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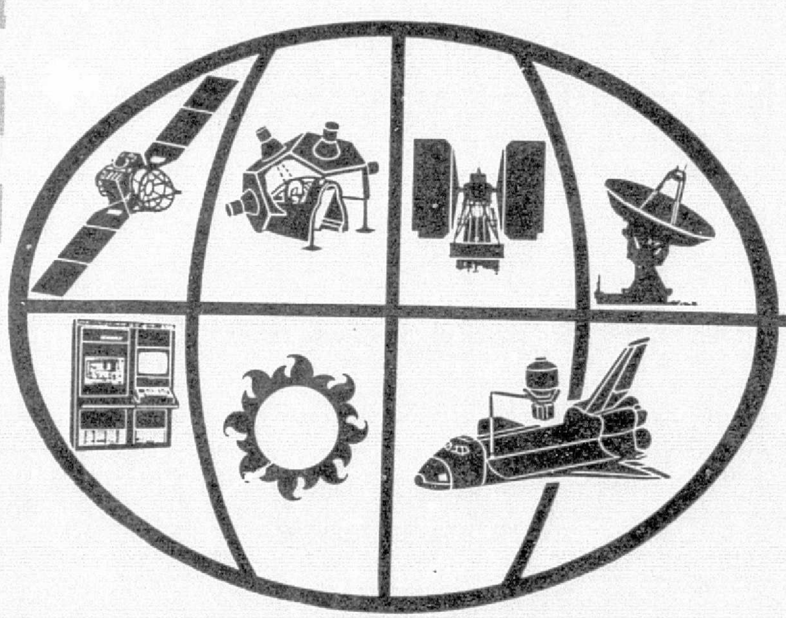
September 16, 1977

SHUTTLE PAYLOAD
VIBROACOUSTIC TEST PLAN EVALUATION

FREE FLYER PAYLOAD APPLICATIONS
AND
SORTIE PAYLOAD PARAMETRIC VARIATIONS

Prepared Under: Contract NAS 5-23840

Prepared for
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center



space division

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FOREWORD

The study, "Shuttle Payload Vibroacoustic Test Plan Evaluation, Free Flyer Payload Applications and Sortie Payload Parametric Variations", presented herein was performed by the General Electric Space Division, Valley Forge, Pennsylvania, for the NASA Goddard Space Flight Center under contract NAS 5-23840. The Program Manager was Clyde V. Stahle and the principal investigator was Harold R. Gongloff. The NASA technical monitors, who provided valuable guidance throughout the course of this study, were W. Brian Keegan and Joseph P. Young.

This study is a continuation of the study performed for NASA-GSFC under contract NAS 5-20906. The results of that study are contained in two GE-SD reports:

1. GE Document No. 76SDS4223, "Vibroacoustic Test Plan Evaluation", three volumes, June 1, 1976.
2. GE Document No. 76SDS4285, "Vibroacoustic Test Plan Evaluation, Parameter Variation Study", December 31, 1976.

SUMMARY

In this study the effort was directed at a preliminary assessment of vibroacoustic test plan optimization for free flyer STS payloads and evaluating the effects on alternate test plans for Spacelab sortie payloads of the number of missions, the component vibration failure probability and the number of components in the housekeeping subassemblies. The statistical decision model developed in the previous study was extended to include operational strategies for free flyer payloads and used directly for Spacelab sortie payload parameter variations. The decision models used in this study evaluate the cost effectiveness of seven alternate test plans using protoflight hardware: no testing, component testing, subassembly testing, system testing and combinations of component and subassembly testing or component and system testing. Either no structural test or a protoflight structural test is included in the test plans. The decision model determines the expected project cost by combining the direct costs which are known to be incurred with a particular test plan and the probabilistic costs of failures during ground testing and flight. The decision models determine the minimum expected cost of each test plan and the associated design/test levels. By comparing the minimum costs obtained with the various test plans, the test plans can be ranked on a cost basis. Similarly, the payload reliability (the probability of losing any payload data during flight) associated with the minimum expected project cost is determined, providing a reliability ranking of the alternate test plans.

The STS free flyer statistical decision models were developed considering operational strategies that enable the payload to be flown, returned, or replaced, depending on its condition prior to release from the shuttle. The strategies consider the types of

failures encountered, the number of experiment failures, and either a geosynchronous or near earth orbit. Two free flyer payloads, whose configurations are representative of Landsat-D and Solar Maximum Mission payloads, were evaluated for each type of orbit. For either orbit, the three test plans having the lowest cost were the subassembly test, system test, and component and subassembly test options. The no-test option shifted from a cost rank of 7 for geosynchronous payloads to a cost rank of 4 for near earth payloads. The test plan reliability ranking generally followed the cost rank, except for the no-test option which provided the lowest flight reliability regardless of cost rank. A $4M expected cost variation occurred between the least costly and most costly test plan. The component design/test vibration levels and the assembly acoustic test levels associated with the optimum cost were significantly higher for the geosynchronous orbit than for the near earth orbit. Because the free flyer results are limited to a single set of preliminary cost estimates, additional parameter variations should be made before the results are generalized.

Three spacelab sortie payload configurations of the previous study were used to evaluate the effects on the expected costs for the seven protoflight test plans of the number of missions, the component failure probability and the number of components in the housekeeping subassemblies. Evaluation of the test plans for 1, 8 and 15 mission payloads indicated major changes in cost rank, reliability and design/test levels. Although subassembly testing and system testing remain the most cost effective, the no-test option is elevated to third cost rank for the single mission payloads, using ruggedized component design which may not be realistically costed or practically obtainable. The design/test levels and the expected costs are significantly reduced as the number of missions is reduced. The effect of varying the proportion of components which fail at a given vibration level by ±20 percent has a large effect on cost and component design/test levels but has a small effect on the cost ranking of the alternate test plans and the associated reliability. The effect of the number of components in the housekeeping subassemblies was investigated by considering the components to be added to the experiments or deleted from the payload. These changes did not significantly affect the cost ranking of the alternate test plans but did affect the costs and design/test levels. Removing components from the housekeeping subassemblies and adding them to each experiment increases the optimum cost and the corresponding design/test levels while a deletion of components reduces the expected cost.

This study and the resulting OCTAVE (Optimized Costs of Testing for Acoustic and Vibration Environments) computer code have demonstrated the application of statistical decision theory to vibroacoustic test plan evaluations. OCTAVE provides a viable tool for the quantitative evaluation and tailoring of vibroacoustic test plans to specific payloads. However, the modeling simplifications must be understood and considered in interpreting and using the results obtained.

In view of the success of this study in developing a methodology for evaluating alternate vibroacoustic test plans, it is recommended that the application of decision models to thermal-vacuum testing and other environmental tests be considered. A feasibility study of thermal vacuum testing that draws heavily on the vibroacoustic decision model is suggested as a first step in the continued development of cost effective test methods.

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SECTION 1

INTRODUCTION

The study presented in this report extends previous Shuttle payload vibroacoustic test plan cost effectiveness studies to free flyer payloads and evaluates the sensitivity of sortie payload test plan evaluations to selected payload parameters. Previous studies have demonstrated that statistical decision models provide a viable method of evaluating the cost effectiveness of alternate vibroacoustic test plans and the associated test levels. The methodology, References 1 to 4, provides a major step toward the development of a realistic tool to quantitatively tailor vibroacoustic test programs for specific STS payloads. Testing is considered at the component, subassembly, or system (payload) level of assembly. Component redundancy, partial loss of flight data, flight by flight failure probabilities, and the cost of designing components for higher vibration requirements are considered. Direct and probabilistic costs influencing test plan selection are determined and incipient failures resulting from ground tests are treated. For the test plans considered in this portion of the study optimums defining both component and assembly test levels are indicated. However, in interpreting the results for a particular STS payload the modeling simplifications must be considered. These simplifications are described in detail in the previous reports for sortie payloads and additional simplifications for free flyer payloads are presented herein. Because the methodology has not changed significantly, a complete description of the modeling is not included in this report.

Although nine basic plans involving vibroacoustic tests at various levels of assembly have been examined, the present investigation is limited to the six most recent test plans. All of the test plans are shown in Table 1-1. The test plan matrix shows the level of assembly at which tests are performed and the type of hardware tested, e.g., Test Plan 9 includes random vibration testing of protoflight components followed by a test of the complete flight payload using acoustic excitation. In this study, Test Plans 4 to 9 were evaluated because earlier evaluations indicated the cost of test dedicated prototype hardware was excessive. For the structure, a no test and a protoflight structural test is considered. It will be noted that Test Plan 6 is a "no test" option which eliminates all vibroacoustic and structural tests.

Statistical decision theory is used to formulate a model to determine the optimum test plan and the related test levels to be used. The decision tree or action space shown in Figure 1-1 defines the various alternatives considered in this study. The alternative actions consist of selecting a test plan and applicable component and assembly test levels. In each test plan the component test level and the assembly test level are treated as continuous variables. This is indicated in Figure 1-1 by the fan shaped displays. Having selected a test option, the "State-of-nature", i.e., the probability of failures, is determined and the expected utility can be obtained. The test option that provides the maximum expected utility is then selected.

In classical decision theory, the concept of utility is used since monetary considerations alone may not govern a decision, particularly on a short range basis. However, in the long range, decisions which minimize cost should ultimately be preferred. Because cost is not subjective and should govern long term decisions, it is used in this study. Thus, the test option selected is the one which minimizes the total expected program cost. The resulting test levels are directed toward cost minimization and are not the customary "acceptance" or "qualification" levels.

Table 1-1

Vibroacoustic Test Plan Matrix

Test Plan No.	Component Test	Subassembly Test	System Test	Structure Test
1	Mix*	-	-	-
1A	Mix	-	-	SDM**
2	Mix	Protoflight	-	Protoflight
3	Mix	-	Protoflight	Protoflight
3A	Mix	-	Protoflight	SDM
4	-	Protoflight	-	Protoflight
5	-	-	Protoflight	Protoflight
6	-	-	-	-
7	Protoflight	-	-	-
7B	Protoflight	-	-	Protoflight
8	Protoflight	Protoflight	-	Protoflight
9	Protoflight	-	Protoflight	Protoflight

* Prototype housekeeping components and protoflight experiment components

** Prototype Structural Development Model

NOTE: Test Plans 1 - 5 were considered in the Phase B study of contract NAS 5-20906
Test Plans 4 - 9 were considered in the Phase C study of contract NAS 5-20906 and in this study.

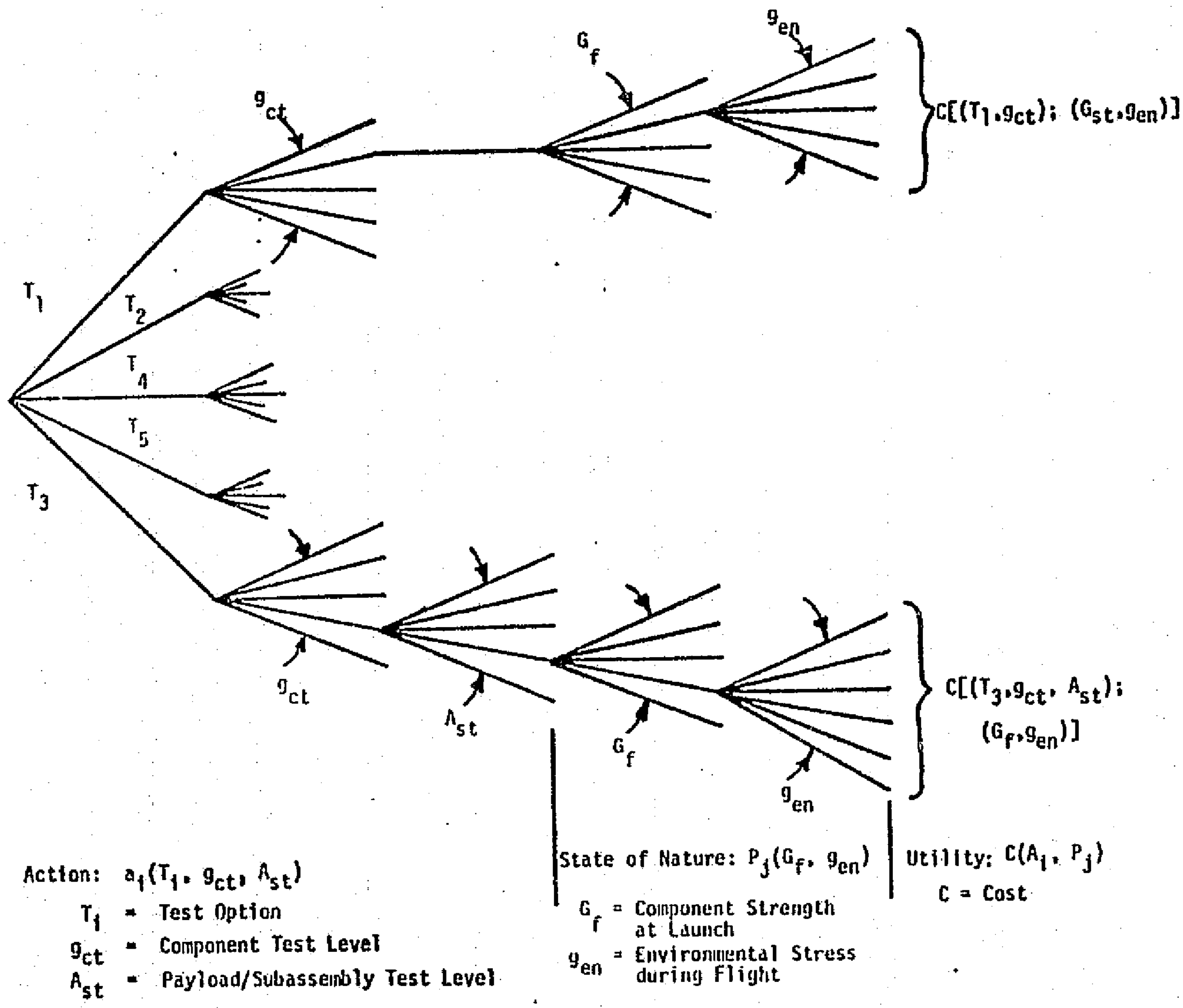


Figure 1-1 Decision Tree for Alternate Test Plans

Failures during testing and flight are determined from a stress-strength statistical analysis shown schematically in Figure 1-2. The probability density of the component strength and of the environment is shown as a function of the vibration level. During component testing, a deterministic value of the test level (g_t) is used. This results in the failure of a portion of the components, as shown by the shaded area in Figure 1-2(a). These components are redesigned so that they pass the test, resulting in a strength distribution that is truncated at the component test level, as shown in Figure 1-2(b). During assembly level testing the component vibration environment will vary with location and direction, as shown by the probability density distribution of the environment. The stress-strength analysis determines the failure probability from the statistical distributions of the stress and strength. It is used for determining failure proabilities during assembly level tests and flight.

When a particular test plan is selected there are some direct costs which are certain to be incurred. These costs are included for each test plan. It should be noted that costs common to all test plans do not need to be included because they will not affect the cost differences between the test plans. For those test plans which do not include a structural test, a cost increase associated with an increased weight due to designing with a higher safety factor is included.

The probabilistic costs are those costs which result from failures during ground testing and flight. This cost is the sum of the products of the failure costs and the associated probability of occurrence. The expected cost of a test option is determined by summing the direct costs and the expected costs associated with the test plan.

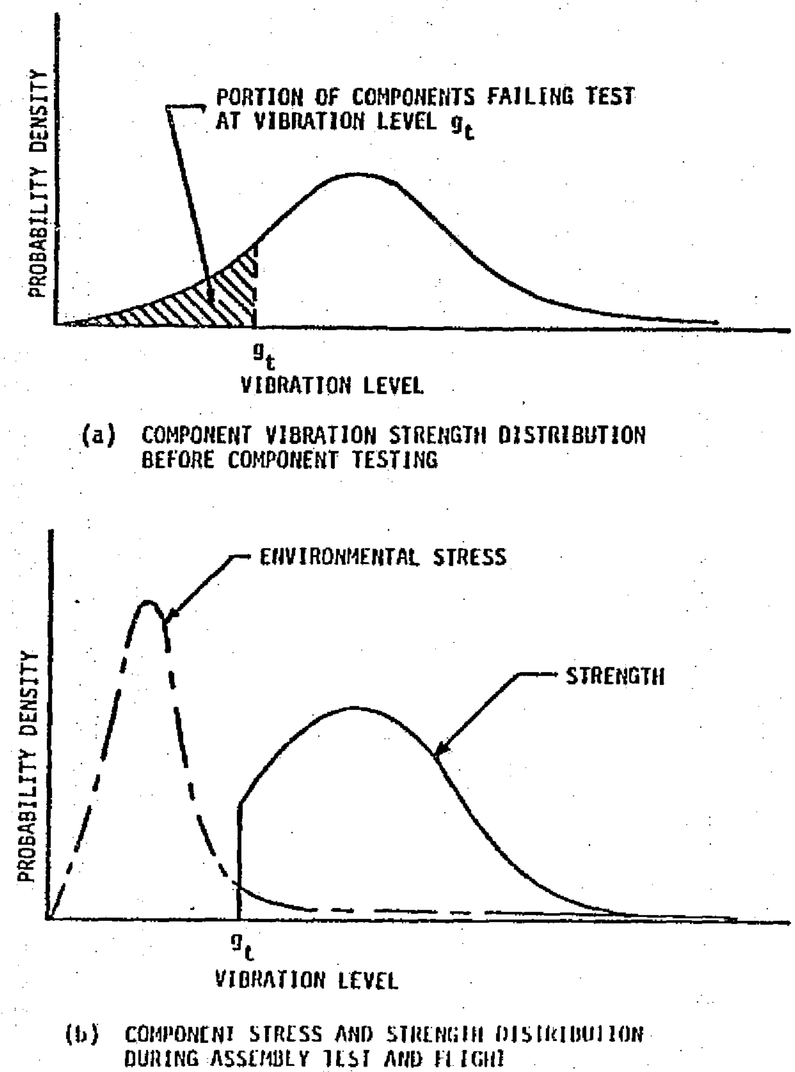


Figure 1-2 Schematic of Stress-Strength Analysis

A payload reliability model, Figure 1-3, is used to estimate the probability of achieving the flight objectives. The model represents the payload system as a series of redundant components and a group of parallel experiments. The series components represent the basic subsystems used for "housekeeping" functions and are assumed to have single redundancy, except for the structure. These components are essential to the success of the flight. Each experiment is composed of a number of series components and does not include any redundancy. The payload subassemblies are considered to be the experiments, the structure and three "housekeeping" subassemblies.

The OCTAVE computer code (Optimized Costs of Testing for Acoustic and Vibration Environments) developed in the previous studies was revised and used for this investigation. To evaluate the free flyer test plans, the code was revised to include the expected costs of returning a payload, replacing a payload, refurbishing a payload and/or relaunching a payload. For the sortie payloads, the code was used to evaluate the effects of varying the number of payload missions, the component failure probability and the number of components in the housekeeping subassemblies. The shuttle payload bay internal acoustic environment (145 dB OA) of the STS Payload Accommodations document, Reference 5, was used to define the vibroacoustic environment. The STS launch cost per flight was changed from $13,500,000 used in the previous studies to $17,500,000 to reflect current launch cost estimates.

The study results are presented in two main sections. Section 2 describes the modeling used for the free flyer payloads and includes test plan evaluations for two payloads representative of LANDSAT D and SMM payload configurations. Section 3 presents the results of the sortie payload parameter variations. Section 4 gives the conclusions and recommendations of the study.

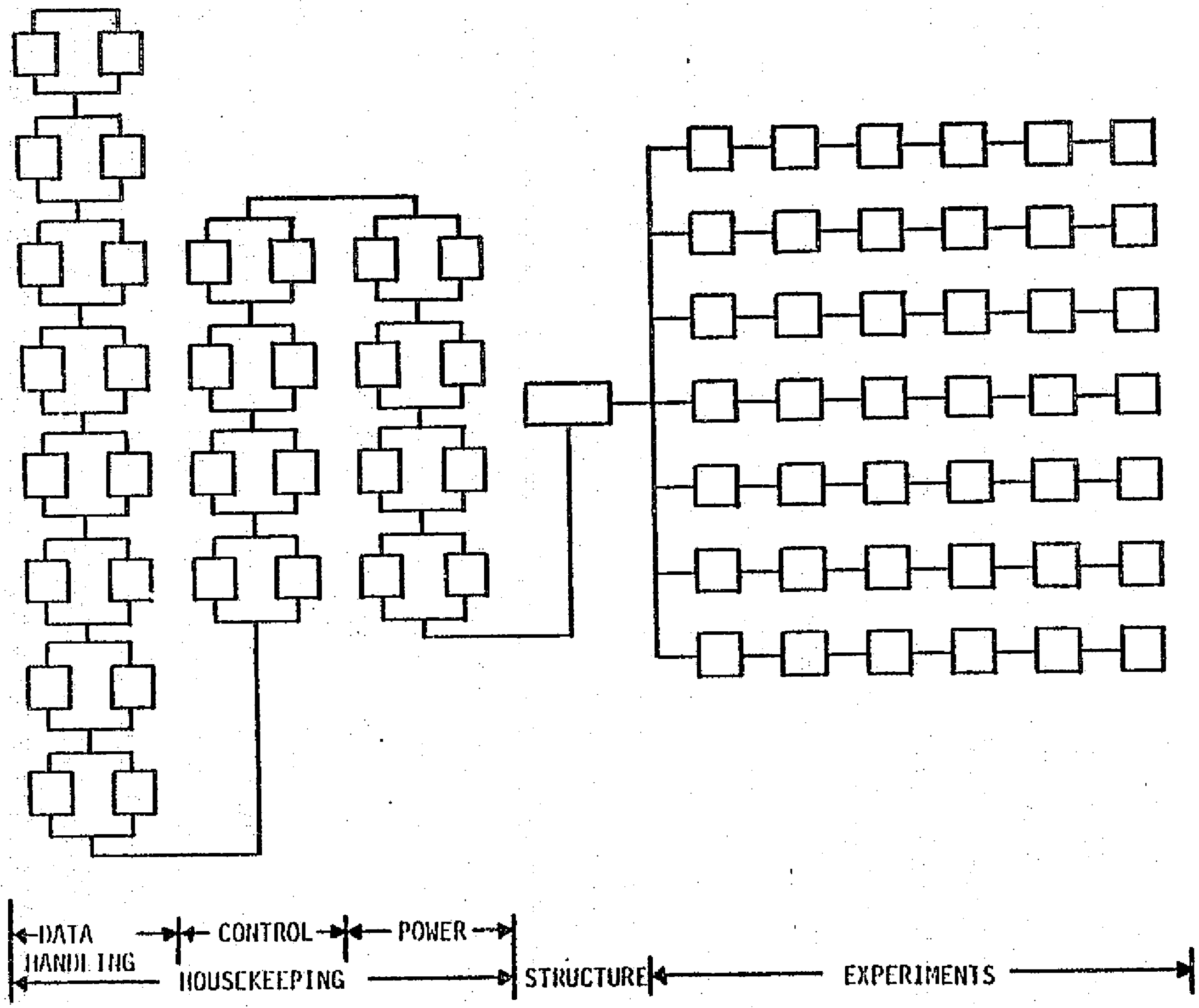


Figure 1-3 Payload Reliability Modal

SECTION 2

FREE FLYER PAYLOADS

2.1 OPERATIONAL DECISION MODEL

Up to this time the development and applications of the methodology for evaluating alternate vibroacoustic test plans has been restricted to a facility type payload that weighs 7500 pounds and occupies approximately 25% of the shuttle orbiter payload bay. In addition to flying this type of payload on sortie missions, the STS will also be used to deploy payloads into other orbits, to service payloads that are in orbit, or to retrieve and return payloads to earth. The free flying payloads will perform a wide variety of earth orbiting missions at orbital altitudes from near earth (NE) to geosynchronous (GS). They will require the use of additional equipment items that are chargeable to the payload, e.g., a flight support system (FSS), the Spacelab, Mission Kits to extend basic orbiter capability, upper stages, special equipment such as spin tables, and/or deployment mechanisms.

The STS provides the capability of checking out a free flyer payload before deploying it. This feature permits the user to make decisions for free flyer payloads that are not necessary for sortie payloads. The first decision is the "go" or "no go" decision based on the condition of the free flyer, i.e., the payload survived the STS launch and successfully completed the checkout or it did not. If the payload is in a "go" condition, the payload is delivered and the mission is continued. If the payload is in a "no go" condition, as a result of not meeting the success criteria established for the checkout, the user makes the next decision, the "return" or "no return" alternative. If the payload is in a satisfactory "return" mode it is either returned by the STS on that mission for refurbishment and relaunch or placed into a parking orbit for subsequent retrieval and return by the STS. If the payload is in a "no return" mode, the payload is released. Since the payload can not be returned, it must be replaced and launched at a later date. The payload must be in a stable condition before it can be returned, e.g., once a payload is spun up, it must be released.

The decisions associated with the various types of failures and orbits are summarized in Table 2-1. The operational decision criteria considers the types of failures encountered and the type of mission planned for the payload.

1. Structural Failures

For this study, if the structure fails, the mission is considered a complete loss. The payload is released and must be replaced and launched again.

2. Housekeeping Component Failures

For the purposes of this study, it was considered that for a geosynchronous orbit, single component failures in the housekeeping section require the payload to be returned, refurbished, and relaunched if the payload is in a "return" mode. For a near earth orbit, the payload is delivered for later retrieval.

If a redundant housekeeping failure occurs, i.e., both portions of the component fail, the payload is returned, refurbished, and relaunched, since the loss of a redundant housekeeping component results in the loss of all data from the mission.

3. Experiment Failures

Even though he loses a portion of the experiments in the payload instrument module, the user may decide that he can achieve a successful mission. He can specify the

Table 2-1

FREE FLYER PAYLOAD DECISIONS

		Geo-Synchronous					Near-Earth				
		Go	No Go				Go	No Go			
			Return		No Return			Return		No Return	
		Deliver	Refurb	New Launch	Replace HDW	New Launch	Deliver	Refurb	New Launch	Replace HDW	New Launch
1.	Structure Failure				X	X				X	X
2.	Single HSKP Failure		X	X			X				
					X	X					
3.	Redundant HSKP Fail.		X	X				X	X		
					X	X				X	X
4.	≤ NEXPR EXPT Fail.	X					X				
5.	> NEXPR EXPT Fail.		X	X				X	X		
					X	X				X	X

number of experiment failures (NEXPR) that he will accept and still meet his mission success criteria. Then if this number of experiment failures is not exceeded ($\leq$ NEXPR), the payload is delivered. If more than this number of experiments fail (> NEXPR), the payload is returned, refurbished, and relaunched if the payload is in a "return" mode. The user can likely accept more experiment failures for a payload in a near earth orbit than for a payload in a geosynchronous orbit.

For comparison, the options for free flyer payloads and sortie payloads are given in Table 2-2 for the various types of failures. Major differences are indicated for structural failures, housekeeping component failures, and experiment failures. For sortie payloads the payload is returned if a structural failure occurs; for free flyers it is replaced. When a single housekeeping component failure occurs, the decision is made to return the payload if it is a geosynchronous satellite. When experiment failures occur, the mission is continued for sortie payloads, but a decision to return the payload may be made for free flyers, depending upon the number of experiments that fail.

The cost portions of the OCTAVE computer code were revised to provide the capability to consider the above decisions for the free flyer study. Because the emphasis for this study was to establish the methodology required to include the free flyer capability and to modify the OCTAVE computer code accordingly, only a limited number of free flyer payloads were evaluated for a single set of cost parameters.

2.2 FREE FLYER PAYLOAD CONFIGURATIONS

The payload configurations selected for study were representative of the Multimission Modular Spacecraft (MMS) with a Solar Maximum Mission (SMM) instrument module consisting of eight experiments and a Landsat-D instrument module consisting of two experiments. The payload configurations are summarized in Table 2-3. Each experiment consisted of

Table 2-2

Comparison of Decisions for Free Flyer and Sortie Payloads

	Free Flyer		Sortie
	Geosynchronous	Near Earth	
Structure Failure	Replace	Replace	Return
Single HSKP Failure	Return	Continue	Continue
Redundant HSKP Failure	Return	Return	Return
≤ NEXPR Expt Failure	Continue	Continue	Continue
> NEXPR Expt Failure	Return	Return	Continue

Table 2-3

Free Flyer Payload Configurations

	Geosynchronous		Near Earth	
	SMM	Landsat-D	SMM	Landsat-D
Number of Experiments	8	2	8	2
Number of Components per Experiment	6	6	6	6
Number of Components in ACS	10	10	10	10
Number of Components in MPS	10	10	10	10
Number of Components in C&DH	10	10	10	10
Payload Weight (pounds)	7868	7868	7000	7000
Launch Cost Factor	0.448	0.448	0.400	0.400

six components with no redundancy. For this study the attitude control subsystem (ACS) module, the modular power subsystem(MPS), and the communications and data handling (C&DH) module each consisted of ten components with single redundancy.

For geosynchronous orbits these spacecraft were combined with the Delta PAM to give a payload weight of 7868 pounds and a payload bay load factor of 0.336 for a launch cost factor of 0.448. The load factor was governed by the payload length, 20.167 feet. For near earth orbits these spacecraft were combined with the MMS flight support system(FSS) to give a payload weight of 7000 pounds and a payload bay load factor of 0.300 for a launch cost factor of 0.400. Here, too, the load factor was governed by the payload length, 18.0 feet.

For the SMM payload in a geosynchronous orbit the number of experiment failures accepted for a successful mission was considered to be two; in a near earth orbit, four. For the Landsat-D payload in a geosynchronous or near earth orbit one experiment failure was accepted for a successful mission.

For all the cases of this study it was assumed that the payloads were in a satisfactory "return" mode, i.e., they could be returned on that STS mission for refurbishment and relaunch. As a result, a hardware replacement cost was required only for structural failures during flight. A value of $10,000,000 was used for this cost. No in-orbit repair capability was considered for this study.

Cost optimized test levels were obtained for the four payload configurations given in Table 2-3. Data were obtained for Test Plans 4 to 9 of Table 1-1. Except for the values mentioned above and the dedicated launch cost of $17,500,000, the parameters used for the baseline condition of the sortie parameter study, Reference 4, were used for the free flyer study. The results obtained for the free flyer payloads are discussed in Section 2.3.

2.3 TEST PLAN EVALUATION FOR FREE FLYER PAYLOADS

The results obtained from applying the decision models for Test Plans 4 to 9 to the four free flyer payload configurations are presented and discussed in this section. All data were generated by the OCTAVE computer code as modified to include the free flyer capability. The payloads were of the free flyer type having a single planned STS flight. The payload complexity was varied by considering eight experiments for the representative SMM spacecraft and two experiments for the representative Landsat-D spacecraft. The payload weight and the amount of the STS payload bay occupancy were varied to account for the type of orbit the payload would fly, near earth or geo-synchronous.

The expected cost as a function of the component vibration level and the assembly acoustic test level was determined for each configuration. The vibration level has a dual meaning. For those test plans that consider component testing, Test Plans 7, 7B, 8, and 9, the vibration level is the component test level. For Test Plans 4, 5, and 6, which do not consider component testing, the vibration level represents the component design requirement. As described in Section 3 of Reference 3, the component strength distribution is considered to be a function of the component vibration test/design level, so the vibration strength of the untested components continually increases as the vibration level is increased. As described in Section 2 of Reference 4, the cost of designing components to higher vibration levels increases as the vibration level is increased.

Optimum test levels were obtained for each test plan for each payload configuration. The optimum cost data is summarized by payload in Table 2-4 and by test plan in Table 2-5. Table 2-4 has four parts, one for each payload configuration. For each payload configuration values are given at the minimum cost point for the case code, the test plan, the payload configuration, the optimum expected cost in millions of dollars, the standardized vibration variable (U_V), the component vibration test/design level (GQ) in g rms, and the assembly acoustic test level (SPL) in dB. Also given are the associated vibroacoustic flight failure probability (FFP), the cost rank, and the reliability rank. The flight failure probability is the probability of losing data from any experiment during the flight. Table 2-5 groups the data according to test plan, but gives the flight success probability (FSP) instead of the cost and reliability ranks for each case.

Figures 2-1 to 2-4 compare the data given in Tables 2-4 and 2-5 by showing the expected costs of failures for the assembly test level of the minimum cost point. For Test Plans 6, 7, and 7B, which consider no assembly testing, the curves on these figures are simply the expected costs for these test plans. Examination of these tables and figures indicates that the expected cost is minimized for component vibration levels between approximately 9 and 55 g rms with assembly acoustic test levels between 129 and 149 dB. For the SMM payload in a near earth orbit the lowest expected cost was obtained for an assembly test level of 129 dB for Test Plans 5 and 9. Since this was the lowest assembly test level considered for this study, these may not be true optimums.

Table 2-4

Free Flyer Study
Optimum Cost Data Summary
By Payload

Case Code	Test Plan	Payload	Orbit GS	Orbit NE	Optimum Cost ($*10^6)	Optimum U_V	Optimum GQ g_{rms}	Optimum SPL dB	Associated Vibroacoustic FFP	Cost Rank	Reliay Rank
111110	4	8,6 (SMM)	X		1.056	1.75	16.321	147	0.02181	1	1
211110	5				1.617	2.10	25.521	141	0.04709	2	3
311110	6				5.686	2.55	45.342	-	0.41274	7	7
411110	7				4.232	2.10	25.521	-	0.15611	6	6
511110	7B				4.168	2.10	25.521	-	0.15550	5	5
611110	8				2.414	1.40	10.438	147	0.02907	3	2
711110	9				3.267	1.75	16.321	143	0.04757	4	4
121110	4	2,6 (LSD)	X		0.784	1.80	17.397	149	0.00336	1	1
221110	5				1.302	2.15	27.204	143	0.00813	2	3
321110	6				5.083	2.70	54.917	-	0.10524	7	7
421110	7				3.354	2.20	28.997	-	0.03474	6	6
521110	7B				3.293	2.20	28.997	-	0.03404	5	5
621110	8				1.714	1.45	11.126	149	0.00437	3	2
721110	9				2.440	1.85	18.544	143	0.01076	4	4
130110	4	8,6 (SMM)		X	0.619	1.50	11.860	139	0.12940	1	1
230110	5				0.709	1.750	16.321	129	0.22687	2	3
330110	6				1.538	2.150	27.204	-	0.60644	3	7
430110	7				2.011	1.50	11.860	-	0.41177	6	6
530110	7B				1.966	1.50	11.860	-	0.41134	5	5
630110	8				1.873	1.25	8.618	139	0.17286	4	2
730110	9				2.130	1.50	11.860	129	0.33911	7	4
140110	4	2,6 (LSD)		X	0.439	1.60	13.475	139	0.03027	1	2
240110	5				0.627	1.80	17.397	131	0.05246	2	3
340110	6				1.323	2.25	30.910	-	0.18845	4	7
440110	7				1.526	1.60	13.475	-	0.10731	6	6
540110	7B				1.482	1.60	13.475	-	0.10666	5	5
640110	8				1.291	1.30	9.186	141	0.03024	3	1
740110	9				1.608	1.55	12.642	133	0.06963	7	4

Table 2-5

Free Flyer Study
Optimum Cost Data Summary
By Test Plan

Case Code	Test Plan	Payload	Orbit GS	Orbit NE	Optimum Cost ($*10^6)	Optimum UV	Optimum GQ g_{rms}	Optimum SPL dB	Associated Vibroacoustic FFP	Associated Vibroacoustic FSP
111110	4	SMM	X		1.056	1.75	16.321	147	0.02181	0.97819
121110		LSD	X		0.784	1.80	17.397	149	0.00336	0.99664
130110		SMM		X	0.619	1.50	11.860	139	0.12940	0.87060
140110		LSD		X	0.439	1.60	13.475	139	0.03027	0.96973
211110	5	SMM	X		1.617	2.10	25.521	141	0.04709	0.95291
221110		LSD	X		1.302	2.15	27.204	143	0.00813	0.99187
230110		SMM		X	0.709	1.75	16.321	129	0.22687	0.77313
240110		LSD		X	0.627	1.80	17.397	131	0.05246	0.94754
311110	6	SMM	X		5.686	2.55	45.342	-	0.41274	0.58726
321110		LSD	X		5.083	2.70	54.917	-	0.10524	0.89476
330110		SMM		X	1.538	2.15	27.204	-	0.60644	0.39356
340110		LSD		X	1.323	2.25	30.910	-	0.18845	0.81155
411110	7	SMM	X		4.232	2.10	25.521	-	0.15611	0.84389
421110		LSD	X		3.354	2.20	28.997	-	0.03474	0.96526
430110		SMM		X	2.011	1.50	11.860	-	0.41177	0.58823
440110		LSD		X	1.526	1.60	13.475	-	0.10731	0.89269
511110	7B	SMM	X		4.168	2.10	25.521	-	0.15550	0.84450
521110		LSD	X		3.293	2.20	28.997	-	0.03404	0.96596
530110		SMM		X	1.966	1.50	11.860	-	0.41134	0.58866
540110		LSD		X	1.482	1.60	13.475	-	0.10666	0.89334
611110	8	SMM	X		2.414	1.40	10.438	147	0.02907	0.97083
621110		LSD	X		1.714	1.45	11.126	149	0.00437	0.99563
630110		SMM		X	1.873	1.25	8.618	139	0.17286	0.82714
640110		LSD		X	1.291	1.30	9.186	141	0.03024	0.96976
711110	9	SMM	X		3.267	1.75	16.321	143	0.04757	0.95243
721110		LSD	X		2.440	1.85	18.544	143	0.01076	0.98924
730110		SMM		X	2.130	1.50	11.860	129	0.33911	0.66089
740110		LSD		X	1.608	1.55	12.642	133	0.06963	0.93037

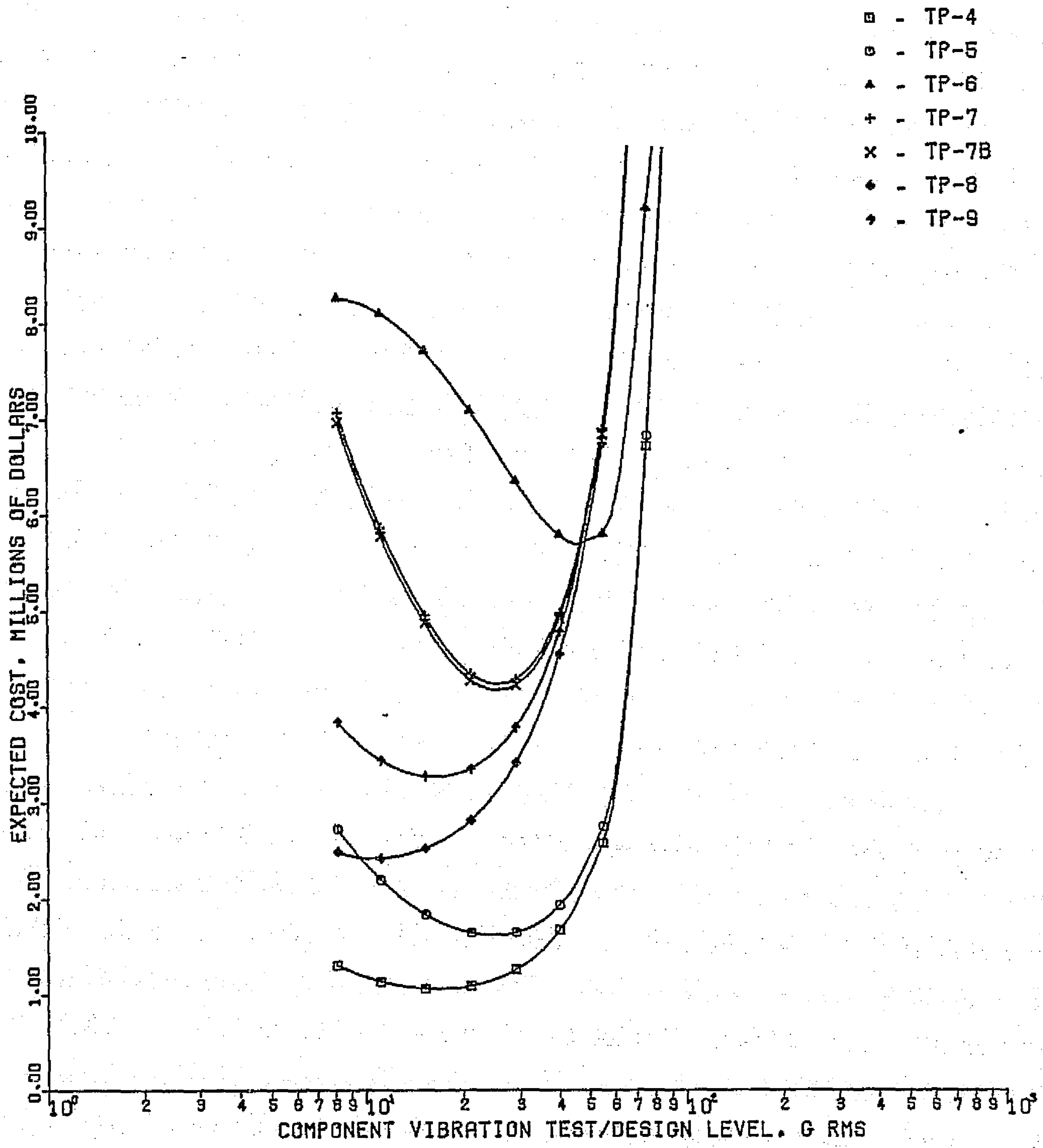


Figure 2-1 Optimum Costs for Each Test Plan, SMM Payload in a Geosynchronous Orbit

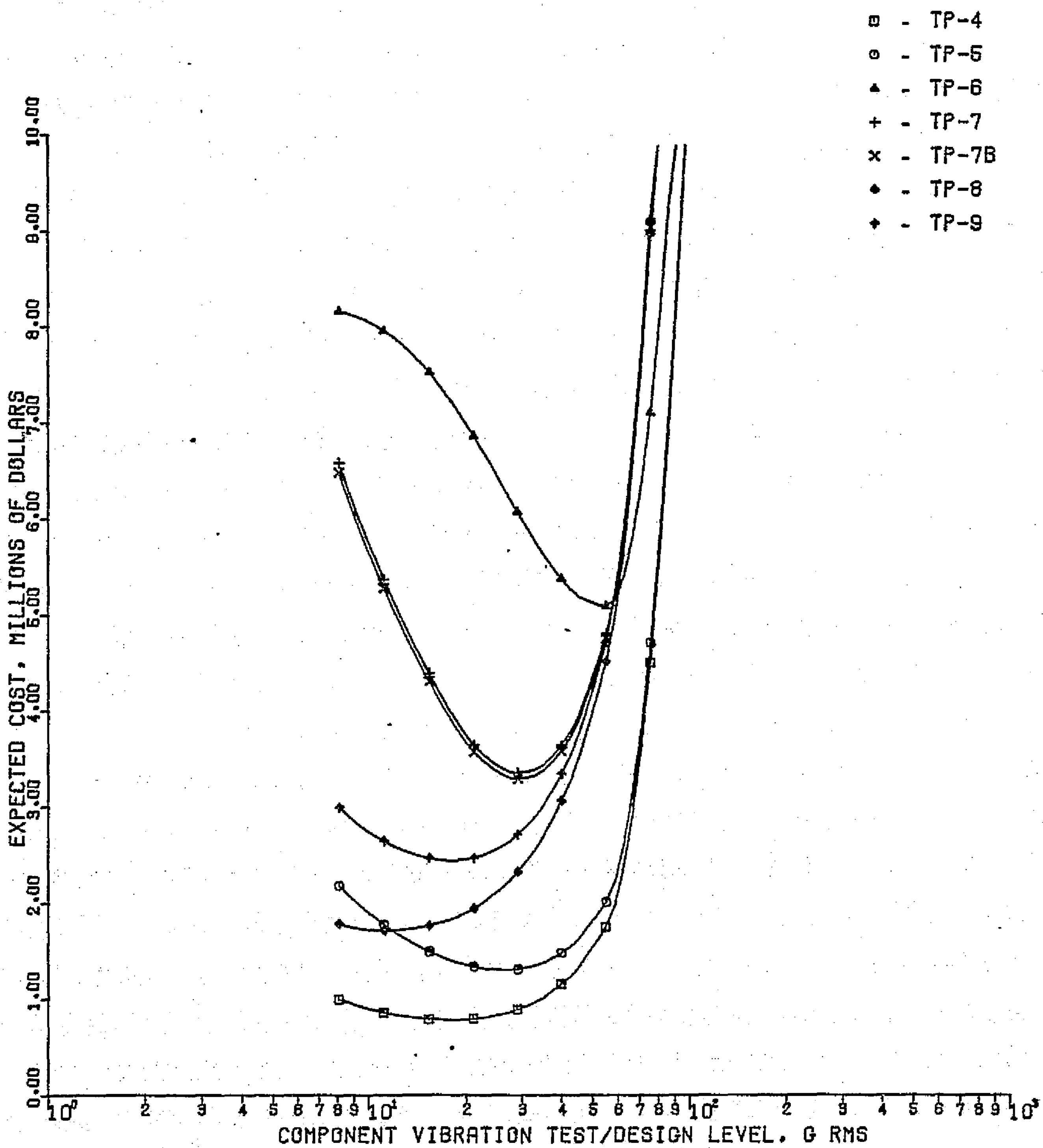


Figure 2-2 Optimum Costs for Each Test Plan, Landsat-D Payload in a Geosynchronous Orbit

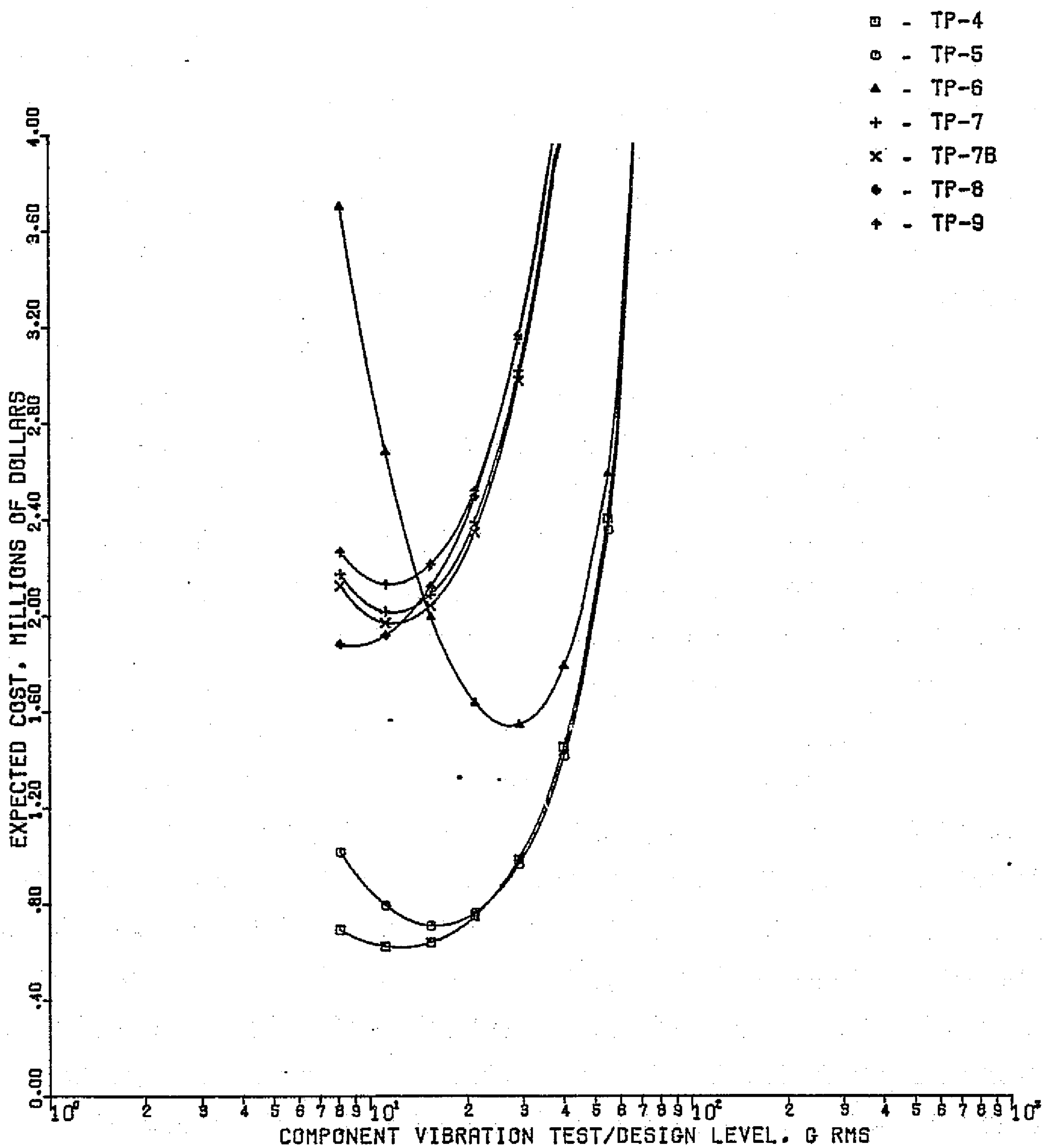


Figure 2-3 Optimum Costs for Each Test Plan, SMM Payload in a Near Earth Orbit

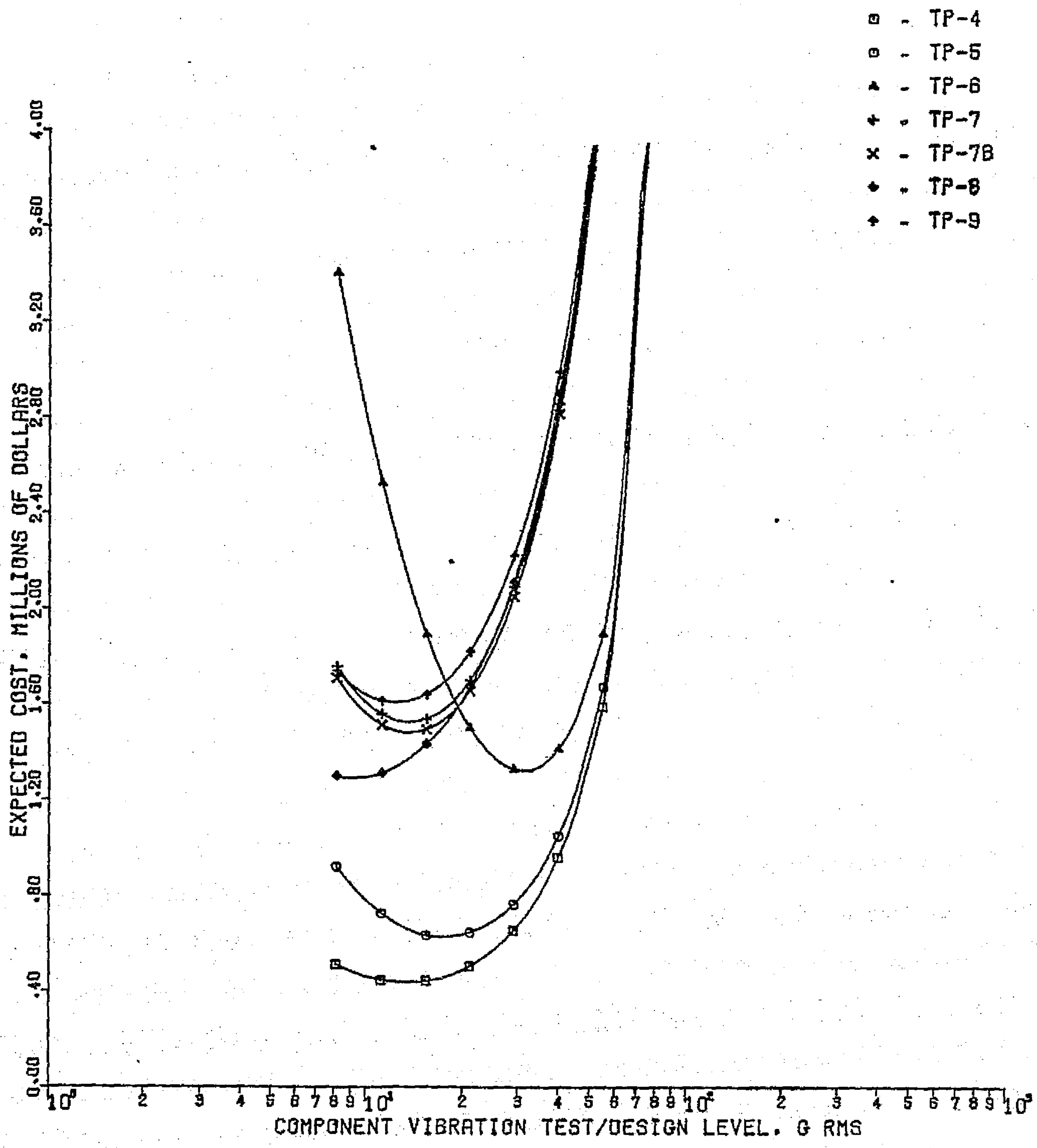


Figure 2-4 Optimum Costs for Each Test Plan, Landsat-D Payload in a Near Earth Orbit

Comparison of the optimum expected costs indicates that Test Plans 4, 5, 8 and 9 are the most attractive for the geosynchronous orbit conditions, while Test Plans 4, 5, 6, and 8 are the most attractive for the near earth orbit conditions. Minimum cost is achieved with Test Plan 4, which involves subassembly testing only, for all of the payload configurations analyzed. The assembly acoustic test level at which the optimum cost occurs varies from 139 to 149 dB for Test Plan 4. Test Plan 5, which involves system testing only, ranks second for all of the payload configurations analyzed with the assembly test level varying from 129 to 143 dB. For the geosynchronous cases, Test Plan 8 (component and subassembly testing) ranks third, followed by Test Plan 9 (component and system testing), Test Plan 7B (component and protoflight structure testing), Test Plan 7 (component testing only), and Test Plan 6 (no testing). This cost ranking is the same as that obtained for sortie payloads in References 3 and 4. For the near earth cases, Test Plan 6 and Test Plan 8 rank third or fourth, followed by Test Plans 7B, 7, and 9. It also should be noted that the optimum cost varied with the payload configuration. For the SMM payload in a geosynchronous orbit the variation was $4.6M; with the Landsat-D payload it was $4.3M. For the SMM payload in a near earth orbit the variation was $1.5M; with the Landsat-D payload it was $1.2M.

The variations of the expected costs with assembly acoustic test level are shown in Figures 2-5 to 2-20 for Test Plans 4, 5, 8, and 9 for the four payload configurations. The expected costs for Test Plans 6, 7, and 7B are shown in Figures 2-1 to 2-4. The OCTAVE computer code permits the use of nine assembly test levels for each case. Two ranges were considered for this free flyer study, either 129 to 143 dB or 143 to 157 dB. The range considered for each case is indicated on the figures. The complete set of results are provided in a separate data package.

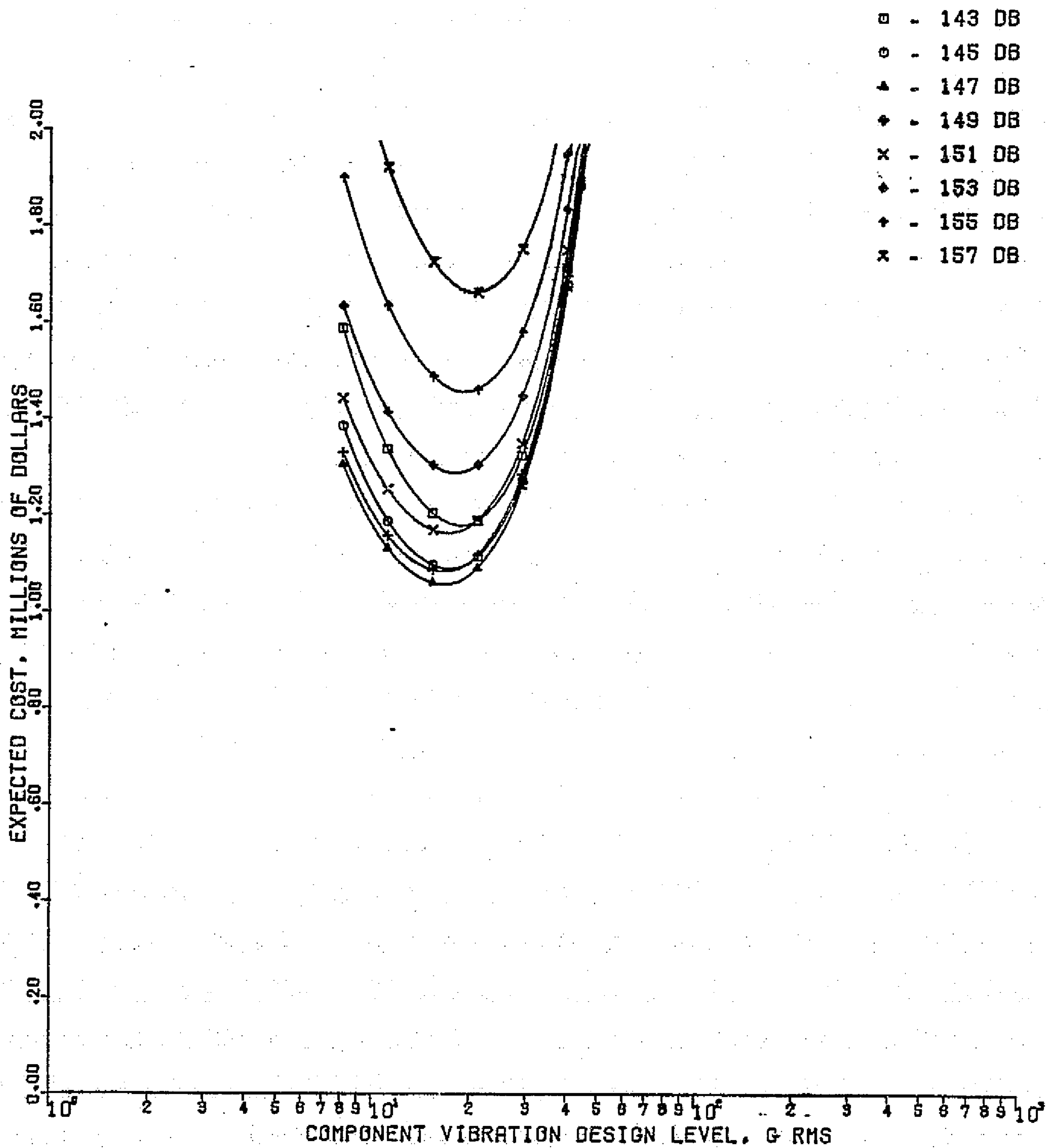


Figure 2-5 TECF Data, Test Plan 4, SMM Payload in a Geosynchronous Orbit

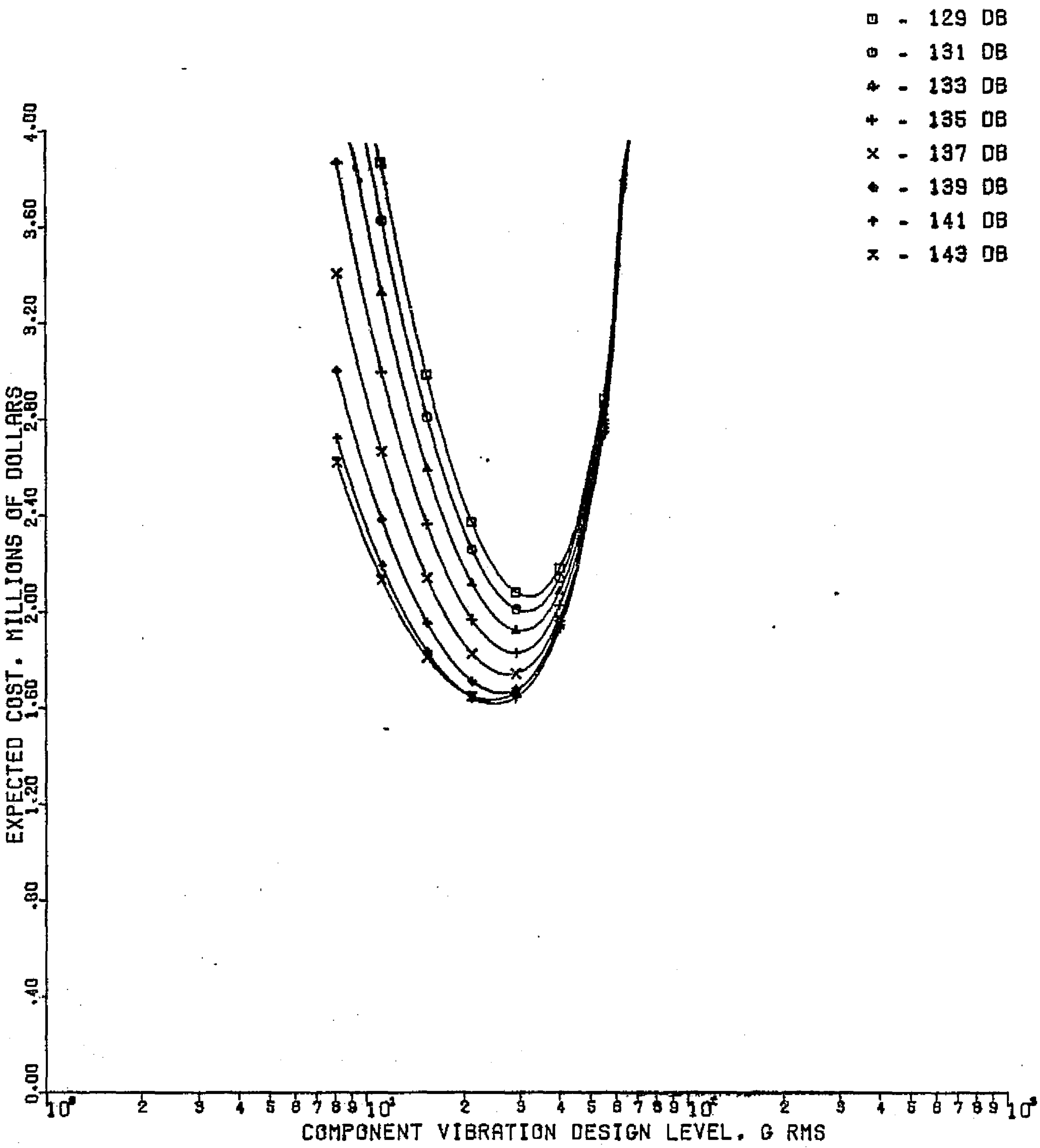


Figure 2-6 TECF Data, Test Plan 5, SMM Payload in a Geosynchronous Orbit

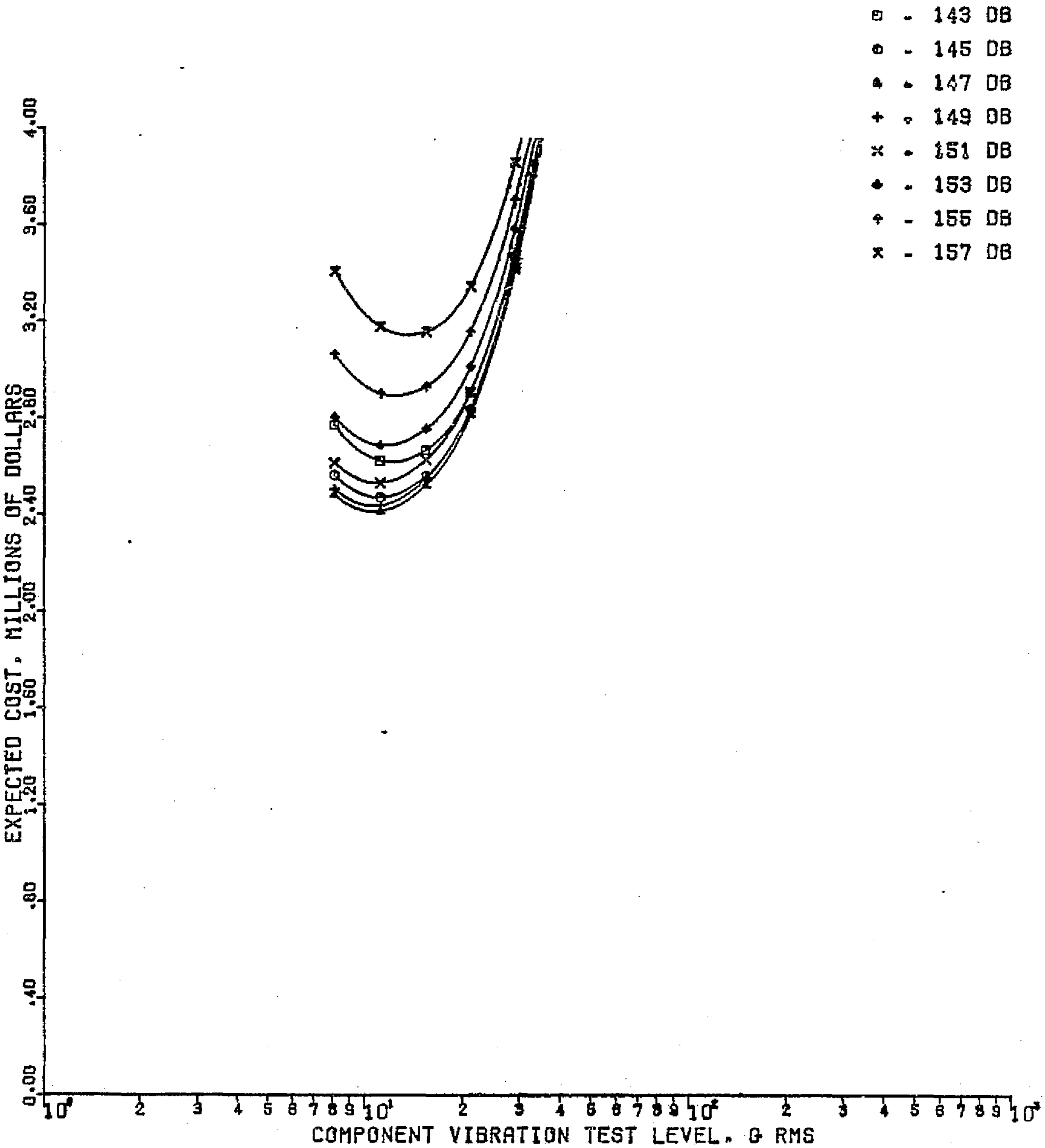


Figure 2-7 TECF Data, Test Plan 8, SMM Payload in a Geosynchronous Orbit

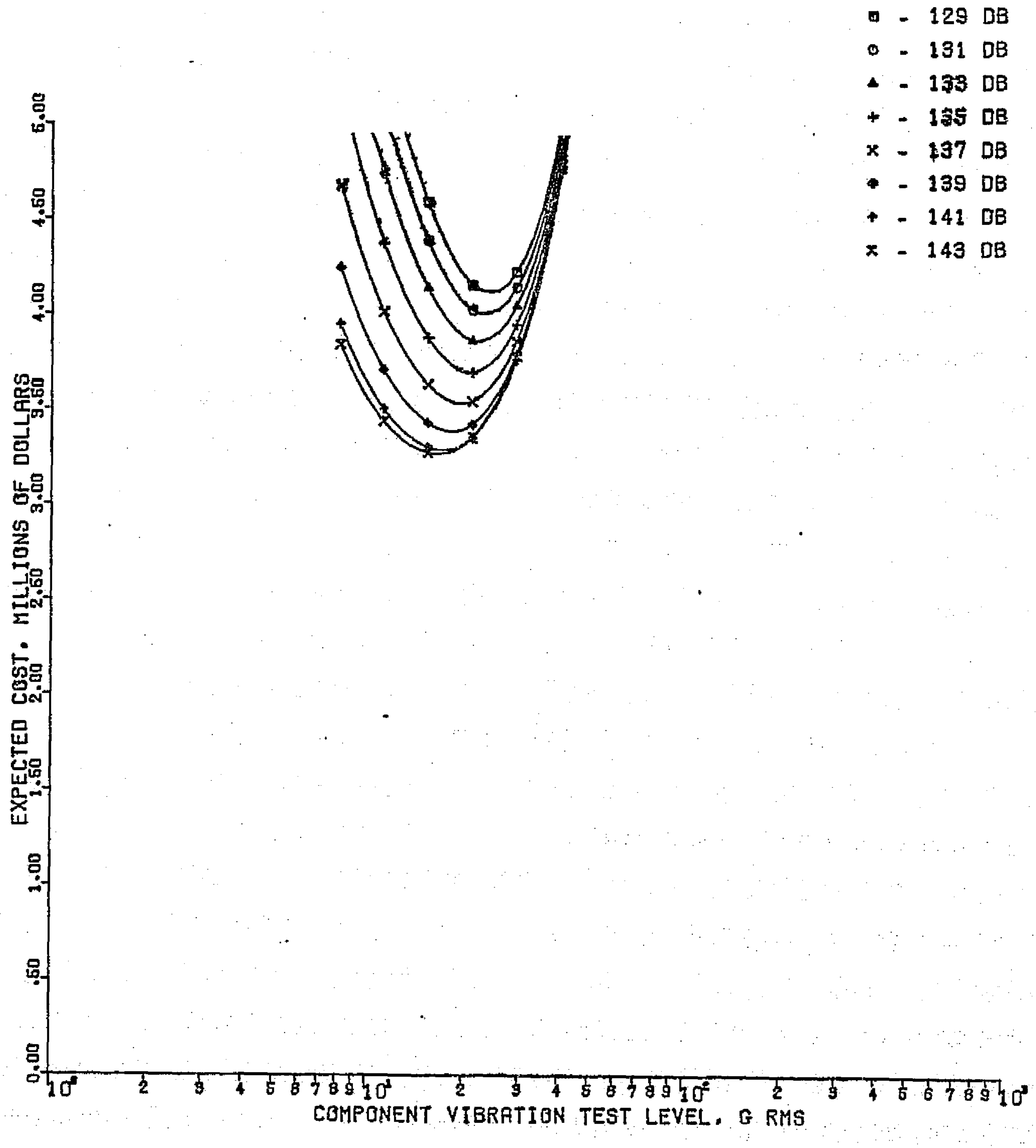


Figure 2-8 TECF Data, Test Plan 9, SMM Payload in a Geosynchronous Orbit

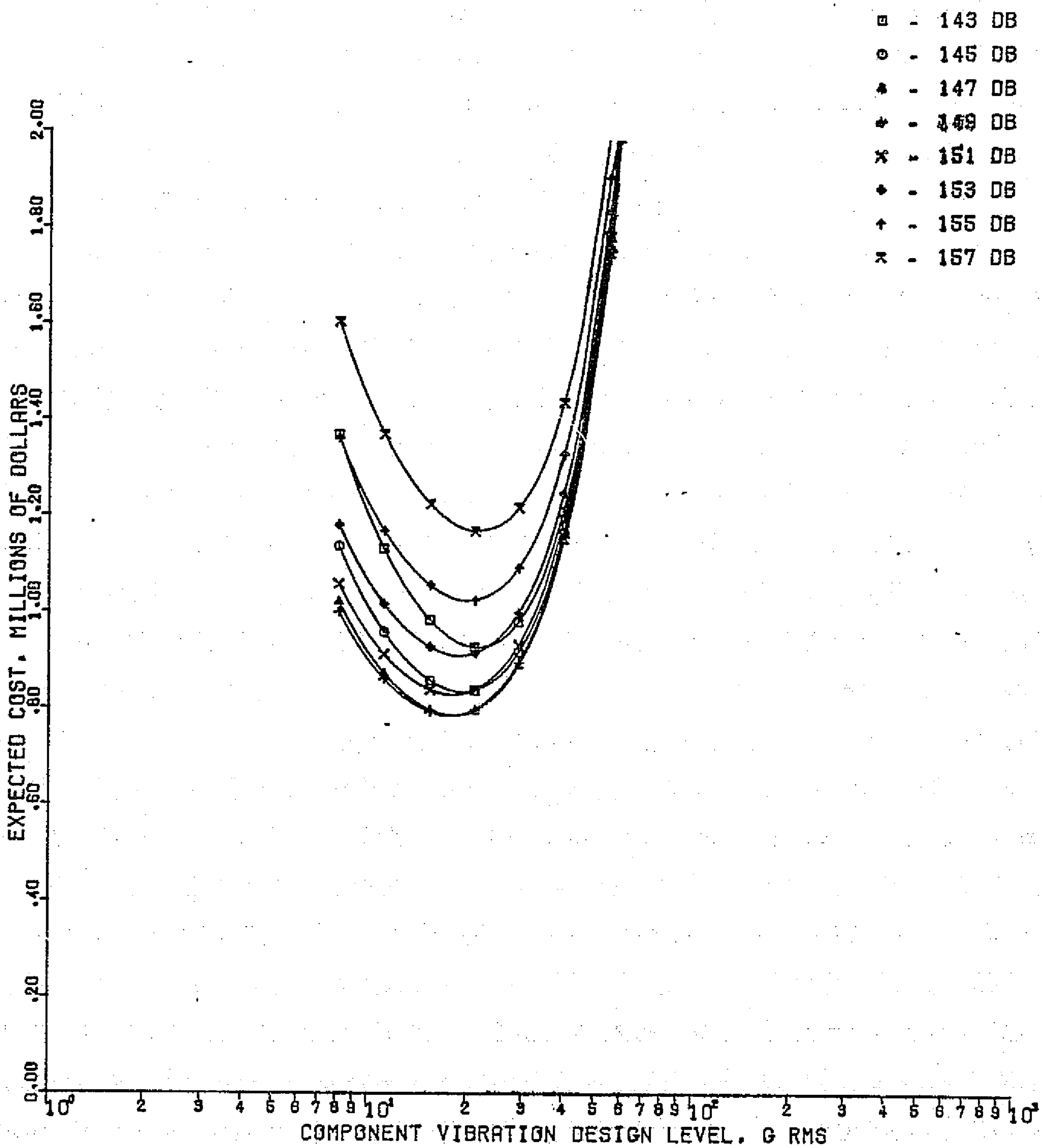


Figure 2-9 TECF Data, Test Plan 4, Landsat-D Payload in a Geosynchronous Orbit

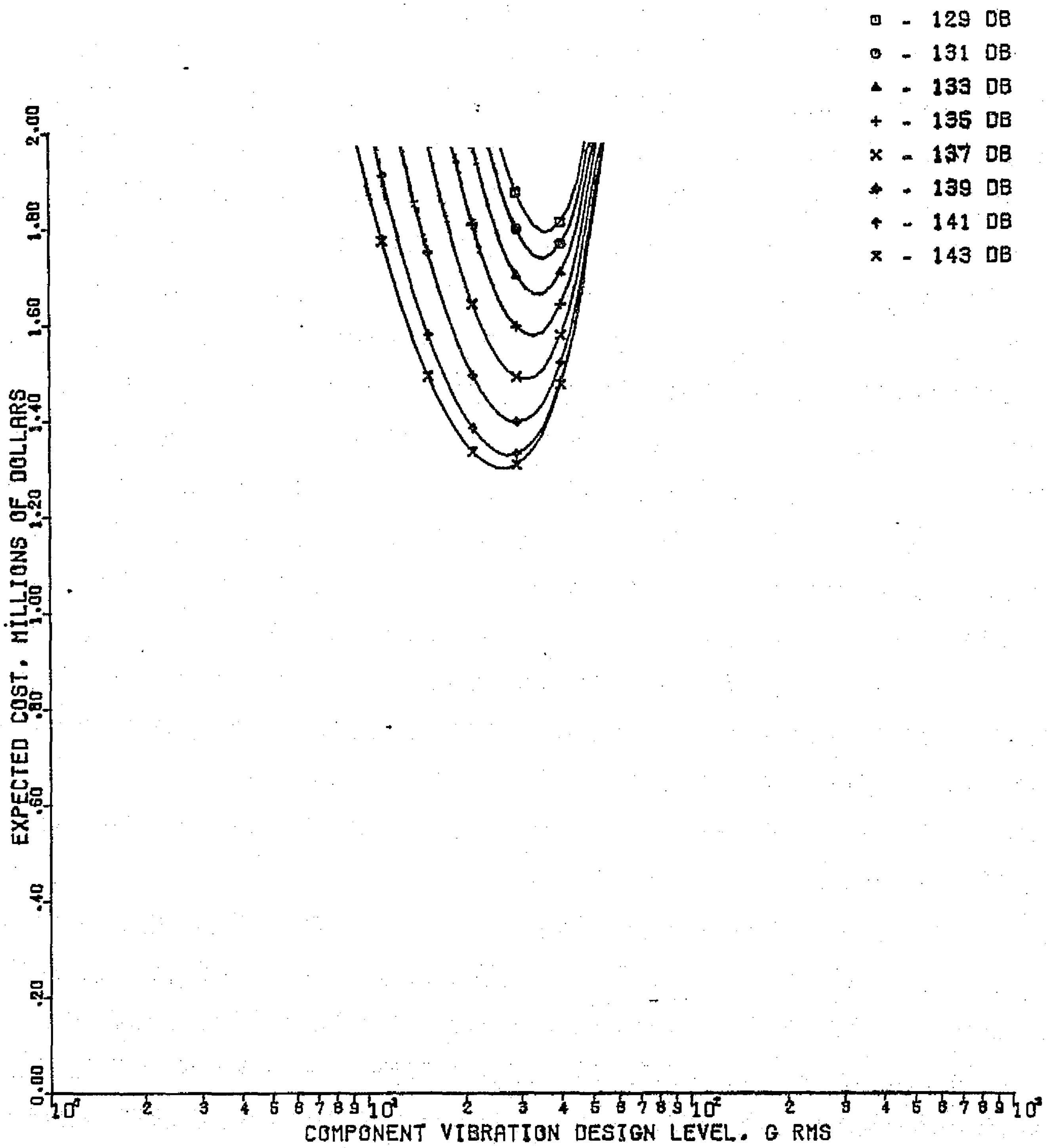


Figure 2-10 TECF Data, Test Plan 5, Landsat-D Payload in a Geosynchronous Orbit

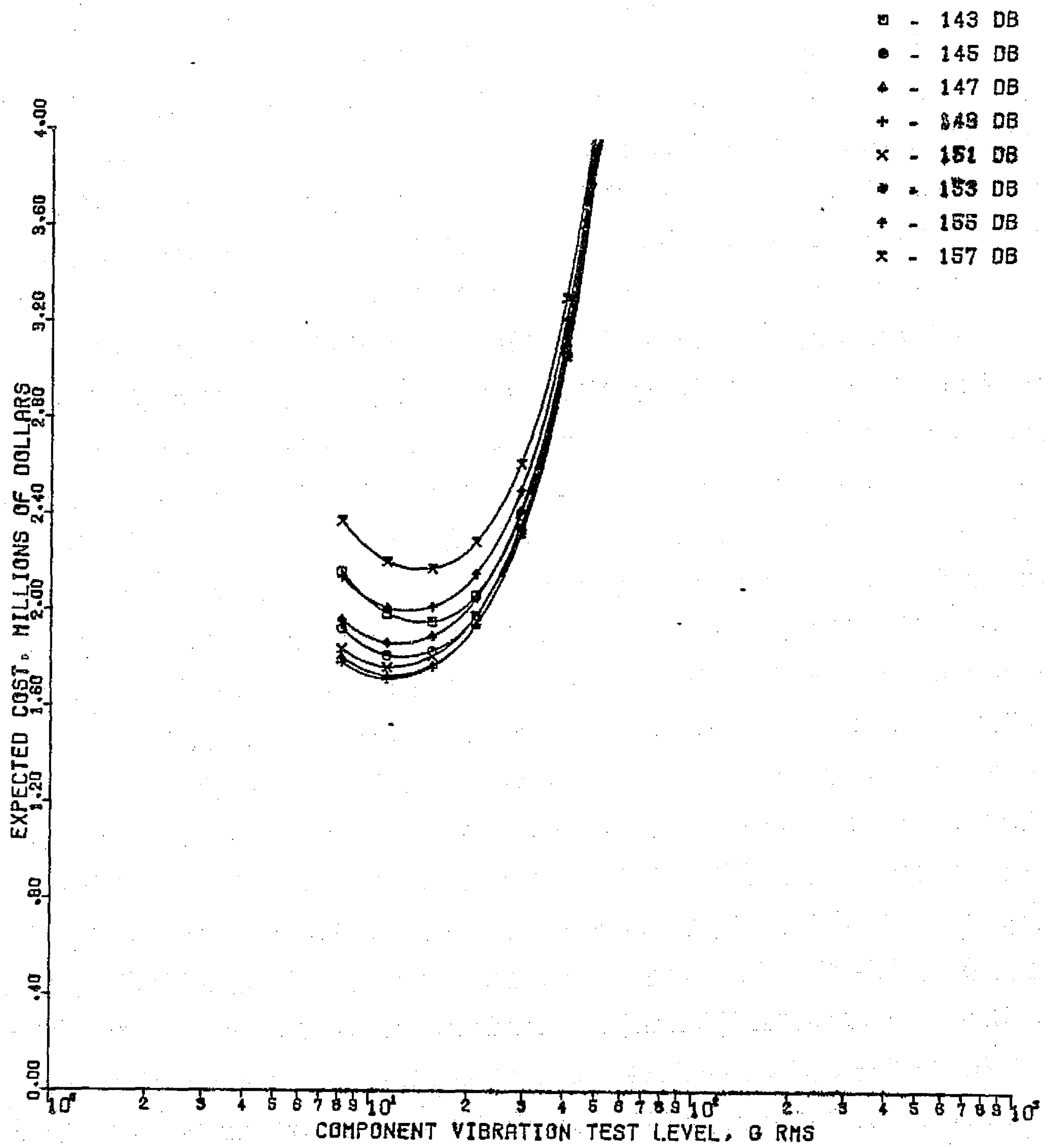


Figure 2-11 TECF Data, Test Plan 8, Landsat-D Payload in a Geosynchronous Orbit

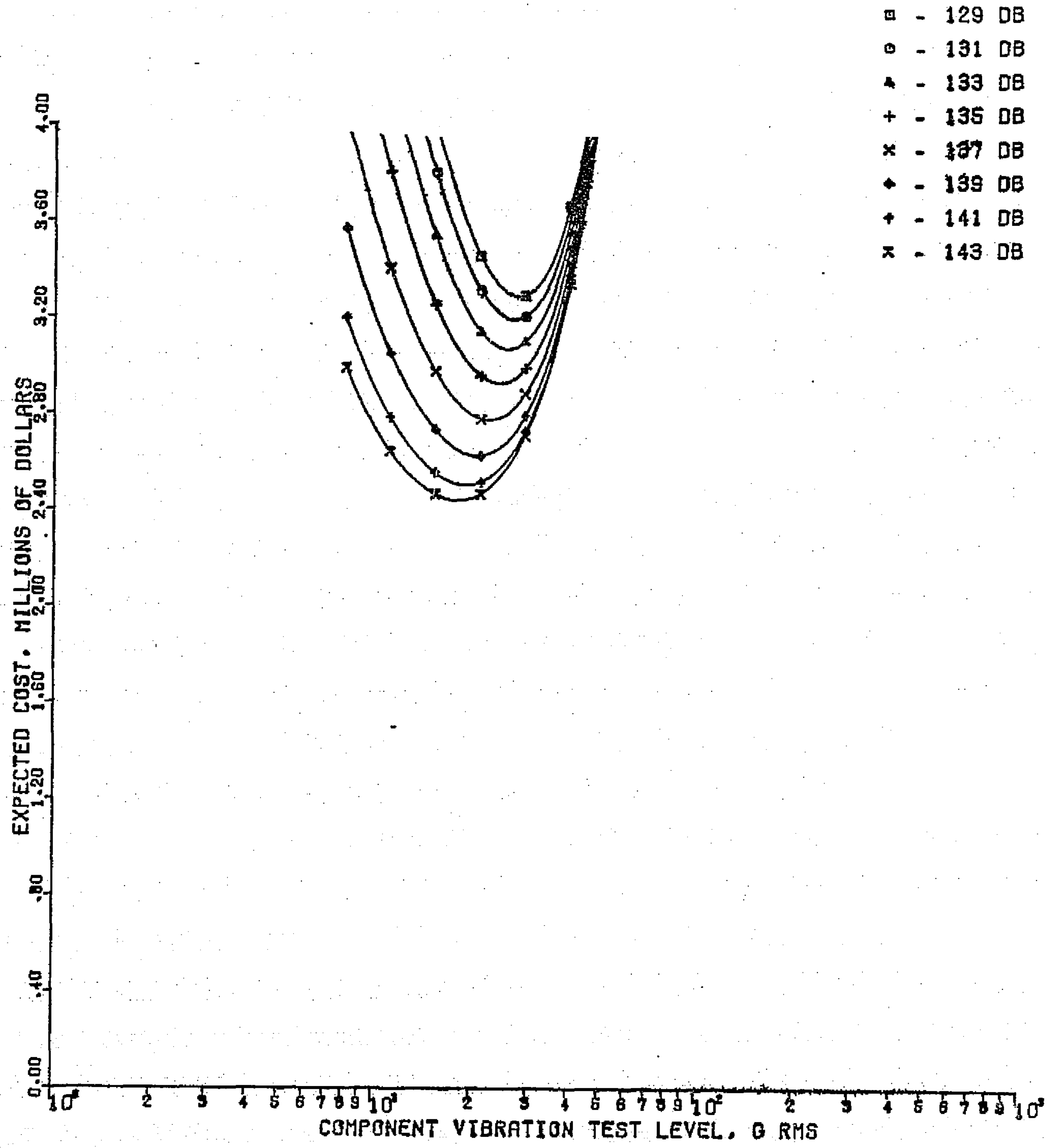


Figure 2-12 TECF Data, Test Plan 9, Landsat-D Payload in a Geosynchronous Orbit

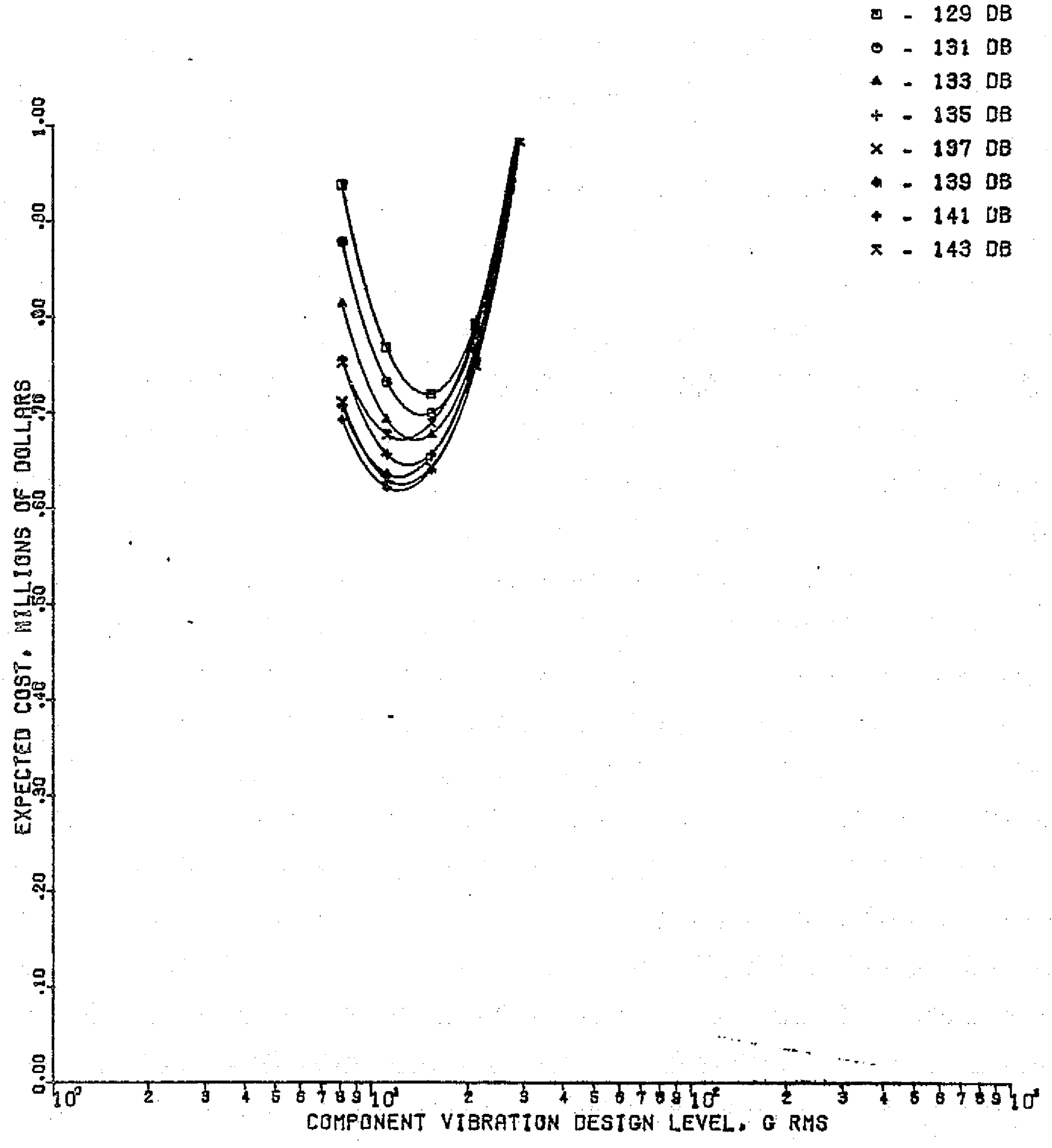


Figure 2-13 TECF Data, Test Plan 4, SMM Payload in a Near Earth Orbit

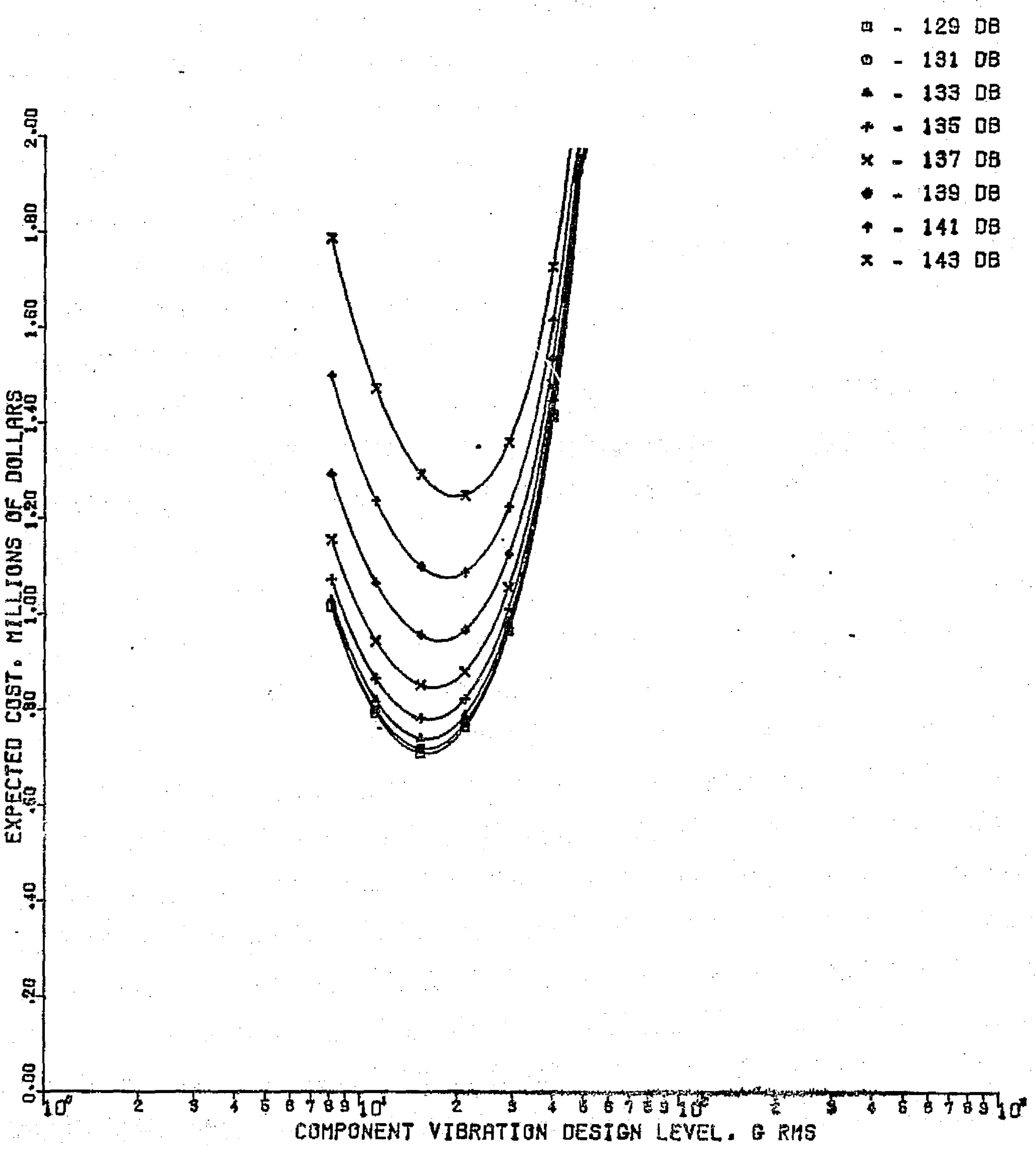


Figure 2-14 TECF Data, Test Plan 5, SMM Payload in a Near Earth Orbit

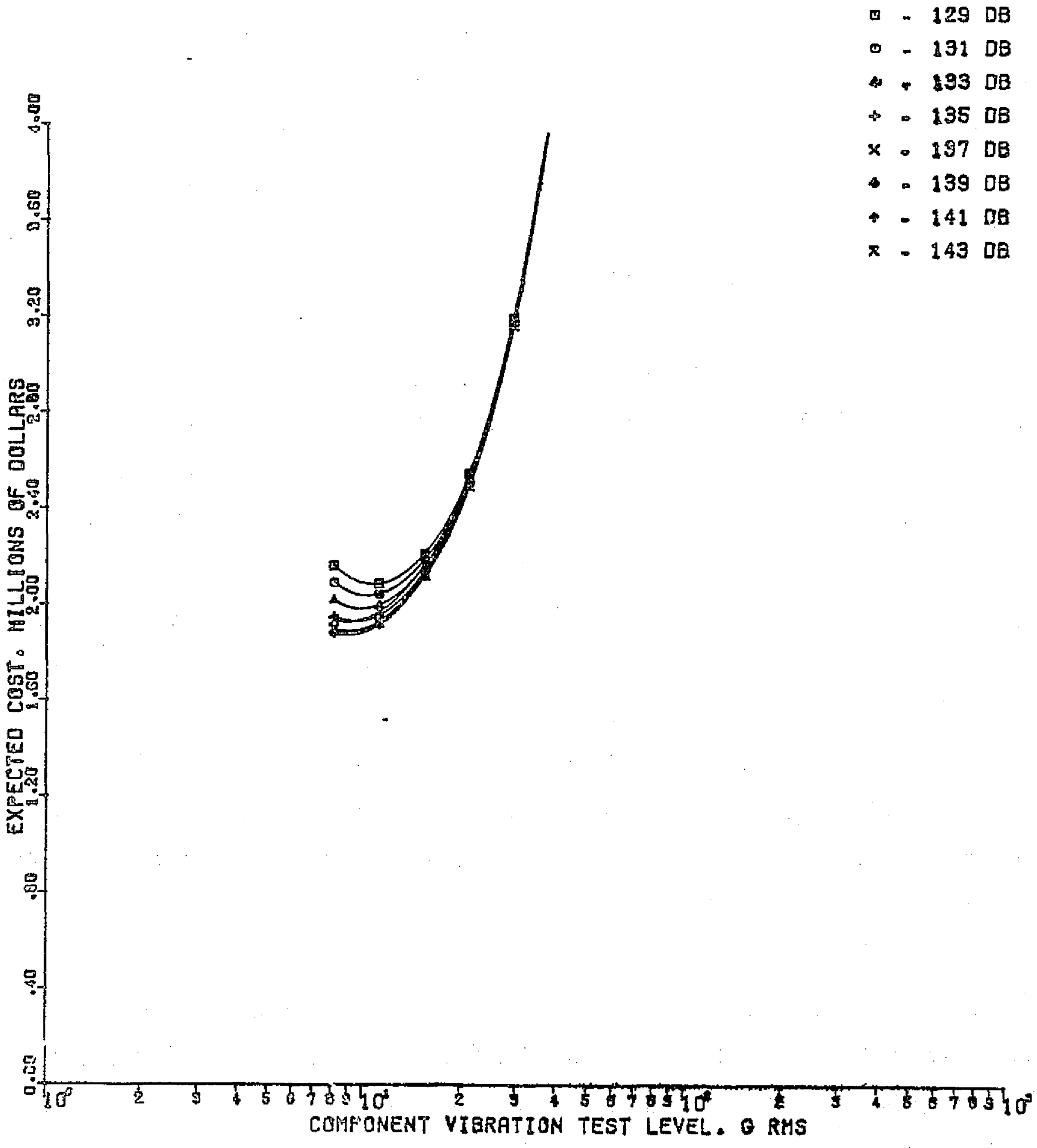


Figure 2-15 TECF Data, Test Plan 8, SMM Payload in a Near Earth Orbit

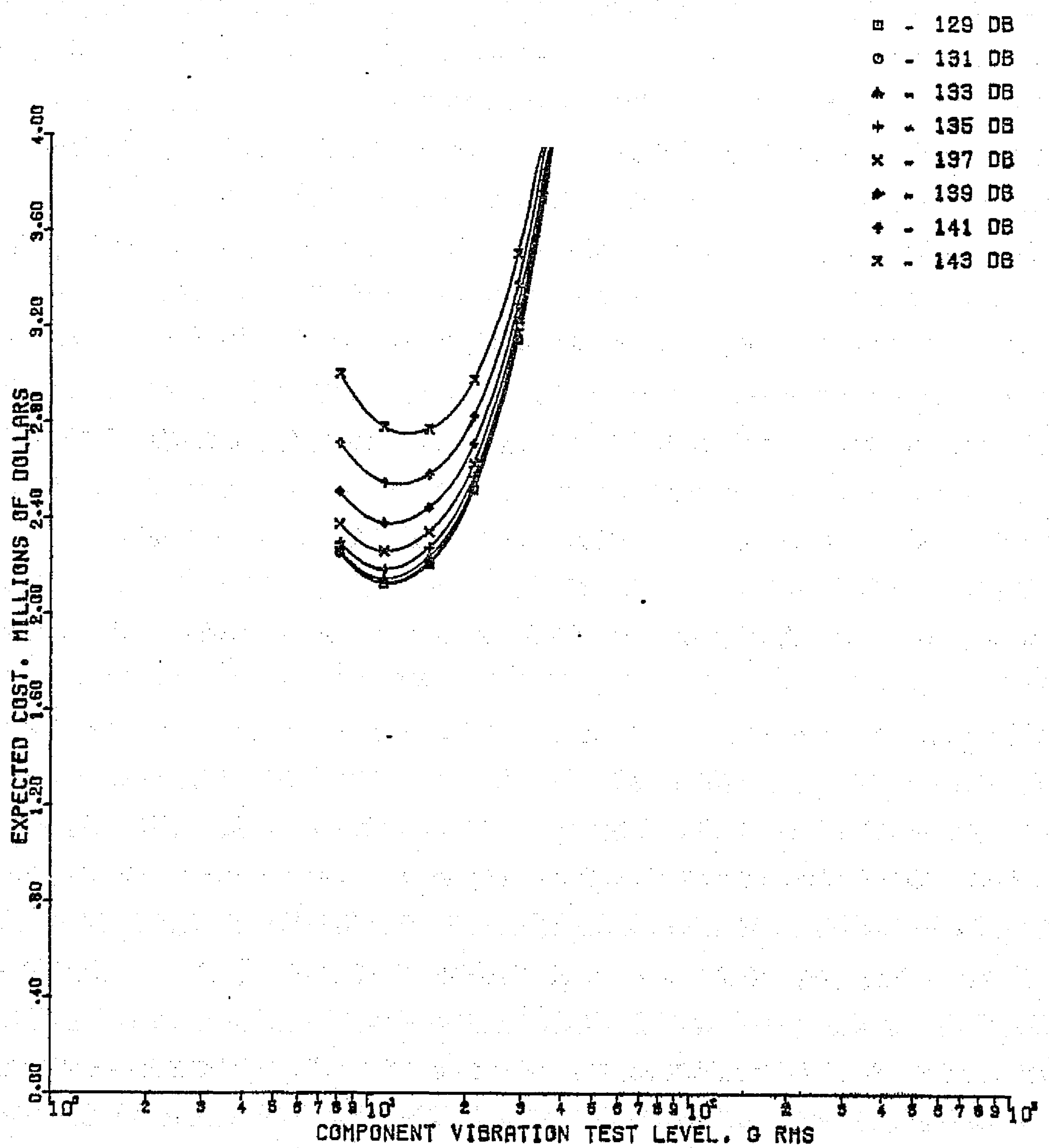


Figure 2-16 TECF Data, Test Plan 9, SMM Payload in a Near Earth Orbit

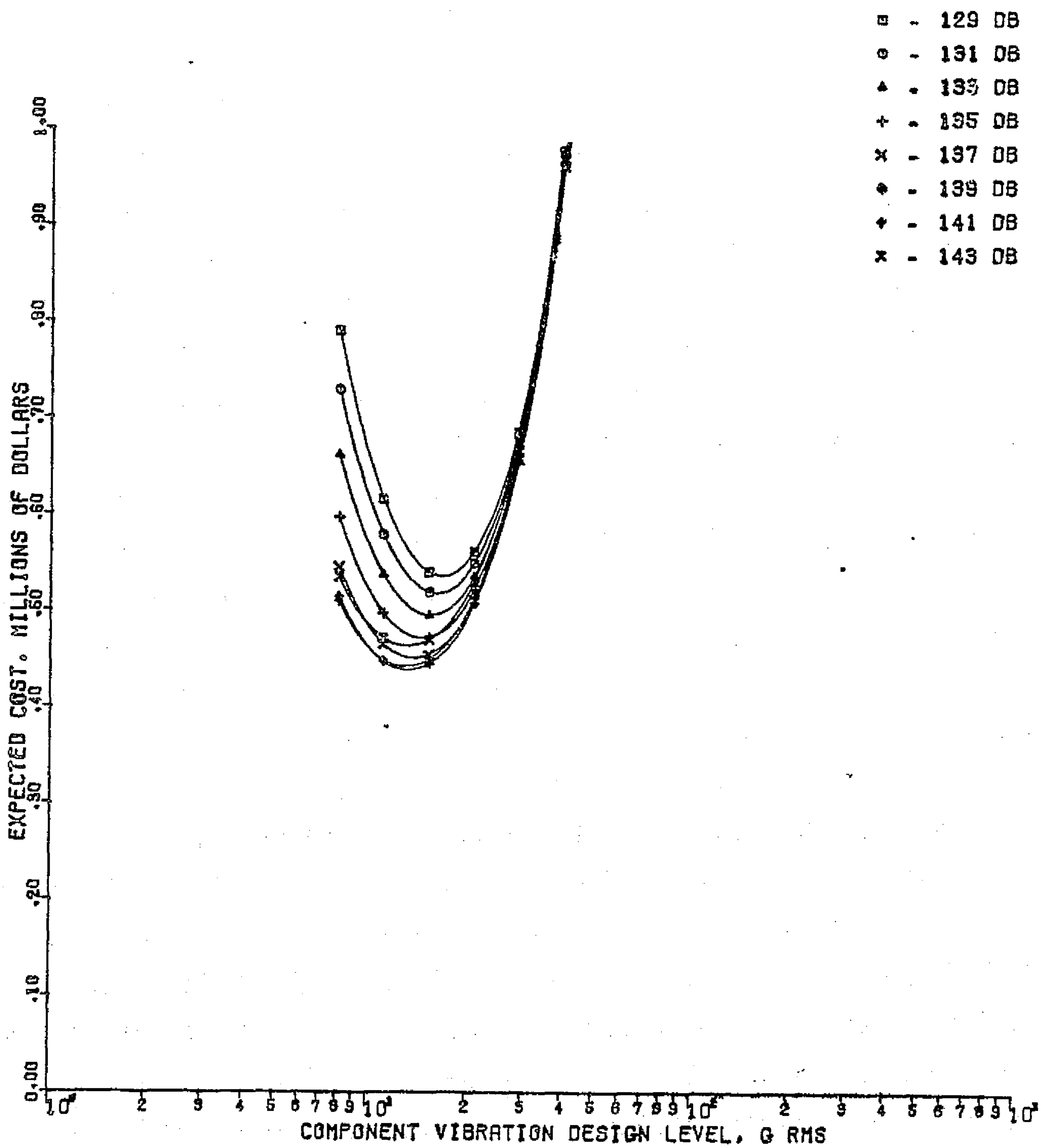


Figure 2-17 TECF Data, Test Plan 4, Landsat-D Payload in a Near Earth Orbit

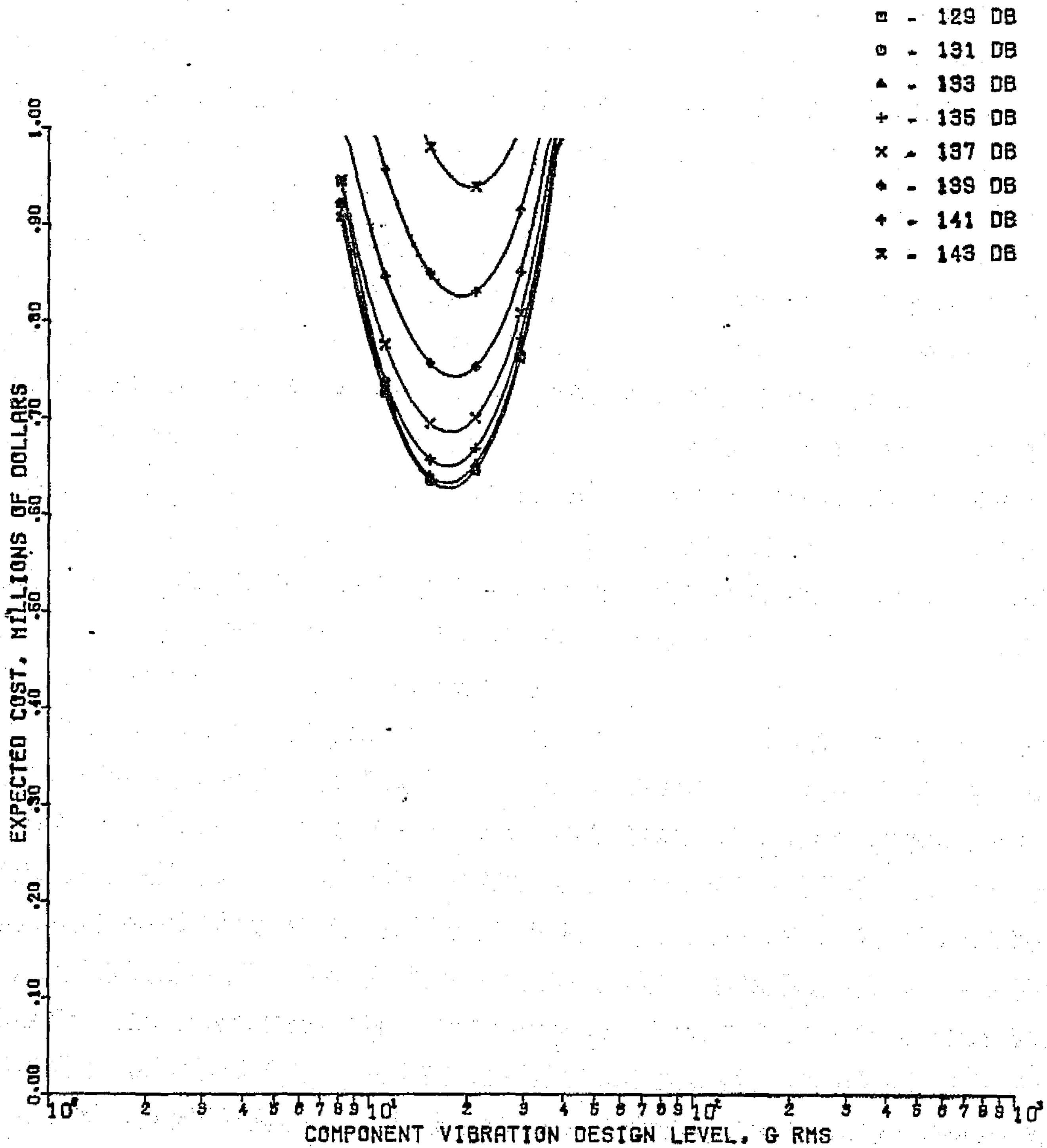


Figure 2-18 TECF Data, Test Plan 5, Landsat-D Payload in a Near Earth Orbit

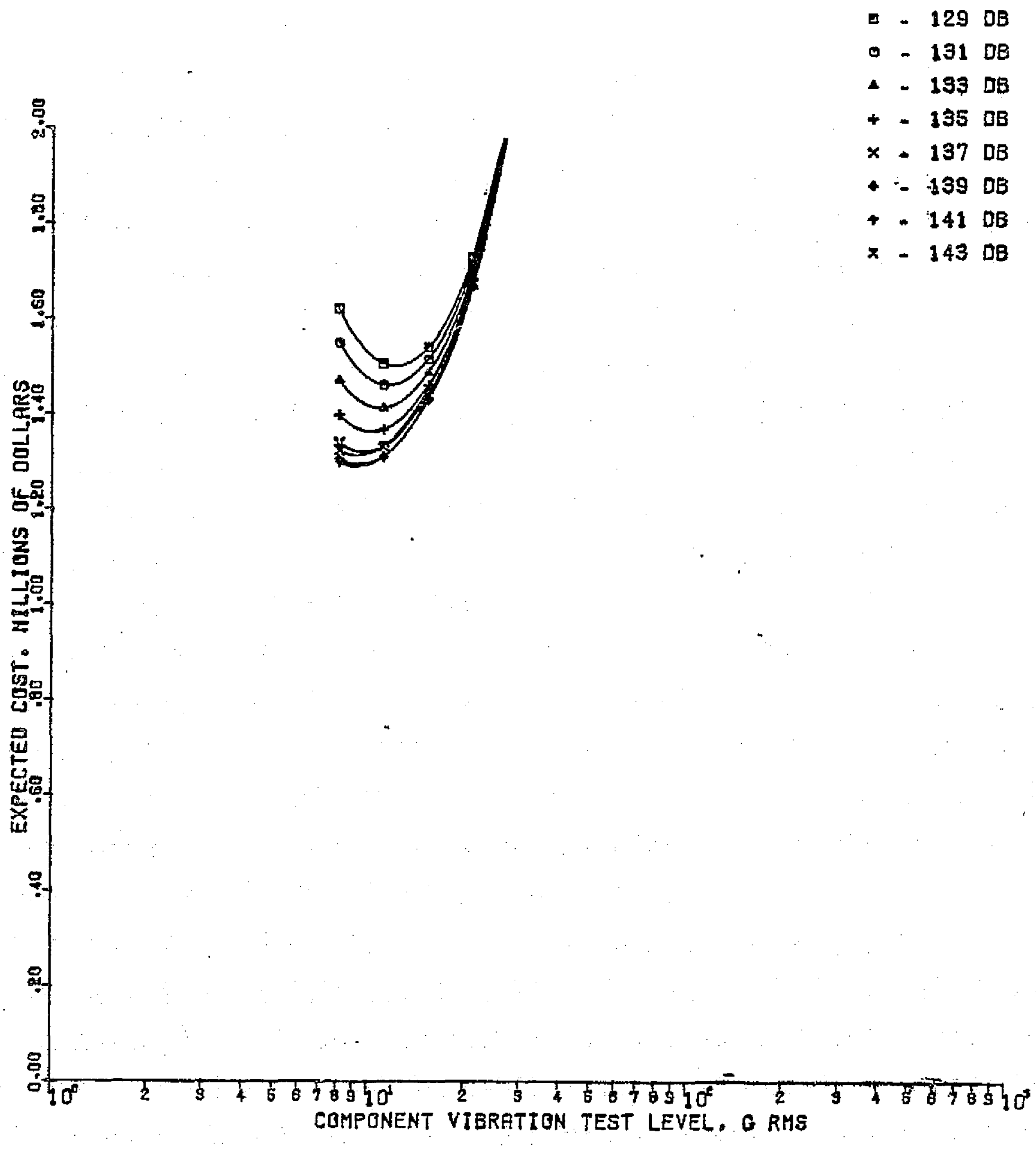


Figure 2-19 TECF Data, Test Plan 8, Landsat-D Payload in a Near Earth Orbit

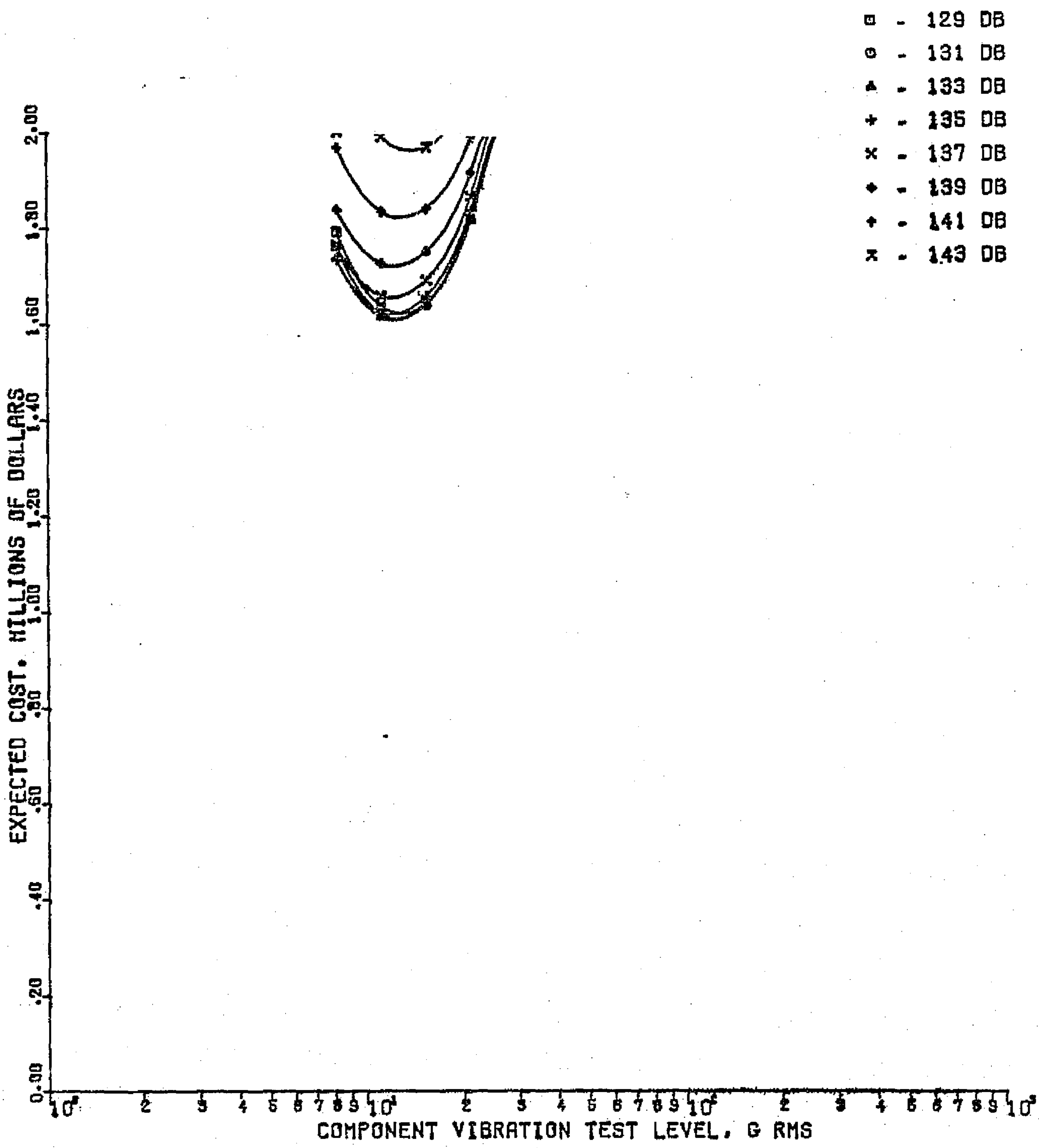


Figure 2-20 TECF Data, Test Plan 9, Landsat-D Payload in a Near Earth Orbit

The expected costs for each test plan are obtained by summing the direct costs, the design costs, and the probabilistic costs associated with each test plan. The cost elements for the SMM payload in a geosynchronous orbit are shown in Figures 21 to 27 for the seven test plans. For Test Plans 4, 5, 8, and 9 the cost elements are given for the assembly test level at which the optimum cost occurs. The cost elements are the following:

TECF	-	Total expected cost of failures
CD	-	direct cost
CDES	-	cost of designing components to higher vibration levels
ECSFST	-	expected cost of structure failures during protoflight structure test
ECCTF	-	expected cost of component test failures
ECSTF	-	expected cost of subassembly or system test failures
ECFLF	-	expected cost of flight failures

For Test Plans 4, 5, 8, and 9 the cost of structure failures (ECSFST) is included in the cost of assembly test failures (ECSTF); the costs of structure failures are very small, as shown in Figure 2-25. These figures show that the direct costs (CD) are constant for a given test plan. The cost of designing components to higher vibration levels (CDES) and the expected cost of component test failures (ECCTF) increase as the vibration level is increased. The expected costs of assembly test failures (ECSTF) and flight failures (ECFLF) decrease as the component vibration level is increased. The contribution of each cost element to the total expected cost varies with test plan and component vibration level.

The payload flight vibroacoustic reliability data associated with the optimum costs are also given in Tables 2-4 and 2-5. In this study the flight vibroacoustic reliability is defined as the probability of no data loss from the payload as a result of a

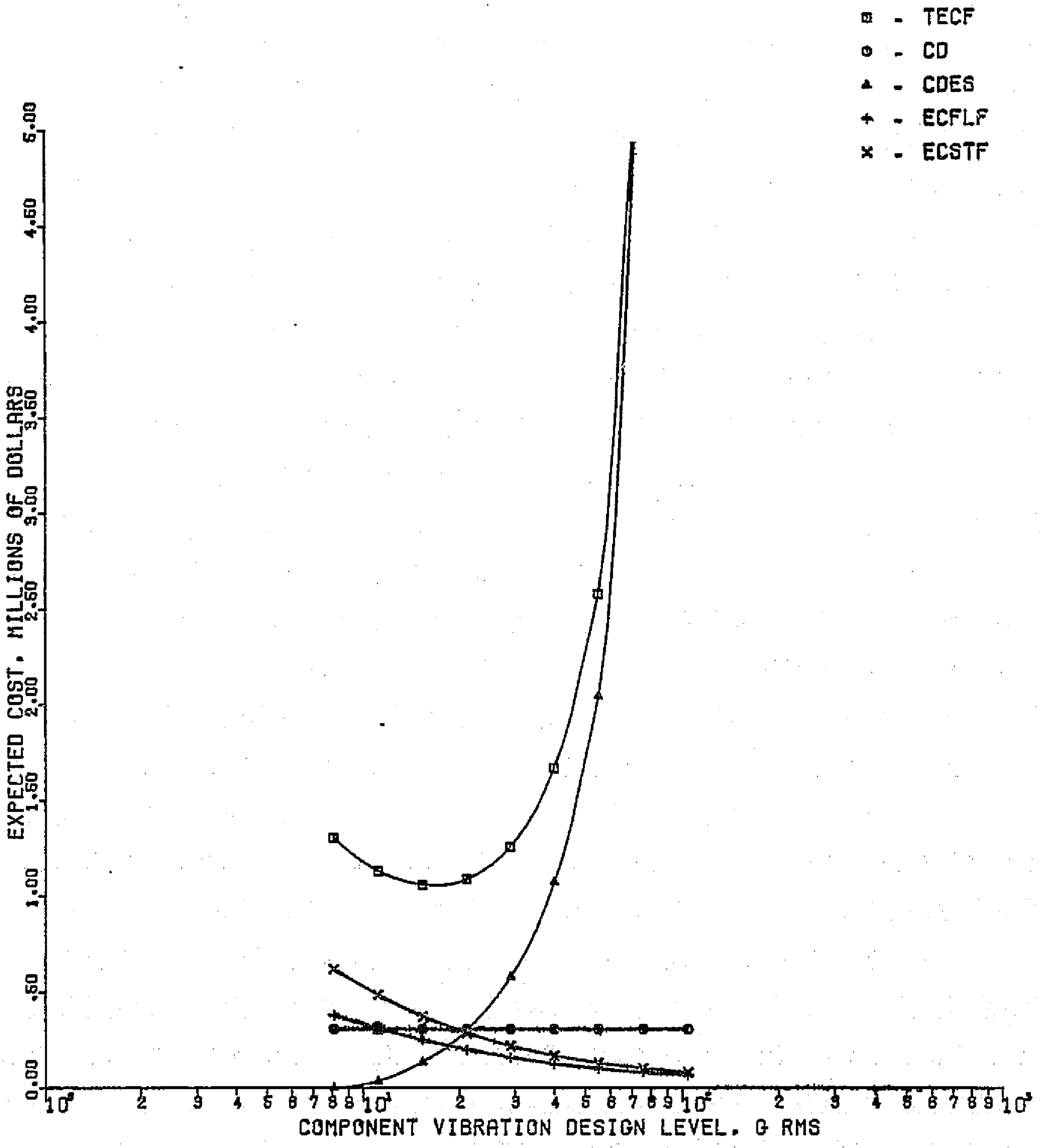


Figure 2-21 Cost Element Data, Optimum Assembly Test Level of 147 dB, Test Plan 4, SMM Payload in a Geosynchronous Orbit

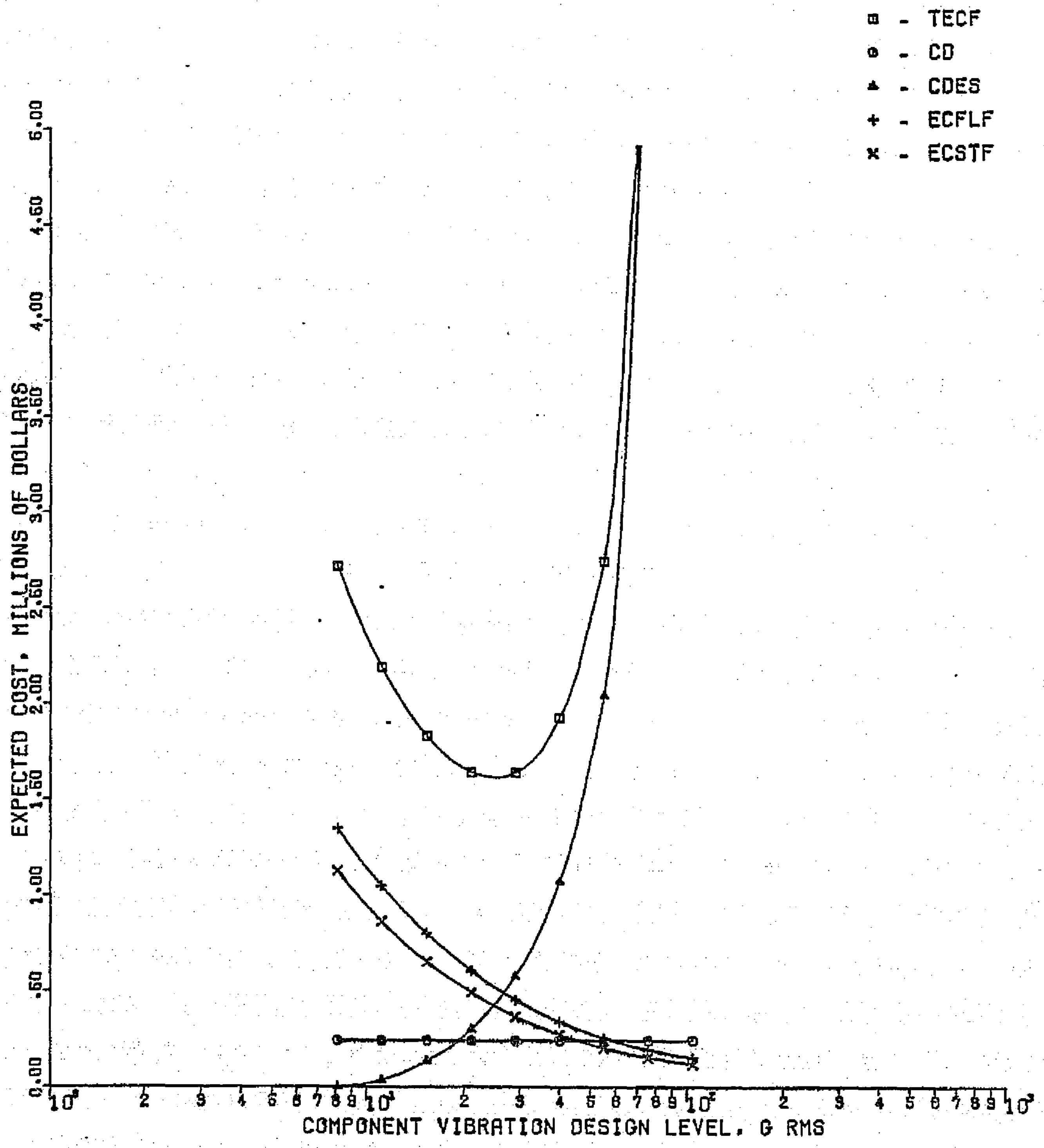
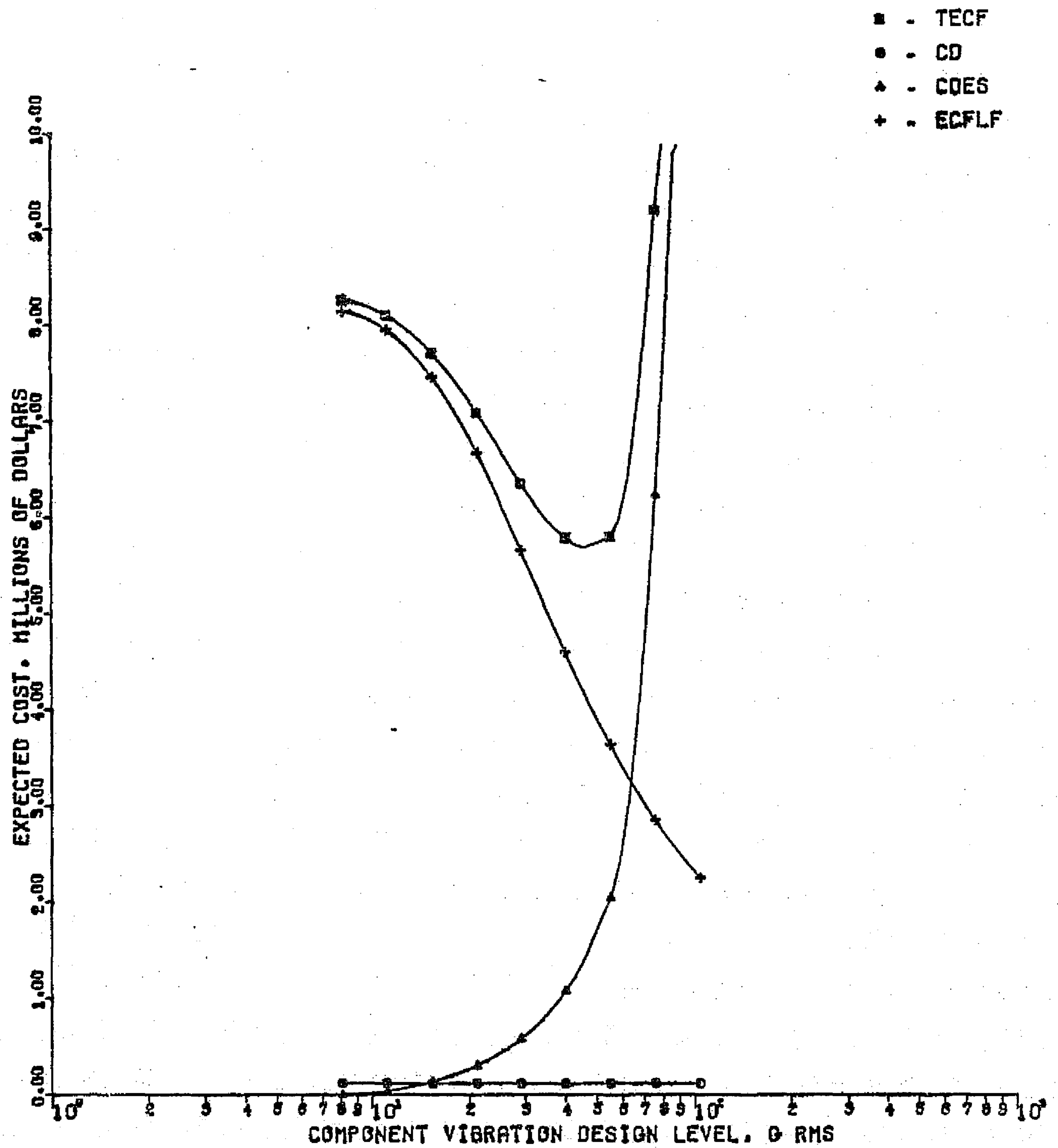


Figure 2-22 Cost Element Data, Optimum Assembly Test Level of 141 dB, Test Plan 5, SMM Payload in a Geosynchronous Orbit



rigure 2-23 Cost Element Data, Test Plan 6, SMM Payload in a Geosynchronous Orbit

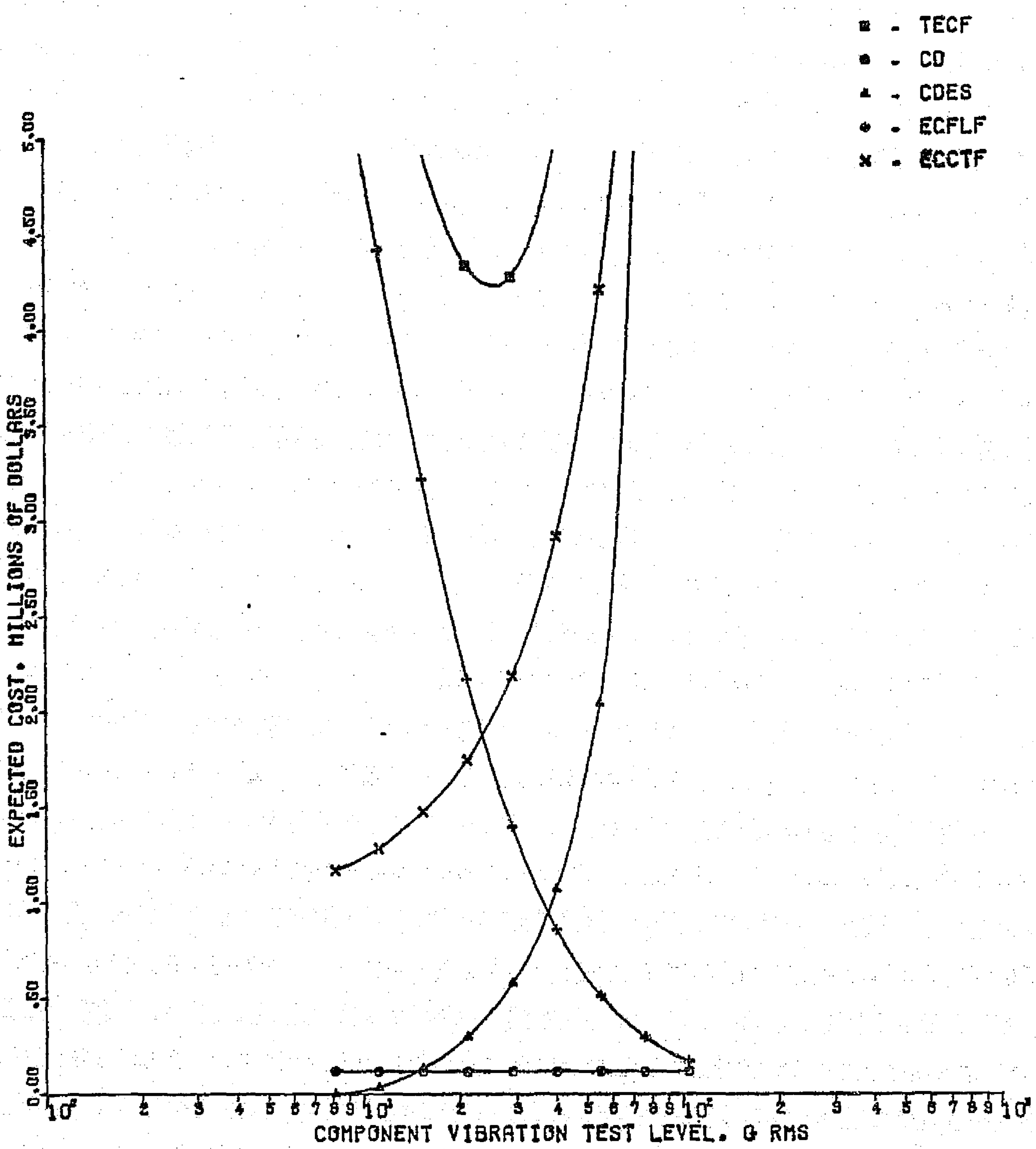


Figure 2-24 Cost Element Data, Test Plan 7, SMM Payload in a Geosynchronous Orbit

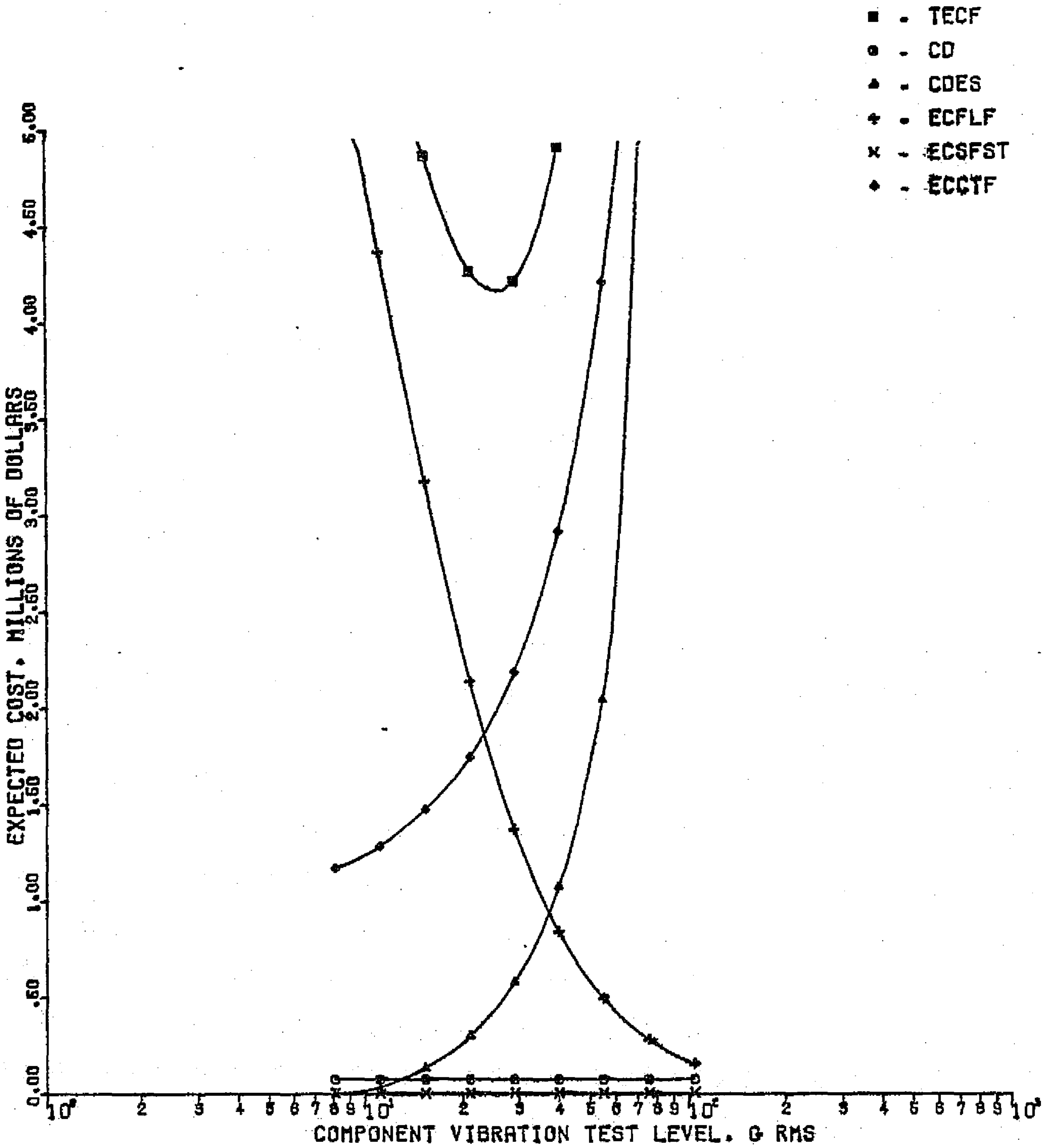


Figure 2-25 Cost Element Data, Test Plan 7B, SMM Payload in a Geosynchronous Orbit

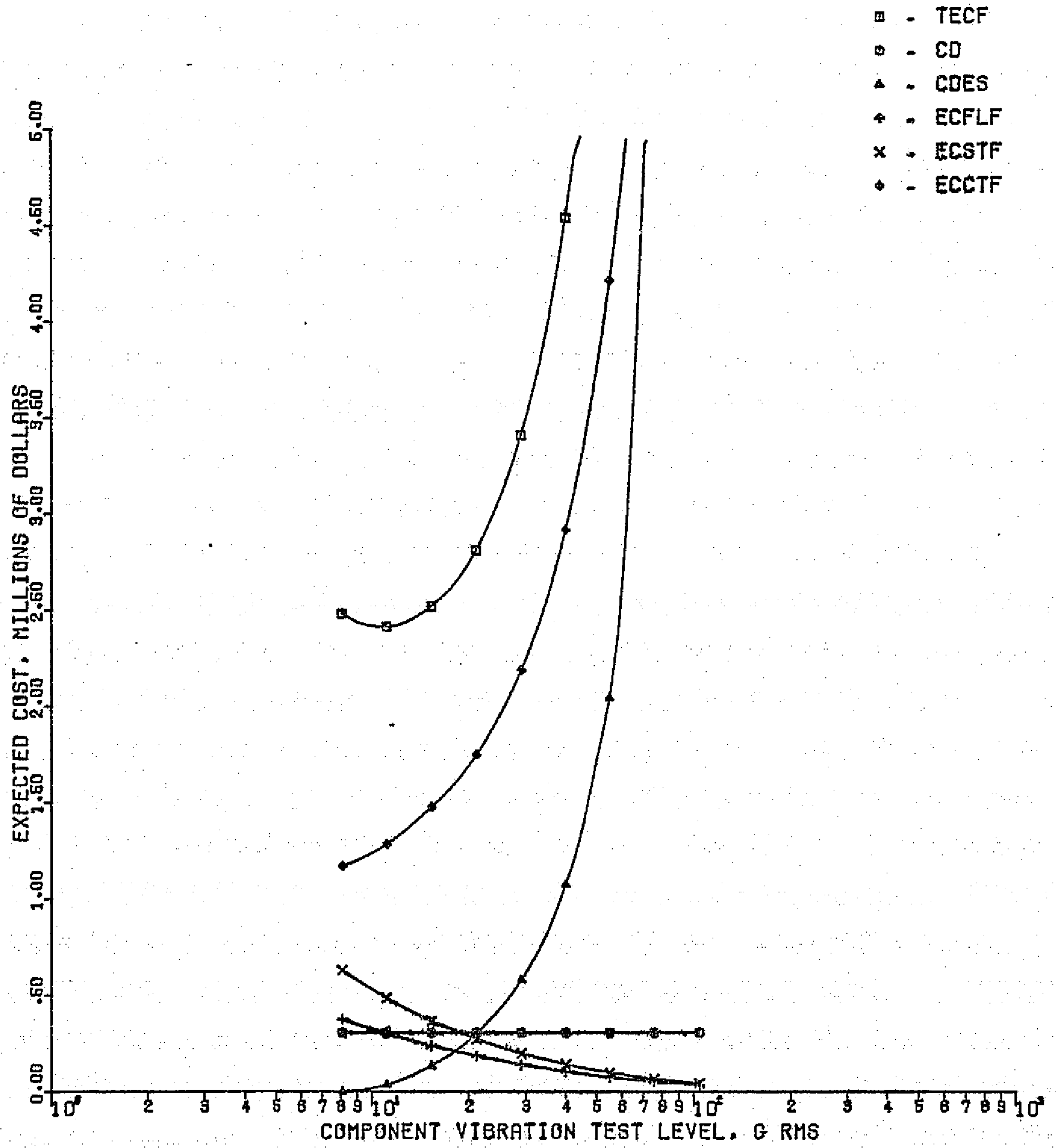


Figure 2-26 Cost Element Data, Optimum Assembly Test Level of 147 dB, Test Plan 8, SMM Payload in a Geosynchronous Orbit

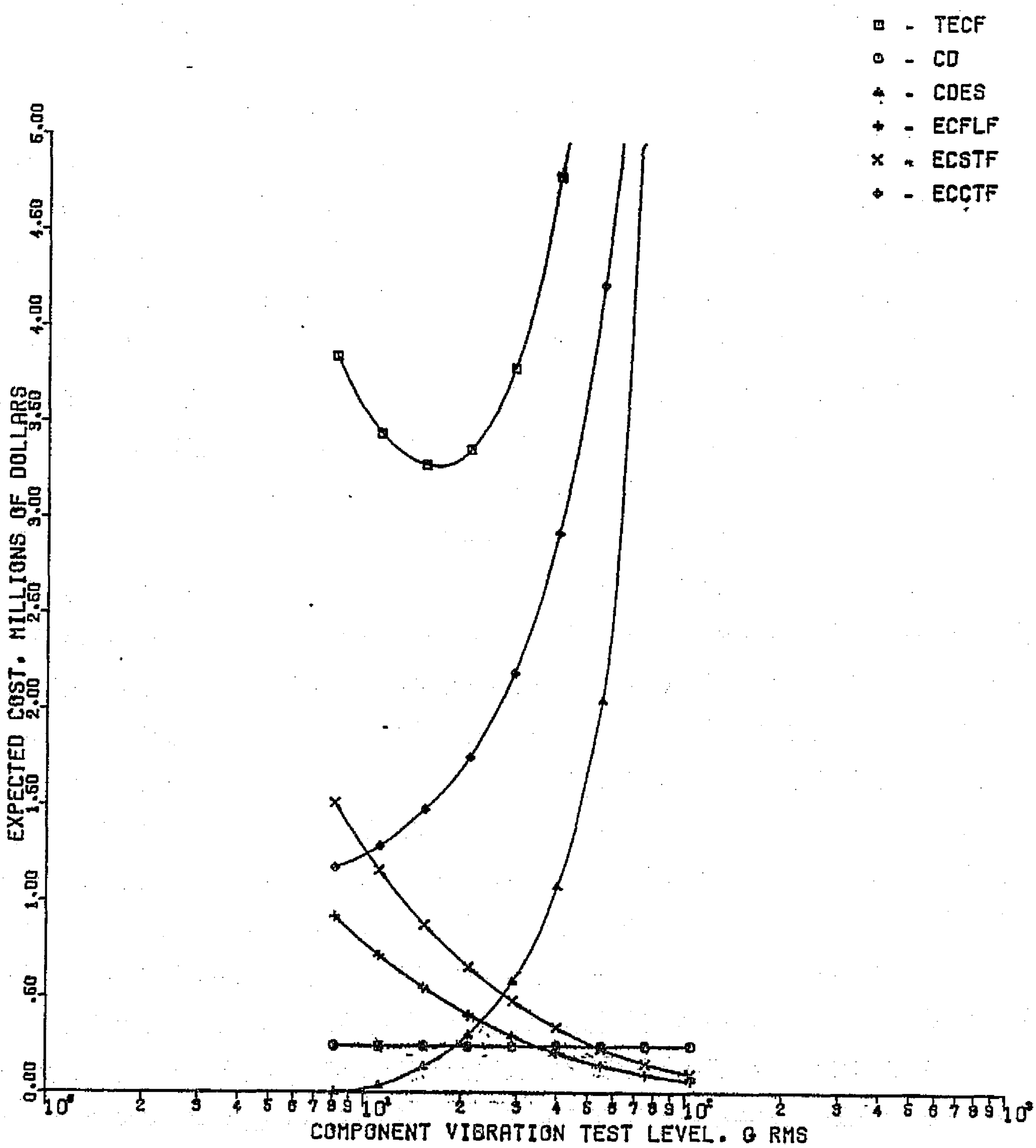


Figure 2-27 Cost Element Data, Optimum Assembly Test Level of 143 dB, Test Plan 9, SMM Payload in a Geosynchronous Orbit

vibration failure of a component. The variations of the flight failure probability (FFP) with assembly acoustic test level are shown in Figures 2-28, 2-29, 2-33, and 2-34 for Test Plans 4, 5, 8, and 9, respectively. The FFP data for Test Plans 6, 7, and 7B are shown in Figures 2-30 to 2-32, respectively. Only FFP data for the SMM payload in a geosynchronous orbit are shown in this report. The FFP data for all of the payload configurations analyzed are available in a separate data package.

The vibroacoustic reliability rank does not vary significantly with the payload configurations considered. Test Plan 4 has the highest vibroacoustic reliability, followed by Test Plans 8, 5, 9, 7B, 7, and 6, except for the Landsat-D payload in a near earth orbit. For this configuration the rank of Test Plans 4 and 8 is reversed.

For all test plans the Landsat-D payload in a geosynchronous orbit has the highest vibroacoustic reliability and the SMM payload in a near earth orbit has the lowest vibroacoustic reliability. The SMM payload in a geosynchronous orbit has the second highest vibroacoustic reliability for Test Plans 4, 5, 8, and 9, which involve assembly testing, and the Landsat-D payload in a near earth orbit has the second highest vibroacoustic reliability for Test Plans 6, 7, and 7B, which involve no assembly testing.

The flight failure probability varies most for the SMM payload; the variation is from 0.02 to 0.41 for this payload in a geosynchronous orbit and from 0.13 to 0.61 for this payload in a near earth orbit. For the Landsat-D payload the FFP varies from 0.003 to 0.105 for a geosynchronous orbit and from 0.03 to 0.19 for a near earth orbit.

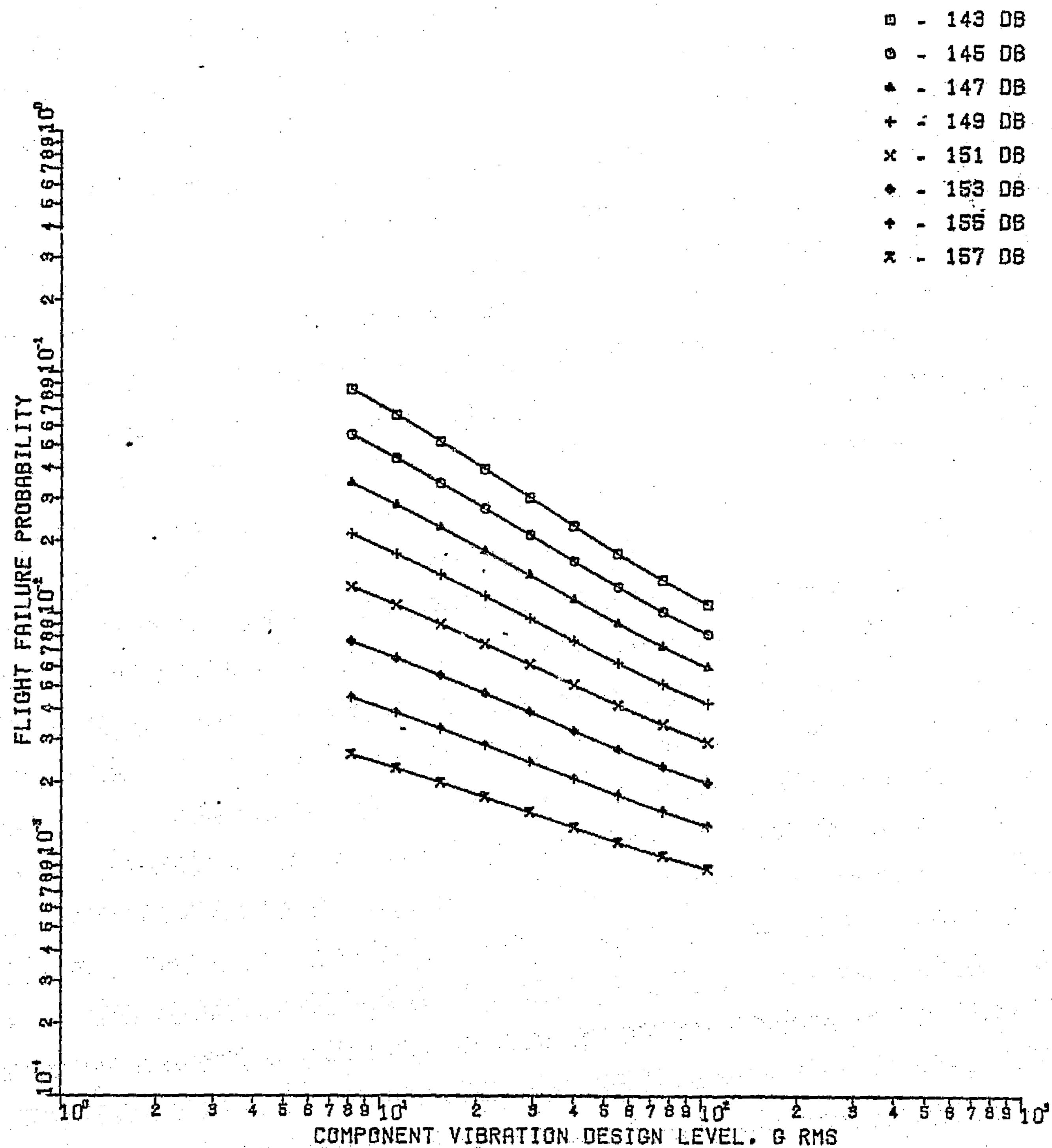


Figure 2-28 FFP Data, Test Plan 4, SMM Payload in a Geosynchronous Orbit

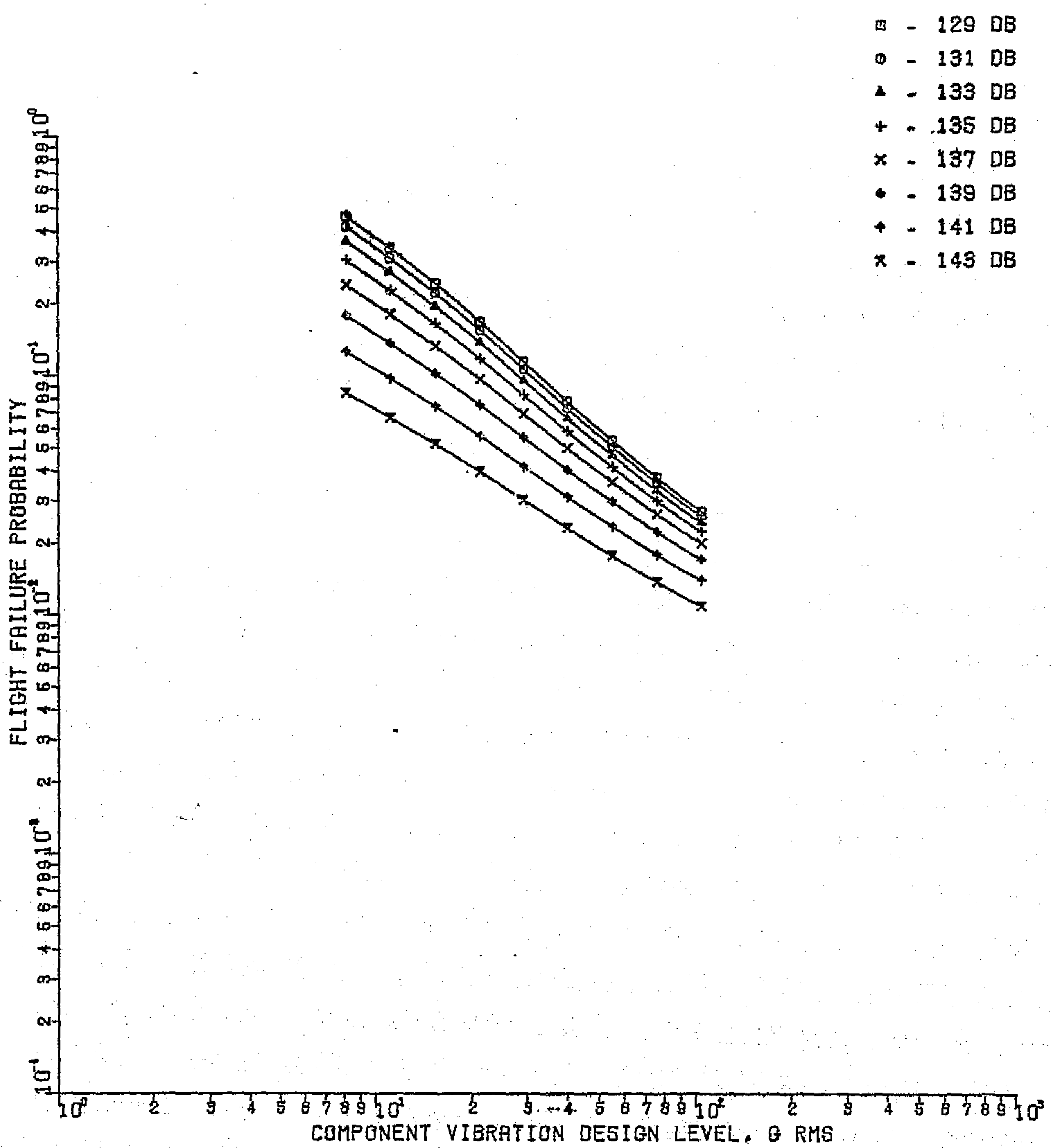


Figure 2-29 FFP Data, Test Plan 5, SMM Payload in a Geosynchronous Orbit

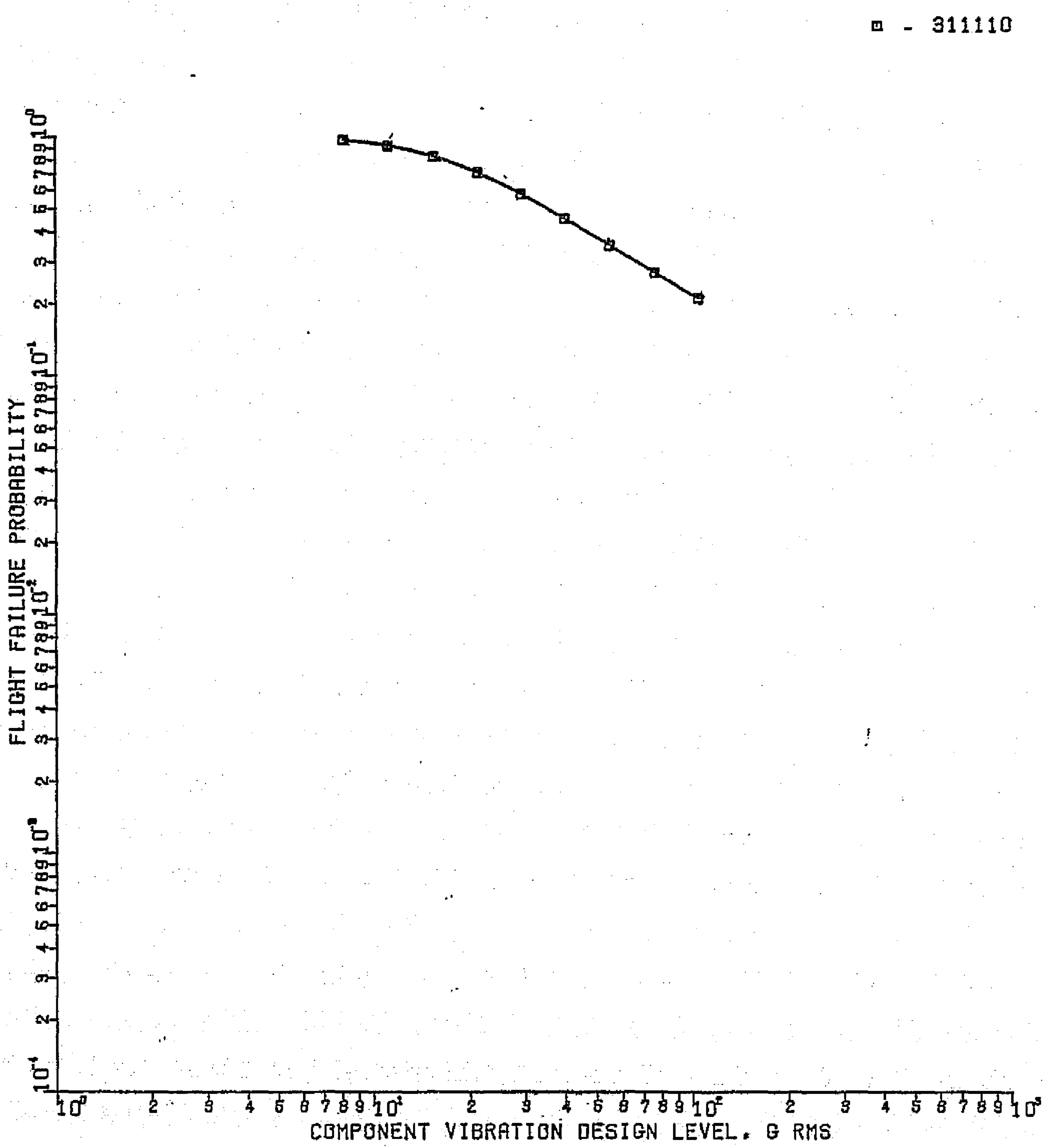


Figure 2-30 FFP Data, Test Plan 6, SMM Payload in a Geosynchronous Orbit

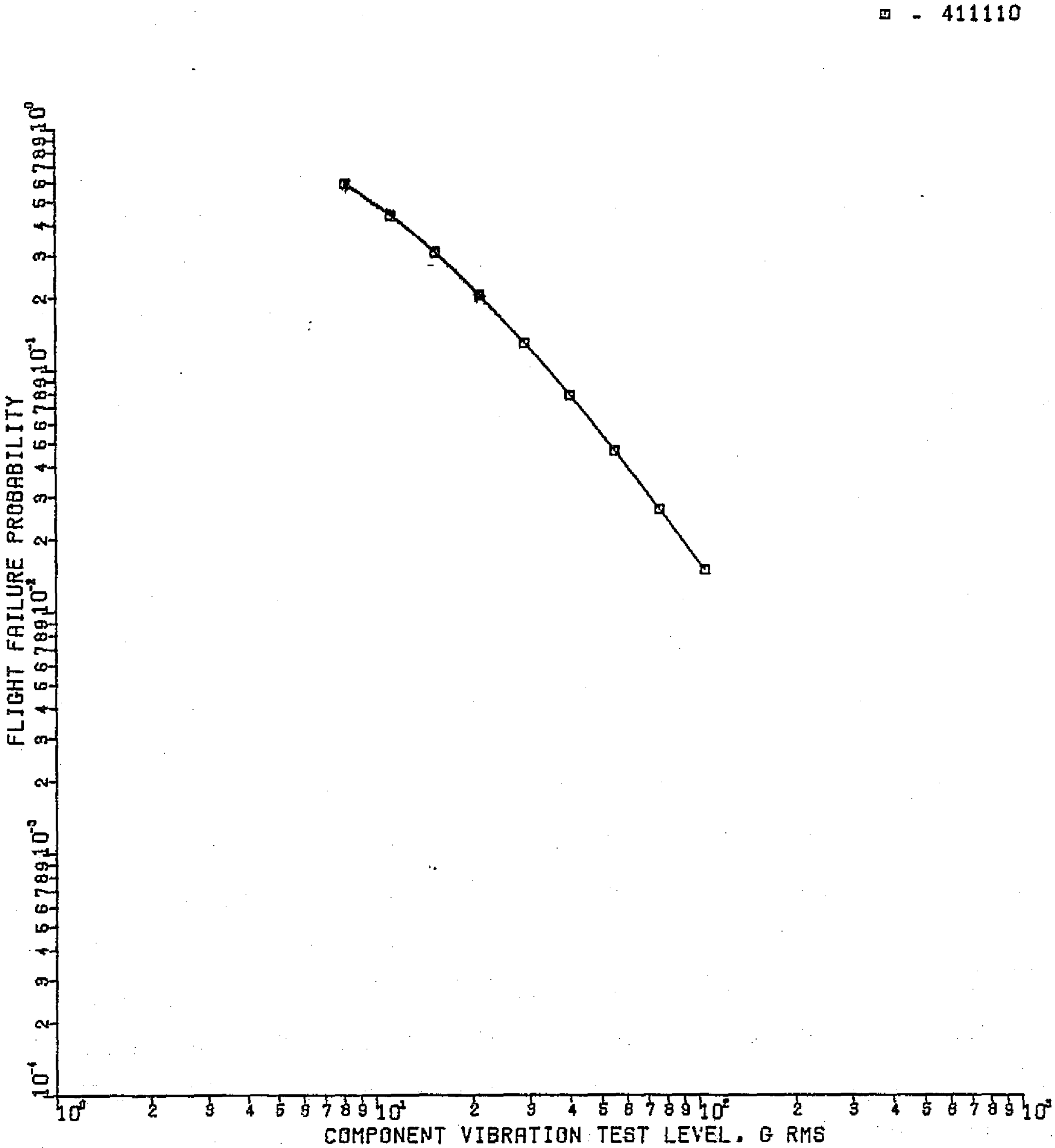


Figure 2-31 FFP Data, Test Plan 7, SMM Payload in a Geosynchronous Orbit

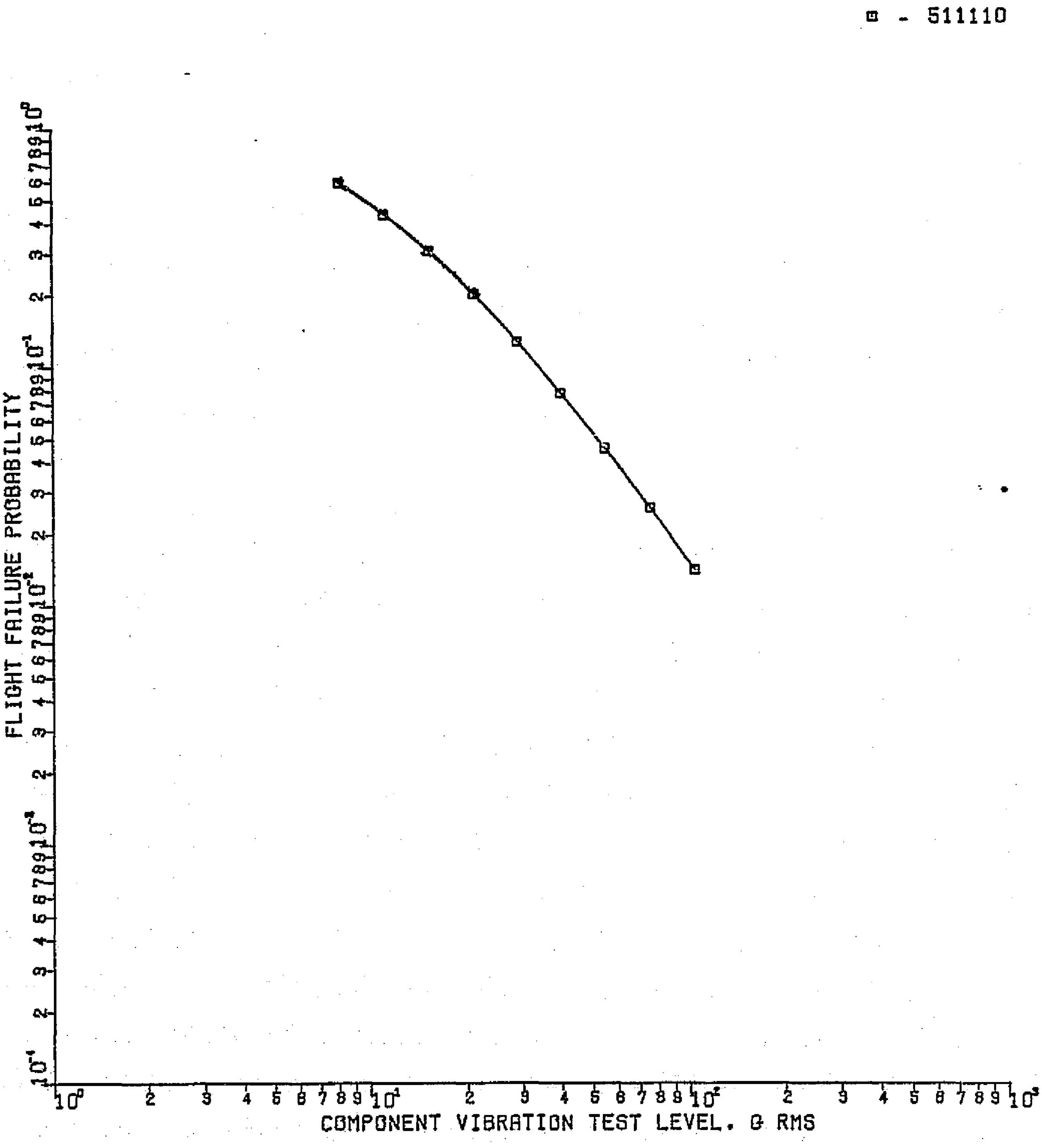


Figure 2-32 FFP Data, Test Plan 73, SMM Payload in a Geosynchronous Orbit

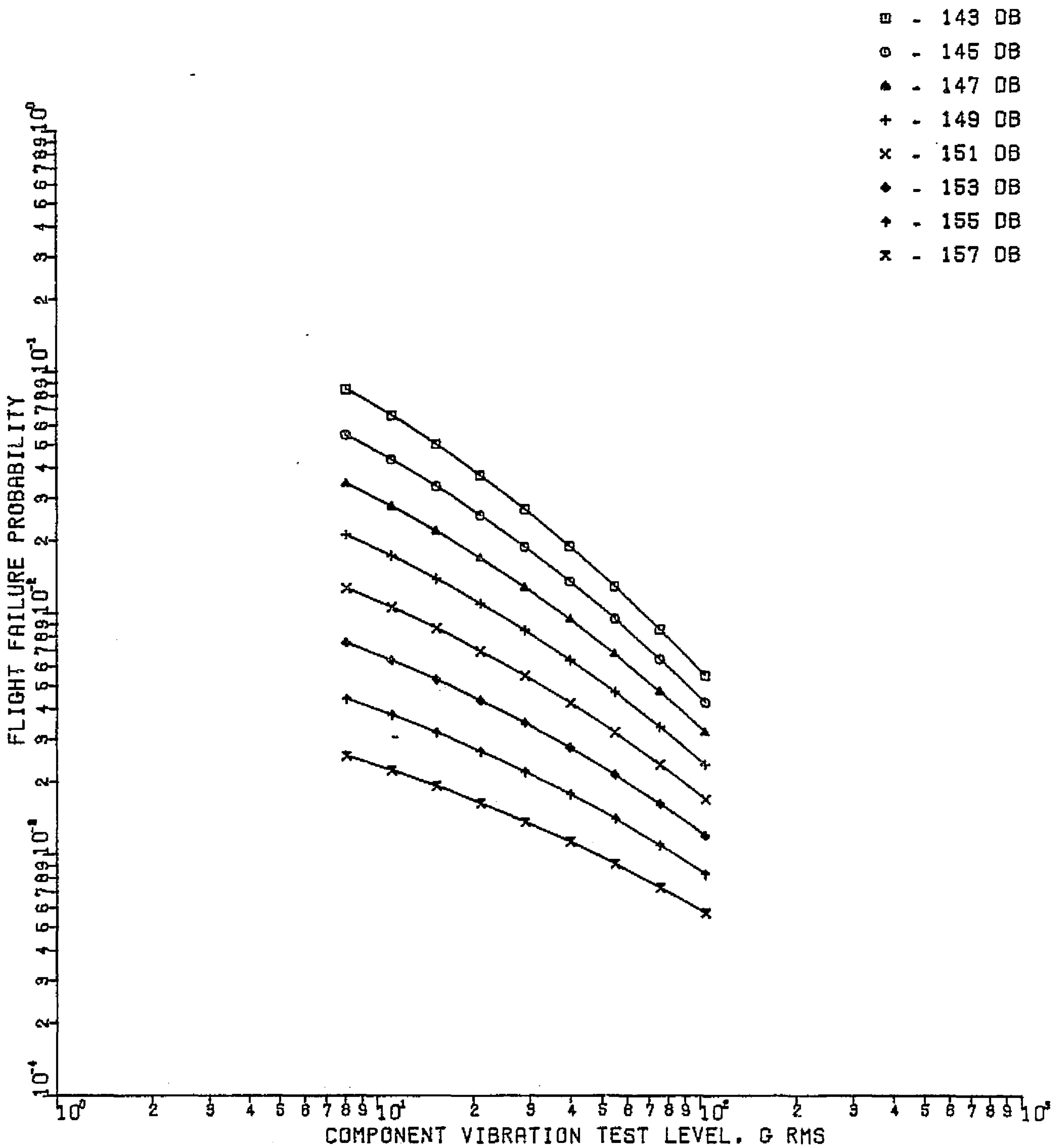


Figure 2-33 FFP Data, Test Plan 8, SMM Payload in a Geosynchronous Orbit

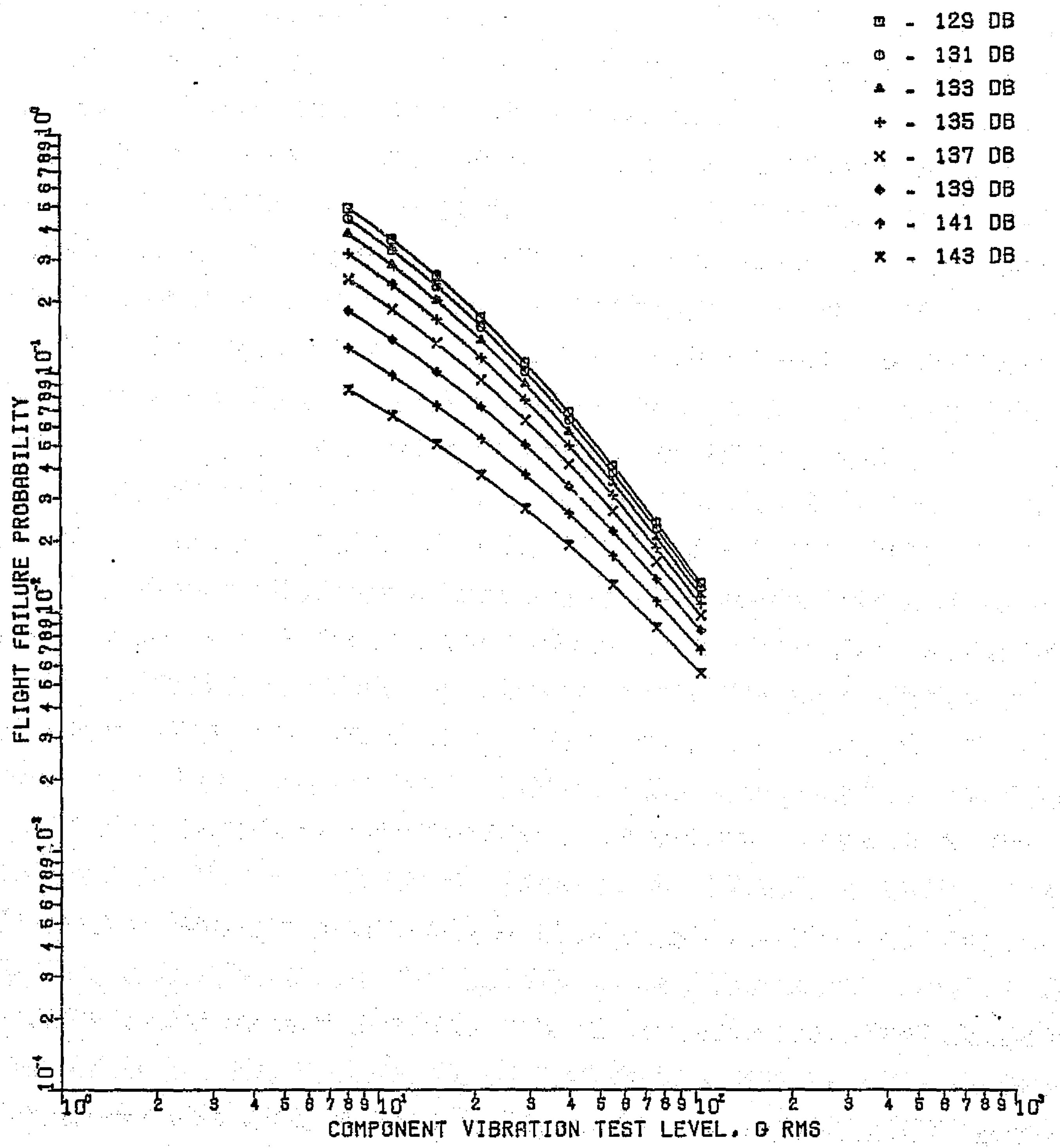


Figure 2-34 FFP Data, Test Plan 9, SMM Payload in a Geosynchronous Orbit

SECTION 3

STS SORTIE PAYLOAD PARAMETER STUDY

In order to further examine the effects of key parameter variations on alternate vibroacoustic test plans and the associated test requirements, a parameter study, similar to that presented in Reference 4, was performed. First the baseline data for this study was established using the increased launch cost. Then the following parameters were varied:

Number of Missions - The number of missions that a payload would be flown was anticipated to have a significant effect on test plan selection. The previous studies were for a 15 mission facility type payload. As the number of missions is reduced, it was anticipated that it could be cost effective to lower the vibroacoustic reliability resulting in reduced test levels and possibly select an alternate test plan. To evaluate this effect, three payload configurations from the previous studies were chosen with the number of missions reduced to 1 and 8.

Component Failure Probability - One of the most difficult parameters to quantify is the component failure probability. The probability of a component failing as a function of the vibration level is based on earlier studies by Stahle, Reference 7. Because this parameter is fundamental to all test plans and its effects are difficult to anticipate, the component failure probability was increased and decreased by a factor of approximately one-third.

Number of Housekeeping Subassembly Components - As a result of discussions at GSFC, it was recommended that changes to the reliability model of the payload be investigated by removing housekeeping components from the basic subassemblies and including them in the individual experiments. It was anticipated that this would enhance the vibroacoustic reliability by reducing the number of serial redundant housekeeping components. Three variations were made to investigate the influence of the payload housekeeping configuration on the test plan evaluation.

A total of 168 cases were studied. This consisted of eight conditions (baseline, two mission variations, two failure probability variations, and three component variations) for each of 3 payloads for each of seven test plans.

Because of the large amount of data, the sortie parameter variations are presented and discussed in three subsections. Section 3.1 presents the general results including a "case code" used to identify the individual computer runs. Section 3.2 presents the results for the baseline test plan evaluation including the revised launch cost. Sections 3.3, 3.4 and 3.5 present the parametric variations for the number of missions, component failure probability and housekeeping components, respectively.

3.1 GENERAL RESULTS

The decision model for each test plan was exercised for three STS sortie payload configurations. The payloads had either one, eight, or fifteen planned flights. The payload complexity was varied by considering either one or seven experiments. Each experiment was comprised of either two, six, or ten components. The housekeeping section of the payload was also varied and consisted of either two or three subassemblies having a total of either eight, twelve, or sixteen singly redundant components and the structure. The power subassembly was not changed and had four components. The control subassembly was varied and had either zero or four components. The data handling subassembly was also varied and had either four or eight components.

A six-digit case code for this portion of the study was established in order to identify the data generated for the 168 cases in the parameter study for STS sortie payloads. Where applicable, a "0" is used to denote the baseline value. Each digit represents a particular parameter:

1st and 2nd digit - Test Plan

Value	Test Plan
40	4
50	5
60	6
70	7
7B	7B
80	8
90	9

3rd digit - Payload

Value	Number of Experiments	Components per Experiment
1	1	2
2	7	2
3	7	6

4th digit - Number of Missions

Value	Missions
0	15 (Baseline)
1	8
2	1

5th digit - Component vibration failure probability

Value	Failure Probability
0	Baseline
1	Reduced Failure Probability
2	Increased Failure Probability

6th digit - Number of components in housekeeping subassemblies

Value	Power	Control	Data Handling	Experiments
0	4	4	8	2 or 6
1	4	4	4	6 or 10
2	4	0	8	2 or 6
3	4	0	4	6 or 10

This case code is used in this report. It is the value given in the key to the symbols of the curves on the optimum cost graphs, Figures 3-1 to 3-21. The variations are discussed in the appropriate subsection. The test plans are defined in Table 1-1. The payload identification gives the number of experiments (NEXP) and the number of components peculiar to each experiment (NCPE). For example, Payload 7,2 is the STS sortie payload configuration that has 7 experiments with 2 components in each experiment. The other parameters used in the parameter variation definitions are:

NF = number of missions

DYDGQ = slope of component vibration strength distribution curve

NCCPS = number of components in power subassembly

NCCCS = number of components in control subassembly

NCCDS = number of components in data handling subassembly

The components in the housekeeping subassemblies are common to all experiments and are singly redundant for this study. The components in the experiments have no redundancy.

In the discussion a three-digit number is used in some places to indicate the variation being discussed. This number is the last three digits of the basic six-digit case code.

In this study only one parameter (or parameter group) was varied at a time, so that in each case either two or three of the last three digits in the case code are zero. The following examples demonstrate the use of the case code.

401000 - baseline data for Payload 1,2 of Test Plan 4

502100 - data for the first number of missions variation (NF = 8) for Payload 7,2 of Test Plan 5

7B3020 - data for the second component vibration failure rate variation for Payload 7,6 of Test Plan 7B

901003 - data for the third number of components in housekeeping subassemblies variation (NCCPS = 4, NCCCS = 0, NCCDS = 4, NCPE = 6) for Payload 1,2 of Test Plan 9

The Optimum Cost Data Summaries, Tables 3-1 to 3-7, present the optimum costs and related test levels by test plan. The values for the varied parameters are given in the tables. Each of the tables is partitioned vertically into three parts, one for each payload. Values are given for the case code, the number of missions (NF), the component vibration failure rate (DYDGQ), the number of housekeeping subassemblies (NHS), the number of experiments (NEXP), the total number of components in the housekeeping portion of the model (NCCE), the number of components in each experiment (NCPE), the number of components in the power subassembly (NCCPS), the number of components in the control subassembly (NCCCS), and the number of components in the data handling subassembly (NCCDS).

For each case the component vibration test/design level and the assembly test level were varied to determine the optimum test/design values.

Each table gives the optimum data for each variation of the three payload configurations. Values are given for the minimum expected cost in millions of dollars and, at the minimum cost, the standardized vibration variable, the component vibration test/design level (g rms), and the assembly acoustic test level (dB). Also given are the associated vibroacoustic flight failure probability and flight reliability.

Table 3-1

Optimum Cost Data Summary
Test Plan 4
Protoflight Subassemblies / Structure Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ ($x10^{-3}$)	NHS	NEXP	NCCE	NCPE	NCCPS	NCCCS	NCCDS	Expected Cost ($\$x10^6$)	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
401000	1,2	15	- 8.805	3	1	17	2	4	4	8	1.154	1.950	21.071	153	0.00125	0.99875
401100		8	- 8.805	3	1	17	2	4	4	8	0.754	1.850	18.544	149	0.00222	0.99778
401200		1	- 8.805	3	1	17	2	4	4	8	0.247	1.500	11.860	137	0.00804	0.99196
401010		15	- 5.638	3	1	17	2	4	4	8	1.107	1.900	19.767	153	0.00114	0.99886
401020		15	-12.681	3	1	17	2	4	4	8	1.202	1.950	21.071	153	0.00140	0.99860
401001		15	- 8.805	3	1	13	6	4	4	4	1.386	2.150	27.204	155	0.00199	0.99801
401002		15	- 8.805	2	1	13	2	4	0	8	1.073	1.950	21.071	153	0.00125	0.99875
401003		15	- 8.805	2	1	9	6	4	0	4	1.285	2.250	30.910	155	0.00186	0.99814
402000	7,2	15	- 8.805	3	7	17	2	4	4	8	1.374	1.900	19.767	151	0.01448	0.98552
402100		8	- 8.805	3	7	17	2	4	4	8	0.946	1.800	17.397	149	0.01596	0.98404
402200		1	- 8.805	3	7	17	2	4	4	8	0.387	1.450	11.126	135	0.07311	0.92689
402010		15	- 5.638	3	7	17	2	4	4	8	1.314	1.900	19.767	151	0.01258	0.98742
402020		15	-12.681	3	7	17	2	4	4	8	1.438	1.900	19.767	151	0.01636	0.98364
402001		15	- 8.805	3	7	13	6	4	4	4	1.823	2.000	22.461	153	0.02484	0.97516
402002		15	- 8.805	2	7	13	2	4	0	8	1.298	1.950	21.071	153	0.00866	0.99134
402003		15	- 8.805	2	7	9	6	4	0	4	1.739	2.050	23.942	153	0.02397	0.97603
403000	7,6	15	- 8.805	3	7	17	6	4	4	8	1.877	1.950	21.071	153	0.02573	0.97427
403100		8	- 8.805	3	7	17	6	4	4	8	1.330	1.900	19.767	149	0.04335	0.95665
403200		1	- 8.805	3	7	17	6	4	4	8	0.505	1.550	12.642	137	0.14226	0.85774
403010		15	- 5.638	3	7	17	6	4	4	8	1.761	1.950	21.071	153	0.02255	0.97745
403020		15	-12.681	3	7	17	6	4	4	8	1.996	2.000	22.461	153	0.02798	0.97202
403001		15	- 8.805	3	7	13	10	4	4	4	2.283	2.000	22.461	153	0.04105	0.95895
403002		15	- 8.805	2	7	13	6	4	0	8	1.794	2.000	22.461	153	0.02484	0.97516
403003		15	- 8.805	2	7	9	10	4	0	4	2.199	2.050	23.942	153	0.03963	0.96037

Table 3-2

Optimum Cost Data Summary
Test Plan 5
Protoflight System / Structure Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ ($x10^{-3}$)	NHS	NEXP	NCCE	NCPE	NCCPS	NCCCS	NCCDS	Expected Cost ($\$x10^6$)	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
501000	1,2	15	- 8.805	3	1	17	2	4	4	8	1.634	2.300	32.948	147	0.00354	0.99646
501100		8	- 8.805	3	1	17	2	4	4	8	1.110	2.200	28.997	143	0.00521	0.99479
501200		1	- 8.805	3	1	17	2	4	4	8	0.368	1.650	14.364	129	0.01305	0.98695
501010		15	- 5.638	3	1	17	2	4	4	8	1.518	2.250	30.910	147	0.00299	0.99701
501020		15	-12.681	3	1	17	2	4	4	8	1.768	2.300	32.948	149	0.00282	0.99718
501001		15	- 8.805	3	1	13	6	4	4	4	1.843	2.350	35.121	151	0.00437	0.99563
501002		15	- 8.805	2	1	13	2	4	0	8	1.508	2.300	32.948	149	0.00235	0.99765
501003		15	- 8.805	2	1	9	6	4	0	4	1.675	2.400	37.437	153	0.00269	0.99731
502000	7,2	15	- 8.805	3	7	17	2	4	4	8	1.843	2.250	30.910	147	0.02534	0.97466
502100		8	- 8.805	3	7	17	2	4	4	8	1.248	2.150	27.204	143	0.03730	0.96270
502200		1	- 8.805	3	7	17	2	4	4	8	0.390	1.600	13.475	129	0.09172	0.90828
502010		15	- 5.638	3	7	17	2	4	4	8	1.698	2.250	30.910	147	0.02052	0.97948
502020		15	-12.681	3	7	17	2	4	4	8	2.002	2.300	32.948	147	0.02927	0.97073
502001		15	- 8.805	3	7	13	6	4	4	4	2.535	2.300	32.948	149	0.04783	0.95217
502002		15	- 8.805	2	7	13	2	4	0	8	1.724	2.300	32.948	147	0.02418	0.97582
502003		15	- 8.805	2	7	9	6	4	0	4	2.394	2.300	32.948	149	0.04783	0.95217
503000	7,6	15	- 8.805	3	7	17	6	4	4	8	2.669	2.300	32.948	149	0.04784	0.95216
503100		8	- 8.805	3	7	17	6	4	4	8	1.873	2.200	28.997	145	0.07324	0.92676
503200		1	- 8.805	3	7	17	6	4	4	8	0.548	1.700	15.311	129	0.21640	0.78360
503010		15	- 5.638	3	7	17	6	4	4	8	2.422	2.250	30.910	149	0.04121	0.95879
503020		15	-12.681	3	7	17	6	4	4	8	2.933	2.300	32.948	149	0.05686	0.94314
503001		15	- 8.805	3	7	13	10	4	4	4	3.281	2.300	32.948	149	0.07843	0.92157
503002		15	- 8.805	2	7	13	6	4	0	8	2.535	2.300	32.948	149	0.04783	0.95217
503003		15	- 8.805	2	7	9	10	4	0	4	3.126	2.300	32.948	151	0.05172	0.94828

Table 3-3

Optimum Cost Data Summary
Test Plan 6
No Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ ($x10^{-3}$)	NHS	NEXP	NCCE	NCPE	NCCPS	NCCCS	NCCDS	Expected Cost ($\$x10^6$)	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
601000	1,2	15	- 8.805	3	1	17	2	4	4	8	3.710	2.700	54.917		0.01982	0.98018
601100		8	- 8.805	3	1	17	2	4	4	8	2.228	2.550	45.342		0.02435	0.97565
601200		1	- 8.805	3	1	17	2	4	4	8	0.457	2.000	22.461		0.05543	0.94457
601010		15	- 5.638	3	1	17	2	4	4	8	3.243	2.700	54.917		0.01318	0.98682
601020		15	-12.681	3	1	17	2	4	4	8	4.337	2.700	54.917		0.02894	0.97106
601001		15	- 8.805	3	1	13	6	4	4	4	5.783	2.800	62.399		0.04778	0.95222
601002		15	- 8.805	2	1	13	2	4	0	8	3.519	2.700	54.917		0.01951	0.98049
601003		15	- 8.805	2	1	9	6	4	0	4	5.507	2.850	66.514		0.04469	0.95531
602000	7,2	15	- 8.805	3	7	17	2	4	4	8	4.000	2.700	54.917		0.12022	0.87978
602100		8	- 8.805	3	7	17	2	4	4	8	2.414	2.500	42.537		0.15443	0.84557
602200		1	- 8.805	3	7	17	2	4	4	8	0.503	1.950	21.071		0.30781	0.69219
602010		15	- 5.638	3	7	17	2	4	4	8	3.472	2.550	45.342		0.10202	0.89798
602020		15	-12.681	3	7	17	2	4	4	8	4.666	2.700	54.917		0.16910	0.83090
602001		15	- 8.805	3	7	13	6	4	4	4	6.793	2.750	58.539		0.29953	0.70047
602002		15	- 8.805	2	7	13	2	4	0	8	3.809	2.700	54.917		0.11994	0.88006
602003		15	- 8.805	2	7	9	6	4	0	4	6.578	2.750	58.539		0.29933	0.70067
603000	7,6	15	- 8.805	3	7	17	6	4	4	8	7.001	2.700	54.917		0.31634	0.68366
603100		8	- 8.805	3	7	17	6	4	4	8	4.369	2.600	48.333		0.35225	0.64775
603200		1	- 8.805	3	7	17	6	4	4	8	0.992	2.100	25.521		0.58236	0.41764
603010		15	- 5.638	3	7	17	6	4	4	8	5.695	2.700	54.917		0.22332	0.77668
603020		15	-12.681	3	7	17	6	4	4	8	8.686	2.750	58.539		0.40549	0.59451
603001		15	- 8.805	3	7	13	10	4	4	4	9.656	2.750	58.539		0.44690	0.55310
603002		15	- 8.805	2	7	13	6	4	0	8	6.793	2.750	58.539		0.29953	0.70047
603003		15	- 8.805	2	7	9	10	4	0	4	9.442	2.750	58.539		0.44675	0.55325

Table 3-4

Optimum Cost Data Summary
Test Plan 7
Protoflight Components Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ ($x10^{-3}$)	NHS	NEXP	NCCE	NCPE	NCCPS	NCCCS	NCCDS	Expected Cost ($\$x10^6$)	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
701000	1,2	15	- 8.805	3	1	17	2	4	4	8	4.038	2.450	39.906		0.01564	0.98436
701100		8	- 8.805	3	1	17	2	4	4	8	2.459	2.200	28.997		0.01853	0.98147
701200		1	- 8.805	3	1	17	2	4	4	8	0.649	1.400	10.438		0.02991	0.97009
701010		15	- 5.638	3	1	17	2	4	4	8	3.527	2.500	42.537		0.01161	0.98839
701020		15	-12.681	3	1	17	2	4	4	8	4.713	2.350	35.121		0.02230	0.97770
701001		15	- 8.805	3	1	13	6	4	4	4	5.249	2.700	54.917		0.02682	0.97318
701002		15	- 8.805	2	1	13	2	4	0	8	3.697	2.500	42.537		0.01407	0.98593
701003		15	- 8.805	2	1	9	6	4	0	4	4.745	2.750	58.539		0.02428	0.97572
702000	7,2	15	- 8.805	3	7	17	2	4	4	8	4.513	2.400	37.437		0.10532	0.89468
702100		8	- 8.805	3	7	17	2	4	4	8	2.791	2.150	27.204		0.12314	0.87686
702200		1	- 8.805	3	7	17	2	4	4	8	0.795	1.350	9.792		0.18659	0.81341
702010		15	- 5.638	3	7	17	2	4	4	8	3.911	2.450	39.906		0.07899	0.92101
702020		15	-12.681	3	7	17	2	4	4	8	5.302	2.300	32.948		0.14581	0.85419
702001		15	- 8.805	3	7	13	6	4	4	4	7.129	2.550	45.342		0.21971	0.78029
702002		15	- 8.805	2	7	13	2	4	0	8	4.205	2.450	39.906		0.09608	0.90392
702003		15	- 8.805	2	7	9	6	4	0	4	6.753	2.550	45.342		0.21960	0.78040
703000	7,6	15	- 8.805	3	7	17	6	4	4	8	7.490	2.500	42.537		0.23920	0.76080
703100		8	- 8.805	3	7	17	6	4	4	8	4.701	2.300	32.948		0.25534	0.74466
703200		1	- 8.805	3	7	17	6	4	4	8	1.364	1.450	11.126		0.39750	0.60250
703010		15	- 5.638	3	7	17	6	4	4	8	6.219	2.550	45.342		0.18238	0.81762
703020		15	-12.681	3	7	17	6	4	4	8	9.199	2.450	39.906		0.29827	0.70173
703001		15	- 8.805	3	7	13	10	4	4	4	9.948	2.550	45.342		0.33809	0.66191
703002		15	- 8.805	2	7	13	6	4	0	8	7.129	2.550	45.342		0.21971	0.78029
703003		15	- 8.805	2	7	9	10	4	0	4	9.573	2.550	45.342		0.33800	0.66200

Table 3-5

Optimum Cost Data Summary
Test Plan 7B
Protoflight Components / Structure Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ ($x10^{-3}$)	NHS	NEXP	NCCE	NC^{P}E	NCCPS	NCCCS	NCCDS	Expected Cost ($\$x10^6$)	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
7B1000	1,2	15	- 8.805	3	1	17	2	4	4	8	2.998	2.450	39.906		0.01493	0.98507
7B1100		8	- 8.805	3	1	17	2	4	4	8	1.921	2.200	28.997		0.01781	0.98219
7B1200		1	- 8.805	3	1	17	2	4	4	8	0.615	1.400	10.438		0.02920	0.97080
7B1010		15	- 5.638	3	1	17	2	4	4	8	2.490	2.500	42.537		0.01089	0.98911
7B1020		15	-12.681	3	1	17	2	4	4	8	3.667	2.350	35.121		0.02159	0.97841
7B1001		15	- 8.805	3	1	13	6	4	4	4	4.197	2.700	54.917		0.02611	0.97389
7B1002		15	- 8.805	2	1	13	2	4	0	8	2.657	2.500	42.537		0.01336	0.98664
7B1003		15	- 8.805	2	1	9	6	4	0	4	3.694	2.750	58.539		0.02357	0.97643
7B2000	7,2	15	- 8.805	3	7	17	2	4	4	8	3.471	2.400	37.437		0.10467	0.89533
7B2100		8	- 8.805	3	7	17	2	4	4	8	2.252	2.150	27.204		0.12250	0.87750
7B2200		1	- 8.805	3	7	17	2	4	4	8	0.760	1.350	9.792		0.18600	0.81400
7B2010		15	- 5.638	3	7	17	2	4	4	8	2.873	2.400	37.437		0.08594	0.91406
7B2020		15	-12.681	3	7	17	2	4	4	8	4.253	2.300	32.948		0.14518	0.85482
7B2001		15	- 8.805	3	7	13	6	4	4	4	6.068	2.550	45.342		0.21914	0.78086
7B2002		15	- 8.805	2	7	13	2	4	0	8	3.164	2.400	37.437		0.10445	0.89555
7B2003		15	- 8.805	2	7	9	6	4	0	4	5.692	2.550	45.342		0.21903	0.78097
7B3000	7,6	15	- 8.805	3	7	17	6	4	4	8	6.425	2.500	42.537		0.23864	0.76136
7B3100		8	- 8.805	3	7	17	6	4	4	8	4.149	2.300	32.948		0.25480	0.74520
7B3200		1	- 8.805	3	7	17	6	4	4	8	1.327	1.450	11.126		0.39706	0.60294
7B3010		15	- 5.638	3	7	17	6	4	4	8	5.164	2.550	45.342		0.18178	0.81822
7B3020		15	-12.681	3	7	17	6	4	4	8	8.123	2.450	39.906		0.29776	0.70224
7B3001		15	- 8.805	3	7	13	10	4	4	4	8.864	2.550	45.342		0.33761	0.66239
7B3002		15	- 8.805	2	7	13	6	4	0	8	6.068	2.550	45.342		0.21914	0.78086
7B3003		15	- 8.805	2	7	9	10	4	0	4	8.488	2.550	45.342		0.33751	0.66249

Table 3-6

Optimum Cost Data Summary
Test Plan 8
Protoflight Components / Subassemblies / Structure Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ $(x10^{-3})$	NHS	NEXP	NCCE	NCPE	NCCPS	NCCCS	NCCDS	Expected Cost $(\$x10^6)$	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
801000	1,2	15	- 8.805	3	1	17	2	4	4	8	1.619	1.600	13.475	153	0.00154	0.99846
801100		8	- 8.805	3	1	17	2	4	4	8	1.199	1.500	11.860	149	0.00289	0.99711
801200		1	- 8.805	3	1	17	2	4	4	8	0.639	1.250	8.618	137	0.01151	0.98849
801010		15	- 5.638	3	1	17	2	4	4	8	1.512	1.700	15.311	153	0.00131	0.99869
801020		15	-12.681	3	1	17	2	4	4	8	1.733	1.500	11.860	153	0.00177	0.99823
801001		15	- 8.805	3	1	13	6	4	4	4	1.849	1.850	18.544	155	0.00229	0.99771
801002		15	- 8.805	2	1	13	2	4	0	8	1.437	1.650	14.364	153	0.00148	0.99852
801003		15	- 8.805	2	1	9	6	4	0	4	1.641	1.900	19.767	155	0.00221	0.99779
802000	7,2	15	- 8.805	3	7	17	2	4	4	8	1.998	1.550	12.642	151	0.01827	0.98173
802100		8	- 8.805	3	7	17	2	4	4	8	1.537	1.450	11.126	149	0.02070	0.97930
802200		1	- 8.805	3	7	17	2	4	4	8	0.911	1.250	8.618	137	0.07505	0.92495
802010		15	- 5.638	3	7	17	2	4	4	8	1.859	1.650	14.364	151	0.01535	0.98465
802020		15	-12.681	3	7	17	2	4	4	8	2.145	1.450	11.126	153	0.01267	0.98733
802001		15	- 8.805	3	7	13	6	4	4	4	2.763	1.650	14.364	153	0.03048	0.96952
802002		15	- 8.805	2	7	13	2	4	0	8	1.818	1.600	13.475	153	0.01066	0.98934
802003		15	- 8.805	2	7	9	6	4	0	4	2.577	1.700	15.311	153	0.02935	0.97065
803000	7,6	15	- 8.805	3	7	17	6	4	4	8	2.916	1.650	14.364	153	0.03049	0.96951
803100		8	- 8.805	3	7	17	6	4	4	8	2.330	1.550	12.642	151	0.03470	0.96530
803200		1	- 8.805	3	7	17	6	4	4	8	1.372	1.300	9.186	137	0.19602	0.80398
803010		15	- 5.638	3	7	17	6	4	4	8	2.661	1.750	16.321	153	0.02584	0.97416
803020		15	-12.681	3	7	17	6	4	4	8	3.181	1.500	11.860	153	0.03627	0.96373
803001		15	- 8.805	3	7	13	10	4	4	4	3.618	1.650	14.364	155	0.03038	0.96962
803002		15	- 8.805	2	7	13	6	4	0	8	2.732	1.650	14.364	153	0.03048	0.96952
803003		15	- 8.805	2	7	9	10	4	0	4	3.424	1.700	15.311	155	0.02935	0.97065

Table 3-7

Optimum Cost Data Summary
Test Plan 9
Protoflight Components / System / Structure Testing

Code	Pay Load	Parameter									Optimum				Associated Vibroacoustic	
		NF	DYDGQ ($x10^{-3}$)	NHS	NEXP	NCCE	NCPE	NCCPS	NCCCS	NCCDS	Expected Cost ($\$x10^6$)	Standard Vibration Variable	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Flight Failure Probability	Flight Reliability
901000	1,2	15	- 8.805	3	1	17	2	4	4	8	2.221	1.950	21.071	149	0.00297	0.99703
901100		8	- 8.805	3	1	17	2	4	4	8	1.668	1.850	18.544	145	0.00498	0.99502
901200		1	- 8.805	3	1	17	2	4	4	8	0.797	1.400	10.438	129	0.02195	0.97805
901010		15	- 5.638	3	1	17	2	4	4	8	2.008	2.100	25.521	147	0.00339	0.99661
901020		15	-12.681	3	1	17	2	4	4	8	2.449	1.850	18.544	149	0.00359	0.99641
901001		15	- 8.805	3	1	13	6	4	4	4	2.391	2.100	25.521	151	0.00486	0.99514
901002		15	- 8.805	2	1	13	2	4	0	8	1.964	2.000	22.461	149	0.00282	0.99718
901003		15	- 8.805	2	1	9	6	4	0	4	2.080	2.150	27.204	153	0.00292	0.99708
902000	7,2	15	- 8.805	3	7	17	2	4	4	8	2.629	1.950	21.071	147	0.03123	0.96877
902100		8	- 8.805	3	7	17	2	4	4	8	1.994	1.850	18.544	143	0.04917	0.95083
902200		1	- 8.805	3	7	17	2	4	4	8	0.957	1.350	9.792	129	0.14493	0.85507
902010		15	- 5.638	3	7	17	2	4	4	8	2.354	2.050	23.942	147	0.02462	0.97538
902020		15	-12.681	3	7	17	2	4	4	8	2.939	1.850	18.544	147	0.03817	0.96183
902001		15	- 8.805	3	7	13	6	4	4	4	3.685	2.000	22.461	149	0.05703	0.94297
902002		15	- 8.805	2	7	13	2	4	0	8	2.389	2.000	22.461	147	0.02956	0.97044
902003		15	- 8.805	2	7	9	6	4	0	4	3.418	2.050	23.942	149	0.05425	0.94575
903000	7,6	15	- 8.805	3	7	17	6	4	4	8	3.943	2.000	22.461	149	0.05704	0.94296
903100		8	- 8.805	3	7	17	6	4	4	8	3.087	1.900	19.767	145	0.09261	0.90739
903200		1	- 8.805	3	7	17	6	4	4	8	1.505	1.450	11.126	129	0.32498	0.67502
903010		15	- 5.638	3	7	17	6	4	4	8	3.479	2.100	25.521	149	0.04577	0.95423
903020		15	-12.681	3	7	17	6	4	4	8	4.457	1.900	19.767	149	0.06864	0.93136
903001		15	- 8.805	3	7	13	10	4	4	4	4.911	2.000	22.461	151	0.06043	0.93957
903002		15	- 8.805	2	7	13	6	4	0	8	3.685	2.000	22.461	149	0.05703	0.94297
903003		15	- 8.805	2	7	9	10	4	0	4	4.624	2.000	22.461	151	0.06043	0.93957

The expected costs for the assembly test level at which the minimum cost occurs are shown in Figures 3-1 to 3-21. These figures show the expected cost, in millions of dollars, versus the component vibration test or design level, in g rms. Each figure shows the eight variations for one test plan/ payload combination. The symbols used on the curves are identified according to the six-digit case code presented previously.

The expected cost variation was plotted for each assembly test level and payload variation. A total of 105 figures were plotted and have been provided in a separate data package. Typical variations for a baseline Payload 7,6 are shown in Figures 3-22 to 3-25 for Test Plans 4, 5, 8, and 9, respectively. These figures show the expected cost, in millions of dollars, versus the component vibration test/design level, in g rms. Each figure shows the cost variation for eight assembly acoustic test levels, for one test plan/payload combination. Since there is no assembly acoustic testing in Test Plans 6, 7, and 7B, the cost variation for a test plan/payload combination plots on a single curve. The test levels that produced the minimum cost for each of the eight variations for a test plan/payload combination were plotted on a single figure and are shown in Figures 3-7 to 3-15. When there is assembly acoustic testing (Test Plans 4, 5, 8, 9), the curve yielding the lowest expected cost is taken from each set to obtain the optimum cost data plotted in Figures 3-1 to 3-6 and Figures 3-16 to 3-21.

The total expected costs of failures shown in the figures are obtained by adding the direct costs, the design costs, and the expected costs of failures during ground testing and flight. The number of cost elements varies with the test plan. A total of 168 cost element figures were plotted. Typical cost element data for the baseline Payload 7,6 are shown in Figures 3-26 to 3-32 for the seven test plans, respectively.

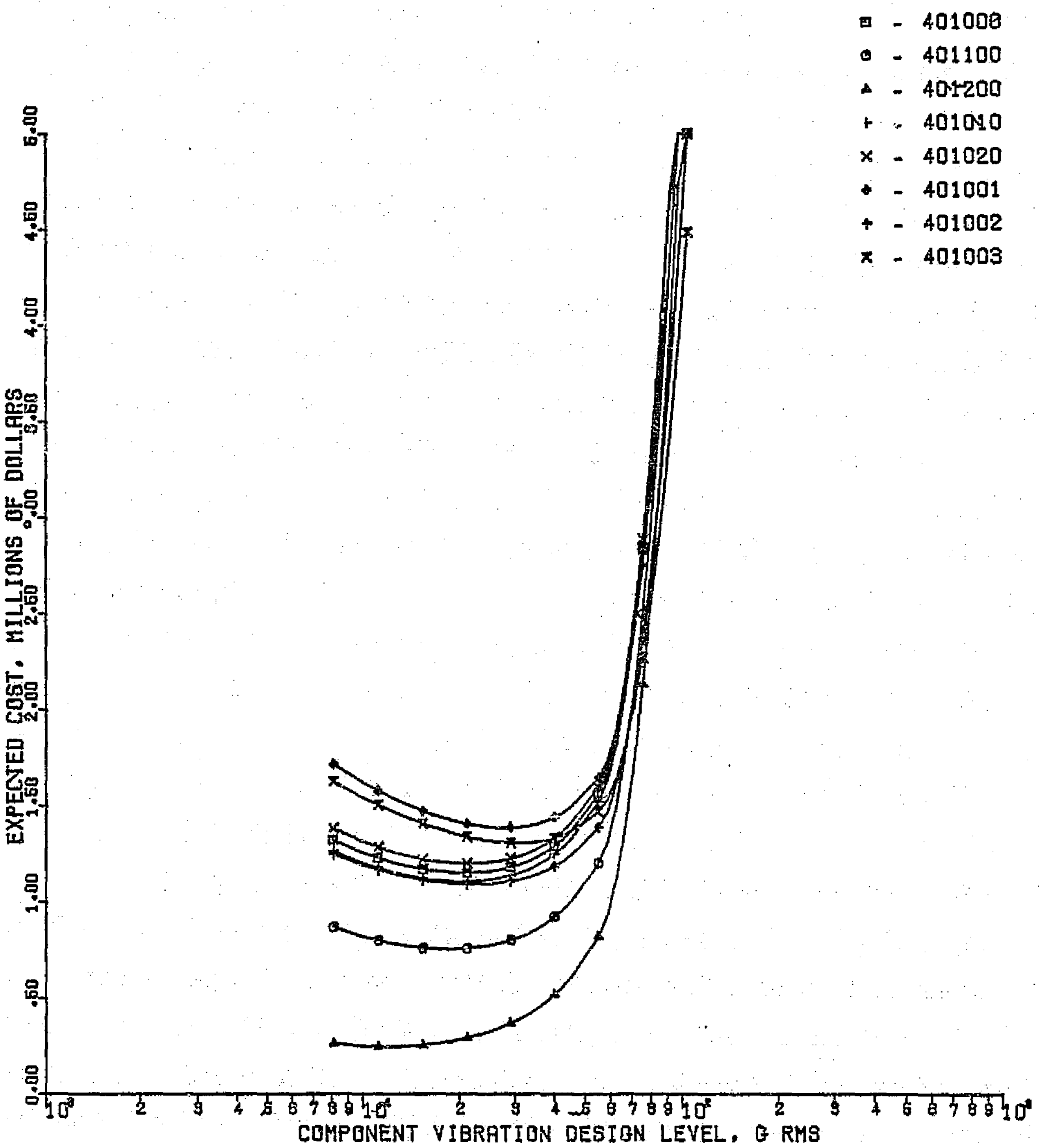


Figure 3-1 Optimum Cost Data, Test Plan 4, Payload 1,2

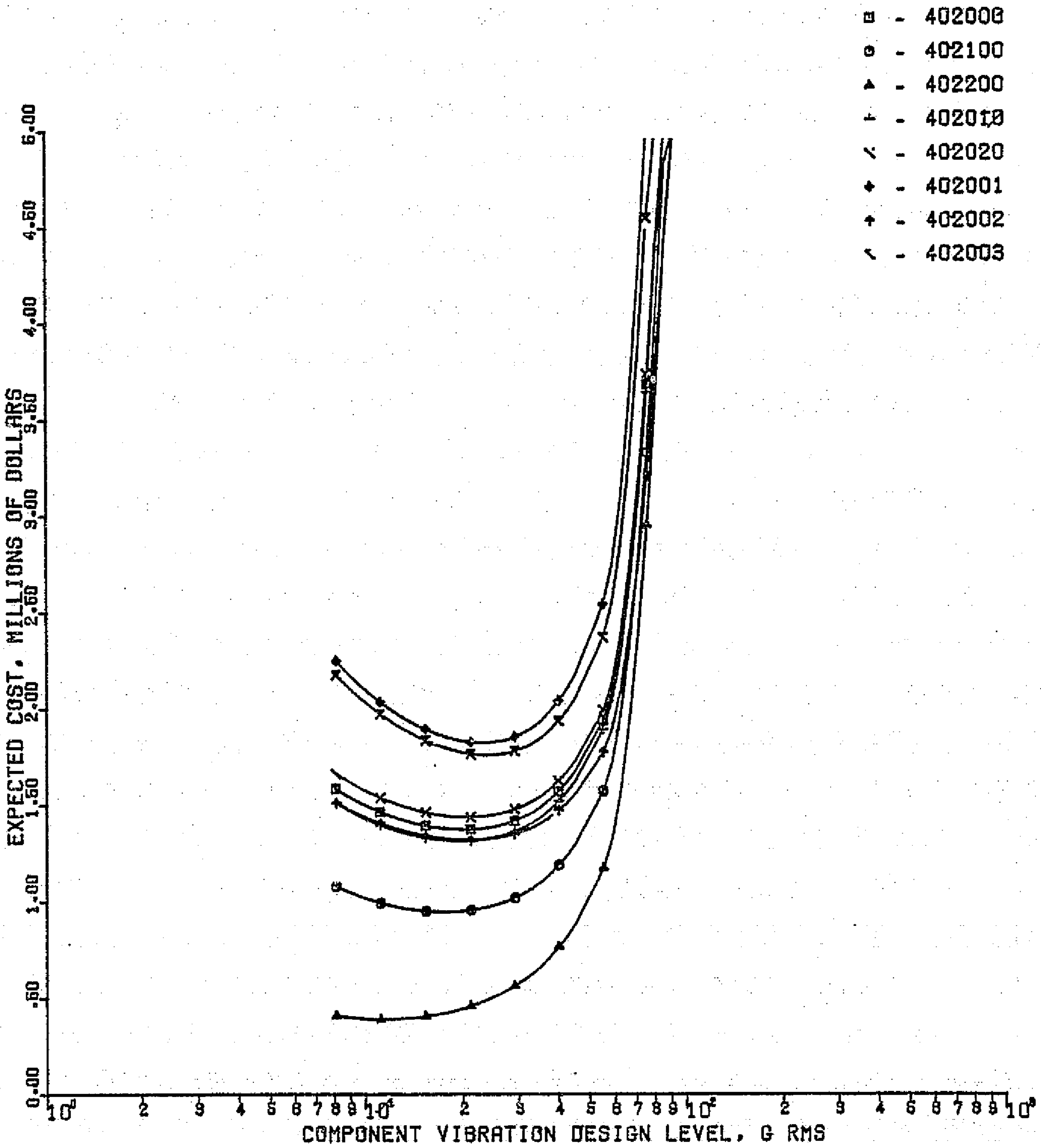


Figure 3-2 Optimum Cost Data, Test Plan 4, Payload 7,2

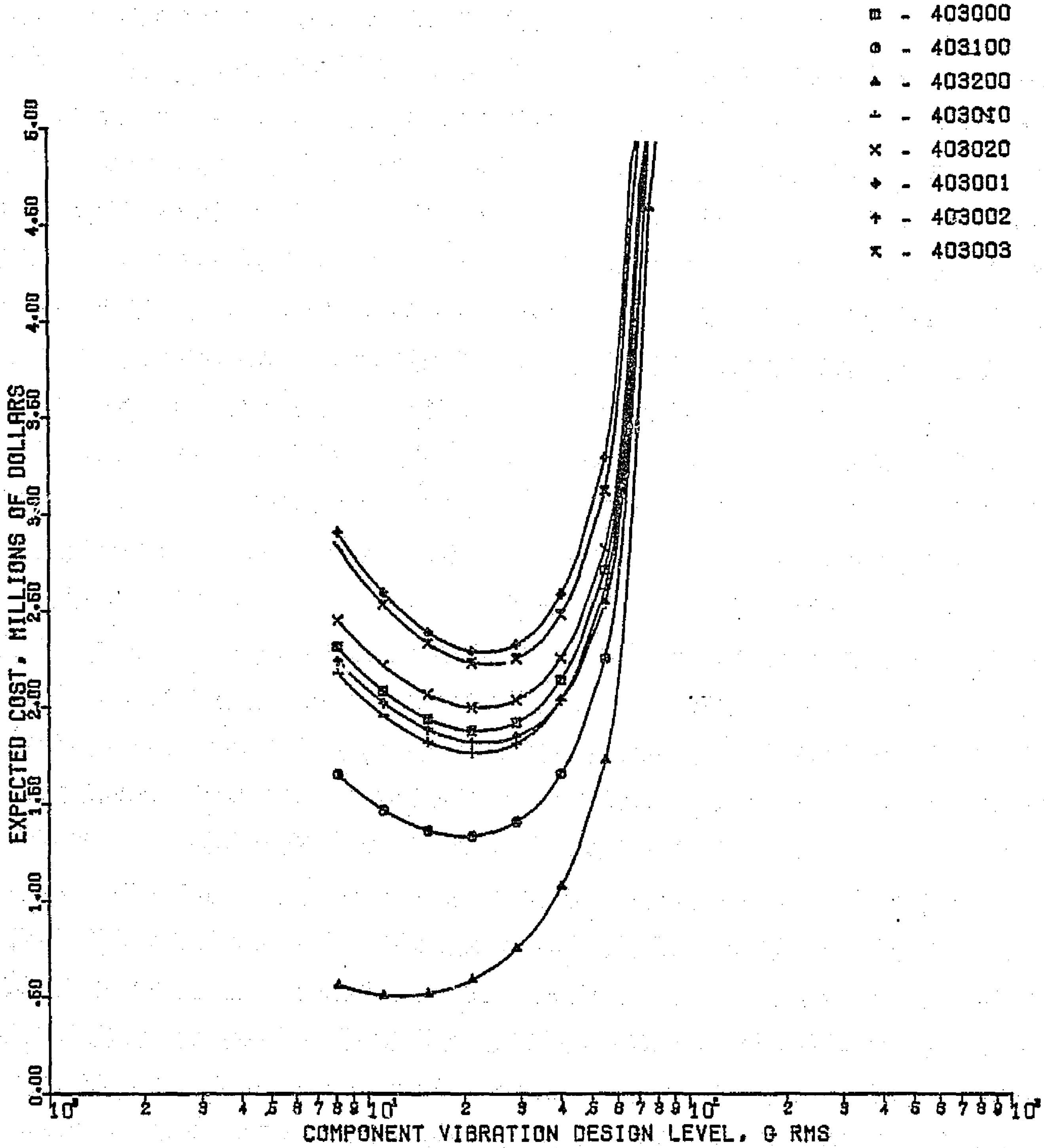


Figure 3-3 Optimum Cost Data, Test Plan 4, Payload 7,6

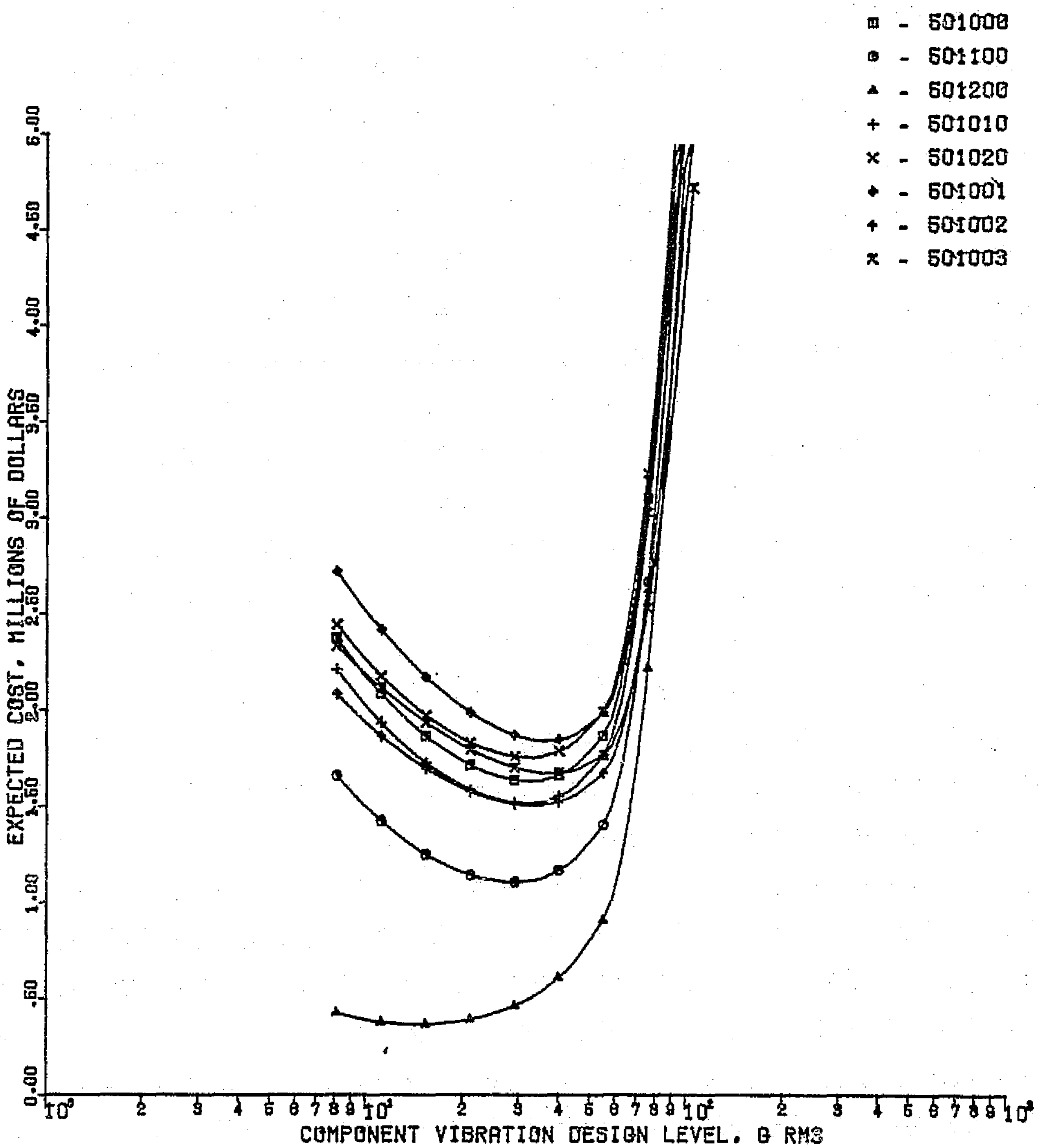


Figure 3-4 Optimum Cost Data, Test Plan 5, Payload 1,2

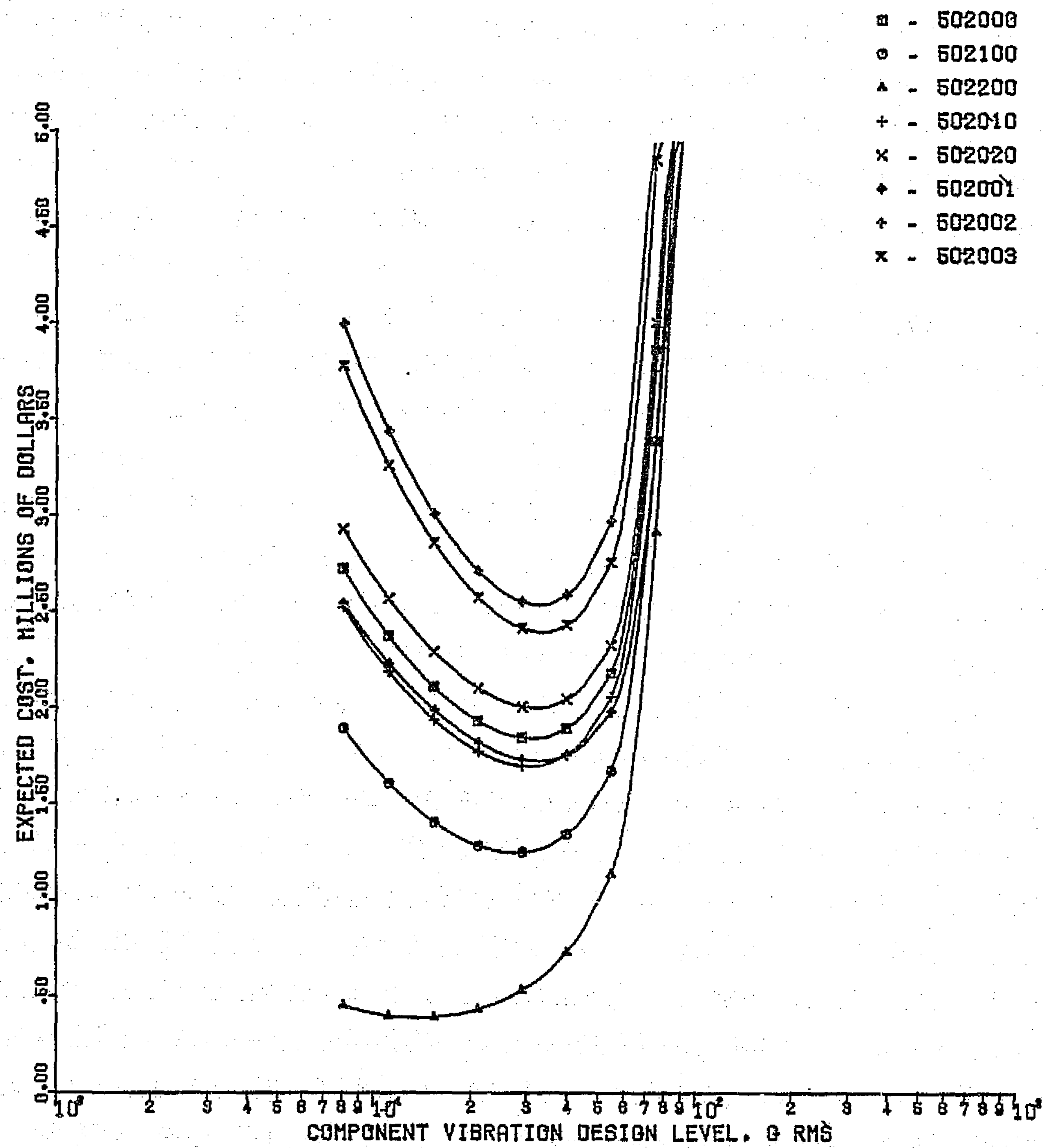


Figure 3-5 Optimum Cost Data, Test Plan 5, Payload 7,2

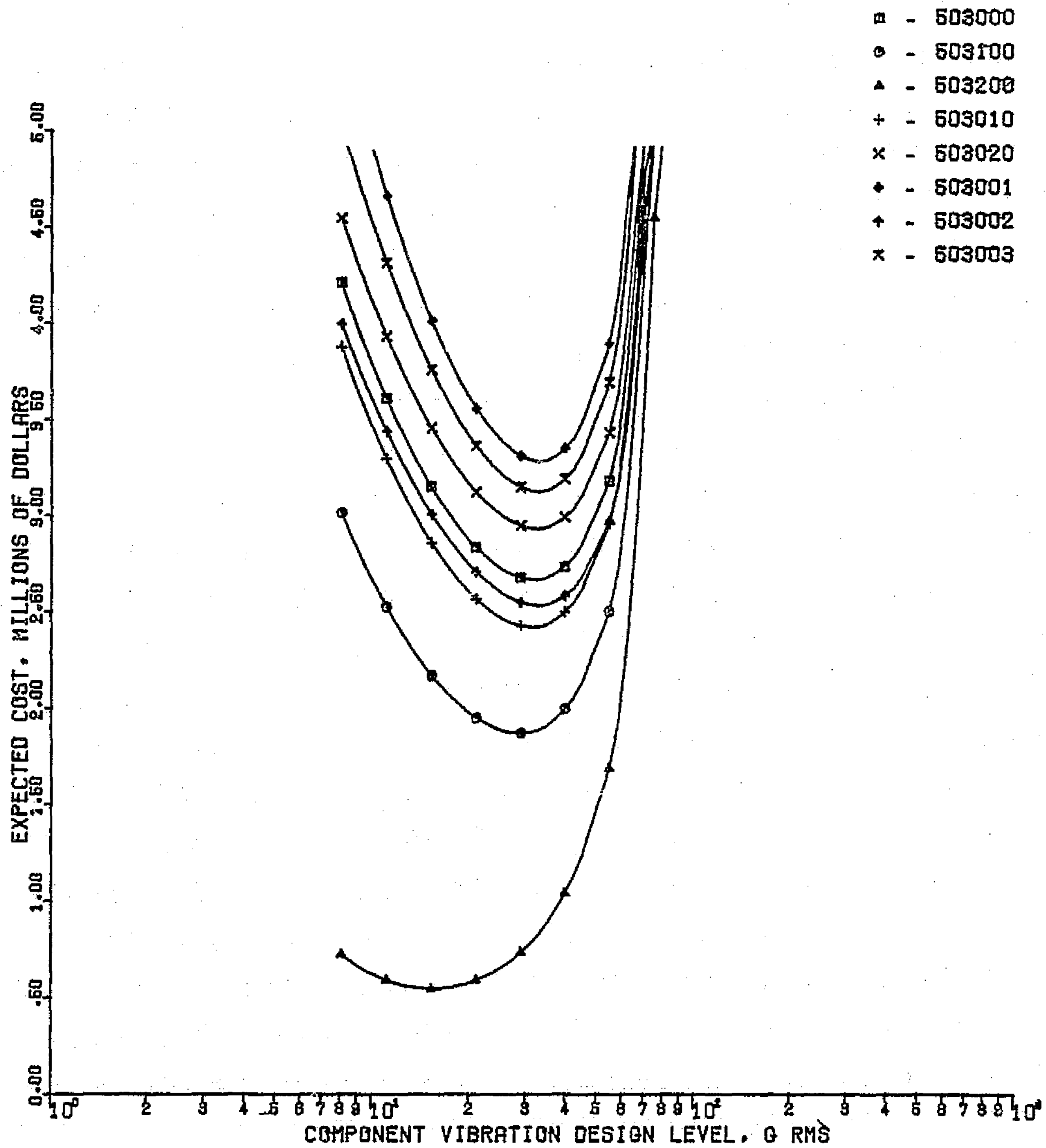


Figure 3-6 Optimum Cost Data, Test Plan 5, Payload 7,6

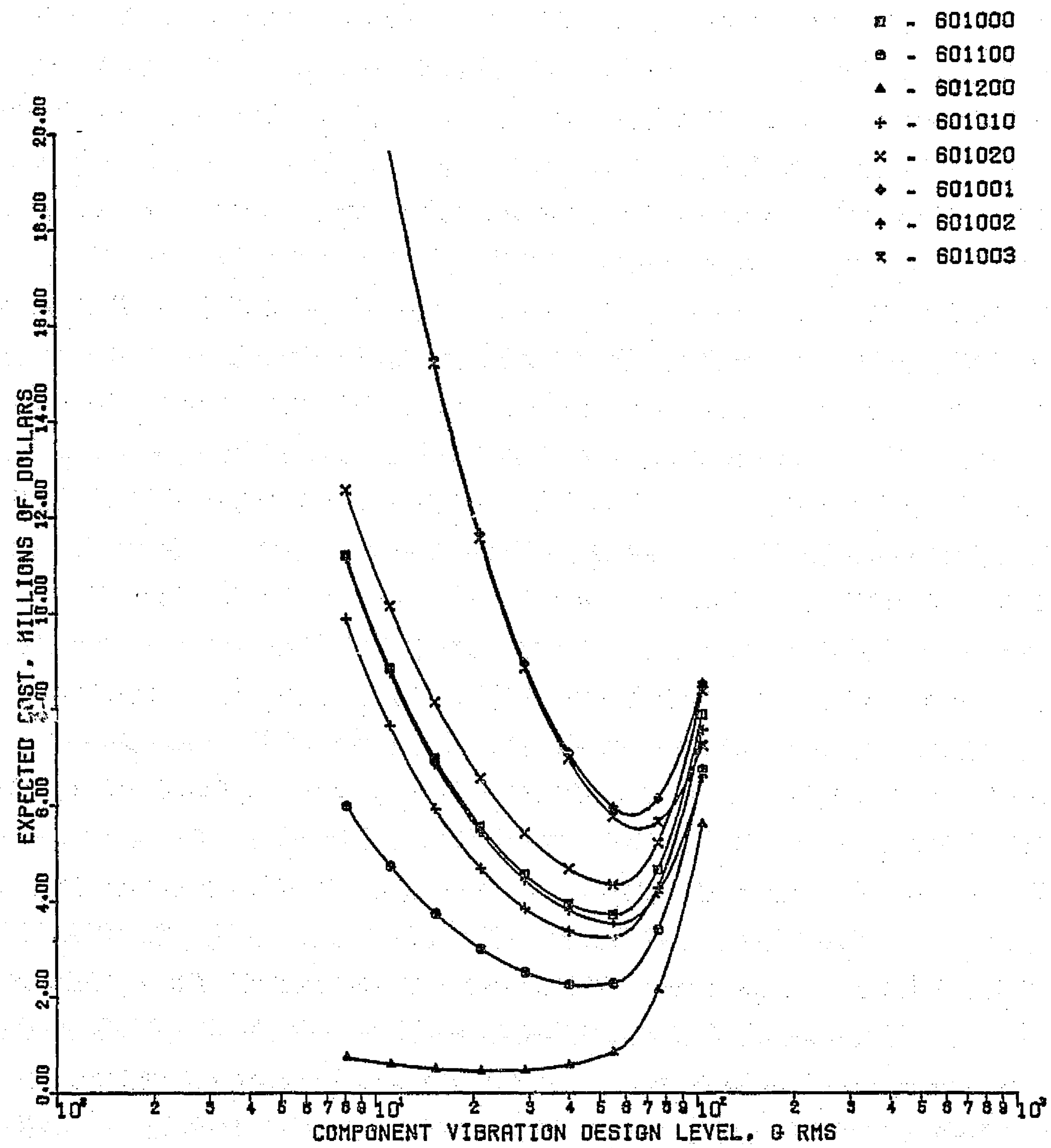


Figure 3-7 Optimum Cost Data, Test Plan 6, Payload 1,2

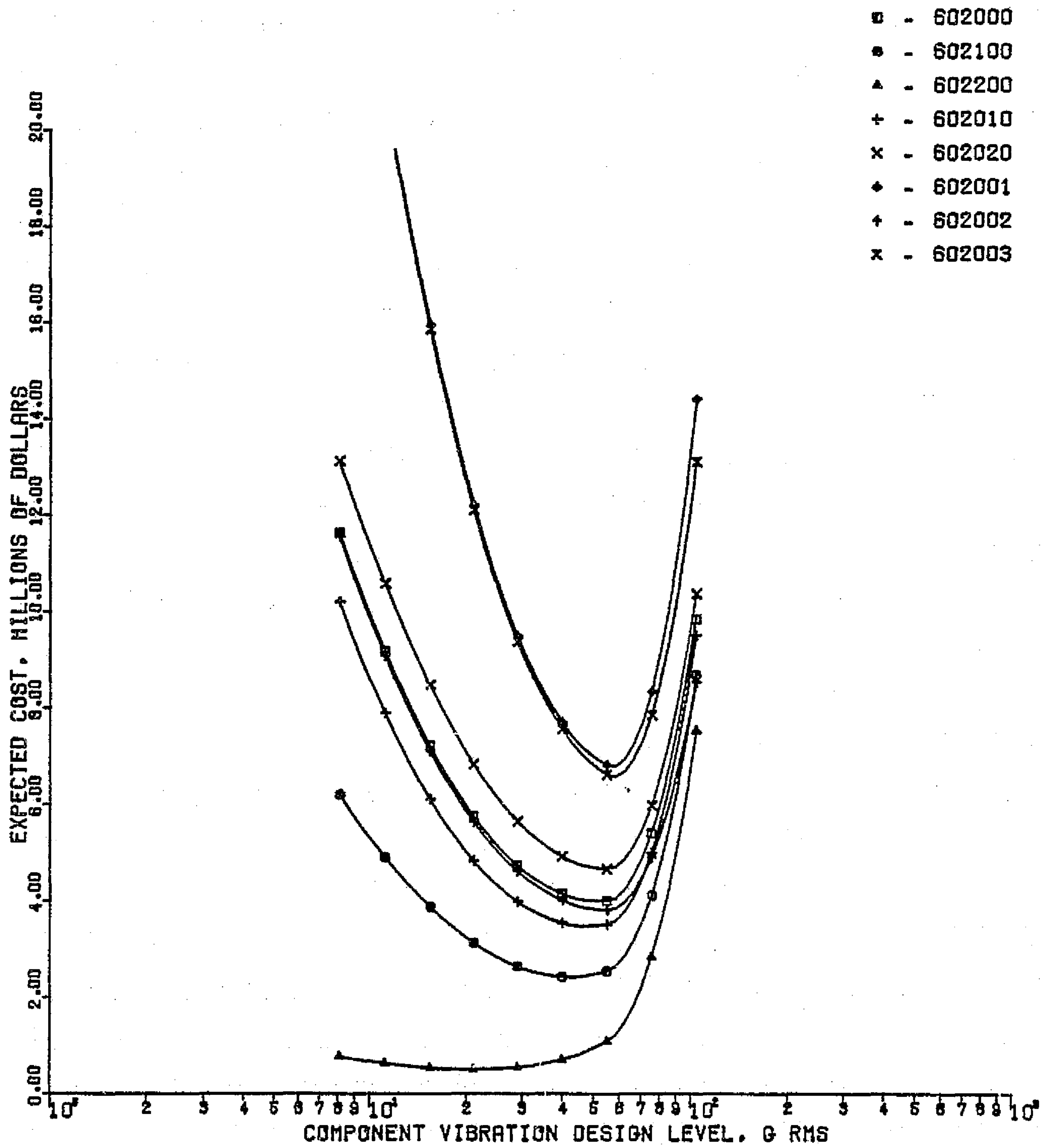


Figure 3-8 Optimum Cost Data, Test Plan 6, Payload 7,2

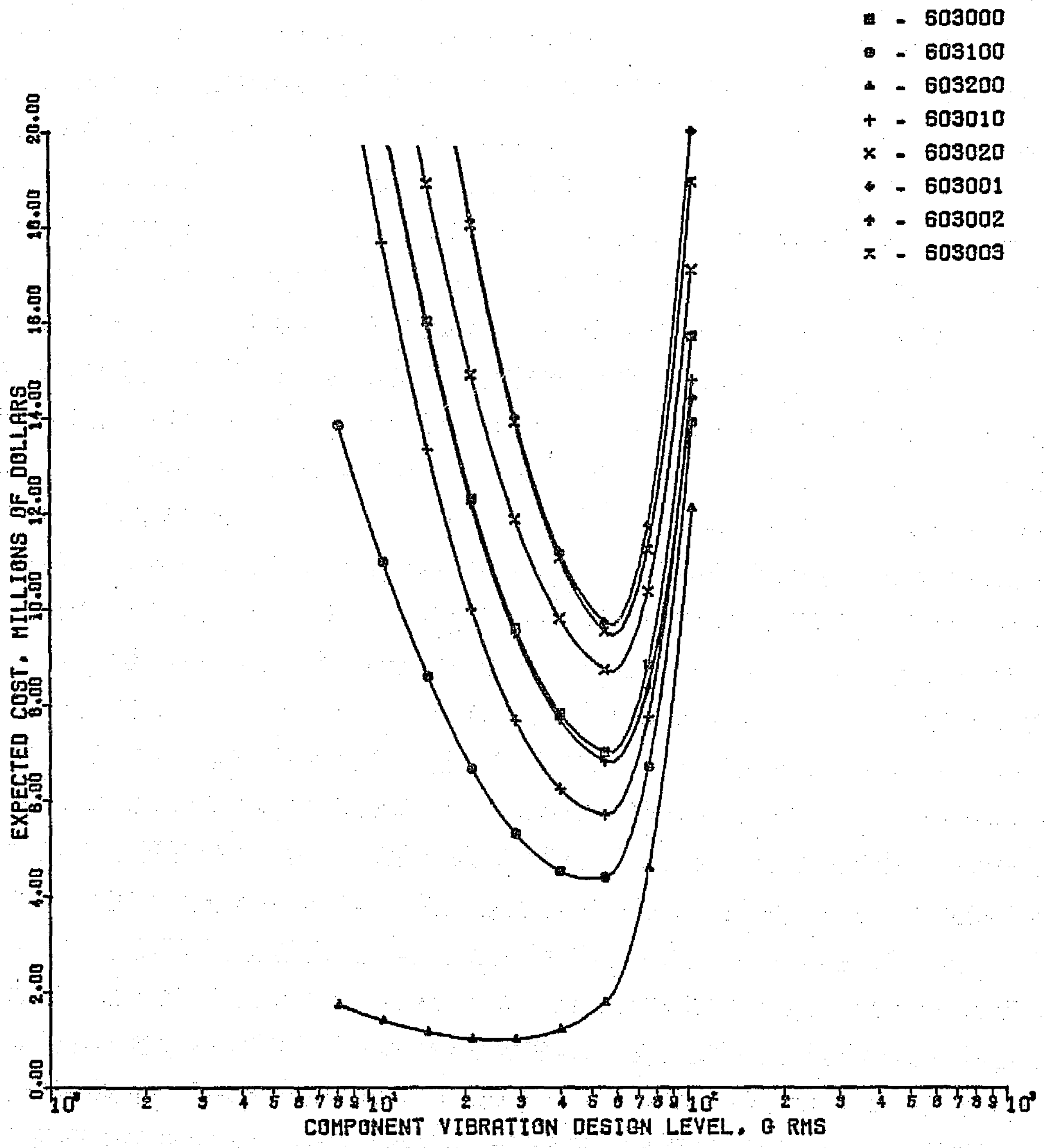


Figure 3-9 Optimum Cost Data, Test Plan 6, Payload 7,6

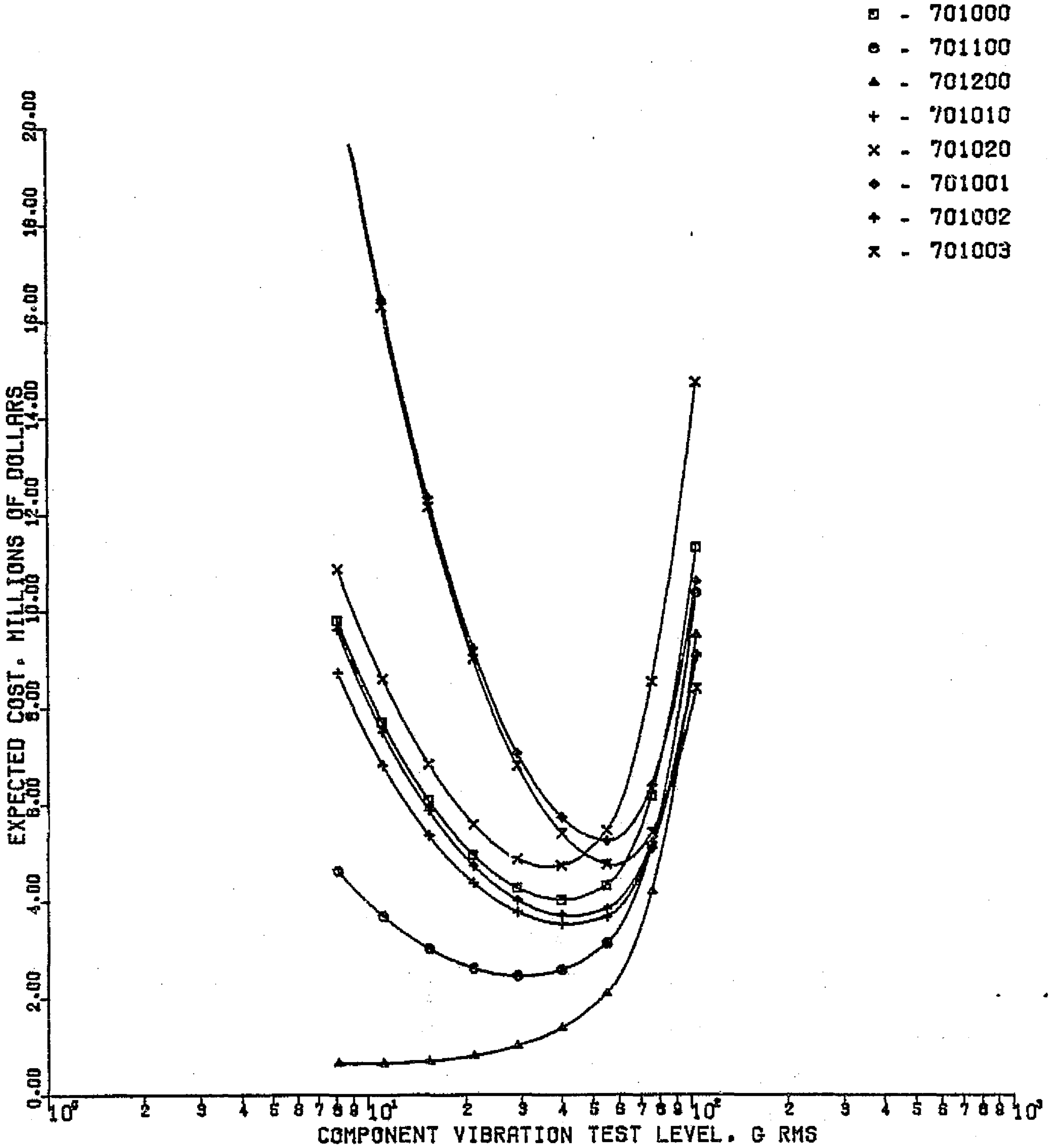


Figure 3-10 Optimum Cost Data, Test Plan 7, Payload 1,2

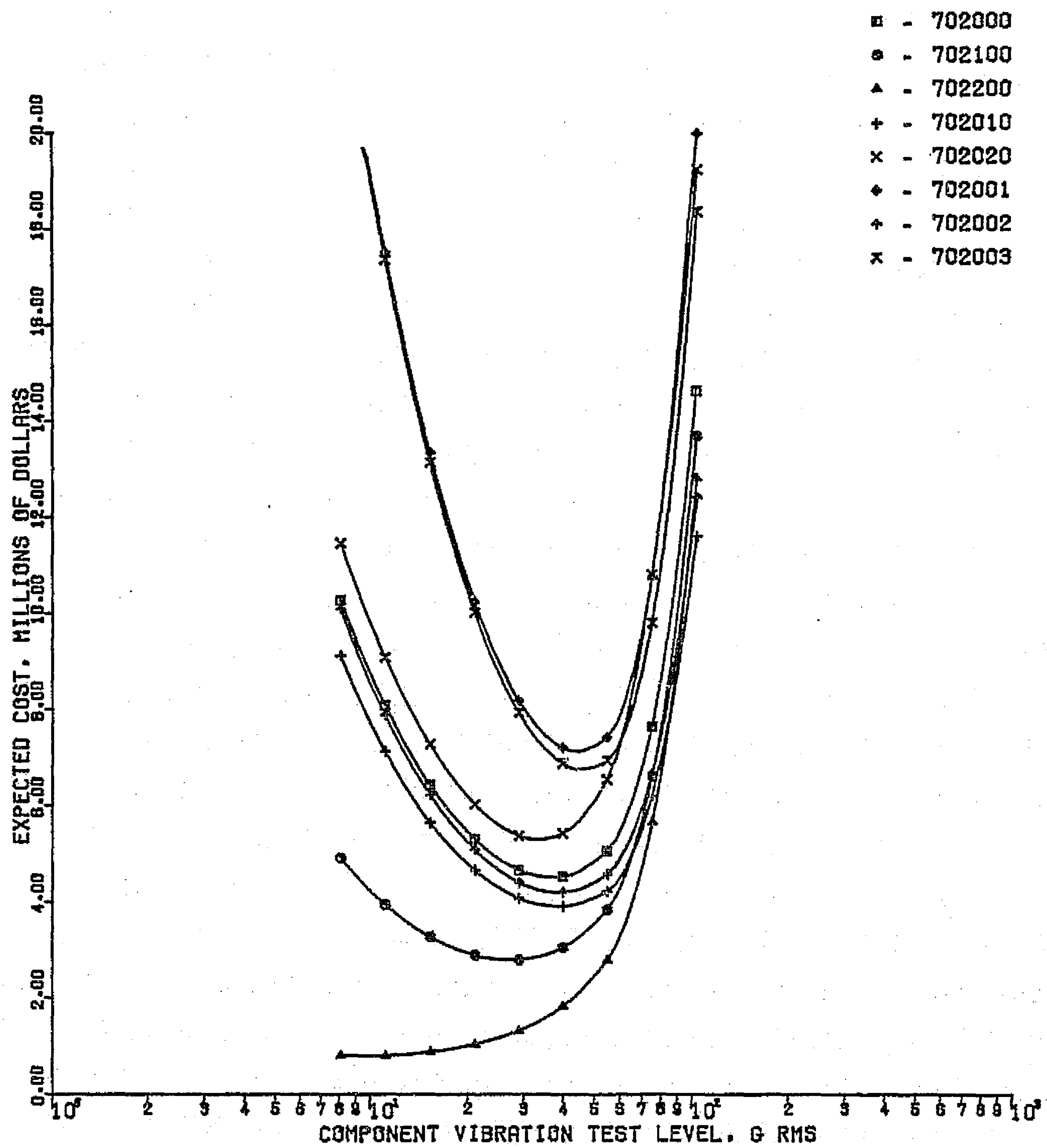


Figure 3-11 Optimum Cost Data, Test Plan 7, Payload 7,2

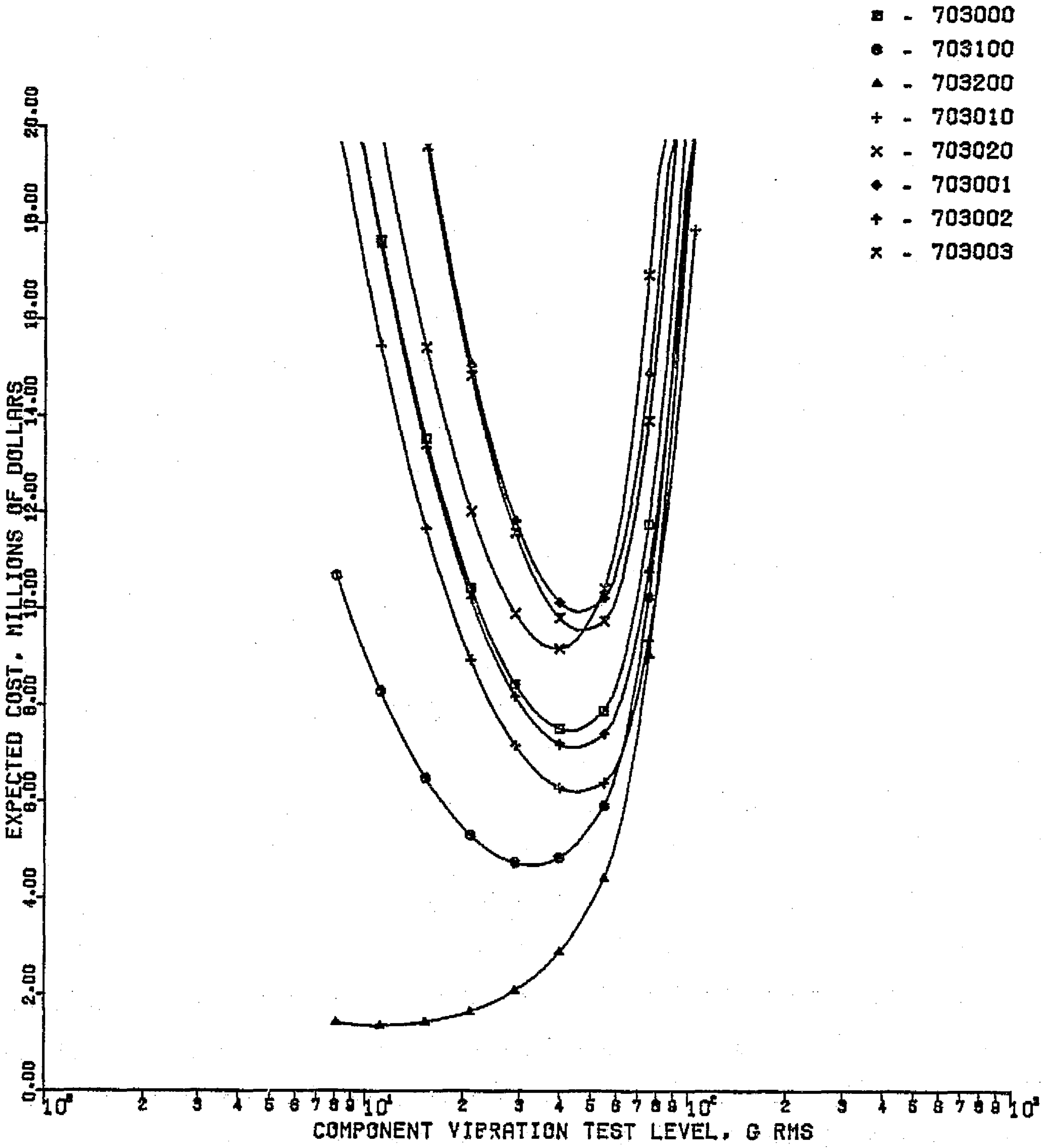


Figure 3-12 Optimum Cost Data, Test Plan 7, Payload 7,6

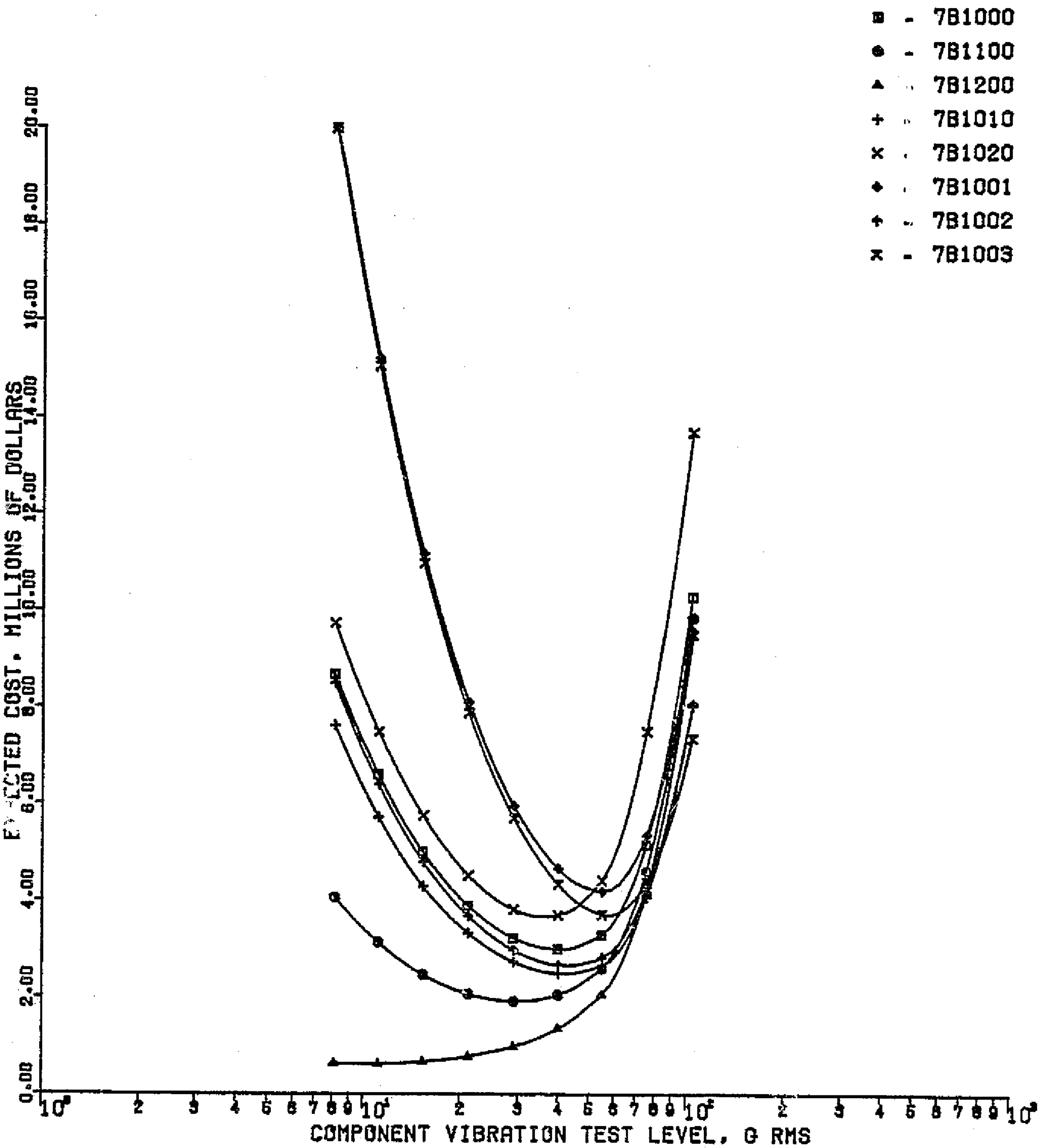


Figure 3-13 Optimum Cost Data, Test Plan 7B, Payload 1,2

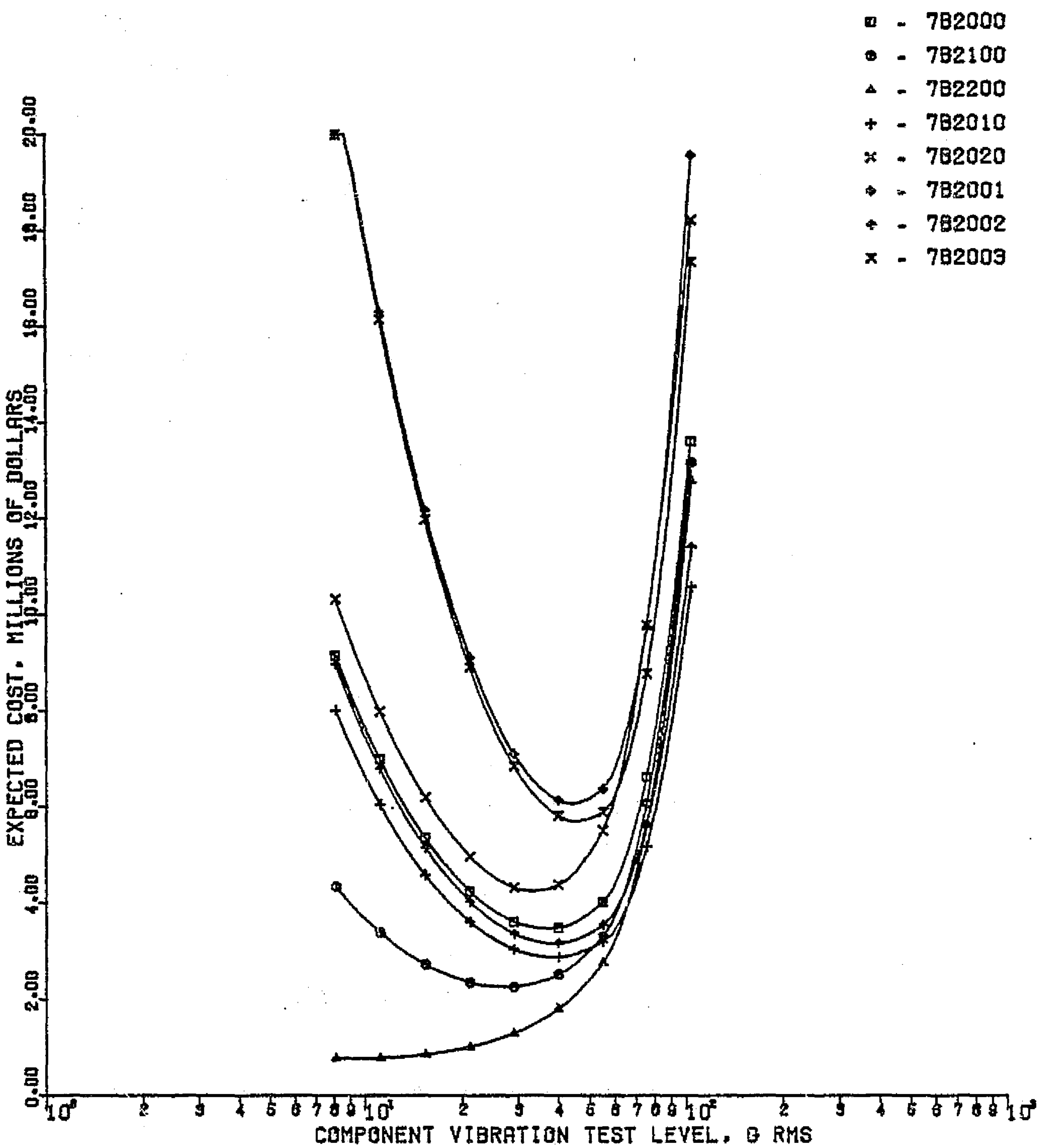


Figure 3-14 Optimum Cost Data, Test Plan 7B, Payload 7,2

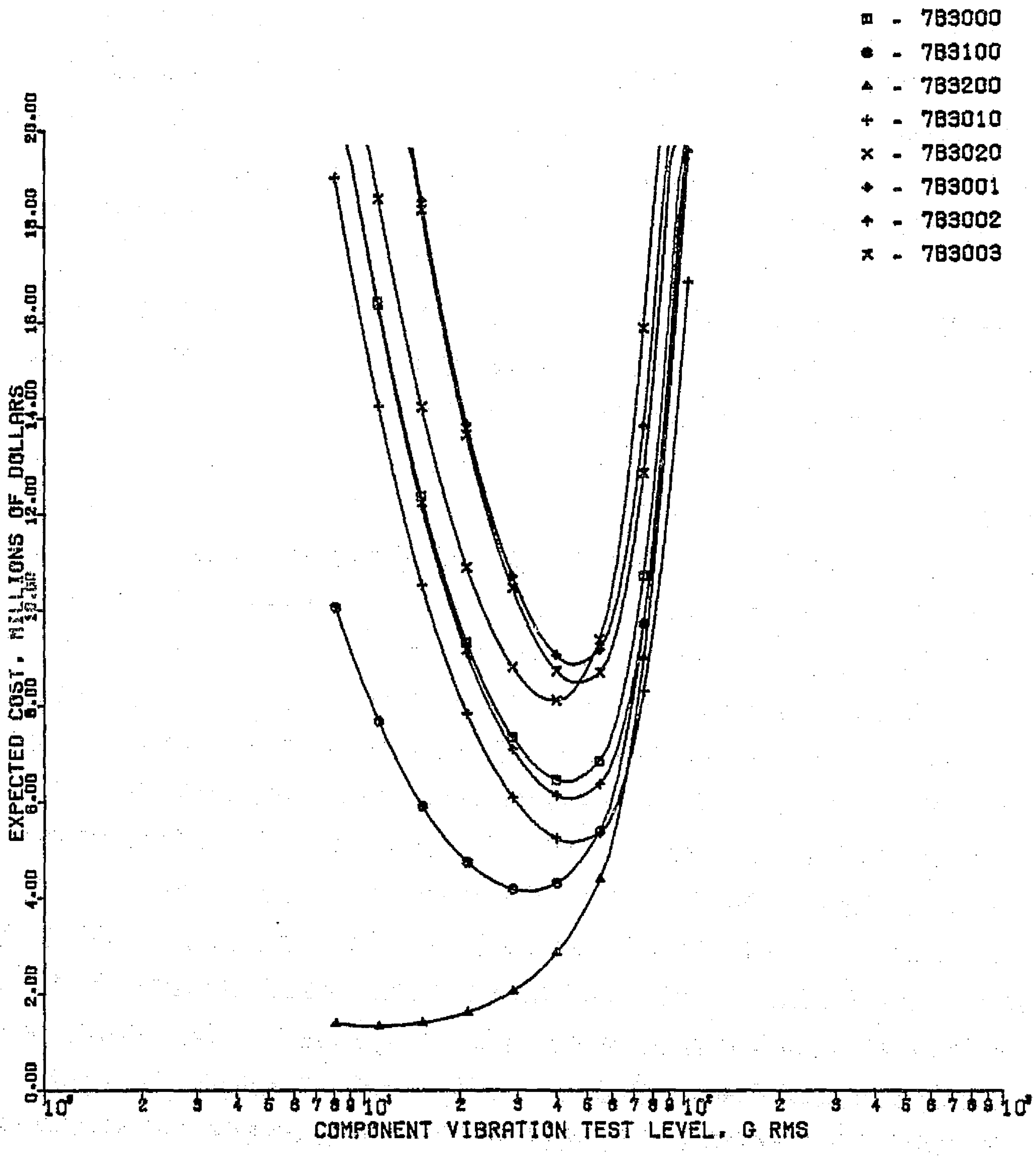


Figure 3-15 Optimum Cost Data, Test Plan 7B, Payload 7,6

C-2

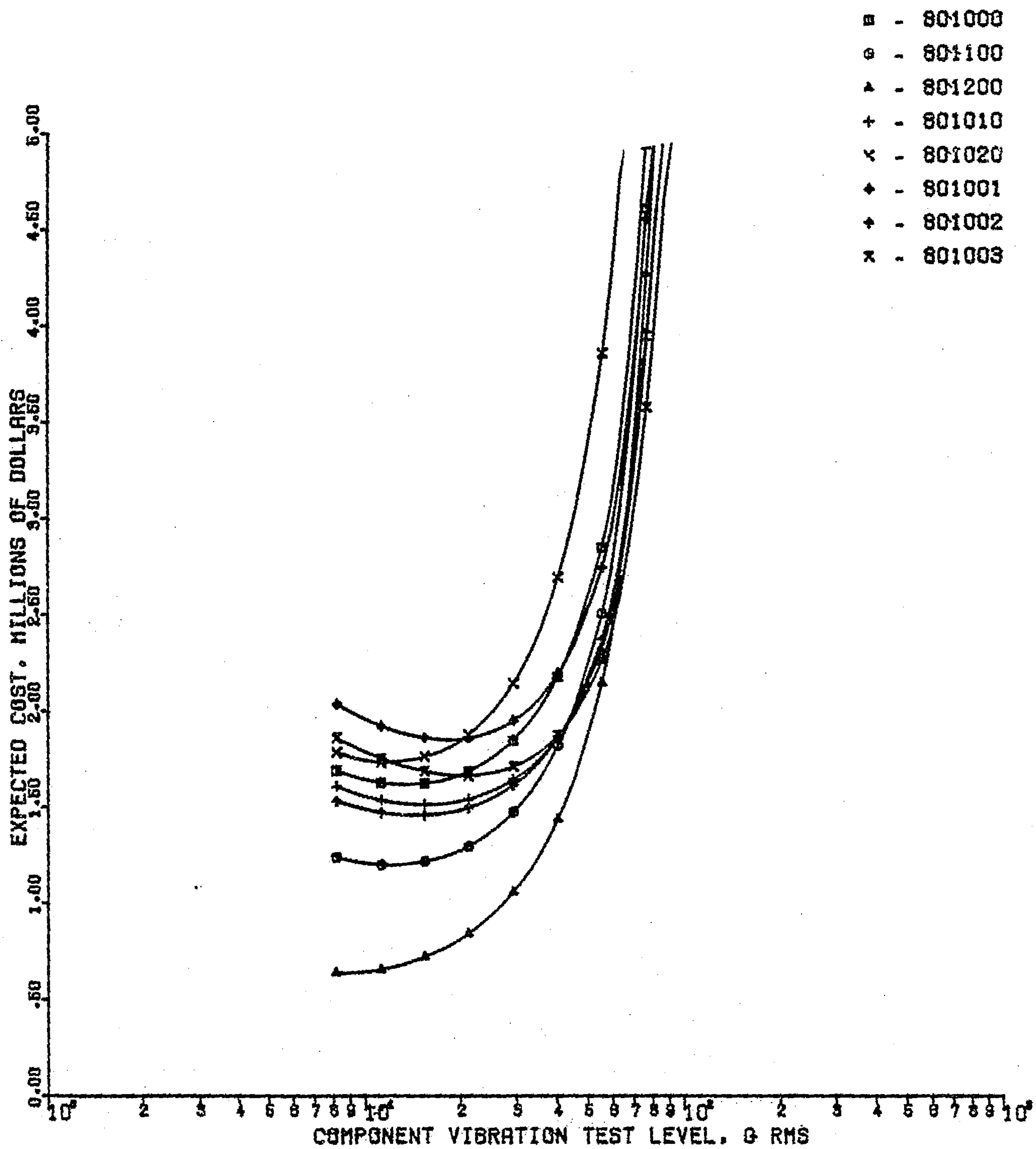


Figure 3-16 Optimum Cost Data, Test Plan 8, Payload 1,2

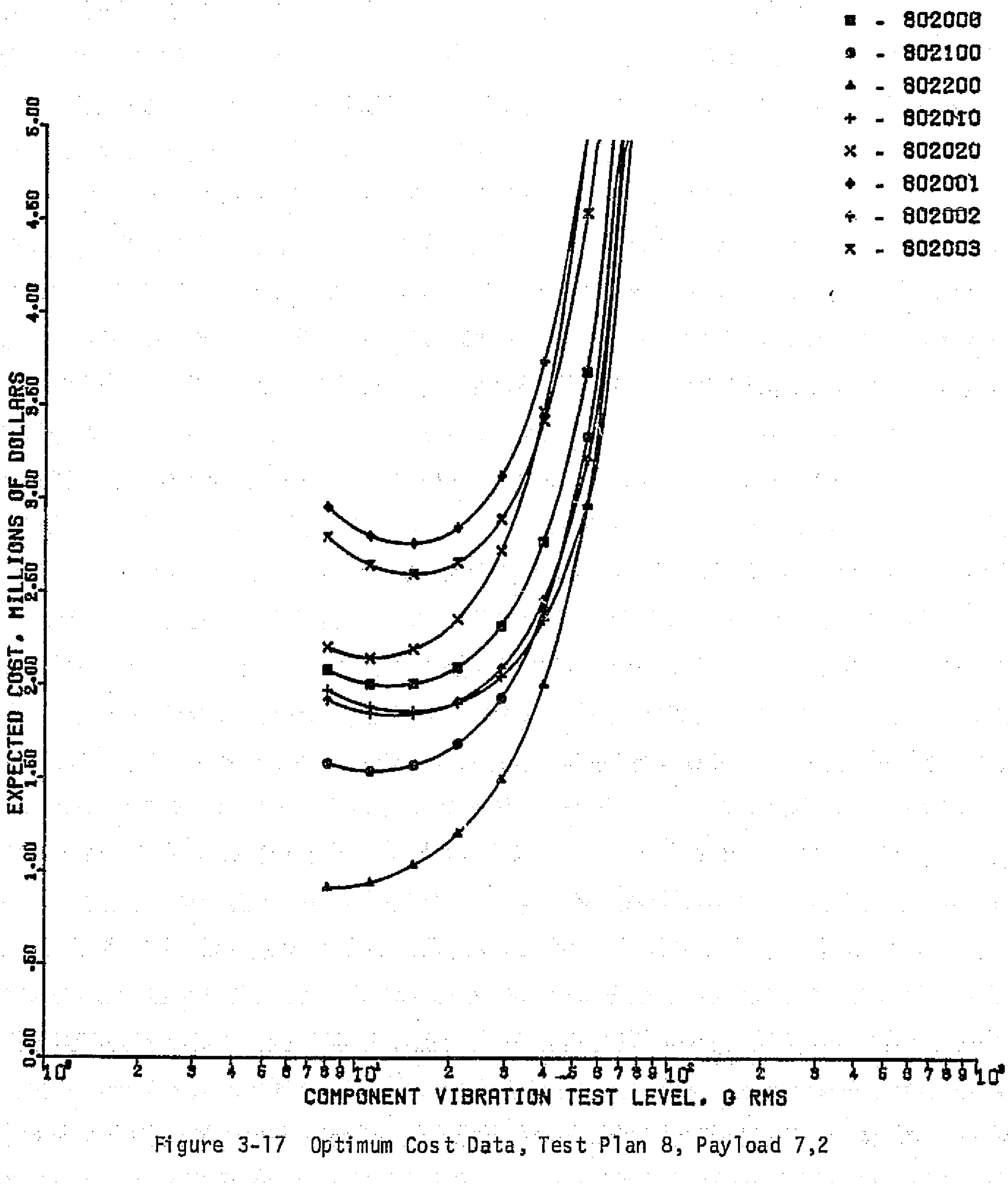


Figure 3-17 Optimum Cost Data, Test Plan 8, Payload 7,2

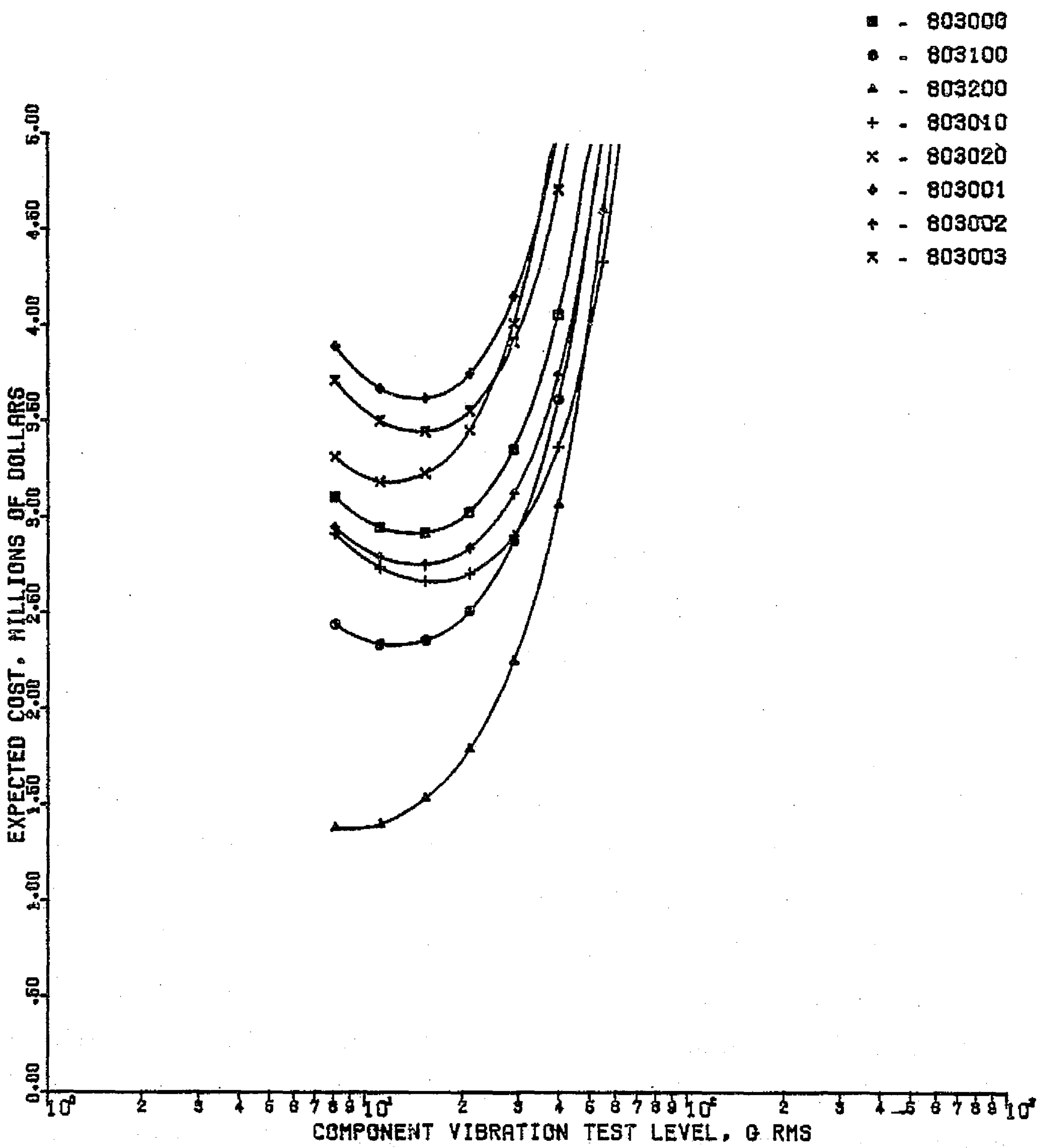


Figure 3-18 Optimum Cost Data, Test Plan 8, Payload 7.6

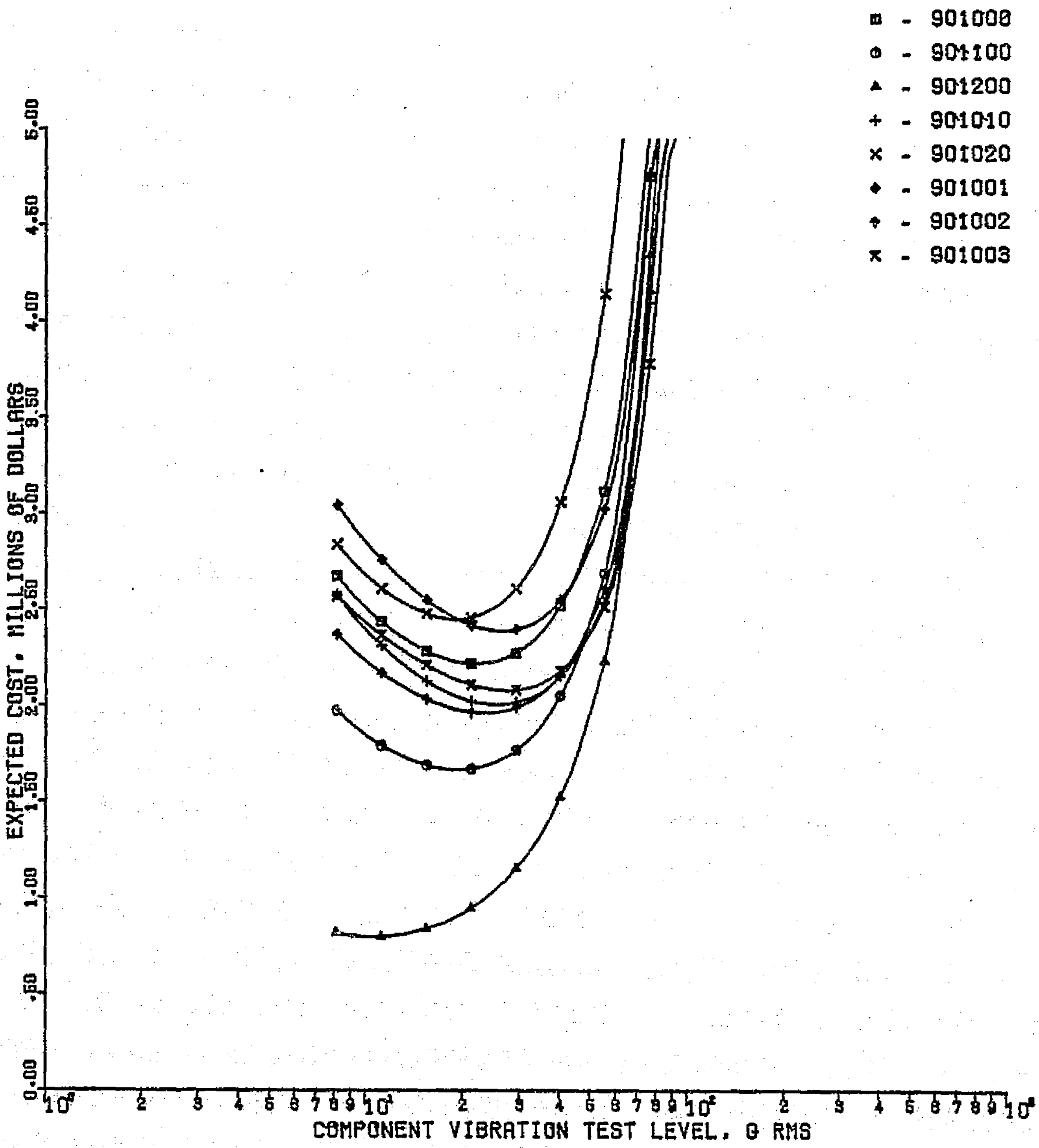


Figure 3-19 Optimum Cost Data, Test Plan 9, Payload 1,2

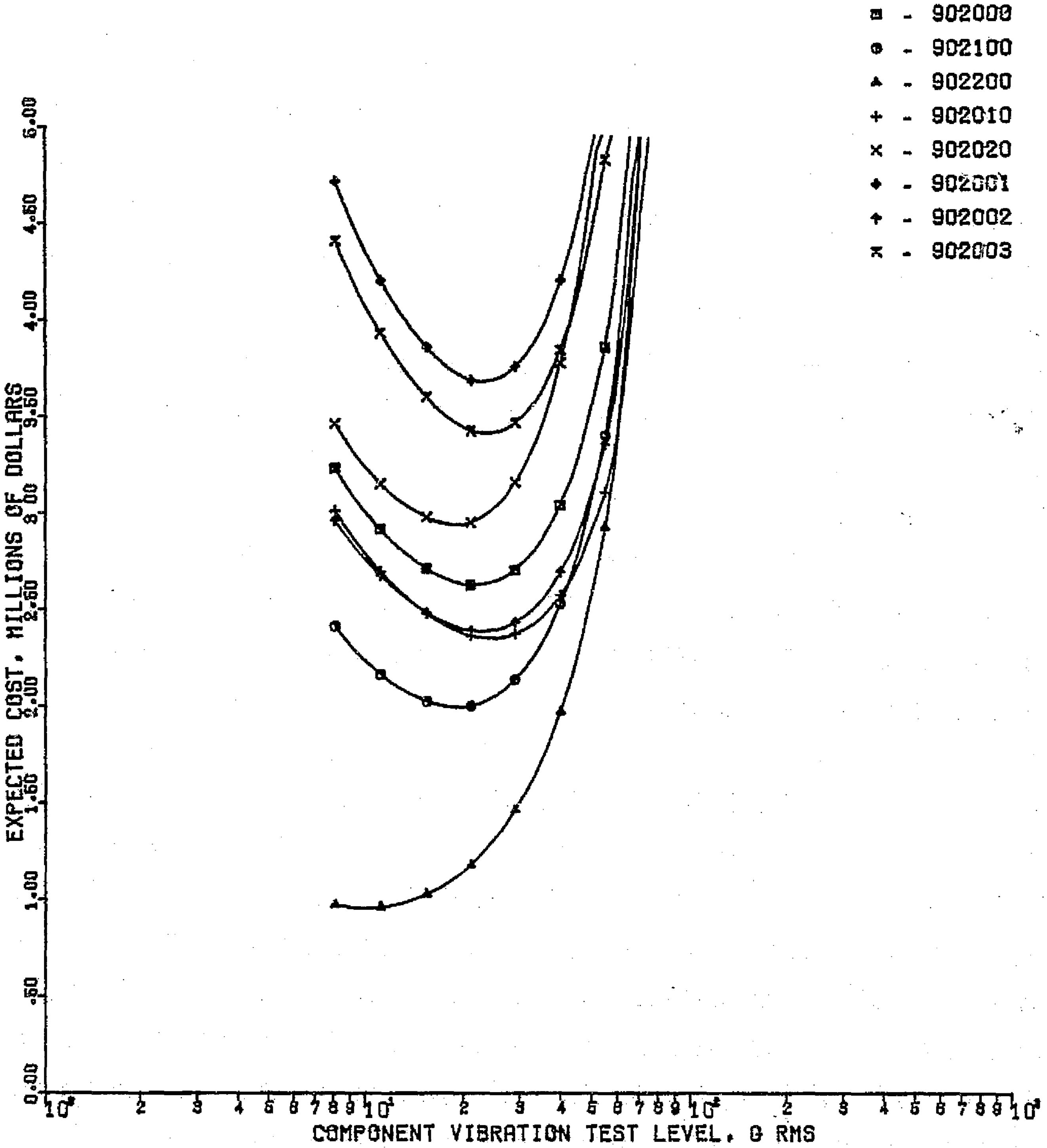


Figure 3-20 Optimum Cost Data, Test Plan 9, Payload 7,2

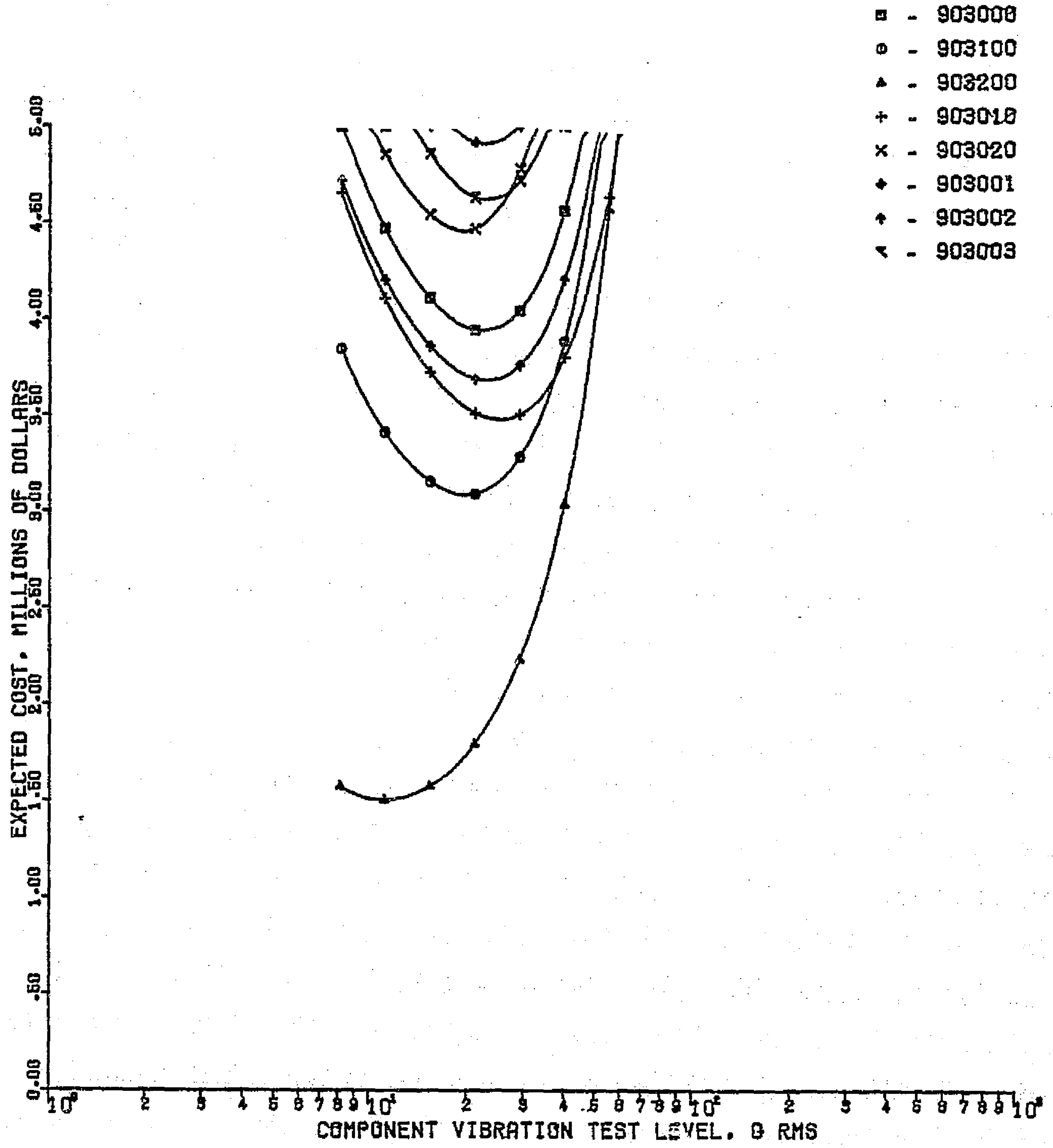


Figure 3-21 Optimum Cost Data, Test Plan 9, Payload 7,6

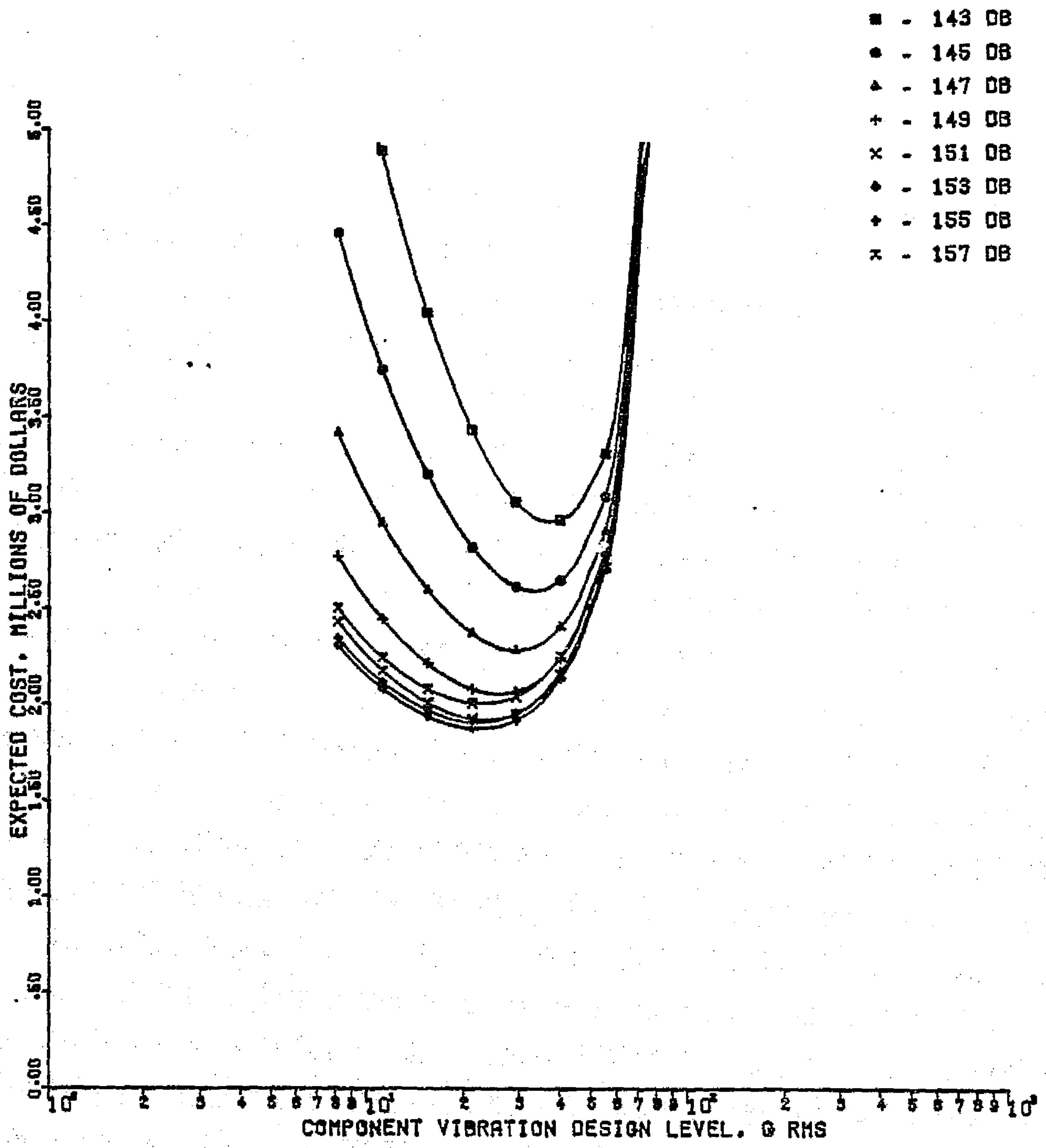


Figure 3-22 TECF Data, Baseline Condition, Test Plan 4, Payload 7,6

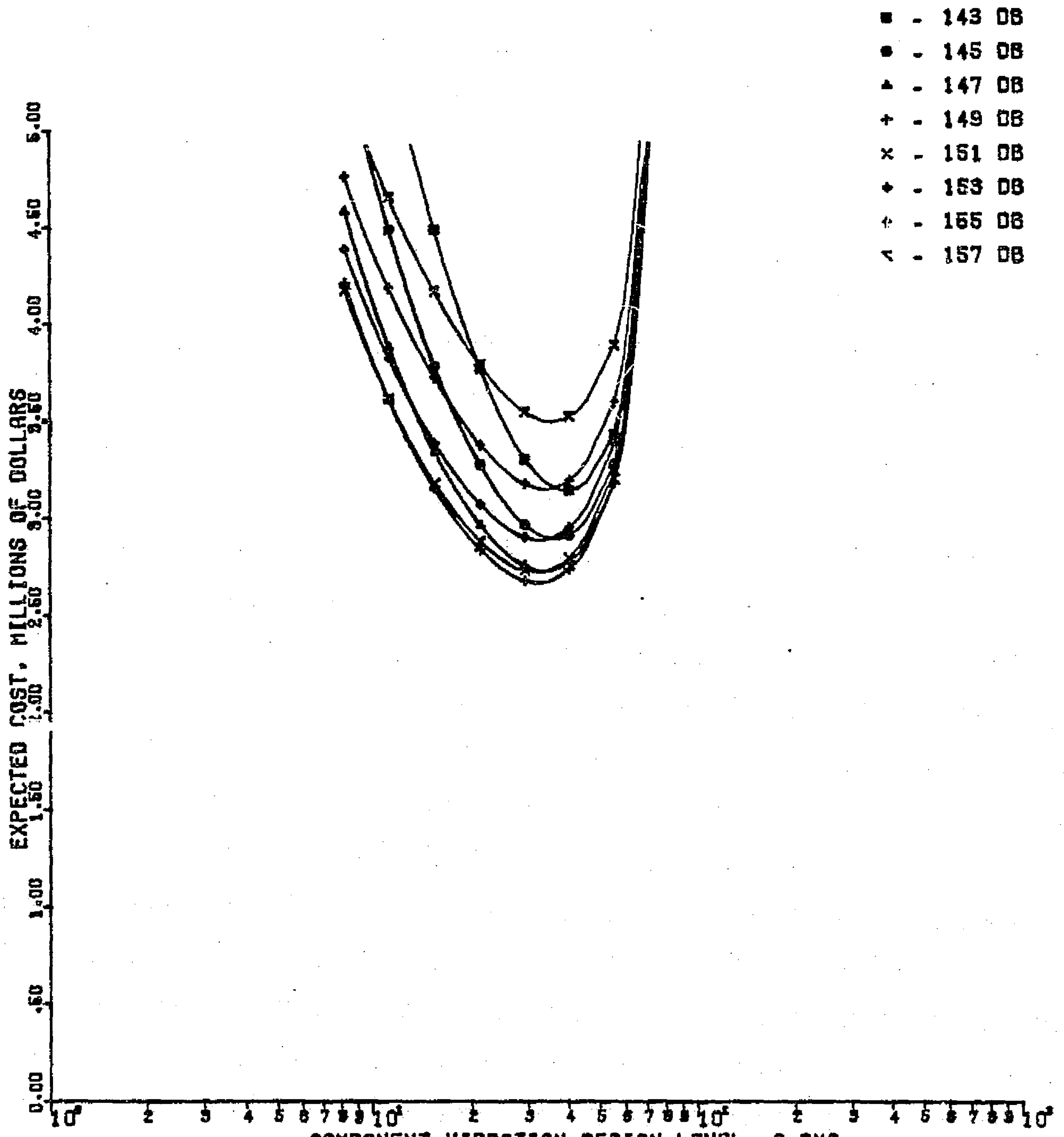


Figure 3-23 TECF Data, Baseline Condition, Test Plan 5, Payload 7,6

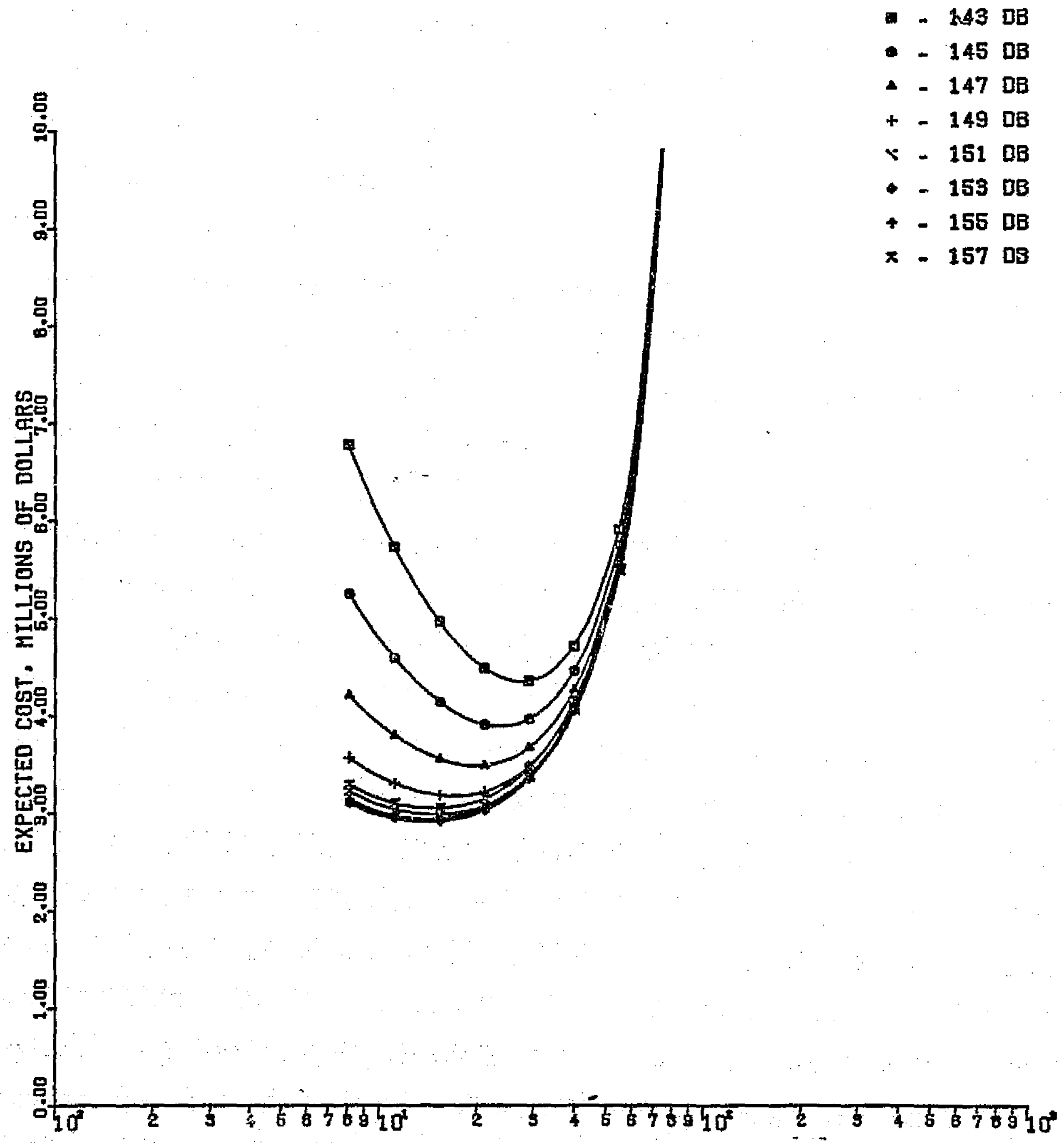


Figure 3-24 TECF Data, Baseline Condition, Test Plan 8, Payload 7,6

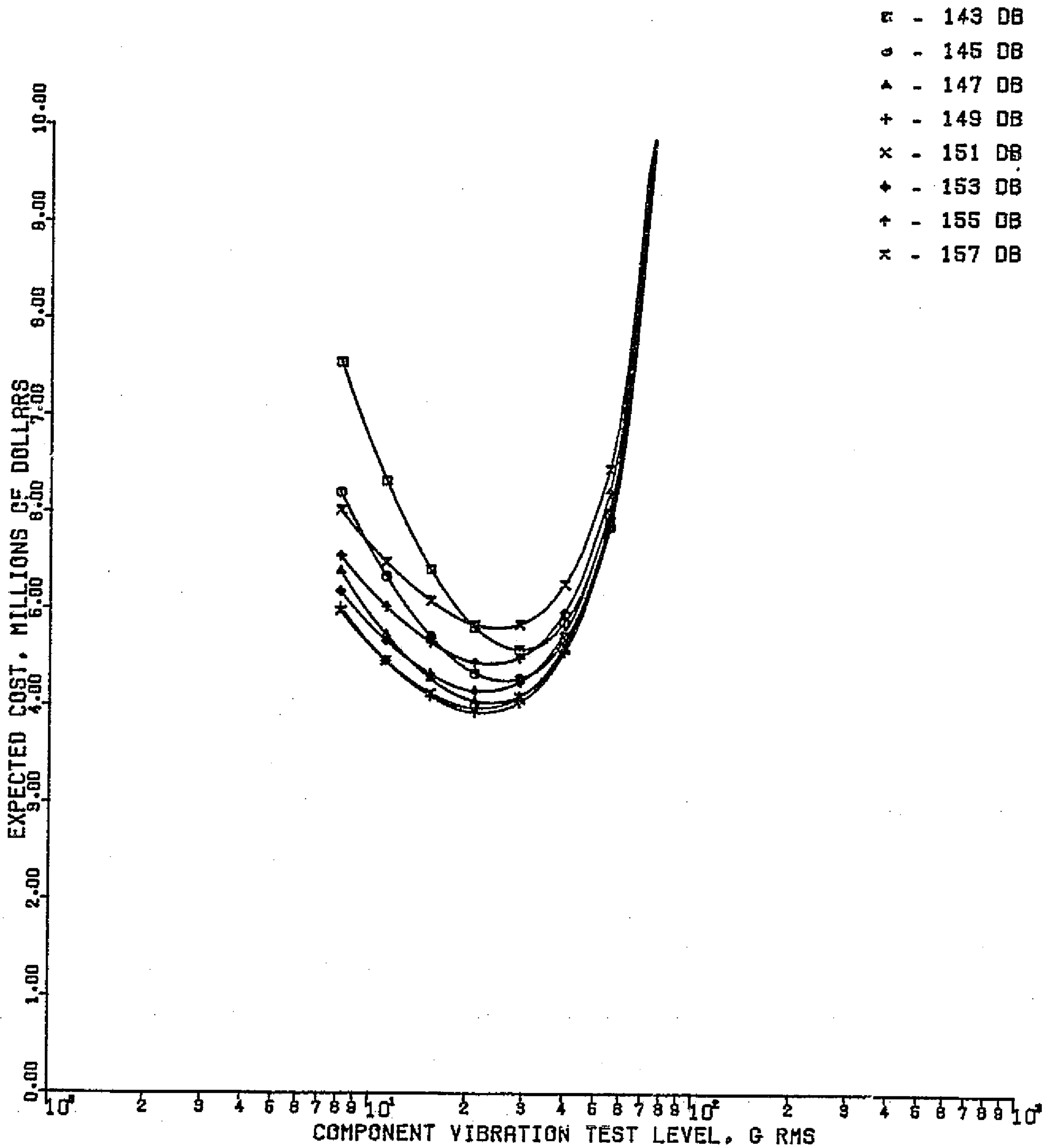


Figure 3-25 TECF Data, Baseline Condition, Test Plan 9, Payload 7,6

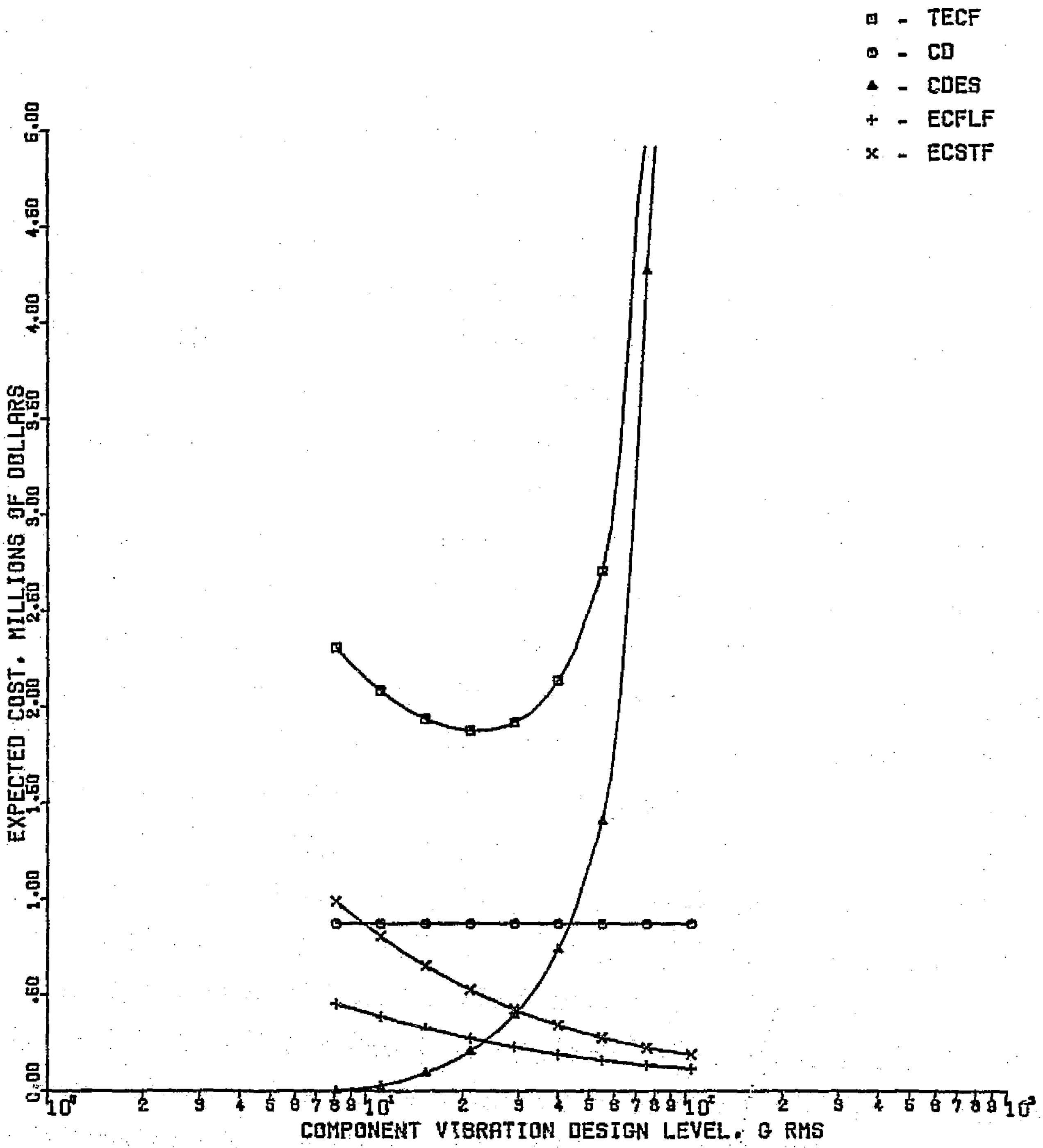


Figure 3-26 Cost Element Data, Baseline Condition, Optimum Assembly Test Level of 153 dB, Test Plan 4, Payload 7,6

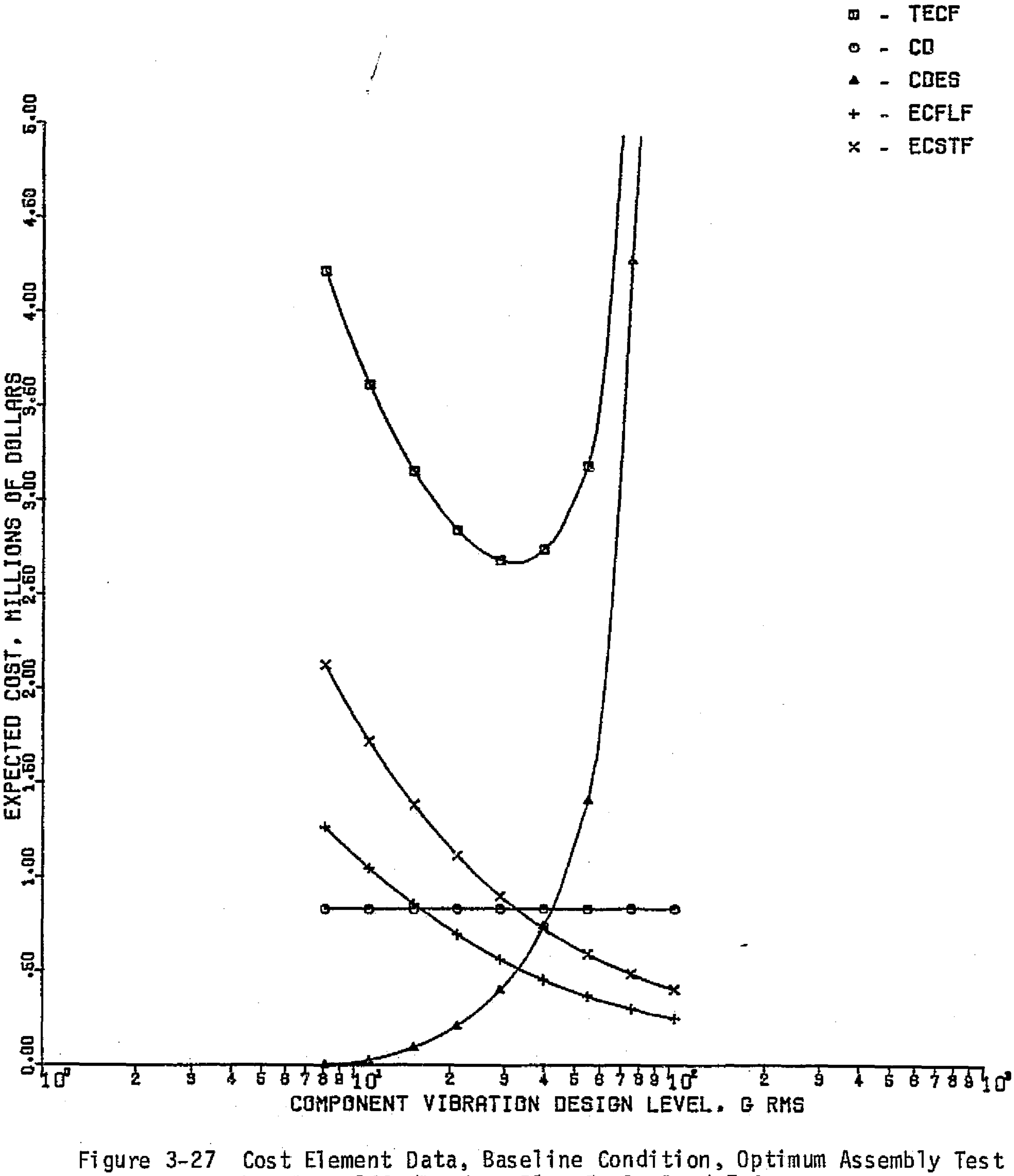


Figure 3-27 Cost Element Data, Baseline Condition, Optimum Assembly Test Level of 149 dB, Test Plan 5, Payload 7,6

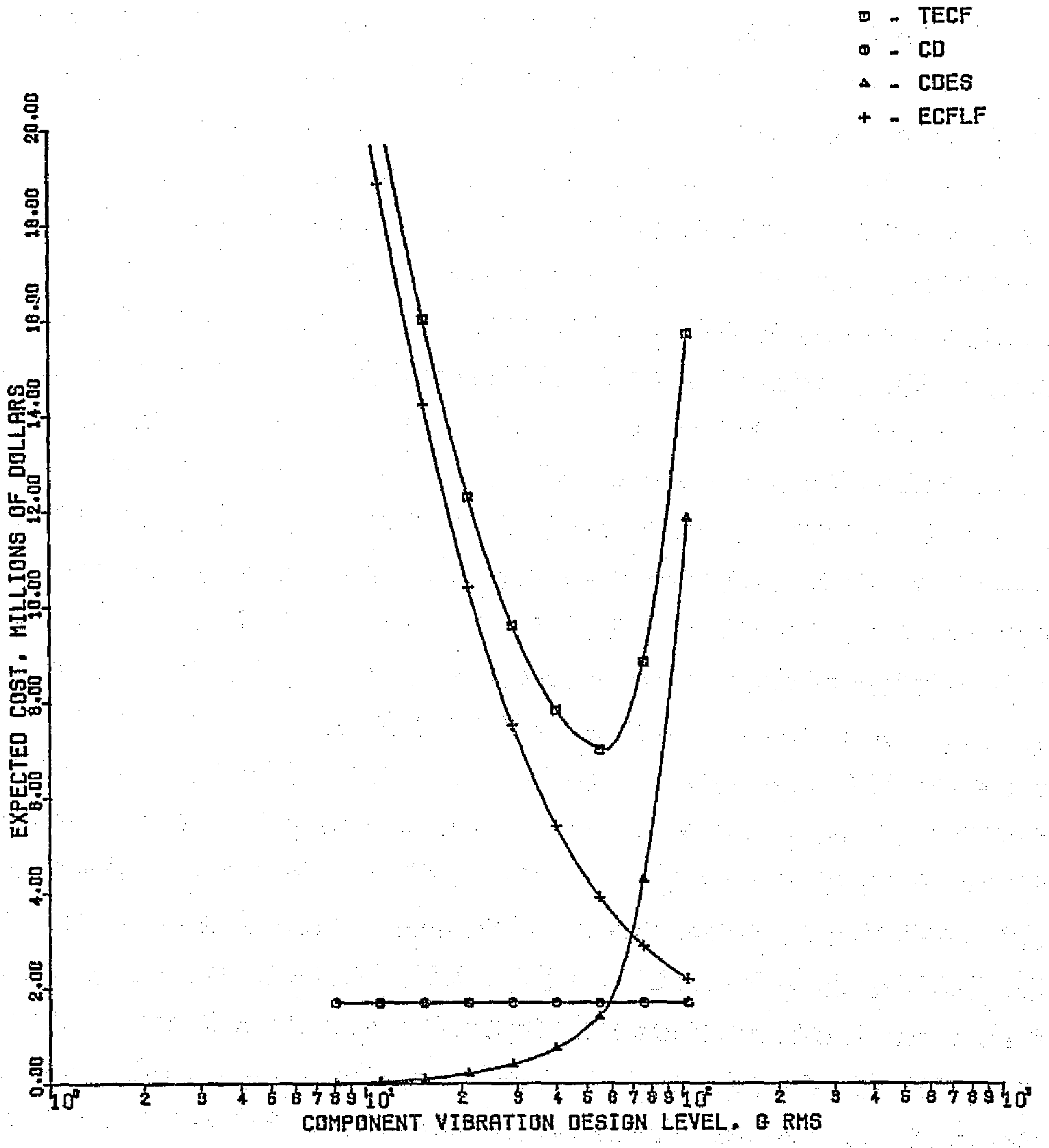


Figure 3-28 Cost Element Data, Baseline Condition, Test Plan 6, Payload 7,6

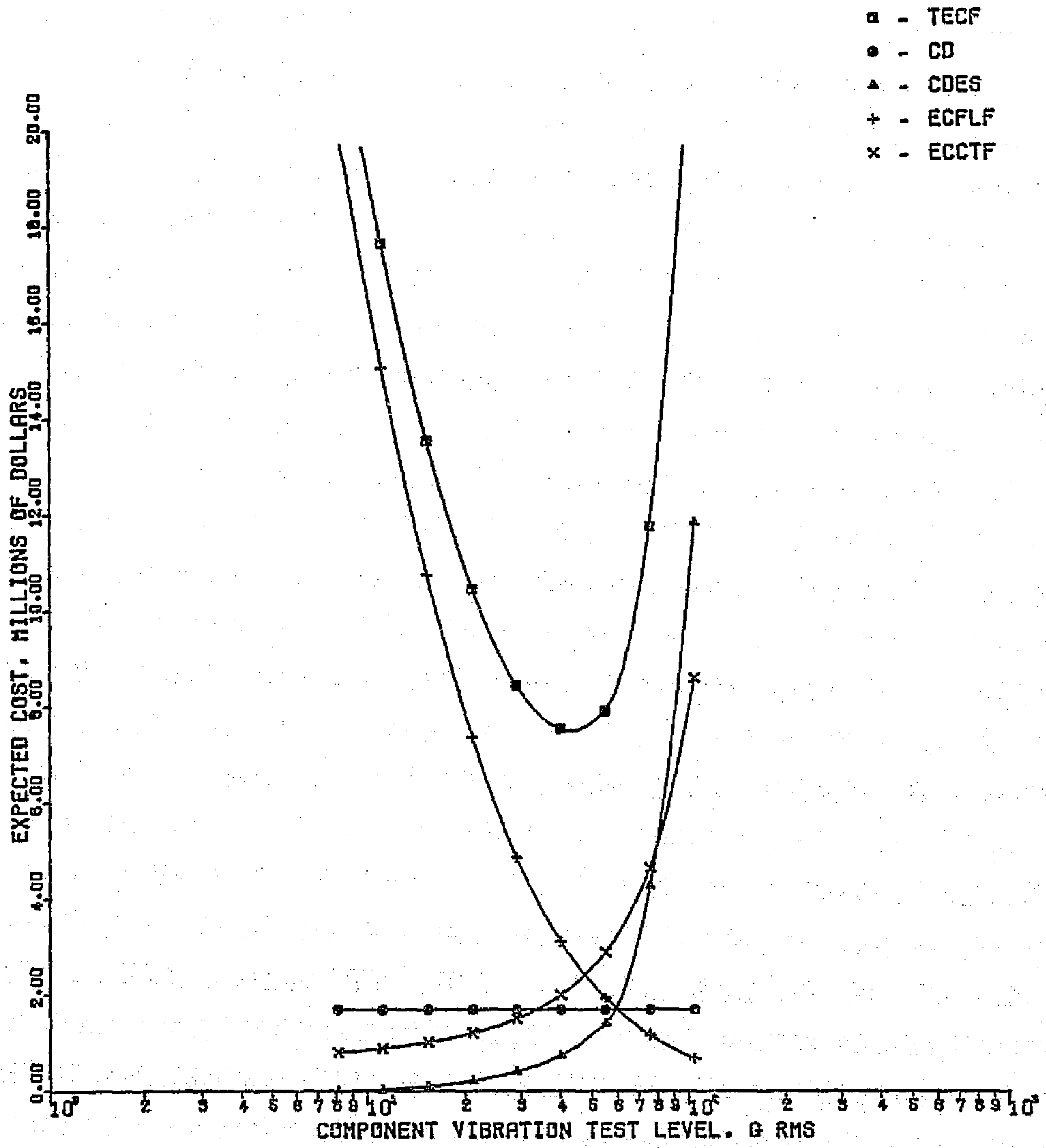


Figure 3-29 Cost Element Data, Baseline Condition, Test Plan 7, Payload 7,6

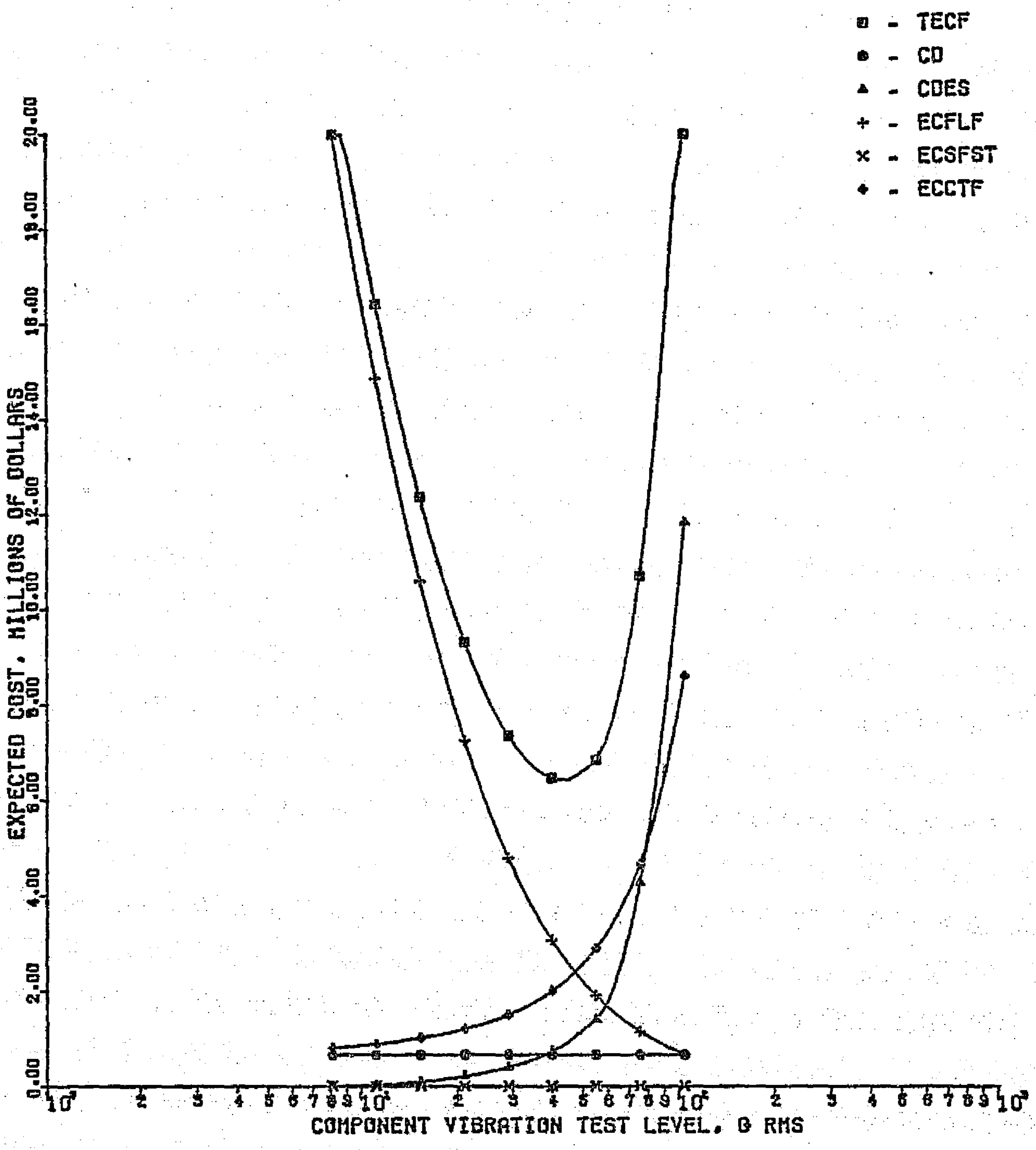


Figure 3-30 Cost Element Data, Baseline Condition, Test Plan 7B, Payload 7,6

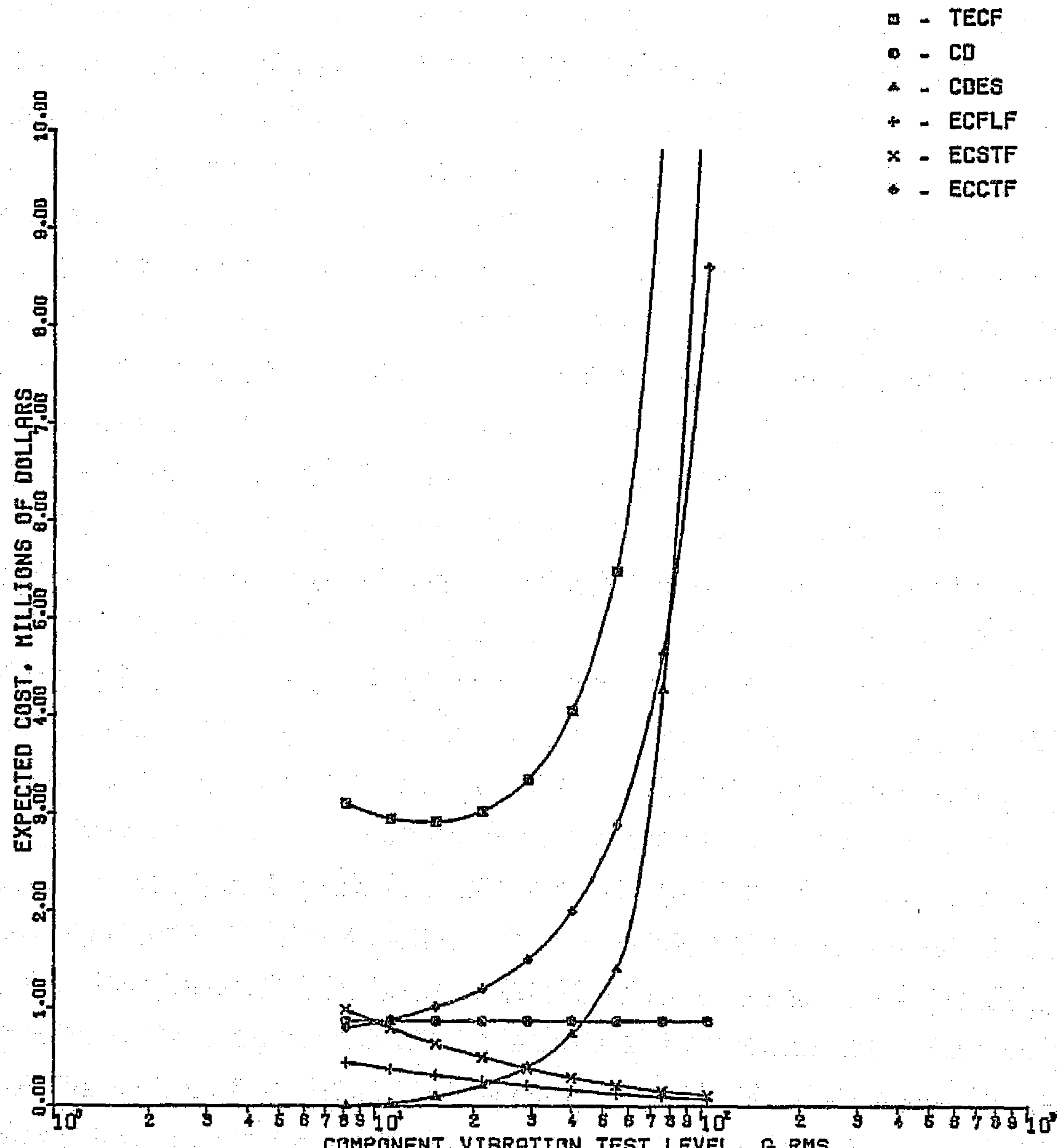


Figure 3-31 Cost Element Data, Baseline Condition, Optimum Assembly Test Level of 153 dB, Test Plan 8, Payload 7,6

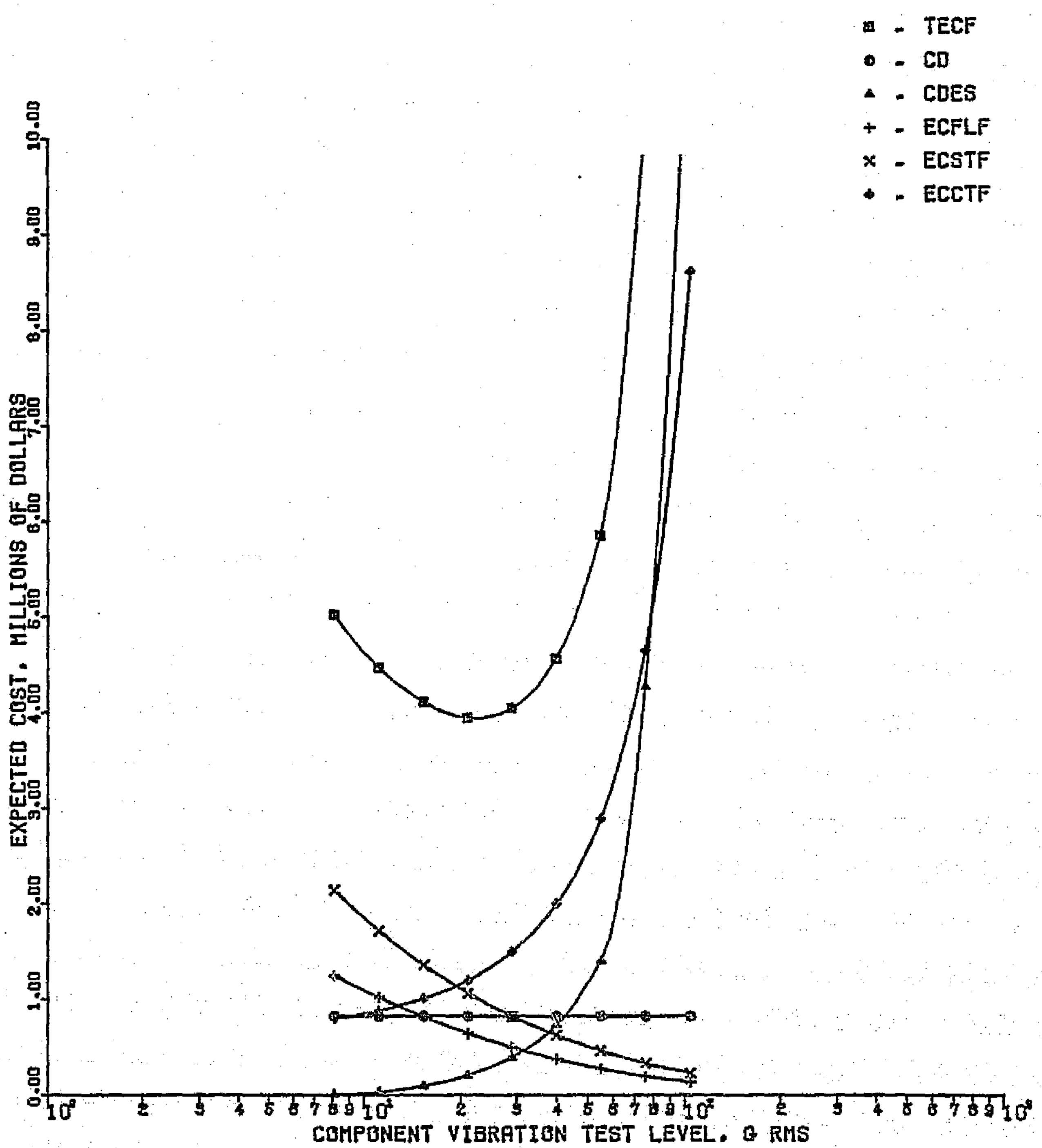


Figure 3-32 Cost Element Data, Baseline Condition, Optimum Assembly Test Level of 149 dB, Test Plan 9, Payload 7,6

These figures show the expected cost versus the component vibration test level or design level. The cost elements for the optimum cost curve for a test plan/payload combination are identified on these figures:

TECF	-	total of the expected costs of failures, the design costs, and the direct costs
CD	-	direct costs
CDES	-	design costs
ECFLF	-	expected cost of flight failures
ECSTF	-	expected cost of assembly (subassembly or system) test failures
ECCTF	-	expected cost of component test failures
ECSFST	-	expected cost of structure failures during protoflight structure tests

For Test Plans 4, 5, 8, and 9, the values for ECSFST are included in the values for ECSTF. As shown in Figure 3-30, these values are very small.

The data plotted in Figures 3-26 to 3-32 show how the elemental costs vary with the component vibration test/design level. The design costs (CDES) and the expected costs of component test failures (ECCTF) increase as the component level increases. The expected costs of assembly test failures (ECSTF) and flight failures(ECFLF) decrease as the component level increases. The direct costs and the expected costs of structure failures during protoflight structure tests are constant for a test plan/payload combination. It should be noted that for those test plans that consider no component testing (Test Plans 4, 5, 6) the optimum costs are possible only because of the inclusion of the design costs (CDES). Also note that the data shown in Figures 3-26 and 3-31 are for an assembly acoustic test level of 153 dB, while the data shown in Figures 3-27 and 3-32 are for an assembly acoustic test level of 149 dB.

Typical flight failure probability curves for a baseline Payload 7,6 are shown in Figures 3-33 to 3-39 for the seven test plans. The complete set of failure data, a total of 105 figures, were plotted and have been provided in a separate data package. These figures show the flight failure probability, i.e., the probability of losing experiment data during flight, versus the component vibration test/design level. In Figures 3-35 to 3-37 each figure shows the flight failure probability for the eight variations for a test plan/payload combination. In Figures 3-33, 3-34, 3-38, and 3-39 each figure shows the flight failure probability for the eight assembly acoustic test levels, for a test plan/payload combination.

A comparison of the various optimums for each of the test plans is shown in Figures 3-40 to 3-42 for the three baseline payloads. These figures show the expected cost, in millions of dollars, versus the component vibration test/design level. Each figure shows the seven test plans for one baseline payload.

3.2 BASELINE EVALUATION

No major revisions were made to the statistical decision models for the seven vibro-acoustic test plans considered for this portion of the study. The values used for the input data parameters were reviewed. Except for the launch cost per flight, the baseline data used for the parameter study of Reference 4 were retained for this study. The launch cost per flight was revised from $13,500,000 to $17,500,000 to reflect the current STS prices. A summary of the values used for the various input data parameters is given in Table 3-7A for reference.

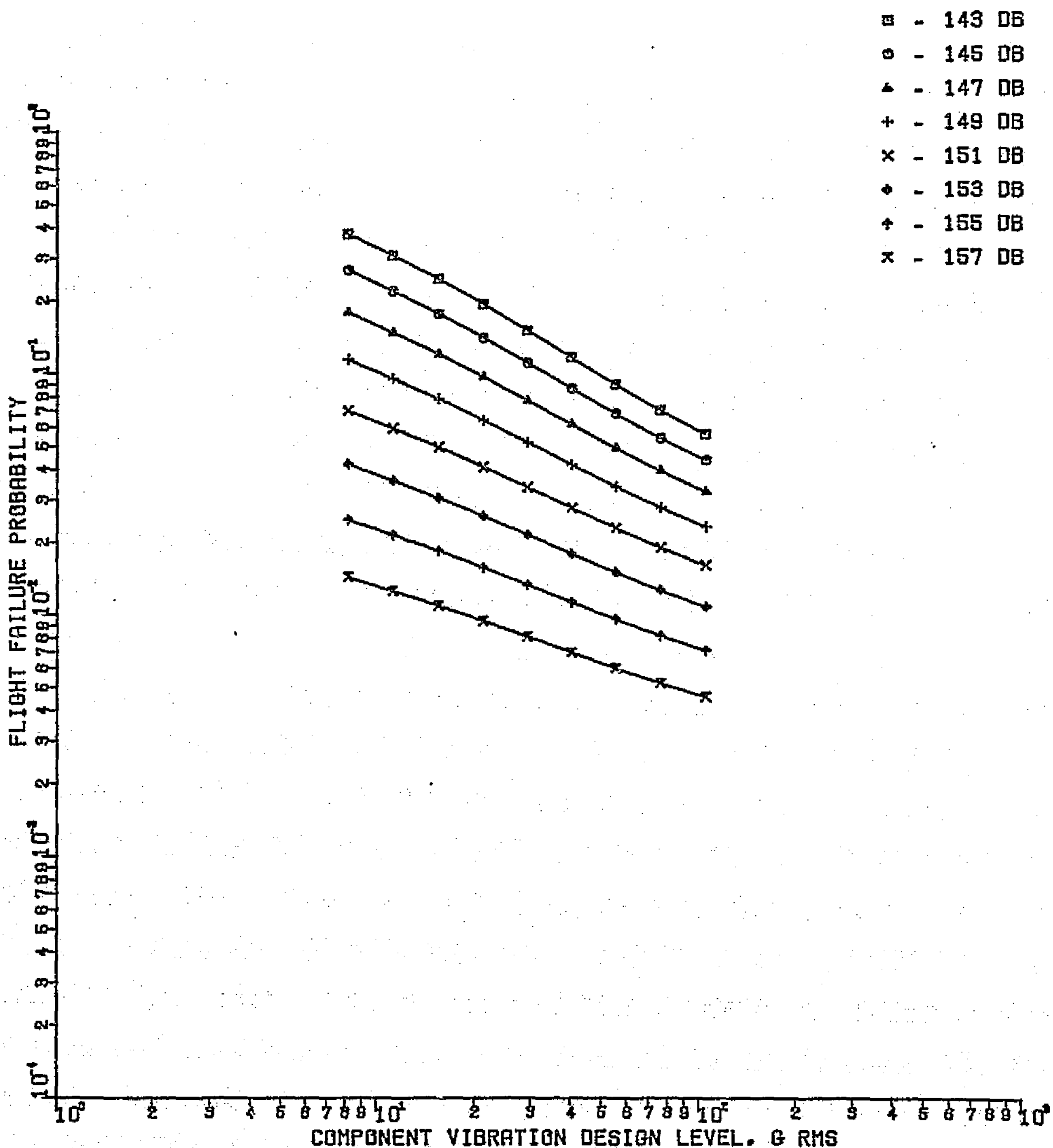


Figure 3-33 FFP Data, Baseline Condition, Test Plan 4, Payload 7,6

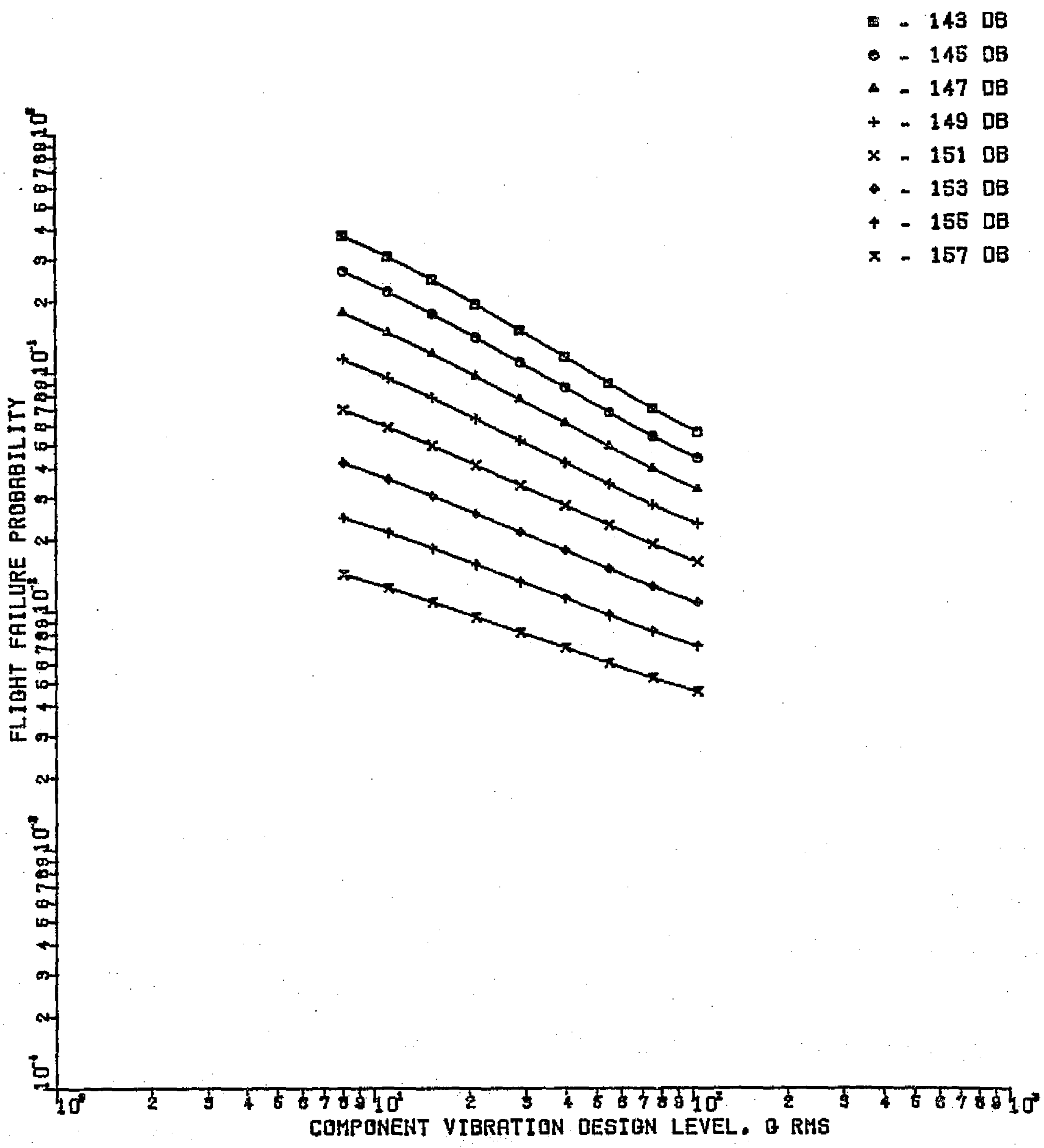


Figure 3-34 FFP Data, Baseline Condition, Test Plan 5, Payload 7,6

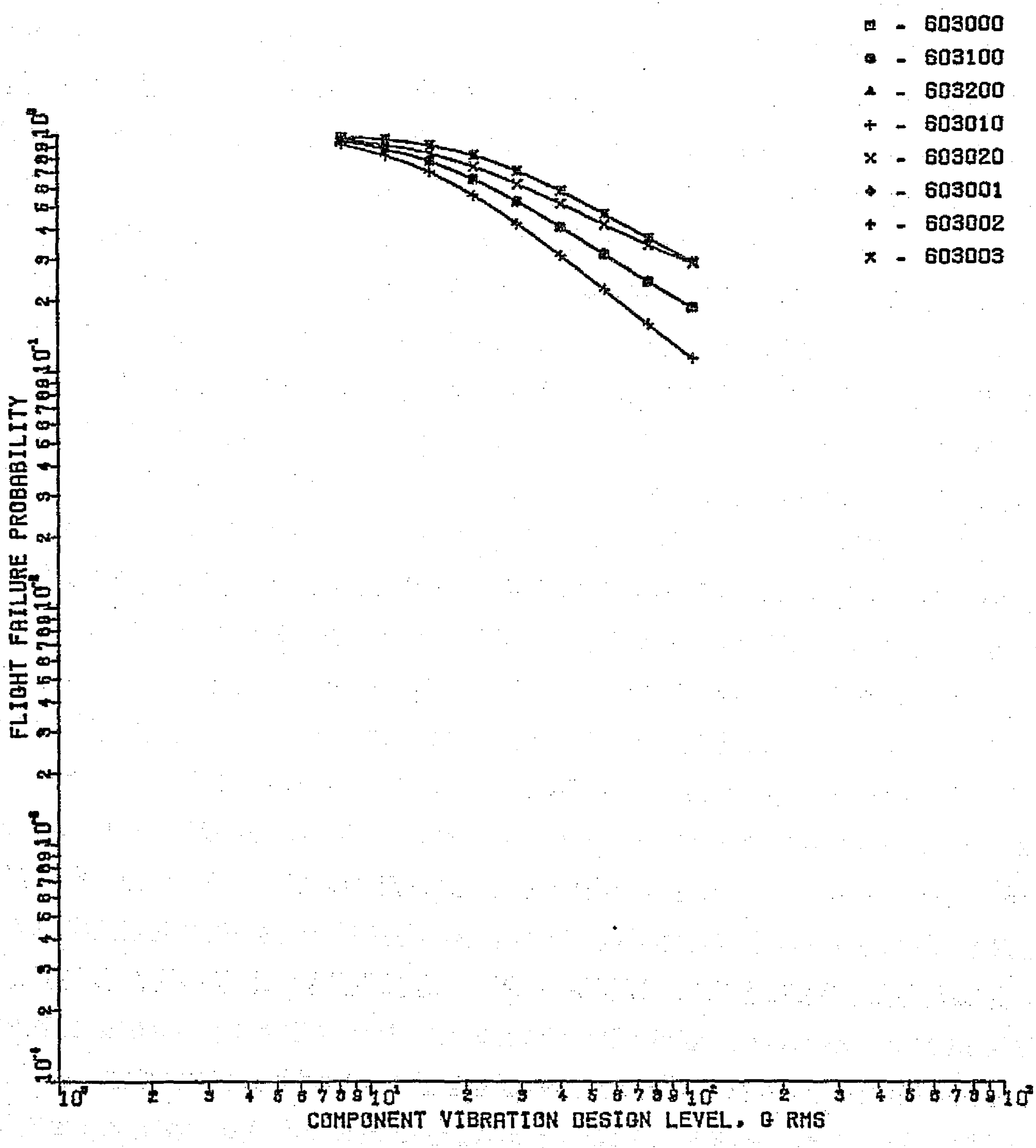


Figure 3-35 FFP Data, Eight Variations, Test Plan 6, Payload 7,6

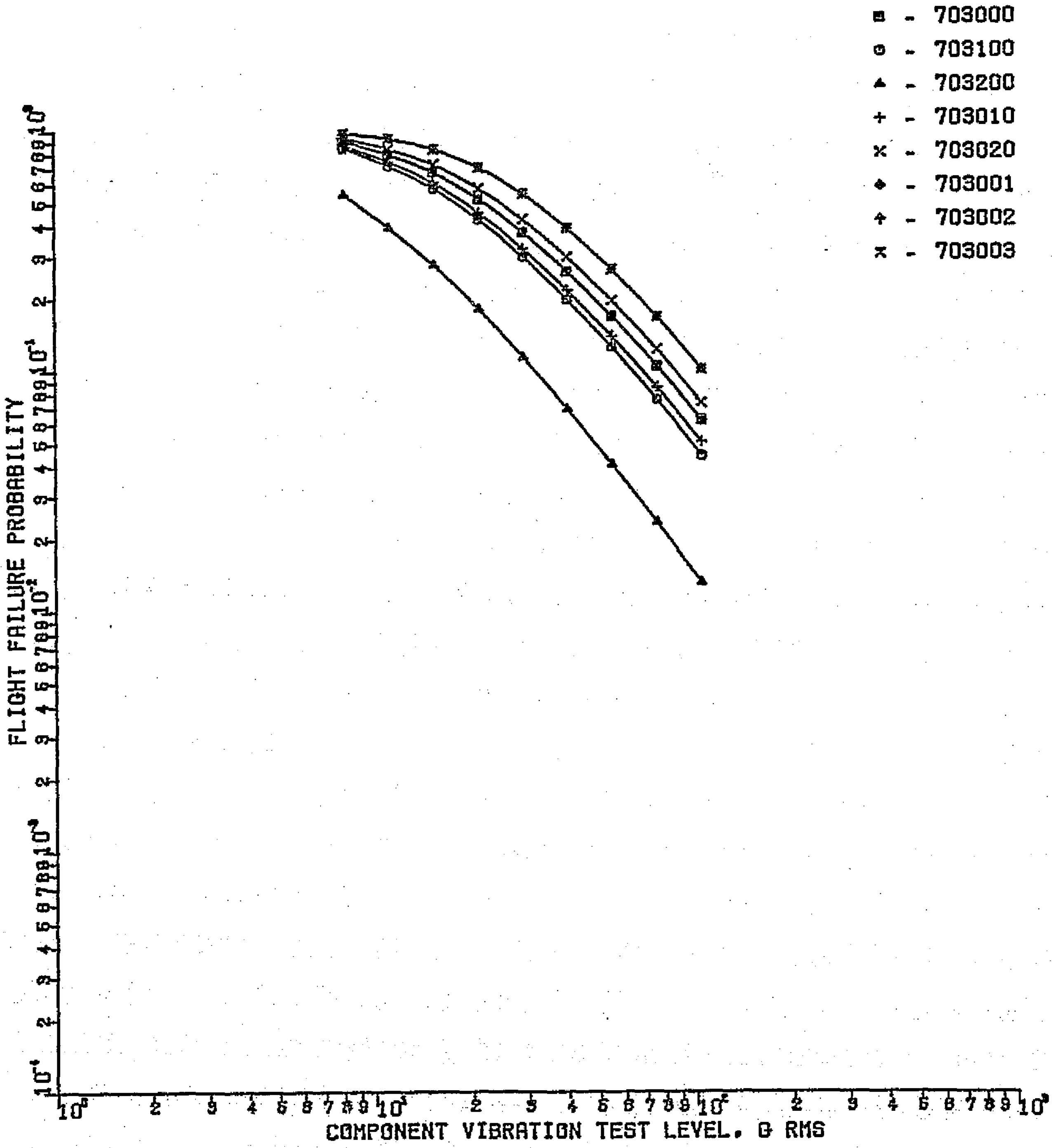


Figure 3-36 FFP Data, Eight Variations, Test Plan 7, Payload 7,6

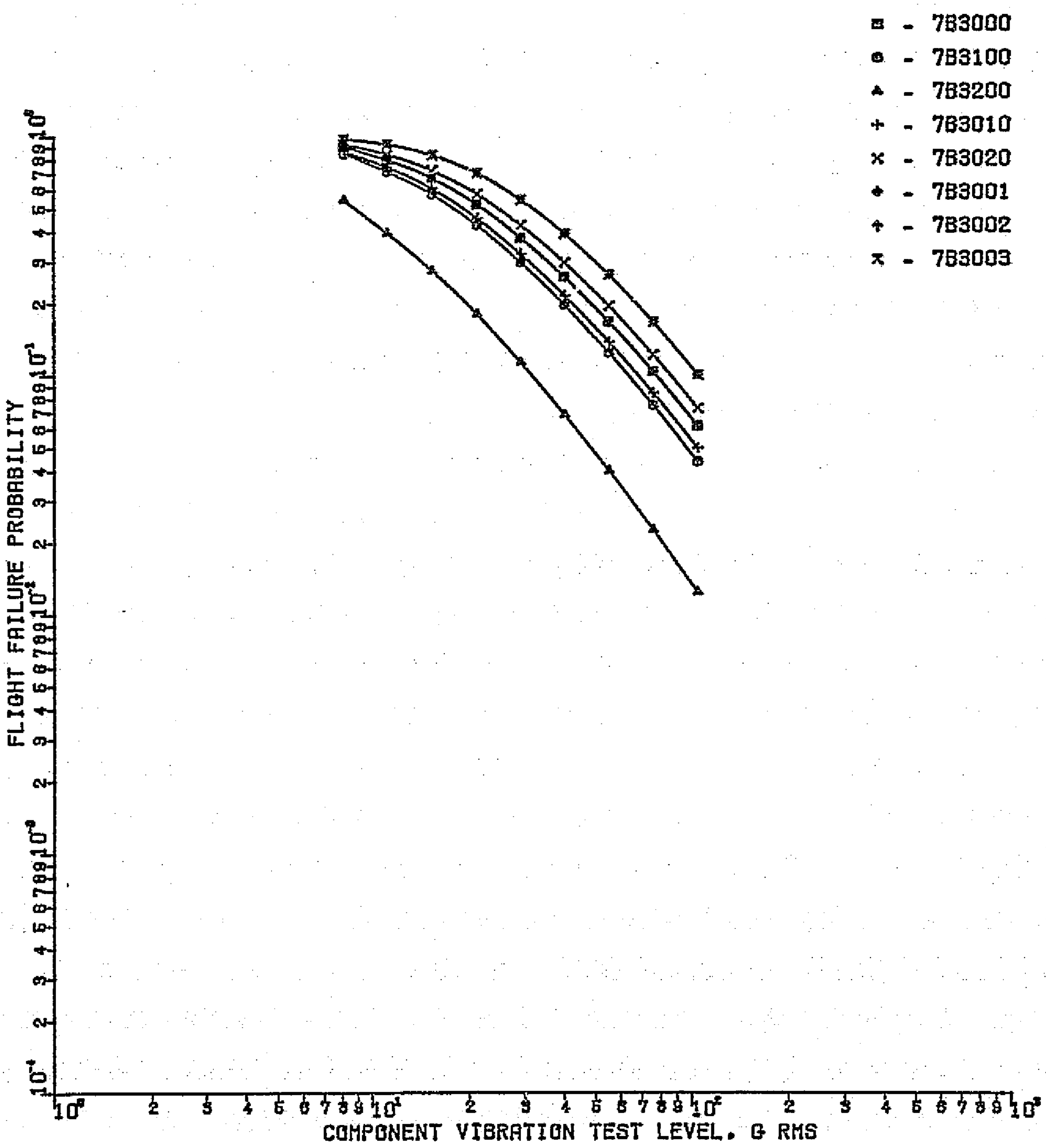


Figure 3-37 FFP Data, Eight Variations, Test Plan 7B, Payload 7,6

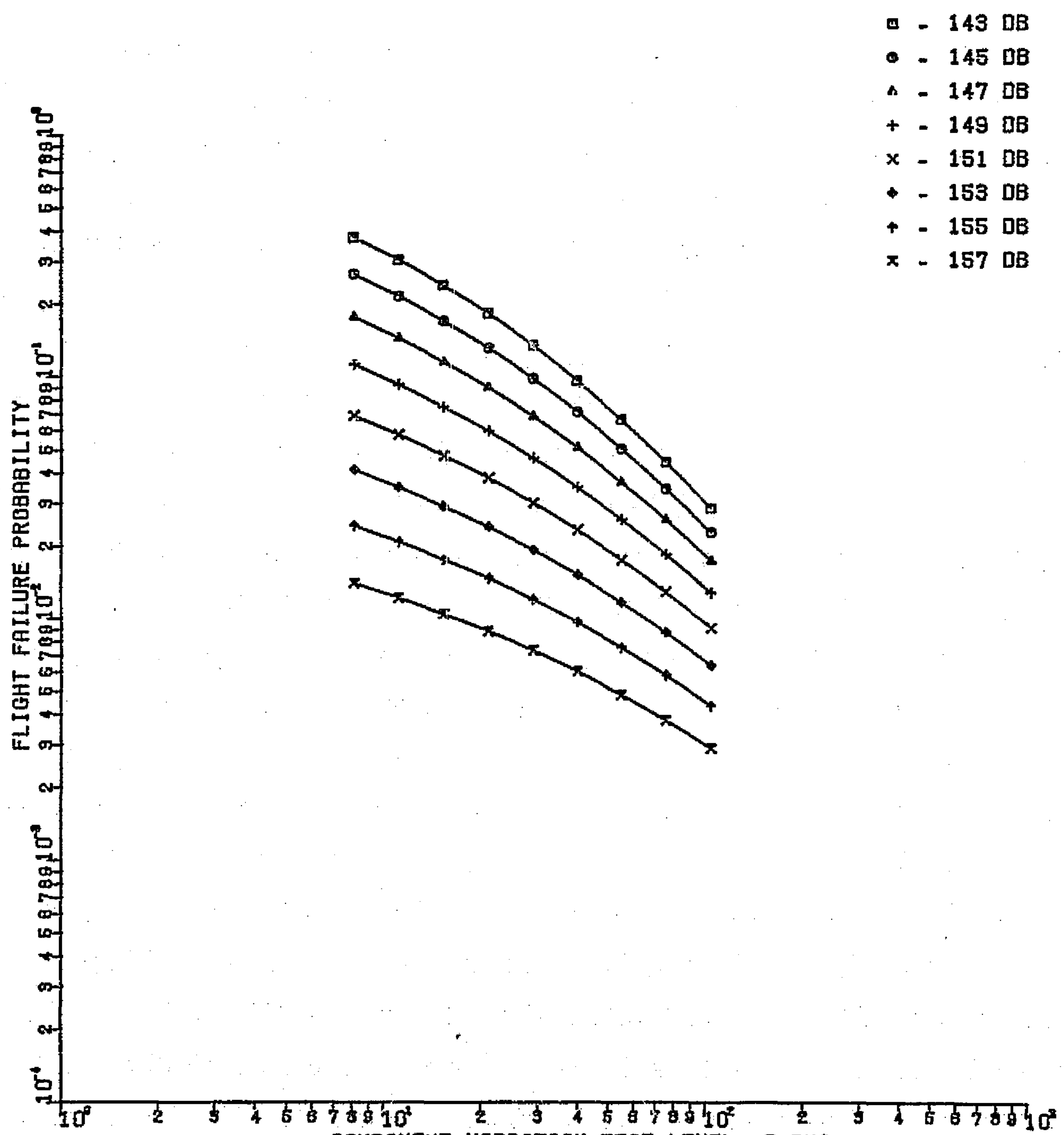


Figure 3-38 FFP Data, Baseline Condition, Test Plan 8, Payload 7,6

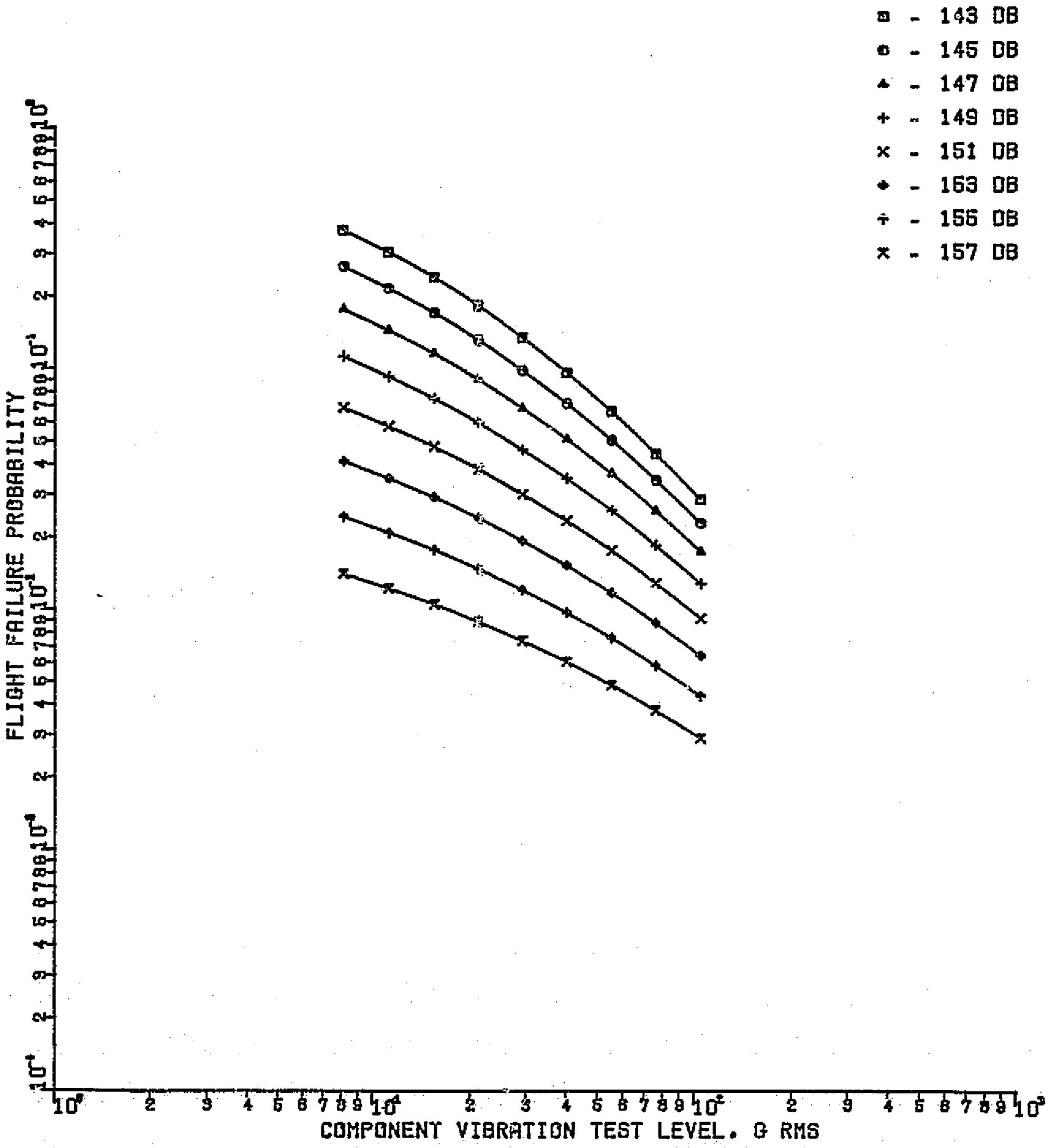


Figure 3-39 FFP Data, Baseline Condition, Test Plan 9, Payload 7,6

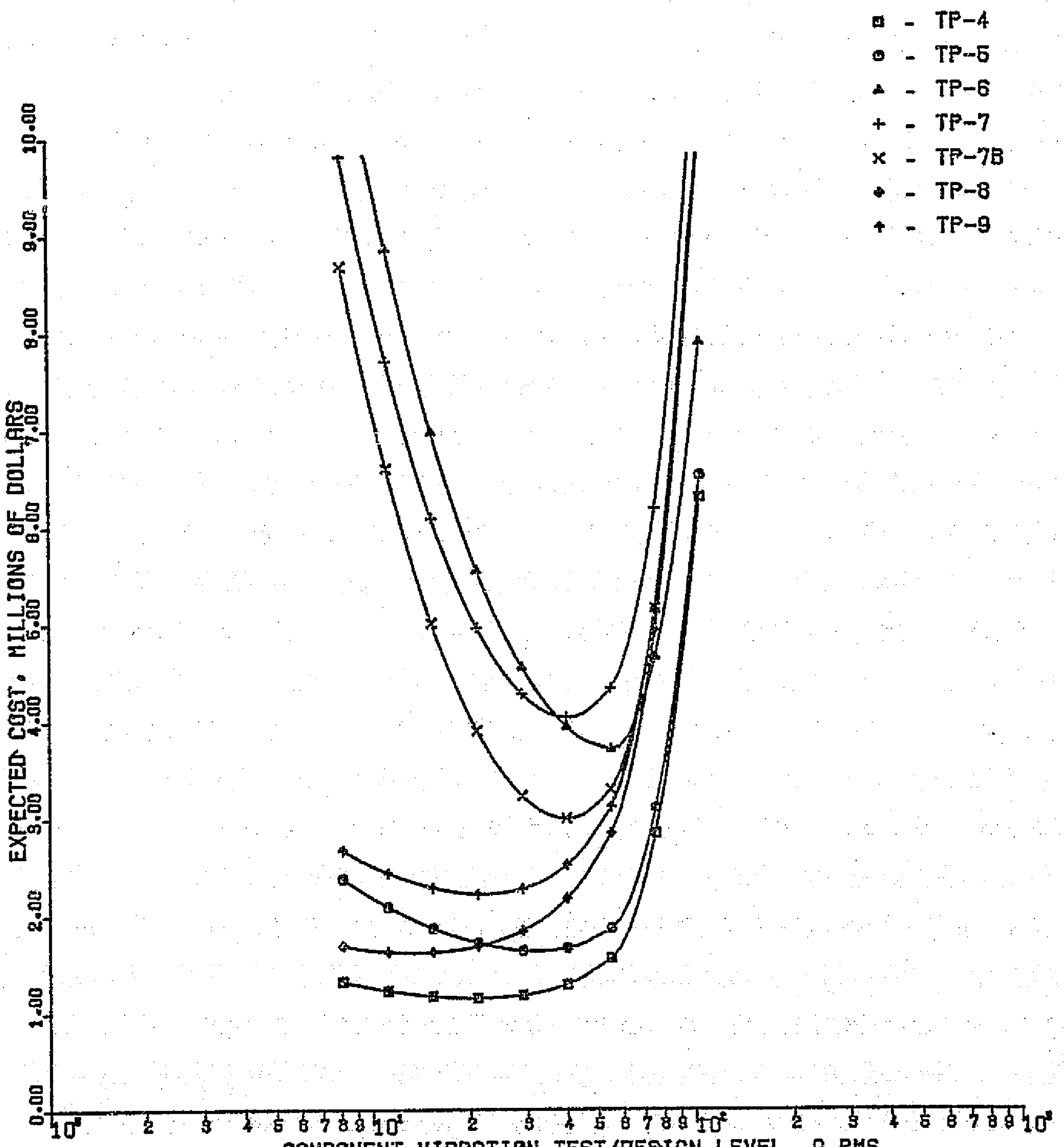


Figure 3-40 Optimum Costs for Each Test Plan, Baseline Condition, Payload 1,2

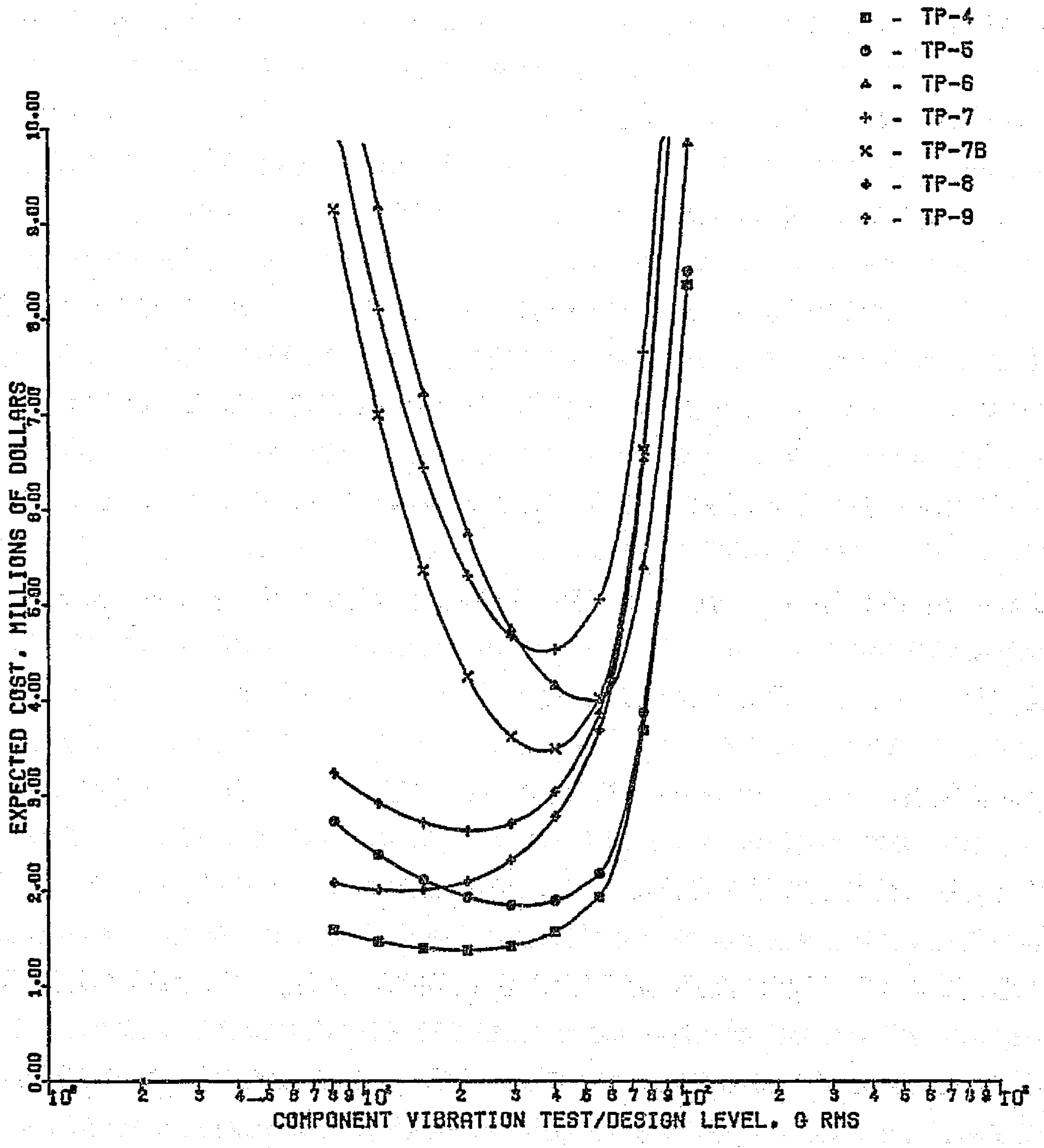


Figure 3-41 Optimum Costs for Each Test Plan,Baseline Condition, Payload 7,2

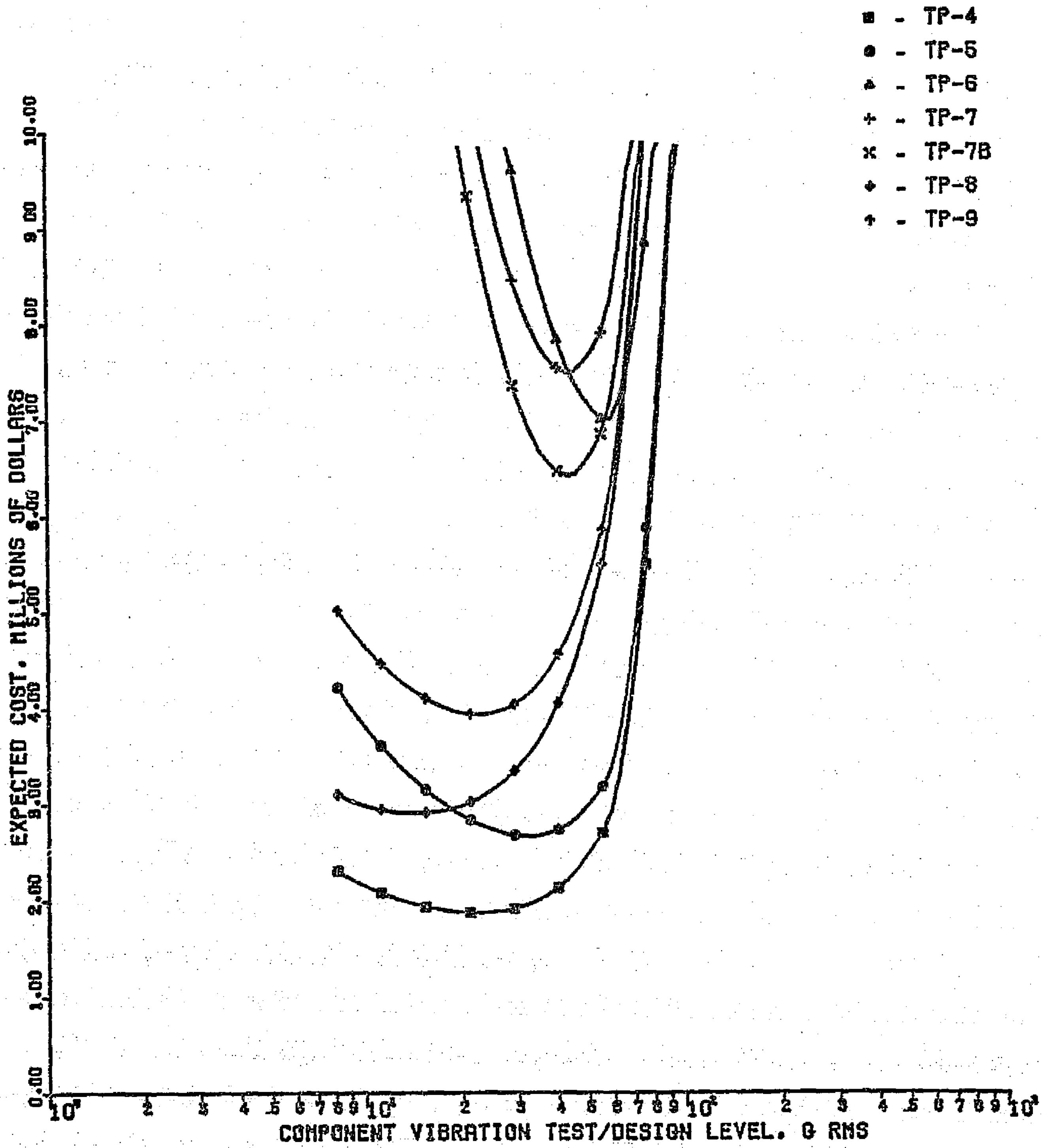


Figure 3-42 Optimum Costs for Each Test Plan, Baseline Condition, Payload 7,6

Table 3-7A

Cost Summary

Cost Parameter	Test Plan 4	5	6	7	7B	8	9
Initial Component Test	-	-	-	8.	8.	8.	8.
Initial Subassembly Test	21.	-	-	-	-	21.	-
System Test	-	167.	-	-	-	-	167.
Protoflight Structure Test	32.	32.	-	-	32.	32.	32.
Structural Weight (per pound)	0.215	0.215	0.215	0.215	0.215	0.215	0.215
Component Design Cost	*	*	*	*	*	*	*
Component Failure during Component Test, Redesign/Retest	-	-	-	15.	15.	15.	15.
Component Failure during Subassembly Test, Redesign/Retest	15.	-	-	-	-	15.	-
Component Failure during System Test, Redesign/Retest	-	15.	-	-	-	-	15.
Component Failure during Flight, Redesign/Retest	15.	15.	15.	15.	15.	15.	15.
Subassembly Test Failure	13.	-	-	-	-	13.	-
In-line Subassembly Test Failure	120.	-	-	-	-	120.	-
Structure Failure during Structure Test	150.	240.	-	-	150.	150.	150.
System Test Failure	-	120.	-	-	-	-	120.
Functional Test	16.	16.	16.	16.	16.	16.	16.
Launch Cost, per Flight	17500	17500	17500	17500	17500	17500	17500

$$\text{*Component Design Cost} = \frac{1800}{(100-g)} - 20 \qquad 10 \le g \le 100$$

where g is the component design/test level

NOTE: Costs are given in thousands of dollars

Although some of the input data of the baseline presented in Reference 4 have been changed, the overall results for the baseline configurations were not changed significantly. A representative pictorial presentation of data for the baseline is given in Section 3.1 for Payload 7,6. The expected cost variation for the assembly acoustic test level at which the optimum cost occurs are shown in Figures 3-1 to 3-21. The case code for the baseline data is XXY000, where XX denotes the test plan and Y denotes the payload ID defined previously. On the figures the symbol for the baseline symbol is ◘ . A summary of the baseline optimum data by payload is given in Table 3-8 which includes the cost and reliability ranks.

Because the launch cost was varied in the previous study, variation 0100 of Reference 4 is the same as the baseline (variation 000) for this study. The data given in Table 3-8 should agree with the data given in Table 4-12 of Reference 4. There is agreement in the values given in the two tables for the component vibration test/design level, the assembly acoustic test level, the associated vibroacoustic reliability, and the reliability rank, but there are differences in the values given for the expected cost and the cost rank. One of the reasons for the differences is an error that was found in the computer coding in the calculation of the expected costs of failures during component tests. Test Plans 7, 7B, 8, and 9 were affected. The error was payload dependent; for Payload 1,2 the values in Table 3-8 are 0.231 less than those of Reference 4; for Payload 7,2, 0.315; for Payload 7,6, 0.511. There was also a small error found in the value input for the cost of a system test. Reference 4 used a value of $199,000 for the cost of a protoflight system test and a cost of $32,000 for the cost of a protoflight structure test. This study used values of $167,000 and $32,000 for these respective costs, because included in the $199,000 value is $32,000 for a protoflight

Table 3-8

Summary of Optimums By Payloads
Variation 000
Baseline Condition

Payload	Test Plan	Expected Cost ($\$x10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	1.154	21.071	153	0.99875	1	1
	5	1.634	32.948	147	0.99646	3	4
	6	3.710	54.917	-	0.98018	6	7
	7	4.038	39.906	-	0.98436	7	6
	7B	2.998	39.906	-	0.98507	5	5
	8	1.619	13.475	153	0.99846	2	2
	9	2.221	21.071	149	0.99703	4	3
7,2	4	1.374	19.767	151	0.98552	1	1
	5	1.843	30.910	147	0.97466	2	3
	6	4.000	54.917	-	0.87978	6	7
	7	4.513	37.437	-	0.89468	7	6
	7B	3.471	37.437	-	0.89533	5	5
	8	1.998	12.642	151	0.98173	3	2
	9	2.629	21.071	147	0.96877	4	4
7,6	4	1.877	21.071	153	0.97427	1	1
	5	2.669	32.948	149	0.95216	2	3
	6	7.001	54.917	-	0.68366	6	7
	7	7.490	42.537	-	0.76080	7	6
	7B	6.425	42.537	-	0.76136	5	5
	8	2.916	14.364	153	0.96951	3	2
	9	3.943	22.461	149	0.94296	4	4

structure test. These costs are included in the direct costs. Test Plans 5 and 9 are affected by this difference, so the values in Table 3-8 are 0.032 less than those of Reference 4. These differences account for the change in the cost rank of Test Plans 5 and 8 for Payload 1,2; there were no cost rank changes for Payloads 7,2 and 7,6.

A comparison of the expected costs given in Table 3-8 indicates that Test Plans 4, 5, and 8 are still the most attractive. Minimum cost is achieved with Test Plan 4, which involves protoflight subassemblies testing only. Except for Payload 1,2, Test Plan 5 (protoflight system testing only) ranks second, followed by Test Plan 8 (protoflight components and subassemblies testing), Test Plan 9 (protoflight components and system testing), Test Plan 7B (protoflight components and structure testing), Test Plan 6 (no testing) and Test Plan 7 (components testing only). For Payload 1,2 the cost ranks of Test Plans 5 and 8 are reversed.

The optimum component vibration test/design level varies from 20 to 21 g rms for Test Plan 4, from 31 to 33 g rms for Test Plan 5, from 37 to 43 g rms for Test Plans 7 and 7B, from 13 to 14 g rms for Test Plan 8, and from 21 to 22 g rms for Test Plan 9. It is 55 g rms for Test Plan 6. The lowest component vibration levels are obtained for Test Plan 8, followed by Test Plan 4, Test Plan 9, Test Plan 5, Test Plans 7 and 7B, and Test Plan 6, which has the highest component vibration test levels.

The optimum assembly acoustic test level varies from 151 to 153 dB for Test Plans 4 and 8, and from 147 to 149 dB for Test Plans 5 and 9. The lowest assembly acoustic test levels are, therefore, obtained for those test plans that utilize protoflight system testing, Test Plans 5 and 9, while the highest assembly levels are obtained for those test plans that utilize protoflight subassemblies testing, Test Plans 4 and 8.

The payload flight vibroacoustic reliability associated with the optimum cost is also given in Table 3-8 for the revised baseline. In this study the flight vibroacoustic reliability is defined as the probability of no data loss from the payload experiments as a result of a vibration failure of a component. For all payload configurations the test plans that utilize subassembly testing, Test Plans 4 and 8, rank first and second. The test plans that utilize system testing, Test Plans 5 and 9, rank third and fourth. Test Plans 7B, 7, and 6 rank fifth, sixth and seventh, respectively.

For all payload configurations a cost savings of $1,000,000 is achieved when protoflight structural testing, Test Plan 7B, is used instead of no structural testing, Test Plan 7.

The effects of parameter variations are discussed in the following sections. That discussion compares the data for each variation with the baseline discussed in this section.

3.3 NUMBER OF MISSIONS

For the development of the methodology the payload configurations were considered to be multi-mission STS sortie payloads that were flown for 15 missions, References 1, 3, and 4. The application of the methodology to other specific payloads indicated that the number of missions varied appreciably for a variety of experiments planned for the EVAL (Earth Viewing Applications Laboratory) payload, Reference 6. For that study the 18 experiments were grouped according to the number of missions that were planned for each experiment. Within these groups the number of components peculiar to each experiment was averaged. As a result, each configuration had a different number of total components and a different number of missions. The results showed that the optimum expected costs and the associated test levels increased as the number of missions increased. For the 2-mission configuration a true optimum assembly test level was not obtained for the range of assembly test levels considered, i.e., the minimum cost occurred at the lowest assembly level considered.

The effects of the number of missions were examined by considering it as a variable in this study. Cases were selected for a single mission, an intermediate number of missions (8), and the baseline 15 missions. The variations considered for this study are:

1. Baseline - 15 missions
2. 1st Variation - 8 missions
3. 2nd Variation - 1 mission

The case codes for the data of these variations are XXY100 and XXY200 for the eight-mission and one-mission cases, respectively, where XX denotes the test plan and Y denotes the payload (Section 3.1). The cost variation for the assembly test level at which the optimum occurs are shown in Figures 3-1 to 3-21. On the figures the symbols for these variations are o and Δ for the eight-mission and one-mission cases, respectively. Summaries of the optimum data by payload are given in Tables 3-9 and 3-10 for the eight-mission and one-mission cases, respectively.

A comparison of Tables 3-9 and 3-10 with Table 3-8 shows that the single-mission cases have a significant effect on the cost ranks. There are six rank changes for Payload 1,2 and five rank changes for Payloads 7,2 and 7,6. Except for Payload 1,2, Test Plan 4 (subassembly testing) ranks first, followed by Test Plan 5 (system testing), Test Plan 6 (no testing), Test Plan 7B (component and structure testing), Test Plan 7 (component testing), Test Plan 8 (component and subassembly testing), and Test Plan 9

Table 3-9

Summary of Optimums By Payloads
Variation 100
8 Missions

Payload	Test Plan	Expected Cost ($\$ \times 10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	0.754	18.544	149	0.99778	1	1
	5	1.110	28.997	143	0.99479	2	4
	6	2.228	45.342	-	0.97565	6	7
	7	2.459	28.997	-	0.98147	7	6
	7B	1.921	28.997	-	0.98219	5	5
	8	1.199	11.860	149	0.99711	3	2
	9	1.668	18.544	145	0.99502	4	3
7,2	4	0.946	17.397	149	0.98404	1	1
	5	1.248	27.204	143	0.96270	2	3
	6	2.414	42.537	-	0.84557	6	7
	7	2.791	27.204	-	0.87686	7	6
	7B	2.252	27.204	-	0.87750	5	5
	8	1.537	11.126	149	0.97930	3	2
	9	1.994	18.544	143	0.95083	4	4
7,6	4	1.330	19.767	149	0.95665	1	2
	5	1.873	28.997	145	0.92676	2	3
	6	4.369	48.333	-	0.64775	6	7
	7	4.701	32.948	-	0.74466	7	6
	7B	4.149	32.948	-	0.74520	5	5
	8	2.330	12.642	151	0.96530	3	1
	9	3.087	19.767	145	0.90739	4	4

Table 3-10

Summary of Optimums By Payloads
Variation 200
1 Mission

Payload	Test Plan	Expected Cost ($\$ \times 10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	0.247	11.860	137	0.99196	1	1
	5	0.368	14.364	129	0.98695	2	3
	6	0.457	22.461	-	0.94457	3	7
	7	0.649	10.438	-	0.97009	6	6
	7B	0.615	10.438	-	0.97080	4	5
	8	0.639	8.618	137	0.98849	5	2
	9	0.797	10.438	129	0.97805	7	4
7,2	4	0.387	11.126	135	0.92689	1	1
	5	0.390	13.475	129	0.90828	2	3
	6	0.503	21.071	-	0.69219	3	7
	7	0.795	9.792	-	0.81341	5	6
	7B	0.760	9.792	-	0.81400	4	5
	8	0.911	8.618	137	0.92495	6	2
	9	0.957	9.792	129	0.85507	7	4
7,6	4	0.505	12.642	137	0.85774	1	1
	5	0.548	15.311	129	0.78360	2	3
	6	0.992	25.521	-	0.41764	3	7
	7	1.364	11.126	-	0.60250	5	6
	7B	1.327	11.126	-	0.60294	4	5
	8	1.372	9.186	137	0.80398	6	2
	9	1.505	11.126	129	0.67502	7	4

(component and system testing). For Payload 1,2 the cost ranks of Test Plans 7 and 8 are reversed. For the eight-mission cases there are two cost rank changes for Payload 1,2 and no cost rank changes for Payloads 7,2 and 7,6. The cost ranks for Test Plans 5 and 8 are reversed.

The optimum expected costs decrease as the number of missions decrease. The amount of the decrease varies with payload and test plan. The smallest decrease for a test plan occurs for Payload 1,2 and the largest decreases occur for Payload 7,6. In all cases the smallest decrease is obtained for Test Plan 4, followed by Test Plans 8, 5, 9, 7B, 6, and 7, which has the largest decrease. For the eight-mission cases the decrease varies from $0.400M for Payload 1,2 with Test Plan 4 to $2.789M for Payload 7,6 with Test Plan 7. For the single-mission cases the decrease varies from $0.907M for Payload 1,2 with Test Plan 4 to $6.126M for Payload 7,6 with Test Plan 7.

The optimum component vibration test/design levels decrease as the number of missions decrease. The amount of the decrease varies with payload and test plan. For the eight-mission cases the decrease varies from 1.304 g rms for Payload 7,6 with Test Plan 4 to 12.380 g rms for Payload 7,2 with Test Plan 6. For the single-mission cases the decrease varies from 4.024 g rms for Payload 7,2 with Test Plan 8 to 33.846 g rms for Payload 7,2 with Test Plan 6. For the eight-mission cases the ranks of the decreases differ for each payload. For the single-mission cases for Payloads 1,2 and 7,2 the smallest decrease is obtained for Test Plan 8, followed by Test Plans 9, 5, 7, 7B, and 6. For Payload 7,6 Test Plan 6 and Test Plans 7 and 7B are reversed.

The optimum assembly acoustic test levels decrease as the number of missions decrease. For the eight-mission cases the decrease is either 2 or 4 dB, varying with the payload and test plan. For the single-mission cases the decrease is pronounced, varying from

14 to 20 dB. For Test Plans 4 and 8 the decrease is either 14 or 16 dB. For Test Plans 5 and 9 the decrease is either 18 or 20 dB. To achieve the optimums for Test Plans 4 and 8 the range of the assembly test level was changed from 143 to 157 dB to 129 to 143 dB. The data shown here for Test Plans 5 and 9 is also for the assembly test level range of 129 to 143 dB, but true optimums have not been verified for these test plans. It will be noted that for the single mission, the flight exposure duration is significantly less than the test duration (8 seconds compared to 120 seconds) which accounts for a large part of this change. From these data it can be seen that the number of missions has a significant effect on the optimum assembly test level.

A comparison of Tables 3-9 and 3-10 with Table 3-8 shows the effect of the number of missions on the vibroacoustic reliability ranks. For the eight-mission cases there are no rank changes for Payloads 1,2 and 7,2 and two rank changes for Payload 7,6. Test Plans 4 and 8 are reversed. For the single-mission cases there are two rank changes for Payload 1,2 and no rank changes for Payloads 7,2 and 7,6. Test Plans 5 and 9 are reversed.

3.4 COMPONENT VIBRATION FAILURE PROBABILITY VARIATION

Fundamental to the estimation of failure probabilities during ground testing and in flight is the vibration strength of untested components. The untested component strength distribution used in this study is based on the results of previous studies by Stahle, Reference 7. This is shown in Figure 3-43. This graph shows the proportion of components that pass vibration tests at various component test levels. The equation of the curve is

$$\log R = -0.004100 - 0.008805\ (\underline{g}) \qquad (3.4\text{-}1)$$

where R is the proportion of components that pass. For example, at a component test level of 10 g RMS, approximately 80% of the components pass the test. Equation (3.4-1)

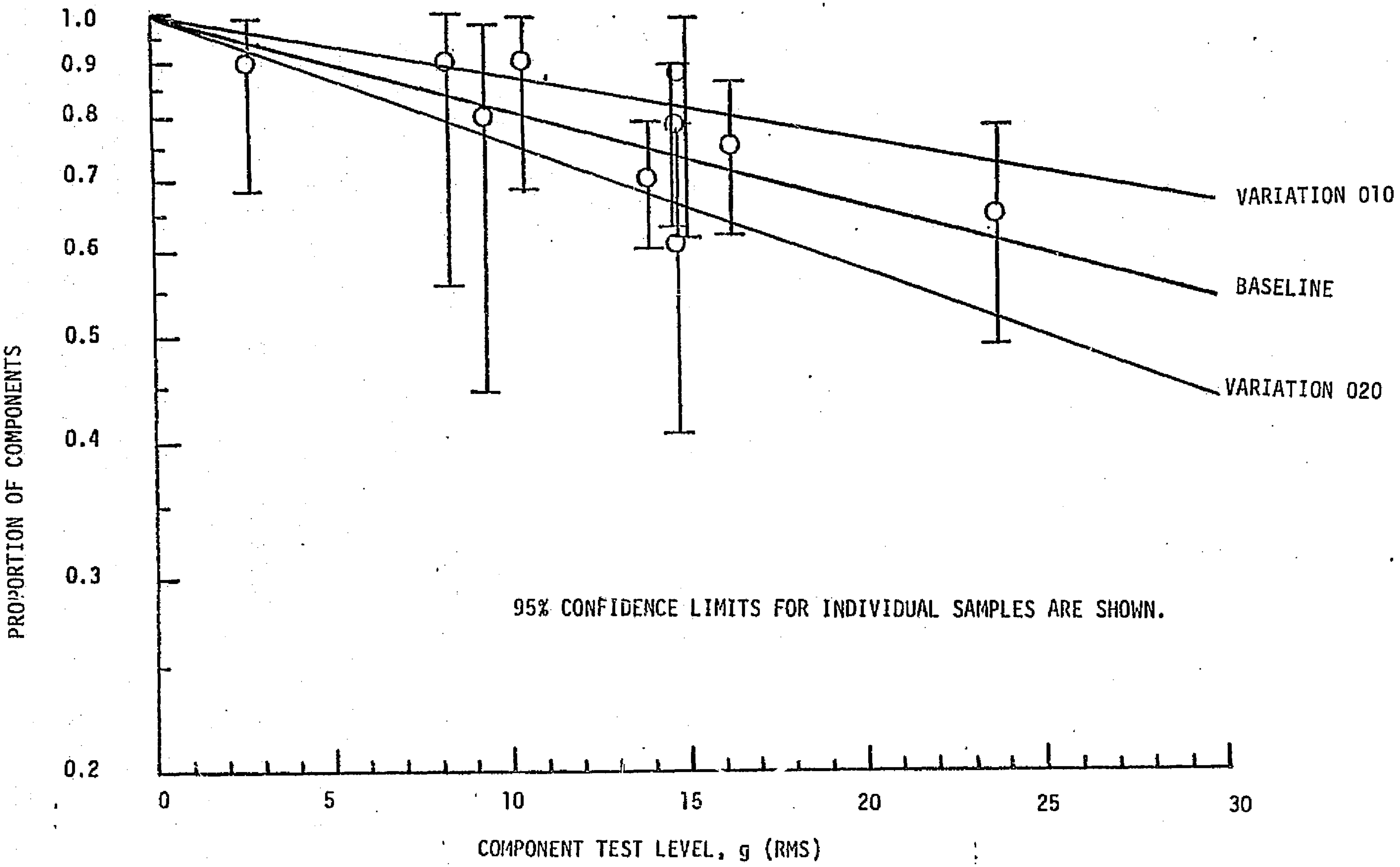


Figure 3-43 Proportion of Spacecraft Components that Pass Vibration Tests

can be written symbolically as

$$\log R = AY + DYDGQ\ (g) \tag{3.4-2}$$

Changes in the component strength can be obtained by varying the slope of this curve, DYDGQ.

For this study it was decided to examine the effects of the component vibration failure probability by considering ±20% failures at a component vibration test level of 25 g rms. On the baseline curve at 25 g rms 59.7% of the components pass the vibration test, i.e., R = 0.597. For 20% more components to pass the test, i.e., R = 1.2 * 0.597 = 0.716, the slope of the curve becomes -0.005638. For 20% less components to pass the test, i.e., R = 0.8 * 0.597 = 0.477, the slope of the curve becomes -0.012681. As a result the variations considered for this portion of the study are:

1. Baseline - DYDGQ = -0.008805
2. Vibration 1 - DYDGQ = -0.005638 (+20%)
3. Variation 2 - DYDGQ = -0.012681 (-20%)

These variations are also plotted in Figure 3-43.

The fifth digit of the six-digit case code identifies the component vibration failure rate. The case codes for the data of these variations are XXY010 and XXY020 for the 20% more and 20% less cases, respectively. The cost variation for the assembly test level at which the optimum cost occurs are shown in Figures 3-1 to 3-21. On the figures the symbols for these variations are + and X for the 20% more and 20% less cases, respectively. Summaries of the optimum data by payload are given in Tables 3-11 and 3-12.

Table 3-11

Summary of Optimums By Payloads
Variation 010
20% More Components Pass Test at 25 g rms

Payload	Test Plan	Expected Cost ($\$x10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	1.107	19.767	153	0.99886	1	1
	5	1.518	30.910	147	0.99701	3	3
	6	3.243	54.917	-	0.98682	6	7
	7	3.527	42.537	-	0.98839	7	6
	7B	2.490	42.537	-	0.98911	5	5
	8	1.512	15.311	153	0.99869	2	2
	9	2.008	25.521	147	0.99661	4	4
7,2	4	1.314	19.767	151	0.98742	1	1
	5	1.698	30.910	147	0.97948	2	3
	6	3.472	45.342	-	0.89798	6	7
	7	3.911	39.906	-	0.92101	7	5
	7B	2.873	37.437	-	0.91406	5	6
	8	1.859	14.364	151	0.98465	3	2
	9	2.354	23.942	147	0.97538	4	4
7,6	4	1.761	21.071	153	0.97745	1	1
	5	2.422	30.910	149	0.95879	2	3
	6	5.695	54.917	-	0.77668	6	7
	7	6.219	45.342	-	0.81762	7	6
	7B	5.164	45.342	-	0.81822	5	5
	8	2.661	16.321	153	0.97416	3	2
	9	3.479	25.521	149	0.95423	4	4

Table 3-12

Summary of Optimums By Payloads
Variation 020
20% Less Components Pass Test at 25 g rms

Payload	Test Plan	Expected Cost ($\$ \times 10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	1.202	21.071	153	0.99860	1	1
	5	1.758	32.948	149	0.99718	3	3
	6	4.337	54.917	-	0.97106	6	7
	7	4.713	35.121	-	0.97770	7	6
	7B	3.667	35.121	-	0.97841	5	5
	8	1.733	11.860	153	0.99823	2	2
	9	2.449	18.544	149	0.99641	4	4
7,2	4	1.438	19.767	151	0.98364	1	2
	5	2.002	32.948	147	0.97073	2	3
	6	4.666	54.917	-	0.83090	6	7
	7	5.302	32.948	-	0.85419	7	6
	7B	4.253	32.948	-	0.85482	5	5
	8	2.145	11.126	153	0.98733	3	1
	9	2.939	18.544	147	0.96183	4	4
7,6	4	1.996	22.461	153	0.97202	1	1
	5	2.933	32.948	149	0.94314	2	3
	6	8.686	58.539	-	0.59451	6	7
	7	9.199	39.906	-	0.70173	7	6
	7B	8.123	39.906	-	0.70224	5	5
	8	3.181	11.860	153	0.96373	3	2
	9	4.457	19.767	149	0.93136	4	4

A comparison of Tables 3-11 and 3-12 with Table 3-8 shows that the variations in the component vibration failure probability considered in this portion of the study have no effect on the cost ranks. For the three payloads studied the cost ranks are all the same as the cost ranks of the baseline.

The optimum expected costs are lower than the baseline costs when 20% more components pass the vibration test. The amount of the decrease varies with payload and test plan from $0.047M for Payload 1,2 with Test Plan 4 to $1.306M for Payload 7,6 with Test Plan 6. In all cases the smallest decrease for a test plan occurs for Payload 1,2, followed by Payload 7,2 and Payload 7,6, which has the largest decrease. For Payloads 1,2 and 7,2 the smallest decrease is obtained for Test Plan 4, followed by Test Plans 8, 5, 9, 6, 7B, and 7. For Payload 7,6 the smallest decrease is obtained for Test Plan 4, followed by Test Plans 5, 8, 9, 7B, 7, and 6, which has the largest decrease.

The optimum expected costs are higher than the baseline costs when 20% less components pass the vibration test. The amount of the increase varies with payload and test plan from $0.048M for Payload 1,2 with Test Plan 4 to $1.709M for Payload 7,6 with Test Plan 7. In all cases the smallest increase for a test plan occurs for Payload 1,2, followed by Payload 7,2 and Payload 7,6. For Payloads 1,2 and 7,2 the smallest increase is obtained for Test Plan 4, followed by Test Plans 8, 5, 9, 6, 7B, and 7. For Payload 7,6 the smallest increase is obtained for Test Plan 4, followed by Test Plans 5, 8, 9, 6, 7B, and 7.

The optimum component vibration test/design levels vary considerably when the component vibration failure probability is varied. When 20% more components pass the vibration test the levels decrease for Test Plan 4, 5, and 6 and increase for Test Plans 7, 7B, 8, and 9. When 20% less components pass the vibration test the levels increase for Test Plans 4, 5, and 6 and decrease for Test Plans 7, 7B, 8, and 9. When 20% more components pass, the biggest decrease is 9.575 g rms for Payload 7,2 with Test Plan 6 and the biggest increase is 4.450 g rms for Payload 1,2 with Test Plan 9. When 20% less components pass, the biggest decrease is 4.785 g rms for Payload 1,2 with Test Plans 7 and 7B and the biggest increase is 3.622 g rms for Payload 7,6 with Test Plan 6.

The optimum assembly acoustic test levels are not very sensitive to variations in the component vibration failure probability variation. When 20% more components pass the vibration test the optimum assembly acoustic test level changed for only one case; it dropped 2 dB for Payload 1,2 with Test Plan 9. When 20% less components pass the vibration test the optimum assembly acoustic level increased in two cases, for Payload 1,2 with Test Plan 5 and for Payload 7,2 with Test Plan 8.

A comparison of Tables 3-11 and 3-12 with Table 3-8 shows the little effect of variations in the component vibration failure probability on the vibroacoustic reliability ranks. When 20% more components pass the vibration test there are two rank changes for Payloads 1,2 and 7,2 and no rank changes for Payload 7,6. For Payload 1,2 Test Plans 5 and 9 are reversed. For Payload 7,2 Test Plans 7 and 7B are reversed. When 20% less components pass the vibration test there are two rank changes for Payloads 1,2 and 7,2 and no rank changes for Payload 7,6. For Payload 1,2 Test Plans 5 and 9 are reversed and for Payload 7,2 Test Plans 4 and 8 are reversed.

3.5 HOUSEKEEPING COMPONENT VARIATION

For the data presented in References 3 and 4, the housekeeping portion of the reliability model was fixed. It had four components in the power subassembly, four components in the control subassembly, and eight components in the data handling subassembly. These housekeeping components are common to all of the experiments, i.e., the failure of any housekeeping component causes the loss of all data from the experiments. Furthermore, all housekeeping components are redundant in the reliability model used in this study. The degree of redundancy was varied in Reference 4. For this study single redundancy is considered.

The effects on cost optimization caused by decreasing the capability of the housekeeping portion of the payload reliability model were examined. This was done in two ways. Components were removed from the control subassembly, assuming these capabilities would be provided by the shuttle. Components were removed from the data handling subassembly, but these capabilities were assimilated into the individual experiments. These two changes were made individually and then together. As a result, the variations considered for this portion of the study are:

	NCCPS	NCCCS	NCCDS	NCPE
1. Baseline	4	4	8	2 or 6
2. 1st Variation	4	4	4	6 or 10
3. 2nd Variation	4	0	8	2 or 6
4. 3rd Variation	4	0	4	6 or 10

The case codes for the data of these variations are XXY001, XXY002, and XXY003 for the first, second, and third groups of housekeeping components, respectively. The cost variations for the assembly test level at which the optimum cost occurs are shown in Figures 3-1 to 3-21. On the figures the symbols for these variations are

◇ , ↑, and X̄ for the first, second, and third groups of housekeeping components, respectively. Summaries of the optimum data by payload are given in Tables 3-13, 3-14, and 3-15 for the first, second, and third groups of housekeeping components, respectively.

A comparison of Tables 3-13, 3-14, and 3-15 with Table 3-8 shows that the variations in the number of components in the housekeeping subassemblies considered in this portion of the study have no effect on the cost ranks for Payloads 7,2 and 7,6. For Payload 1,2 there are four cost rank changes for the first group of housekeeping components, no rank changes for the second group, and two rank changes for the third group. For the first group Test Plans 5, 6, 7, and 8 are affected; for the third group, Test Plans 6 and 7. For the first group Test Plan 4 ranks first, followed by Test Plans 5, 8, 9, 7B, 7 and 6, which has the highest optimum cost. For the third group the cost ranks of Test Plans 6 and 7 are reversed.

The optimum expected costs are higher than the baseline costs when components are removed from the data handling subassembly and added to the experiments. Except for Payload 1,2 with Test Plan 9, this variation yielded the highest expected costs for this parameter study. The amount of the increase varies with payload and test plan from $0.170M for Payload 1,2 with Test Plan 9 to $2.793M for Payload 7,2 with Test Plan 6. In all cases the smallest increase for a test plan occurs for Payload 1,2, followed by Payload 7,6 and Payload 7,2, which has the largest increase. For Payloads 7,2 and 7,6 the smallest increase is obtained for Test Plan 4, followed by Test Plans 5, 8, 9, 7B, 7, and 6. For Payload 1,2 Test Plans 4 and 9 are reversed.

Table 3-13

Summary of Optimums By Payloads
Variation 001
NCCPS=4, NCCCS=4, NCCDS=4

Payload	Test Plan	Expected Cost ($\$x10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	1.386	27.204	155	0.99801	1	1
	5	1.843	35.121	151	0.99563	2	3
	6	5.783	62.399	-	0.95222	7	7
	7	5.249	54.917	-	0.97318	6	6
	7B	4.197	54.917	-	0.97389	5	5
	8	1.849	18.544	155	0.99771	3	2
	9	2.391	25.521	151	0.99514	4	4
7,2	4	1.823	22.461	153	0.97516	1	1
	5	2.535	32.948	149	0.95217	2	3
	6	6.793	58.539	-	0.70047	6	7
	7	7.129	45.342	-	0.78029	7	6
	7B	6.068	45.342	-	0.78086	5	5
	8	2.763	14.364	153	0.96952	3	2
	9	3.685	22.461	149	0.94297	4	4
7,6	4	2.283	22.461	153	0.95895	1	2
	5	3.281	32.948	149	0.92157	2	4
	6	9.656	58.539	-	0.55310	6	7
	7	9.948	45.342	-	0.66191	7	6
	7B	8.864	45.342	-	0.66239	5	5
	8	3.618	14.364	155	0.96962	3	1
	9	4.911	22.461	151	0.93957	4	3

Table 3-14

Summary of Optimums By Payloads
Variation 002
NCCPS=4, NCCCS=0, NCCDS=8

Payload	Test Plan	Expected Cost ($\$ \times 10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	1.073	21.071	153	0.99875	1	1
	5	1.508	32.948	149	0.99765	3	3
	6	3.519	54.917	-	0.98049	6	7
	7	3.697	42.537	-	0.98593	7	6
	7B	2.657	42.537	-	0.98664	5	5
	8	1.437	14.364	153	0.99852	2	2
	9	1.964	22.461	149	0.99718	4	4
7,2	4	1.298	21.071	153	0.99134	1	1
	5	1.724	32.948	147	0.97582	2	3
	6	3.809	54.917	-	0.88006	6	7
	7	4.205	39.906	-	0.90392	7	5
	7B	3.164	37.437	-	0.89555	5	6
	8	1.818	13.475	153	0.98934	3	2
	9	2.389	22.461	147	0.97044	4	4
7,6	4	1.794	22.461	153	0.97516	1	1
	5	2.535	32.948	149	0.95217	2	3
	6	6.793	58.539	-	0.70047	6	7
	7	7.129	45.342	-	0.78029	7	6
	7B	6.068	45.342	-	0.78086	5	5
	8	2.732	14.364	153	0.96952	3	2
	9	3.685	22.461	149	0.94297	4	4

Table 3-15

Summary of Optimums By Payloads
Variation 003
NCCPS=4, NCCCS=0, NCCDS=4

Payload	Test Plan	Expected Cost ($\$x10^6$)	Component Vibration Test/Design Level (g rms)	Assembly Acoustic Test Level (dB)	Associated Vibroacoustic Reliability	Cost Rank	Reliability Rank
1,2	4	1.285	30.910	155	0.99814	1	1
	5	1.675	37.437	153	0.99731	3	3
	6	5.507	66.514	-	0.95531	7	7
	7	4.745	58.539	-	0.97572	6	6
	7B	3.694	58.539	-	0.97643	5	5
	8	1.641	19.767	155	0.99779	2	2
	9	2.080	27.204	153	0.99708	4	4
7,2	4	1.739	23.942	153	0.97603	1	1
	5	2.394	32.948	149	0.95217	2	3
	6	6.578	58.539	-	0.70067	6	7
	7	6.753	45.342	-	0.78040	7	6
	7B	5.692	45.342	-	0.78097	5	5
	8	2.577	15.311	153	0.97065	3	2
	9	3.418	23.942	149	0.94575	4	4
7,6	4	2.199	23.942	153	0.96037	1	2
	5	3.126	32.948	151	0.94828	2	3
	6	9.442	58.539	-	0.55325	6	7
	7	9.573	45.342	-	0.66200	7	6
	7B	8.488	45.342	-	0.66249	5	5
	8	3.424	15.311	155	0.97065	3	1
	9	4.624	22.461	151	0.93957	4	4

The optimum expected costs are lower than the baseline costs when the control subassembly is removed from the housekeeping section. The amount of the decrease varies with payload and test plan from $0.076M for Payload 7,2 with Test Plan 4 to $0.361M for Payload 7,6 with Test Plan 7. In all cases the smallest decrease for a test plan occurs for Payload 7,2, followed by Payload 1,2 and Payload 7,6, which has the largest decrease. For all payloads the smallest decrease is obtained for Test Plan 4, followed by Test Plans 5, 8, 6, 9, 7B, and 7.

The optimum expected costs are higher than the baseline costs when components are removed from the data handling subassembly and added to the experiments and the control subassembly is removed from the housekeeping section, except for Payload 1,2 with Test Plan 9, which has a lower cost. The amount of the increase varies with payload and test plan from $0.022M for Payload 1,2 with Test Plan 8 to $2.578M for Payload 7,2 with Test Plan 6. In all cases the smallest increase for a test plan occurs for Payload 1,2, followed by Payload 7,6 and Payload 7,2, which has the largest increase. For Payloads 7,2 and 7,6 the smallest increase is obtained for Test Plan 4, followed by Test Plans 5, 8, 9, 7B, 7 and 6. For Payload 1,2 the smallest increase is obtained for Test Plan 8, followed by Test Plans 5, 4, 7B, 7, and 6.

The optimum component vibration test/design levels increase when components are removed from the housekeeping subassemblies. For each variation the largest increase occurs for Payload 1,2 with Test Plans 7 and 7B. When components are removed from the data handling subassembly and added to the experiments this increase is 15.011 g rms. When the control subassembly is removed from the housekeeping section this increase is 2.631 g rms. When the control subassembly is removed and components are removed from the data handling subassembly and added to the experiments this increase is 18.633 g rms. In 10 of the 63 cases there was no change in the component vibration test/design level when the number of components in the housekeeping subassemblies is varied.

The optimum assembly acoustic test levels increase when components were removed from the housekeeping subassemblies. The amount of the increase varies with payload and test plan. When components are removed from the data handling subassembly and added to the experiments, the acoustic level for Test Plans 8 and 9 increases by 2 dB. For all payloads. For Payloads 1,2 and 7,2 the increase for Test Plan 4 is 2 dB. For Test Plan 5 the increase in 4 dB for Payload 1,2 and 2 dB for Payload 7,2. There are no changes for Payload 7,6 with Test Plans 4 and 5. When the control subassembly is removed from the housekeeping section the increase is 2 dB for Payload 1,2 with Test Plan 5 and for Payload 7,2 with Test Plans 4 and 8. For the combined variation the increase is 2 dB for Payload 1,2 with Test Plans 4 and 8, for Payload 7,2 with Test Plans 4, 5, 8, and 9, and for Payload 7,6 with Test Plans 5, 8, and 9. For Payload 1,2 with Test Plan 9 and Test Plan 5 the increases are 4 and 6 dB, respectively.

A comparison of Tables 3-13, 3-14, and 3-15 with Table 3-8 shows a small effect of variations in the number of components in the housekeeping subassemblies on the vibro-acoustic reliability ranks. When components are removed from the data handling sub-assembly and added to the experiments there are two rank changes for Payload 1,2; Test Plans 5 and 9 are reversed. There are no changes for Payload 7,2. For Payload 7,6 there are four rank changes; Test Plans 4 and 8 and Test Plans 5 and 9 are reversed. When the control subassembly is removed from the housekeeping section there are two rank changes for Payloads 1,2 and 7,2 and none for Payload 7,6. For Payload 1,2 Test Plans 5 and 9 are reversed. For Payload 7,2 Test Plans 7 and 7B are reversed. When the combined variation is made there are two rank changes for Payloads 1,2 and 7,6 and none for Payload 7,2. For Payload 1,2 Test Plans 5 and 9 are reversed and for Payload 7,6 Test Plans 4 and 8 are reversed.

3.6 PARAMETER VARIATION OVERVIEW

Although the variation of key parameters has shown that the cost and vibroacoustic reliability ranks vary with the payload, test plan, and parameter variation, an overall assessment of the various test plans has been made to indicate the general trends. The cost ranks are summarized by payload in Table 3-16 and the vibroacoustic reliability ranks are summarized by payload in Table 3-17. In Table 3-16 only Test Plan 4 holds the same cost rank for all cases. In Table 3-17 only Test Plan 6 holds the same reliability rank for all cases.

The overall influence of the various parameters on the cost and reliability ranks is illustrated in Figure 3-44. This figure shows histograms of the ranks for each test plan. These histograms consider the ranks of the test plans for all 24 cases. The cost histograms show that, for the majority of the 24 cases, Test Plan 4 ranked first, Test Plan 5 ranked second, Test Plan 8 ranked third, Test Plan 9 ranked fourth, Test Plan 7B ranked fifth, Test Plan 6 ranked sixth, and Test Plan 7 ranked seventh. The vibroacoustic reliability histograms show that, for the majority of the 24 cases, Test Plan 4 ranked first, Test Plan 8 ranked second, Test Plan 5 ranked third, Test Plan 9 ranked fourth, Test Plan 7B ranked fifth, Test Plan 7 ranked sixth, and Test Plan 6 ranked seventh.

Table 3-16

Expected Cost Rank

Payload	Test Plan	Parameter Variation							
		000	100	200	010	020	001	002	003
1,2	4	1	1	1	1	1	1	1	1
	5	3	2	2	3	3	2	3	3
	6	6	6	3	6	6	7	6	7
	7	7	7	6	7	7	6	7	6
	7B	5	5	4	5	5	5	5	5
	8	2	3	5	2	2	3	2	2
	9	4	4	7	4	4	4	4	4
7,2	4	1	1	1	1	1	1	1	1
	5	2	2	2	2	2	2	2	2
	6	6	6	3	6	6	6	6	6
	7	7	7	5	7	7	7	7	7
	7B	5	5	4	5	5	5	5	5
	8	3	3	6	3	3	3	3	3
	9	4	4	7	4	4	4	4	4
7,6	4	1	1	1	1	1	1	1	1
	5	2	2	2	2	2	2	2	2
	6	6	6	3	6	6	6	6	6
	7	7	7	5	7	7	7	7	7
	7B	5	5	4	5	5	5	5	5
	8	3	3	6	3	3	3	3	3
	9	4	4	7	4	4	4	4	4

Table 3-17

Associated Vibroacoustic Reliability Rank

Payload	Test Plan	Parameter Variation							
		000	100	200	010	020	001	002	003
1,2	4	1	1	1	1	1	1	1	1
	5	4	4	3	3	3	3	3	3
	6	7	7	7	7	7	7	7	7
	7	6	6	6	6	6	6	6	6
	7B	5	5	5	5	5	5	5	5
	8	2	2	2	2	2	2	2	2
	9	3	3	4	4	4	4	4	4
7,2	4	1	1	1	1	2	1	1	1
	5	3	3	3	3	3	3	3	3
	6	7	7	7	7	7	7	7	7
	7	6	6	6	5	6	6	5	6
	7B	5	5	5	6	5	5	6	5
	8	2	2	2	2	1	2	2	2
	9	4	4	4	4	4	4	4	4
7,6	4	1	2	1	1	1	2	1	2
	5	3	3	3	3	3	4	3	3
	6	7	7	7	7	7	7	7	7
	7	6	6	6	6	6	6	6	6
	7B	5	5	5	5	5	5	5	5
	8	2	1	2	2	2	1	2	1
	9	4	4	4	4	4	3	4	4

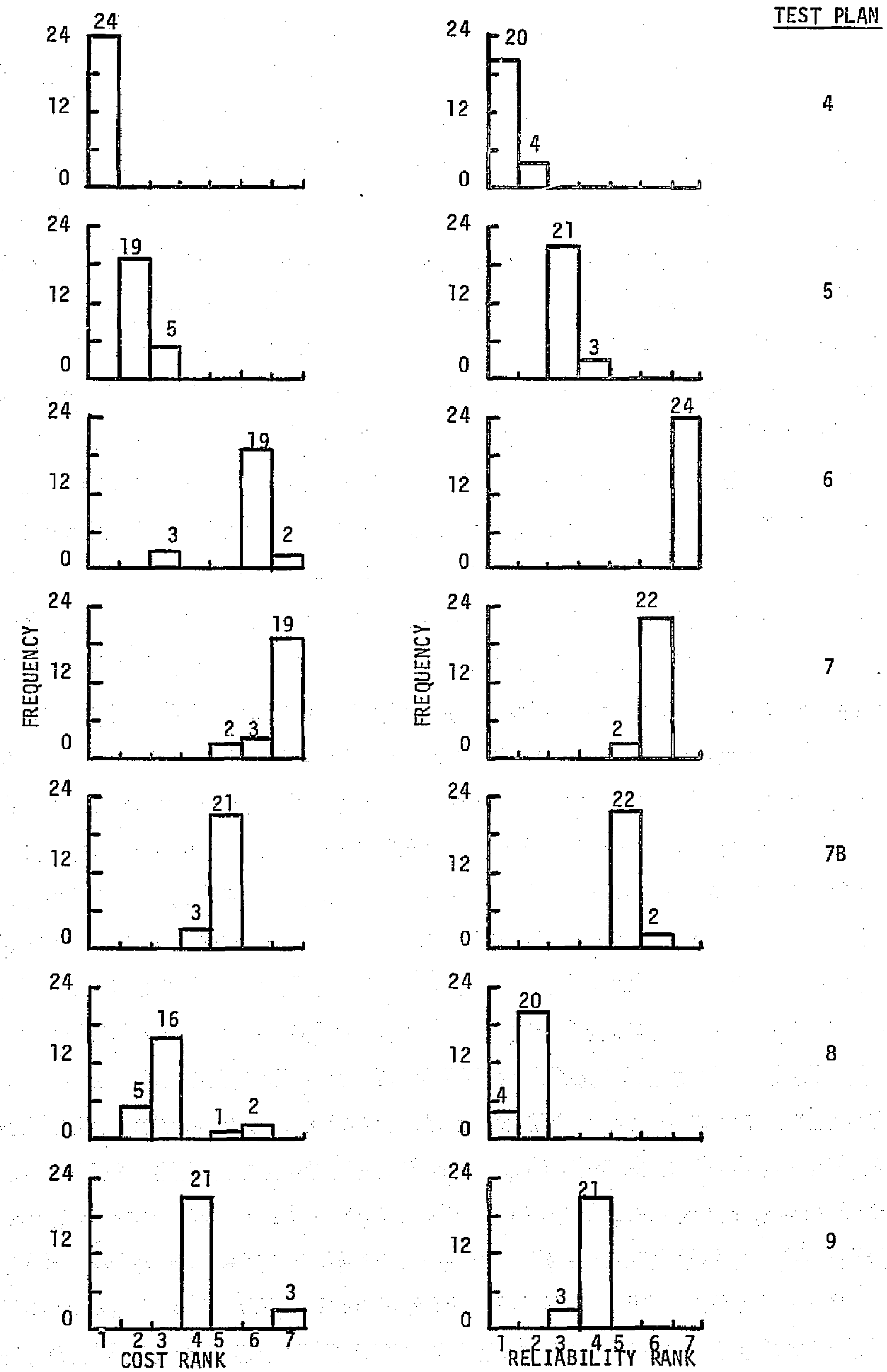


Figure 3-44 Cost Rank and Vibroacoustic Reliability Rank Histograms

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Based on the results of this study of free flyer payloads whose configurations were representative of Landsat-D or Solar Max Mission payloads, the following conclusions are made:

1. Statistical decision models have been developed to evaluate alternate vibroacoustic test plans for STS launched free flyer payloads. The models are based on operational strategies that enable the payload to be flown, returned or replaced depending on its condition prior to release from the STS. The strategies consider the types of failures encountered, the number of experiment failures, and either a geosynchronous or near earth orbit. Using these strategies in conjunction with the estimated direct and probabilistic costs, the minimum expected program cost with the associated test levels and failure probabilities are determined for alternate vibroacoustic test plans. The decision models, developed from the previous sortie studies, consider protoflight test hardware for each of seven alternate test plans using no tests or combinations of component, subassembly and system testing.

2. For geosynchronous orbits, the results for both payloads are similar to those obtained for sortie payloads with regard to both cost and associated flight reliability. For the single set of cost parameters the cost and reliability rank of the alternate test plans (TP) are:

	Cost Rank	Reliability Rank
TP4 Subassembly Only	1	1
TP5 System Only	2	3
TP8 Component and Subassembly	3	2
TP9 Component and System	4	4
TP7B Component and Structure	5	5
TP7 Component Only	6	6
TP6 No Testing	7	7

   The expected costs vary by approximately $4M from the least costly to the most costly test plan. The component design/test vibration levels and assembly acoustic test levels associated with the optimum test point are significantly higher than single mission sortie payloads.

3. For near earth orbits, the results vary slightly for each of the two payloads and differ from previous results for multi-mission sortie payloads with regard to cost rank. For the single set of cost parameters the cost and reliability rank of the alternate test plans are:

	Cost Rank	Reliability Rank
TP4 Subassembly Only	1	1-2
TP5 System Only	2	3
TP8 Component & Subassembly	3-4	1-2
TP6 No Testing	3-4	7
TP7B Component & Structure	5	5
TP7 Component Only	6	6
TP9 Component and System	7	4

The reliability rank is similar to that of the geosynchronous and sortie payloads. The cost variation is significantly less than for the geosynchronous payload differing by approximately $1M between Test Plan 4 and Test Plan 9. The test/design vibration and acoustic levels are slightly higher than those of single mission sortie payloads. Although the no-test option ranks relatively high, the design requirements are high and the cost model for high design requirements may not be realistic.

4. Because only two payload configurations were investigated using only a single set of preliminary cost estimates, the results should not be generalized.

Based on the results of the sortie payload parametric variations investigating the effects of the number of missions, the component failure probability,and the number of housekeeping components, the following conclusions are made:

1. The number of missions (examined by evaluating three payloads for 1, 8 or 15 missions) has a major effect on the test plan evaluation with regard to cost rank, reliability and design/test levels. The cost and reliability rank trends are indicated below for the more complex payloads:

	Single Mission Cost Rank	Single Mission Rel. Rank	8 Mission Cost Rank	8 Mission Rel. Rank	15 Mission Cost Rank	15 Mission Rel. Rank
TP4 Subassembly Only	1	1	1	1	1	1
TP5 System Only	2	3	2	3	2	3
TP6 No Testing	3	7	6	7	6	7
TP7B Component & Struct.	4	5	5	5	5	5
TP7 Component	5	6	7	6	7	6
TP8 Subassembly & Comp.	6	2	3	2	3	2
TP9 System & Comp.	7	4	4	4	4	4

The major change in cost rank for the single mission payload occurs for the no-test option(raised from sixth to third) and the Component & Subassembly Test option (lowered from third to sixth). The reliability rank is not changed significantly. However, ruggedized component designs are required (20 to 25 g rms) with the no-test option. Major reductions in the component design/test levels and the expected costs are shown as the number of missions is reduced. However, Subassembly Testing (TP4) and System Testing (TP5) are the minimum cost vibroacoustic test plans regardless of the number of missions.

3. The effect of component failure probability (investigated by varying the proportion of component failures at a given vibration level by ± 20 percent) has no significant effect on the cost ranking of the alternate test plans, and a small effect on reliability, but does affect cost and component design/test levels. While the optimum cost with subassembly testing varies only \$0.1M, the no-test optimum cost varies by \$6M. Although the optimum assembly acoustic test levels are not changed, the component design/test levels vary by as much as 40 percent depending on the test plan.

4. For the multimission payloads, the effects of removing components from the housekeeping section and placing them in the experiments or deleting them from the payload indicate that these changes do not significantly affect the cost ranking of the alternate test plans. Subassembly acoustic testing provides the minimum cost for all payload configurations. Although the four test plans providing the highest reliability do not change as a group, the reliability ranking for component and assembly testing tends to be raised within the group when the number of components in the experiments is increased. Adding components to the experiments increases the optimum expected costs and the associated component design/test levels and assembly acoustic test levels. Deleting components reduces the expected test plan cost.

4.2 RECOMMENDATIONS

The following specific recommendations are made:

1. The decision models should be applied to a variety of planned shuttle payloads to determine the optimum vibroacoustic test plan and guide their development. Major emphasis should be placed on minimizing cost. By quantitatively evaluating the cost effectiveness of alternate vibroacoustic test plans early in the conceptual design phase, requirements can be established for specific payloads which result in reduced development costs.

2. The evaluation of the alternate vibroacoustic test plans for free flyers and payloads using expendible launch vehicles should be investigated. Because major changes to current practices are planned for shuttle payloads, these types of payloads have been examined. However, the methodology is also applicable to current payloads. Potential cost savings for these payloads should be examined considering the higher failure costs due to vibroacoustic induced failures.

3. The current reliability model requires that each experiment has the same number of components. To provide greater flexibility in studying a variety of payloads consideration should be given to modifying the computer code to include variations in the number of components in each experiment.

4. Parameter variations should be made to evaluate their effects on test plan selection and the associated test levels for free flyer payloads. Parameters that should be examined include the acoustic environment and the probability of not being able to return a free flyer due to STS limitations. This last parameter has been included in the OCTAVE code but not exercised.

5. As we reach the shuttle era, plans should be made to obtain data to correlate with the results of this study and improve the decision model. A key feature for sortie payloads is the capability to return the payload and subject it to detailed evaluation when a malfunction occurs. As a result, vibration induced failures will be clearly defined and the necessary data to assess the adequacy of design and test practices will be available. By establishing a basic plan for acquiring data from all STS payloads in the proper format, "lessons learned" can be disseminated throughout the STS user community.

6. In using the results of this study or the OCTAVE computer code, it is imperative that the modeling simplifications be understood and considered in interpreting the results. The modeling is described in detail in the previous study reports and in this report. Model changes which more accurately represent a particular project should be considered when significant differences are found.

7. In view of the success of the application of statistical decision theory to vibroacoustic test plan evaluation, extensions of the methodology to thermal-vacuum and other test environments should be considered. Thermal-vacuum testing, in particular, has been an effective test screen and is also a major source of flight failures. It is recommended that a feasibility study be performed to determine the critical thermal parameters involved and the related methodology, drawing heavily on the existing decision modeling techniques.

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SORTIE PAYLOAD PARAMETER STUDY

6-DIGIT CASE CODE

1st & 2nd DIGIT - TEST PLAN ID

40 = TP-4, Test Plan 4
50 = TP-5, Test Plan 5
60 = TP-6, Test Plan 6
70 = TP-7, Test Plan 7
7B = TP-7B, Test Plan 7B
80 = TP-8, Test Plan 8
90 = TP-9, Test Plan 9

3rd DIGIT - PAYLOAD ID

1 = 1,2, Payload 1,2
2 = 7,2, Payload 7,2
3 = 7,6, Payload 7,6

4th DIGIT - NUMBER OF MISSIONS ID

0 = Baseline - NF = 15
1 = 1st Variation - NF = 8
2 = 2nd Variation - NF = 1

5th DIGIT - COMPONENT VIBRATION FAILURE RATE ID

0 = Baseline -
1 = 1st Variation - Reduced Failure Probability
2 = 2nd Variation - Increased Failure Probability

6th DIGIT - NUMBER OF COMPONENTS IN HOUSEKEEPING SUBASSEMBLIES ID

	Power NCCPS	Control NCCCS	Data Handling NCCDS	Experiment NCPE
0 = Baseline -	4	4	8	2 or 6
1 = 1st Variation -	4	4	4	6 or 10
2 = 2nd Variation -	4	0	8	2 or 6
3 = 3rd Variation -	4	0	4	6 or 10

NOTE: 3-DIGIT CASE CODE IS LAST FOUR DIGITS OF 6-DIGIT CASE CODE