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Some Polyethylene Balloon Statistics

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Abstract

Some pertinent details of the balloon-data-sorting program are presented together with general descriptions of the balloons studied.

The cross section of designs and the quantities thereof, though not extremely large, represent probably the best study sample taken to date.

Fairly conclusive evidence is presented that environmental temperatures at or below the cold brittle transition temperature of polyethylene are not sufficient to produce balloon burst. Finally, it is shown that ambient launch temperature appears to be a critical factor both statistically and from an engineering viewpoint.

The first problem encountered in the analysis of balloon performance was selection of a data-storage system. It was desired that such a system provide for both efficient data retrieval and data processing. Magnetic tape storage in a format designed for multivariable sorting was found to be both efficient and adequate to our needs. However, the current AFCRL balloon-data-sorting program is far from optimum. It simply enables the storage, sorting and retrieval of balloon structural characteristics, ascent data, and environmental factors, all of which are considered relevant to flight performance. Future versions of this program are envisioned to be capable of accomplishing simple correlations.

Table 1 shows the balloon structural information included in the tape storage (fields 10 through 20). Fields 10 through 17 and field 20 are self explanatory. Field 18 shows the printout code for a gore tailored to the theoretical shape. Field 19 consequently shows zero departure from the theoretical shape at both the nadir and apex gore positions. Were the described balloon a 128TT, field 18 would contain the code R-R, designating a rectangular end section at both the nadir and apex. Field 19 would indicate 50.0-64.0, the full gore width, in inches, of the respective end sections.

Table 1. Balloon Structural Information

10. BALLOON VOLUME (cu ft)	5,025,000
11. BALLOON GORE LENGTH (ft)	324.0
12. SIGMA	0.40
13. MATERIAL	POLY
14. MATERIAL THICKNESS (mils)	1.00
15. NUMBER OF GORES	120
16. TAPE STRENGTH (lb)	500
17. TAPE TYPE	FORTISAN
18. GORE PATTERN	FT-FT
19. GORE DIMENSIONS (in.)	00.0-00.0
20. DUCT LOCATION	0.4506

In the second edition printout under this program, sorting by balloon type is greatly simplified. This is accomplished by assigning a design number for each unique set of values in fields 10 through 20.

Table 2 lists some of the flight characteristics and environmental factors considered critical with respect to balloon performance. Among these parameters are ascent rate, wind speed, wind shear, temperature and altitude: of these, a combination such as large wind shear and a temperature near or below the material's ductile brittle transition temperature could well be catastrophic.

The mechanics of data processing having been determined, a second, and more critical problem, remained. This was the two-fold problem of the sufficiency and accuracy of data for each flight to be studied.

Historically, researchers acknowledged their ignorance and maintained detailed records of many of the known and determinable experimental variables, even those

Table 2. Flight Characteristics and Environmental Factors

34. MAX ASCENT RATE (FT/MIN)	43. BURST ALTITUDE (FT x 10^3)
35. MAX ASCENT RATE ALTITUDE (FTx10^3)	44. BURST TEMPERATURE (°C)
36. MAX ASCENT RATE TEMPERATURE (°C)	45. BURST ASCENT RATE (FT/MIN)
37. MIN TEMP (°C)	46. MAX WIND (DEG/KNOTS)
38. MIN TEMP ALTITUDE (FT x 10^3)	47. MAX WIND ALTITUDE (FT x 10^3)
39. MIN TEMP ALTITUDE WIND (DEG/KNOTS)	48. MAX WIND ALTITUDE TEMPERATURE (°C)
40. MIN TEMP ALTITUDE ASCENT RATE (FT/MIN)	49. MAX WIND SHEAR (KNOTS/1000 FT)
41. TROPOPAUSE HEIGHT (FT x 10^3)	50. MWS ALTITUDE BAND (FT x 10^3)
42. TROPOPAUSE TEMP (°C)	51. MIN TEMP (°C) IN MWS ALTITUDE BAND

apparently unrelated to their experiments. Thereby they were eventually able to discern the apparent casual relationships that form the bases of current physical laws and theories. Unfortunately, this diligence is infrequently the case today, particularly in fields such as balloon technology where the crush of operational requirements and the complexities of recording minute details are not always completely compatible. Often, until a problem arises, the need for detailed performance data goes unrecognized. Likewise, this need is often forgotten once the problem is solved. Consequently, data are frequently sporadic and incomplete.

The validity of the conclusions derived from the analysis of flight data depends directly upon the accuracy of the input data. In this regard, summarized records are less desirable than careful analysis of the systematic plot of data telemetered from on-board radiosondes and barocoders. Quite properly, this procedure requires a supervised team to insure consistent application of subjective judgments. To be sure, this ideal has not been achieved in the case of all, or most, of the flights studied, but conscientious contractor supervision and data analysis by Mr. Joseph Hess (of AFCRL) have provided a quantity of such flights. Considerations such as these should help to explain the apparently arbitrary selection of our data.

Since design is per se a substantial factor in flight performance, and since success-failure data are plentiful, the approximately 300 flight records stored on the program tape were selected on the basis of balloon design, complemented by as much atmospheric and flight characteristic data as were obtainable. Much of the weather data was derived from the most nearly contemporaneous preflight or post-flight radiosonde run taken at the station nearest the launch site. An additional hand compilation contains data on balloon design and temperatures for the balance of flights since August 1962, at which time the need for recording a minimum of analytical data became more evident.

Two points should be made here. First, al' flights studied to date pertain to balloons fabricated from DFD 5500 resin. Second, all of the success-failure statistics are based upon flights during which the balloons either burst on ascent or successfully reached float altitude. Balloons that leaked have not been included.

In order to get a broad picture, first consideration is given to a breakdown of the balloons studied herein. Table 3 shows the variety of these balloons and lists

Table 3. Study Balloons

VOLUME (million cu ft)	MATERIAL THICKNESS (mil)	BALLOON TYPE	NUMBER
13.6	0.75	Taped (cap)	3
11.85	1.0	Taped	2
5.27	0.75	Taped	2
5.27	1.0	Taped	14
5.02	1.0	Taped (cap)	25
5.02	1.0	Taped	2
4.85	0.75	Taped	22
3.8	2.0	Taped	1
3.2	2.0	Taped	2
2.94	1.5	Taped	129
2.68	1.5	Tapeless	6
2.66	1.0	Taped (cap)	1
2.4	1.5	Taped	1
2.0	1.5	Taped	12
2.0	1.0	Taped	2
2.0	0.75	Taped	1
1.68	2.0	Taped	7

Table 3. Study Balloons (Cont.)

VOLUME (million cu ft)	MATERIAL THICKNESS (mil)	BALLOON TYPE	NUMBER
1.31	2.0	Taped	7
1.25	1.0	Taped	4
128 feet (diam)	2.0	Tapeless	32
111 feet (diam)	1.5	Tapeless	11
111 feet (diam)	2.0	Tapeless	2
107 feet (diam)	2.0	Tapeless	17
104 feet (diam)	1.5	Tapeless	1
66 feet (diam)	2.0	Tapeless	3

some pertinent information on their design and the number of each studied. In volume, they range from approximately 13.6 million cu ft to 125,000 cu ft. In construction they include: (1) taped balloons with fully tailored gores (for example, 5.025×10^6 cu ft); (2) taped balloons with 5-inch, taper-tangent end sections (for example, 2.94×10^6 cu ft); (3) taped balloons with rectangular end sections (for example, 4.85×10^6 cu ft); (4) tailored tapeless balloons (for example, 2.68×10^6 cu ft and the ever popular 128TT); and (5) cylindrical tapeless balloons, the work horse 66CT.

It is appropriate to note here the predominance of 1.5 mil balloons (160 each), most of which are of the so-called 2.94 design. The representation of other film thicknesses is not as great as was desired, but this condition will be remedied in the next general analysis. The second most plentifully represented film is 2.0 mils thick (71) followed by 1.0 mil and 0.75 mil film, with representations of 50 and 28 respectively.

Table 4 shows seven balloon sizes, each of which has a reasonable representation in the study. Caution is advised against the first impression that larger balloons should fare better than smaller ones. The relationship actually implied here is subtly masked by a coincidence, which will become evident later. Probably volume is significant, but neither in the manner nor to the degree here depicted.

Next in the general picture is the overall percentage of success. The record for the 309 flights is 78 percent.

From this point on, the data presented is not general and descriptive. Success percentages were computed with respect to two air-temperature points in the ascent history of the balloons. Material thickness is the only other factor given consideration. There are four reasons for this. First, there is some indication that

Table 4. Breakdown by Volume

VOLUME IN MILLIONS OF CUBIC FEET	NUMBER OF CASES	PERCENT SUCCESS
5.27	16	87
5.02	27	74
4.85	22	72
2.94	129	90
2.0	15	100
0.80	32	59
0.4	17	58

temperature is critical. Second, temperature records of the accuracy required for the analysis were most abundant. Third, although there are indications that other factors such as high ascent rate may adversely affect the flight, no simple relationship between these parameters and the balloon material properties is known. Finally, a valid analysis including other parameters would require a detailed study of each ascent trajectory, a study not suited to our simple program.

With this reasoning established, the first additional bit of information to be presented is percent success versus minimum temperature encountered during ascent. No graph is needed: study of success versus failure over the range of minimum temperature encountered by 196 flights shows variations in the percent success of only ± 2 percent. This is, to say the least, unexpected, but not unacceptable. Experience of quite a few years ago in Hawaii, using the "128TT", showed no problem in passing through temperatures as low as -90°C. The minimum temperature encountered in our 196 flights was -76°C, and 64 of these flights penetrated temperatures below -68°C.

The second temperature selected for study was launch temperature. The primary reason for this choice is its relation to creep, a subject discussed in depth by Dr. Kerr.

The information shown in Figure 1 is somewhat disturbing in its implications. The number 47 represents the approximate number of flights in each temperature range, ranges made arbitrarily large in order to achieve these relatively equal samples. It can be seen that launch temperatures between -10°C and + 6°C have an accompanying 80 percent success record. Those between + 6°C and + 12°C have an accompanying record of 79 percent success; those between + 12°C and + 19°C a record of 70 percent success; and those between + 19°C and + 31°C a record of 57 percent success.

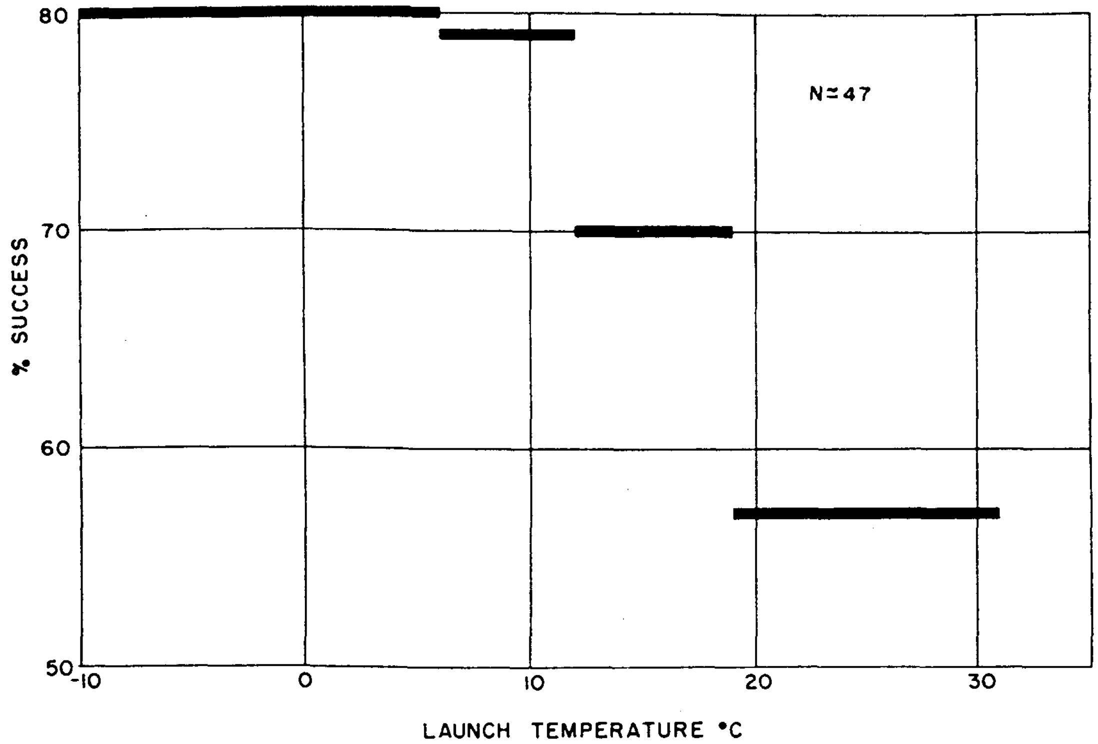

Figure 1. Percent Success Versus Launch Temperature

The 57 percent success record at launch temperatures warmer than 18°C made it imperative that the contributing flight records be more closely examined. Further analysis revealed that approximately half of the balloons in this grouping were made from 2.0 mil film, which dictated that the overall record of percent success versus film thickness be studied. This was done and the record showed clearly that the 2.0 mil film balloons in this study had an inferior record. The percent success record was: 1.5 mil, 91 percent; 1.0 mil, 80 percent; 0.75 mil, 72 percent; and 2.0 mil, 51 percent. These results were sufficient to warrant discarding the 2.0 mil balloons statistics. However, we did not reject them, but merely set them aside for a reason that will soon become apparent.

The new record (2.0 mil film balloons excluded) was encouraging in that the overall success record was nearly 83 percent for 248 flights. Again the minimum temperature relationship was evaluated, and the variation in percent success was only ± 2 percent.

A second look at dependence upon launch temperature showed that for four approximately equal samples (temperature range again free to change with sample size), the record was: -10°C to +4°C, 86 percent success; 4°C to 11°C, 86 percent success; 11°C to 18°C, 79 percent success; and greater than 18°C, 71 percent success.

Again, we are back to what appears to be a significant decrease in success for the warmer launch temperatures. Certainly the warmer launch temperature appears to be considerably more critical than the minimum temperature. In the original sample and in the sample reduced by removing the 2.0 mil film balloons, the percent success for flights with minimum temperature at or below the specified cold brittle temperature (-68°C) was 74 percent and 82 percent respectively.

Both laboratory and operational experience have shown that elevated temperatures can cause large deformations in stressed polyethylene film structures. The deformations due to inflation and launch stresses were fatal in some of the cases and may have been nearly so in others. Certainly balloons with large cylinder-end sections and massive rudders provide food for thought in this regard.

It is now appropriate to reconsider the 2.0 mil film balloons. Figure 2 shows the minimum temperature and launch temperature for the three predominant designs

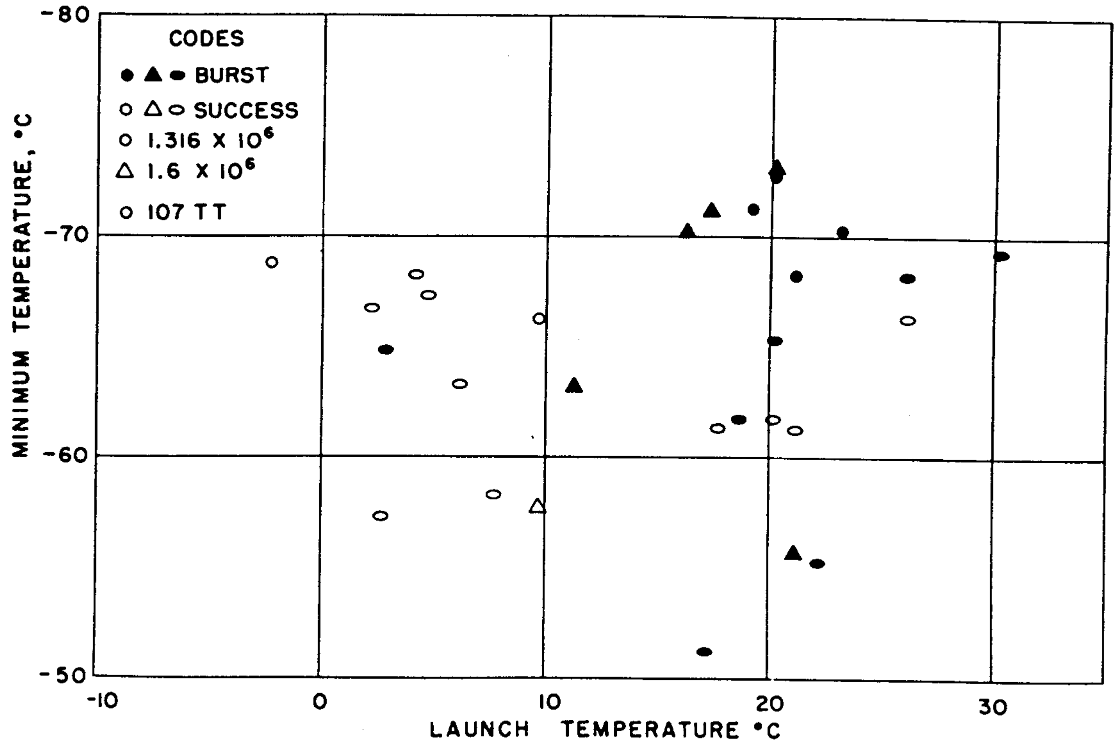

Figure 2. Balloon Performance Versus Launch Temperature and Minimum Ascent Temperature

included in the study. All of these balloons have cylinder end sections. The 1.6 million cu ft balloon also has nylon tapes. Note that the two lone successes with the 1.316 million cu ft balloon occur at the cooler launch temperatures. The payloads on these were 100 to 200 lb heavier than were the payloads on the four balloons of this type that failed. The sole success with the 1.6 balloon also occurs at a cooler launch temperature, and the percent success of the 107TT is much nearer the overall average at launch temperatures cooler than 10°C.

This poor record with the 2.0 mil balloons contradicts AFCRL's experience with a much larger number of 2.0 mil balloons that are not included in this study. These latter balloons are the 128TT balloons flown under the VHA project and the early heavy-load balloons, one to three million cubic feet in volume, all of which were made with 2.0 mil film furnished by the Government from the first volume production under MIL-P-4640A (USAF).

This last bit of information, together with an appreciation for the problems of obtaining uniform resin lots and the difficulties involved in obtaining quality and uniformity with small quantity extrusion orders, might go a long way in explaining sudden rashes of failure with a balloon of proven design.

Since the launch temperature effect appears not to be confined to balloons made from 2.0 mil film, a look at some other balloon statistics is in order. Figure 3 shows a major portion of the record of the capped 5.025 balloon. Again a pattern of bursts in the warmer temperature range appears. If this effect is truly related to the launch temperature, and possibly to the creep phenomenon, it may help to explain why some of these balloons succeeded with payloads of 3000 lb (cool launch temperatures) and failed with payload of 2500 lb (around 20°C launch temperature).

Obviously, this possible factor cannot be the whole story, for there is some indication that at launch temperatures above 18°C the percentage of bursts increases with decreasing minimum ascent temperature values. Surely, too, if this factor is important, gross load and length of time at elevated launch temperature are necessarily relevant. These are questions which this study has created. Their analysis, in greater depth, will be next year's work.

Although our results, to date, certainly have not solved the complex problem of ascent burst, we have made a profitable start. An adequate data-storage program was set up and is proving its utility. Moreover, we are able at last to view the record as it stands, and to discard some of our surmises regarding the burst phenomenon. More important even, at this point, the results reemphasize the necessity for: (1) obtaining many more sets of continuous data on the finer structure of the balloon-ascent environment; and (2) searching for a more accurate description of the relationships between the mechanical properties of polyethylene film and the thermal and dynamical properties of the atmosphere.

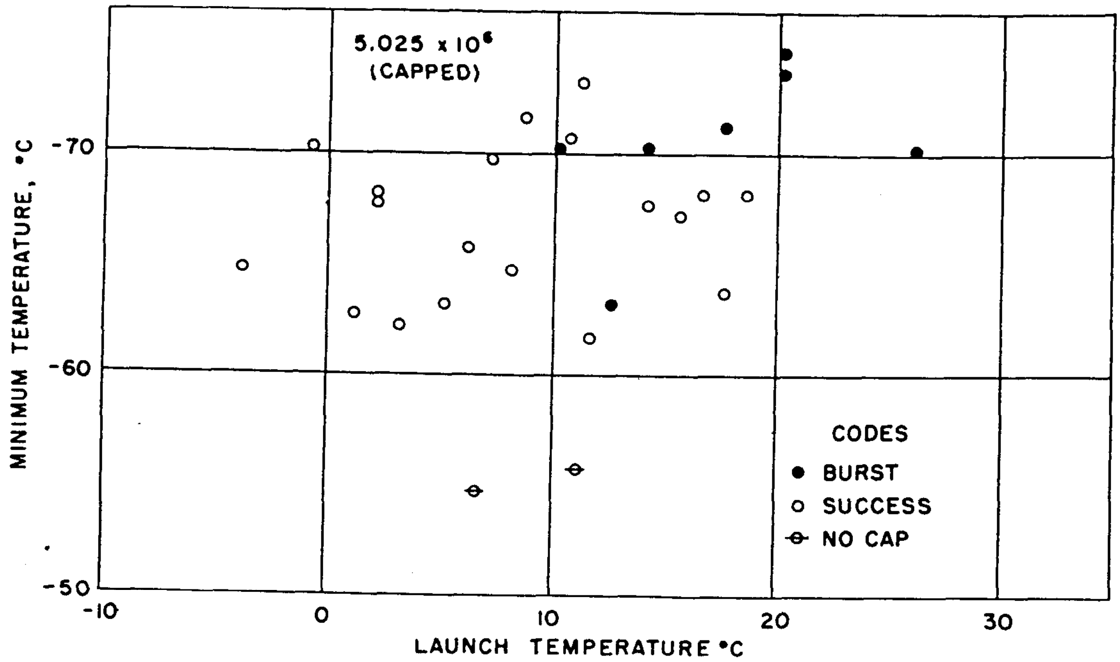

Figure 3. Balloon Performance Versus Launch Temperature and Minimum Temperature