

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 |

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|-------------------------|------|--|--|
| 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 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.

Lewis contact: Robert L. Fusaro, (216) 433-6080, Robert.L.Fusaro@grc.nasa.gov

Author: Robert L. Fusaro

Headquarters program office: OA (Chief Engineer)

Programs/Projects: Safety and Mission Assurance