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SOUNDING ROCKET PARAMETERS VERSUS FLIGHT RELIABILITY

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GODDARD SPACE FLIGHT CENTER
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Test and Evaluation Division
Systems Reliability Directorate

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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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VERSUS FLIGHT RELIABILITY

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REPORT STATUS

This report describes the investigation of various flight parameters of Sounding Rocket payloads versus their correlation with flight failure or success. It is intended to fill gaps in knowledge of the Sounding Rocket Program Success history and to serve as a basis for further study in the area of test planning versus resultant success.

Authorization

Test and Evaluation Division Charge No. 326-879-60-25-01

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by

Brian C. Pierman

SUMMARY

The physical parameters of Sounding Rockets, flight weight and number of telemetry channels were compared to flight failure rates for the purpose of developing a basis for the selection of environmental tests to be applied to Sounding Rocket payloads. Correlation between greater weight and decreased flight success is established, while no correlation is established between telemetry channels and flight success.

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SOUNDING ROCKET PARAMETERS VERSUS FLIGHT RELIABILITY

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INTRODUCTION

This study was performed to provide a better understanding of Sounding Rocket failures and to aid in the selection of environmental tests applicable to particular Sounding Rocket payloads.

In general, all rocket payloads are subjected to flight-level sine and random vibration testing. Other appropriate testing, such as shock, acceleration, spin deployment, and corona is accomplished according to the characteristics of the individual payload. It is with respect to the selection of these optional tests that sophistication is desired, to increase the probability of selecting optimum environmental tests for high space-hardware reliability.

The goal is to establish a correlation between some payload constant and a relational effect on flight reliability. In this area, various parameters of NASA/GSFC spacecraft have been investigated.[1] The most common data has been spacecraft weight, number of component parts, and last, the number of telemetry channels aboard. A primary problem with previous research, the sample size for orbital spacecraft (usually limited to a flight, prototype, and engineering test unit for a particular type spacecraft), does not exist when conducting studies in the Sounding Rocket program, due to the fact that in excess of one thousand rocket launches have been conducted to date by NASA. With these thoughts in mind, data collection and analysis proceeded.

DATA

Sounding Rocket flight data was collected from flight plans located in the Sounding Rocket Branch files. Included were flight weight, less ballast, and the number of telemetry channels on-board rockets flown from July 1, 1963 to October 3, 1967. Excluded from the sample were test flights and Arcas Rocket flights, the number of which were small and not considered representative as a sub-category of the sample. The sample surveyed, less exclusions, totaled

1. Unpublished research of A. Timmins, Flight Program Office, Test and Evaluation Division, Goddard Space Flight Center.

547 flights. Flight results, in categories, success, partial success, or failures, were taken from the Compendium of Sounding Rocket Flights, printed by Vehicles Section, Sounding Rocket Branch. Partial success and successful flights were considered together and compared to flight failures. Flights which were failures due to Rocket malfunction were eliminated from the sample since they were not related to payload reliability.

The size of the remaining sample, 547 flights, was considered large enough for analysis.

ANALYSIS, WEIGHT VERSUS RELIABILITY

Two assumptions are basic to this portion of the investigation:

1. That increased weight of a payload indicates an increase in complexity (due to the greater number of components and subsystems contributing to the weight increase).

2. That this increased complexity leads to greater numbers of flight malfunctions.

It is possible to point to violations of these assumptions, a simple detector which requires a very heavy structure to maintain alignment, being one. However, due to the rarity of these exceptions, and the broad data base studied, the assumptions were considered appropriate. Examination of the data showed the following:

1. That the average weight of successful and partially successful (hereafter referred to as successful) flights in the sample was 102 pounds, there being 501 flights in this category.

2. That the average weight of flight failures in the sample was 126 pounds, there being 46 of these.

The 24 pound difference between average success and failure weight, 23.5 percent greater weight of failures versus successes, indicates a basis for the assumptions and prompts further investigation.

Breakdown of these statistics by type of launch vehicle further defines the relationship between average payload weight and success in flight. As shown in Table 2, similar relationships exist in all but the Javelin history. This discrepancy, based on one failure per 26 flights, is considered a sampling problem rather than a deviation from the general correlations existing in other rocket areas. This data is presented in Table 2.

TABLE 1
Flight Weight Versus Flight Results

	Flight Success	Flight Failure	Total Sample
Number of Payloads	501	46	547
Percent of Payloads	92%	8%	100%
Average Weight Per Payload (#)	102#	126#	105#

TABLE 2
Weight of Flight Successes and Failures by Launch Vehicle

Type of Vehicle	Total Flights in Sample	Number of Flight Successes	Number of Failures	Average Weight of Flight Successes	Average Weight of Flight Failures
Aerobee	126	113	13	211	233
Apache	243	220	23	69	71
Cajun	152	143	9	79	100
Javelin	26	25	1	120	99

In addition, a check of the statistical difference between the failure sample and the total Aerobee weight sample was conducted using the Student's Test. (This test was confined to the Aerobee samples since all other groups were found not normally distributed.) The difference in mean weights was found to be significant at the 95% confidence level for a "t" of 2.7, using twelve degrees of freedom. This value indicates that a genuine difference exists in the failure sample versus the total Aerobee sample.

Expanding the relationship between payload weight and flight failure, it is possible to determine the failure rate of payloads whose weight falls within a chosen bracket, such as 60 to 80 pounds or 61 to 81 pounds. Doing this for many weight groups, and plotting the values, results in portrayal of the change in reliability with increasing payload weight. It should be noted that the average weight in a particular bracket only approximates the median of the bracket, but for large samples, the approach produces good results. Such a plot is presented in Figure 1 for the Apache payloads in the sample. All twenty-pound brackets between 40 to 60 and 90 to 110 pounds were calculated and plotted.

The failure rate in the plot rises fairly linearly with increasing payload weights, as expected. A similar plot is presented in Figure 2 for payloads launched on Aerobee vehicles. This presentation indicates a reversal from decreasing to increasing reliability as the weight bracket passes approximately 200 to 300 pounds and increases. This observation appears to contradict the basic suppositions. To better understand the anomaly in the Aerobee statistics, a weight versus frequency plot was constructed, shown in Figure 3. The plot is nearly symmetrical and lends itself to statistical analysis. The standard deviation was calculated with the following results:

1. Flights with weights less than minus one standard deviation (-1σ) had a failure rate of 4%.

2. Flights with weights falling in the ±1 standard deviation area had a failure rate of 12%.

3. Flights with weights in the greater than one standard deviation ($+1\sigma$) failed at the rate of 10%.

These calculations also show a decrease, albeit small, in failure rate at high weight levels. The anomaly is believed to be due to the grouping of partial success and successful flights together, and the increased probability of partial success, with multiple experiments, per a single payload. Examination of the utilization of dual experiments on Aerobee launch vehicles indicates increased prevalence above approximately 230 pounds, continuing to the vehicle maximum weight of 360 pounds.

As a sidelight, the need for more extensive payload testing, in actuality, does increase in some fashion with increasing weight. This is portrayed by Figure 4 in terms of percentage of payloads in a 100 pound moving weight bracket having been tested. One can see the increase in testing with weight increase of payloads.

ANALYSIS, TELEMETRY CHANNELS VERSUS RELIABILITY

Similar assumptions as were presented in the weight analysis are pertinent to the discussion of telemetry channels, namely, complexity of the payload is directly related to number of telemetry channels, and that greater complexity

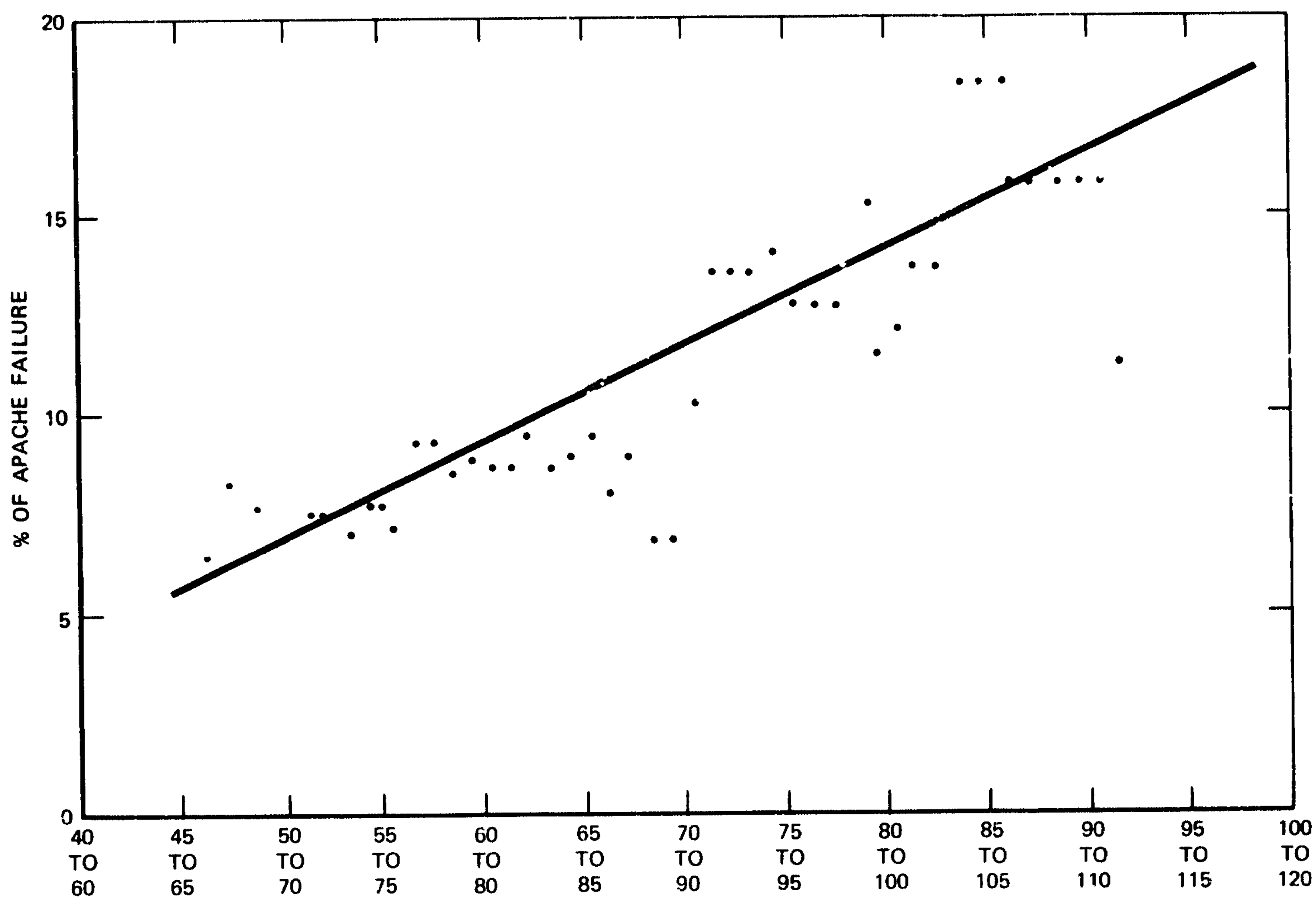

Figure 1. Percentage of Apache Failure Per Flights Falling in a 20 lb, Moving Weight Bracket

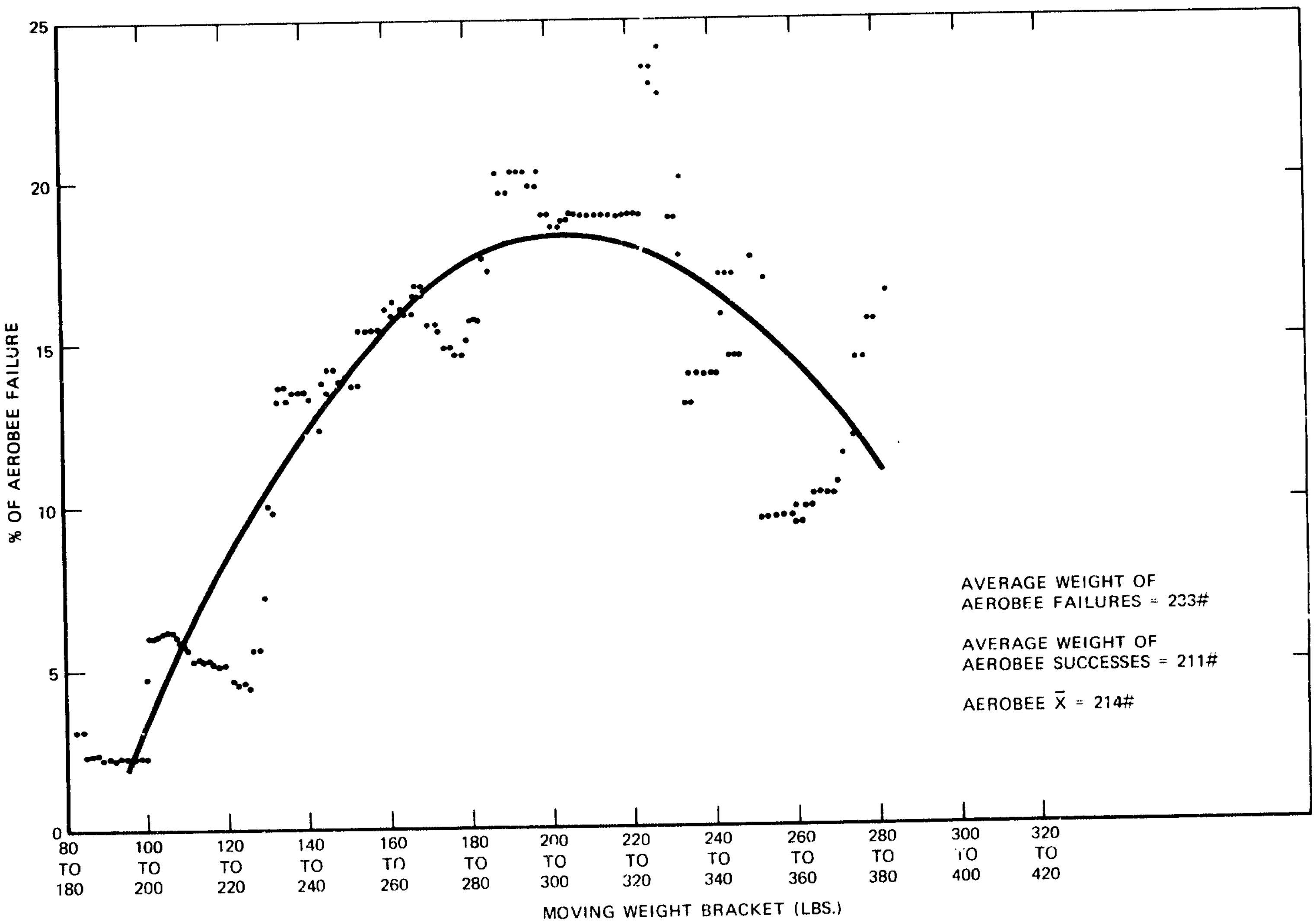

Figure 2. Percentage of Aerobee Failure Per Flights Falling in a 100 lb, Moving Weight Bracket

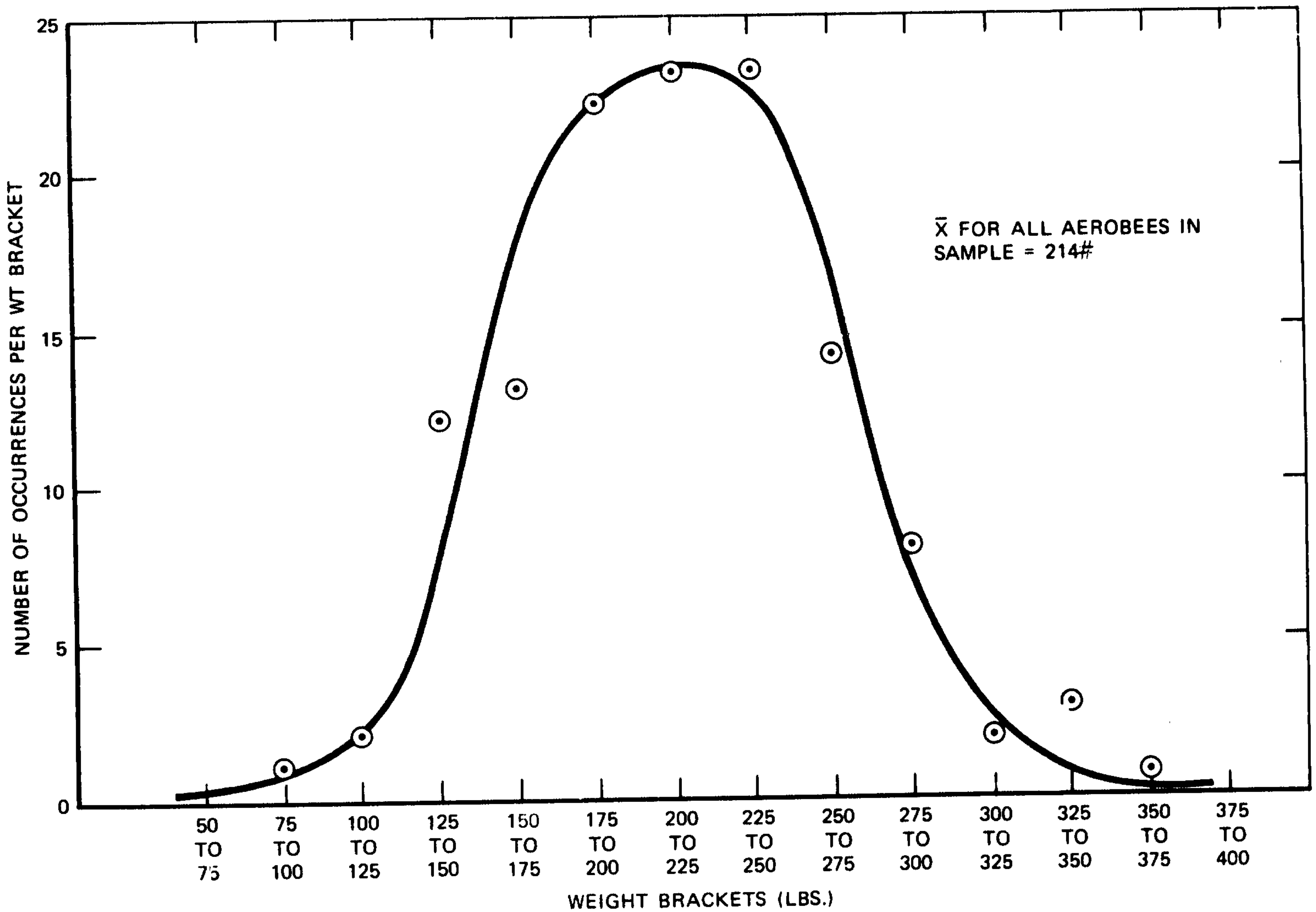

Figure 3. Occurrence of Aerobee Flights in Given, Moving Weight Brackets

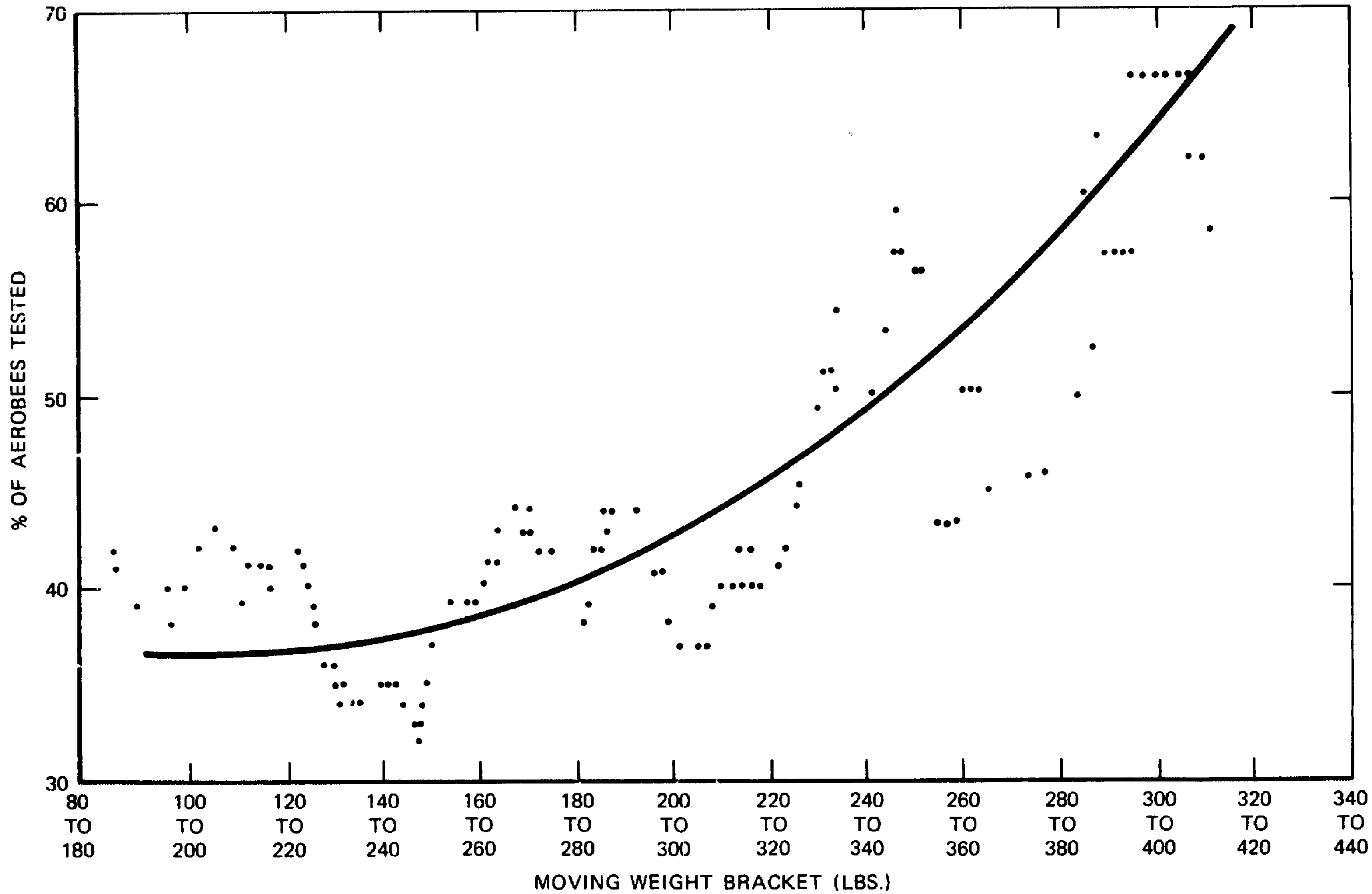

Figure 4. Percentage of Aerobees Tested Per Flights Falling in a 100 lb, Moving Weight Bracket

increases the probability of flight malfunction. Such assumptions, in this case, cannot be justified by the data analysis. As shown in Table 3, the average number of TM channels per successful flights was found to be 6, compared to 7 channels per the flight failures. A total of 511 successful flights and 44 flight failures were analyzed. These data are also presented in Table 3. This table seems to indicate that increased TM channel allocation is related to increased failure rate. Examination of the breakdown by vehicle, as presented in Table 4, indicates the channel averages for successful Aerobees, Apaches, and Javelins are nearly identical to the corresponding failure averages for those vehicles. Since only

TABLE 3
Flight Telemetry Statistics

	Flight Success	Flight Failure	Total Sample
Number of Payloads	511	44	555
Percent of Payloads	92%	8%	100%
Average Number of TM Check Per Payload	6	7	6

TABLE 4
Number of Channels on Flight Successes and Failures by Launch Vehicle

Type of Vehicle	Total Flights In Sample	Number of Flight Successes	Number of Flight Failures	Average TM Channels of Successes	Average TM Channels of Failures
Aerobee	127	113	14	13.1	13.4
Apache	243	220	23	4.3	4.3
Cajun	152	143	9	3.3	1.1
Javelin	26	25	1	11.6	12.0

one of the four vehicles analyzed displayed the necessary relationship in distinct terms, the suitability of this indicator of reliability is questionable. The character of the data, after thorough investigation is attributed to the following considerations:

1. For Aerobee users, the PPM telemetry system is available and often times desirable. This system provides a standard 16-channel format whether the total 16 channels are required by the experimenter or not. A simple experiment then is recorded as utilizing 16 channels. The same experiment utilizing an FM-FM tailored system may only carry 8 or 10 channels.

2. The character of the data is another consideration which vastly changes the channel situation. The retrieval of slowly changing data can economically be accomplished by commutation of many instruments on a single channel. If the data is fast changing, such a method may be replaced with an individual channel for each information stream. Such idiosyncrasies alter the character of channel statistics, and not necessarilly in a manner functionally related to increased complexity of payloads.

CONCLUSIONS

Analysis of a large sample of Sounding Rocket data, specifically, flight weight, number of telemetry channels aboard, and flight results, indicates a relationship between increased flight weight and decreased reliability, strengthening the assumption that reliability decreases with increasing complexity, and that complexity on the whole, increases with weight.

Conversely, the evaluation of telemetry channels compared to flight reliability shows no significant correlation between the two, attributed primarily to the following considerations:

1. Utilization of channel commutation allows receipt of multiple bits of slowly changing data on a single channel. This method is extremely effective in saving telemetry channels, but compromises the study since it is dependant on a certain type of data.

2. Standard telemetry systems such as the PPM system provide a fixed number of channels such as sixteen, whether or not needed. This system is commonly used on Aerobee launched payloads.

Because decisions to test a rocket payload must be based on particular characteristics of that payload, specific test criteria will not be derived using the data presented herein. It is believed, however, the awareness of past payload weights and corresponding failure rates represents an alert system to experimenters who, for weighty payloads, may consider the following:

(a) Supplemental instrumentation during vibration testing to detect critical vibration loads throughout the payload.

(b) Necessity for complete turn-on during vibration to qualify all payload functions.

(c) Necessity for pressurization to 15 psi above atmosphere during all testing of subsystems which are sealed and must remain sealed during flight.

With these observations, coupled with other considerations such as cost of testing, cost of payloads and rockets, and characteristics of individual payloads, it is believed that a sophisticated approach to test design may be achieved. It is with this goal in mind that the study is presented.