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Statistical Analysis of Microgravity Experiment Performance Using the "Degrees of Success" Scale

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Abstract

This paper describes an approach to identify factors that significantly influence microgravity experiment performance. Investigators developed the "Degrees of Success" scale to provide a numerical representation of success. A degree of success was assigned to 293 microgravity experiments. Experiment information including the degree of success rankings and factors for analysis was compiled into a database. Through an analysis of variance, nine significant factors in microgravity experiment performance were identified. The frequencies of these factors are presented along with the average degree of success at each level. A preliminary discussion of the relationship between the significant factors and the degree of success is presented.

Introduction

Shuttle-based microgravity experiment performance is an important consideration given the time, effort, and cost involved in space research. The reliability of these experiments is currently determined at the micro (component) level. The reliability of these components are determined either by testing, historical performance data or by vendor data, which may include both testing data and performance data. These reliability measures are then used to calculate a system reliability using well documented mathematical probability models. The risk to mission success is then based on the value of the system reliability. This process overlooks the external effects on the system reliability with exception to component derating. This study is an investigation into those external effects; an approach to the system (experiment) reliability from a macro-level.[1]

Several studies have addressed microgravity experiment performance. In a 1986 study of 117 active Get Away Special (GAS) experiments, Rex Ridenoure found that 40 percent of these experiments obtained all of the desired data.[2] In another study, Cheryl Winter and Jonathan Jones found that 64 percent of the 100 experiments examined from their fluids and materials processing database obtained at least 75 percent of the desired data.[3] Having both presented a significant number of experiments with anomalies, these studies show that an effort to enhance the performance of microgravity experiments is worthwhile.

These two studies have identified types of experiment failures and quantified the percentage of experiment objectives affected. However, there is a need to identify the factors that significantly influence experiment performance, as discussed by Thaggard and Morilak.[4] To satisfy this need requires three main actions: (1) define successful performance, (2) select factors for analysis, and (3) compile information for analysis. Investigators for this project have created a numerical

*NASA Resident Research Associate at Lewis Research Center representation of successful experiment performance, the "Degrees of Success" scale and selected 26 factors from a list compiled by Thaggard and Morilak in 1991. Also, investigators have compiled a database of 391 experiments, the Lewis Research Center Microgravity Database (LMDB). Since these actions have been taken, it is possible to determine the significance of factors that influence experiment success. Principal investigators (PIs) may use the results of the data analysis presented in this report during preflight development to enhance experiment performance.

In addition to the results of data analysis, this report describes the Degrees of Success scale and the methodology used to develop the LMDB. In preview of the LMDB description, this project excludes the following four categories of experiments: (1) experiments flown prior to 1981 or after 1991, (2) GAS experiments, (3) experiments flown on the Long Duration Exposure Facility (LDEF), and (4) student experiments. Because experiment results were frequently unavailable, only 293 of the 391 LMDB experiments are included in the present evaluation. Criteria for exclusion are explained in a later section of this paper.

Methodology

Select Performance Factors

As the first major requirement of this research, Thaggard and Morilak compiled a list of 32 factors that could influence microgravity experiment performance. Table I shows an alphabetical listing of the 26 factors that are included in this analysis. Factor definitions are in Appendix B. Modifications to the original list of factors were made through the course of this study as investigators found that data was unavailable for these factors, and that some factors were redundant.

Modifications to the list of factors include the addition of one category, type of orbital crew involvement, and the elimination of six categories, set-up time, upweight, downweight, experiment duration, hardware, and apparatus. Also, two categories were combined, storage container and storage location into a new category, storage location. This new category is a more detailed description of storage location than the original definition. Also, changes to the factor levels were made.

Table I Performance Influencing Factors

Experiment Specific Factors:

- Active (Yes/No)
- Altitude Requested
- Experiment Location
- Experiment Type
- Failure Detection
- Inclination Requested
- Interface
- Iteration
- Level of Ground Crew Involvement
- Level of Orbital Crew Involvement
- Minimum Time On-orbit
- Number of Lockers
- Organization
- Storage Location
- Type of Orbital Crew Involvement

Mission Specific Factors:

- Crew Size
- Flight Altitude
- Flight Duration
- Flight Inclination
- Launch Delay Cause
- Launch Delay Duration
- Number of Experiments On-board
- Orbiter
- Orbiter Pad Weather
- Time Between Previous Flight
- Wait Time on Pad

As previously stated, the main reason that some factors have been eliminated is because the required information could not be found in the available documents. For instance, data for set-up time, the time taken to unstore the experiment and initiate operation, was not available for any of the LMDB experiments.

Two other factors that were eliminated are upweight and downweight. These factors represent experiment weight during launch and landing respectively. These categories were eliminated for three reasons: (1) weights could not be found for nearly 60 percent of the experiments, (2) a strong correlation was found between experiment weight and experiment location, thus experiment weight duplicates information specified in experiment location, and (3) no variation was found between upweight and downweight.

The remaining factors, experiment duration, hardware, and apparatus, were eliminated for the following reasons: (1) nearly 80 percent of the experiments were missing experiment duration data, (2) hardware and apparatus did not provide any useful information for this study as defined in the original list of factors. None of the six factors that have been eliminated could be used in analysis.

Compile Database

Establish criteria

After the list of factors was developed, the next step was to compile the LMDB. Because of the massive amounts of information that has been published on microgravity experiments to date, it was necessary to establish guidelines. As previously mentioned, four categories of experiments were not included in the database. The reasons these categories were not included are as follows: (1) based on the first Space Shuttle mission being in 1981 and a chosen 1991 cutoff date based on availability of microgravity experiment data, the 1981-1991 time window was established, (2) GAS experiments were thoroughly reviewed by Rex Ridenoure in 1986, and (3) LDEF and student experiments were not included because they are too unique for their analysis to have broad-based applications.[4]

LMDB Development

Having established criteria for LMDB experiments, the LMDB was developed and includes 52 fields and 391 experiments. The main sources for experiment information were NASA RECON, ARINC, and the AMPTS database maintained at NASA JSC. By the end of 1992, there were approximately 370 experiments in the database.[4] Since then, 30 experiments have been added. The source of most of these additional experiments was the MSAMS database compiled by Winters and Jones at NASA MSFC which is now available through a computational network.[3]

Missing Data Status

Most records in the LMDB are complete in general experiment information such as experiment objectives. Similarly, mission specific information such as flight altitude, flight inclination, and crew size are readily available. However, experiment specific information such as weight, duration, and the prelaunch specifications, minimum time on-orbit, requested altitude, and requested inclination, has proven difficult to obtain. Therefore, there is a high percentage of missing data in these experiment specific areas. In addition to missing a high percentage of some experiment specific information, results were missing for around 100 experiments. Most of the PIs contacted to find this information indicated that these results had not been published. Based upon the ability to obtain the necessary results to assign a degree of success, the present analysis includes 293 experiments.

The Degrees of Success Scale

Background

The last requirement in this research was to define successful performance. Rex Ridenoure defined success of an experiment as achieving all of the objectives, and failure as achieving none or only part of the objectives.[2] In the study conducted by Cheryl Winter and Jonathan Jones, success was defined in four basic ways: (1) just being able to fly an experiment aboard the Space Shuttle, (2) no anomalies, (3) meeting the objectives, and (4) advancing the materials science field.[3] The measure of successful performance in this project, the Degrees of Success scale, incorporates many aspects from these earlier studies; however, it is numerical, rather than categorical.

Development

The Degrees of Success scale is based on the following criteria: (1) objectives, (2) results, (3) problems encountered and (4) the minimum success requirement, achieving at least one objective (Figure 1). Based on these criteria, an experiment that achieved the full objective without any problems would

Figure 1 Degrees of Success Scale

WORST BEST

1,2	3	4	5	6,7	8	9	10
Test not attempted.	Full Obj. not achieved. Min. Success Requirements not achieved.	Full Obj. not achieved. Min. Success Requirements not achieved. Some data.	Full Obj. not achieved. Min. Success Requirements obtained. Problems encountered. (Related to design.)	Full Obj. not achieved. More than Min. Success Requirements obtained. Problems encountered. (Not Related to design.)	Full Obj. achieved. Problems encountered.	Full Obj. achieved. No problems.	Full Obj. achieved. No problems. Additional results.

receive a "9". Similarly, an experiment that achieved the full objective without any problems, and also obtained data beyond the full objective would receive a "10". On the other hand, an experiment that was not attempted at all would receive a "1" or "2" depending on whether problems were related to design. An experiment would receive "1" for a design problem. For mid-range values of the Degrees of Success scale, the type of problem encountered is also taken into account where experiments encountering a problem unrelated to design or development receive a higher rating. Despite the subjective nature of the degree of success scale, this numerical definition of success offers opportunities for statistical analysis which non-continuous, categorical definitions cannot provide.

Data Analysis

As previously mentioned, 293 of the 391 LMDB experiments were assigned a degree of success and used in the data analysis. For each of the 26 factors that were selected, the frequency of their levels in the 293 experiments was identified. Also, an Analysis of Variance (ANOVA) was conducted to determine the significance of the factors that influence experiment success using SPSS PC+, version 5.0.

The frequency of each degree of success ranking is shown in Table II. Approximately 44 percent of the experiments are ranked 9, and 22 percent are ranked 8. Including the experiments ranked 10, around 70 percent of the experiments achieved their full objectives. On the other hand, around 8 percent of the experiments did not meet their minimum success requirements.

Table II Frequency of Degree of Success Rankings

Rank	Frequency	Percent
1	1	0.3
2	1	0.3
3	5	1.7
4	16	5.5
5	24	8.2
6	18	6.1
7	27	9.2
8	63	21.5
9	128	43.7
10	10	3.4

The ANOVA produced the following results. Four factors, failure detection, active, altitude requested and experiment type, are significant at the 0.01 level (99 percent confidence level). Moreover, level of ground crew involvement, minimum time on-orbit and storage location are significant at the 0.05 level, and level of orbital crew involvement and orbiter pad weather are significant at the 0.1 level. The results of the ANOVA for each factor are shown in Appendix A.

Discussion

For the nine factors which significantly influence experiment performance, the frequencies of their levels are identified along with the average degree of success at each level. This data is presented in Tables III-XI.

Table III shows the frequency counts and average degree of success for each level of the failure detection. The main purpose of the failure detection factor is to determine whether detecting a problem on-orbit rather than post-flight will influence the performance of an experiment. The more problems encountered by an experiment, the lower the average degree of success. In addition to the influence of the frequency of problems, there was a slight difference between the degree of success ranking of experiments with problems detected on-orbit and those with problems detected post-flight.

As shown in Table IV, of the 293 experiments assigned a degree of success, 34 were passive (required no crew involvement) and 259 were active (automated or required crew involvement). Passive experiments received a higher average degree of success than the active experiments.
The frequency of the different types of LMDB experiments along with the average degree of success for that type of experiment are given in Table VI. The experiments with the highest average degree of success are Environments and Biological experiments while the experiments with the lowest average degree of success are Metals/Alloys and Crystal Growth.

Table X shows the frequency and average degree of success of the storage location levels. Experiments stored on the spacelab pallet and self-contained experiments had a high average degree of success.

Table XI shows the frequency of the levels of launch pad weather and their average degree of success. The results indicate that the average degree of success increases along with increases in temperature.

Table III Frequency and Average Degree of Success for Failure Detection

Level	Frequency	Average Degree of Success
Problem Detected On-orbit	66	6.5
Problem Detected Post-flight	62	6.6
Problems Detected On-orbit and Post-flight	8	5.6
No Problems Reported	138	9.0
Missing	19	6.4

Table IV Frequency and Average Degree of Success for Active

Level	Frequency	Average Degree of Success
Passive	34	8.5
Active	259	7.6

Table V Frequency and Average Degree of Success for Altitude Requested

Level	Frequency	Average Degree of Success
130 km	5	8.4
135	47	7.2
137	6	5.8
150	3	7.3
160	13	8.7
175	67	7.7
186	15	8.2
190	27	8.3
200	1	9.0
250	4	9.3
Missing	105	7.6

Table VI Frequency and Average Degree of Success for Experiment Type

Level	Frequency	Average Degree of Success
Hardware/Instruments	16	7.3
Metals/Alloys	44	6.9
Biological	69	8.2
Fluids & Chemicals	37	7.6
Environments	13	8.5
Crystal Growth/Crystallography	33	7.2
Astronomy	17	7.9
Photography	11	7.9
Radiation	13	8.0
Orbiter	40	7.7

Table VII Frequency and Average Degree of Success for Level of Orbital Crew Involvement

Level	Frequency	Average Degree of Success
No Involvement	85	7.7
Casual Involvement	51	7.3
Considerable Involvement	24	7.5
Extensive Involvement	76	8.0
Missing	57	7.7

Table VIII Frequency and Average Degree of Success for Level of Ground Crew Involvement

Level	Frequency	Average Degree of Success
No Involvement	173	7.7
Casual Involvement	36	8.1
Considerable Involvement	20	6.6
Extensive Involvement	9	8.2
Missing	55	7.7

Table IX Frequency and Average Degree of Success for Minimum Time On-Orbit

Level	Frequency	Average Degree of Success
One day	3	8.7
Two	6	5.8
Four	1	5.0
Five	2	8.0
Six	7	8.5
Seven	79	7.8
Eight	42	8.2
Nine	53	7.4
Missing	100	7.6

Table X Frequency and Average Degree of Success for Storage Location

Level	Frequency	Average Degree of Success
Locker	73	7.4
Rack	45	7.2
Pallet	5	8.4
Self-Contained	58	8.1
Other	17	7.6
Not Applicable	11	8.3
Missing	84	7.8

Table XI Frequency and Average Degree of Success for Pad Weather

Level	Frequency	Average Degree of Success
11 °C - 15 °C	11	6.18
16 °C - 20 °C	9	7.2
21 °C - 25 °C	142	7.6
26 °C - 30 °C	129	7.95
> 30 °C	1	9
Missing	1	8

Conclusions

This study presents an approach to identify factors that significantly influence experiment performance. Investigators developed a Degree of Success scale to provide a numerical representation of success. Subsequently, a degree of success was assigned to 293 microgravity flight experiments. A microgravity flight experiment database (the LMDB) was compiled which included 26 factors for analysis. Of these factors, nine significant factors in experiment performance were identified using an analysis of variance. The frequencies of the levels of the significant factors were compared with the average degree of success at that level.

This study has used the Degrees of Success scale to successfully identify significant performance influencing factors. The future plan for this study is to extend the results of the present data analysis by providing an optimal level for each factor and a predictor model of experiment performance. This information will enhance the design and development of future microgravity flight experiments.

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Appendix A
ANOVA for Each Factor

Factor	Levels	Significance Level	Number of Experiments Used
Failure Detection	4	0.0001	274
Active	2	0.003	293
Altitude Requested	10	0.008	188
Experiment Type	10	0.01	293
Level of Ground Crew Involvement	4	0.018	238
Minimum Time On-Orbit	8	0.025	193
Storage Location	6	0.044	209
Level of Orbital Crew Involvement	4	0.091	236
Orbiter Pad Weather	5	0.094	292
Launch Delay Cause	4	0.232	288
Orbiter	5	0.255	293
Wait Time on Pad	20	0.261	282
Launch Delay Duration	4	0.312	288
Flight Altitude	22	0.362	292
Interface	9	0.407	258
Time Between Previous Flight	29	0.413	292
Flight Duration	9	0.440	293
No. of Experiments On-Board	18	0.470	291
No. of Lockers	8	0.597	74
Type of Orbital Crew Involvement	29	0.677	228
Experiment Location	11	0.833	289
Inclination Requested	6	0.868	183
Flight Inclination	7	0.880	292
Iteration	9	0.907	285
Organization	6	0.946	289
Crew Size	6	0.959	293

Appendix B
Factor Definitions

1. **Active (Yes/No):** requires crew involvement or is automated

2. **Altitude Requested:** altitude requested by principal investigator for optimal experiment performance

3. **Experiment Location:** where the experiments are located during operation on the orbiter

4. **Experiment Type:** type of experiment (ex. hardware/instruments, biological)

5. **Failure Detection:** where problem was detected (on-orbit or post-flight)

6. **Inclination Requested:** inclination requested by principal investigator for optimal performance

7. **Interface:** service provided by the orbiter which the experiment incorporates into its design

8. **Iteration:** number of times the experiment has been executed on the orbit

9. **Level of Ground Crew Inv.:** an estimate of the number of hours an orbital crew member works with an experiment divided by the experiment's total time of operation

10. **Level of Orbital Crew Inv.:** an estimate of the number of hours a ground crew member can influence experiment operation divided by the experiment's total time of operation

11. **Minimum Time On-orbit:** the time the principal investigator felt was needed to run an experiment

12. **Number of Lockers:** number of lockers occupied by the experiment during operation

13. **Organization:** group which developed experiment

14. **Storage Location:** where the experiment was stored on-orbit prior to operation

15. **Type of Orbital Crew Involvement:** lists specific activities required for experiment operation

16. **Crew Size:** number of crew members for a particular mission

17. **Flight Altitude:** altitude for a particular mission

18. **Flight Duration:** duration of a particular mission

19. **Flight Inclination:** inclination for a particular mission

20. **Launch Delay Cause:** examples: weather, orbiter

*21

22. **Number of Experiments On-board:** number of experiments for a particular mission

*23

24. **Orbiter Pad Weather:** weather at time of launch

25. **Time Between Previous Flight:** time between previous shuttle mission

26. **Wait Time on Pad:** includes loading time and delays

*21,23: Launch Delay Duration, Orbiter (self-explanatory)

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