NASA Space Mechanisms Handbook--Lessons Learned Documented

The need to improve space mechanism reliability is underscored by a long history of flight failures and anomalies caused by malfunctioning mechanisms on spacecraft and launch vehicles. Some examples of these failures are listed in the table. Mechanism anomalies continue to occur and to be a cause of catastrophic mission failures. Several factors cause problems for space system mechanisms. The space environment produces wide temperature ranges, thermal gradients, and rapid changes in temperature, which can bind the moving parts of mechanisms. Ultraviolet radiation and vacuum cause the properties of many materials to degrade to unacceptable levels or to behave differently in space than on Earth, making it difficult to simulate operation during ground tests. The lack of gravity in space causes mechanisms to operate differently than on the ground. Sometimes the effects of zero gravity can be simulated to some degree in ground testing, such as by offloading the weight of a deployable appendage. Other effects, such as lubricant migration, cannot be simulated and must be considered in the design. Finally, the launch environment imposes severe dynamic loads on mechanisms and can cause structural damage, loosen fasteners, and damage delicate surfaces.

SUMMARY OF SPACECRAFT MECHANISM FAILURES

Program	Date	Problem	Cause
Program 461	1964	Solar array failed to deploy fully	Mishandling during stowage
STP 67-2 (OV2-5)	1968	Solar array booms failed to deploy fully	Field modification problem
777	1970	Omni antenna latch broke during spin-up	Attitude control instability
Program A	1971	Antenna failed to deploy fully	Wire harness binding
Program B	1971	Solar array deployed late	Silicon rubber sticking
STP 71-5	1972	Boom failed to deploy	Dynamic clearance problem
Skylab	1973	Solar array failed to deploy	Interference with cabling or thermal blankets
Transit	1975	Solar array failed to deploy fully; cable hung up	Anomalous flat trajectory caused high heating rates
Viking	1975	Sampling arm failed to deploy	Debris in gear train
STP 74-1 (Solrad)	1976	Solar panel failed to deploy	Release mechanism binding
DMSP F-1	1976	Solar array failed to deploy fully	Excessive wire harness stiffness
DMSP F-2	1977	Solar array delayed release	Friction welding
DMSP F-2	1977	Science boom failed to deploy fully	Microswitch failed
Voyager	1977	Science boom failed to deploy fully	Microswitch failed
Voyager	1977	Scan platform gearbox seized	Lubricant failed
Voyager	1977	Magnetometer boom misaligned	Unknown
Seasat	1978	Spacecraft power failed	Slip ring debris between power and ground rings
Apple	1981	Solar array failed to deploy	Failure of deployment device
DE	1981	Sensing antenna failed to deploy	Unknown

Insat 1	1982	Solar sail failed to deploy	Unknown
ERBS	1982	Solar array failed to deploy	Unknown
GLOMR	1985	Spacecraft failed to separate from orbiter	Canister door did not open fully
VUE	1988	Telescope failed to rotate about azimuth	Inadequate torque margin on azimuth caging arm
Galileo	1989	High-gain antenna failed to deploy	Cold welding in ball and socket joint
Galileo	1989	Instrument cover jettisoned late	Thermal binding
Magellan	1989	Solar array failed to latch at end of travel	Microswitch misadjusted
Macsat	1990	Gravity gradient boom failed to deploy	Inadequate force margin
CRRES	1990	Magnetometer boom failed to orient fully	Interference between thermal blanket Velcro and wiring harness
Ulysses	1990	Spin-stabilized spacecraft wobbled	Antenna boom thermal distortion caused spacecraft center-of-gravity offset
Hubble	1990	Solar array booms jittered as telescope went between sun and shade	Thermal gradient across boom diameter
ANIK E2	1991	C-band antenna failed to fully deploy	Thermal blanket interference
Unknown		Sampling arm failed to deploy	Screw backed out and wedged against housing
Tether Satellite System	1993	Reel-out mechanism jammed	Screw added for structural margin interfered with reel-out mechanism
GOES 10	1997	Solar Array Drive malfunctioned	Under investigation

Given these complexities, it is not surprising that it is not always possible to uncover and correct all the hidden problems with mechanisms prior to launch. Fortunately, there are ways to reduce the number of failures involving mechanisms and/or mitigate the effects of a failure of a component. In many cases, failures were caused by design problems that have caused similar failures in the past, and thus could have been avoided had the designers been aware of the past mistakes. Because much experience has been gained over the years, many specialized design practices have evolved and many unsatisfactory design approaches have been identified. In many cases, however, this knowledge has remained with the individual mechanism designer and has not been widely shared.

To alleviate this situation, NASA and the NASA Lewis Research Center conducted a Lessons Learned Study (refs. 1 and 2) and wrote a handbook to document what has been learned in the past. The primary goals of the handbook were to identify desirable and undesirable design practices for space mechanisms and to reduce the number of failures caused by the repetition of past design errors. Another goal was to identify a variety of design approaches for specific applications and to provide the associated considerations and caveats for each approach in an effort to help designers choose the approach most suitable for each application. The handbook also provides some design principles. These principles, which can be applied to any mechanism to avoid common failure modes, can be particularly useful for the esoteric mechanism configurations that dwell on topics that are not unique to space applications, it does does cite references, where appropriate, for additional information or more indepth discussion of specific topics.

The handbook is divided into six parts. Part I, *Introduction to Space Mechanisms*, starts with an overview of various types of spacecraft mechanisms. It then discusses the requirements that are typically imposed on space mechanisms, their implications, and what steps can be taken to ensure that the requirements are met. The discussion concludes with a description of a typical mechanism design process and addresses how the design evolves from concept to fabrication. Part II, *Design Considerations for Space Mechanisms*, provides guidelines for recommended design practices for most spacecraft mechanisms. It also contains subsequent chapters that are devoted to guidelines applicable to specific types of mechanisms. Part III, *Space Mechanism Components*, proceeds to the next level of detail and discusses design considerations for mechanisms. This part is divided into general design guidelines that are applicable to the various components of spacecraft mechanisms. Part IV delves into two areas of testing, environmental testing and tribological testing of space mechanisms. Part V lists expert areas and the names and addresses of individuals who are experts in those areas of testing. Finally, Part VI lists testing laboratories and the individuals involved in the testing programs.

We anticipate that this handbook will be useful to a variety of readers. By studying the numerous guidelines presented in this handbook, entry-level design engineers will be able to quickly gather practical information on how to avoid common pitfalls. Experienced mechanical design engineers who are new to space mechanism applications will benefit from learning the unique requirements created by the space and launch environments. Also, users who need to evaluate their suppliers' products, but have little personal experience in the design of mechanisms, can find useful information on identifying key performance, risk, and cost drivers for most space mechanisms and components. The Space Mechanisms Handbook is available from Lewis' Mechanical Components Branch.

References

1. Shapiro, W., et al.: Space Mechanisms Lessons Learned Study, Volume I--Summary. NASA TM-107046, 1995.

2. Shapiro, W., et al.: Space Mechanisms Lessons Learned Study, Volume II--Literature Review. NASA TM-107047, 1995.

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