Space-Flight Validation Opportunities for Low-Temperature Technologies

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ABSTRACT

The New Millennium Program (NMP) is a space flight test program aimed at flight validating new technologies to reduce the risk and cost to NASA's Earth and space science missions. At the current time, the Earth Observing-3 (EO3) project, to launch in 2005, plans to fly a two-stage mini-cryocooler: 30 to 150 K cooling capability, a factor of four reduction in mass per unit power over coolers of similar capability, and a life expectancy of 7 years. Another cryogenic technology, candidate for Space Technology 6 (ST6), is scheduled to launch in mid-2004. It is a closed-cycle dilution cryocooler with a 50 mK cooling capability. This paper will describe the NMP flight validation requirements and encourage the cryogenic technology community to propose experiments that require the environment of space for technology validation.

Keywords: NMP, Cryogenics, Space Test

1. INTRODUCTION: In 1994 the National Aeronautics and Space Administration (NASA) created the New Millennium Program (NMP). The objective of this program is to conduct space flight validation of breakthrough technologies that will significantly benefit future space-and Earth-science missions. Selected technologies are focused on enabling new science capabilities to fulfill NASA's Space Science Enterprise (SSE) and Earth Science Enterprise (ESE) objectives and reducing the cost of future space and Earth science missions.

2. OVERVIEW: The NMP flight schedule is shown in Fig. 1. The designation for the SSE flights began with the Deep Space (DS) series but has since been replaced by the Space Technology (ST) series. The designation for ESE flights is Earth Observing (EO). As seen in the figure, the flight schedule has been one flight per year. Due to funding limitations, there are no flights between 2001 to 2003. When flights resume, the schedule calls for about two flights per year. Descriptions of the existing flights can be obtained from the NMP web site: http://nmp.jpl.nasa.gov.

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The flights shown in Fig. 1 are either in the flight/infusion phase or in the implementation phase. The NMP validation flights are divided into classes: system and subsystem. The resources allocated to each of these is given in Table 1. The table also indicated that there are two classes, termed normal and occasional and are distinguished by the level of investment. In this paper, the difference between system and subsystem flights is illustrated by the EO3 cryocooler and the ST6 candidate dilution cooler technology, respectively.

Thus far the existing NMP flights have been system level flight. Those in implementation are system level with the exception is ST6 which is a sub-system level. In the future, the plan is to prepare an equal number of system and subsystem-level flights. *The next opportunity for the flight validation of new technology is ST8 which will be formulated this fall with a technology call expected about January 2002 and flight expected in 2006.*

As depicted in Fig. 2, the NMP flight validation process [1] has a cluster of three activities: formulation, implementation, and flight/infusion. As indicated in the figure, each activity cluster has a number of sub-activities. The formulation process begins with the gathering and identification of the new technology from users and the NASA theme technology needs. The process then proceeds into technology maturation and readiness where the technologist is asked to demonstrate the readiness of the technology for flight and to refine the cost estimate. Once chosen, the technology proceeds into the implementation process that consists of further partnering, resolution of access-to-space, and initiation of the flight validation project. During this process the details are encoded in the validation and infusion plan that is frequently updated during the implementation process. The flight/infusion process consists of the flight of the technology and the transformation of flight results into data that is used to infuse the new technology in future Earth and space science missions.

3. TECHNOLOGY SELECTION PROCESS: The elements involved in technology selection are shown in Fig. 3. The process begins by gathering technology from the users and the four NASA themes (ASO, ESS, SEC, and SEU). The technology readiness is based on the nine NASA technology readiness levels (TRLs) [2] listed in the figure. NMP is concerned with technology that has achieved a maturity above TRL4. Once flown the technology is considered to be at TRL7. Other factors include the cost to fly the technology and access to space. The NMP has under taken an effort, termed the NM Carrier, to aid technologist in getting technology into space. Finally, the selection of the technology depends on the flight justification.

The flight justification factors are listed in Table 2. The first four factors are concerned with interactions between the environment and the technology. In short these factors justify flight validation for the technologies that cannot be tested on the ground. The most familiar factor is microgravity that affects thin-film technologies such as solar sails and membrane optics and for the case of cryogenic technologies, influences the performance of the dilution cooler. The fifth factor is concerned with complex interactions that lead uncertainties in performance of the technology in space. The sixth factor is concerned with fundamental changes that have not been attempted before.

Flight validation is used to reduce the risk and identify any "unknown unknowns". Effects that are relevant to the cryogenic technologies are indicated by an asterisk in the table.

4. FLIGHT VALIDATION: The validation of a technology in space is a difficult and expensive task and should only be undertaken with much forethought. The illustration in Fig. 4 mentions that space tests are greatly constrained over ground tests. In addition the figure illustrates that a key part of flight validation is the identification of technology specific data that is down-linked from space. If technology specific data cannot be identified, then NMP considers the technology to be flight *demonstrated* and not flight *validated.*

Flight validation is used (a) to confirm that the results obtained in space are satisfactorily close to those determined on the ground, (b) to add to the knowledge base in the case where ground tests are impossible or where unexpected fault scenarios are uncovered, and (c) to better define parameters used in simulator and model algorithms. The net result of flight validation is the reduction in risk and cost of using new technology thus enabling the use of the technology in Earth and Space science missions.

Subsystem technology validation is illustrated by the chart seen in Fig. 5. This chart is typical of charts prepared in the early stage of technology selection. It contains a description of the technology, flight justification, customers, validation measurements, and the technology status. The flight justification is based on the gravity sensitivity of the He-3 and He-4 used to achieve temperatures in the tens of mK range. Subsystem flight validations can be highly comprehensive because the focus is solely on the characterization of one technology.

System-level technology validation is illustrated by the chart seen in Fig. 6. This cryocooler is used to cool the GIFTS (Geosynchronous Imaging Fourier Transform Spectrometer) focal plane arrays and the interferometer. The flight validation of this technology is based on uncertainties in characterizing the temperature stability and vibration factors on the ground. Since this technology is used as on integral part of a spectrometer, its flight validation is challenging. The validation can be made more comprehensive by proper instrumentation and careful utilization of operational scenarios that vary thermal loads so as to validate more of the coolers capability. However, it appears that the flight validation of technology at the system level is generally less thorough than at the sub-system level.

5. CRYOGENIC TECHNOLOGISTS ACTION PLAN: The following steps are suggested as an approach to assessing if a technology is worthy of flight validation and a process for interfacing with NMP. In addition, useful URL's are also indicated.

- Identify the Needed Technology (See URLs):
  - Identify Mission application
  - Determine if a NASA Theme(s) is interested
- Determine if the Technology is ready for Flight Validation:
  - Determine if the technology maturity (TRL)
  - Decide on the Flight Justification (Is FltVal needed?)
  - Determine if the Cost is reasonable
  - Identify Access-to-Space options

- Advertise:
  - Inform the NMP and the NASA Theme(s) of the technology
  - Participate in an NMP Formulation Workshop (Jan 2002)
  - For ST8, watch NMP web site starting in Oct 2001.
  - Respond to an NMP TA (Technology Announcement): March 2002.

- Useful URLs:
  - NMP: http://nmp.jpl.nasa.gov/
  - OSS: http://spacescience.nasa.gov/
  - SEE: http://sse.jpl.nasa.gov/
  - SEU: http://universe.gsfc.nasa.gov/
  - SEC: http://sec.gsfc.nasa.gov/
  - ASO: http://origins.jpl.nasa.gov/

6. REFERENCES

1. C. P. Minning, M. G. Buehler, T. Fujita, F. Lansing, G. Man, A. Aljabri, and C. Stevens, "Technology Selection and Validation: New Millennium Flight Projects" 2000 IEEE Aerospace Conference (March 2000).
2. J. C. Mankins, "Technology Readiness Levels" (April 6, 1995)

7. ACKNOWLEDGEMENTS: The authors wish to thank the NMP technologists C. P. Minning, T. Fujita and F. Lansing for providing critical comments to this manuscript and J. Stocky and C. Stevens for encouraging this method of outreach to the technical community. File: CoolWork1713.doc

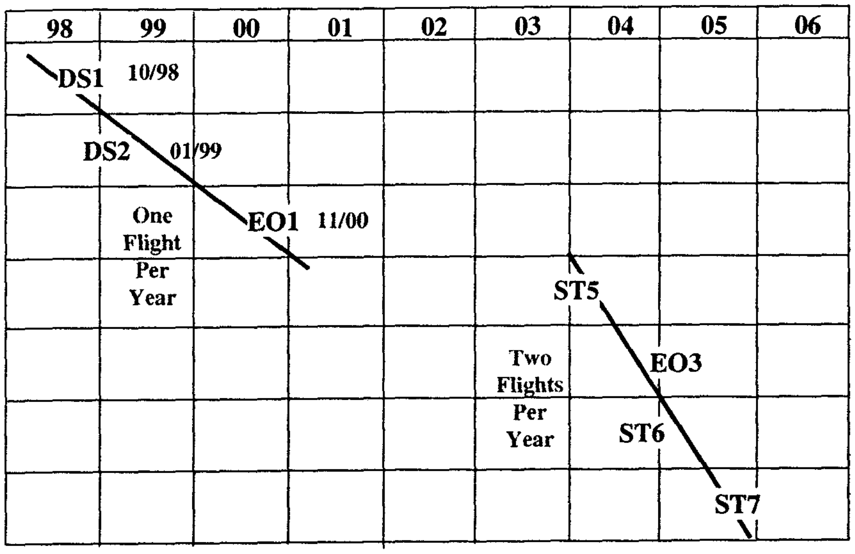


Figure 1. NMP launch schedule

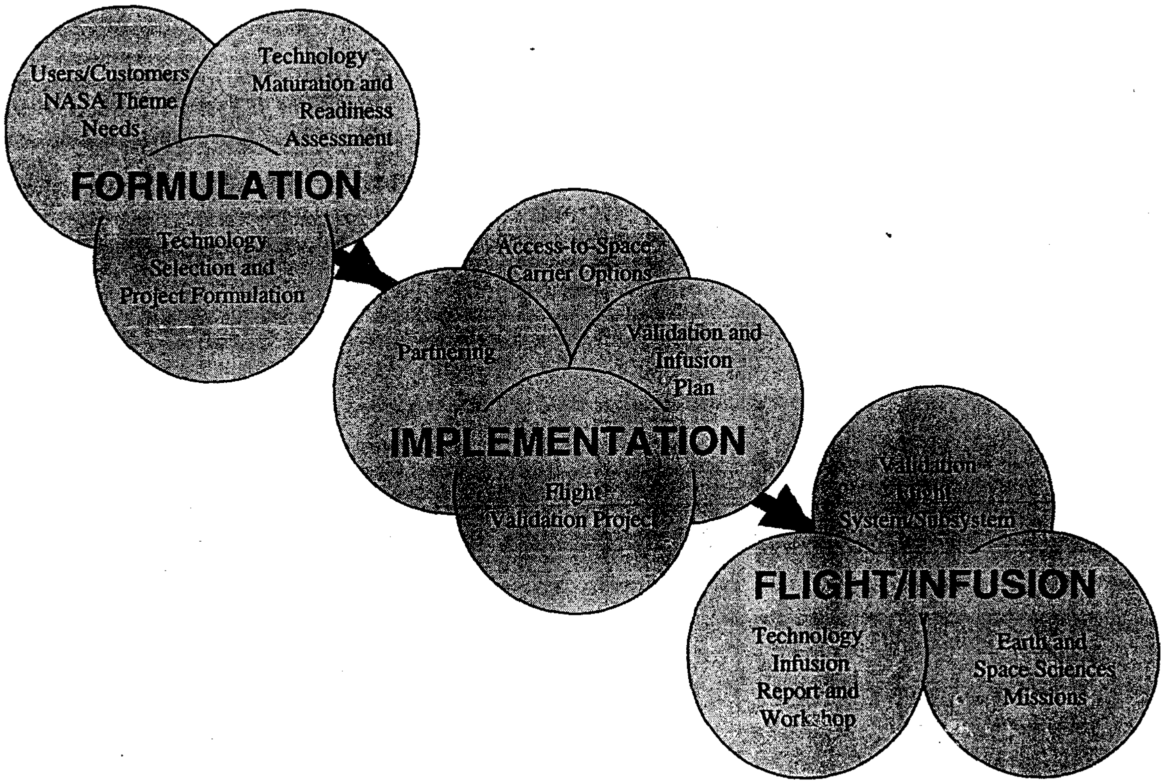


Figure 2. NMP flight validation process includes a triad of activities.

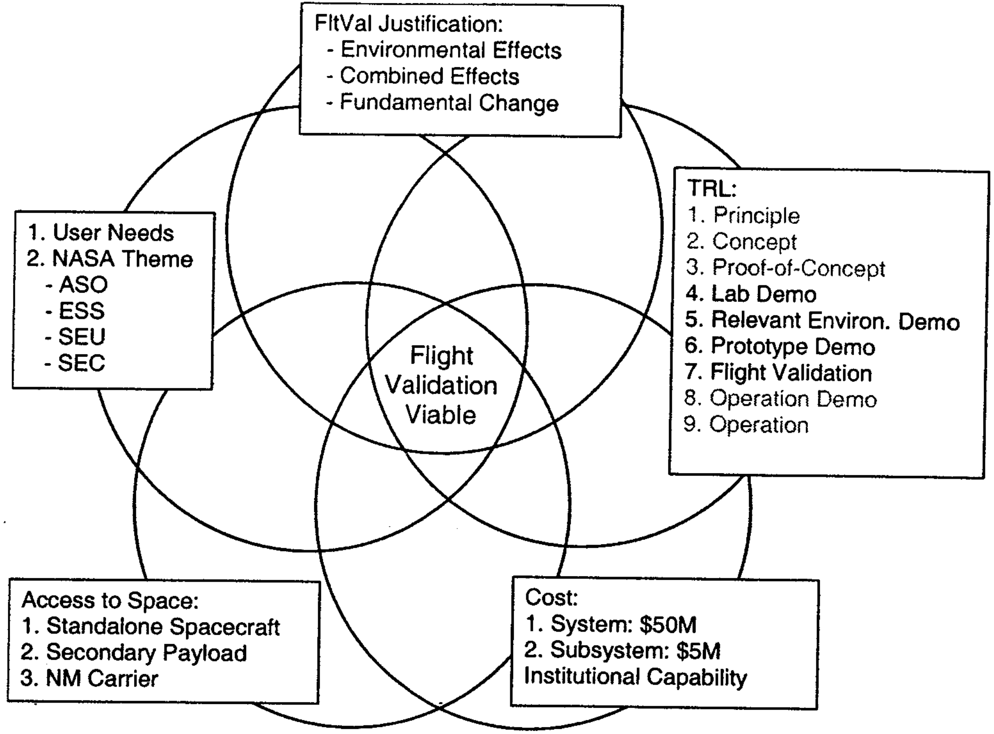


Figure 3. NMP flight validation selection criteria.

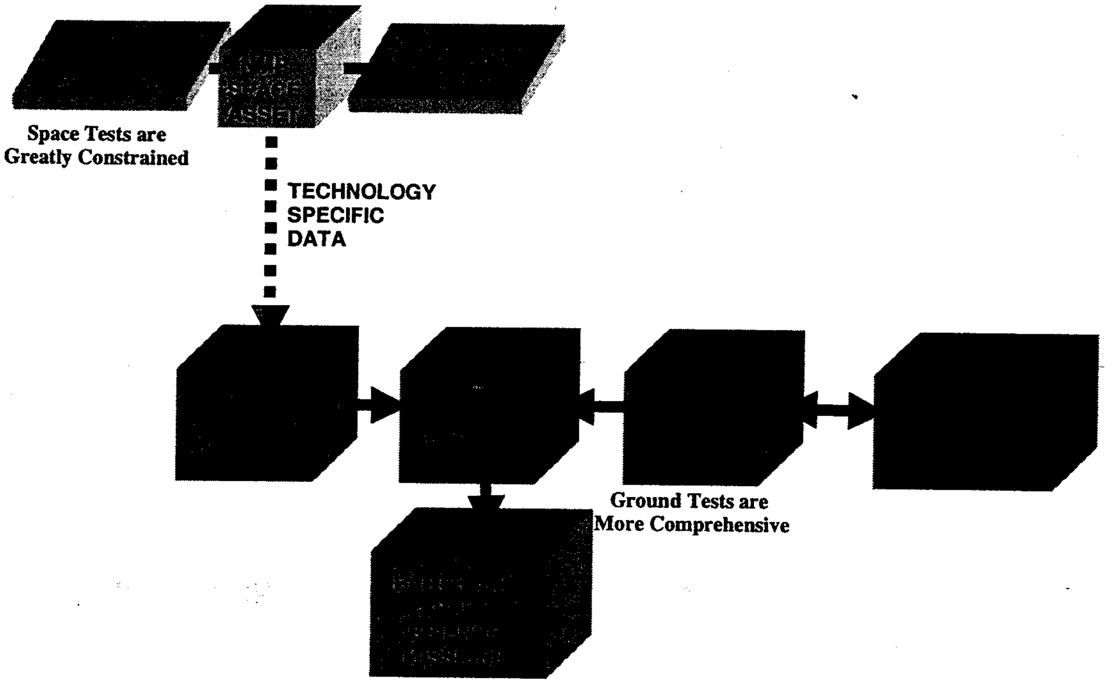
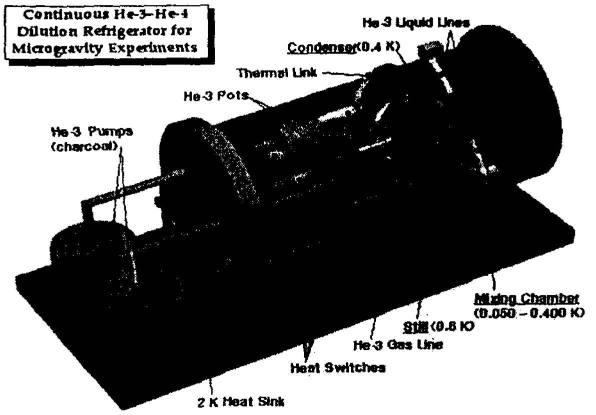


Figure 4. Flight validation elements.



- ***Technology Description:***

Cryocoolers enable the use of low temperature detectors that measure photons with energies ranging between X-rays through IR. The dilution cryocooler uses liquid helium to achieve temperatures between 50 and 300 mK. Cooling occurs without the use of stored cryogens, with no moving parts, no vibration and no magnetic fields. The size is 25 cm dia. X 40 cm long. The mass is < 10 kg. The average heat load on the 2 K heat sink is about 60 mW.

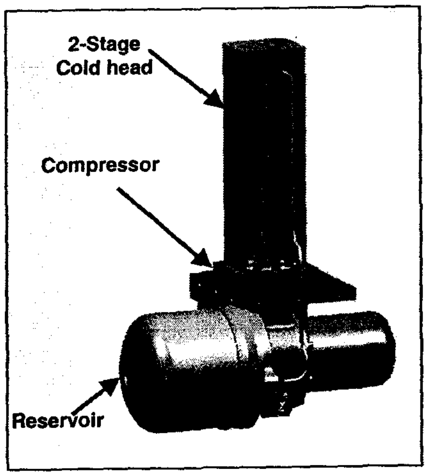
- ***Flight Validation Justification:***
  - Dilution cryocoolers are difficult or impossible to test on the ground due to gravity sensitive of the He-3 and He-4 and require flight validation to demonstrate their performance in a space.

- ***Customers:***
  - Missions with X-ray or IR requirements.
  - FIRST, Constellation-X, SOFIA, Plank (ESA), SPECS, HIRLODLS; NGST; SUVO

- ***Validation Measurements:***
  - Measure the temperature of the dilution cryocooler in space to determine its stability and dynamic behavior.
  - Measure the power required to reach lowest temperatures.

- ***Technology Status:***
  - A single-cycle prototype with necessary porous material for controlling the liquid has been demonstrated on the ground. It is being modified to operate continuously. The technology is expected to reach TRL 4 by FY02.

Figure 5. Subsystem-level validation: ST6 candidate dilution-cooler technology.



EO3 GIFTS Two-Stage Cryocooler

- ***Technology Description:***

The two-stage pulse-tube cooler is capable of second stage cooling between 30 and 150 K with 50 mK stability. For GIFTS the focal plane array, mounted on the second stage, will be cooled to 55 K (2-W load). For zonal cooling of the instrument, the cooler first-stage will be cooled to ~140 K (7-W load), allowing the interferometer to operate at a lower background noise. Mass is <10 kg including electronics, power is 160 W, and ambient temperature is –40 and 60°C.

- ***Flight Validation Justification:***
  - The steady state and dynamic temperature response in space is difficult to predict based on ground tests due to complex interactions.
  - The space cooler vibration performance is difficult to predict based on ground tests due to complex interactions.

- ***Customers:***
  - Enabling technology for NOAA, ONR, FAA, and NASA's Earth and Science Enterprises.

- ***Validation Measurements:***
  - Measure the input power and cooler temperature to determine the power efficiency (<10 W/W)
  - Measure the cooler temperature sensor to determine the temperature stability (~ 50 mK)
  - Measure the cooler accelerometer to gather vibrational and perhaps mechanical reliability statistics.

- ***Technology Status:***

Bench model of the cooler currently under test has demonstrated a factor of four improvement in mass per unit power over coolers of similar capacity (GIFTS versus AIRS/TES). The technology is expected to reach TRL 5 by FY02.

Figure 6. System-level validation: EO3 miniaturized pulse-tube cryocooler.

Table 1 Attributes of NMP System and Subsystem Validation Flights

ATTRIBUTE	SYSTEM	SUBSYSTEM
Normal Project Class	Cost: $50M	Cost: $25M supporting several technologies (ST6 Candidate Technology: Dilution Cooler)
Occasional Project Class	Cost: $100-$150M (EO3: Cryocooler)	Cost: $25M supporting several technologies.

Table 2 Flight Validation Justification Factors

JUSTIFICATION FACTORS	EXAMPLE EFFECTS
1. PERSISTENT EFFECTS are steady space/planetary environments acting on the technology.	Zero Gravity* Radiation Effects* Temperature Cycling*
2. TRANSIENT EFFECTS are impulse type space or planetary environments acting on the technology.	Cosmic Rays* Temperature Spike* Vibration* Coronal Mass Ejection Dust Devils
3. PHYSICAL INTERACTIONS are environments used by the technology to accomplish something.	Planetary Atmospheres Solar Wind Magnetic Fields
4. RELIABILITY HAZARDS are space or planetary environments that degrade performance.	Micrometeorites Dust Accumulation Atomic Oxygen Radiation Effects*
5. COMBINED EFFECTS are complex interactions that occur at the interface between advanced technology and other parts of the system.	Thermal Loads* Thermal Radiators* Contamination*
6. FUNDAMENTAL CHANGE is a revolutionary way of designing, assembling, fabricating, testing, integrating, or operating	Ground operations change in switching from chemical to ion propulsion