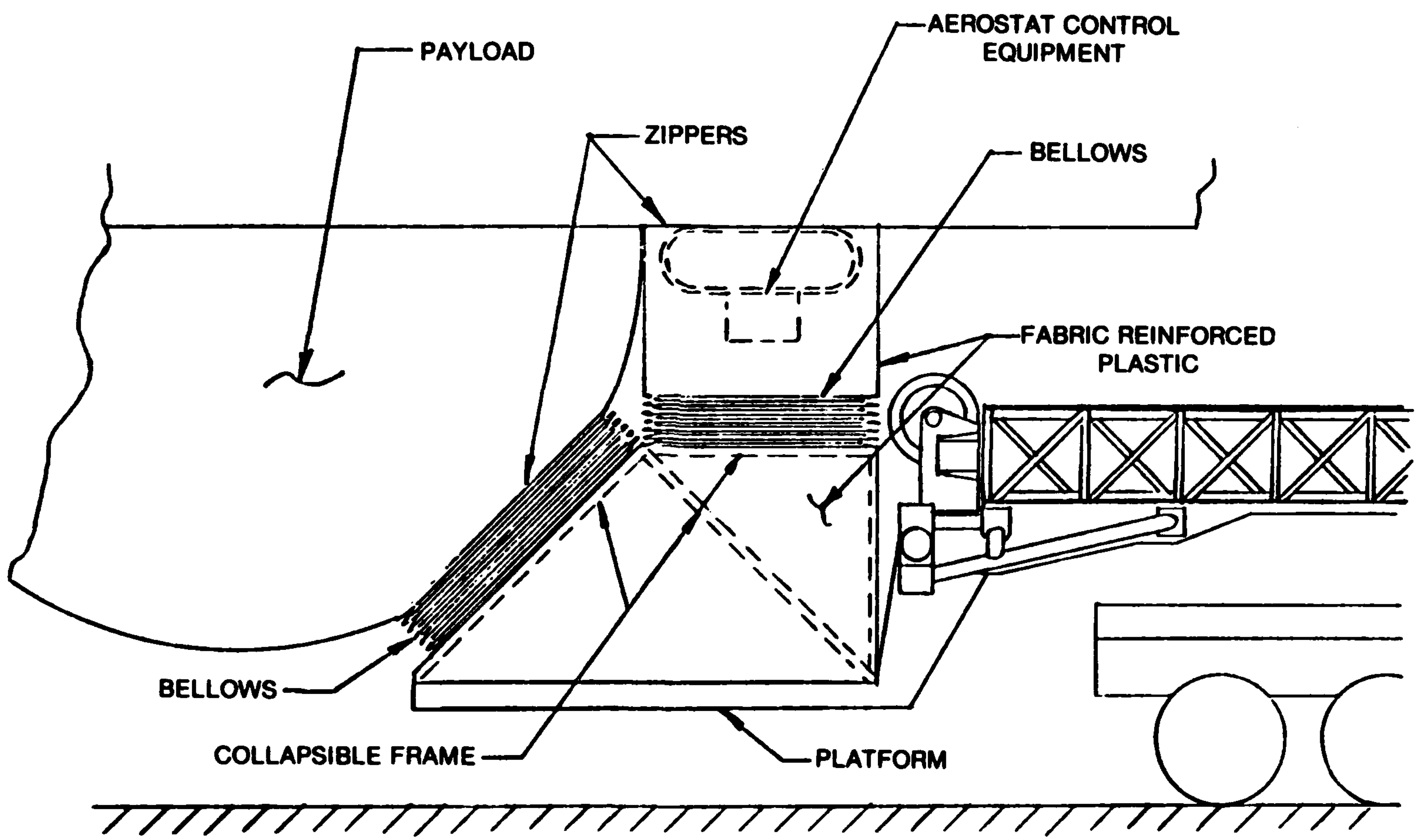

Figure 48. Aerostat Servicing Enclosure

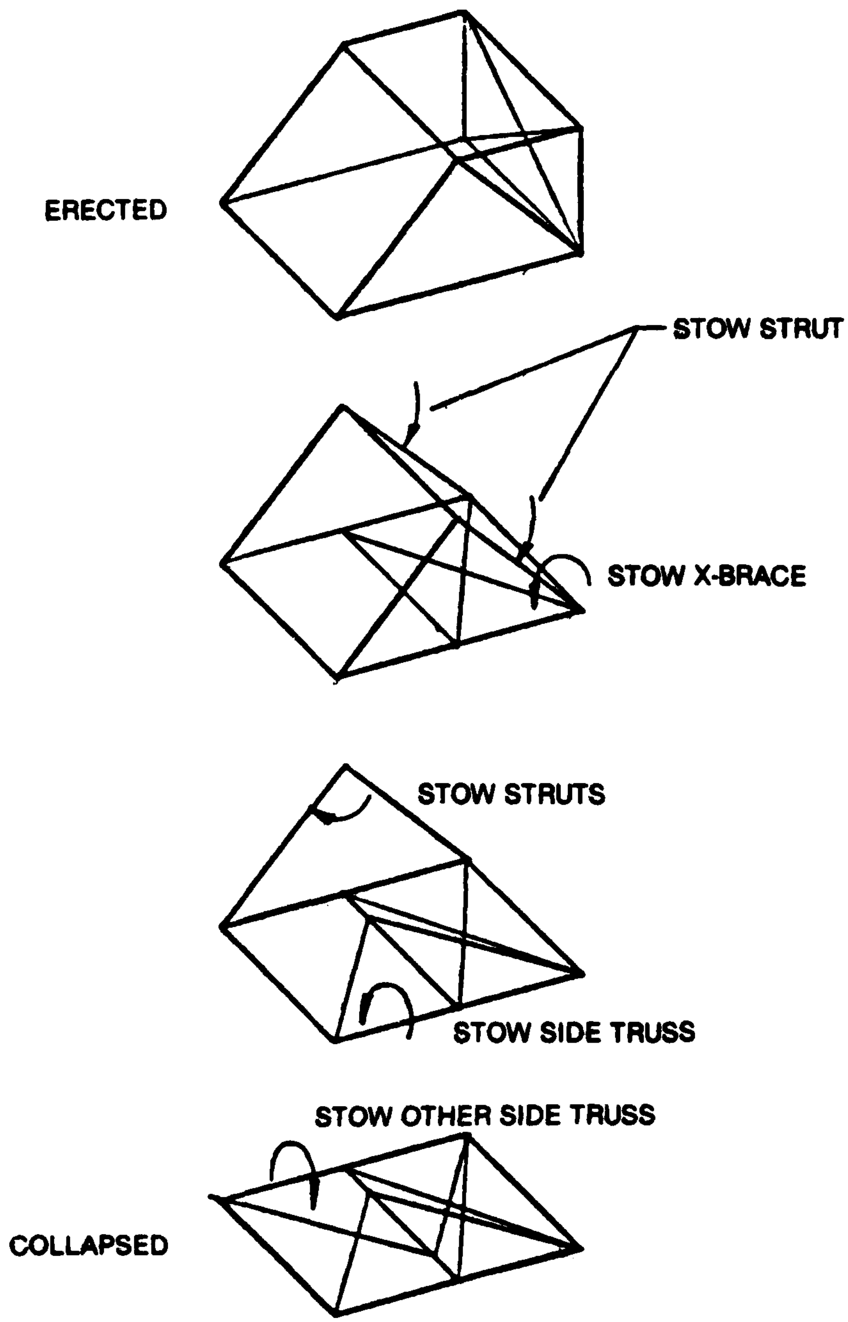

Figure 49. Collapsible Frame for Servicing Enclosure

During the Penguin system operation, no cabling problems were experienced in removal of equipment from the aerostat. However, it would be advisable to provide a hot air gun to melt any ice which might cover and lock connectors in place. The gun would also be used to dry the connectors before remating to prevent moisture-induced shorts.

Another tool which would be useful in cold weather would be a connector strap wrench. This would allow the uncoupling of connectors without the technician removing his gloves.

L. DIESELS

Power to the TCOM system is provided by a Detroit Diesel 4-53 electric set. Cold weather operation of diesel engines at temperatures below −40° F requires modification of certain equipment and the application of aids to assist engine starting.

This discussion will address the following three areas:

Preparation

- Lubricating Oil — Detroit Diesel recommends the use of MIL-L-2104B, SAE 30 lube oil. Since oil viscosity increases with decreasing temperatures, a lube oil heater is provided. This heater is discussed below.

- Fuel Oil — TCOM presumes that kerosene type distillates of 55° F to 600° F distillation end point temperature is available on site. The fuel must be low in sulphur content to minimize fire ring face wear, and have a cetane number of 45, or better. A 140-gallon fuel tank is provided within the enclosure, and while this should offer suitable protection for Vermont-type conditions, Dew Line conditions may require a fuel tank heater to maintain the fuel at a temperature above the fuel's cloud point.

- Coolant — The antifreeze solution used to protect the engine is composed of 63 percent ethylene glycol, and the balance is water. This will protect the engine to temperatures as low as -75° F. This should be adequate for both Vermont and Dew Line applications.

- Battery — A 150-amp hour battery is provided to run the cranking motor. Optimum operating temperature for a lead acid battery is 80° F, therefore a battery heater is employed to obtain maximum power from the battery.

- Cranking Motor — A 12-VDC electric starting motor is provided, and as the battery lube oil and coolant is heated, is expected to be adequate for Vermont use. Dew Line applications may require the installation of an additional battery and changing the starter motor to 24 VDC.

Starting

- Engine Cylinder Temperature — To start a diesel engine, engine combustion air temperature at full compression must be higher than the auto ignition temperature of the fuel.

  Factors which affect cylinder temperature are:

  1. Cylinder wall temperatures due to low coolant or block temperatures.
  2. Ambient air temperature entering cylinder.
  3. Lower cranking speeds at low temperatures due to greater lube oil viscosity and decreased battery efficiency.
  4. Fuel temperature, as reduced by low ambient temperature will decrease the temperature.

These factors are addressed in the following paragraphs.

- Coolant Heaters — TCOM uses a thermostatically controlled tank-type electrical resistance heater to preheat the coolant in the engine block. Coolant enters at one point of the tank, is heated, and at another point. Heated coolant then circulates through the engine by convection.

  The 1500-watt heater employed on the diesel engine will raise the coolant temperature of a cold soaked 4-53 engine 85° F in one hour and 100° F in two hours. This heater is adequate to maintain coolant temperatures in the +70° F to +80° F temperature range in Vermont, assuming a -30° F cold soak. Dew Line conditions would require a 2.2-kW heater to be used with this engine to provide a 150° F temperature rise in three hours from a cold soaked (-70° F) condition to reach a coolant temperature of +80° F. The thermostat trip level is set for 100° F.

- Lube Oil Heaters — TCOM uses a thermostatically controlled electrical resistance immersion type lube oil heater. The heater consumes 250 watts of power and will produce a temperature rise of 90° F in 10 hours in the oil sump. Two of these heaters would be required for Dew Line operation.

  An aluminum sheath on the heater prevents coking, and provides for better heat transfer.

  The thermostat turns the heater off when a lube oil temperature of 80° F is reached.

- Battery Heaters — Batteries which produce 100% of battery cranking power at 80° F will provide only 40% of max power at 9° F. TCOM uses a thermostatically controlled electric heater to warm the battery and is designed to cut off at +80° F. Dew Line operation would require that the battery box be redesigned to allow warm coolant to circulate through passages in the box. Electric heaters are limited as to their watt densities, since temperatures in excess of 125° F could damage the battery case.

- Combustion Air Heaters — TCOM does not provide any combustion air heaters. The diesel engine is operated within an enclosure, and once the engine reaches operating temperature, the air will be heated by the engine. In the Dew Line environment, however, an auxiliary combustion heater (kerosene or fuel oil fired) will be required to preheat the air to aid in diesel starting.

Operation

- Idling and Light Load — While idling is not a problem for a diesel electric set (1800 rpm is required for frequency regulation) prolonged light load operation must be avoided to prevent lube oil dilution due to unburned fuel condensation. TCOM provides a dummy load that is used to force the engine to maintain proper operational temperature during periods of low power consumption by the aerostat and mooring system.

- Environmental Protection — The diesel engine power unit and all controls are completely enclosed within a watertight shelter. To help maintain a minimum coolant temperature of 160° F, thermostatically controlled air discharge louvers are employed. The thermostat is set to open the louvers at 10° F above the engine thermostat operating point (185° F). For Dew Line operations, a thermostatically controlled fan will have to be provided, and should be set to operate the fan at 10° F higher than the discharge louvers.

  The diesel engine compartment is currently uninsulated. Insulation and electrical heaters would have to be added for Dew Line operations as a starting aid and to reduce the heat loss due to wind chill factors during operation.

- Maintenance — The fuel tank must be kept filled to reduce condensation and insure undiluted fuel.

M. SLIPRING ASSEMBLY

The slipring assembly which is incorporated as part of the tether swivel is a commercial product designed and manufactured by IEC Corporation of Austin, Texas. Specifications for this item do not include a low temperature operational limit.

In an attempt to ascertain the low temperature capability of the slipring assembly, TCOM contacted IEC for any available pertinent information. As a result of this inquiry, it was learned that an IEC slipring assembly of similar design and identical materials had been successfully operated in a test chamber at a temperature of -40° F. These data indicate that the TCOM sliprings should function with no problems in a wintertime Vermont environment.

No data are available for operation of the sliprings in an arctic (-70° F) environment. Also, TCOM is not aware of the exact materials used in the assembly, so cannot evaluate their low temperature characteristics. As with all electrical apparatus, there is concern for the mechanical integrity of both rigid and normally flexible insulation at these temperatures. Further tests and possible materials substitution appear necessary.

N. THE LOW TEMPERATURE EFFECTS ON TETHER CABLES

An analysis was made to determine the suitability for use at arctic temperatures of all materials used in TCOM STARS tether cables. Major emphasis was given to the Kevlar tethers since they are the prime choice for use by AFGL. Results indicate that all materials are suitable for use in a demo program and all but one material are suitable for use in a final system configuration. The only marginal material was identified as the jacket used on the Kevlar tether. Lab tests indicate that the material is suitable at -55° F temperatures on a short term basis; however, the manufacturer's low-temperature embrittleness rating of -49° F warrants a change in the jacket material on future arctic-bound Kevlar tether cables in order to survive in the -70° F environment.

An investigation was performed to determine the low temperature effects on existing STARS tether cables. The study focused on an analysis of all materials used in construction of both the Kevlar and steel version tethers. The following text provides a brief summary of the findings for each material on a point-by-point basis.

KEVLAR TETHER ANALYSIS

Kevlar cables have been used as pendant lines in offshore drilling rigs in the arctic and also as guy lines for antenna towers in cold regions of Vermont. However, due to the unique characteristics of the electromechanical aerostat tether cables, typical applications are not available for comparison and review.

In an attempt to define and quantify low temperature effects on the Kevlar E/M tether cables, each of the materials is discussed in the following text:

Kevlar(R) 29 Aramid Fiber

Use — Strength member and core center strand filler.

Kevlar aramid fibers are members of a family of aromatic polyamide fibers made by DuPont which posses extremely high strength, high modulus and low elongation. Since 1972, Kevlar has been used commercially as a strength member in various cable and tether applications. Its properties are such that, as an organic fiber, it can be considered for applications previously reserved for inorganics such as glass and steel.

The thermal stability of Kevlar 29 yarns is excellent at both high and low temperatures. The fibers do not have a melting point but char and decompose at 800° F. However, because of oxidation effects, long-term service at temperatures above 300° F is not recommended.

At cryogenic temperatures, the mechanical properties of Kevlar 29 actually increase. DuPont claims that the fiber loses virtually none of its characteristics at the extremely low temperatures and the only precaution to be taken for rope and cable applications for use in arctic conditions would be to extrude a jacket over the Kevlar strength member.(1) The jacket provides protection to the yarns from the highly abrasive effects of ice formations.

Table 28 provides a comparison of properties of Kevlar-29 at arctic vs. 75° F ambient temperatures. At arctic temperatures of -70° F, it exhibits essentially no embrittlement or degradation of fiber properties.(2) It may be worth noting also that in contrast to other organic fibers, Kevlar fibers have near zero shrinkage on heating. The longitudinal coefficient of thermal expansion is -2×10^{-6}/°C.

TABLE 28. TENSILE PROPERTIES OF "KEVLAR" 29 AT ARCTIC TEMPERATURES

	75° F	– 70° F
TENACITY, GM/DENIER	19.1	19.8
TENSILE STRENGTH, LB/IN²	351,700	364,600
ELONGATION, %	4.1	3.9
MODULUS, GM/DENIER	425	521
MODULUS, 10^6 LB/IN²	7.82	9.59

TWISTED "KEVLAR" 29 CORD
6.5 TWIST MULTIPLIER
10%/MIN. ELONGATION
10" GAGE LENGTH
TESTED AT TEMPERATURE

Dacron Type D608 Polyester Yarn

Use — As core interstice filler and stabilizer in pre-jacket braid.

Dacron polyester strands have been used in rope and cable constructions for many years. Typical use has been as the primary strength member, however, due to its high elongation and good mechanical properties, Dacron polyester is very suitable for use in jacket reinforcement and as strand filler in Kevlar electromechanical cable applications.

Due to the high strength and low thermal conductivity properties of Dacron polyester yarn, its use in the construction of cryogenic equipment was investigated by the National Bureau of Standards Boulder Laboratories circa 1958.[4] Work performed by Reed and Mikesell concluded that Dacron strands are as strong at -325° F as they are at +75° F. Between the range of -70° F and +75° F one may conclude that there are very minimal changes in the properties of Dacron polyester yarn inclusive of tensile strength, elongation and impact energy absorption.

Mylar Polyester Film

Use — As a binder for the electrical core and also as a separator between each of four Kevlar Strength member layers.

Mylar is essentially a polyester film as opposed to Dacron polyester fiber. Mylar retains good physical properties over a wide temperature range (-94° F to +302° F) and is even used at temperatures ranging from -418° F to +392° F.

Work performed by Reed and Mikesell of the National Bureau of Standards [4] concluded that strands of Mylar film were somewhat weaker than polyester yarns at low temperature. However, between the range of -55° F and +75° F the changes in properties of Mylar film are negligible.

Figure 50 illustrates the tensile properties of Mylar vs. temperature. One may note that the tensile strength at lower temperatures actually increases.[5]

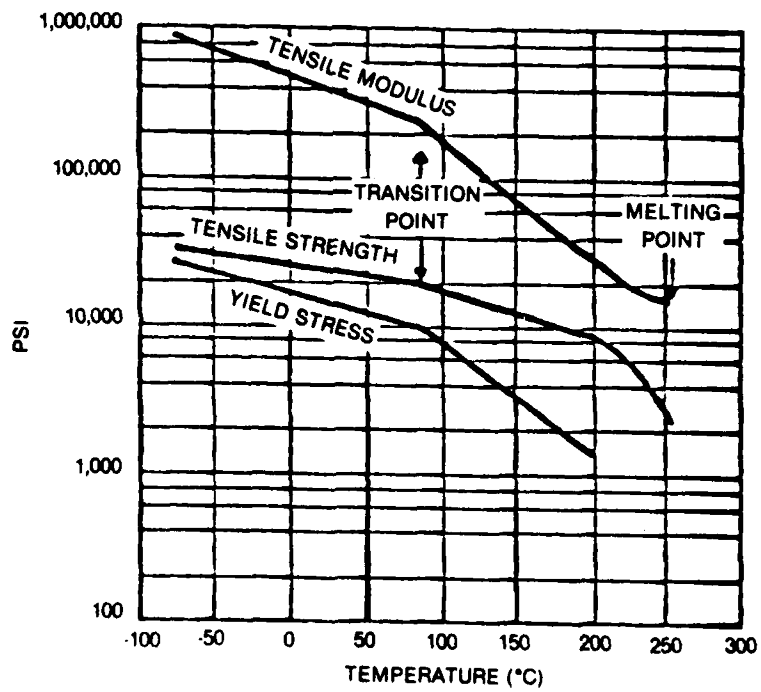

Figure 50. Tensile Properties vs. Temperature (Mylar Film)

Copper Wire

Use — As conductor for power, and as ground/lightning shield.

Copper as a power conductor in very cold regions has received conflicting press as to its usefulness for low-temperature applications. The basic problem for any metal used in very cold arctic conditions is the inescapable fact that materials become more brittle at lower temperatures. "For metals, the result is a decrease in the impact resistance, or technically, a change to brittle (cleavage) type failure from ductile (shear) type failure."[6]

One source of information on materials for use in arctic conditions states that copper as a fully tensioned line conductor is subject to brittleness by continuous, extreme low temperatures.[7] This may not be too relevent, however, since the design of the tether cable core and helix is such that the conductors see very minimal strain during tension excursions which load the Kevlar (or steel) strength member.

Another source claims that copper encounters no low-temperature brittleness.[8]

TCOM has experience with use of a steel tether cable in the arctic environment which indicates that the stranded copper conductors are sufficient for use in the cold environment. However, as part of the AFGL study effort, a test was conducted on a Kevlar and steel tether cable at -55° F to determine any detrimental effects to the conductors. Results indicate that the conductors experience no detrimental degradation.

Olefinic Thermoplastic Rubber (Uniroyal TPR 5280)

Use — As dielectric for the three power conductors and as strands for core filler.

The olefinic thermoplastic rubbers are regarded highly for use as insulation at low temperatures. They offer an excellent balance of electrical properties, thermal aging and heat deformation resistance along with excellent flexibility at ambient and low temperatures.[9] Typical usage ranges are from -100° F to +260° F. Uniroyal Chemical reports the brittle point for TPR 5280 at less than -100° F, and recommends its use in arctic cables.

Tefzel (Fluoropolymer)

Use — Tefzel is not presently used in the STARS cable designs. It will be used to replace the TPR 5280 in all future cables due to its better mechanical properties at both low and high temperatures.

Tefzel flouropolymers are melt-processible thermoplastics which are part of a family of fluorine-based products which includes Teflon TFE, Teflon FEP, and Teflon PFA fluorocarbon resins. Tefzel is called out as a wire insulation in MIL-W-81822/13, a U.S. Navy Specification on solderless wrap wire. It is also covered in MIL-W-22759/16/17/18 and 19, a joint services specification for aircraft wire. It is also called out in various industrial specifications for wire insulation and cable jacketing.

Mechanically, Tefzel is tough, has medium stiffness (200,000 psi), excellent flex life, impact and cut-through and abrasion resistance.

Its continuous use ratings are from -95° F to +300° F. Low temperature embrittlement determined per ASTM D746 is rated at less than -150° F.

Polyethylene (Union Carbide DHDA-7704 Black 55)

Use — As cable jacket material.

Bakelite Polyethylene Compound DHDA-7704 Black 55 is a thermoplastic semiconductive compound. Polyethylenes of this type are typically used in the temperature range of -75° F to +175° F. Low temperature flexibility is good to excellent; however, Union Carbide rates this particular compound to have a brittleness temperature per ASTM D746 of -49° F.

As part of this study effort, a specimen of the STARS tether cable jacketed with DHDA-7704 was subjected to cyclic bending at -55° F to determine the effects of low temperature on the jacket. The results indicate that there was no apparent degradation of the jacket material in laboratory conditions, however, it is recommended that future Kevlar cables for use in arctic conditions have a more suitable jacket material which is rated for embrittleness at temperatures in the range of -70° F to -100° F.

STEEL TETHER ANALYSIS

Steel strength member E/M cables have been used in extremely cold environments for well-logging, among other uses. Cables of this type have a fairly good record for use in cold environments.

It should be noted that the STARS cable core is identical in both the Kevlar and steel tether configurations, therefore the previous text applies to all component materials with the exception of the steel wires and Zytel Nylon jacket.

Steel (GXIPS)

Use — As a strength member.

The only effective means of determining the suitability of the cold-drawn steel armor wires as a strength member in cold environments is by means of testing. As part of this study, a test was performed on a steel tether specimen at -55° F to determine if any degradation would occur to the strength and integrity of the steel wires when flexed under tension in a cyclic-bend-over sheave mode. Results are reported elsewhere in this report. However, it is concluded that the steel tether is suitable for use in arctic conditions. (To support this conclusion, TCOM has successfully used a steel tether cable in arctic conditions on the Penguin project.)

Zytel Nylon

Use — Cable Jacket

Zytel Nylon 91 HS has been used successfully as a jacket for the steel tether cable in an arctic environment. The rated brittleness temperature per ASTM D746 is -98° F in the dry as-molded condition. At a saturated 50% relative humidity, the brittleness temperature approaches -40° F.

Conclusions

All materials used on both the steel and Kevlar STARS tether cables are suitable for use in a demo program subjected to low temperature conditions. However, it is recommended that one material used in the Kevlar cable be changed prior to customer use of a Kevlar cable in final service conditions. The polyethylene utilized as the jacket on the Kevlar tether should be changed to a material with a lower low temperature embrittlement value to provide a safety factor in its use. All other materials are suitable for use in the arctic environment.

VII. CONCLUSIONS AND RECOMMENDATIONS

The results of our past experience in cold weather operation of tethered aerostats has been reviewed. Problem areas have been examined, specific studies and tests have been conducted to address the problems, and some possible solutions have been identified. From the results of all of our experiences, studies and tests, it is concluded that:

1. Aerostat operations will be seriously affected by the accumulation of ice (clear or rime) and snow (wet or dry) under those very special temperature and weather conditions when these phenomena occur.
2. Aerostat operations are most seriously affected when the temperature is in the zone of about +4° C to -10° C.

3. Clear ice formation can be cracked loose from the aerostat hull surface by cycling the internal pressure between 1.5 IWG and 4.5 IWG. However, it is not clear that the ice will always fall free (once cracked loose) or that a vibrator system will assist the shedding of ice.
4. Rime ice will not break free with hull pressure pulsing. It cannot be shaken loose with a vibrator system.
5. Rime ice formation is rare, but must be avoided. In the event of persistent rime ice formation, aerostat flight operations must be terminated, the aerostat moored and ground ice removal procedures instituted.
6. Destructive accumulations of wet or dry snow can collect on a moored aerostat during very light wind conditions. Moored aerostat snow removal procedures (use of scraper boards) must be instituted.
7. Snow will not accumulate on an aerostat in flight except in very light wind conditions. When snow accumulation is evidenced by the persistent loss of free lift or increasing pitch angle, aerostat flight must be terminated, the aerostat moored and ground snow removal procedures instituted.
8. A hydrophobic coating on the Tedlar aerostat surface may not be desirable since it causes formation of small globules of ice instead of a sheet of ice. The small globules of ice cannot be loosened by pressure pulsing.
9. Tests of a vibrator may have been masked by scaling effects in that the vibrator was tested on a small air inflated bag coated with ice. Vibrators are used extensively in industry to cause various materials to slide freely on inclined planes. A vibrator system on the aerostat should be effective in causing snow to slide free of the inclined lower fin surfaces and all but the very top portion of the hull.
10. The aerostat, the Kevlar tether and the mooring system operation will not be adversely affected by the cold weather extremes expected at Fort Ethan Allen, Vermont.
11. The extremes of arctic cold (about -70° F) will cause structural brittleness problems with certain components of the mooring structure and with the Kevlar tether protective jacket.

Based on our prior cold weather flight experience and the results and conclusions of studies and tests, it is recommended that:

1. A comprehensive adverse weather flight doctrine be developed and implemented in the Fort Ethan Allen, Vermont, test program. There are certain snow and icing conditions that probably will occur that can only be dealt with if the aerostat is moored. Some snow and ice conditions may best be countered with the aerostat in flight. We must determine how to distinguish between the sets of conditions and develop the procedures to best cope with each.
2. The transition temperature (+ 4° C to -10° C) weather conditions must be anticipated and proper flight or moored aerostat snow/ice removal procedures instituted.
3. The pressure pulse system be implemented on the aerostat to operate between 1.5 and 4.5 IWG, and a doctrine for its proper use formulated.

4. A variable speed vibrator system be installed on the aerostat and a doctrine for its operation be determined.
5. Aerostat flight operations in rime ice conditions be terminated, the aerostat moored and ground ice removal procedures instituted.
6. Snow scraper boards or tag lines to facilitate their rapid employment be permanently installed on the aerostat.
7. Aerostat flight be considered as a means of avoiding snow accumulation when there are winds of 15 knots or more at flight altitude.
8. A hydrophobic coating as recommended by CRREL be used on the upper surface of part of one aerostat fin and a selected small section of the aerostat hull to observe its effect on snow and ice accumulation and removal. Additional coating can be applied in the field if favorable results of the test areas are observed.

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ATTACHMENT A

AEROSTAT SIZE AND PAYLOAD ESTIMATING

ATTACHMENT A — AEROSTAT SIZE AND PAYLOAD ESTIMATING

The ultimate objective of the STARS cold weather tests is to determine the feasibility of operating tethered aerostats on a year-round basis in an arctic environment. Although the STARS system is appropriate, if not ideal, for determining feasibility of arctic operations, it is not of adequate size to carry a suitable payload to the altitude to satisfy the mission requirements. Iterative computer programs are available to accurately select an aerostat size and match it to a payload weight and mission altitude. However, in this case it has been determined that whatever payload is selected, it must be carried to a predetermined altitude in order for it to meet the mission requirements. Therefore, a series of graphs have been prepared that will permit the reader to select an appropriate payload weight and determine the approximate size (volume) of the aerostat that will be required.

Four charts are presented, Figures A-1 through A-4. The first two charts are for dual aerostat operation at DEW Line locations, one aerostat at Dye Main and one aerostat at Dye One. Figure A-1 is the sizing chart for the aerostat operating at 5200 feet AMSL at Dye Main and Figure A-2 is a similar chart for the aerostat operating at 8300 feet AMSL at Dye One. Figures A-3 and A-4 are for single aerostat systems operating at either Dye Main or Dye One at 9,000 feet AMSL and 13,000 feet AMSL, respectively.

Each chart is constructed for a specific flight altitude from a pad of given altitude. First, the total lift is determined; the slope of this line is dependent only on the desired operating altitude. Second, the free lift line is constructed. It can be seen that this line is not a straight line. It is the free lift value taken from our large aerostat operation (3,000 pounds for the 365,000-cubic-foot aerostat) and scaled in proportion to the volume to the 2/3 power.

The aerostat weight line and the tether weight line are each constructed to be the proper "distance" below the free lift line to account for the aerostat and tether weights as a function of aerostat volume. The portion left over (below the tether weight line) is the allowable payload.

For an example of the use of the graphs, assume that it has been determined that a suitable payload could be constructed at a total weight of 750 pounds. Entering Figure A-1 at 750 gives an aerostat volume of 67,000-cubic-feet required at Dye Main and an aerostat volume of 100,000 cubic feet at Dye One. (See Figure A-2.)

Now compare these figures for dual aerostat operations with the single aerostat at either site. Using Figure A-3, it would require an aerostat volume of about 145,000 cubic feet at Dye Main; using Figure A-4 gives an aerostat volume of about 300,000 cubic feet at Dye One.

These charts, of course, give approximate answers, but with a tolerance suitable to study the economic impact of different aerostat sizes. Of importance in any economic analysis is the estimate that a portable mooring system similar to the STARS system probably can be employed with aerostats up to a volume of about 100,000 cubic feet. Beyond that size it may be necessary to make a more permanent, higher cost, mooring system installation.

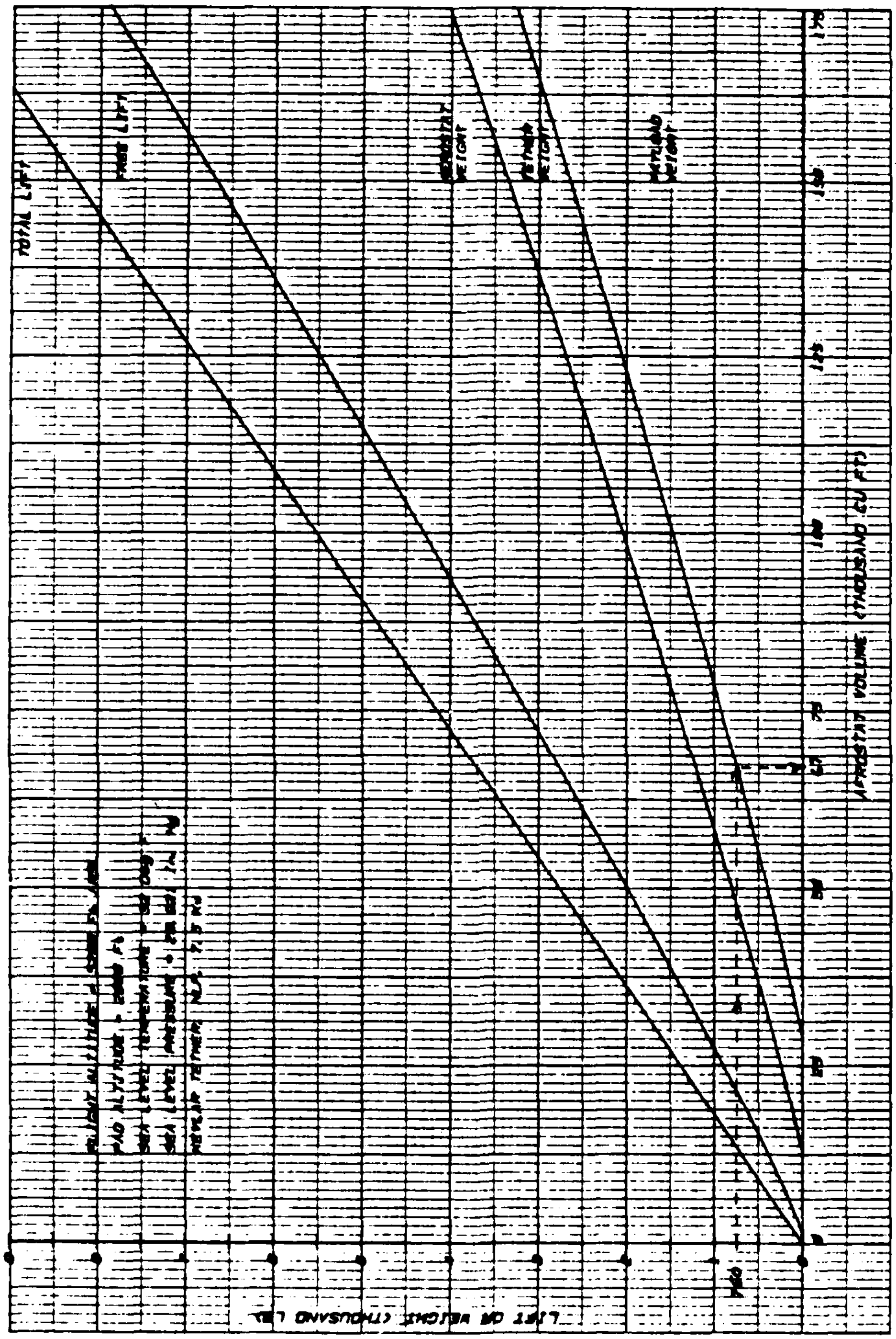
TOTAL LIFT
FREE LIFT
AEROSTAT WEIGHT
TETHER WEIGHT
PAYLOAD WEIGHT
AEROSTAT VOLUME (THOUSAND CU FT)
LIFT OR WEIGHT (THOUSAND LB)

Figure A1.

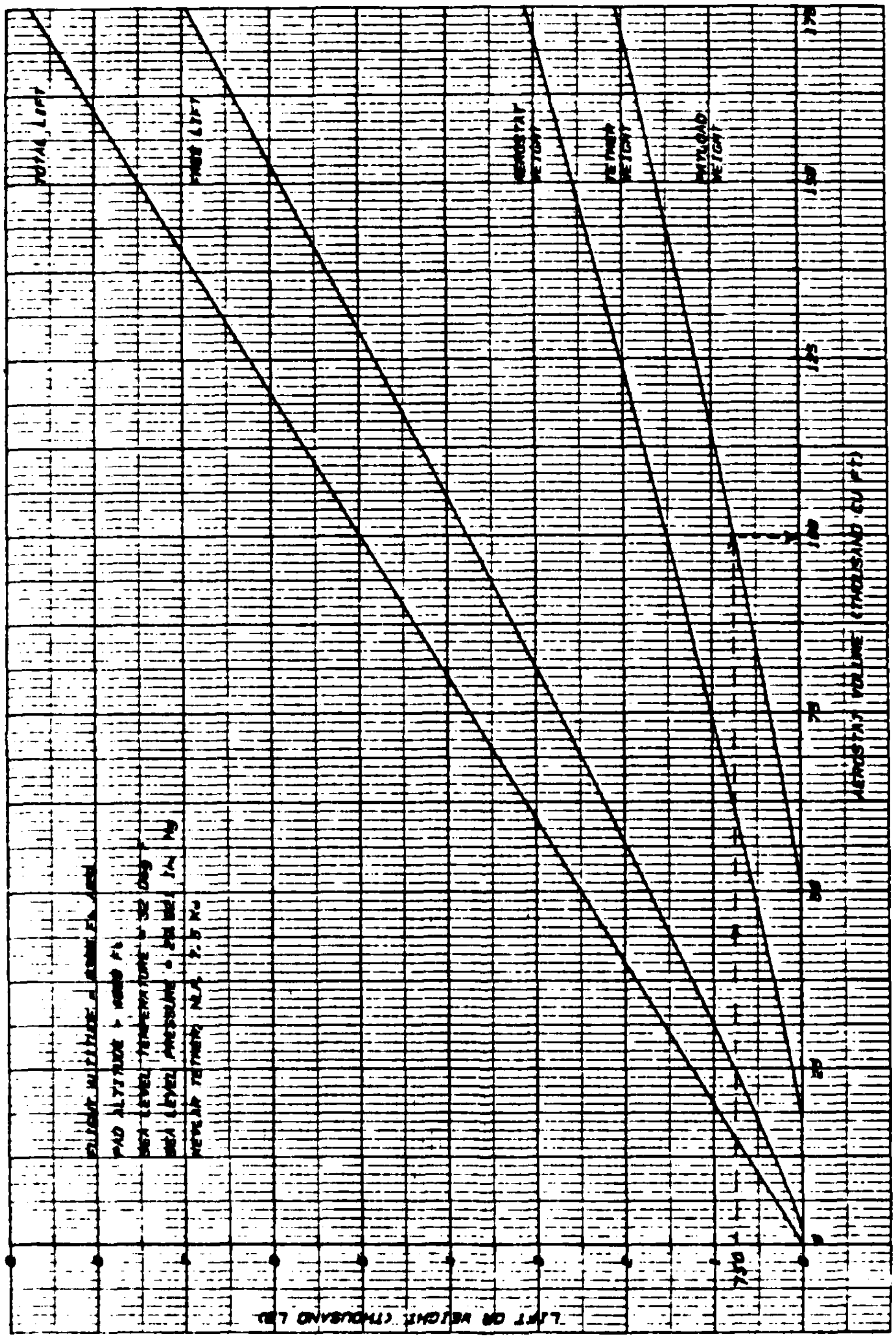
TOTAL LIFT
FREE LIFT
AEROSTAT WEIGHT
TETHER WEIGHT
PAYLOAD WEIGHT
AEROSTAT VOLUME (THOUSAND CU FT)
LIFT OR WEIGHT (THOUSAND LB)
0
25
50
75
100
125
150
175

FIGURE A2.

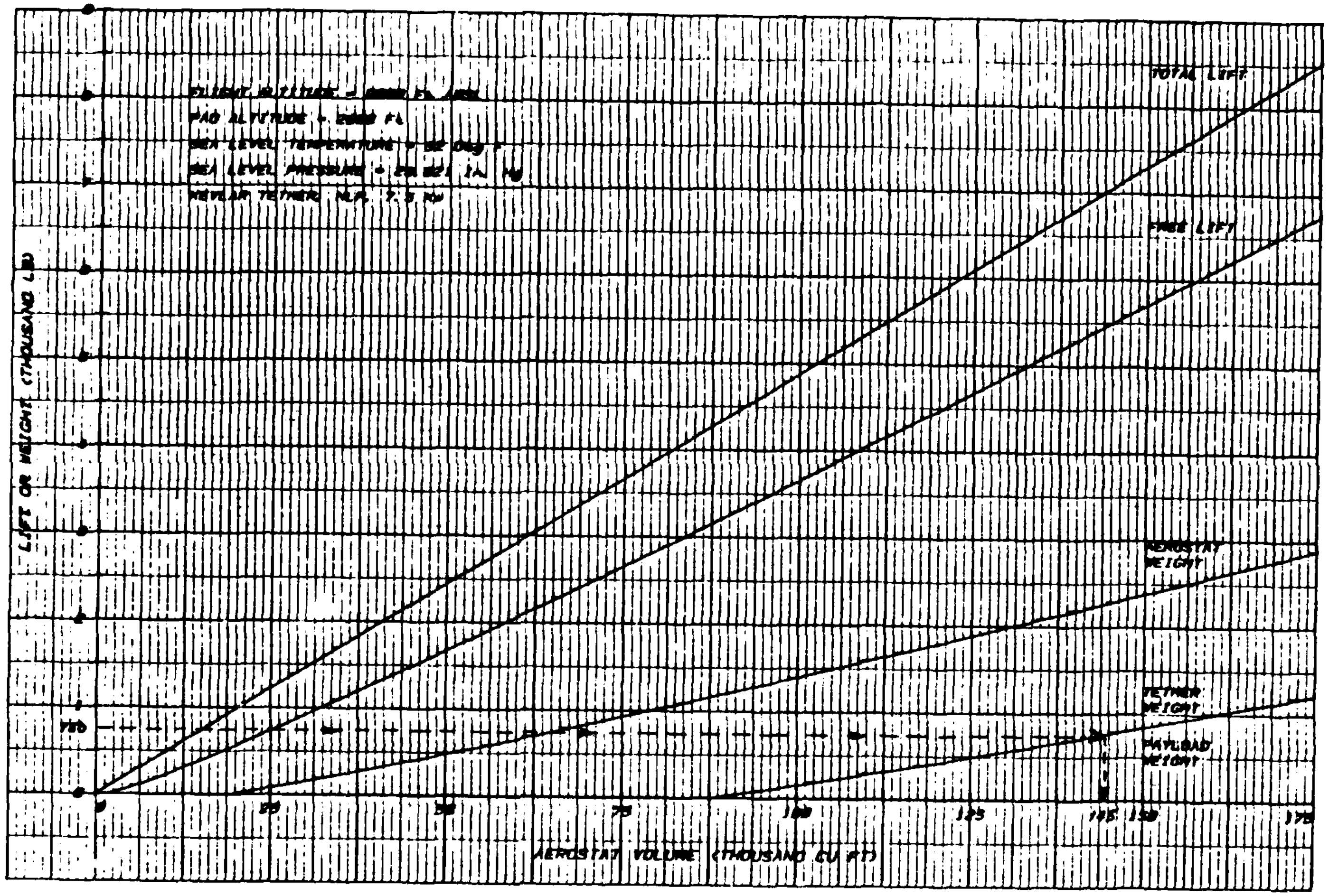
TOTAL LIFT
FREE LIFT
AEROSTAT WEIGHT
TETHER WEIGHT
PAYLOAD WEIGHT
750
0
25
50
75
100
125
145
150
175
LIFT OR WEIGHT (THOUSAND LB)
AEROSTAT VOLUME (THOUSAND CU FT)

Figure A3

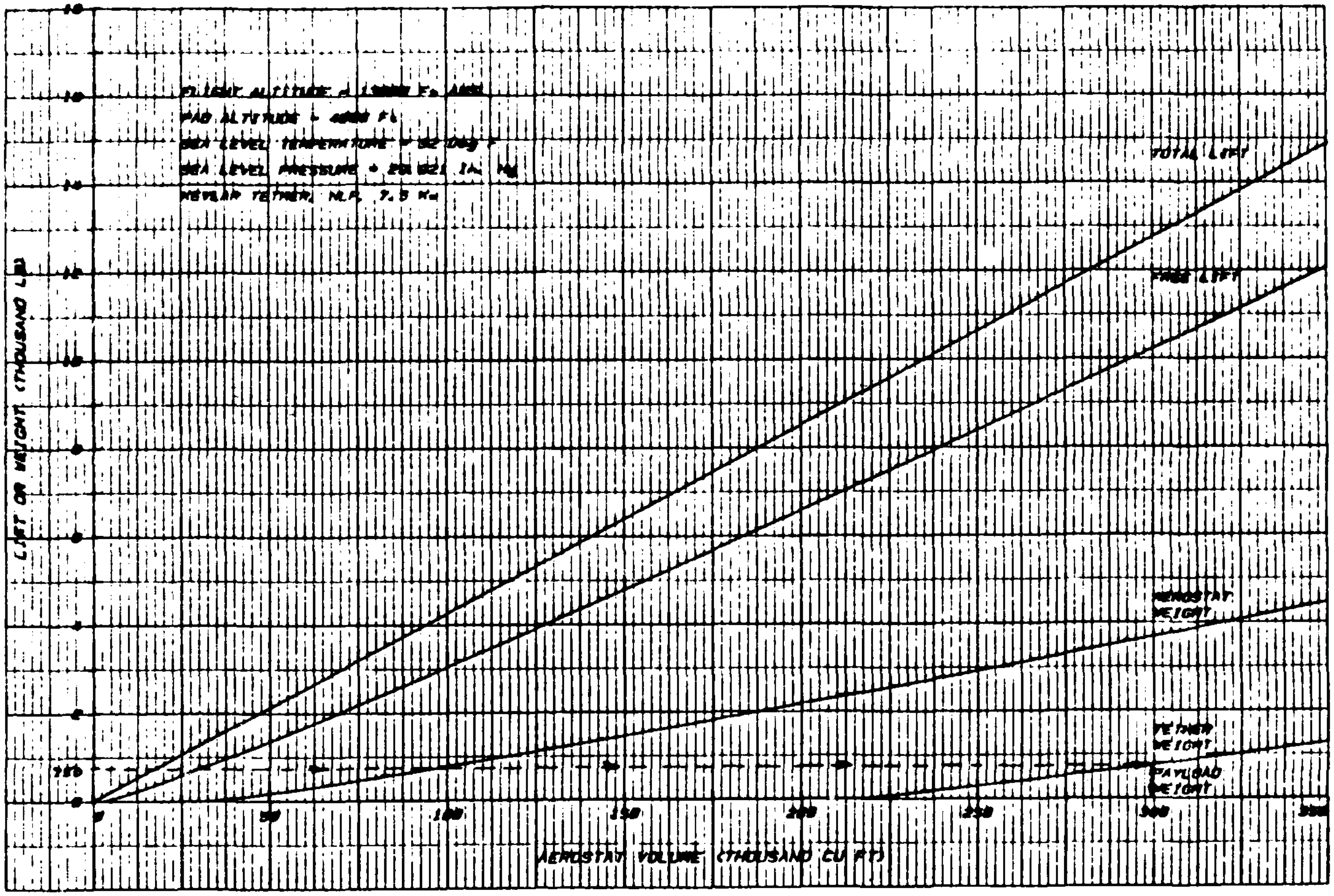
TOTAL LIFT
FREE LIFT
AEROSTAT WEIGHT
TETHER WEIGHT
PAYLOAD WEIGHT
AEROSTAT VOLUME (THOUSAND CU FT)
LIFT OR WEIGHT (THOUSAND LB)
0
50
100
150
200
250
300
350

Figure A4.

ATTACHMENT B

COLD BEND TESTS OF STARS STEEL AND KEVLAR TETHER CABLES

FINAL REPORT

on

COLD BEND TESTS OF "STARS" STEEL AND KEVLAR TETHER CABLES

to

TCOM CORPORATION
Purchase Order TC-BW-35246

September 16, 1982

By

Philip T. Gibson

TENSION MEMBER TECHNOLOGY
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COLD BEND TESTS OF "STARS" STEEL AND KEVLAR TETHER CABLES

By

Philip T. Gibson
Tension Member Technology

INTRODUCTION

This report describes the cyclic-bend-over-sheave fatigue and tensile tests conducted on specimens of the "STARS" steel and Kevlar tether cables to determine cable performance in a cold environment. The cable specimens were provided to Tension Member Technology by TCOM Division of Westinghouse Electric Corporation. The tests were conducted in accordance with TCOM Purchase Order TC-BW-35246.

DESCRIPTION OF TEST SPECIMENS

The "STARS" steel tether cable contained a core consisting of three #20 AWG copper power conductors and three jacketed optical fibers. Over this core were two layers of contrahelically served armor wires and a black Zytel nylon jacket. The overall cable diameter was 0.36 inch.

The "STARS" Kevlar tether cable also had a core containing three copper power conductors, but, in this case, no optical fibers were included. The strength member of this cable consisted of multiple layers of contrahelically served Kevlar fiber. An overall polyethylene jacket brought the cable diameter to 0.46 inch.

TEST SPECIMEN PREPARATION

One specimen of each cable type was prepared for testing by the installation of one-half inch forged steel open sockets using a polyester resin potting compound. The resin used for socketing the steel tether was Socketfast, and the resin used for socketing the Kevlar tether was Socketfast Blue. Both of these resins are manufactured by Philadelphia Resins Corporation, Montgomeryville, Pennsylvania. Core pigtails were allowed to extend through the sockets of both specimens to allow electrical and optical testing. The free length of cable between sockets was 18'-8". The overall electrical length of each specimen was 33'-8".

TEST APPARATUS AND PROCEDURES

The cyclic-bend-over-sheave (CBOS) fatigue tests were conducted on a vertical machine using the setup shown schematically in Figure 1. A single test specimen was wrapped around two test sheaves with the ends connected through a Miller C-3 ball bearing swivel. The sheaves used for the steel tether had a tread diameter of 18.75 inches and a groove diameter of 0.37 inch. The sheaves used for the Kevlar tether had a tread diameter of 18.43 inches and a groove diameter of 0.47 inch. In each case, the included angle between the sheave groove flanges was 30 degrees.

The uppermost sheave assembly was attached to a hydraulic tensioning cylinder through a load cell having a calibration traceable to the National Bureau of Standards. The output of the load cell was fed into a single conditioner which provided a continuous digital display of tension. The lower sheave was connected to a hydraulic torque motor which caused the cable specimen to cycle back-and-forth with a stroke of 42 inches. The tests were performed at a cable tension of 2,000 pounds.

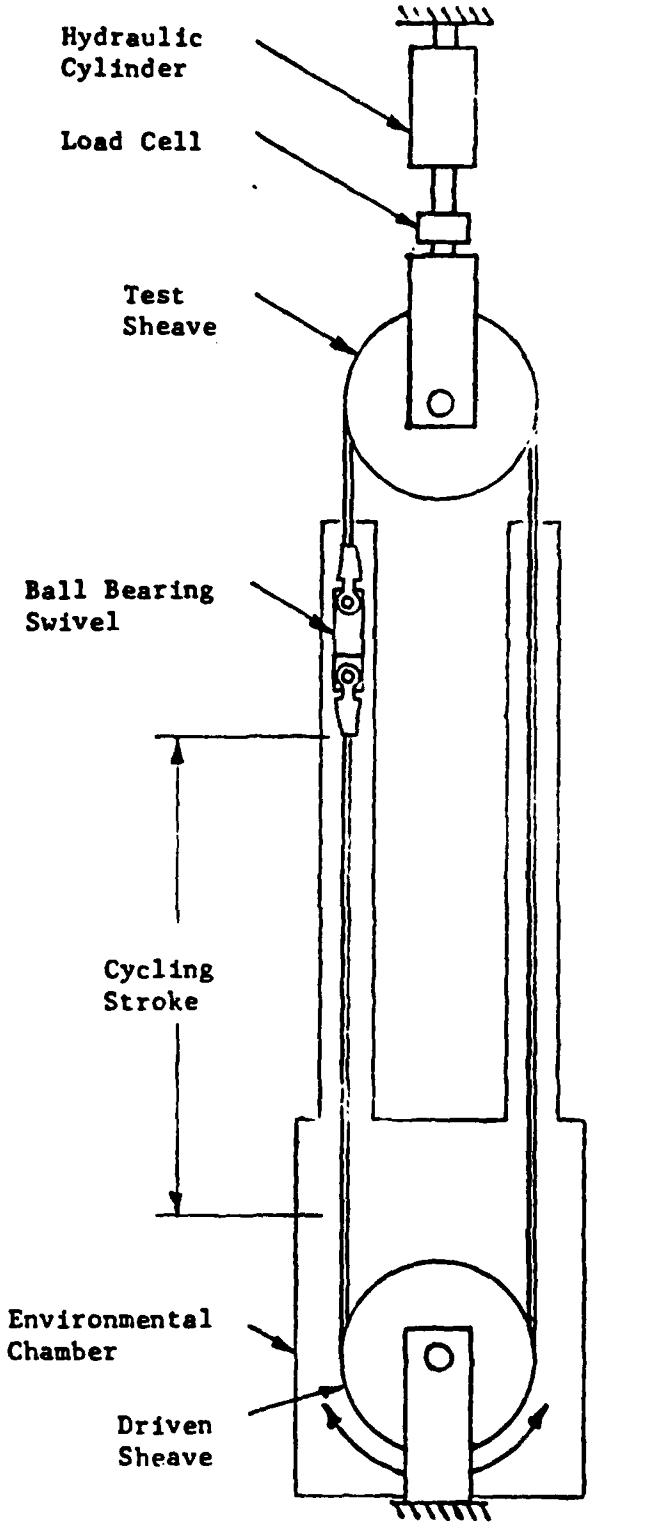


FIGURE 1. DIAGRAM OF CYCLIC-BEND-OVER-SHEAVE FATIGUE TEST APPARATUS

The 42-inch cycling stroke was sufficient to allow a 12-inch section of the cable at each sheave to pass onto, around, and off of the sheave with each stroke of the machine. Thus, each complete machine cycle produced two straight-bent-straight bending cycles of two sections of each specimen. The number of fatigue cycles was recorded automatically on a totalizing counter. The cycling rate was 1,000 bending cycles per hour.

The loop resistance of all electrical conductors wired in series was continuously monitored during the test. At increments of 500 bending cycles, a record was made of conductor loop resistance, and, in the case of the steel tether, the optical fibers were checked for optical continuity.

The lower test sheave and a major portion of the cable specimen were enclosed within an environmental chamber as shown in Figures 2 through 5. During each test, the temperature within this chamber was maintained at -55 $\pm$ 5 degrees F using dry nitrogen gas and a thermostically controlled valve. The temperature within the chamber was allowed to stabilize prior to the initiation of each fatigue test.

After completion of the cyclic-bend-over-sheave fatigue tests, both specimens were cut approximately in half, and another resin socket was installed to allow a breaking strength test to be conducted on that portion of the cable which had experienced bending at a reduced temperature. This final tensile test was conducted using the apparatus shown schematically in Figure 6. One end of the specimen was connected to a hydraulic tensioning cylinder through a strain gauge load cell having a calibration traceable to the National Bureau of Standards. This end of the cable specimen was restrained from rotation. The other end of the specimen was attached to a friction-compensated swivel which allowed free end rotation of the specimen during the tensile test. A rotation sensor within the swivel allowed a continuous record of cable rotation versus tension to the point of failure. An additional plot of conductor loop resistance versus tension was also made during each tensile test. The test specimens were subjected to nine preconditioning cycles to a peak tension of 1500 pounds prior to being pulled to failure.

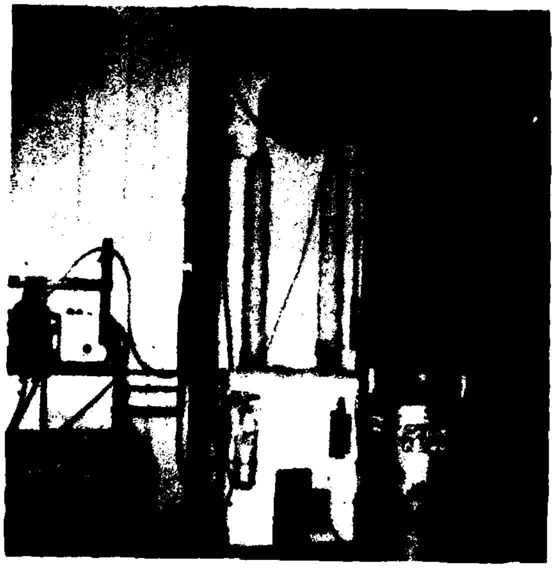


FIGURE 2. CBOS FATIGUE TEST APPARATUS

FIGURE 3. ENVIRONMENTAL CHAMBER AND NITROGEN SUPPLY

FIGURE 4. LOWER SHEAVE EXPOSED

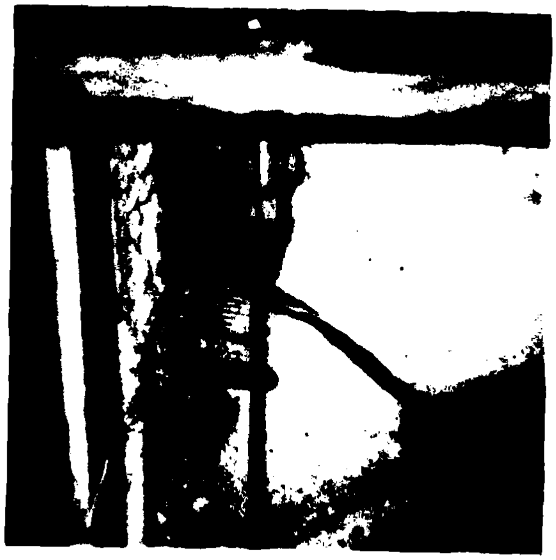


FIGURE 5. CABLE SOCKET AND PIGTAIL

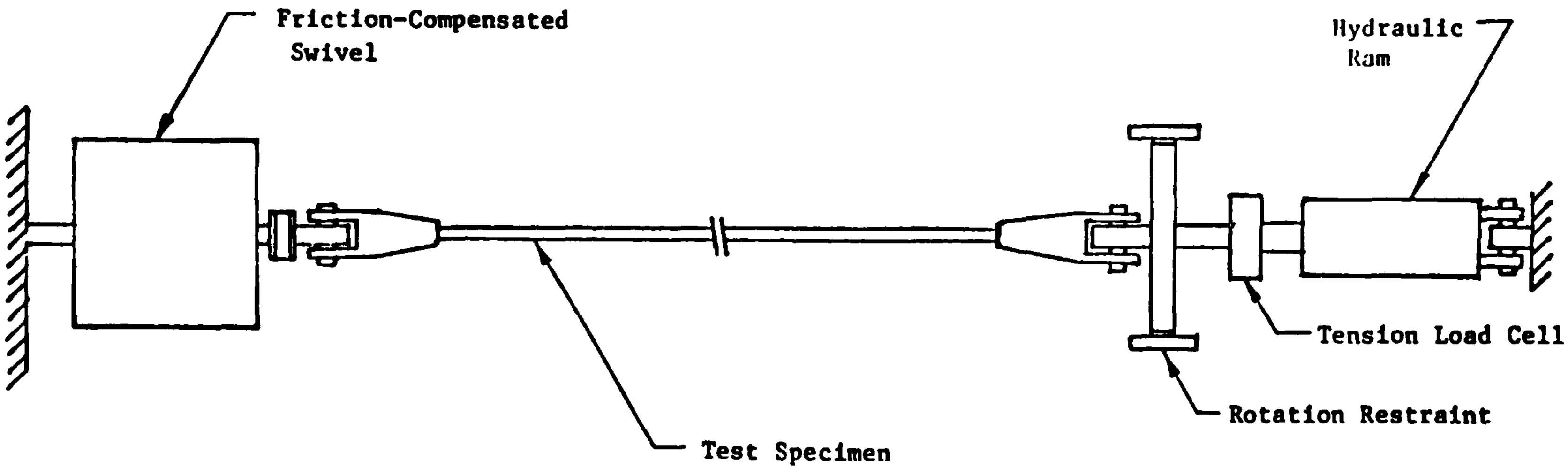


FIGURE 6. DIAGRAM OF APPARATUS USED FOR MEASUREMENTS OF CABLE ROTATION AND BREAKING STRENGTH

A complete list of the laboratory equipment used during this test program appears in Appendix A.

TEST RESULTS

The results of the cyclic-bend-over-sheave fatigue tests are contained in Appendix B. Both cable specimens survived 3,000 bending cycles at 2,000-pounds tension without mechanical, electrical, or optical failure.

The "STARS" Kevlar tether exhibited a peculiar twisting during the test. As fatigue cycling progressed, the cable specimen rotated on its axis relative to the test sheaves over its entire length. No net cable rotation occurred at the swivel connecting the two cable ends. Because of this rotation, the test had to be interrupted periodically to allow the conductor pigtails to be unwound from around the cable. At approximately 1,750 bending cycles, the pigtails had accumulated five turns of rotation. At 2,500 bending cycles, the pigtails had accumulated an additional three turns of rotation. At the conclusion of the test at a total of 3,000 bending cycles, the pigtails exhibited an additional one turn of rotation. All rotation was in the direction as shown in the photograph in Figure 5.

The values of conductor loop resistance shown in Appendix B for the steel tether cable indicate the total resistance of both the test specimen and the electrical leads. It was not practical to open the environmental chamber every 500 bending cycles in order to make resistance measurements of the conductors alone. In the case of the Kevlar tether cable, some resistance values are provided for the cable conductors alone, as measured before and after the cold bend test. It should be noted that during the cyclic-bend-over-sheave fatigue tests, portions of both the cable specimens and the electrical leads remained within the environmental chamber, while other portions either remained outside of the chamber or alternately passed into and out of the chamber. Each time the machine was stopped to allow optical and electrical measurements, portions of the cable specimen and electrical leads experienced some minor change in temperature while the cable specimen remained at rest. This change in temperature, in turn, affected the measured values of loop resistance shown in Appendix B. Thus, some of the variations in these measured values can be attributed to variations in the time interval between test interruption (at a 500 bending cycle increment) and measurement of the loop resistance. In the final analysis, no significant change in conductor resistance was detected.

The results of the remaining breaking strength tests on these two specimens are contained in Appendix C. For each test, the specimen was subjected to nine preconditioning cycles to 1500-pounds tension with one end free to rotate. The graphs in Appendix C show the conductor loop resistance and the cable rotation versus tension recorded during the final pull to failure.

The steel tether cable exhibited very little change in conductor loop resistance during this tensile test. The specimen exhibited a rotation of approximately 14.2 degrees per foot at a failing load of 7,300 pounds. Cable failure occurred at the nose of one socket. The optical fibers remained continuous to the point of cable failure. These results are nearly identical to those recorded previously for a specimen of as-manufactured cable which had not been subjected to a low-temperature cyclic-bend-over-sheave fatigue test.

The Kevlar tether cable also exhibited very little change in conductor loop resistance during the breaking strength test. The specimen exhibited a rotation of less than one degree per foot over the entire load range up to the failing load of 10,250 pounds. Cable failure occurred at the nose of one socket. Again, these results are similar to those recorded previously for a specimen of as-manufactured cable which had not been subjected to a low-temperature cyclic-bend-over-sheave fatigue test.

APPENDIX A

LABORATORY EQUIPMENT

APPENDIX A

LABORATORY EQUIPMENT

The following tables present a partial listing of equipment available in the Tension Member Technology Laboratory. Those items which were used during this test program are indicated with a check mark.

Current calibrations are maintained for all items of test equipment, and calibration records are available for inspection in TMT's instrumentation laboratory.

TABLE A-1. PARTIAL LISTING OF LABORATORY EQUIPMENT

Check	Instrument	Manufacturer	Model Number	Serial Number
	100-lbf Load Cell	Interface	SSM-100-AJ	7658
	1,000-lbf Load Cell	Ditto	SSM-AN-1000	5004
	1,000-lbf Load Cell	"	1210 AF	17570
	10,000-lbf Load Cell	"	1210 AF	9405
✓	25,000-lbf Load Cell	"	1220 AF	9895
	25,000-lbf Load Cell	"	1220 AF	12145
	50,000-lbf Load Cell	Sensotec	41	55250
	50,000-lbf Load Cell	Ditto	41	55251
	50,000-lbf Load Cell	"	41	55252
✓	50,000-lbf Load Cell	"	41	55253
	100,000-lbf Load Cell	Interface	1232 AF	7057
	200,000-lbf Load Cell	Sensotec	41	55589
	350,000-lbf Load Cell	TMT	1635	128
	500,000-lbf Load Cell	TMT	1650	135
✓	Signal Conditioner	Himmelstein	6-269.3976	6-139
	Load Indicator/Controller	Daytronic	3370	55
✓	Load Indicator/Controller	Ditto	3370	56
	Load Indicator/Controller	"	3370	61
	Load Indicator/Controller	"	3370	276
	Load Indicator/Controller	"	3370	277
	Load Indicator/Controller	"	3370	289

TABLE A-2. PARTIAL LISTING OF LABORATORY EQUIPMENT

Check	Instrument	Manufacturer	Model Number	Serial Number
	Elongation Sensor	TMT	TMT-2	1
	Elongation Sensor	TMT	TMT-3	3
	LVDT	Schaevitz	5000-HPD	106
✓	Rotation Sensor	TMT	FCS-40K	1
	Rotation Sensor	TMT	FCS-300K	3
	Corona Test Set	TMT	TMT-1A	100
	Hypot Test Set	Associated Research	5220	1065
✓	Milliohmmeter	TMT	TMT-2	10
	Capacitance Meter	ECD Corporation	100	15832
✓	Temperature Meter	Doric	430A	42976
	Continuity Meter	TMT	ACM-1	1
✓	X-Y Recorder	Hewlett-Packard	7044 A	1605A01638
✓	Chart Recorder	Hewlett-Packard	7132 A	1606A00613
✓	X-Y Recorder	Hewlett-Packard	7044 B	2047A00188
	Optical Multimeter	Photodyne	22XL	10425
	F/O Signal Source	Fotec	S210	S22202
	F/O Converter	Ditto	C200	C22202
	F/O Converter	"	C200	C22203
	F/O Converter	"	C200	C22204
	F/O Converter	"	C200	C22205

APPENDIX B

DATA SHEETS FOR COLD BEND TESTS

DATE 8 SEPT 1982

SPECIMEN 348-A2
'STARS' STEEL WITH FIBER OPTICS

Bending Cycles	Tension, (lbs)	Temperature °F	Loop Resistance (Ohms)	Optical Continuity
0	0	AMB.	(1.397)*	OK
0	2000	AMB.	(1.369)	OK
0	2000	-55	(1.319)	OK
500	2000	-55	(1.246)	OK
1000	2000	-55	(1.238)	OK
1500	2000	-55	(1.248)	OK
2000	2000	-55	(1.227)	OK
2500	2000	-55	(1.214)	OK
3000	2000	-55	(1.225)	OK
3000	0	AMB	(1.273)	OK

* TOTAL RESISTANCE OF CABLE AND ELECTRICAL LEADS.

DATE SEPT 13 1982

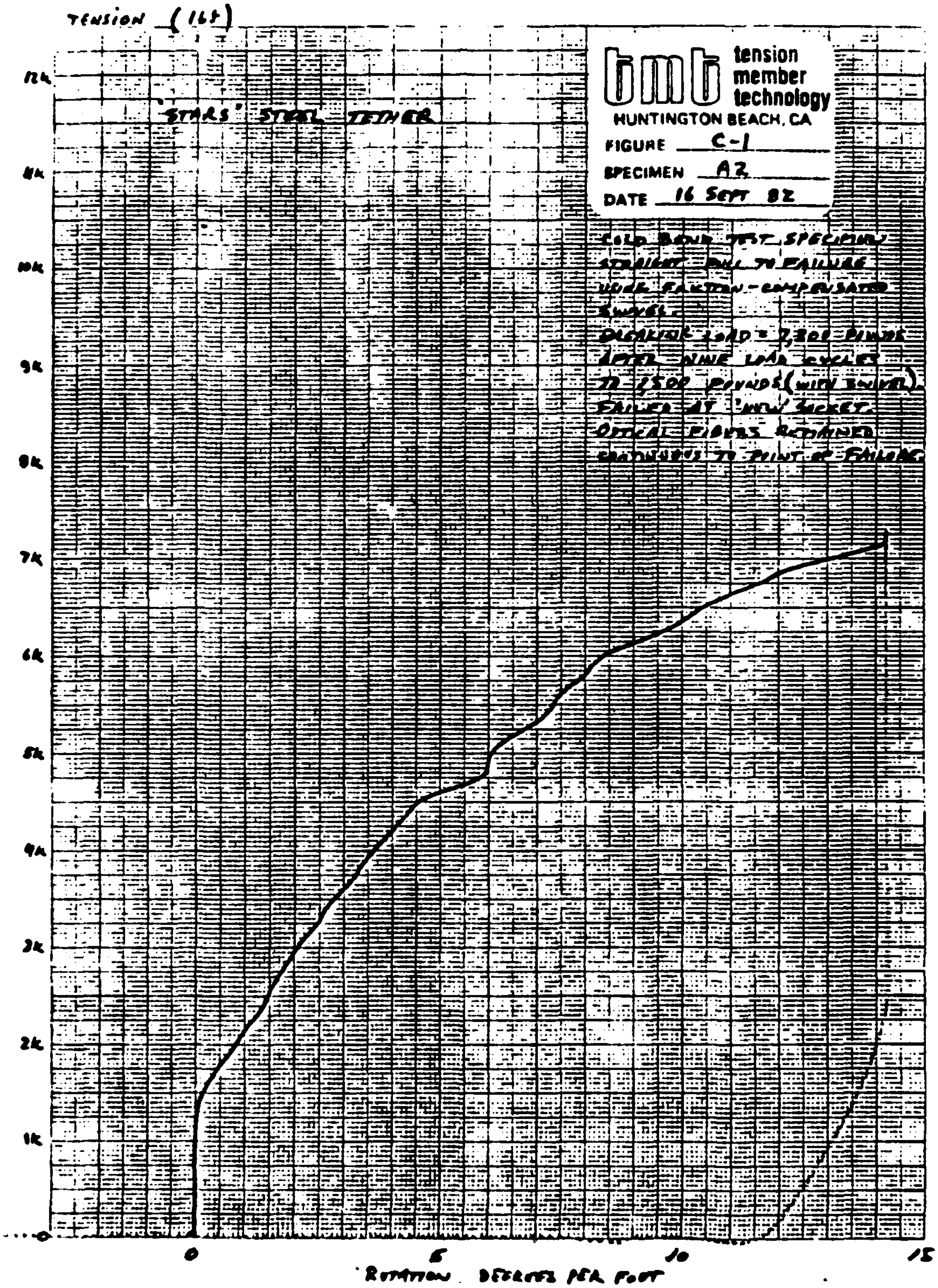
SPECIMEN 348-11C-2
'STARS' KEVLAR

Bending Cycles	Tension, (lbs)	Temperature °F	Loop Resistance (Ohms)	Optical Continuity
0	0	75°	.946	-
0	2,000	75°	1.003 (1.265)*	-
0	2,000	-55°	(1.150)	-
500	2,000	-55°	(1.163)	-
1000	2,000	-55°	(1.176)	-
1500	2,000	-55°	(1.170)	-
2000	2,000	-55°	(1.203)	-
2500	2,000	-55°	(1.193)	-
3000	2,000	-55°	(1.192)	-
3000	0	70°	.948 (1.247)	-

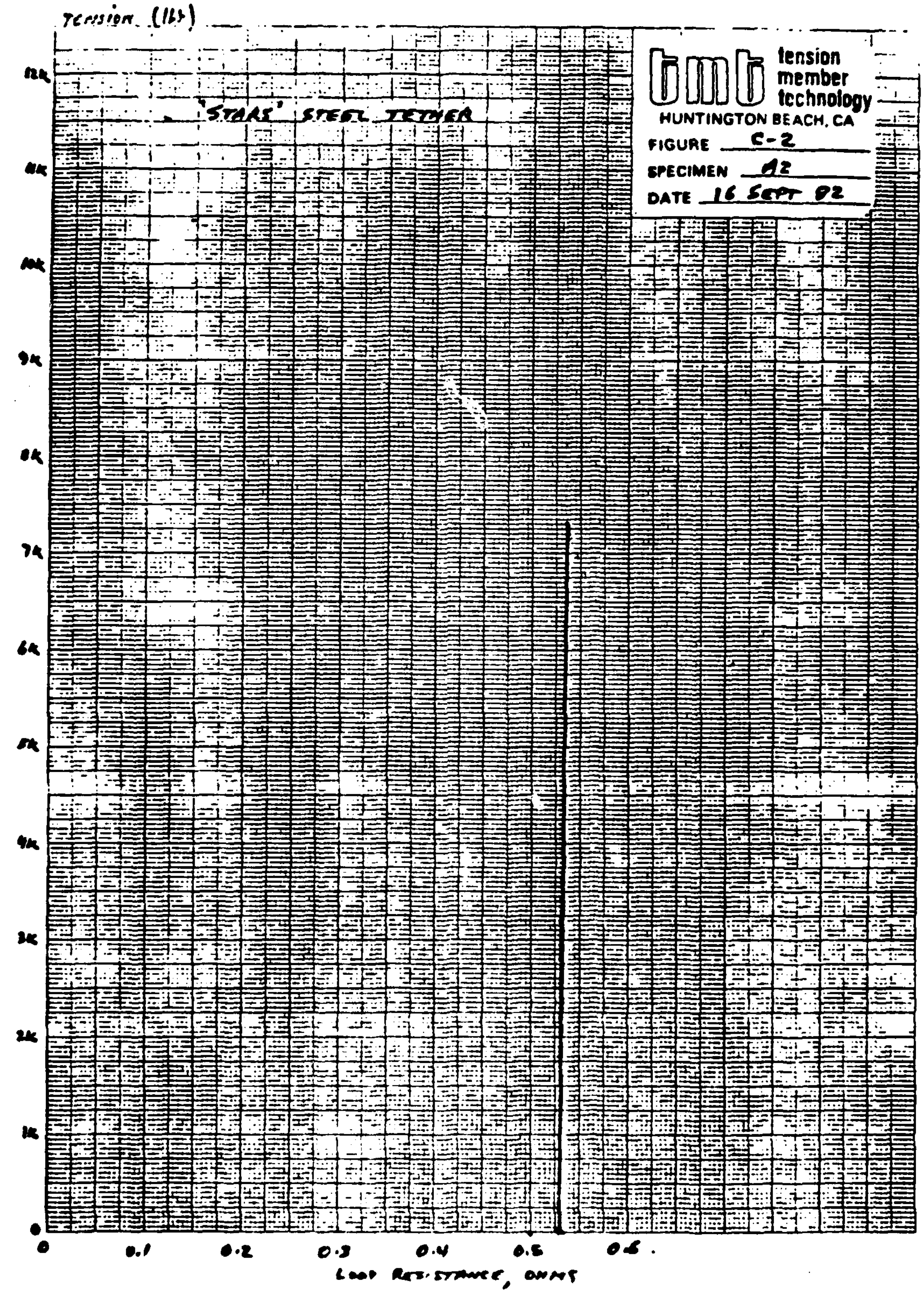
* TOTAL RESISTANCE OF CABLE AND ELECTRICAL LEADS.

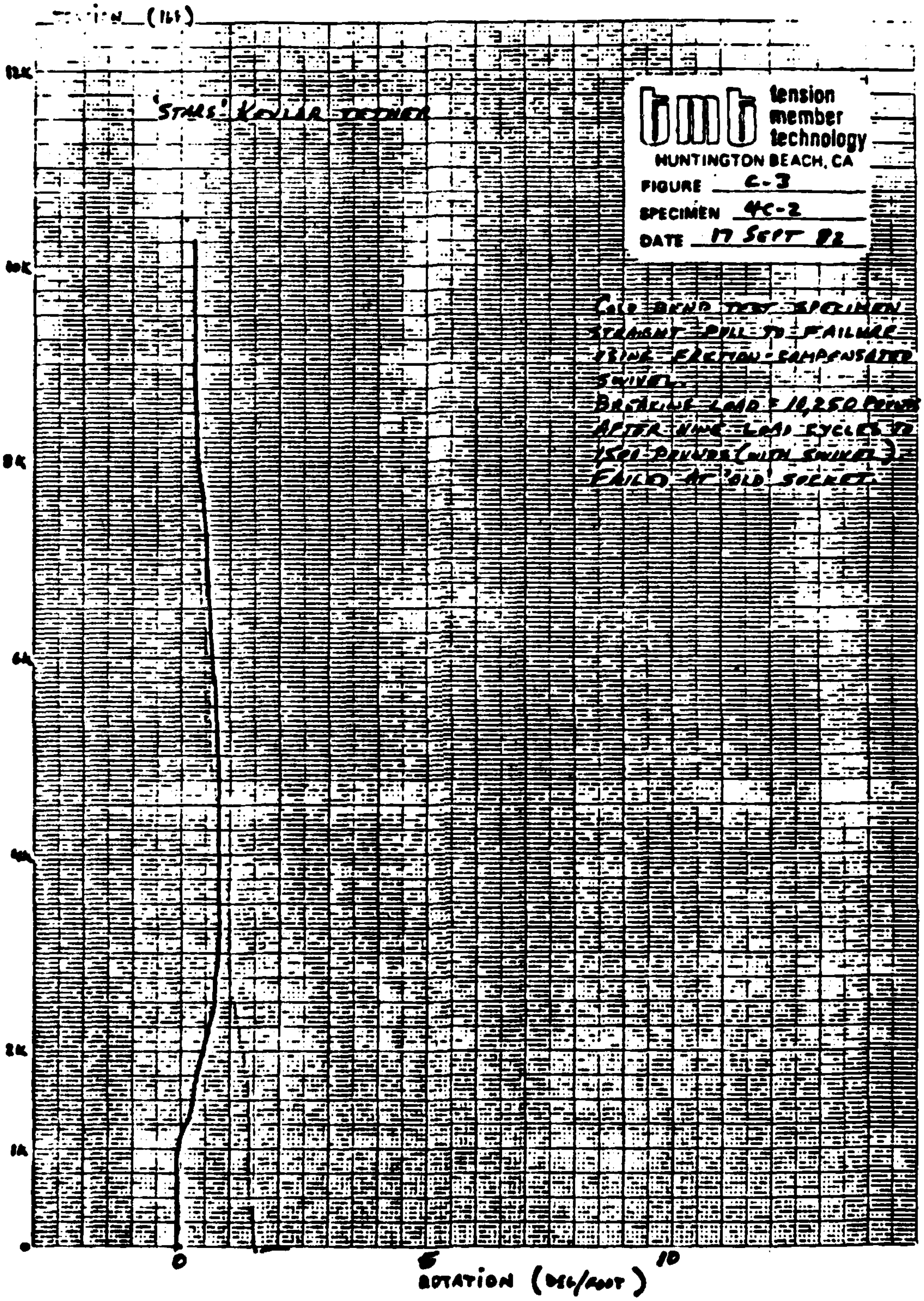
APPENDIX C

DATA SHEETS FOR TENSILE TESTS

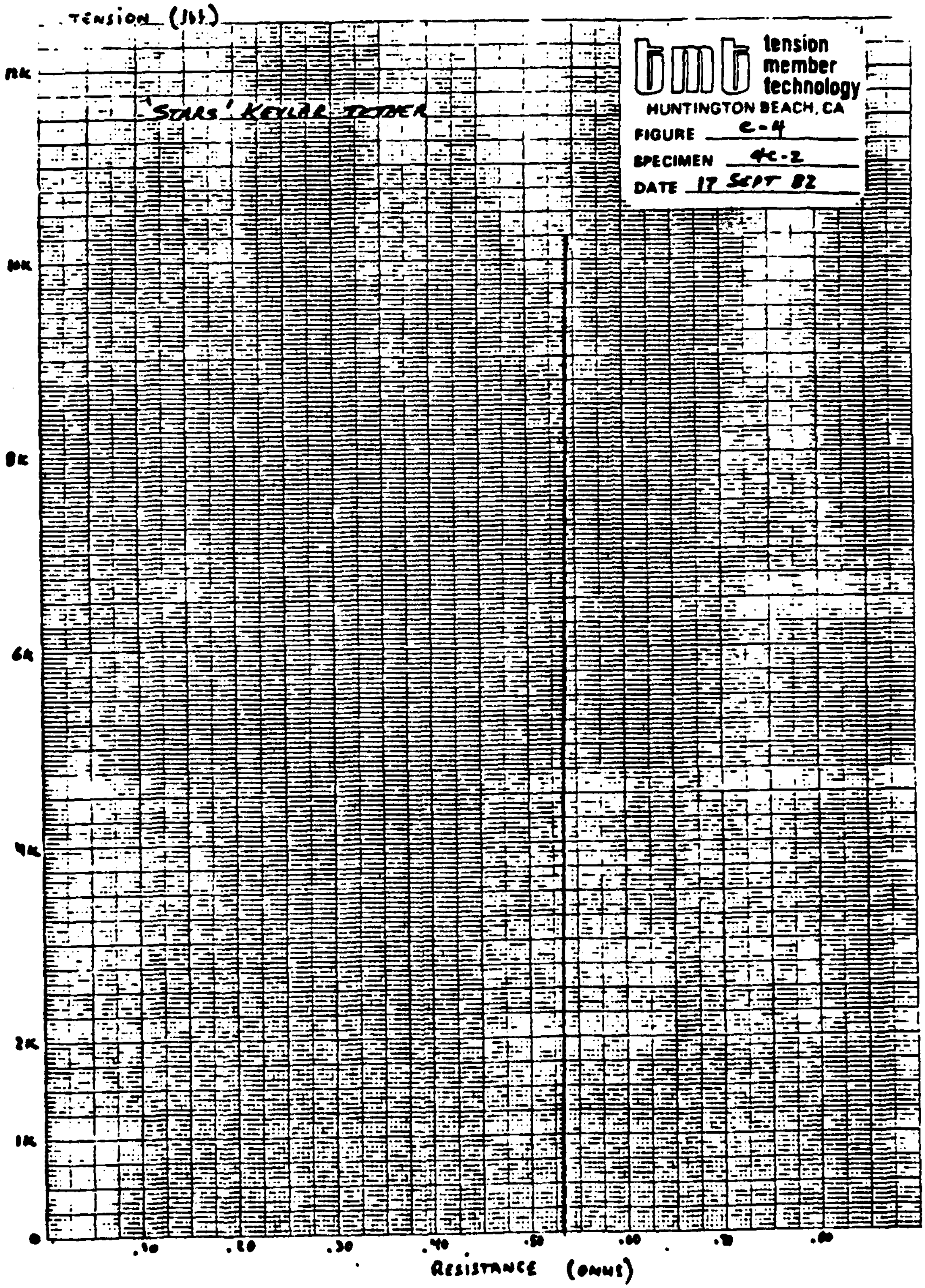


TENSION (lbf)
"STARS" STEEL TETHER
tmt tension member technology
HUNTINGTON BEACH, CA
FIGURE C-1
SPECIMEN A2
DATE 16 SEPT 82
12k
11k
10k
9k
8k
7k
6k
5k
4k
3k
2k
1k
0
0
5
10
15
ROTATION DEGREES PER FOOT


TENSION (lbs)
'STARS' STEEL TETHER
tension member technology
HUNTINGTON BEACH, CA
FIGURE C-2
SPECIMEN A2
DATE 16 SEPT 82
0
0.1
0.2
0.3
0.4
0.5
0.6
LOOP RESISTANCE, OHMS



tension
member
technology
HUNTINGTON BEACH, CA
FIGURE C-3
SPECIMEN 4C-2
DATE 17 SEPT 82
12K
10K
8K
6K
4K
2K
1K
0
0
5
10
ROTATION (DEG/FOOT)



TENSION (lbs)
'STARS' KEVLAR TETHER
tension member technology
HUNTINGTON BEACH, CA
FIGURE C-4
SPECIMEN 4C-2
DATE 17 SEPT 82
12K
10K
8K
6K
4K
2K
1K
0
.10
.20
.30
.40
.50
.60
.70
.80
RESISTANCE (OHMS)