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A SYSTEMS-LEVEL PERFORMANCE HISTORY OF GET AWAY SPECIALS AFTER 25 SPACE SHUTTLE MISSIONS

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This paper summarizes the results of a thorough performance study of Get Away Special (GAS) payloads that was conducted in 1986. During the study, a complete list of standard and non-standard GAS payloads vs. Shuttle mission was constructed, including specific titles for the experiments in each canister. A broad data base for each canister and each experiment was then compiled. Performance results were then obtained for all but a few experiments. The canisters and experiments were subsequently categorized according to the degree of experiment success. For those experiments that experienced failures or anomalies, several correlations and generalizations were extracted from individual subsystem performance data. Recommendations are made which may enhance the success and performance of future GAS payloads.

INTRODUCTION

This report summarizes the results of general systems-level performance review the GAS payloads launched to date. The study was started in early 1986 (February) and continued for six months on a part time basis. Initially, the author was merely constructing a complete list of GAS experiments for each Shuttle mission, since one did not exist anywhere else. This list was to be used by student GAS experimenters at Utah State University as a mechanism for understanding what others were doing in the field as well as a tool for stimulating thought relevant to their own experiments.

However, soon after the search for input data began, it became apparent that many GAS experiments experienced severe troubles during their mission. Some GAS canisters didn't turn on, others turned on at the wrong time, and numerous individual experiments inside the cans came back to earth with little or no meaningful data. The author decided to complete the GAS payloads list and then study the array of failures and problems that many encountered. Such analysis would augment the basic GAS payloads list with performance summaries and would also provide an opportunity to step back during the break in Shuttle activity and reflect on the GAS performance record after the first 25 Shuttle missions. Some of these results are surprising and somewhat alarming!

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THE GAS CANISTER MANIFEST HISTORY

Prior to conducting a systematic study of GAS experiment results, a complete list of launched GAS canisters was required. At the start of this study, 25 Shuttle missions had been launched, including the ill-fated last one, STS 51-L. Unfortunately, this number will remain 25 for at least until early 1988.

A complete list of all standard NASA GSFC GAS canisters launched to date was available from Mariann Albjerg at NASA JSC. These canisters are tracked by the reservation number, such as G-001. Over 600 reservations have been received by NASA for canisters of this type; 50 have been launched, plus three relaunches (or reflights), making a total of 53. Note, however, that several other varieties of GAS can have been launched as well: the West Germans have their own version, GSFC has several versions, and some canisters were adapted for special applications that are worth mentioning. The total number of "nonstandard" GAS cans launched is 24, making the total of all cans 77. (Identifying these canisters and their experiments required two months of inquiry and detective work!)

For this study, any canister with the same fundamental cylindrical volume of a standard NASA GSFC GAS can was included for analysis, even though such canisters are nonstandard and thus not "official" GAS cans. All cans were included because most of the integration problems encountered with standard GAS cans are encountered with the nonstandard cans as well.

To enhance the visibility of canister variety, a nomenclature was utilized that identifies the canister by type. For this paper, a detailed discussion of each type is not required; the table below is included, however, to summarize the number distribution of each type.

GAS CODE	GAS TYPE	STANDARD GSFC GAS	NONSTANDARD GAS
G-NNN	Standard GSFC GAS	50	
G-NNNR	Standard GSFC GAS Reflight	3	
DG-NNN	West German GAS (MAUS)		17
G-AAA	Special GSFC Test GAS		2
HHG-N	GSFC Hitchhiker GAS		2
G-XXX	Unassigned GAS (Postal Covers)		8
NAVEX-N	West German NAVEX Pallet GAS		3
C-360	Cinema 360, Inc. camera carrier		2
	TOTALS	53 +	34 = 77

Notes: 1) NNN = a number
2) AAA = an acronym
3) The first five types above employ NASA nomenclature; the last three are the author's own convention.

The 8 postal cover canisters were used to carry First Day Covers for the U.S. Postal Service's 25th Anniversary. Since this application did little to advance the body of scientific and technical knowledge, these cans were disregarded during the study. Thus, 69 canisters formed the basis of the analysis.

Some of the more interesting and meaningful facts about these canisters are summarized below.

- 10 of 25 Shuttle missions (40%) had no GAS cans onboard. Of the 15 missions with cans, the number of cans per mission ranged from 1 to 15, with an average of 5.13 and a median of 3.

- 58 cans (84%) had a volume of 5 ft^3; 11 (16%) were 2.5 ft^3. (One user requested and paid for 2.5 ft^3, but due to availability constraints, a 5 ft^3 can was used.) Thus, 5 of every 6 cans were the larger volume.

- 47 cans were sponsored by U.S. organizations, followed by 16 from West Germany, 4 from Japan, and 2 from Canada. Thus, nearly 1/3 of the cans were foreign-sponsored, and 3/4 of those were from West Germany.

- For all 69 cans, the distribution of primary developing and/or sponsoring organizations was:

DEVELOPER OR SPONSOR	U.S. CANS	%	FOREIGN CANS	%
NASA GSFC	13	19%	N/A	
DFVLR (W. Germany)	N/A		13	19%
Department of Defense (DoD)	3	4%	0	0%
Other Government Agency	1	1%	1	1%
Aerospace Company	1	1%	1	1%
Electronics Company	4	6%	3	4%
Non-Aero/Elec Organizations	7	10%	2	3%
University/College	13	19%	0	0%
High School/Grade School	5	7%	2	3%
TOTALS	47	67%	22	32%

  Note that over 40% of all canisters were sponsored by NASA GSFC, DFVLR, and the U.S. DoD. Strong participation (26%) by U.S. schools is evident, as well as by non-aerospace/electronics organizations (13%). The lack of independent participation by aerospace companies worldwide and foreign universities is surprising.

- 2/3 of all cans (42) were installed in the front half of the orbiter cargo bay and 1/3 (28) in the aft half. The distribution between port and starboard sides of the bay was nearly equal (33 vs. 37, respectively). 4 cans operated while on a deployed spacecraft (SPAS) and were subsequently retrieved. 18 cans were mounted on a pallet (OSTA-2 and NAVEX)) or bridge structure (GAS Bridge) rather than the cargo bay sill.

- 9 cans (13%) had special modifications such as externally mounted experiments, opening lids, and externally mounted transmitter antennas. 6 cans (two sets of 3) were connected together electrically with harnesses.

THE GAS EXPERIMENTS

For this study, GAS experiments were defined primarily by the experimenters, either in written form (published papers, articles, etc.) or verbally over the phone. Facts about these include:

- In the 69 cans, 141 experiments were identified. 48 cans (70%) had only one experiment; one can had 13. 90% of the cans had between 1 and 4 experiments in them. The average number of experiments per can was 2.06, and the median was 1.

- 123 of the 141 experiments could be classified into one of the categories listed below; 18 of the 141 experiments fit equally well into two categories. So, a total of 159 experiment objectives (123 + 18 + 18) were addressed. The distribution of experiment objectives vs. category was:

EXPERIMENT CATEGORY	U.S. EXPT	U.S. %	FOREIGN EXPT	FOREIGN %	ALL EXPT	ALL %
Materials and Fluids	44	37%	25	64%	69	43%
Technology Demonstration	26	22%	6	15%	32	20%
Biological Studies	23	19%	3	8%	26	16%
Environmental Measurements	18	15%	2	5%	20	13%
Art Projects	6	5%	0	0%	6	4%
Satellite Deployments	3	3%	0	0%	3	2%
Miscellaneous Science Support	0	0%	3	8%	3	2%
TOTALS	120	101%	39	100%	159	100%

Foreign users (mostly West Germany) have concentrated most efforts in the materials processing and technology demonstration categories, whereas U.S. users have in addition expanded significantly into biological and environmental studies.

GAS EXPERIMENT RESULTS

At the time of writing this paper, results from 11 GAS cans (17 experiments) had not been obtained. These cans were all foreign: DG-301, DG-301R, DG-302, DG-303, DG-303R, DG-315, NAVEX 1, NAVEX 2, and NAVEX 3 from West Germany (DFVLR), and G-032 and G-035 from Japan (Asahi National Broadcasting Company/NEC). So, the results presented herein do not consider these experiments. However, 84% of the cans and 88% of the experiments were considered, which is still a representative sample of the total. Thus, the initial input for the results analysis was 58 GAS canisters containing 124 individual experiments and 142 objectives.

To simplify matters, overall canister performance was assessed first in those cases where all experiments inside the canister had similar results.. Three cans were loaded with passive experiments (4 total), so little can be said about these, since active experiments were the focus of study. Next, it turns out that 22 canisters apparently operated without anomalies. And it is worth noting that all of these canisters were single-experiment cans! At the other extreme, 8 cans suffered turnon failures which precluded any chance of acquiring data from their 31 experiments. After these three cuts were made, 25 canisters were left to analyze. These cans contained 67 experiments.

At this point, individual experiments had to be studied, since all remaining cans contained a mix of experiment results. Using an appraoch similar to that used for the canisters, it was found that 3 experiments were passive and 14 operated smoothly without anomalies, leaving 50 experiments that suffered some degree of failure.

Of the final 50 experiments, 28 had severe failures and thus produced no data, whereas 13 failed moderately and provided some data, but did not adequately meet the experiment objectives. The remaining 9 experiments provided enough quality data to meet the objectives, but still experienced anomalies that are worth mentioning.

This analysis reveals that 94% of the 124 experiments studied were active, the rest passive. Considering the systems-level performance of the 117 active experiments, the following record can be stated:

Completely successful; no anomalies:	36	31%
Successful, with anomalies:	9	8%
Partially successful; some data:	13	11%
Unsuccessful; no data:	59	50%

So, the bottom line is that roughly 40% of the active experiments met their objectives, and the other 60% resulted in little or no data.

GENERALIZATIONS AND CORRELATIONS

On the overall canister performance level, it was noted above that all of the canisters that operated without anomalies (22) had only a single experiment in them. All but one of those that suffered turnon failures (8) had two or more experiments. Also, the causes for the turnon failures were <u>all</u> different! A similar spectrum of surprises was experienced by the individual experiments that failed (severely or moderately; 41 total) or had anomalies, even though they worked (9).

All failures studied were categorized according to the following applicable "subsystems":

Experiment Control: Turnon/off, relays/latches, actuators, data storage
Mechanical Design: Mounting structures, boxes, seals, joints
Power Supply: Batteries, fuses, harness
Thermal Design: Passive thermal control, heaters, thermal blankets
Atmospherics: Vacuum systems, purges, pressurized systems, venting
Science Design: Experiment concept and execution, timeline, scaling

Correlating the degree of failure with the failed subsystem generated the following data:

FAILED SUBSYSTEM	SUCCESSFUL (w/anomalies)	PARTIALLY SUCCESSFUL (some data)	UNSUCCESSFUL (no data)	ALL CASES	
Experiment Control	4	2	6	12	24%
Mechanical Design	2	3	2	7	14%
Power Supply	0	0	6	6	12%
Thermal Design	1	5	11	17	34%
Atmospherics	0	2	3	5	10%
Science Design	2	1	0	3	6%
TOTALS	9	13	28	50	100%

Experiment control and thermal problems dominated the failure history for GAS experiments (58%), followed evenly by mechanical, power supply, and atmospherics problems (36%). The following list is a nutshell summary of nearly all failures encountered.

EXPERIMENT CONTROL
- Blown fuses at turnon (wrong size fuse installed at launch site)
- Ground loop problems
- No turnon due to dead batteries
- No turnon due to stuck relays
- Wrong switch setting during final integration
- Incomplete actuator movement (jamming, loss of power)
- Turnon at KSC; a Delta launch activated an acoustic switch (!)
- No turnon due to miswired NASA/GAS interface connector
- No turnon for an undetermined reason
- Connector pulled loose by launch vibrations
- Failure of tape recorders (jamming, wrong track, controller)
- Failed cameras (jamming during launch, controller)
- Film fogging due to long wait at launch site
- Bad data storage due to low battery voltage

MECHANICAL DESIGN
- Failure of battery mechanical supports due to launch vibrations
- Cracked boxes due to freezing water expansion
- Cracked boxes due to launch vibrations leading to fluid leaks
- Dried out O-ring seals due to long waits at the launch site
- Leaking seals, leading to pressure changes and fluid leaks
- Damaged hardware during shipment to launch site
- Broken glass tube due to shipping or launch vibrations
- Membrane broken during shipment, leading to premature application of fixative to living organisms
- Canister lid failed to close due to a design flaw

POWER SUPPLY
- Dead or weak batteries due to inadequate screening and preparation
- Dead or weak batteries due to long wait at launch site
- Dead or weak batteries due to exposure to cold and vacuum in space
- Dead or weak batteries due to exposure to cold winter at launch site
- Dead batteries due to relay flip before launch
- Undersized battery packs, leading to premature turnoff
- Leaking batteries, leading to fluid contamination all over experiment
- Undetected short of power diodes during integration at launch site
- Diode fracture during launch vibration
- Intermittent shorts and relays (lights, cameras, devices)
- Sneak circuit paths, leading to excess battery drain

THERMAL DESIGN
- Frozen fluids, leading to all kinds of problems
- Severely inhibited organic growth due to low temperatures
- Stuck linear actuators and syringes due to low temperatures
- Blown fuses due to syringe actuation against frozen fluids
- Undersized heaters, leading to low temperatures and inadequate melting
- Low temperatures due to lack of thermal convection in microgravity
- Low temperatures due to heater failure or dead batteries

THERMAL DESIGN (Continued)

- High temperatures while on ground, leading to fogged film
- High temperatures due to shadowing in bay by another payload, which inhibited heat rejection to space; led to premature turnoff
- Circuit failure due to low temperatures
- High or low temperatures due to poor design of thermal control system
- Low temperatures due to off-nominal orbiter attitude history

ATMOSPHERICS

- Dead organisms due to dehydration from GAS can purge (dry air)
- Arcing vacuum tubes due to helium purge gas infiltration
- Fluids evaporated during long wait at launch site
- Arcing in vacuum during sputtering process; inadequate outgassing
- Stuck syringes due to long wait at launch site; dried out seal

SCIENCE DESIGN

- Fluids failed to mix due to surface tension
- Late turnon or early turnoff due to other mission problems
- Substandard purity of processed samples
- Incomplete dissolving of solids in liquids
- Unexpected gas bubbles in solids and liquids
- Higher than expected g-levels due to crew motion in cabin
- Launched without required fluid due to last-minute leak at KSC
- Not launched because experiment integration was not done in time!

It was mentioned previously that the 124 experiments studied had 142 objectives, since some experiments fit into two categories. (Most of the dual-objective experiments were materials processing technology demonstrations combined with a materials or fluids experiment.) Active experiments account for 134 objectives, or 94%. It is instructive to compare the success/failure results within these experiment categories, as shown below. (Here, success means the objectives were achieved; failure means the objectives were not achieved or partially achieved.)

EXPERIMENT CATEGORY	SUCCESS	FAILURE
Materials and Fluids	20	35
Technology Demonstration	16	15
Biological Studies	0	21
Environmental Measurements	12	7
Art Projects	4	1
Satellite Deployments	2	1
Miscellaneous Science Support	---No Data---	
TOTALS	54	80

Especially notable here is the high proportion of failures (some caused by GAS can turnon failures) in the biological and materials processing categories. Active biological studies have had zero success!

Some correlation between experiment success and developer group was found. NASA GSFC and U.S. non-aerospace companies had a good record of success (28 of 34; 82%), whereas U.S. schools had a dismal string of failures (54 of 63; 86%). The number of foreign experiments was too small to readily see a pattern in the data.

THE FUTURE ...

If the historical rate of GAS launches is maintained once the Shuttle activity resumes, we can expect to see another 250 to 500 GAS canisters launched before the end of the century. These cans would contain 500 to 1000 experiments of all types. New GAS features will evolve to meet user demands: longer cans, wider cans, expanded power supplies, and a host of innovative interfaces. Satellite ejections will likely be commonplace in a few years.

Besides the normal hardware and parts problems, this study has illuminated several areas of experiment design and testing that have been causing problems for GAS experimenters to date, namely:

- Operating temperatures in orbit have been frequently overestimated, resulting in frozen liquids, poor electrical and mechanical performance, underperforming heaters, and slow chemical reaction rates. Hot temperatures are also common.
- The long prelaunch wait (up to 2-3 months) precipitates battery drain problems, O-ring and seal dryout, biological organism stress, and thermal concerns, especially during winter.
- Several failures have been caused by improper experiment configuring during final integration. More extensive prelaunch functional tests might alleviate many such problems.
- Launch vibration has caused several mechanical and electrical failures involving experiment cases, relays, and wire harnesses.
- The prelaunch purge has stressed or killed biological organisms and has migrated into experiment vacuum chambers.
- Multiple experiment integration invites problems of all types.

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The author assumes responsibility for any inaccuracies or misrepresentations with respect to the experiment descriptions, classifications, and results. Given the proper inputs and enough time, such errors should gradually get corrected.

REFERENCES

An extensive reference listing of sources consulted during this study is available from the author. Is was not printed here so that most of the eight pages could be used for presenting the study results.