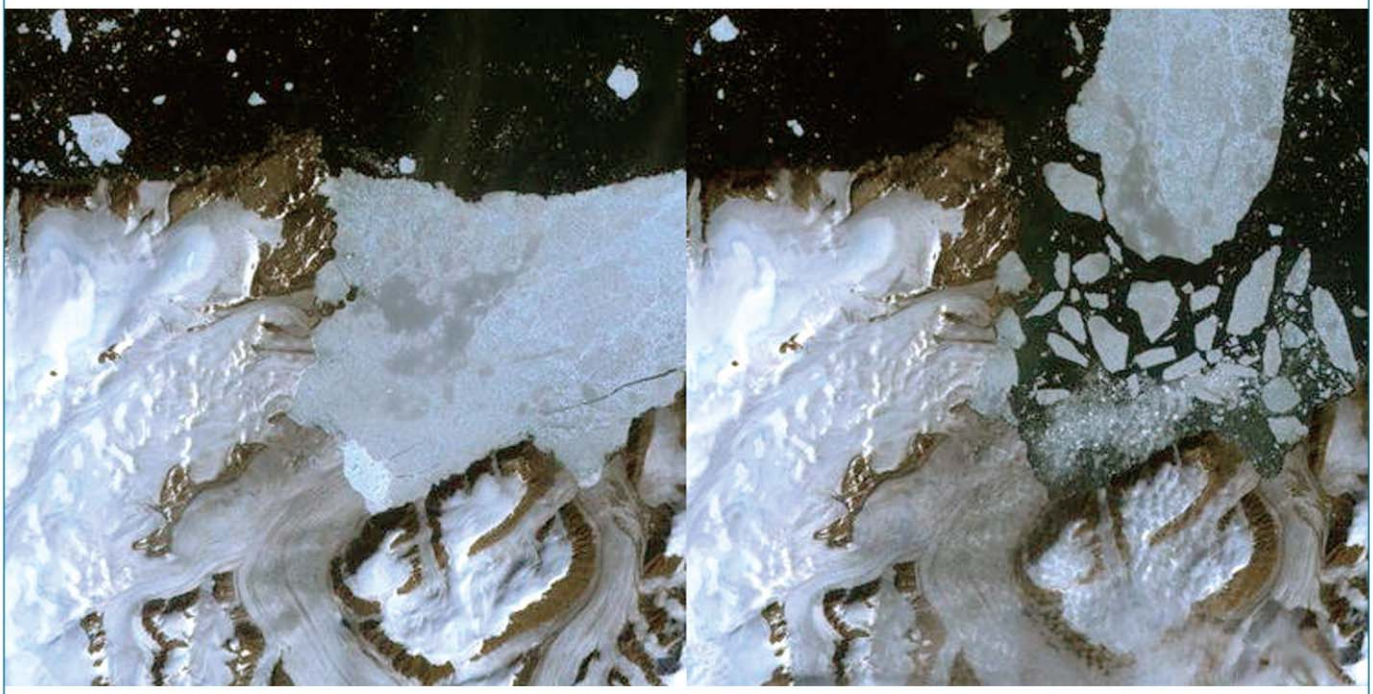
國家太空中心
NATIONAL SPACE ORGANIZATION
NSPO
民國九十八年年報

ANNUAL REPORT 2009



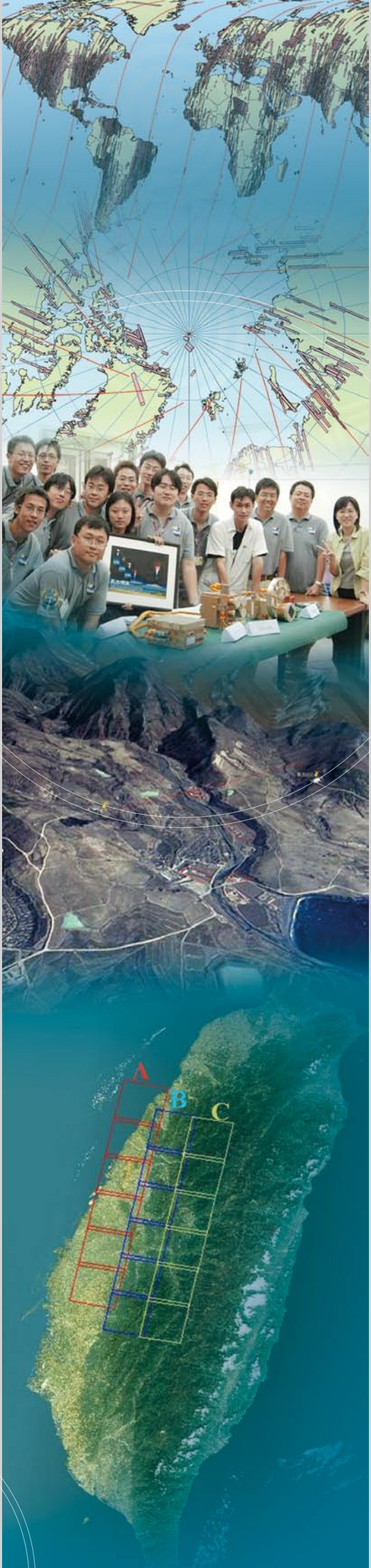
加拿大貝兒雀冰河融解
Belcher Glacier, Canada

National Space Organization

科技發展加劇地球的暖化
人類生活也面臨急遽的轉變
福爾摩沙衛星二號從太空中守護著地球
以清晰的影像監測呈現地球轉變的樣貌
藉以喚起人類的自覺與反思
為人類的幸福悉心守護

太空中心秉持踏實深耕、精益求精的初衷
致力追求台灣太空科技的卓越與進步
期以精湛的技術
為人類永續的未來向前邁進

封面圖片：
加拿大貝兒雀冰河融解前（左圖）
加拿大貝兒雀冰河融解後（右圖）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主任的話

2009年國家太空中心與國內外產學研單位共同攜手合作，在衛星操作、衛星計畫及太空科技研發等三方面，皆有顯著的成果。首先，福衛二號衛星（FORMOSAT-2）在2009年5月21完成了它原規劃的5年任務，現在衛星仍在軌道繼續正常的運作，提供國內外使用者寶貴的每日再訪影像。其次，福衛三號衛星（FORMOSAT-3）自2006年4月15日發射升空以來，這六顆微衛星所組成的星系每日可提供1500至2000組大氣資料，給大氣科學界與氣象中心使用，至目前為止，使用者遍及50個國家，超過1,100位。在此也特別感謝美國大學聯盟大氣研究中心（UCAR），在這個計畫中為本中心的長期夥伴，對推廣福衛三號數據應用於大氣科學研究與氣象預報不遺餘力。第三，在本中心、中山科學研究院與中央大學共同合作下，探空七號火箭與科學酬載已完成各項檢查與測試工作，預計於2010年發射。

本中心正在執行福衛五號衛星（FORMOSAT-5）計畫，該衛星預計2013底到2014年間發射。屆時，福衛五號衛星將取代福衛二號衛星，持續提供使用者所需的衛星影像資料。2009年，福衛五號衛星計畫在衛星設計方面有了重要的進展，包括完成了系統設計審查以及互補式金屬氧化層半導體（CMOS）感測器遙測酬載的可行性分析。

在本中心的內部技術研發方面，2009年我們獲得了不少重要成果，收錄於此報告中。舉例如下，本中心研製多年的太空級GPS信號接收器，最近已通過了環境測試，未來將裝載在探空火箭從事飛行測試。福衛五號衛星所開發的指令和資料管理單元（CDMU），被視為衛星本體的關鍵元件，它的特色是以LEON3處理器為核心具有高速的運算能力，最近CDMU工程體也已經完成並通過驗證。再者，本中心累積多年熱管研發技術，最近已完成自製太空級熱管雛型體的設計與開發。

2009年，本中心與國內多所學術研究單位的合作成果亦收錄於此報告中。例如，在上述的探空火箭七號計畫中央大學負責提供科學酬載；在福衛三號衛星計畫，中央大學GPS-ARC中心負責推廣福衛三號衛星資料應用於學術研究與氣象、氣候預測模式的改良；福衛五號衛星遙測酬載是由本中心、儀器科技研究中心與國內產業共同合作研製；探空火箭的推進技術分別由成功大學及交通大學進行研究；除上述之外，另有與未來衛星任務相關的科學酬載也正委由大學團隊研究。

由於本中心為國內唯一太空事務專責機構，因此兼具有執行大型衛星計畫與提升我國太空科技能力的雙重任務。為了達成任務，本中心不僅有效地運用中心內部人力與資源，且加強與國內外大學、研究機構和產業界合作，以達成所規劃的目標。在此，歡迎並感謝 您對於2009年報提出指教與建議。

國家太空中心　　苗君易

Message from the Director General

During 2009, NSPO has scored significant achievements in satellite operations, satellite program development, and collaboration with universities and industrial organizations in aerospace science and technology. First, I wish to note that the FORMOSAT-2 completed its 5-year mission on May 21, 2009. The satellite is remaining in orbit and continuing its normal operations, and is providing valuable daily-revisit images to domestic and international users. Second, the FORMOSAT-3 satellites, a cluster of six microsatellites launched on April 15, 2006, are fully operational, and are providing 1500 to 2000 soundings of atmospheric data daily to users for science research and weather operation. Currently, the FORMOSAT-3 satellites have over 1,100 users from 50 countries. I wish to take this opportunity to sincerely thank the University Cooperation of Atmospheric Research (UCAR), USA, the long-term partner of NSPO in this project, for promoting data utilization by the international science community and weather operation organizations. Third, the Sounding Rocket 7, as a result of a joint effort involving NSPO, Chung-Shang Institute of Science and Technology (CSIST) and National Central University, is ready for launch, which is scheduled to occur in 2010.

FORMOSAT-5 is the satellite program under development, and is scheduled for launch during late 2013 to 2014. FOROSAT-5, a remote sensing satellite, will replace FORMOSAT-2 as a source of optical image data to users. During 2009, significant advancements have been made in the design of FORMOSAT-5, including the completion of the System Design Review and a feasibility analysis of the use of CMOS sensor technology for on-board remote sensing instruments.

In-house technology development in NSPO has scored various successes in 2009, as detailed in this report. Briefly, the flight-grade GPS receiver, which has long been under development in NSPO, was recently qualified by environmental testing. Consequently, flight testing will be scheduled during the next sounding rocket launch campaign. The Command and Data Management Unit (CDMU) of FORMOSAT-5 is being developed in NSPO, and features a LEON3 processor and high data rate Space Wire bus. Recently, the Engineering Model of the CDMU has been completed and verified. The proposed CDMU is denoted as a key component of FORMOSAT-5. NSPO has devoted years of effort to the development of space-grade heat pipe, in cooperation with domestic industry. Recently, the self-made 6063T6 aluminum/acetone heat-pipe was qualified by environmental testing, and is now ready for flight testing.

During 2009, NSPO has conducted significant space science and technology development in cooperation with universities and research institutes in Taiwan. Specifically projects have included National Central University providing the science payload of the Sounding Rocket 7. Moreover, applications of the FORMOSAT-3 data for atmospheric research and weather prediction are being coordinated by the GPS-ARC center, National Central University. Additionally, the remote sensing instrument of FORMOSAT-5 is being jointly developed by the Instrument Technology Research Institute, NARL, CSIST and domestic industry. The propulsion technology for sound rocket is being jointly studied in National Cheng Kung University and National Chiao-Tung University. Additionally, numerous university teams are studying science payloads for future satellite missions.

Serving as the space agency of Taiwan, the mission of NSPO includes both implementing satellite programs and promoting national space science and technology development. To meet its mission requirements, NSPO is not only dedicating its manpower and resources to fulfill the needs, but also promoting collaboration with domestic and overseas universities, research institutes and industrial organizations to achieve planned goals. Your comments and suggestions on this annual report are welcome and highly appreciated.

Director General Jiun-Jih Miau

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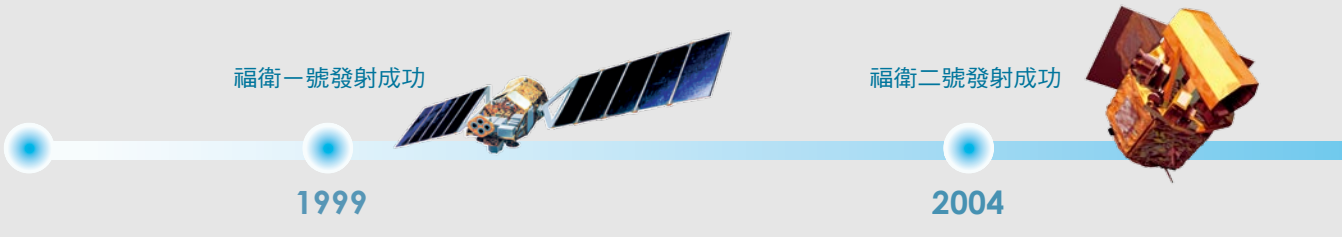


1991年10月行政院核定通過「國家太空科技發展長程計畫」（簡稱第一期太空科技計畫），同時由國家科學委員會設立「國家太空計畫室籌備處」，正式開啟了台灣的太空計畫。2005年4月為達到台灣太空科技自主發展的目標，更名為國家太空中心，隸屬於財團法人國家實驗研究院。國家太空中心是台灣唯一太空相關事務的專責單位，兼具國家太空科技政策執行機構（National Space Agency）與太空科技發展機構（Space Research and Development Organization）的特性，其主要職掌包括：我國太空政策的推動、太空計畫的執行、太空科技的發展與太空科普教育的推廣。

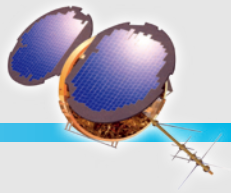
國家太空中心現有194名員工，研發工程人員共156名，佔總名額80%，其中博士級研發人員36名，碩士級研發人員90名。國家太空中心的組織架構下分為系統發展、系統操作與技術發展以及行政支援三大群，其中系統發展室負責執行衛星系統發展計畫，由計畫主持人統籌執行計畫相關工作；系統操作與技術發展室負責提供計畫執行所需技術資源、衛星系統任務操作及研發未來計畫所需的關鍵技術；而行政支援室則負責提供行政資源予中心內部並執行內部行政業務計畫工作。

第一期太空科技計畫（1991-2006年），除完成發展國家太空計畫所需的組織與技術、培養太空計畫所需的人力資源及建購衛星整測廠房與地面操控系統等基礎設施外，並成功發射福爾摩沙衛星一號、二號、三號，共八顆衛星，順利地執行既定的任務與科學實驗，為我國太空科技發展奠定良好的根基。

第二期太空科技計畫自2004年開始，除延續第一期太空科技計畫的成果外，我們將以建立完整自主太空科技能量及運用衛星技術與資料滿足民生需求為目標。於學術合作上，國家太空中心提供研發平台，推動前瞻太空科學研究，並與國內學研界共同研發，建構我國太空科學與技術發展體系。於產業發展上，國家太空中心期能藉由衛星元件的共同研發，帶動國內廠商產品升級，並能推廣衛星技術於民生應用。於社會貢獻上，國家太空中心以衛星資料的提供者自許，協助國土監控、勘災救災、農林規劃、氣象預報、氣候變遷研究，期能降低天然災害的損失。同時，推動太空科技教育，培育種子人才，推廣衛星科技於民生用途。

本份年報主要是介紹國家太空中心今（2009）年度主要的工作成果，內容包括：（1）執行與推動中的計畫現況，如福衛二號、福衛三號及其後續計畫與次軌道科學實驗計畫等，（2）中心內各技術單位的技術能量與工作，（3）中心對外服務與科普教育成果，以及（4）中心今年度一些特別活動與成就的專題報導，如：研討會、科技研發成果(含專利)等。我們希望藉由這份年報的出版，使國人更能瞭解我國太空科技的發展現況，持續給我們鼓勵支持與指教。

福衛三號發射成功



福衛五號預計升空

2006 2009 2013

In October of 1991 the Executive Yuan formally approved the "long-term National Space Technology Development Plan" (also known as the first phase of the Space Science and Technology Development program) which the National Science Council considered a guideline in establishing the "National Space Program Office," thus formally initiating a new chapter in Taiwan's national space program. In April of 2005, in a bid to boost national development and increase the ability of Taiwan to independently develop space technology, the program office was formally renamed the National Space Organization (also NSPO) affiliated to the National Applied Research Laboratory. NSPO is considered the only institute in Taiwan that assumes all space related activities and is characterized as a National Space Agency and Space research and development organization involved in space policy advocacy, space program execution, space technology development and space education promotion.

NSPO currently has 194 employees, 80% of them engineers, including 36 Ph.D. educated R & D personnel and 90 master educated R & D personnel. The organization comprises three divisions: system development/operation, technology development and administrative support. The system development/operation group is responsible for implementing satellite development plans, from plans to host co-ordinate the implementation of work-related programs. Meanwhile, the system operation/technology development group is responsible for providing the technical resources required for project implementation, satellite systems, mission operations, and R & D on key technologies required for future plans. Finally, the administrative support group is responsible for providing administrative support to the Center and implementing the internal administration of the business plans.

The 1st Phase Space Technology Program (1991-2006), in addition to the initiation of organization, establishment of fundamental technology and manpower, infrastructure construction of satellite integration and test facility and ground mission operation/control system needed for space program, was marked by three successful satellite missions, FORMOSAT-1, FORMOSAT-2 and FORMOSAT-3, up to total 8 satellites, for their completion of designated tasks, science experiments.

Unveiled in 2004, the 2nd Phase Space Technology Program not only succeeds the fruitful accomplishments but also peruses the goal of building up full autonomy of space technology in Taiwan and advocating the civil applications of satellite technology and data. For the perspective of academic cooperation, NSPO provides a R&D platform for space science research where joint development among various research institutes and universities may be promoted for dedicated space science and technology. In the perspective of industrial applications, through the joint development of space grade components, NSPO wish to lead the technology upgrade of potential domestic corporations and promote certain satellite technology suitable for civil services. For contribution to society, deemed as satellite data supplier, NSPO pledge its effort to land monitoring, disaster relief, agriculture and forestry planning, weather forecasting and climate change research and wish to alleviate the impact by various natural disasters. Meanwhile, by doing so, NSPO may promote space technology education and incubate personnel dedicated for the promotion of satellite technology in civil services.

This report focuses on the achievements of NSPO during 2009, including: (1) the status update of FORMOSAT-2, FORMOSAT-3, their follow up programs and and sub - orbital science experiments, (2) the accomplishments of specific technology development among various divisions and projects within the organization, (3) major events of NSPO outreach services and space science education promotion, and (4) coverage of various special activities and research results including seminars and patents. Hopefully, the publication of this annual report can help people better understand the development status of Taiwan's space technology, receive comments from all circles and gain public support and encouragement for us.

福爾摩沙衛星二號任務成果

福爾摩沙衛星二號（簡稱福衛二號）為台灣第一顆高解析度光學遙測衛星，其對地解析度為黑白影像2米彩色影像8米，衛星上除光學遙測酬載外也同時搭載高空向上閃電儀。福衛二號於2004年5月21日成功發射至今，目前衛星健康狀況良好，可持續進行遙測取像及高空向上閃電觀測任務。

福衛二號今（2009）年度任務成果，可從任務操作、遙測取像以及科學實驗三方面分別來說明。

在任務操作方面，本年度主要成果，包括：完成五週年健康狀況審查，確定衛星各次系統健康狀態良好，可持續支援衛星遙測與科學任務；完成第四次軌道維護工作，包括衛星傾角及高度的調整，以避免地面軌跡持續偏離台灣本島，並恢復原先規劃通過台灣上空的時間。

在遙測取像方面，除了例行性取像任務外，2009年遙測取像主要用在支援全球環境監控與緊急災害救助，總計完成支援國內國土規劃及監測等重大計畫56次，國際重大災區即時性緊急拍攝需求超過20次以及國際合作計畫APEC海洋資源保育工作小組的SAKE計畫近百次等。如Fig. 1所示，為今年洪都拉斯/貝里斯發生地震後9小時，福衛二號即時提供災後影像給相關單位進行救援工作。

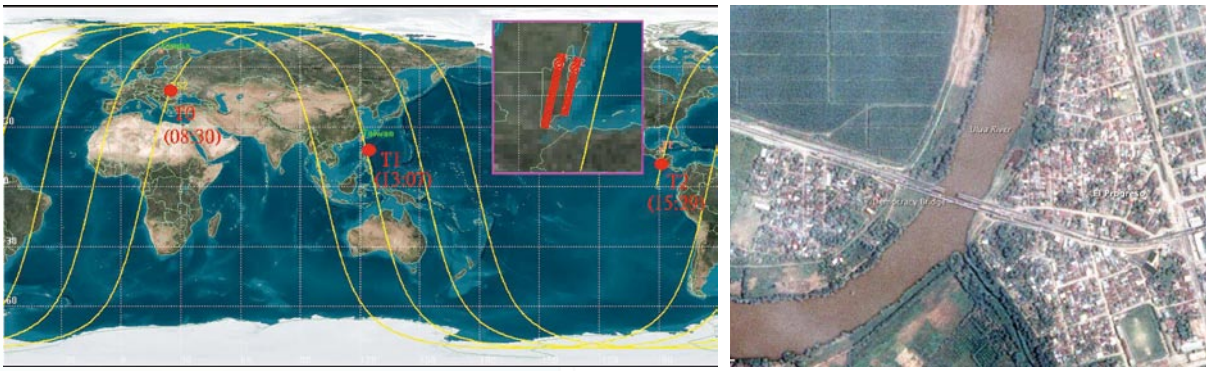


Fig. 1 地震後9小時提供洪都拉斯/貝里斯災後影像。
(Provides Honduras/Belize Image Data in 9 Hours after Earthquake Disaster.)

在科學實驗方面，高空大氣向上閃電儀完成的科學任務，包括：（1）確定高空短暫發光現象的動態演歷及頻譜變化，以解開高空短暫發光現象發生之謎；（2）從事高空短暫發光現象UV波段探索，以尋找新物理及未知現象；（3）確定高空短暫發光現象時大氣的離子化程度，以協助解開閃電上空珈瑪射線輻射產生之謎；（4）建立高空短暫發光現象全球分佈統計數據資料（如Fig. 2所示，為高空大氣向上閃電儀所觀測到高空短暫發光現象全球發生密度分佈圖）；（5）建立大氣暉光、重力波及極光的全球分佈與極地附近極光隨著海拔高度變化的觀測資料庫等。高空大氣向上閃電儀科學團隊未來將持續利用福衛二號進行科學觀測，並與日本東北大學、美國杜克大學（Duke University）等國內外9個團隊合作執行資料分析與驗證等研究。

FORMOSAT-2 Mission Achievements

FORMOSAT-2 is a high resolution optical remote sensing satellite with 2m Ground Sampling Distance (GSD) in Panchromatic (PAN) band and 8 m GSD in Multi-spectral (MS) bands in the Nadir direction. Besides the remote sensing instruments, FORMOSAT-2 also carries Imager of Sprites on the Upper Atmospheric Lightning (ISUAL) for measuring upper atmospheric lightning phenomena. FORMOSAT-2 was successfully launched on 21st May 2004. The satellite remains in good working order and is continuously taking images and conducting ISUAL scientific missions.

FORMOSAT-2 achieved significant things during 2009 in the following three areas: mission operations, image taking and scientific experiments. Regarding the mission operations, key achievements in 2009 include the completion of 5 years of satellite state-of-health (SOH) reviews, confirming that all subsystems are in good condition and can continuously support satellite missions and the completion of the 4th Orbit Maintenance (OM#4) for adjusting inclination angle and altitude. Following this operation, the Local Time of Descending Node (LTDN) returns to the value from its initial orbit in 2004 enabling the ground track to continue passing over Taiwan. On its current ground track, FORMOSAT-2 can perform imaging activities over Taiwan from a better viewing angle.

Regarding the image taking, since the image data are widely used over the industries, various government institutes, academia, research communities and the public. Image taking achievements during 2009 have mainly involved supporting global environmental monitoring and disaster rescue. To summarize, this study supports the domestic major projects on the land planning and monitoring for 56 times, the real-time emergent imaging for the international severe disasters for more than 20 times (one of the example can be found in Figure 1.), and near the international cooperation project SAKE which is under the APEC ocean resource protection team for more than one hundred times. A notable example of cooperation on international disaster relief involves the use of FORMOSAT-2 to provide imaging for use in coordinating relief efforts within 9 hours of the devastating Honduras/Belize earthquake in 2009.

Regarding scientific research, work completed during 2009 includes: (1) Ascertaining the dynamic evolution and spectrum variation of the Transient Luminous Event (TLE) phenomena to clarify the occurrence of the TLEs; (2) Searching for the UV band of the TLE to identify new physical explanations and unknown phenomena; (3) Confirming the ionization level of the TLE to help the occurrence mystery of y-ray radiation on the upper of the flashing lightning; (4) Building the TLE global distribution statistics database shown in Fig. 2; (5) Building observation databases for the global distribution of airglow, gravity wave and aurora, and for the variation of aurora with altitude in polar regions, etc. In the future, the ISUAL science team will continuously perform those observations and cooperate with nine teams worldwide, including Tohoku University, Japan, and Duke University, USA, to perform data analysis and verification research.

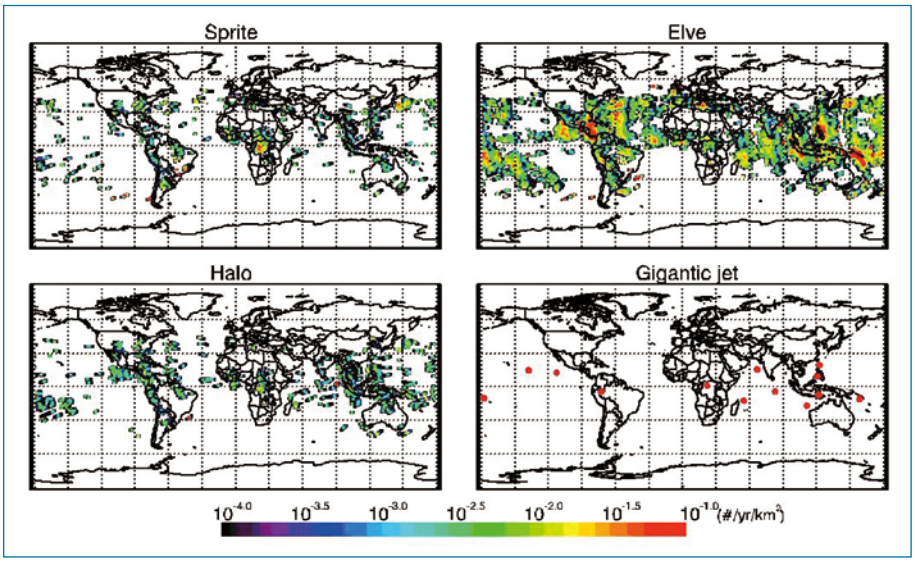


Fig. 2 高空大氣向上閃電儀所觀測到之高空短暫發光現象全球發生密度分佈圖。
(Global Occurrence Density of TLEs Observed by ISUAL.)

福爾摩沙衛星三號任務成果

福爾摩沙衛星三號(簡稱福衛三號)是一大型台美雙邊國際合作計畫，其利用6顆微衛星建立起全球大氣即時觀測網，是全世界第一個以星系觀測方式，進行掩星觀測的計畫。福衛三號星系自2006年4月15日發射至今（2009）年已邁入第4年，衛星對氣候、氣象與電離層現象持續進行觀測，觀測資料並通過地面觀測站分送給各地研究人員。福衛三號不僅在學界及研究單位受到許多佳評外，同時對氣候與氣象作業中心帶來新的能量，因此獲得「太空中最精準的溫度計」的美譽。

目前全世界共有50個國家超過1,100個使用者註冊使用福衛三號觀測資料，歐盟、法國、美國、日本、韓國等氣象中心已陸續將資料納入氣象預報系統中，今（2009）年7月中央氣象局亦正式納入福衛三號掩星資料進行氣象預報工作。另外，中央大學GPS-ARC中心負責推廣福衛三號衛星資料應用於學術研究與氣象、氣候預測模式的改良，許多研究均指出，不論是對全球或是區域性的氣象數值預報模式、颱風路徑與強度預測，福衛三號資料都產生了正面的貢獻。除此之外，針對2006年的珊珊颱風、2008年辛樂克與卡玫基颱風，以及2009年莫拉克颱風的研究報告中也指出，福衛三號資料對進行的颱風路徑預測有正面的幫助。

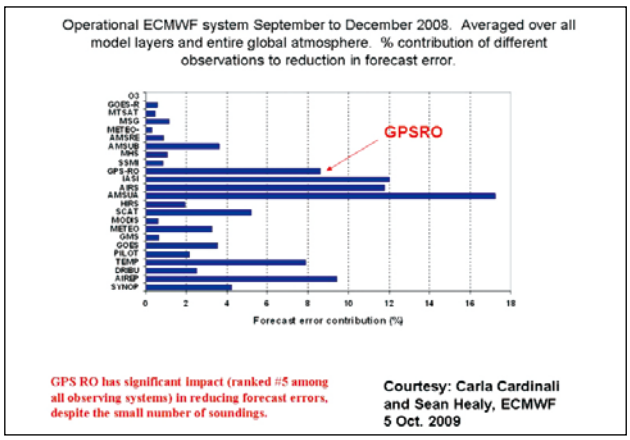
依據歐洲氣象中心所發表的研究報告顯示（如Fig.1所示），在2008年9至12月間，無線電掩星資料占所有衛星（含飛機）資料的4.7%，但是它對減少預報誤差的貢獻佔8.5%，在全球所有24種氣象資料中排名第五，這顯示福衛三號所提供的低成本高效率掩星觀測資料對天氣預報模式有極大的貢獻。

由於福衛三號掩星資料的實質效用，包括美國、英國、德國、丹麥和韓國等國的科研單位與我方分別簽訂國際合作協議或備忘錄，進行雙邊互惠合作，進一步提升台灣的國際地位。在各國氣象中心陸續匯入福衛三號資料後發現有利於相關的氣象預報和模擬，因此免費開放我方使用其所獲得的其他氣象資料，再次突破過去我國氣象資料來源受限的屏障。例如2009年台灣與歐洲氣象中心簽署氣象資料共享的協議。

福衛三號操作運轉，預計於2011年到期（設計壽命5年），亟需新的後續星系補位以持續提供相關的氣象資料。由於福衛三號的無線電掩星技術驗證成功和成效顯著，世界氣象組織（WMO）曾於2007年年會正式建議國際上相互合作以延續並發展更多無線電掩星技術的氣象衛星星系，以提升數值天氣預報的準確性。美國國家研究委員會（NRC）亦強烈建議美國國家海洋暨大氣總署（NOAA）應將無線電掩星技術的氣象衛星任務列為其主要發展的氣象觀測任務。

規劃中的福衛三號後續星系（如Fig. 2所示）由12顆新的微衛星組成，接收GPS/GALILEO/GLONASS訊號，將比目前所能提供的掩星資料相對地密集5倍，可以滿足未來作各種尺度氣象預報所需用到的資料量。福衛三號後續計畫在未來將承接福衛三號目前的優勢，並將擴大提供有用的衛星掩星氣象資料，對於我國的民生福祉、社會貢獻、學術研究、數值預報模式、儀器發展及任務型微衛星自主發展等將有重大幫助。

Fig. 1 歐洲氣象中心的研究顯示，在2008年9至12月間，無線電掩星資料占所有衛星(含飛機)資料的 4.7%，但是它對減少預報誤差的貢獻佔8.5%，在全球所有24種氣象資料中排名第5。
(ECMWF reported that RO measurement contribute 8.5% to their prediction error reduction effort, with a volume of 4.7% out of all satellites (including airplanes) collected measurements, a performance ranked number 5 among 24 meteorological datum.)



FORMOSAT-3 Mission Achievements

The FORMOSAT-3 Program is a major collaboration between Taiwan and the US to implement a Constellation Observation System for Meteorology, Ionosphere, and Climate (COSMIC) using Global Positioning System (GPS) Radio Occultation (RO). The FORMOSAT-3 approach provides near real-time data to support research and practical projects involving weather prediction, space weather forecasting, and climate monitoring, and is the pioneering technique in this area. The FORMOSAT-3 constellation has been in orbit around 4 years, since April 15 of 2006. All collected RO measurements were freely distributed globally to international registered users three months after the commissioning of all six satellites. The FORMOSAT-3 constellation represents a new chapter in research on meteorology and weather forecasting, and has increased the profile and reputation of NSPO and Taiwan. This project is universally recognized by its users as “the world's most accurate, precise, and stable atmospheric thermometer in space.”

As of the end of 2009 over 1,165 registered users from 50 nations have signed up for access to the FORMOSAT-3 measurements. Furthermore, weather forecasting centers in the EU, France, United States, Japan and Korea have begun to incorporate those measurements into their systems. Since July 2009, the Central Weather Forecasting Bureau of Taiwan has also formally included FS-3 RO data in their weather predictions. Moreover, applications of the FORMOSAT-3 data for atmospheric research and weather prediction are being coordinated by the GPS-ARC center, National Central University; Numerous studies recognize the significant contribution of FS-3 measurements to numerical weather prediction both locally and globally. For example, FS-3 RO data assisted route prediction for typhoons Shanshan in 2006, Sinlaku and Kalmaegi in 2008 and Morakot in 2009.

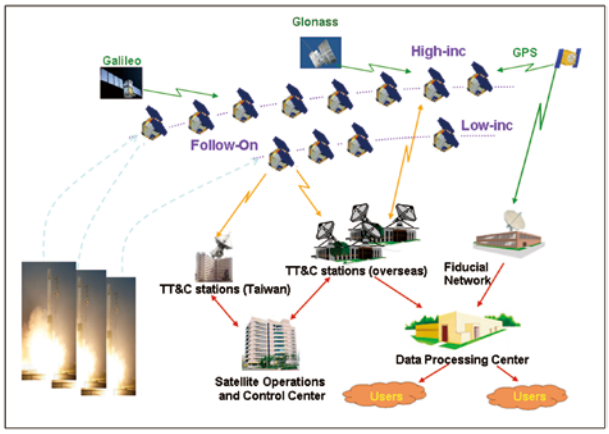
Furthermore, a report filed by the European Centre for Medium Range Weather Forecasting reveals that RO measurement, with a volume of 4.7% out of all satellites (including airplanes) globally collected measurements, contributes 8.5% of the prediction error reduction achieved by these satellites, and thus ranks fifth among 24 meteorological datum in terms of performance (as shown in Fig. 1). This evidence implies that FS-3 RO measurement contributes significantly to weather prediction.

Owing to the significant impact of FS-3 RO data on meteorological research, various institutions in the United States, Great Britain, Germany, Demark and Korea have signed memorandums on mutual research collaboration. Thanks to these cooperation frameworks, Taiwan has been able to access data from partners, significantly reducing constraints on meteorological data sharing. The meteorological data sharing agreement between Taiwan and the European Centre for Medium Range Weather Forecasting provides a great example of such cooperation.

FORMOSAT-3 is expected to have a mission lifetime of 5 years, ending in 2011. Given the enormous success of the FORMOSAT-3 program, in 2007 the World Meteorological Organization (WMO) recommended international collaboration to continue RO observations and urged that the current mission be continued. NSPO and NOAA have taken the initiative in planning a future mission to continue providing benefits for the global weather community.

The FORMOSAT-3 Follow-on mission is a significantly improved constellation system comprising a new constellation of 12 low-Earth orbiting satellites tracking GPS, GALILEO and GLONASS navigation systems (see Fig. 2). The new system can potentially provide up to 14,000 RO soundings per day, representing a density five times that of the current system, and will help ensure FORMOSAT-3 continues benefiting Taiwan and the world.

Fig. 2 福衛三號後續星系任務架構圖。(The Mission Architecture of the FORMOSAT-3 Follow-on Mission.)



福爾摩沙衛星五號

依據「第二期國家太空科技發展長程計畫（2004~2018）」，國家太空中心規劃發展兩顆遙測衛星，以建立我國衛星本體與遙測酬載自主發展的能量，並接續福衛二號遙測影像的供應。所規劃第一顆自主發展的遙測衛星命名為福爾摩沙衛星五號（簡稱福衛五號），其任務軌道為高度720公里再訪週期為2天的太陽同步軌道，福衛五號將攜帶對地解析度2米（全色相）及4米（多頻譜）光學遙測酬載，執行對地觀測任務。福衛五號計畫除將繼續提供全球影像服務任務外，並期能藉由本計畫的執行，建置我國光學遙測酬載與衛星本體研製能量。福衛五號飛行示意圖，如Fig. 1所示。

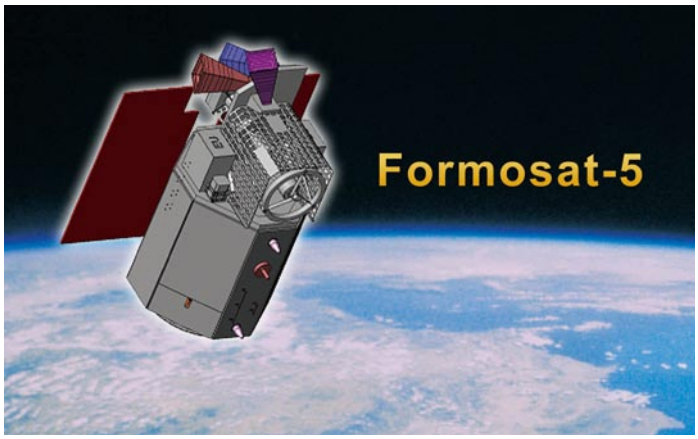


Fig. 1 福衛五號示意圖。
(The Flight Configuration of FORMOSAT-5.)

此次福衛五號計畫遙測酬載，完全由國內自主研發，其中聚焦面組合中關鍵感測器元件，是由國內廠商開發互補式金屬氧化層半導體（CMOS）感測器，來取代傳統光學遙測酬載使用的電荷耦合元件（CCD）感測器，以掌握關鍵元件來源，落實自主發展太空科技的計畫目標。為了審慎評估上述計畫的可行性，國家太空中心首先完成「福衛五號國內研製CMOS感測器可行性評估報告」，並邀請數位國內外專家學者籌組獨立評審委員會，於2009年7月召開技術可行性評估會議進行評審，會中達成以下共識：在目前國內時空環境下，CMOS感測器發展（晶片、封裝與濾光片等）的產業技術，可以回饋到太空技術，未來研發的成果亦可回饋到產業界，因此一致贊成太空中心進行國內研製CMOS感測器。

遙測酬載發展團隊是由國家太空中心與儀器科技研究中心共同組成，本（2009）年度首先導入整合產品團隊（Integrated Product Team） 運作管理模式，以期提升團隊運作效率與能量整合。在分工上，國家太空中心負責系統整合與影像儀機構設計和熱控分析，儀器科技研究中心則協助執行光學設計與雜光分析，本年度共同完成遙測影像儀光學基線設計及分析，包括立體構型建立、成像品質MTF與SNR分析、雜光分析及遮筒設計、主鏡減重結構設計與分析、RSI機構基線設計、初步RSI熱分析等。另外也進行系統所需硬體、設備及服務規劃重要合約採購作業。

福衛五號計畫於2008年9月完成系統設計審查，同時於今（2009）年分別完成（1）衛星本體設計展示，衛星本體元件配置及遙測酬載構型，如Fig. 2所示，以確認各次系統需求及其設計符合系統需求規格，（2）召開「福衛五號使用者會議」，協助國內遙測影像使用者，瞭解福衛五號遙測酬載發展策略的改變及遙測影像模擬結果等，（3）召開「福衛五號系統設計後續審查會議」，確認任務成功定義、衛星元件環境規格及科學酬載資源配置等三項重要議題及更新需求，（4）修定福衛五號執行計畫書，主要變更遙測酬載自主策略及以2013年發射為目標。

FORMOSAT-5 Mission

The FORMOSAT-5 Program is one of the major satellite programs planned as part of the 2nd Phase Space Technology Development Plan of Taiwan (2004~2018). FORMOTSAT-5 will carry an electro-optical Remote Sensing Instrument (RSI) with ground resolutions of 2m panchromatic band and 4m multi-spectrum bands to perform earth observation (Fig. 1). The satellite will be deployed in a sun-synchronous orbit with an altitude of 720km and a revisit cycle of 2 days. The mission of FORMOSAT-5 will serve as a follow-on mission of FORMOSAT-2, commissioned in May 2004, to continuously provide images for domestic and global users. The FORMOSAT-5 program is also considered a serious major step in demonstration of the self-reliant space technology in Taiwan.

The RSI acquisition strategy of the FORMOSAT-5 Program is to acquire two key components, Focal Plane Assembly (FPA) and Electronic Unit (EU), domestically rather than out-sourcing to foreign suppliers. The CMOS (Complementary Metal-Oxide-Semiconductor) image sensor is selected to replace the CCD image sensor to build a partnership with the domestic CMOS industry. FORMOSAT-5 is anticipated to be one of the first satellites to be flown with the advanced CMOS Image Sensor (CIS). To achieve this goal, NSPO performed a feasibility study with the conclusions summarized in “The Feasibility Study of Domestic Development of CMOS Sensor for FORMOSAT-5”. In July 2009, a review board comprising CMOS scholars and experts came to a conclusion that the domestic development of CIS on FORMOSAT-5 is technically feasible and promising to Taiwan’s space program. Besides CIS, NSPO also decided to obtain the Electric Unit (EU), which is fitted with functions of image processing unit and solid state recorder, from a domestic supplier. To ensure sufficient domestic resources to support RSI development, NARL also conducted a review meeting examining the feasibility of domestic RSI development in August of 2009. The review committee strongly supported the revised acquisition plan, and believes that this approach will significantly benefit the FORMOSAT-5 program and contribute to achieving the long-term goal of space technology development in Taiwan.

NSPO and ITRC also formed an Integrated Product Team (IPT) to improve teamwork and synergy in RSI development. Under the IPT framework, NSPO leads system integration, as well as mechanical and thermal design while ITRC is responsible for optical design and stray light analysis. To date, the IPT has completed a baseline system design and analysis of the RSI Configuration 3D Model, MTF & SNR Analysis, Stray Light Analysis and Baffle Design, Main Mirror Weight Reduction Analysis and Design, RSI Structure Design, and Preliminary RSI Thermal Analysis. The required hardware, equipment, and service derived from the system design baseline have been sourced from either in-house development or procurement accordingly.

Kicked off in July 2008, the FORMOSAT-5 Program completed a System Design Review (SDR) in September, 2008. The FORMOSAT-5 program has accomplished: (1) satellite bus design demonstration focused on clarifying subsystem design requirements, the layout of the spacecraft components and the configuration of the remote sensing instrument (as shown in Fig. 2), (2) FORMOSAT-5 user conference for domestic remote sensing image users to update FORMOSAT-5 payload acquisition strategy revision and imaging simulation results, (3) FORMOSAT-5 delta System Design Review to review the action items arising in the SDR meeting and requirement updates, (4) FORMOSAT-5 Implementation Plan (revised vision) mainly changed with self-reliant remote-sensing payload strategy and 2013 launch as the goal.

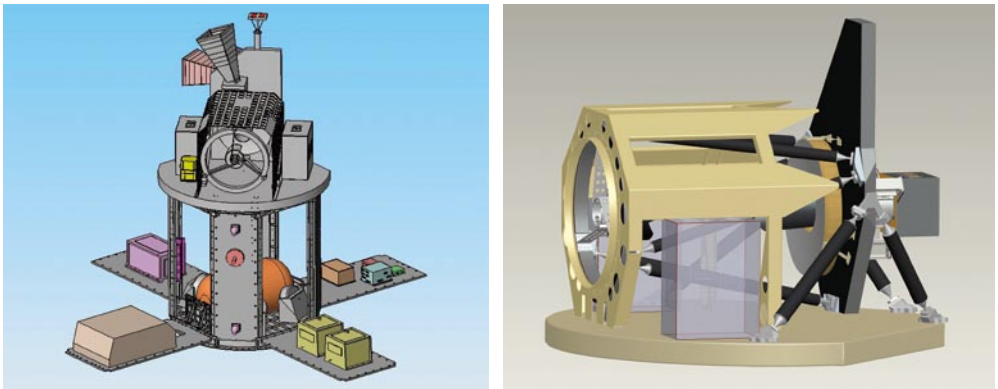


Fig. 2 衛星本體元件配置及遙測酬載構型。
(The Layout of Spacecraft Components and Configuration of the Remote Sensing Instrument.)

任務發展計畫

任務發展計畫主要是為發展台灣未來衛星任務，同時兼具發展任務系統及其技術而成立。透過衛星遙測技術達到「環境觀測、災害防救」是任務的願景，也是本計畫目前發展的重點。然而為達到此種任務發展工作的成熟階段，國內太空科技界除了需要加強光學/微波酬載研發能力外， 也需要（一）建立高精準度指向的微衛星平台來承載輕小型且被動的光學/微波酬載儀器；（二）繼續小衛星平台發展工作，例如福衛五號。

在光學/微波酬載研發方面，首先一專為台灣量身打造的合成孔徑雷達（SAR，Synthetic Aperture Radar）任務概念已經完成，其主要任務儀器將裝置在未來國家太空中心研製的小衛星平台。此一任務概念的形成是透過中央大學與國家太空中心發展團隊經過嚴格的應用需求、任務概念設計及其系統分析推導而得。經過上述程序建立的台灣首次星載合成孔徑雷達應用需求，同時也在今（2009）年10月底國內舉辦合成孔徑雷達（SAR）使用者研討會發表並形成共識。此次研討會來自國內各個不同的使用族群共約100人，會前也邀請了各使用群組的專家學者進行多次準備的工作。此一星載合成孔徑雷達任務發展工作仍將持續進行，未來工作首先是任務系統可行性的建立、任務概念確定與酬載系統/次系統設計分析，以確定此一合成孔徑雷達任務概念可滿足台灣未來需求。

除了合成孔徑雷達外，國家太空中心於今（2009）年內又確定另外兩個任務構想可進入任務發展工作的第一階段， （一）可搭載於高精準度指向微衛星平台的高光譜影像儀（HSI，HyperSpectral Instrument），（二）可搭載於高精準度指向微衛星平台或小衛星平台的微波輻射計（MWR，MicroWave Radiometer）。

另外，成功大學光學酬載發展團隊在國家太空中心的協助下，發展出一由四個CCD照相機與四個CMOS照相機形成的一組探測儀器，成功大學團隊準備藉由此一儀器進行垂直大氣耦合探測。在其初步設計審查（PDR）會議中，他們已成功地展示由CMOS晶片組件組裝出的CMOS照相機，此一經驗與能力展示，將有助於國家太空中心在遙測影像儀（RSI）與高光譜影像儀（HSI）的發展工作。

在微衛星發展方面，由成功大學與國家太空中心團隊共同發展的CKUTEX衛星，如Fig.1所示，已獲得重大成果，CKUTEX衛星各次系統、酬載已於今（2009）年12月28日通過「細部設計審查」（CDR）。這是國內首次有一大學科技團隊在國家太空中心的指導與協助下，而能達到如此微衛星自主發展的成就。此一微衛星雖不能滿足高精準度指向的需求，但若經過國家太空中心已有的高精準度指向的設計與製作能力來加強並改進，未來當可為災害防救與環境觀測等任務提供一低成本又快速發展的微衛星平台。

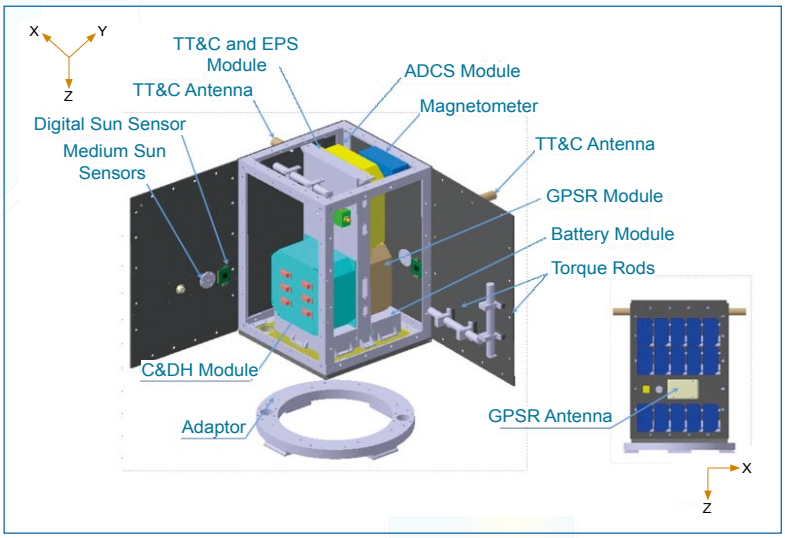


Fig. 1 | CKUTEX為衛星外觀。
(CKUTEX Micro-satellite Configuration.)

Mission Development Program

The Missions Development Program is to develop future satellite missions along with the development of essential mission system elements and technologies for Taiwan. The missions vision has been established as “Environments Observation,Disasters Prevention and Rescue” through satellite remote sensing techniques and it has been the current focus of the missions development program. The approaches for achieving the matured work of such missions development will require the strengthening of spaceborne optical and microwave remote sensing payloads development, and also require (1) an establishment of a high-accuracy pointing remote sensing micro-satellite platform for accommodating the small and lightweight passive optical or microwave payload instrument(s) and (2) the continuation of small satellite platform development such as the effort for the FORMOSAT-5 satellite.

One mission concept formed within this year is a tailored SAR (Synthetic Aperture Radar) for Taiwan’s remote sensing needs. The mission will require the SAR as the main instrument on a small satellite platform. The mission concept has been derived based on a rigorous applications requirements derivation process in Taiwan performed by the NCU/NSPO team through mission conceptual design and system analyses. The established applications requirements were then examined in a domestic users conference with participants near 100 people from various user groups after many preparation meetings with the user field experts and SAR mission system engineering support. Continued effort will be taken for mission system feasibility establishment and mission definition along with its satellite payload development to make sure the mission being defined will be ready for a future space program in Taiwan.

Two other missions identified and undertaken are (1) an optical HSI (HyperSpectral Instrument) upon a high-accuracy pointing remote sensing micro-satellite platform, (2) a MWR (MicroWave Radiometer) either upon a high-accuracy pointing micro-satellite platform or upon a small satellite platform.

There is also a payload development effort which may pave ways for future optical instrument development in Taiwan. The E-VAC instrument team of NCKU just passed its PDR in NSPO, and the equipment is currently under design comprises four CMOS and four CCD cameras for their scientific investigations. They have demonstrated their ability to assemble a CMOS camera from a CMOS chip incorporating custom-made electronic circuits designed and built in-house. Owing to the hands-on skills and experience of this team, the bench tests (with calibrations) conducted in their optical laboratory will benefit both the RSI development and HSI mission development.

The most important effort in relation to the micro-satellite platform development carried out in Taiwan this year is the CKUTEX satellite development performed by the NCKU/NSPO team. Figure 1 shows the payloads and subsystems under design has just completed the Critical Design Review (CDR) approved by NSPO on December 28, 2009. This is the first time in Taiwan that a university team with technical guidance and assistance from NSPO has been able to perform such a sophisticated micro-satellite design from a formulated mission within one year. The satellite may not meet the standards of future high-accuracy pointing remote sensing micro-satellites, as described above. However, this achievement does demonstrate that this team can develop space systems in low cost and speedily. The missing capability is in the area of high-accuracy satellite attitude control which NSPO has already demonstrated this capability by developing the FORMOSAT-5 space system.

探空七號火箭科學酬載發展

依據「第二期國家太空科技發展長程計畫（2004~2018）」中次軌道科學實驗計畫，國家太空中心預計發射10至15具探空火箭。此計畫執行至今總共進行6次探空實驗，包括：高空流場的三甲基鋁（TMA）釋放量測、電離層光度計實驗、全球定位儀測試、電離層離子探測器實驗、鼻錐罩開啟設計研發、衛星推進次系統研發測試及回收機構設計測試等。國家太空中心與國內學研界合作執行次軌道科學實驗計畫，為台灣累積了探空科學酬載自主發展的經驗與能量。台灣探空火箭是採用中山科學研究院研發的無控火箭，該型火箭採自由彈道飛行方式，以氣動力翼翅或裙狀外型，使氣動力中心位於重心之後，以保持火箭穩定飛行。

探空七號任務是由國家太空中心、中央大學以及中山科學研究院共同合作，進行台灣上空電離層不規則體量測，其中國家太空中心負責任務模擬與系統整合，中山科學研究院提供無控探空火箭與發射服務，而中央大學團隊則是提供電離層電漿量測儀（如Fig. 1所示）與地面雷達同時進行科學實驗。電離層電漿量測儀雖已在探空五號任務執行測試，本次試驗進行改良，將平面式電漿探測儀改為斜切式並增加姿態量測模組，以改進火箭姿態所造成量測影響。

Fig. 1 探空七號的科學酬載。
(Science Payload for the Sounding Rocket No.7.)

探空七號科學實驗目的，是以現場量測電離層離子密度與溫度，同時配合地面雷達的即時觀測，研究台灣地區高度80至280公里間電離層的電漿密度與溫度隨高度的變化情形以及電漿不規則體結構與產生機制。此不規則體的出現，將導致人造衛星與地面通信品質降低，嚴重時甚至可能斷訊。為確保此次實驗資料的品質，電離層電漿量測儀（如Fig.2所示）包含：平面式電漿探測儀、阻滯電位分析儀與姿態量測模組。姿態量測模組包括一個磁力式姿態計與兩個離子捕獲器，其中平面式電漿探測儀可量測電子溫度，阻滯電位分析儀可量測離子溫度與成份，姿態量測模組除了可獲得火箭攻角外，也可獲得高解析度離子密度。透過各項儀器量測，將可獲得當時電離層完整的電漿特性，有助於了解台灣上空電離層電漿不規體的結構。

Sounding Rocket No. 7 Scientific Payload

During the second phase of the long-term development plan for National Space Technology, NSPO plans to launch 10~15 sounding rockets. The Suborbital Scientific Experiment program has completed six flight missions to date, including TMA, Photometer, GPS Receiver, Ion Probe, Recovery Capsule, N2H4 Thruster, Payload Fairing Opening, and Payload Separation experiments. From these missions, the science teams have accumulated enormous experience in developing scientific payloads. The sounding rocket, provided by CSIST, was a pre-mixed solid propellant rocket without flight control design. Throughout its free flight course, the rocket was designed to ensure flight stability by keeping its aerodynamic center (AC) behind its center of gravity (CG) using fins and flares.

The mission of the Sounding Rocket No. 7 involves joint efforts from NSPO, CSIST, and NCU. NSPO performed mission simulation and system integration analysis. CSIST provided a free-flight solid rocket and launch services. Furthermore, Professor Chu's NCU team developed the scientific payload (Fig. 1) and ground radar systems for use in the sounding rocket experiment. [A precedent experiment had been performed in the Sounding Rocket No. 5 mission. Due to the uncertain interpretation of the experimental results related to rocket re-entry course, the science team proposed an additional flight to explore the effects of rocket attitude on data quality by slightly modifying the design of the Langmuir Probe.

The scientific mission of sounding rocket No. 7 is to gather in-situ measurements of plasma density and temperature profiles of the ionosphere over southern Taiwan. With the aid of instantaneous measurements from ground radar, the rocket thus can investigate plasma irregularities within the ionosphere around 80~280 km above the Earth. Plasma irregularities in ionospheric E and F regions are very common [over the low-latitude region of Taiwan, and are generated via respective plasma instability processes. These plasma irregularities are responsible for causing the amplitude and phase of scintillations that may impair the communication between satellites and ground stations. The Space Payload Laboratory of NCU provides Ionospheric Plasma Sensors for measuring the mechanism of plasma irregularity. (Fig. 2) To enhance the scientific quality, Ionospheric Plasma Sensors comprise Planer Langmuir Probe, Retarding Potential Analyzer and Aspectmeter, which include a single Tri-axis Fluxgate Magnetometer and two Ion Traps. Planer Langmuir Probe can measure electron temperature. Meanwhile, Retarding Potential Analyzer can obtain ion temperature and ingredients. Besides measuring sounding rocket angle of attack, Aspectmeter can also obtain high-resolution ion density. The plasma characteristics of the ionospheric regions can be exploited by suitable arrangement of Ionospheric Plasma Sensors. These data can help clarify the mechanisms influencing plasma irregularity over Taiwan.

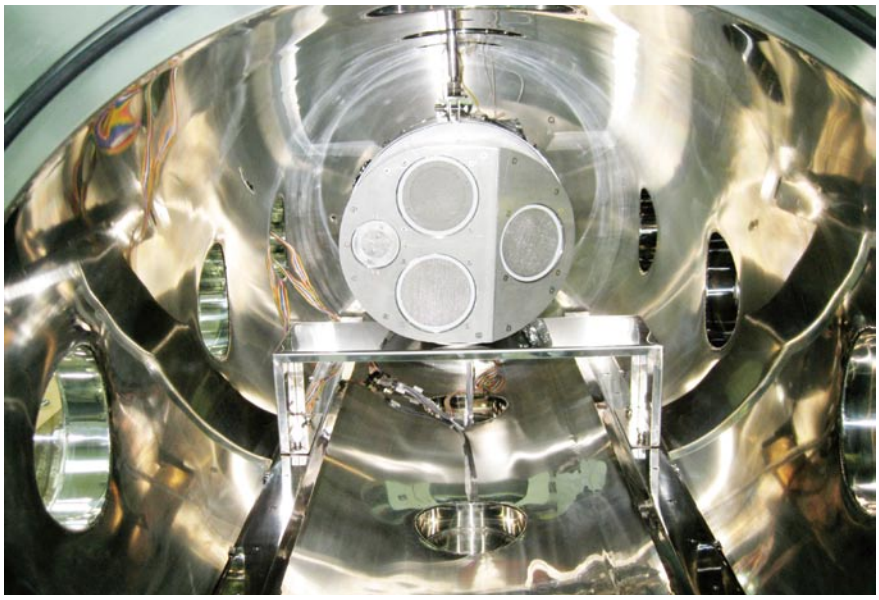


Fig. 2 探空七號酬載安置於太空電漿模擬艙。
(Science Payload Installed in the Sounding Rocket No.7.)

系統工程

系統工程組主要任務是以系統工程的技術與方法，提供太空計畫發展過程中系統層次的規劃、分析、擇優與管理。除此之外，為符合技術革新與支援計畫的任務目標，近年來系統工程組持續致力於系統設計分析工具的開發，2008年底到今（2009）年度主要完成的工作，包括：衛星發射載具彈道設計模擬、衛星模擬器開發與非同步取像影像模擬與影像品質分析。

火箭彈道設計在衛星發射載具系統發展初期或是最後操作階段皆扮演重要的角色。系統工程組已成功發展火箭軌跡最佳化模擬軟體，該軟體採用混合式演算法，結合基因演算法與隨機搜尋法的優點，求解衛星發射載具彈道軌跡設計最佳化問題。其設計結果可以作為未來載具與衛星耦合負載分析的基礎，同時可以結合蒙地卡羅法進行衛星入軌精度（見Fig. 1）與火箭飛行安全散佈分析工作。

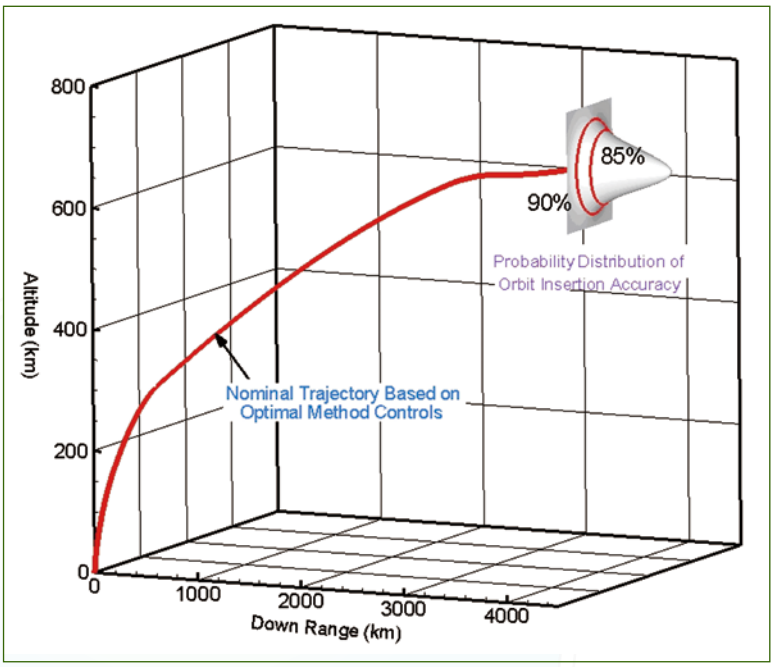


Fig. 1 | 入軌精度機率分佈。
(Probability Distribution of Orbit Insertion Accuracy.)

為了支援國內遙測衛星計畫的發展，系統工程組除了利用即時模擬工具作為平台，發展衛星模擬器軟體外，也進行一系列的模擬影像系統分析。在模擬器發展方面，已完成的基本模組包括：太空環境與衛星動態模型、致動器與感應器模型、飛行電池模型、與簡單控制邏輯。此一衛星模擬器平台可以進一步與衛星軌道模擬軟體連結進行動態展示。

在模擬影像系統分析方面，系統工程組模擬各種衛星取像模式下的影像，以進一步分析影像品質，例如：非同步取像（沿經度線取像）的影像模擬，我們利用衛星軌道資料與取像排程所計算出來的衛星姿態，將原始影像（如Fig. 2A所示）搭配有理多項式參數（RPC），反轉成在非同步取像姿態下的影像（如Fig. 2B所示）。從Fig. 2C可以看出Level 2影像與沿經線取像的模擬影像方向一致。另外，我們也作了調制轉換函數與訊噪比影像分析，這些分析將可作為福衛五號系統發展的重要依據。

Systems Engineering

Planning, analyzing, optimizing and managing the overall space program of NSPO by integrating techniques and experiences of various disciplines is the primary objective of the System Engineering (SE) Division. This work includes numerous individual functions and their interactions in the space, launch, ground and data management segments. To fulfill the mission goals in relation to technical advance and program support, the Systems Engineering Division continually strives to research and develop the following systems analysis tools and yields various fruitful results.

Rocket trajectory design is important in both the initial and final stages of satellite launch vehicle development. NSPO has developed simulation software for optimizing rocket trajectory. This tool is based on a hybrid method that combines the genetic algorithm and localized random search method and applies them to trajectory optimization design via 2-D and 3-D maneuver programs separately. Design analysis employing this tool can also be used in coupled load analysis investigating the launch vehicle and satellite. In the near future, the proposed tool will be integrated with the Monte Carlo method for orbit insertion accuracy and range safety analysis.

To establish the capabilities required to independently develop the space programs of NSPO, the Systems Engineering Division has developed a satellite simulator based on the EuroSim real-time simulation platform; the basic structure of the developed prototype includes: 1. Dynamic model and space environment model containing the Sun/Moon Models etc, 2. Actuator/Sensor model construction based on the predecessor of the FS-5 satellite, which contains a general Noise Model, 3. Flight battery model based on the FS-5 predecessor, 4. A simple control law. Furthermore, the simulation platform can be linked to STK to conduct a real-time demonstration involving] dynamic visualization.

To perform imaging quality analysis, various imaging scenarios are considered in simulation. For the case of the asynchronous imaging mode, the tool translates the initial image incorporating RPC parameters into a simulated image using ephemeris of satellite orbit and attitude for certain imaging tasks (Fig. 2B). Clearly, the simulated raw image and the geometric corrected Level 2 image share identical orientation. Additionally, to evaluate image quality it is necessary to simulate the images using different system parameters, such as SNR and MTF, via visual demonstration and analysis, thus supporting the evaluation of acceptable image quality parameters for FORMOSAT-5.

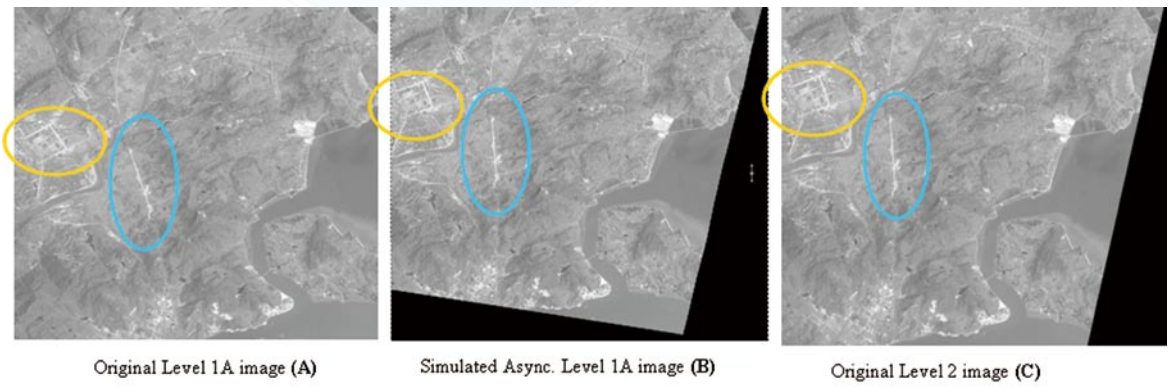


Fig. 2 非同步取像模擬。
(Asynchronous Imaging Simulation.)

電機工程

衛星電機組主要負責衛星上電腦次系統、電力次系統、通信次系統和地面測試系統的設計、分析、驗證與測試工作，同時也負責衛星關鍵電機電子元件自製，如指令與資料管理單元（CDMU）、電力控制與配置單元（PCDU）及遙測酬載電子單元（EU）的發展。透過這些元件的開發所建立的傳承設計，將可應用於其它衛星電子單元設計，更進一步擴大國內在衛星系統發展的自主能力。

指令與資料管理單元，如同人類的大腦一般，為衛星指令控制與資料處理中心，是國內太空科技邁向自主發展的衛星關鍵電子元件。國家太空中心已完成其工程體（如Fig. 1所示）的研製與驗證。此一指令與資料管理單元採用歐州太空總署推展具容忍失效功能的LEON3處理器，與SpaceWire高速資料匯流排。另外，電力控制與分配單元如同人類的心臟一般，為衛星系統電力控制與分配中心。此項元件是國家太空中心與中山科學研究院共同合作發展的衛星關鍵元件，具備超過150個電力輸出通道，現今已完成工程體的研製與驗證，如Fig. 2所示。所建立的傳承設計，可作為下一代衛星電力控制與配置單元的設計基礎。指令與資料管理單元與電力控制與配置單元未來將陸續完成工程驗證體以及飛行體的研製，裝載於福爾摩沙衛星五號。

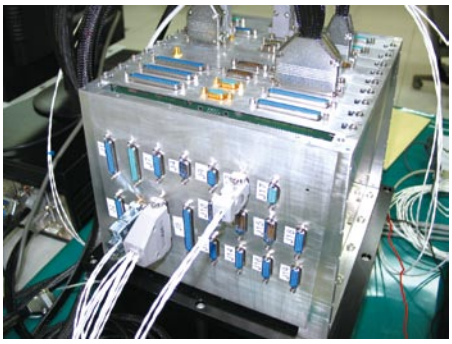


Fig. 1 CDMU工程體。
(CDMU Engineering Model)

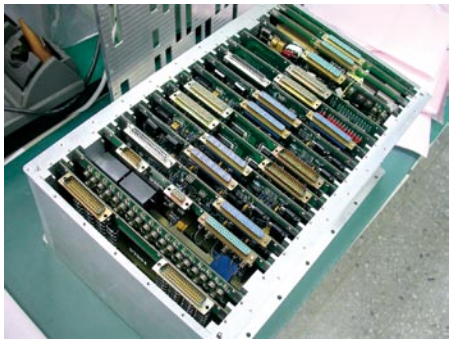


Fig. 2 PCDU工程體。
(PCDU Engineering Model)

由國內自主發展的衛星地面電機支援設備（EGSE），是衛星系統整合測試階段所必需的一項重要設備。如Fig. 3所示，此EGSE架構以網路聯結，具備高度自動化設計，可降低衛星整合與測試時間。在主控軟體發展部份，我們已完成衛星遙測資料CCSDS Reed-Solomon編/解碼、衛星控制指令BCH編/解碼及加密/解密軟體開發。國家太空中心除了具有衛星系統測試設備的開發能力外，亦具備衛星元件測試設備的開發能量，如已完成陀螺儀元件測試設備，及預計2010年完成的具備高度自動化設計的指令與資料管理單元測試設備。

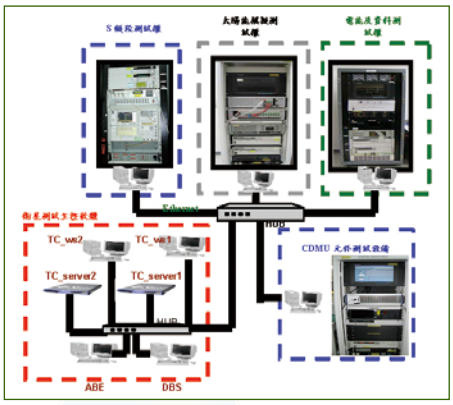


Fig. 3 衛星電機地面輔助設備。
(EGSE)

在衛星通信發展方面，我們除了進行衛星通訊裕度分析、天線場型分析與量測以及射頻元件飛行體的量測外，也與交通大學團隊共同研發出「一位元高精度數位式相位檢測器」（如Fig. 4所示），並已分別向美國與台灣申請發明專利中。此檢測器是以數位觀點來檢測數位訊號相位，不同於傳統以類比訊號的思維來檢測數位訊號相位，此數位方式可大幅降低系統的複雜度並提升接收器的精準度，可廣泛應用於通訊、遙測、姿態控制及全球定位接收器等相關領域。

Electrical Engineering

The development of all electronic satellite sub-systems, including the designs, analyses, validations, and tests involved in the Command and Data Management Sub-system, the Electrical Power Sub-system, the Telemetry, Tracking, and Command Sub-system, and the Electrical Ground Test Sub-system are the primary responsibility of the EE division. Building the capability to manufacture electrical and electronic components domestically is a crucial link in the satellite development process, particularly in the case of key components used onboard the Command and Data Management Unit (CDMU), Power Control and Distribution Unit (PCDU), and payload Electronic Unit. The accumulated experience in component design is expected to be applied to future satellite electronic unit designs, further extending domestic capabilities in the development of this important subsystem.

The Command and Data Management Unit (CDMU), similar to the human brain, serves as a command and data management center and has long been considered one of the key satellite electronic components within the field of space technology in Taiwan. An ESA-proposed fault-tolerant LEON3 processor and a high data-rate SpaceWire bus provide the backbone for CDMU development. This accumulated body of design experience also provides the basis for future CDMU design and a reference for the payload electronic unit. Currently, NSPO has finished developing and verifying the Engineering Model (see Fig. 1). The Engineering Qualification Model (EQM) and Flight Model (FM) will be developed successively in the future, and the FM will be the flight unit onboard the FORMOSAT-5. The Power Control and Distribution Unit (PCDU) illustrated in Fig. 2 acts as the satellite power control and allocation center, similar to a human heart. The key component, of which the Engineering Model has been developed and verified, is co-developed by CSIST and NSPO. The PCDU provides over 150 power outlet channels and, similar to CDMU, the design heritage provides the basis for future PCDU design, as well as a reference design for other self-designed electronic unit power sources. The Engineering Qualification Model (EQM) and Flight Model (FM) remain under development. The implemented FM will be considered for FORMOSAT-5 flight. Furthermore, a high reliability memory module structure design developed as part of the self-reliant CDMU project was granted a Taiwanese patent. For details see Special Report 10.

The Electrical Ground Support Equipment (EGSE) for the satellite I&T was developed by NSPO. The EGSE structure, illustrated in Fig. 3, is linked by the E-Net and thus is highly automatic, significantly reducing the I&T time. With regard to the Satellite Test Controller (STC), the CCSDS Reed-Solomon Encoder/Decoder, Telecommand BCH Encoder/Decoder, and Telecommand Encription/Decription software have also been developed. NSPO is capable of developing component test equipment in addition to building satellite system test equipment. A Gyro Test Set has been implemented and a highly automatic CDMU Test Set will be developed in 2010.

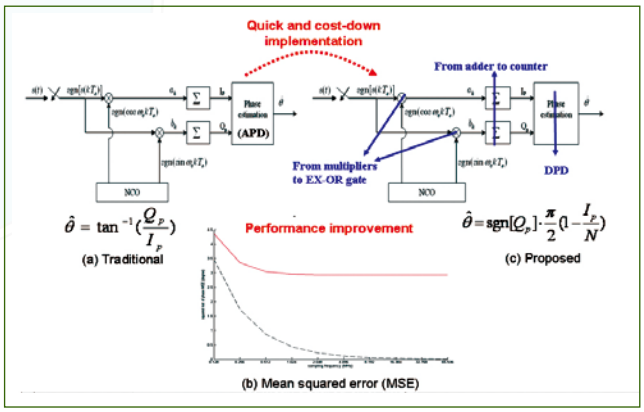


Fig. 4 一位元高精度數位式相位檢測器 。(High Accuracy 1-bit Digital Phase Discriminator.)

Besides performing margin analysis on satellite links, as well as measuring antenna pattern and RF flight model, NSPO is co-operating with the National Chiao Tung University team to develop a “High Accuracy 1-bit Digital Phase Discriminator”, as illustrated in Fig.4, and has applied for both U.S. and Taiwan patents. The discriminator, called digital phase discriminator (DPD), is based on the digital perspective for 1-bit ADC processing receivers, which differs from the traditional analog perspective. The DPD significantly simplifies the system and improves receiving accuracy. The DPD is widely applied in communications, telemetry, attitude control, and GPS/GNSS receivers, to name but a few fields.

飛行控制

飛行控制組的主要任務是要建立衛星姿軌控制與飛行軟體軟、硬體相關次系統與關鍵元件的自主研發能量，以支援下一代遙測衛星與微衛星計畫，並主導或支援福衛二號與三號的姿軌控制備援方案、運轉維護與後續計畫。飛行控制組的工作主軸分為「衛星計畫」、「內部研發」與「對外服務」，此三項工作分頭並進，依序進行。今（2009）年度飛行控制組的主要研發成果包括：（一）與STK介面結合，3D呈現的姿軌控制動態模擬平台、（二）飛行軟體功能驗證平台、等次系統驗證平台開發、（三）『太空級衛星導航接收機』、『抗輻射光纖光源與陀螺儀研發』等關鍵元件研製以及磁矩校準方法的發明專利等。

姿軌控制部門多年來已累積相當自主能量，Fig. 1所示為姿軌控制實驗室內自主開發的『衛星姿軌控制工程體發展與驗證平台』。Fig. 2為導控感測器實驗室內自主開發的『衛星導航接收機即時硬體迴路測試平台』。所有次系統分析、模擬、整合、驗證及元件開發等均可完全自主或結合國內產、學、研一同開發。研發項目包括：高精密的『多軸星象儀結合陀螺儀與導航接收機』的姿控系統；中精度的『多軸星象儀為主/陀螺儀為輔』的姿控平台；中低精度『無陀螺儀』的姿控架構以及受到國外出口管制的『關鍵導控元件』開發。

Fig. 1 姿軌控制實驗室-衛星姿軌控制工程體發展與驗證平台。
(AOCS Engineering Development Model and Validation Bench in AOCS Laboratory)

Fig. 2 導控感測器實驗室-衛星導航接收機即時硬體迴路測試平台。
(GNSS Receiver Hardware-In-The-Loop Test Station in GNC Sensor Lab.)

另外在飛行軟體部門方面，除了在組織架構強化與專業人材的吸收外，也建立了飛行軟體驗證平台的自主開發的能量。Fig. 3顯示飛行軟體實驗室內自主開發的飛行軟體驗證平台，此平台模擬衛星所有硬體裝備與飛行動態環境，可在中央處理模擬器上以接近即時的模式實際運作，同時透過模擬介面與各介面板模擬器作資料交流與監控。2009年度飛行軟體部門更進一步與姿軌控制部門合作開發非即時的『飛行軟體功能驗證平台』，以支援福衛五號姿軌控制飛行軟體的功能驗證，加速飛行軟體整合、除錯、驗證的時程。

除了研發工作外，飛行控制組也創立了對外導控服務平台，提供導航元件如衛星導航接收機與陀螺儀的設計最佳化、製作工藝提升與模擬測試的服務平台。導控元件服務單位數至今已有七個，涵蓋了產、學、研等機構。另外，經由國家科學委員會候鳥計畫與國家太空中心委辦案的管道，飛行控制組也培育了數名國內外的碩、博士生。

Flight Control

The core technologies of the Flight Control (FC) division are sub-system software and hardware associated with Attitude and Orbital Control System (AOCS), and Flight Software. The primary mission of FCis to establish independent research capabilities in key components and sub-systems and thus support the development of next generation remote-sensing satellites and micro-satellites. Additionally, FC supports and maintains the existing FORMOSAT-2 and -3 satellites, their AOCS backup plans and follow-on programs. The daily operations of FC involve performing programming, research, and service activities in parallel with satellite programs having the highest priority in mind. The main research accomplishments during 2009 involved three areas: development platforms, key components, and patents. With regard to development platforms, accomplishments included a 3D AOCS Dynamic Simulator linked to STK, and a Flight Software Functional Validation Bench (FVB). Regarding key components, achievements included demonstrating performance in Space-Borne GNSS Receiver and Radiation Hardened Fiber Light Source and Optical Gyros. Regarding patent applications, an invention patent entitled Residual Magnetic Dipole Compensation under the Presence of Induced Magnetism was awarded by the Intellectual Property Office of Taiwan. For detailed description of the above accomplishments of FC, refer to the Special Topics, and Patents sections of this annual report.

Over the years, the AOCS section has established a solid foundation in independent research capabilities. Figure 1 shows an AOCS Engineering Development Model and Validation Bench located in the AOCS Laboratory. Meanwhile, Fig. 2 shows a GNSS receiver hardware-in-the-loop test station in the GNC Sensor Laboratory. The AOCS team is capable of performing sub-system analysis, simulation, integration, testing, and component development either alone or in partnership with domestic universities, institution, or private industries. The research focus of the AOCS team is high-end systems for export, including Multi-axis star tracker with gyros and GNSS receivers; mid-range platform employed Multi-axis star tracker with gyros as an option, mid-to-low end Gyroless sub-system; and Key navigation sensors.

Besides continuing to build its AOCS capabilities, FC has been cultivating talent and improving the organizational structure of its Flight Software (FSW) team. The FSW is capable of independently performing research and development. Besides supporting satellite programs, the primary research focus of the FSW team is the development of flight software verification and validation facilities. Figure 3 illustrates a Software Validation Facility (SVF) located in the Flight Software Laboratory. The SVF simulates in near real-time the flight computer CPU operationsincluding all satellite hardware and flight dynamics. Furthermore, through the simulated interfaces, data exchange and monitoring are performed just like the hardware operations. In 2009, the FSW team undertook the extra step of working with the AOCS team to integrate the 3D AOCS Dynamic Simulator into a flight software FVB operated in a non real-time environment. The FVB supports the functional validation for the FORMOSAT-5 AOCS flight software, and performs pre-screening prior to running FSW in SVF to accelerate flight software integration, diagnosis and validation.

FC has also established a GNC service platform catering to outside organizations. This platform provides services in design optimization, improving production workmanship, and component simulation and testing for navigation sensors such as GNSS receivers and gyros. FC also participates in the summer program run by NSC for foreign graduate students and local students by partnering with universities on research work. To date, FC has provided services to seven organizations, including universities, research institutes, and private companies.

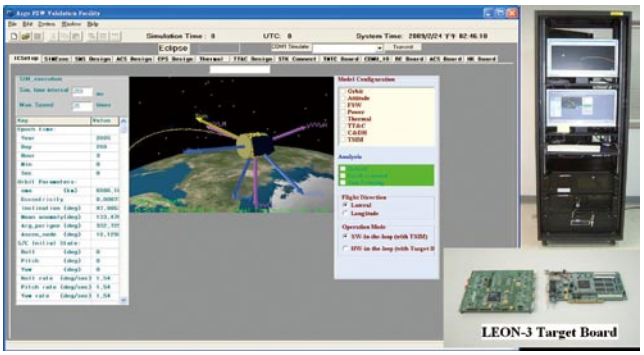


Fig. 3 飛行軟體實驗室-飛行軟體驗證平台。
(Software Validation Facility in Flight Software Lab.)

機械工程

衛星機械組主要工作除了負責執行衛星結構與機構、熱控、推進和光學微系統等次系統的設計、分析與驗證工作，以滿足衛星在地面和軌道上的任務要求外，同時也執行應用於未來衛星計畫技術的發展工作。關於後者，這一兩年衛星機械組進行碳纖維強化複合材料濕膨脹係數研究、環境對光機設計影響研究、太空級熱管研發和微推進系統測試平台之研發等技術的發展，其成果如下。

在碳纖維強化複合材料濕膨脹係數研究部分，由於光機結構對尺寸穩定性要求高，因此由具備高勁度且可改變疊層方向，使得熱膨脹係數趨近於零的碳纖維強化複合材料成為光機結構材料主要選項之一。但因碳纖維強化複合材料會隨著濕氣逸散而變形，所以需藉由實驗量測飽和濕氣濃度、擴散速率及濕膨脹係數，以預測光機結構因濕氣變化所造成的變形量。今（2009）年我們除了完成研究設備的建置外，也進行了碳纖維強化複合材料濕機械性質的量測，奠定了國內相關研究應用於太空領域的基礎。單方向碳纖維/環氧樹脂複合材料試片實物照片如Fig. 1所示。

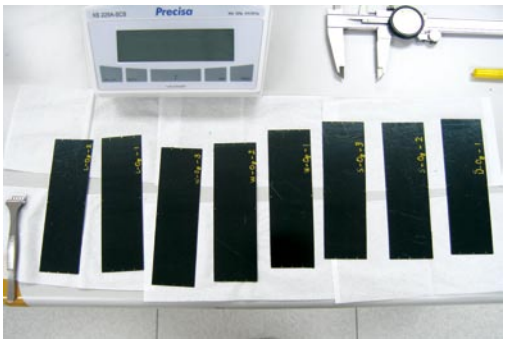


Fig. 1 單方向碳纖維/環氧樹脂複合材料試片。(Uni-Directional(UD) IM7/8552 Carbon Fiber/Epoxy Composite Specimens.)

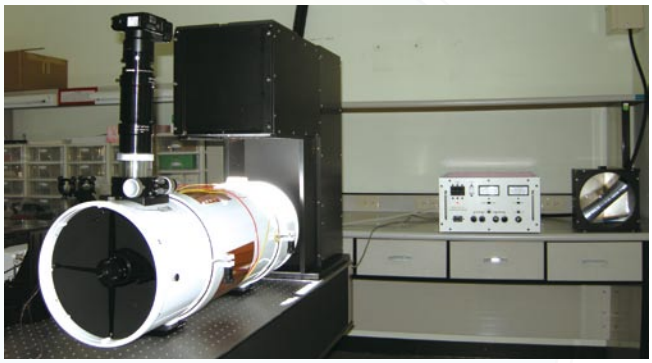


Fig. 2 光機系統環境影響測試。(Environmental Load Test on the Telescope System.)

在環境對光機設計影響研究方面，本研發計畫目的在建立遙測酬載光機結構與熱控設計分析及驗證能量，本年度主要工作是建置實驗設備及進行相關量測驗證，以實驗的方法找出因溫度變化影響的光學成像品質變化，及相對的微位移量。目前實驗所需設備已建置完成，如Fig. 2所示。初步實驗結果可以了解溫度環境變化對光學成像品質的影響，同時藉由相關量測技術與實驗數據可建立遙測酬載光機設計資料庫。

熱管除具有高熱傳導能力可快速傳熱外，其高均溫性、重量輕、無可動件及結構簡單等特性，對於衛星因為微小化、局部散熱增加或對溫度的精度及穩定性需求提高，而造成一般以被動式溫控硬體為主的衛星熱控系統無法滿足溫度範圍的需求時，可提供有效的解決方法。太空級熱管研發計畫已開發出使用鋁擠型製作方式，完成雙翼構型溝槽熱管，如Fig. 3所示。

而在微推進系統測試平台之研發計畫，目前已完成階段性微型衛星推進次系統的技術開發任務。國家太空中心在此計畫除了建立了高濃度過氧化氫製備能力、微推進器功能測試及推力量測能量、微推進器流場觀察設備及分析與效能研究外，同時也開發出符合微小衛星用的微電熱式推進器，並且建立奈米衛星用微推進系統原型的實體製作，如Fig. 4所示。

Mechanical Engineering

The Mechanical Engineering Division (MED) oversees the Structure and Mechanism Subsystem, Thermal Control Subsystem, Propulsion Subsystem, and Optical and Microsystem Engineering and coordinates their contributions to the satellite development project. In these areas, MED must take actions, including design, analysis, and verification, to ensure these subsystems fulfill particular system requirements regarding ground and space environment. Furthermore, MED is also responsible for developing conceivable technologies for application in future satellite programs. In 2009, MED studied the coefficient of moisture expansion (CME) for carbon fiber-reinforced composite materials, the environmental impacts to the optical-mechanics studies, space-grade heat pipe development, and micro-propulsion system development.

Utilizing high stiffness carbon fiber-reinforced polymer (CFRP) with various stacking directions, which effectively has a thermal expansion coefficient of zero, is one way of meeting the rigorous requirements of the dimensional stable for optical structure assembly. Equipment for measuring the moisture related physical/mechanical properties, including moisture level, CME, weight loss, etc., and CFRP deformation measurement, was built to determine the correlations between these experimental data. Figure 1 illustrates the Uni-Directional(UD) IM7/8552 Carbon Fiber/ Epoxy Composite Specimens.

The multi-axis high-precision sub-micron platform and laser sub-micron displacement measurement equipment (shown in Fig. 2) can also be used for optical mechanics thermal impact studies and re-focusing studies. To accompany the reflecting telescope, heat source system, and the impacts of variations in thermal environmental on optical imaging quality are examined experimentally.

Heat pipes are well known to provide excellent heat transfer capabilities for removing heat from hot-spots, precisely controlling temperature, and thus effectively miniaturizing satellite owing to their distinguishing features of high thermal conductivity, high temperature uniformity, light weight, lack of moving parts and simple structure. NSPO has developed the key technology, and successfully demonstrated the manufacturing capabilities of 6063T6 aluminum/acetone space-grade heat-pipes (Fig. 3).

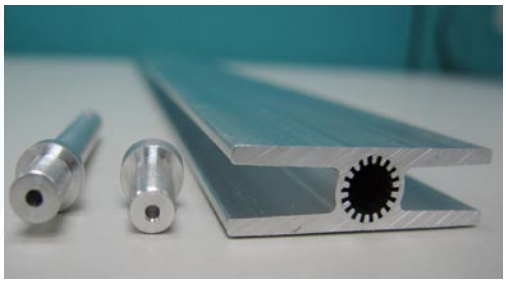


Fig. 3 太空級熱管組件。
(Parts of the Space-Grade Heat Pipe.)

Micro-propulsion system development, another highlight of MED conceivable technologies for future, was supported by NARL through its internal R&D programs, with titles such as "Development of MEMS Based Micro-propulsion System for Satellite - Development of Micro-Propulsion System Test Bed." NSPO has established capabilities for producing space-grade hydrogen peroxide propellant, micro-thrust test stand, micro-flow observation system. Meanwhile, a prototype of the micro-resistojet system (Fig. 4) was assembled to demonstrate the functions on the ground.

Fig. 4 太空微推進系統原型。
(Prototype of the Resistojet-based Micro-Propulsion System.)

衛星影像處理

衛星影像組主要負責福衛二號影像處理系統的維護與操作，同時支援福衛影像全球營運作業。在後續的福衛五號遙測衛星計畫，衛星影像組亦負責新一代遙測影像處理系統的研製與開發。

在持續精進福衛二號遙測影像品質的努力下，使得國家太空中心成為全球重要的遙測影像提供者之一。例如，福衛二號影像絕對幾何精度，透過地面控制點校正在軌遙測影像儀的校直，使得精度自原先的240公尺，可以準確到190公尺。

另外我們也對影像輻射性能作定期的監控，定期的執行絕對與相對的兩類輻射校正工作。自2006年迄今，共完成四次絕對輻射校正，其結果顯示，在遙測取像儀的一個黑白頻段與四個彩色頻段當中，除了頻段1的平均轉換因子約有4.6%的減少外（如Fig. 1綠線所示），其餘頻段則皆無明顯變化。而在相對輻射校正方面，我們也完成九次在軌校正結果（如Fig. 2所示），自2006年開始所有頻段中各個像元的相對反應值，均無明顯的變化，僅有約小於2%的增加趨勢。

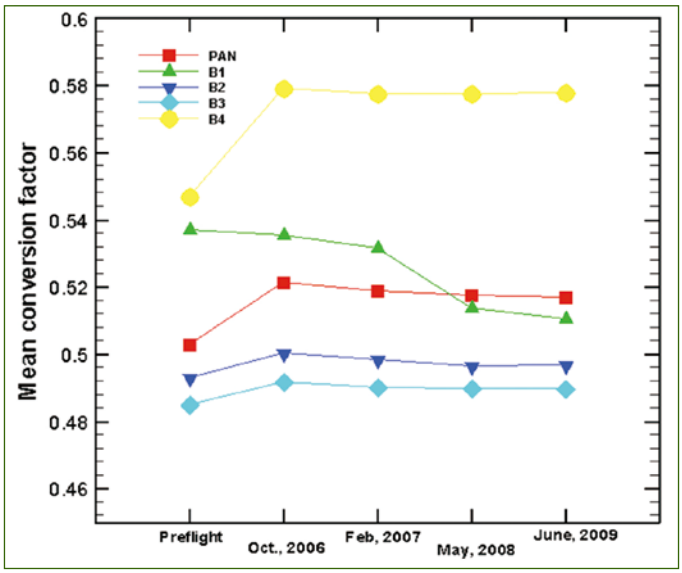


Fig. 1 福衛二號絕對輻射平均轉換因子趨勢圖。
(Absolute Radiometric Mean Conversion Factor Trend.)

在福衛五號的影像處理系統中，除延續福衛二號影像處理系統的部分設計外，另外增加了影像品質次系統與客戶訂單次系統的概念（見Fig. 3）。此次影像處理系統，資料擷取次系統是採取國內自製的發展策略，希望透過此一機會，台灣能完全掌握遙測衛星影像處理系統的關鍵技術。針對福衛五號任務需求，我們也進行一連串取像模擬與系統分析，如取像方向與衛星地面軌跡不平行的非同步取像（如Fig. 4所示）以及衛星抖動對時間延遲積分（TDI）及遙測影像儀調制轉換函數（MTF）的影響分析等，這些技術分析資料，將可作為福衛五號任務設計的重要參考依據。

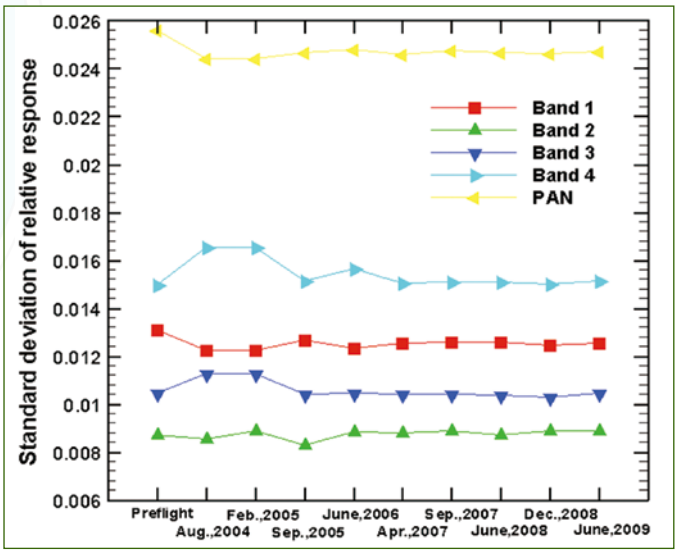


Fig. 2 福衛二號相對輻射平均轉換因子趨勢圖。
(Relative Radiometric Mean Conversion Factor Trend.)

Satellite Image Processing

The Satellite Image Division is responsible for operating and maintaining the Imaging Processing System and supporting the business operations related to OR associated with FORMOSAT-2. Furthermore, the Division also plays a key role in Imaging Processing System development for the FORMOSAT-5 program.

Recently, continuing improvements in FORMOSAT-2 image quality have made NSPO one of the key] remote sensing image providers internationally. We correct the on-orbit RSI alignment via ground control point analysis to improve the geometric accuracy from 240 meters to 190 meters.

This study also monitors FORMOSAT-2 image quality through regular radiometric correction. Four correction experiments were performed involving the absolute radiometric correction, and the results demonstrate that the values of the mean conversion factor, the coefficient used for RSI radiometric conversion model, remain constant for Band-2, Band-3, and Band-4, but not for Band-1, which [is decreased by 4.6%. On the other hand, data obtained from performing nine on-orbit corrections for the relative radiometric correction indicate that the variations in pixel relative responses for each band are indistinguishable after 2006, having increased by less than 2%. Figures 1 and 2 show the trends for absolute and relative radiometric mean conversion factor.

For the FORMOSAT-5 remote-sensing satellite program, this investigation has completed a system design review for the FORMOSAT-5 Image Processing System (IPS). The improved version of IPS incorporates the new gradient, Image Quality Sub-system (IQS) and the concept of Tasking/Product Order System, in addition to the FORMOSAT-2 IPS heritage, which comprises Planning & Scheduling subsystem (PSS), Data Ingestion sub-system (DIS), Data Management Sub-system (DMS) and Data Processing Sub-system (DPS), and whose system architecture is shown in Fig. 3. Regarding the acquisition strategy of DIS, a subsystem that processes the raw data to the Level 0 data, this study adopts the indigenous development approach to gradually establish domestic technological capabilities for satellite imaging.

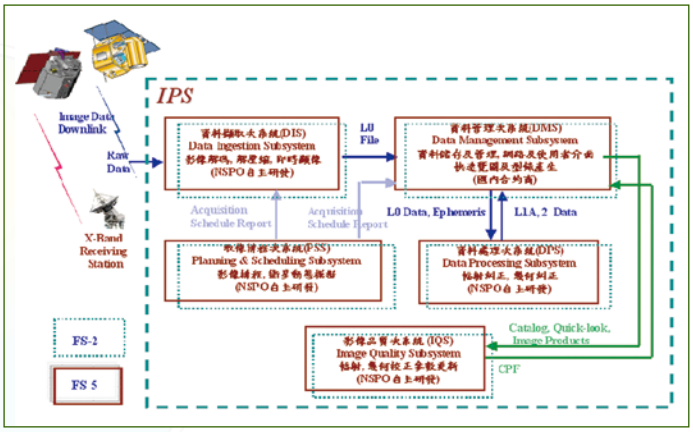


Fig. 3 福衛五號影像處理系統架構圖。
(FOREMOSAT-5 IPS System Architecture.)

Based on the new design requirements for FORMOSAT-5, this study performs a series of asynchronous imaging simulations of situations in which the scanning direction of the Remote Sensing Instrument is not parallel to the satellite ground track, as illustrated in Figure 4, and furthermore conducts sensitivity analysis on MTF for TDI sensor due to jitter effect. These results are considered during the course of the FORMOSAT-5 mission development.

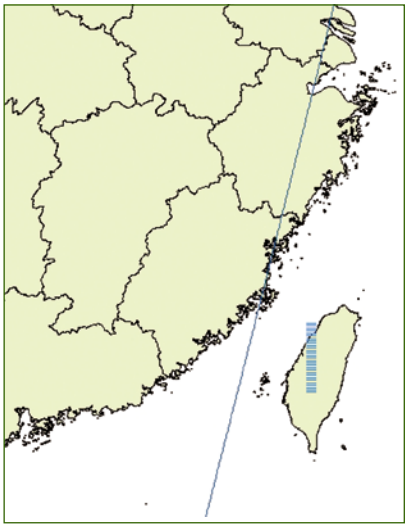


Fig. 4 福衛五號非同步取像模擬。
(FORMOSAT-5 Asynchronous Imaging Simulation.)

衛星操控

1994年位於新竹的「衛星操控中心」委託發展完工，1999年國家太空中心首度成功地追蹤與操控台灣的第一顆衛星－福衛一號，開啟了我國衛星操控的里程碑。福衛一號的操作經驗，奠定了我國單一衛星的操控能力，並培養出優秀的衛星任務操作團隊。至此，如何在既有的基礎上，精進衛星操控及發展多重任務作業，便成為操作團隊後續的努力目標。

2004年6月福衛二號的成功發射，開始為期10餘天的軌道轉換工作，此時衛星操控中心必須同時操控福衛一號及二號兩顆衛星，建立了多重任務的衛星操作基礎。接著2006年4月，福衛三號六顆衛星發射，衛星操控中心更進一步跨入衛星星系操作的領域。歷經了福衛系列衛星的發展，衛星操控中心不斷的累積衛星操作的實務經驗，也孕育了提升衛星操作及自動化發展的動力。

多重衛星或衛星星系的任務操作是衛星操控中心現在及未來無可避免的發展趨勢。因此，如何降低操作人力需求、減少人工操作程序、加速衛星異常的反應速度，就成為衛星操控中心全力發展的目標。衛星操作精進與系統自動化，為達成上述目標的有效途徑。因此，衛星操控中心首先建構了衛星操作時序系統、按鈕操作自動化與衛星異常操作自動擊發機制等，目的就是朝操作精進與系統自動化發展的目標邁進。

衛星操作時序系統是福衛星系自動化操作的靈魂，經由此系統，排定星系衛星接觸時的相關活動，作為地面站自動化連線、衛星指令傳送及科學資料傳輸的依據，更是規劃無人操作時，衛星狀態監視及自動化操作的開端。

按鈕操作自動化是以面板控制大批複雜的衛星操作程序，經按鈕擊敲，並提示確認後，其相關衛星操作的輸入、輸出及對應操作程序，就依衛星別由系統自動載入，使得現行的衛星操控中心節省了大量的操作時間及人力，更減少即時操作時，可能造成的人為錯誤，對目前福衛星系的操作貢獻良多。

另外，衛星異常的即時偵測、迅速反應及明快處理，是衛星操控重要的議題。因此，衛星操控中心為反應衛星的異常，建立了衛星異常自動擊發機制，除對衛星異常進行安全性的即時處置外，也立即地發出電子郵件及手機訊息，通知有關人員衛星的相關狀態。衛星操控因衛星而異，其衛星操作發展也差別甚大，但衛星操控中心已經建立應有的技術能力，對後續衛星計畫的任務操作及自動化發展，將可以自主研製完成。

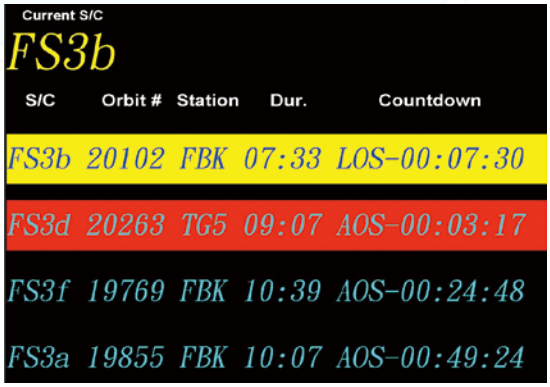


Fig. 1 福爾摩沙衛星操作時序系統
(Satellite Operation Timing System)

Fig. 2 福爾摩沙衛星監控系統
(Satellite Control and Monitor System)

Satellite Operation Control

The Satellite Operation Control Center (SOCC), established in 1994, initiated a new era of satellite operation and control in Taiwan by successfully tracking and operating the FORMOSAT-1 satellite. Building on this foundation, NSPO has gradually developed the capability to operate and control a single satellite. Meanwhile, a professional operating team has been established for conducting mission operations involving NSPO. Furthermore, the goal of this operating team is to enhance the satellite operation and multi-mission development based on the existing infrastructure.

Following the successful launch of FORMOSAT-2, the SOCC had to smoothly manage the early orbit operations of FORMOSAT-2 in addition to the existing mission of FORMOSAT-1. This opportunity nurtured the capability for a multi-mission satellite operation. During April 2006, with the foundation established by the successful missions of the six FORMOSAT-3 spacecraft, SOCC formally entered a new chapter as it developed capabilities in satellite constellation operation. Using a series of FORMSAT satellites, SOCC has continuously accumulated precious real life experience of satellite operation and transformed those practices into a driver of increasing operational advancement and automation.

Multiple-satellite and constellation mission operation are inevitable trends in SOCC capability. Therefore, reducing manpower requirements, human-related operation procedures and response time to satellite anomalies are crucial goals in SOCC development. Enhancing satellite operations an automation offers an effective path to (achieving OR realizing) these goals. Accordingly, SOCC is focused on satellite operation timing system, icon operation automation and auto-trigger mechanism for response to abnormal satellite operations to provide practical goals in relation to system enhancement and automation. Details are given below.

Satellite operation timing system is the core of FORMOSAT satellite and constellation operation automation. Precision timing enables proper scheduling of related activities during satellite contact time. In the future, precision timing will provide the foundation for full-scale automation of ground station connection, satellite command uplink, scientific data transmission, automatic operations and health-status monitoring.

Icon operation automation is dedicated to implementing complex satellite operation procedures via a set of icons displayed on a monitor. Controlled by clicking icons and performing associated confirmation actions, the system automatically loads and executes the input, output and operation procedures for specific satellites. This design significantly reduces the time and manpower requirements of satellite operation. Furthermore, the system considerably reduces the risk of human error during real-time operations and contributes significantly to current FORMOSAT constellation operations.

Other key areas that SOCC has pledged to develop include real-time detection of abnormal satellite operations, quick response and processing. In response to abnormal satellite operations, SOCC has established an auto-trigger mechanism via which certain operating procedures related satellite anomaly are automatically triggered safely and in real time. SOCC also immediately distributes email and cell phone messages to related personnel providing the latest updates on satellite health-status. Although satellite operation process is unique for different spacecraft and its future development, after building up its technology and capability, SOCC is confident for the mission operation and automation of the follow-on satellite projects.

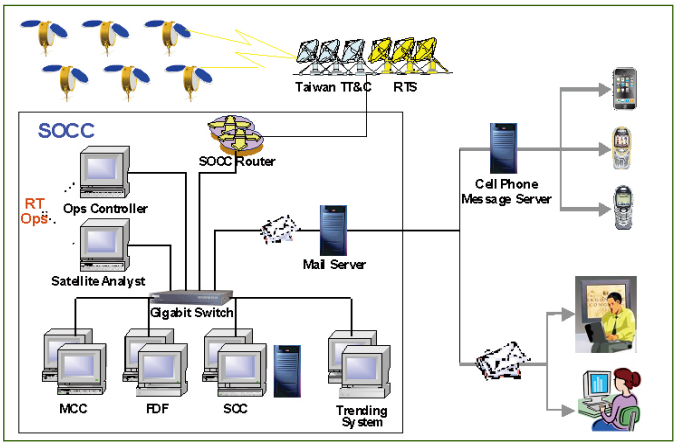


Fig. 3 | 福爾摩沙衛星異常狀態通報及處理系統 (Satellite Anomaly Notification System)

品質保證

品質保證組主要負責推動與執行國家太空中心內部的品質政策，以持續精進各項太空相關計畫的品質、可靠度與安全。今（2009）年度主要工作，包括：太空品質管理的精進、太空品保研究的展開以及商業發展應用與國內產研合作的推動。

在太空品質管理精進方面，我們持續改進品質資訊系統（Quality Information System，QIS），以達到符合太空品質的目標。另外經由全體同仁的努力，國家太空中心於今年亦持續獲得ISO 9001:2000品質管理系統認證（如Fig. 1所示）。除了上述延續性工作外，今年度新增加整體規劃與後勤業務，包括：太空相關計畫的後勤支援、衛星元件儲存以及工程物料庫房管理。依照目前福衛五號計畫時程進度，已有部分衛星元件交貨，這些衛星元件均儲存在嚴格控制的環境，並且定期支援檢測這些高價衛星元件。

Certificate of Registration

QUALITY MANAGEMENT SYSTEM - ISO 9001:2000

This is to certify that:

National Space Organization
8F
9, Prosperity 1st Road
Hsinchu Science Park
Hsin-Chu
Taiwan

Holds Certificate No: FM 85066
and operates a Quality Management System which complies with the requirements of ISO 9001:2000 for the following scope:

The design, installation, integration testing, launching support, spacecraft operational control, data receiving and processing, and technology transfer for satellites.

For and on behalf of BSI:

Managing Director BSI Taiwan, Dr. Yi Min Gao

Originally registered: 11/06/2004 Latest Issue: 23/06/2008 Expiry Date: 24/06/2010

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BSI Management Systems

Fig. 1 ISO 9001:2000証書。
(ISO 9001:2000 Certificate)

在品保研究發展方面，為了瞭解太空輻射對於衛星元件的影響，國家太空中心與清華大學共同合作研究，設計三維幾何模型，模擬衛星形態構造（如Fig. 2所示），再利用三維蒙地卡羅輻射遷移程式，分析太空輻射與電子元件所需材料厚度的關係，同時參考低地球軌道衛星元件總游離劑量，以作為福衛五號衛星設計，與元件選用的依據。

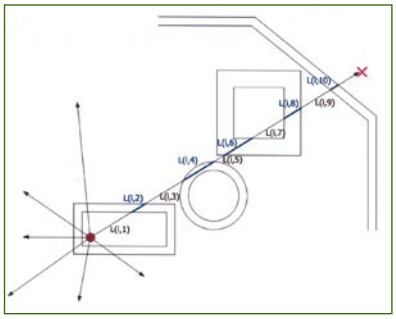

Fig. 2 福衛五號輻射模型研究。
(Space Radiation Model for Formosat-5.)

為了建立自主衛星發展的採購管道，並配合福衛五號計畫核心元件，包括：指令與資料管理單元、遙測光學酬載電子單元以及其他研究計畫等的零件採購需求，我們也規劃進行「太空用被動零件現貨商品升級篩選鑑定評估研究」（如Fig. 3所示），預計研究計畫結束時將可以建立一套應用於太空衛星系統的電子零件耐溫、耐震與壽命鑑定程序。

最後為提升國內大專院校參與國家太空中心各項計畫的品質技術，本年度完成「學界團隊品保技術教育訓練」（如Fig. 4所示），以及「工藝技術訓練」兩項課程。同時為提高國內產業界參與太空計畫的品質水準與意願，我們舉辦了「2009年高可靠度電子產品技術研討會」以及2009年台北國際航太暨國防工業展「參與我國自主衛星系統、次系統與元件研發商機」說明會，這兩次會議各界參與盛況空前，會議圓滿成功。

Quality Assurance

NSPO prioritizes high quality, reliable and safe space products and services over the numerous other tasks for which the Division of Quality Assurance (QA) is responsible. During 2009, several key implementations of the proposed quality policy within the center included improving quality management, related research activities, the commercialization of those research results and cooperation with industries, research institutes and academia in Taiwan.

Improving quality information system (hereafter QIS) is crucial to improving space product quality management. Meanwhile, the long term commitment of all NSPO members to quality assurance has finally paid off, with the award of ISO 9001:2000 certification(Fig. 1) for Quality Management Systems. On top of those continuities, this year the Quality Assurance Division has initiated a new assignment on Integrating Planning and Logistics services and designed to support the storage management of flight components and engineering materials. The newly initiated system has been applied to certain received and accepted flight components belonging to the FORMOSA-5 program. According to the system regulations, these components are scheduled for periodic functional checks pre-flight.

Regarding research on quality assurance, the Quality Assurance Division is collaborating with National Tsing Hua University to design a space radiation model capable of improving understanding of space radiation environment. The proposed model employs Monte Carlo radiation transport codes to reconstruct satellite 3-D model and calculate the omni-directional thickness distribution protecting those electronics against space irradiation (Fig. 2). With the calculated total ionizing dose (TID) data, the FORMOSAT-5 program may consider it as the reference base for satellite design and electronic element selection.

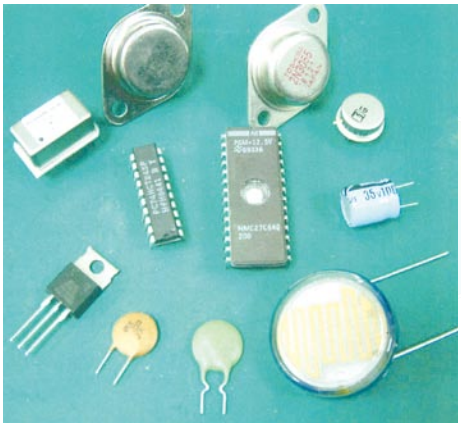

Fig. 3 電子零件品保。(EEE Parts QA)

Fig. 4 學界團隊品保技術教育訓練。(Quality Assurance Training Courses)

The NSPO must establish a space qualified Electrical, Electronic, and Electromechanical, EEE, parts selection program for space programs that will be utilized by the NSPO to independently develop flight components, such as Command and Data Management Unit and Global Navigation Receiver. Consequently, the QA R&D activities focus on satellite flight computer and Remote Sensing Instrument Electronic Unit, concerning the EEE parts procurement resources study this year. The Quality Assurance Division also provides critical parts procurement and engineering support services. Other QA R&D activity focuses on upgrading commercial off-the-shelf EEE parts (Fig. 3) to Hi-Reliability or space qualified parts.

NSPO collaborates with several national universities on research projects. The NSPO QA Division completed the quality assurance training courses (Fig. 4) and the hands-on satellite Integration and Test Technology training courses for professors and students involved in these collaborative arrangements. To promote domestic industry quality, the Quality Assurance Division hosted the 2009 Symposium for Hi-Reliability EEE Part Technology. Furthermore, during the Taipei Aerospace and Defense Technology Exhibition, the Quality Assurance Division hosted the 2009 Forum, a meeting to encourage partnership between the space industry and research facilities. All participants and guests enthusiastically received these successful events.

太空教育

今（2009）年福衛二號發射5週年，同時適逢人類首次登陸月球40週年，國家太空中心舉辦一系列太空科普教育活動，以慶祝台灣與世界前述兩項重要的太空成就。首先登場的活動是自4月6日開始「衛星看我家網路猜獎活動」，「衛星看我家網路猜獎活動」是以網路遊戲方式，讓參加民眾透過衛星影像認識台灣各地區地貌。猜獎活動一連舉辦6週（4月6日至5月15日），共計46,205人次上網參加。

接著7月23日國家太空中心特別邀請任職於德州休士頓的美國航太總署詹森太空中心的女太空人Marsha S. Ivins女士來新竹市舉行演講（如Fig. 1所示）。Marsha S. Ivins女士曾參與5次太空梭飛行任務，太空飛行時數達1,318小時，完成衛星部署，美俄聯合太空任務及多項太空科學實驗等重大挑戰。Marsha S. Ivins女士透過影片及她精心蒐集的精采照片，帶領與會者一起穿梭太空歷史、分享她獨一無二的太空體驗。本次演講報名十分踴躍，座無虛席，與會者多達130人，年齡層自8歲到60歲，學歷自小學生到博士生都有，對於國內太空迷或是對太空科技有興趣的民眾來說，絕對是一次非常難得的親身體驗。

最後壓軸的活動是兩項大型的福衛二號影像展，首先是國家太空中心與高雄國立科學工藝博物館於5月26日到9月30日共同合辦的「福臨天下-福衛二號影像展」（如Fig. 2所示），於高雄所舉辦的衛星影像展，將衛星影像與在地文化結合，藉由影像及高雄古地圖的穿插展示，以圖說方式講述大高屏地區的發展歷史。同時也展出3年來，福衛二號自太空完整紀錄高雄地區主辦世界運動會所發生的變化．在這4個月活動期間內，共計吸引近20萬人次前往參觀，獲得廣大迴響。

另外，國家太空中心也與新竹市政府共同舉辦「福爾摩沙衛星影像展在新竹」（如Fig. 3所示），活動期間自11月4日起至12月13日止，此次展覽主題除了以衛星影像介紹新竹市與她的姊妹市外，其他世界各國的知名景點也會經由福衛二號影像呈現在新竹市民眼前。

Fig. 1 | 美國太空人Marsha S. Ivins女士在新竹的演講。
(NASA Ms. Marsha S. Ivins' Speech in HsinChu)

Space Education Outreach

2009 was an extraordinary year for both NSPO and the history of human space exploration in general, as FORMOSAT-2 entered its 5th year of service and the world marked the 40th anniversary of the first moon exploration. To mark these significant anniversaries, NSPO held a series of space science and technology related educational activities to attract talented individuals to become involved in innovation and systems integration.. From April, NSPO held a prize drawing via the Web-based game,"My Home From FORMOSAT", which incorporated both educational and entertaining dimensions and was designed to help Taiwanese better understand the geology of Taiwan. The six-week activity attracted considerable attention and the website received over 46,205 visitors.

For educational outreach, NSPO proudly invited Ms. Marsha S. Ivins, a veteran astronaut and program director of NASA's Johnson Space Center, to give a speech in Hsin-Chu City (experiments performed on board a spacecraft. Ms. Ivins took the audience on a space journey by sharing her unique experiences via her collection of video footage and photos. The speech was well received by a large audience, comprising over 130 individuals aged 8 to 60 years old and with various educational backgrounds.

Another two notable highlights during 2009 were the FORMOSAT-2 Fifth Anniversary Exhibition, co-hosted with the National Science and Technology Museum, and the "Satellite Images in Hsin-Chu" Exhibition, held at Vision Hall in Hsin-Chu City. The first exhibition combined satellite images with elements of local culture and history by interweaving ancient maps and satellite images, presenting a visual narrative of the history of the Kao-Shiung/Ping-Tung area. This activity was an enormous success, and allowed over 200 thousand people to see the world from a fresh angle, via the studding photos taken by FORMOSAT-2 during the three years leading up to the World Games of 2009.

The exhibition "Satellite Images in Hsin-Chu"sponsored by the Hsin-Chu city government, besides its primary theme of introducing Hsin-Chu and her sister cities, also displays satellite images of famous scenic spots around the world.

Fig. 2 「福臨天下-福衛二號影像展」開幕典禮。(Opening of the FORMOSAT-2 Fifth Anniversary Exhibition in Kaohsiung)

Fig. 3 「福爾摩沙衛星影像展在新竹」。(Opening of the FORMOSAT-2 Imagery Exhibition in Hsinchu City)

衛星影像推廣

福衛二號5年來已為台灣累積豐碩的遙測影像資料，截至2009年止總取像面積超過585,047,327平方公里（合計約16,000多個台灣）。近5年來，遙測影像產業價值鍊，由於受到地理資訊系統（GIS）產業的蓬勃發展，有了新的變化。除了資料本身的品質之外，如何將衛星影像資料以更多元、更快速與更貼近使用者需求的方式對外提供服務，已是全球的趨勢。在此趨勢驅動下，國家太空中心也積極與國內產學合作，發展衛星影像加值應用產品和服務。

2009年3月，國內主要地理資訊系統公司－銳悌科技，發表了國內首創的銳悌線上影像服務系統（RITI-Online）。此一全新的系統，是由國家太空中心提供福衛二號影像，結合台灣大學空間資訊中心影像加值處理技術與銳悌科技的網路服務技術，以資料串流（Streaming）技術，透過網路服務平台，讓用戶可以用較低的成本使用衛星影像服務。圖資內容包含經過正射、鑲嵌及色彩校正處理的全台灣高解析度衛星影像，圖資座標為台灣地區通用的TWD97座標系統標準，與大多數現有圖資相符合，不僅方便專業使用者套疊原本已建置的空間資料，更可以提升使用上的效率，也讓產出的資訊品質提高。

Fig. 1 | 銳悌線上影像服務系統。
(RITI-Online Image Service)

此外，國家太空中心與台灣師範大學地理系及數可科技公司，共同研發製作第一件福衛二號台灣全島影像立體地形圖。其原理是運用DTM（數值地形模型）資料和福衛二號衛星影像圖製作立體地圖，將具有高程資訊的DTM資料與衛星影像圖套疊。再透過地理資訊系統的計算，根據高度比例產生不同程度的突起以製造立體效果，還原成與實地地形相符的塑化模型。雖然目前電腦科技在立體塑型上的處理及模擬已經有驚人的表現，但是無論其有多麼逼真，還是僅能在顯示器上以平面方式呈現。現在透過科技加工方式，讓衛星影像地形圖跳脫從前在平面顯示的限制，將觀測地表影像以立體方式呈現。未來此項產品將可以推廣至地球科學或地理學科等教學應用。

美商Google公司於2005年推出Google Earth，首次將衛星影像直接呈現在每一台電腦上，將地理資訊系統科技，推廣到更生活化的應用層面。現今台灣的軟體，印刷及模具製造等技術，都已具備相當厚實的能力，國家太空中心將會在影像資料與其他科技結合，在創新開發更多元化的影像應用產品上扮演更積極的角色．

Satellite Image Promotion

As of 2009 the FORMOSAT-2 satellite has transmitted remote sensing images covering over 585,047,327 square kilometers (approximately 16,000 times the area of Taiwan) back to earth. During the past five years, the chain of the remote sensing industry has changed significantly owing to the vigorous development of the geographic information systems industry. Besides information quality, strategies for serving customers in a more varied, faster and intimate way have already become a global trend in this business. Accordingly, NSPO is actively promoting domestic collaboration between industry and academia to develop value-added applications of satellite imaging products and services.

In March of 2009, RITI Co. Ltd., the leading GIS System integrator in Taiwan, launched their innovative GIS online service - RITI online. This new Taiwan-focused service platform is a joint venture involving the Spatial Information System Research Center of National Taiwan University, RITI and NSPO. The platform brings together FORMOSAT-2 images delivered from NSPO, Spatial Information Center image processing/value-added technology from NTU and network service from RITI to offer a low-cost satellite image service. Notably, the images supplied via this service have undergone heavy processing, including orthorectification, color balancing and mosaicing, and are aligned with the Taiwan TWD97 coordinate system, which is considered a common standard for presenting spatial information. This processing not only facilitates map overlaying for professional users but also facilitates upward compatibility, thus enhancing service quality.

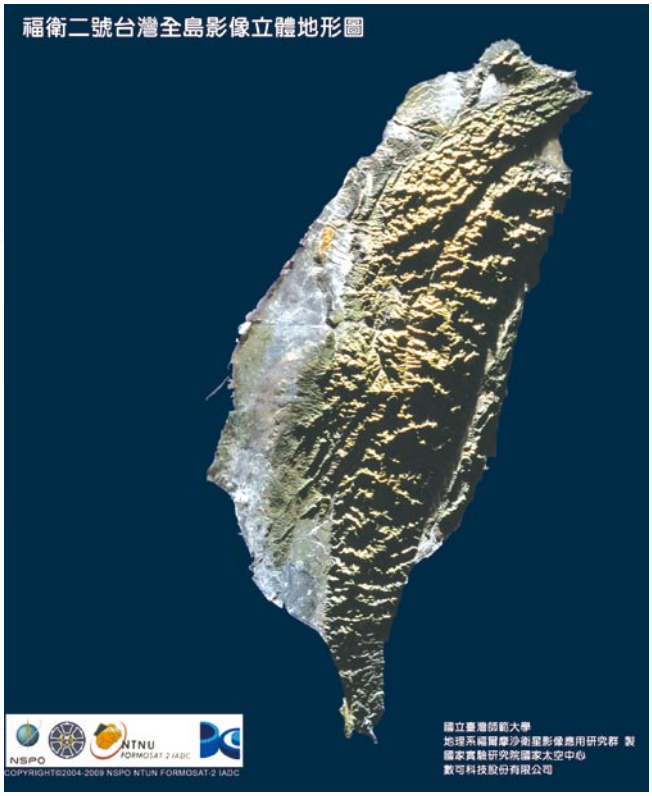

Fig. 1 台灣全島衛星影像立體地形圖。
(The satellite image terrestrial 3d Model of Taiwan.)

Additionally, NSPO, Department of Geography of National Taiwan Normal University and the DigitalCan Corp developed the first satellite image terrestrial 3d Model of Taiwan. The data set combines high-resolution FORMOSAT-2 remote sensing images with DTM (Digital Terrestrial Model) to create an orthorectecfied image product. GIS calculation employs a high ratio of processes of different magnitude to create a three-dimensional effect. Although image technology has excellent performance in 3D modeling, the images produced can only be presented on a 2D monitor. However, new image processing and display technology techniques are reducing the limitations associated with 2D display and making it possible to render images in a 3D manner. The future of this product will be extended via educational applications in earth science or geography.

Google launched their innovative GIS platform, Google Earth, in 2005. This platform makes satellite imagery with geography information available to anyone with an Internet connection. Geographic Information System technology has now been widely applied in civilian applications. In future, NSPO will work closely with industries to generate fresh ideas for combining satellite imagery with other expertise, and thus creating various application services and products.

整合測試

經過第一期國家太空科技計畫的執行，國家太空中心完成建置衛星發展所需的各項基礎設施，包括：衛星整測廠房、地面站系統與各項環境測試設備與專業實驗室。這些設備在不影響中心衛星任務時程的原則並符合中心潔淨管制等規範下，除了可以支援中心內各項技術研發所需的環境測試，為本中心衛星研發能量奠定基礎外，同時也可以對外提供電子、航太及汽車相關產業與學術界等研發測試使用，以善用中心現有設備與技術能量，和達到技術交流的目的。

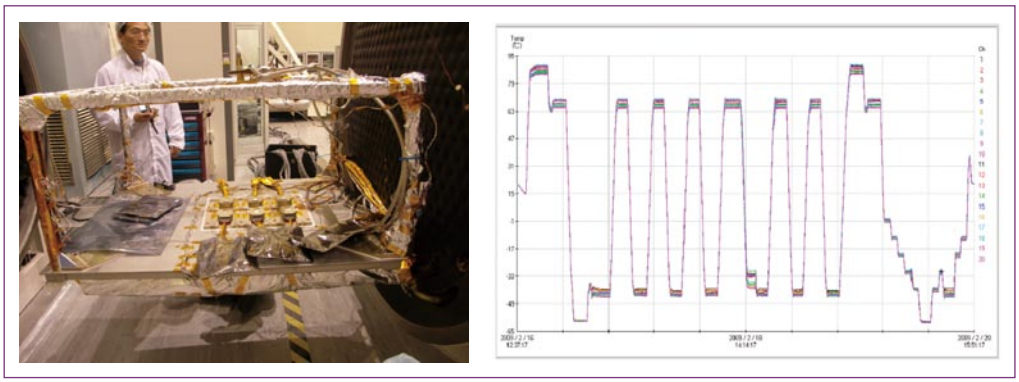

Fig. 1 福衛五號衛星陀螺儀熱真空測試溫度曲線記錄以及。
(Test Configuration and Temperature Profile of FS5 COTS Gyro Thermal Vacuum Test and Pathfinder for Qualification Level Vibration Test)

2009年衛星整測廠房與各項環境測試設備執行了福衛五號衛星商規陀螺儀篩選熱真空及振動評估兩項測試。由機械、品保及飛控共同組成的測試團隊完成了+80°C至-60°C的熱真空測試（如Fig. 1所示）與合格（Qualification）規格的振動測試，這其中也包含了測試執行前的探路（Pathfinder）測試。測試結果顯示這些商規陀螺儀噪訊仍小於額定的0.15°/√hr（如Fig. 2所示），這使得測試團隊對未來遞交一組包含四個合格商規陀螺儀的慣性參考儀（IMU）深具信心。另外，在商規陀螺儀環境測試空檔，我們也進行了微衛星結構板振動測試與模態測試（如Fig. 3所示）以及成功大學委託執行PACE皮米衛星振動測試（如Fig. 4所示）。

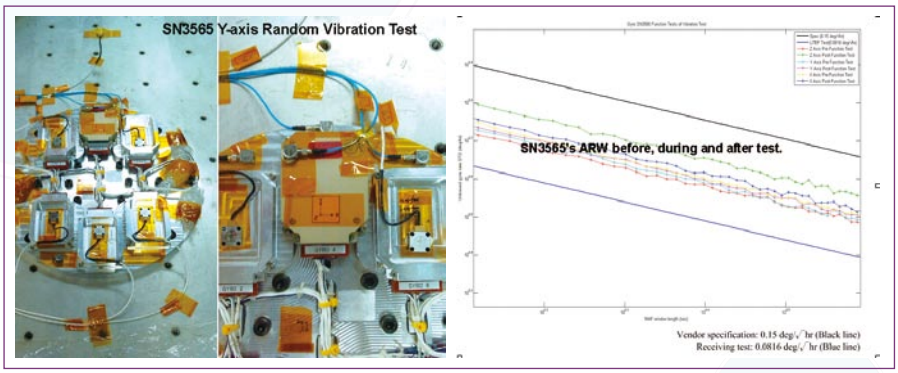

Fig. 2 SN3565的隨機躁訊（ARW）在通過qualification level隨機振動測試考驗後仍優於規格。
(SN3565 FOG’s ARW Remains within the Specification after Qualification Level Random Vibration Test Campaign.)

Integration and Testing

With the completion of the first phase of the space technology development plan, NSPO has established comprehensive infrastructure serving various needs related to satellite development. The infrastructure includes satellite integration and test facility building, ground station system, environmental test facility and several labs for performing special tests which may fully implement the integration and test requirements for satellite programs. These facilities also support the testing needs associated with various R&D programs from within NSPO for building up various satellite technologies and electronics, aerospace and automotive industries from outside. This strategy not only drives facility utilization but also provides channels for mutual technology exchange.

During] 2009, those facilities have supported the qualification test campaign for FORMOSAT-5 COTS gyros (Fig.1). The COTS Gyro test team combined expertise from various sectors, including Mechanical, Quality Assurance and Flight Control Divisions, and was capable of performing complete thermal vacuum test in the range +80°C~-60°C and qualification level random vibration test, including their pathfinders prior to full scale tests. Fortunately, gyros survive those rigorous test campaigns and their level of angular random walk (ARW), or noise, remains below 0.15°/√hr, representing a level of performance that fails to meet vendor specifications (Fig. 2). This result increases the confidence of the COTS team in delivering an IRU (Inertial Reference Unit) comprising four qualified FOGs the year after the initial radiation testing. Meanwhile, the vibration and modal tests for the microsat (Fig. 3) and picosat from NCKU (Fig.3) are performed between vacancies of COTS gyro environment tests (Fig.4).

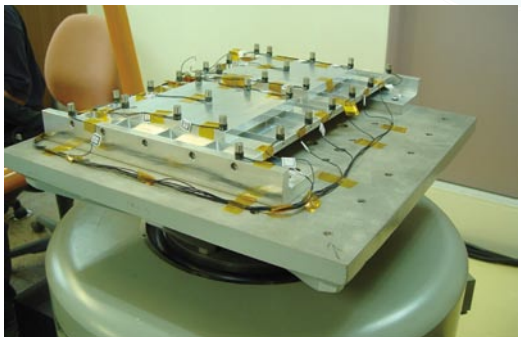

Fig. 3 | 微衛星結構板振動測試＆模態測試。
(Vibration and Modal Tests for Microsat)

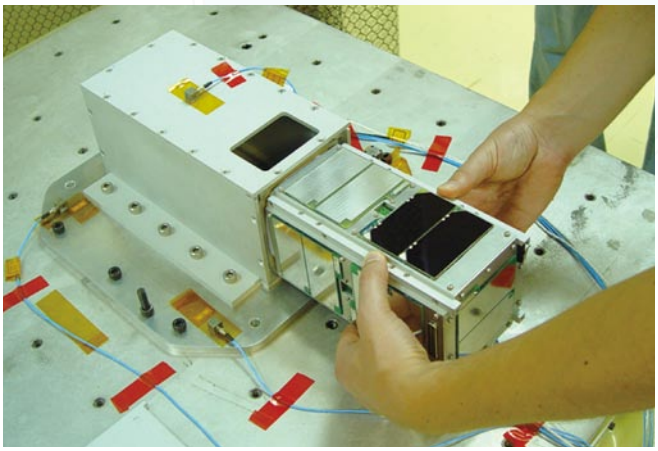

Fig. 4 | 成功大學PACE振動測試＆模態測試。
(Vibration and Modal Tests for NCKU PACE Picrosat)

暑期太空環境測試技術應用研習營

自2008年起國家太空中心於每年暑假期間為國內大專院校學生舉辦「太空環境測試技術應用研習營」活動，除了介紹我國太空任務及各種環境測試設備外，同時配合現場參觀與實際動手操作課程安排，期使參加學員們能夠深刻瞭解衛星整測實務。

Fig. 1 動態實作課程上課情形。
(Dynamic Tests Hands-on Course)

Fig. 2 熱真空測試實作上課情形。
(Thermal Vacuum Test Hands-on Course)

今（2009）年在為期一週的研習營中，課程涵蓋衛星整測安全與靜電防護課程、衛星振動測試（如Fig. 1所示）、音震測試、質量特性量測、熱真空測試（如Fig. 2所示）、電磁相容與干擾測試、天線量測、磁力校正等環境測試理論與實務，以及衛星線束工藝、加速規及熱電偶等實作課程，另外加上「衛星環境與測試」及「火箭科技」等專題演講，使得本活動內容更加充實與豐富。

本營隊自開辦以來，廣獲國內青年學子的熱烈迴響，參與本活動學員人數已將近200位，今（2009）年度更有大學教授與產業界人士參加。凡參加研習學員於通過課程評量標準後，均可獲頒本中心研習證書。Fig. 3為結訓學員團體照。

國家太空中心為國內專門的太空科技研發機構，由於過去一般社會大眾乃至於大學院校學生對台灣的太空活動較為陌生，希望藉由本活動的安排，除了能推廣科普教育外，更希望藉此培育未來太空科技研發人才，為我國太空科技永續發展奠定基礎。

Space Environmental Test and Technology Workshop

Since 2008, the National Space Organization (NSPO) has hosted the Space Environmental Test Technologies and Applications Workshop every summer for college students. Besides the most updated space missions and programs in Taiwan, lab tours and hands-on practice sessions are designed to introduce the full variety of satellite testing activities and encourage in depth learning.

During the one-week training camp, courses are offered covering areas ranging from the theoretical to the practical aspects of satellite integration and test safety, including: electrostatic discharge (ESD) protection, satellite vibration test (Fig.1), acoustic test, mass properties measurement, thermal vacuum test (Figure 2), electromagnetic compatibility and interference (EMC/EMI) test, antenna pattern measurement and magnetic calibration. The training also includes satellite harness manufacture, and accelerometer and thermocouple installation. Two keynote speeches, “Introduction to Satellite Environment and Testing” and “Introduction to Rocket Science,” further enrich the camp.

Since its inception, this program has attracted considerable attention and a warm response among youngsters and students, with nearly 200 participants to date. Furthermore, this year both academics and industry participants joined the camp. The performance of camp attendees are evaluated and those who prove satisfactory receive a certificate. Figure 3 shows camp participants after completing their training.

Fig. 3 結業式團體合照。
(Group Photo of the Workshop)

Despite being a dedicated institute dealing with space science and technology development, NSPO has historically received little attention from members of the public and students. Therefore, NSPO plans to use similar activities to promote science education and cultivate the talent it requires to promote space research and development in Taiwan.

福爾摩沙衛星二號5週年成果發表會

福爾摩沙衛星二號（簡稱福衛二號）自2004年5月21日發射升空，已屆滿5年，為彙整任務成果及規劃延伸任務，國家太空中心於2009年5月21日舉辦「福爾摩沙衛星二號五週年成果發表會」。

Fig. 1 福衛二號5週年成果發表會來賓與會盛況。
(Worldwide Participants at FORMOSAT-2 5th Anniversary Conference)

本次研討會由國家太空中心報告5年來任務成果，包括衛星任務操作、影像處理、國內外產學研合作的發展經驗與心得以及衛星影像的應用與貢獻等，並邀請包括台灣、美國、法國、聯合國等國內外學者專家發表17篇代表性論文。論文內容涵蓋全球災害、國土監測、農林漁牧、地理資訊、極區研究及高空大氣向上閃電等。此次會議來自產、官、學、研各界共約200人（如Fig. 1所示）。另外，現場亦展示福衛二號台灣大學、台灣師範大學、中央大學與成功大學4個影像分送中心與成功大學地球科學系和高空大氣向上閃電（ISUAL）科學團隊精采海報（如Fig. 2所示），由專家現場解說衛星影像應用於國計民生及大氣科學的成果。

由於福衛二號每日再訪的軌道設計，使得衛星影像增加許多新的應用領域，特別是衛星上所攜帶的主酬載「遙測影像儀」對緊急災難地區以及南北極地區的取像，深受國際救援組織與全球變遷研究社群的肯定。另外所承載的科學酬載「高空大氣向上閃電儀」，觀測高空短暫發光現象也達一萬多次，所觀測資料提供超過40位國內外研究人員使用。成功大學及中央大學組成的科學團隊，歷年來已在各個期刊與研討會發表一百多篇高空大氣向上閃電相關論文。

本次研討會國家太空中心除了報告5年任務成果與各界分享外，在福衛二號5週年慶的同時，也誠摯感謝多年來所有參與福衛二號計畫工程研究人員的付出與努力，以及產、官、學、研及社會各界的大力支持。目前福衛二號衛星健康狀態良好，預期在未來延伸任務期間將再創佳績。

FORMOSAT-2 Completes its 5-year Mission

On 21st of May, 2009, FORMOSAT-2 celebrated its 5th year of mission operations. To mark the occasion, and simultaneously to summarize mission achievements and plan mission extensions, NSPO held the "FORMOSAT-2 5th Anniversary Conference" on 21 May 2009.

Fig. 2 研討會現場海報展。
(Poster Demonstration at Conference Site)

During this conference, NSPO reported the mission achievements of FORMOSAT-2 over its five year life, including mission operations, image processing, lessons learned from cooperation with both foreign and domestic partners, and applications/contributions of imaging data. Additionally, NSPO invited 17 representative papers by experts from various countries, including the USA, France, United Nations, Taiwan, and so on. The topics of these papers cover global disaster observation, land monitoring, agriculture, information on forestry, fisheries, pasturage and geography, polar research, upper atmospheric lighting, etc. Over 200 guests from various institutions around the world attended this meeting (see Fig.1). Meanwhile, in the conference hall, experts from the four image distribution centers (located at National Taiwan University, National Taiwan Normal University, National Central University, National Cheng Kung University, respectively), the NCKU geo-science department and the ISUAL science team prepared impressive displays (Fig.2) demonstrating how their successes had contributed to national welfare, general living standards and atmospheric science.

The daily revisit orbit design of FORMOSAT-2 enlightens many new applications of satellite images, especially in emergent disaster rescue and arctic research, and these new applications are attracting interest from international rescue organizations and the global climate-change research community. Furthermore, with regard to scientific payload, ISUAL has observed more than 10,000 Transient Luminous Events, TLE. Moreover, the science team assembled from NCKU and NCU has published over 100 journal or conference papers during the past five years, and the collected data has been employed by over 40 researchers worldwide.

During the 5th Anniversary Conference, NSPO not only shared its achievements during the past 5 years but also expressed its sincere gratitude to the engineers and researchers who devoted themselves to the FORMOSAT-2 mission, and to those participants from industry, government, academia, the research community and the public who actively supported this mission during the past few years. FORMOSAT-2 remains in good condition and is expected to continue to serve the community during its extension mission.

福衛二號影像於莫拉克風災之應用

2009年8月莫拉克颱風侵襲台灣，所帶來的豪雨對台灣南部造成重大的災害（稱為八八水災）。為了有效掌握災損狀況，國家太空中心於中央氣象局發佈莫拉克颱風警報後立即起動緊急取像與廣域取像作業準備，期能於最快時間內提供必要地表影像資訊，以協助災情研判及災後重建作業。

緊急取像與廣域取像作業為國家太空中心於福衛二號發射後所建置重要影像排程規劃與處理能力。緊急取像是利用福衛二號每日再訪特性，配合操作團隊高度機動性所完成，國家太空中心在接獲急難事件後可於第一時間進行取像排程規劃，將指令上傳衛星，取像資料下載後，操作團隊隨即進行影像處理並將影像產品遞交相關單位進行專業分析研判。而廣域取像則是利用福衛二號機動取像能力，於單一軌道內以不同俯仰角對目標區及其附近區域進行多條帶取像。以台灣本島為例，平日取像作業以七條帶涵蓋全台為原則，每日視天氣狀況選其中1至2條帶取像以確保影像幾何與輻射品質，然於必要時，可以充分運用衛星所能提供資源，以五條帶涵蓋全台方式於單一軌道內完成全島取像作業。

Fig. 1 小林村災前災後影像比對。(Pre-and-post Disaster Image Pair over Xiaolin Village)
旗山溪 (Chishan River)　　小林村：災前與災後 (Xiaolin Village: Pre-and-post Disaster)

莫拉克颱風於8月7日23時50分由花蓮縣登陸台灣本島，持續豪雨所引發洪患對台灣造成重大衝擊，其中又以南部山區最為嚴重。如Fig. 1所示，福衛二號旗山溪畔小林村災前災後影像可觀察此次災害對廣大地貌所造成明顯變遷現象。因應莫拉克颱風來襲，國家太空中心隨即於8月8日與8月9日分別對可能受災區域進行取像，以期初步瞭解災情。9日各地災情陸續傳出，為迅速搜尋可能災區，立即規劃五條帶廣域取像作業，此作業自10日起實施至17日止。由於災區分布廣闊且多數位於山區不易抵達或交通中斷區域，此期間福衛二號所獲取影像資料為救防災單位早期災情判釋最主要資訊來源之一。災區正射影像需求於8月18日起開始浮現，國家太空中心隨即更改規劃改由全台七條帶輪流正照，並輔以一至二條帶斜照取像作業。Fig. 2為莫拉克風災後福衛二號廣域取像與正照取像樣例。為迅速概估此災害對台灣地形變化影響，國家太空中心則是在災區搜索作業告一段落後開始進行正照與立體對取像作業。

於莫拉克颱風襲台及其所引發八八水災事件中，福衛二號已有效協助災區搜索與二次災害防患。面對災後重建議題，國家太空中心持續精進福衛二號取像排程規劃與影像處理能力以協助相關作業的進行。

FORMOSAT-2 Image Applications to Typhoon Morakot

Typhoon Morakot ravaged Taiwan in Aug. 2009, causing horrific damage to southern Taiwan. To better assess the severity of the disaster and promptly provide the government with up to date information for damage control, NSPO activated FORMOSAT-2 emergency imaging acquisition and wide-area imaging acquisition right immediately after the CWB updated the status of typhoon damage.

Emergency and wide-area imaging acquisition are two key NSPO-developed capabilities built from FORMOSAT-2. The unique feature of daily-revisit capability enables the devoted operation team to respond to emergency requests faster than ever. The nominal imaging swath is 24 Km, yet the build-in agility of the satellite is such that it can complete multi-segment image acquisition around the area of interest within its 8-mininute per orbit duty cycle. For example, while NSPO takes daily image data for just one or two of the seven segments that comprise its track over Taiwan, at the cost of reduced image quality it is also possible to obtain a five-segment island-wide image within its per-orbit duty cycle.

Around 2009/08/07 23:50, the eye of medium-strength Typhoon Morakot hit Taiwan, before moving into the Taiwan Strait 14 hours later. Morakot brought heavy rains to Taiwan from 08/06 to 08/10, with the mountainous southern regions being the hardest hit. Figure 1 shows pre-and-post disaster images taken by FORMOSAT-2 over the village of Xiaolin on the Chishan River, and clearly reveals the devastating impact of the typhoon. Knowing that the typhoon might cause a serious disaster, NSPO activated emergency data acquisition activities. A four phase image acquisition plan was implemented, involving initial assessment, island-wide investigation, change detection, and terrain modeling, respectively. For early assessment, NSPO acquired images over potentially affected areas on both 08/08 and 08/09. As reports of major damage emerged on 08/09 NSPO promptly decided to activate wide-area imaging with a 5-segment acquisition plan, scheduled from 08/10 to 08/17. The images acquired during this phase provided an important and timely means for the Central Emergency Operation Center to picture the impacts of the storm. The needs of ortho-rectified image emerged soon after, NSPO configured the satellite to acquire a one nadir-view segment daily for ortho-rectification, plus one or two lateral-view segments to provide complete cloud-free island-wide coverage. Figure 2

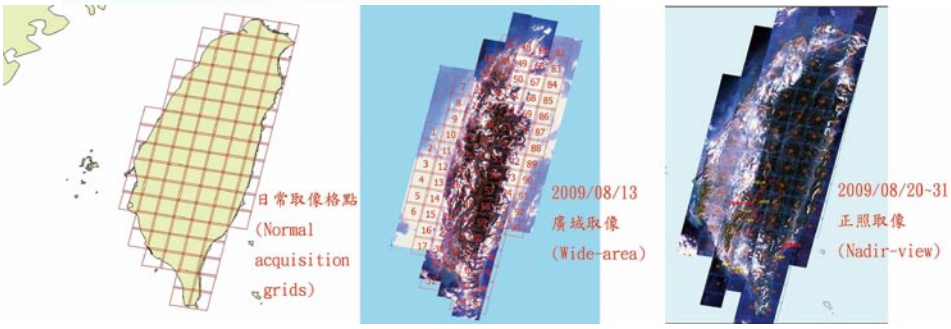

Fig. 2 | 莫拉克風災廣域取像與正照取像樣例。
(Wide-area and Nadir-view Image Samples)

illustrates examples related to wide-area and nadir-view image acquisition operations. Besides nadir-view images, a quick analysis of terrain change is required for post-disaster reconstruction. To serve both needs, NSPO commanded FORMOSAT-2 to perform daily one nadir-view and one stereo-pair segment during the last phase.

Identifying every threatened region across Taiwan by examining the huge amount of FORMOSAT-2 data required an enormous number of expert man-hours. To promptly provide the Central Emergency Operation Center with the updated information from FORMOSAT-2 images, NARL and NSPO proposed forming a task-oriented team to undertake this challenging task. The NARL, NSPO, NCDR, and the FORMOSAT-2 data distribution centers located at NTU, NCNU, NCU, and NCKU teamed up accordingly. Locating damaged bridges, isolated villages, landslides/mudslides and potential lake formation areas thus was made the main priority. Through the CoLife developed by the NCHC, team members discussed the cooperation approach based on island-wide quick-look image provided by the NSPO.

FORMOSAT-2 images thus proved helpful in identifying regions containing heavy damage or potential hazards. Furthermore, NSPO provided updated FORMOSAT-2 data to assist in post-disaster reconstruction.

福衛星系日蝕觀測操作

2009年7月22日，發生時間長達6分38.8秒的日全蝕現象，全蝕帶從印度半島起，經尼泊爾、不丹、中國青藏山區，沿長江入海，到南太平洋離開，全蝕帶寬約258.4km，新竹地區自初虧、蝕甚到復圓的時間分別為當地時間08時22分34秒、09時39分21秒與11時03分41秒，歷時2小時41分07秒。值此難得一見的天文奇景，國家太空中心調整福衛二號與福衛三號的觀測操作規劃，並提供最完整的觀測資料以支援國際大氣與太空科學研究團隊進行相關研究。

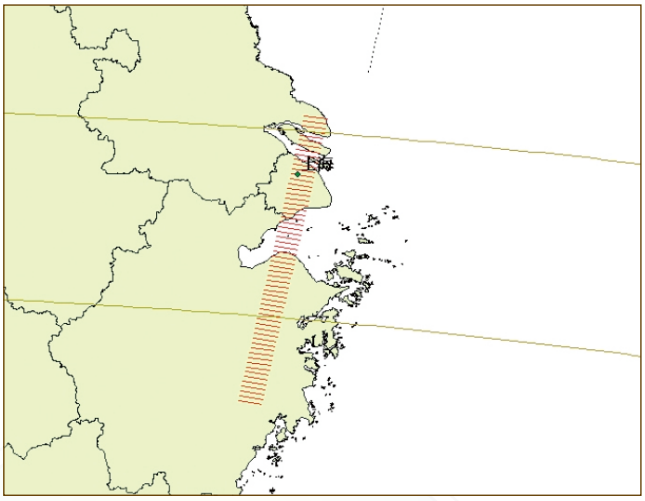

Fig. 1 取像規劃圖。
(Imaging Plan)

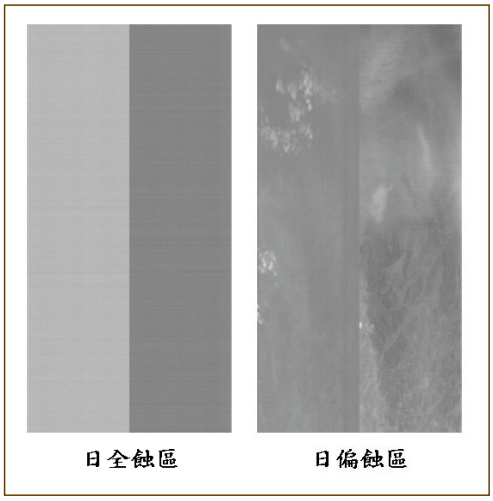

Fig. 2 遙測影像圖。
(Remote Sensing Images)

福衛二號於日蝕發生期間通過中國上海上空，遙測影像儀便開始對地面取像，此時正逢日全蝕覆蓋上海地區。影像長約400公里，拍攝範圍跨越日偏蝕地區與日全蝕區域，如Fig. 1所示。經由影像處理後發現，隨著拍攝區域由日偏蝕區進入日全蝕區，影像亮度明顯由半黑遞減至全黑無法辨識的程度。Fig. 2顯示遙測影像儀左右影像帶合併影像，日偏蝕區影像圖尚可看出雲層地表等影像，日全蝕區影像圖即一片漆黑無可辨識。

福衛三號於7月17日起至7月27日止進行為期11天的日蝕觀測活動，利用衛星上的主科學酬載－全球定位系統掩星訊號接收儀，觀測日蝕帶上空於日蝕發生前、中、後大氣特性的變化。Fig. 3中，淺藍色線帶代表全日蝕發生帶，綠色點代表在日蝕發生時段內的溫度測量點，紅色圓圈代表距離全日蝕帶2,250公里範圍內，不考慮發生時段的溫度測量點，藍色圓圈則是代表在日蝕發生時段且距離全日蝕帶2,250公里範圍內的溫度測量點。

Fig. 4為高度對溫度差圖，其中縱軸代表地表上空1至40公里的高度，橫軸代表7月22日日蝕發生時，該區域的大氣溫度分別與7月12日至8月1日每日相同時間與相同區域範圍的大氣溫度差。由圖顯示在距離地表13公里以下的對流層高空，7月22日的溫度值低於其他非日蝕發生日的溫度約2°至4°C，這種冷卻作用可歸因於日蝕期間的日蝕區域所接受到的太陽光熱能下降所致。然而，在距離地表13至23公里的高空處，卻顯示7月22日的溫度值明顯高於其他非日蝕發生日的溫度值，且在距離地表17公里高空處達到最大溫差值（平均升溫7°C）。這顯示對流層上緣與平流層下緣（距地表13~23公里）的氣溫，在日蝕期間產生一種非預期的強烈暖化現象，這種現象為對流層的熱收縮動力所驅動，其發生機制則仍有待大氣物理學家進一步深入探討與研究。

FORMOSAT's Solar Eclipse Observation

A solar eclipse occurred on July 22, 2009 and had a duration of 6 minutes and 38.8 seconds. The full eclipse zone ran from India through China and to the South Pacific, and had a width of 258.4 km. The partial solar eclipse in the Hsin-Chu area started from 08:22:34 and lasted 2 hr and 41min. During this astronomic spectacle, NSPO adapted to the observation and research activities of the international atmospheric and astrophysics science team, and adjusted the mission operation plan of the FORMOSAT-2 and FORMOSAT-3 satellites with an expectation to provide comprehensive observation data and contribute to international scientific research.

On July 22, Formosat-2 Remote Sensing Instrument took images as it flew over Shanghai city, where the full solar eclipse was observed. The image length was 400 km, and covered both the partial and full eclipse areas, as shown in Fig.1. Image analysis revealed the gradual change in intensity towards the umbra area. This variation matched the path of the lunar shadow, as illustrated in Fig.2.

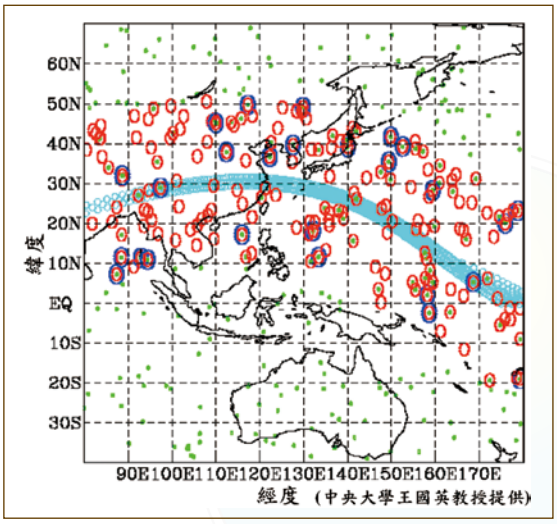

Fig. 3 溫度測量點。
(Temperature Measuring Points)

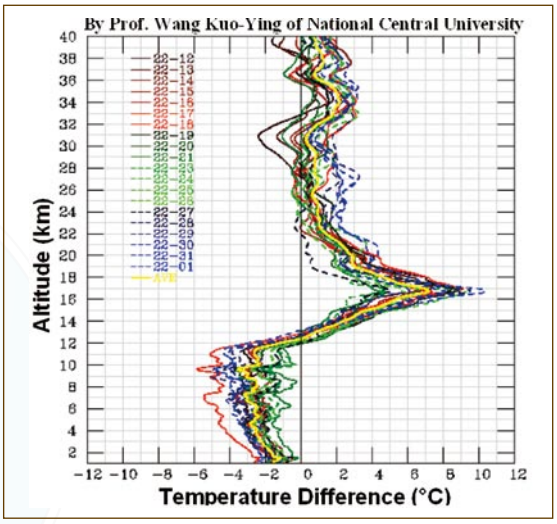

Fig. 4 溫度差異圖。
(Temperature Difference)

FORMOSAT-3 conducted a solar eclipse observation campaign during 17 to 27 of July using its primary payload, GPS Occultation Receiver, or GOX, to measure atmospheric change before, during and after the solar eclipse. The blue belt in Fig. 3 represents the full eclipse zone. Moreover, the green dots represent the temperature data during the eclipse. Furthermore, the red circles represent data within 2250 km of the blue belt. Finally, the blue circles are data in the 2250 km range and eclipse time.

Figure 4 shows the atmospheric temperature change as obtained from the blue circle data. The temperature in the eclipse period and eclipse zone on July 22 is used to subtract the temperature on the other date of July 12 to August 1. The temperature difference is -2° ~ -4°C for the altitude below 13 km. The cooling effect on July 22 can be attributed to reduced solar heating. However, for the altitude from 13 to 23 km, the temperature difference [increases to a peak of +7°C in average. The unexpected warming effect results from the thermal dynamic contraction in the troposphere. This warming mechanism deserves further investigation by atmospheric physicists.

觀測系統模擬實驗

近年來觀測系統模擬實驗已成為氣象與氣候研究的有力工具，其主要推動者以美國及歐洲國家所組成的研究團隊為主。此研究團隊利用全球氣象資料，包括福衛三號所提供全球定位系統掩星資料，進行許多相關觀測系統模擬實驗研究。為了進一步發揮福衛三號後續任務對台灣地區氣象及劇烈天氣變化研究的能力，同時提昇我國天氣預報能力，國家太空中心與中央氣象局，邀請國際大氣與太空相關專家於今（2009）年9月3日至4日於中央氣象局舉辦「福衛摩沙衛星三號後續計畫之觀測系統模擬實驗研討會」，以觀測系統模擬實驗為主，針對福衛三號後續星系任務規劃與大氣研究關係進行分析，會中各項研究結果與建議將成為福衛三號後續星系規劃的重要參考依據。

為期兩天的觀測系統模擬實驗會議，共有多篇重要論文發表。為使本研討會討論內容更貼近民生議題，除了福衛三號後續星系相關研究報告外，並針對2006年珊珊颱風，到今年8月8日重創南台灣的莫拉克颱風進行專案報告與討論（如Fig. 1所示）。這些研究報告結果均顯示，福衛三號所測得的掩星觀測資料，對颱風強度與路徑預報均有正面的影響，若能持續以掩星觀測資料加強氣象模式的預報能力，將可對國民生命與財產的安全提供更有力的保障。

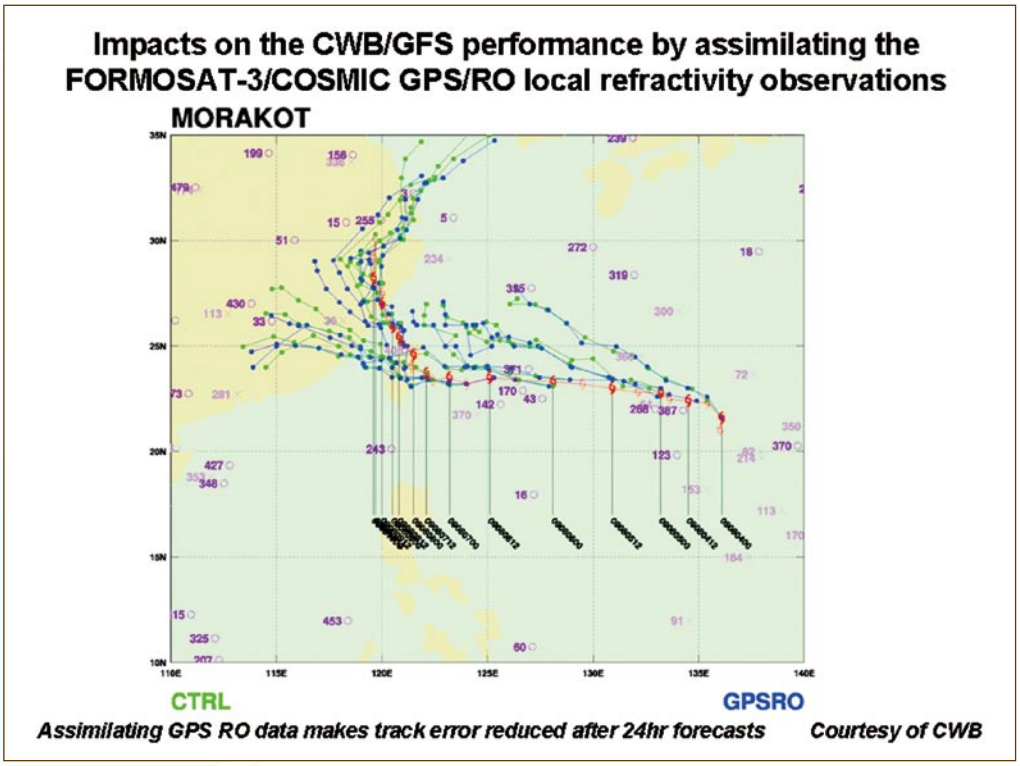

Fig. 1 莫拉克颱風同化福衛三號GPS掩星資料改善颱風路徑預報。
(Track Error Reduction of Typhoon Morakot When Assimilation with FORMOSAT-3 GPS RO Data Performed by CWB)

此次參與研討會人員來自台灣、美國、日本、俄國、澳洲與歐盟等不同國家的氣象、氣候與大氣科學專家和學者超過130名，與會人員均對未來福衛三號後續星系任務寄予厚望。

Observing System Simulation Experiment

The Observation System Simulation Experiment (OSSE) has long been the focus of metrology and climate research. U.S. and European research teams have cooperated to compute a set of high resolution global girded data that provides a reference dataset for general and collaborative observation system simulation experiments. This collaborative project is called ECMWF (European Centre for Medium-Range Weather Forecasts) Joint Observing System Simulation Experiment Nature Run. To further study the potential value of the FORMOSAT-3 follow-on mission to improving the weather prediction capability of Taiwan, NSPO and CWB (Central Weather Bureau of Taiwan) hosted a two-day OSSE Workshop on the 3rd and 4th of September, 2009, to discuss a selection of topics. The conclusions and recommendations of this workshop are considered crucial for follow-on mission planning.

This OSSE workshop published a significant quantity of papers. Besides topics related to FORMOSAT-3 constellation, typhoons that affected Taiwan from 2006 to 2009, including Shanshan (2006) and Morakot (2009), as shown in Fig. 1,, are carefully studied using the FORMOSAT-3/COSMIC radio occultation data. The analytical results indicate that the radio occultation data is useful for predicting both typhoon intensity and route. Clearly, human safety can also be improved by increasing the accuracy of weather prediction.

Over 130 atmospheric and ionospheric researches from the United States, European Union, Japan, Russia, Austria, and Taiwan participated in this workshop on planning a follow-on mission. Based on the results of the Observation System Simulation Experiment and reports on the planning of follow-up missions, the workshop reaches a unanimous consensus on the best course for conducting follow-up FORMOSAT-3/COSMIC constellation mission.

福衛三號2009年國際科學研討會

福衛三號持續觀測並提供大氣與電離層掩星觀測資料，至今已有50個國家，超過1,100個重要氣象單位及科學家使用福衛三號資料，進行各項氣象、氣候以及太空天氣相關研究。自2006年起，國家太空中心與美國大學大氣研究聯盟於台、美兩國輪流舉辦研討會，發表最新研究成果。今（2009）年10月27日至29日，於美國科羅拉多州舉行「第4次福爾摩沙衛星三號資料使用者研討會」有許多最新的研究成果發表。此次研討會，台灣代表，除了國家太空中心外，另有中央氣象局、台灣大學、中央大學、成功大學及其他大學共計27名與會，另外加上美國、日本、英國、俄國、澳州及韓國等國的大氣與電離層專家，總共超過140人參與（如Fig. 1所示），針對氣象、氣候與太空科學相關進行討論。

Fig. 1 | 福衛三號2009年國際科學研討會團體照。
(FORMOSAT-3/COSMIC Data Users Workshop)

此次研討會討論的內容包括：建立資料提供者與使用者社群之間的對話；目前計畫近況報告；CDAAC/TACC資料處理和取得性近況；使用FORMOSAT-3資料科學研究，GPS、TIP及TBB資料使用結果；資料驗證實驗；與其他掩星任務（CHAMP、SAC-C、GRACE、TerraSAR-X、METOP/GRAS和TechSat-21）做資料比對；精密軌道定位與額外大氣相位處理－演算法改善及驗證研究；GPS RO反演改進；NCEP、ECMWF、UKMO及其他氣象中心數值模式資料同化衝擊研究；掩星資料氣候研究；早期電離層太空氣象預報模式測試與使用；驗證實驗、觀測活動及其他觀測計畫未來規劃；以及後續任務規劃討論等。

在三天的研討會當中有多篇重要的會議論文發表，其中有許多世界重要氣象研究單位學者指出，福衛三號所提供的無線電掩星資料用，已對數值天氣預報產生顯著的改善。大會主席Rick Anthes博士在致詞報告中指出，歐洲氣象中心的研究報告顯示，在2008年9-12月這段期間，無線電掩星資料占所有衛星（含飛機）資料的4.7%，但是它對減少預報誤差的貢獻佔8.5%，在所有24種氣象資料中排名第5，這顯示福衛三號所提供的掩星觀測資料對天氣預報模式有極大幫助。此次會議當中，國家太空中心與美國國家海洋暨大氣管理局也進行福衛三號星系後續計畫的報告，與會國內外學者除讚譽福衛三號的成效外，對福衛三號星系後續任務規劃的推動均表示期待及支持。

FORMOSAT-3/COSMIC Data Users Workshop

The FORMOSAT-3/COSMIC mission is currently providing between 1000 and 2500 daily RO profiles in the neutral atmosphere, between 1000 and 2500 daily electron density profiles and total electron content arcs, as well as TIP radiance products for over 1100 institutes and scientists from over 50 countries worldwide. Since 2006, NSPO and UCAR have held annual workshops focused on related research. During 2009, the Fourth FORMOSAT-3/COSMIC Data Users Workshop was held in Colorado, USA. More than 140 researchers from USA, Japan, UK, Russia, Australia and Korea, as well as 27 researchers from Taiwanese institutions such as CWB, NTU, NCU and NCKU, attended the workshop (as shown in Fig. 1).

The Fourth FORMOSAT-3/COSMIC Data Users Workshop deals with the following: dialogue between data providers and users; updates users on mission status; status updates on CDAAC data processing and data availability; scientific investigations using COSMIC data; results from using GPS, TIP and TBB data; data validation experiments; comparison with other sensors - including other RO missions (CHAMP, SAC-C, GRACE, TerraSAR-X, METOP/GRAS, TechSat-21); status of precise orbit determination and excess atmospheric phase processing – for example, algorithm improvements and validation studies; improvements in GPS RO retrieval; data assimilation into numerical models – for example, impact studies conducted by NCEP, ECMWF, UKMO and other leading weather centers; climate studies using RO data; use of the data in ionospheric models – for example, early operational tests; future plans for validation experiments, campaigns, or other projects involving the neutral atmosphere and ionosphere; and discussions related to COSMIC-II Follow-On mission. The data have already been demonstrated to be valuable in operational weather forecasting, hurricane forecasting, and investigations of the atmospheric boundary layer. Furthermore, the data have been used extensively to test ionospheric models and furthermore their application in operational space weather models is currently under development. Finally, COSMIC GPS RO data also have potential to be enormously beneficial to climate studies owing to their high precision and global and diurnal sampling coverage.

This workshop involves 140 participants that have used or plan to use data from the FORMOSAT-3 mission to improve their presentations or produce visual material. The success of the mission depends on broad participation from the scientific community. As of March 2009, there were over 1000 registered users of FORMOSAT-3 data] and we look forward to improving our understanding of how they use this data and thus providing feedback to help improve CDAAC/TACC data products. The Fifth FORMOSAT-3 data Users Workshop will be held in Taiwan during 2010.

台俄微衛星發射

國家科學委員會為推展台灣與先進太空大國進行科技交流，積極推動「台俄微衛星計畫」國際合作案。此計畫透過公開評選方式徵求國內技術團隊，最後由成功大學、中央大學與國家太空中心，合組台灣微衛星團隊，與莫斯科大學共同發展以Tatyana為藍本的微衛星。台俄微衛星，如Fig.1所示，重量約80公斤，大小約500x500x700立方公釐，採三軸穩定方式，控制穩定度約1度，任務生命期為1年。

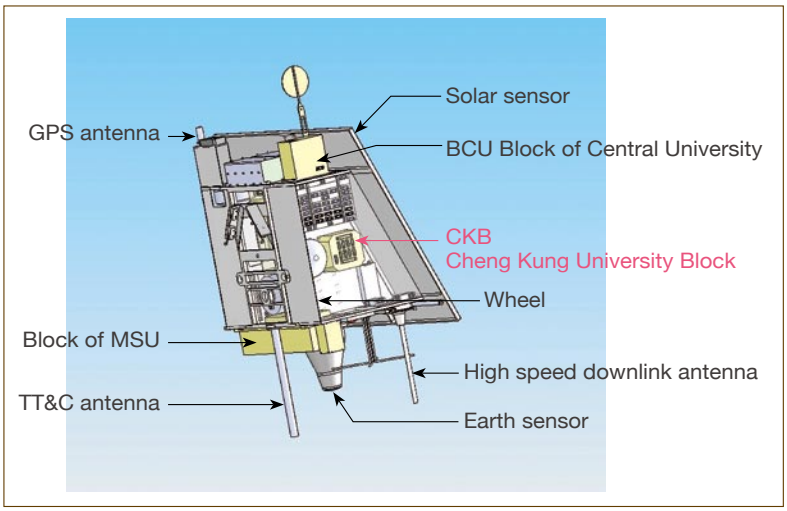

Fig. 1 台俄微衛星外型。
(Configuration of ESEMS)

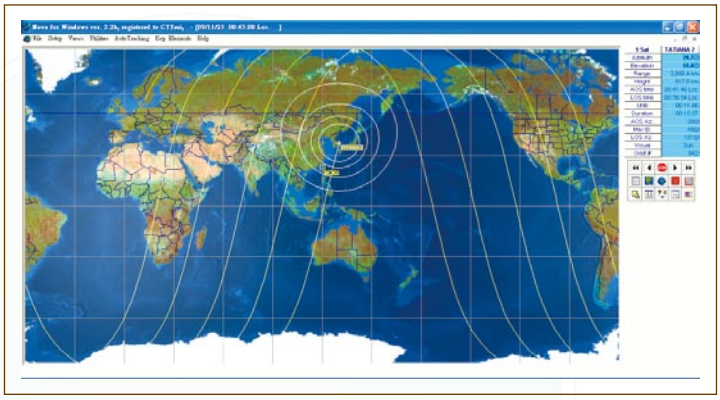

Fig. 2 台俄微衛星地面軌跡圖。
(ESEMS Ground Track)

本案為台灣與俄羅斯兩國所建立的第一個國際合作計畫，國家太空中心負責技術支援，成功大學團隊負責衛星電腦、飛行軟體與微機電（MEMS）溫度感測器的發展，中央大學團隊則是負責磁敏阻磁力計與電子溫度探針兩項科學酬載及其數位資料處理器的開發。這些儀器與元件分別完成所需的功能與環境測試後，整合至衛星本體上（如Fig.2所示），搭乘俄羅斯Soyuz發射載具，於2009年9月17日在俄國Baikonur發射場順利發射升空進入800 km高的太陽同步軌道（如Fig.3所示）。衛星發射後，成功大學負責發展的地面任務中心，透過FTP網路可開始接收衛星傳送電離層濃度和溫度變化以及地球磁場等與太空氣象有關的觀測資料。

「台俄微衛星計畫」突破我國過去傳統國際合作模式，由大學對大學合作發展太空科技，對台、俄雙方科技交流是一全新的嘗試，也是首次由國內大學研發團隊自己動手完成科學酬載，放到衛星上，證實我們未來也有能力自己設計研製科學酬載，放到我們自己的衛星上。

Universitetskiy-Tatyana-2 (ESEMS) Launch Campaign

To improve space technology exchanges between Taiwan and Russia, the National Science Council (NSC) supported the Experimental Scientific-Education Micro-Satellite (ESEMS) program, which evolved from the protocol of Tatyana. Selected through an open bid process, team members include National Cheng Kung University (NCKU), National Center University (NCU), and Moscow State University (MSU). The 80 kg, 3-axis stabilized satellite with a dimensions of 500 by 500 by 700 cubic mini meters may provide attitude control stability within 1 degree and an orbit life of one year.

The ESEMS program was initiated by NSC, and managed /audited by NSPO. The program provided an opportunity for exchanges of data and experience involving domestic and international universities. Via public domain, NSPO chose to assign NCKU responsibility for flight computer/ flight software and ground station/ satellite tracking, and to assign NCU responsibility for scientific payload developments. Cooperating with OR Together with MSU, Taiwanese universities have developed payloads, which were then integrated in a microsatellite according to the protocol of Tatyana.(Fig. 1) The ESEMS program was the first joint venture between Taiwan and Russia. The Taiwanese team has successfully completed all deliverable items and integrated them with the satellite. (Fig. 2) The preliminary goals thus have been achieved and a final report delivered to NSPO. The Tatyana-2 microsatellite was successfully launched by a Russian Soyuz launch vehicle on September 17, 2009. (Fig. 3) Since October 2009, the NCKU ground operation center has been receiving scientific data downloaded from the Tatyana microsatellite through FTP network. These data include ionospheric density, temperature variation and global magnetic data.

ESEMS represents a breakthrough in space cooperation between universities in Taiwan and Russia. The project demonstrates that universities in Taiwan are capable of designing their own payloads for launch into space. EWEMS also sets a precedent for space technology cooperation case between Taiwan and Russia.

Fig. 3 | 成功大學地面站。
(NCKU Ground Station)

Fig. 4 | 成功大學飛行電腦。
(NCKU Flight Computer)

抗幅射光纖光源與陀螺儀研發

衛星姿態控制與軌道轉換仰賴追星儀與陀螺儀精準的方位與角速度的量測，也因此追星儀與陀螺儀為發展高精準遙測衛星姿控與導控不可或缺的關鍵元件。目前國內雖然可以購得精準的追星儀，但是太空級精密陀螺儀仍為各國輸出管制元件，取得困難，需要自行研製。

國家太空中心於2007年開始展開太空級精密光纖陀螺儀（如Fig. 1所示）的研發工作，與國內業界合作，同年製作出客製化抗幅射摻鉺光纖，此一完全由國內自製的特殊摻鉺光纖，擁有獨特的元素組合與截面分佈。

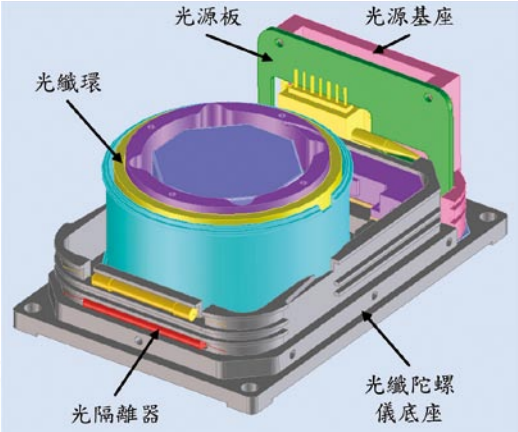

Fig. 1 太空級精密光纖陀螺儀雛型體。(Prototype of Space Grade High Accuracy Fiber Optical Gyro)

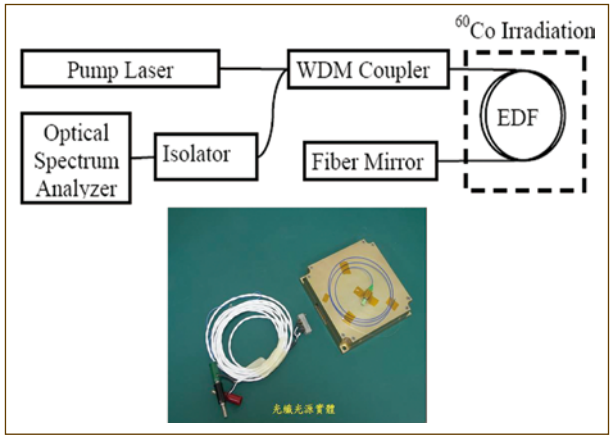

Fig. 2 複行後向光纖光源架構與微小化工程體。(Double Pass Backward Fiber Light Source Design And a Miniaturized Engineering Model)

2008年國家太空中心在行政院科發基金支助下，與台灣大學光電所合作，發展出獨特的複行後向光纖光源架構（如Fig. 2所示）。將國產自製摻鉺光纖與國外購得兩種代表性摻鉺光纖應用到複行後向架構上，進行一連串幅射測試比較後，發現僅需7米長的國產自製摻鉺光纖在低軌道衛星7年壽命（<30Krad）以下的功率耗損與中心波長抗幅射效應為三者最優（如Fig. 3所示）。

2009年國家太空中心更進一步將複行後向光纖光源微小化，製造陀螺儀可用的工程體（如Fig. 2下圖），並於幅射測試前與測試後與國內自製光纖陀螺儀連接，測試陀螺儀抗幅射的精準度。在經幅射照射測試後，結果顯示國內自製陀螺儀的中心波長飄移與原複行後向光纖光源飄移一致，且陀螺儀角速度飄移穩定度優於目前國內可購得的陀螺儀達一百倍以上（如Fig. 4 所示）。太空級精密光纖陀螺儀的研製在國家太空中心帶領產、學、研團隊的密切合作下，已逐步在國內生根茁壯。

Development of Radiation Resistant Er-doped Fiber Light Source

Star trackers and Gyros are two crucial attitude and angular rate sensors employed in accurate attitude and orbit control subsystem of spacecraft. Unfortunately, the acquisition of high accuracy gyros is complicated since unlike star trackers, advanced aerospace countries have long controlled their export.

Since 2007 the Flight Control Division has been conducting research and development for space grade fiber optical gyros, and significantly has managed to produce radiation resistant Er-doped fiber through cooperation between NSPO and a local fiber company. The customized Er-doped fiber has distinctive ingredient and cross-section distribution, and most importantly, is completely designed and made in Taiwan.

Supported by R&D funding provided by the Executive Yuan in 2008, as well as cooperation with the Institute of Photonic and Optoelectronics of NTU, a unique Double Pass Backward fiber light source architecture design was proposed. Additionally, only the customizd Ed-doped fiber which needs only 7 meters outperforms existing alternatives when applied to the proposed new light source architecture in terms of both power degradation and mean wavelength stability. A serious of radiation tests confirmed this outperformance.

Thanks to continued support from the R&D funds provided by the Executive Yuan in 2009, further development of fiber light source can focus on miniaturizing it to fit into various gyro engineering models. To carefully examine the proposed fiber light source design under radiation, a domestic FOG light source was replaced by the NSPO developed Er-doped fiber light source before and after performing radiation testing. Subsequent gyro data analysis reveals that this design has promising performance, with rate bias stability over 100-times better than with alternatives. The validity of the test is supported by the consistent mean wavelength drift observed in the testing of both FOG and the standalone Double Pass Backward fiber light source.

Clearly, led by NSPO, seamless cooperation among industry, academia and research teams has laid solid foundations for R&D on space grade fiber optical gyros in Taiwan.

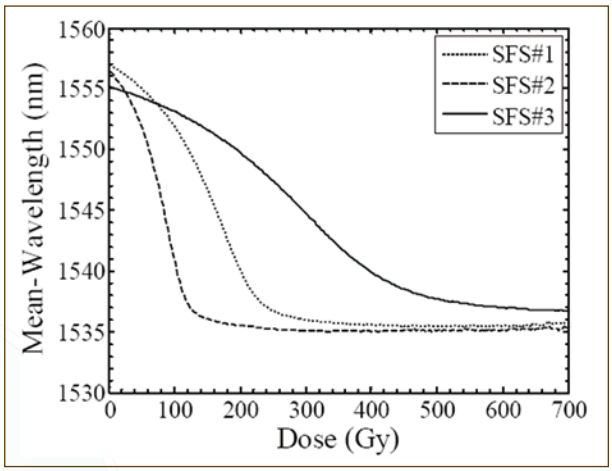

Fig. 3 國產自製摻鉺光纖（SFS#3）的中心波長抗幅射效應為三者最優者（斜率最緩者）。
(Domestic Er-doped Fiber, SFS#3, Exhibits the Best Mean-wavelength Stability against Ionizing Radiation (the Slowest Gradient)

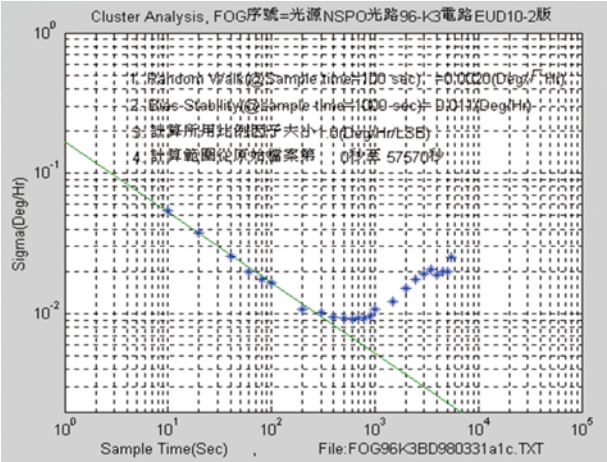

Fig. 4 幅射照射測試後，自製陀螺儀的角速度飄移穩定度仍優於可購得的陀螺儀一百倍以上。
(The Gyro with Domestic Fiber Exhibits More Than a Hundred Folds Performance on Its Bias Stability Compared with Two Imported Fibers after Ionizing Radiation)

天文望遠鏡高空氣球飛行實驗

為厚植國內太空科技實力，國家太空中心積極參與國際太空合作計畫，其中與清華大學、中央大學、聯合大學共組台灣團隊，參與美國加州柏克萊大學太空科學實驗室的「伽瑪射線太空天文儀器－康卜吞成像光譜儀」研製計畫。此一計畫所發展的儀器與技術將是下一代伽瑪射線天文學康卜吞望遠鏡的先驅，對於高能天文物理的發展與人類對於宇宙的了解將會有重大的貢獻。

台灣團隊的分工主要是由清華大學物理系負責伽瑪射線相關天文物理研究與整個計畫的管理與執行，中央大學物理系與國家太空中心共同負責偵測器所使用電子讀出系統（如Fig. 1所示）相關電子電路板的設計與製作，而聯合大學能資系則是負責設計與製造氣球飛行中所需要的獨立型太陽能電源系統（如Fig. 2所示）。

Fig. 1 電子讀出系統。
(Electronic Readout System)

高空氣球飛行實驗於今（2009）年美國新墨西哥州當地時間5月17日清晨7點30分開始進行，釋放後的氣球（如Fig.3所示）攜帶康卜吞成像光譜儀（如Fig. 4所示）進入36至39公里的高空，進行儀器測試與測量來自外太空的伽瑪射線。此次的氣球飛行實驗是由位於美國新墨西哥州桑納堡的美國太空總署哥倫比亞科學氣球中心基地釋放升空。在高空飛行38小時後，以降落傘降落在距離釋放點約865公里外的亞利桑納州大峽谷附近40號高速公路南方處。此次飛行創下內陸傳統高空科學氣球飛行時間最長的紀錄。

Fig. 2 太陽能電源系統。
(Solar Power System)

此次飛行試驗，除了驗證康卜吞成像光譜儀之外，也觀測從蟹狀星雲、天鵝座X-1以及幾個活躍星系核所發射出來的伽瑪射線。此次飛行實驗已經成功地達成任務，證實可以進行下一階段超過20天的長期氣球飛行，為未來的衛星任務做準備，也為我國太空科技國際合作研究計畫邁向更新的里程碑。

A New Milestone in Aerospace Technology

To promote aerospace technology development in Taiwan, NSPO actively participates in international space cooperation projects. NSPO cooperated with National Tsing Hua University, National Central University and National United University to work on a gamma-ray space telescope – the Nuclear Compton Telescope (NCT), which is project of the Space Science Laboratory at UC, Berkeley. The instruments and technology developed by the NCT project will be the forerunners of the next generation Compton telescope of gamma ray astronomy. The results of the NCT project will benefit high-energy astrophysics development and enhance our understanding of the universe.

The Taiwan NCT team is headed by Prof. Hsiang-Kuang Chang from the Department of Physics and Institute of Astronomy at National Tsing Hua University. Prof. H.-K. Chang is responsible for gamma ray astrophysics research and overall project management and implementation. The project's co-chair Prof. Yuan-Hann Chang, of the Department of Physics, National Central University, worked with NSPO on the electronic circuit board design and manufacture for the electronic readout system (Fig. 1) used on the detectors. Finally, Prof. Ming-Huey Huang from the Department of Energy and Resources, National United University, was responsible for the design and manufacture of the solar power system (Fig. 2) deployed on the balloon in flight.

At 7:30 A.M. local time on May 17, the balloon (Fig. 3) was successfully launched from NASA's Columbia Scientific Balloon Facility (CSBF), located in Fort Sumner, New Mexico. The balloon carried the NCT instruments (Fig. 4) to a high altitude of 36 – 39 kilometers. Besides testing the functionality of the NCT instruments, this flight detected gamma rays emitted from the Crab Nebula, Cygnus X-1 and several active galactic nuclei. After flying at high altitude over New Mexico and Arizona for 38 hours, the balloon landed south of Highway 40 near the Grand Canyon in Arizona, about 865 kilometers from the launch site. This flight set a record for the longest inland flight of a conventional high altitude scientific balloon.

This flight represented a successful completion of the original mission, and demonstrated the readiness of NCT for the long-duration balloon flights planned for the next stage of the program, as well as its readiness to participate in future satellite missions. The flight marks a new milestone in NSPO's participation in international research projects.

Fig. 3 釋放後的氣球攜帶康卜吞成像光譜儀。(Balloon successfully launched carrying NCT)

Fig. 4 康卜吞成像光譜儀。(Gamma-ray Space Telescope – the Nuclear Compton Telescope, NCT)

飛行軟體功能驗證平台

飛行軟體扮演著衛星大腦的角色，是衛星的關鍵技術之一。在飛行軟體的發展過程中，除了需遵循軟體需求文件的嚴謹規範外，所產出的程式碼亦需在不同的驗證平台，如模組測試的「模組測試平台」、功能驗證的「功能驗證平台」、近即時化軟硬體模擬測試的「軟體測試驗證平台」與即時化實體測試的「衛星工程體即時驗證平台」上通過一連串的獨立與整合測試驗證，方能實際使用於衛星飛行體上。

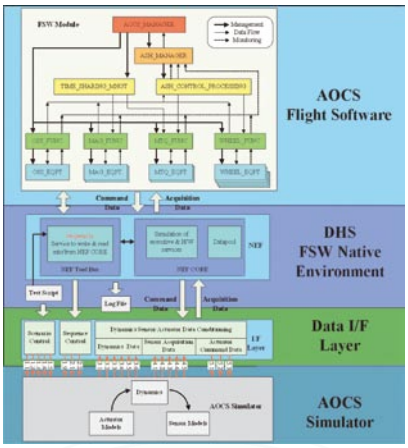

Fig. 1 飛行軟體功能驗證平台。(Flight Software Functional Validation Bench)

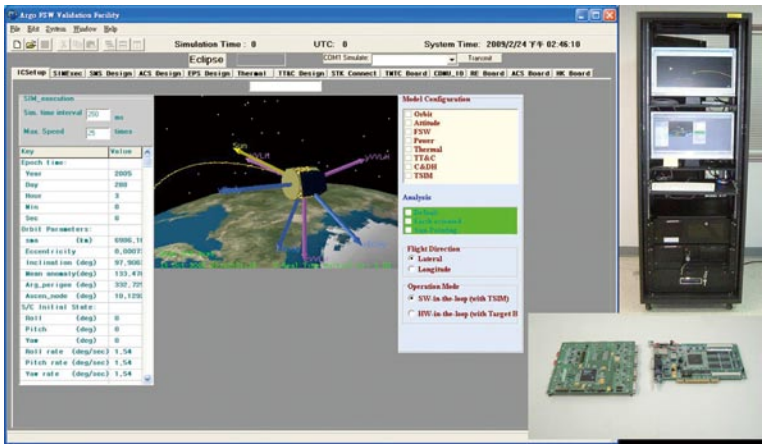

Fig. 2 軟體測試驗證平台。(SVF–Software Validation Facility)

國家太空中心飛行控制組，自主成功地開發出「飛行軟體功能驗證平台」雛型體（如Fig. 1所示），使得開發出的姿軌控制飛行軟體模組能與獨立發展出的姿軌控制模擬器做有效與快速的功能比對、除錯與驗證，確保飛行軟體程式碼的真實度與可靠度，以符合由非即時的功能驗證進一層次在軟體測試驗證平台上進行近即時化軟硬體模擬測試的需求。在成功發展「飛行軟體功能驗證平台」雛型體後，加上飛行控制組早期建置的「模組測試平台」與多年來持續開發升級的「軟體測試驗證平台」（如Fig. 2所示），國家太空中心在飛行軟體的開發與整合測試驗證上，已經建構了完整的能量。

「飛行軟體功能驗證平台」主要由三層軟體工具環境組合而成，此三層工具環境分別為上層的姿軌控制飛行軟體模組，中層的通用環境與資料介面層，以及底層的姿軌控制模擬器（如Fig. 3所示）。這其中最重要的是通用環境層工具環境，它可提供一套完整飛行軟體作業系統執行核心與輸入輸出模擬環境。該模擬環境可在一般的電腦平台上運行（例如：Windows / LINUX / UNIX），提供高階飛行軟體應用程式的執行環境。從軟體功能測試目的而言，此平台不僅可以節省購置真實衛星電腦硬體環境的高昂成本，且可以提供軟體變數資料的檢查與輸出介面，可支援精確的測試數據分析，大幅降低功能驗證平台、軟體測試驗證平台與衛星工程體軟體驗證測試時除錯的困難與複雜度。

Flight Software Functional Validation Bench

During flight software development, on top of strict compliance with the Software Requirement Document, generated source code must undergo a series of tests using various platforms, including (1) “Modular Test Bench” for modular test, (2)“Functional Validation Bench(FVB)”for functional test, (3) “Software Validation Facility(SVF)”for software/hardware integration testing in near real time and (4) “Satellite Engineering Model” for software/hardware integration in true real time. Following rigorous integration testing, those products may be deployed on spacecraft.

To facilitate code comparison, debugging and validation, while ensuring the fidelity and reliability of generated code prior to performing real-time software/hardware integration, a non-real-time Flight Software Functional Validation Bench (see Fig.1) is developed under the cross-department teamwork of Attitude and Orbit Control and Flight Software. Following the success of Flight Software Functional Validation Bench pathfinder, this platform is further enhanced by the existing Modular Test Bench and Software Validation Facility (see Fig.2), thus establishing the cornerstone of flight software development, integration and validation in NSPO.

Figure 1 shows that the Flight Software Functional Validation Bench comprises three layers incorporating attitude and orbit control flight software occupying the top layer and attitude and orbit control dynamics simulator comprising the foundation (see Fig.3). These two layers are linked by the Native Environment (NEF) and Interface (I/F) Layer. Notably, the NEF layer can provide a comprehensive OS kernel and IO emulation environment dedicated for flight software. Furthermore, this layer can be executed on Windows/LINUX/UNIX of common personal computers while providing a runtime environment for high level flight software applications. From the perspectives of testing software function, this platform can not only save on costs for actual flight computer at development stage, perform IO interface and software data check, and identify data trends post-testing, but also dramatically simplify debugging during the FVB, SVF and Satellite Engineering Model stages.

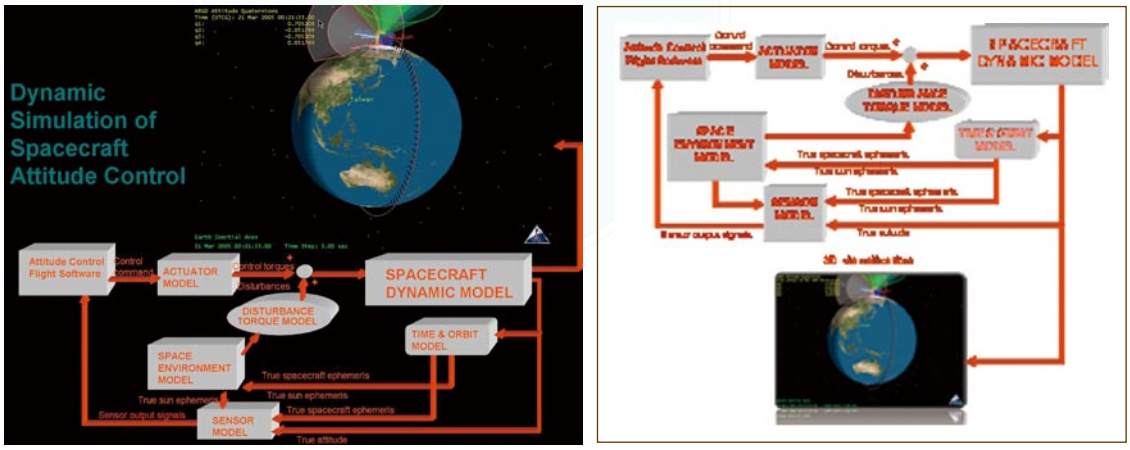

Fig. 3 | 姿軌控制模擬器。
(Attitude and Orbit Control Subsystem Simulator)

太空級衛星導航接收機

導航系統是太空科技的關鍵技術之一。使用衛星導航接收機可大幅增進衛星的自主運作能力，降低衛星操作與任務成本。精密太空級導航接收機目前仍被各主要科技大國列為輸出管制項目，因此我國至今仍無法購得最先進精準的衛星導航接收機，或探空火箭使用的高動態導航接收機。為此國家太空中心於2007年開始進行太空級導航接收機的自主研製計畫，執行至今已獲得多項成果。

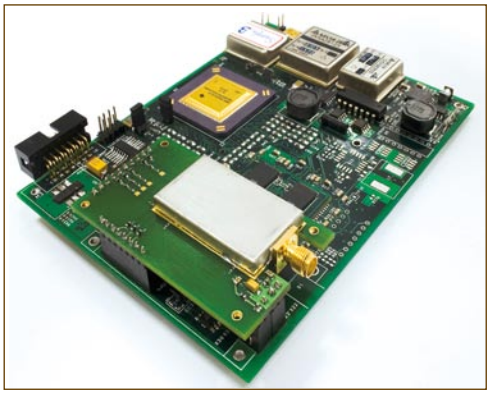

Fig. 1 導航接收機雛型體。
(GPS Receiver Prototype)

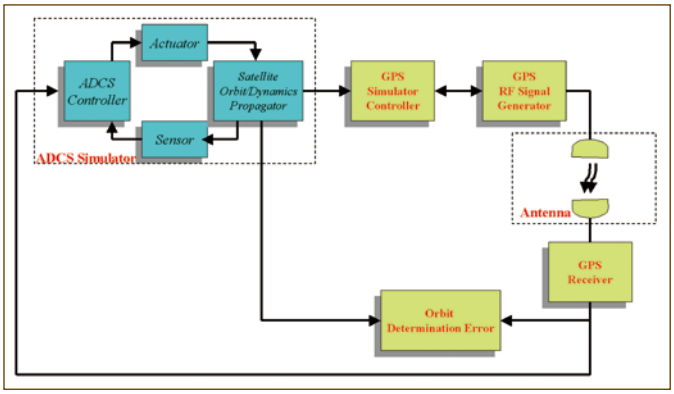

Fig. 2 衛星即時軌道判定硬體迴路系統。
(Real Time Hardware-In-The-Loop System for Satellite Orbit Determination)

2008年中，國家太空中心首先完成衛星導航接收機雛型體製作（如Fig. 1所示），此雛型體包含抗幅射電路機制，可解決接收機電路在太空高能粒子穿透時可能造成的閉鎖與熱損。另外，我們也完成接收機與導航衛星系統模擬器整合的硬體迴路量測系統（如Fig. 2所示），可用於輔助接收機與天線於衛星軌道運轉或高動態探空火箭飛行時的模擬量測與驗證。該雛型體的導航精度在不同運轉或飛行狀態下，均能保持優於8米的量測精度（見Fig. 3），比起目前福衛五號所能購得的22米的衛星導航接收機，精度超出甚多。

2009年起國家太空中心積極進行導航接收機工程體的設計製作，包括電子零件升級與電路板縮裝。同時我們也將完成天線量測、全溫度與振動測試、與介面整合，計畫於2010年初首次將自製導航接收機安裝在探空火箭上，進行實體飛試。在已完成的全溫度循環測試結果顯示，自製導航接收機在攝氏-30至+70度的溫循環境下仍能保持原設計精準度（如Fig. 4所示）。此項全溫度測試是將兩個相同的導航接收機其中一個置於溫櫃內，另一個置於室溫下，同時連接到與導航衛星系統模擬器整合的硬體迴路量測系統，做平行即時量測比對。如Fig. 4所示，紅線與綠線分別代表室溫與溫櫃導航接收機的量測資料，其下圖為量測的溫循起伏範圍，而上圖與中圖為三度空間位置與速度誤差隨溫度的變化情形，結果顯示紅綠線相差不大。

未來國家太空中心將在既有與研發中的軟硬體平台上，拓展太空級衛星導航接收機至多模（GPS / Galileo / GLONASS）多頻架構，並擴展應用由衛星、微衛星、探空火箭至掩星科學接收機應用上。

Development on Space Grade GPS Receiver

Navigation is a key technology in space flight. On-board GPS receiver significantly improves spacecraft autonomy, and thus reduces the costs of satellite daily operation. Unfortunately, constraints on exports prevent Taiwan from acquiring advanced GPS receivers with high accuracy, or GPS receivers that can be adopted by sounding rocket where extreme dynamics may impose upon. Those factors drive the effort of self-development project with NSPO starting from 2007 for space grade GPS receiver and gain certain concrete achievements.

In mid-2008, NSPO delivered its first GPS receiver prototype (see Fig.1), which included radiation resistant circuit design to prevent single event latch-up and disturbances caused by high energy particles. Furthermore, the Hardware-In-The-Loop system, as shown in Fig.2, linking the receiver and GPS RF emulator, was established to thoroughly validate receiver performance subject to satellite orbit motion or extreme dynamics during sounding rocket flight (see Fig.3).

In 2009, NSPO increased its efforts in engineering model development, including electronic parts upgrade and circuit board minimization. Simultaneously, complete antenna measurement, full temperature range test, vibration test and interface integration performed by the end of 2009, and conduct its maiden flight on a sounding rocket in 2010. Thermal cycling indicates that the GPS developed by NSPO may be capable of maintaining the claimed navigation accuracy under -30 to +70°C temperature variation (see Fig.4). The test campaign involves two identical GPS receivers connected to GPS RF HITL emulator but placed in room temperature and thermal chambers, respectively. Real time measurements obtained using both receivers close to one another regardless of temperature variation, as observed] from the red and green lines plotted in Fig. 4.

Working with these existing hardware/software platforms, NSPO will build its capabilities in the area of GSP/Galileo/GLONASS multiband receiver and extend its applications from satellites and sounding rockets to radio occultation.

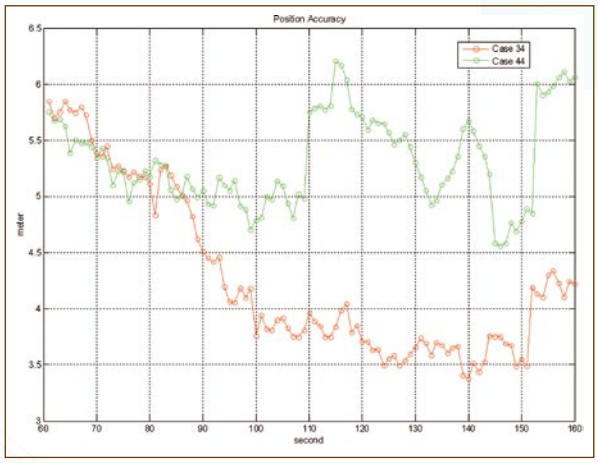

Fig. 3 接收機硬體閉迴路動態模擬量測，均優於8米的導航精度。
(GPS Receiver in Real Time Hardware-in–the- loop Test Demonstrates A Better-than-8-meter Performance)

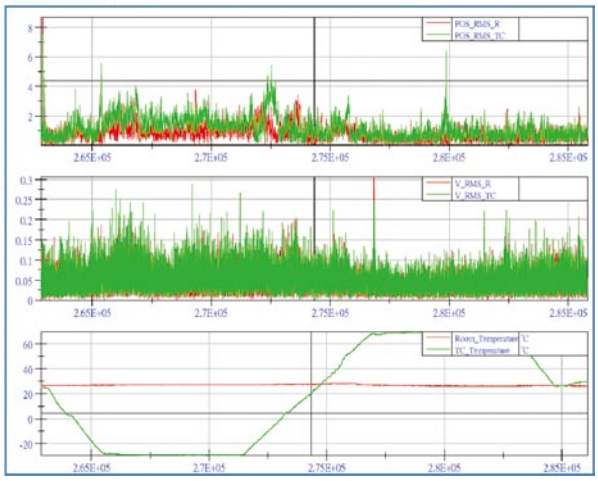

Fig. 4 全溫度循環測試結果，顯示自製導航接收機在極端溫度環境下仍能保持原設計精度。
(GPS Receiver Demonstrates Claimed Performance under Extensive Thermal Cycling Test

混合型火箭技術研發

為使我國未來探空火箭發展計畫由學術界來發展，國家太空中心開始推動混合型火箭系統研發工作，希望能發展一具200公斤級推力火箭，發射3公斤酬載到20公里以上的高空，混合型火箭系統先期研究分別委託交通大學與成功大學團隊來執行。由於混合型火箭系統（如Fig.1所示）是將液態氧化劑與固態燃料分開，所以具有安全性、構造簡單、可多次點火與良好推進性能等優點。此一研發工作，首先進行火箭系統的基礎研究，包括系統整合、空氣動力、飛行環境、推進系統、結構熱傳、燃燒絕熱、發射架等分析模擬與測試工作，最後將由實際飛行任務，以驗證火箭的性能是否能滿足任務需求。

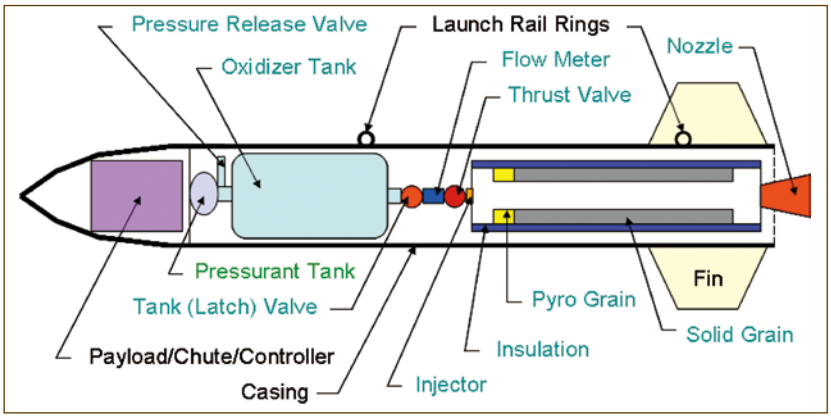

Fig. 1 混合型火箭型態。
(Hybrid Rocket)

混合型火箭在設計階段，需依靠電腦模擬計算並輔以地面測試以驗證其正確性，我們除了使用現有的商用分析軟體外，也利用自行開發具擴充性六自由度火箭飛行任務分析軟體進行模擬計算。另外，我們也將建構一套實體迴路（Hardware-In-the-Loop，HIL）系統，結合上述任務分析軟體，以作為火箭地面飛行測試分析模擬。混合型火箭系統研發工作開始至今已進行多次地面點火測試，實驗室測試台架配置與資料擷取系統，如Fig. 2所示，燃燒室推力試驗與結果，如Fig. 3所示。本計畫的成果除了展示混合式火箭本身的性能外，同時也將驗證國內學術界具備探空火箭系統開發的能力。

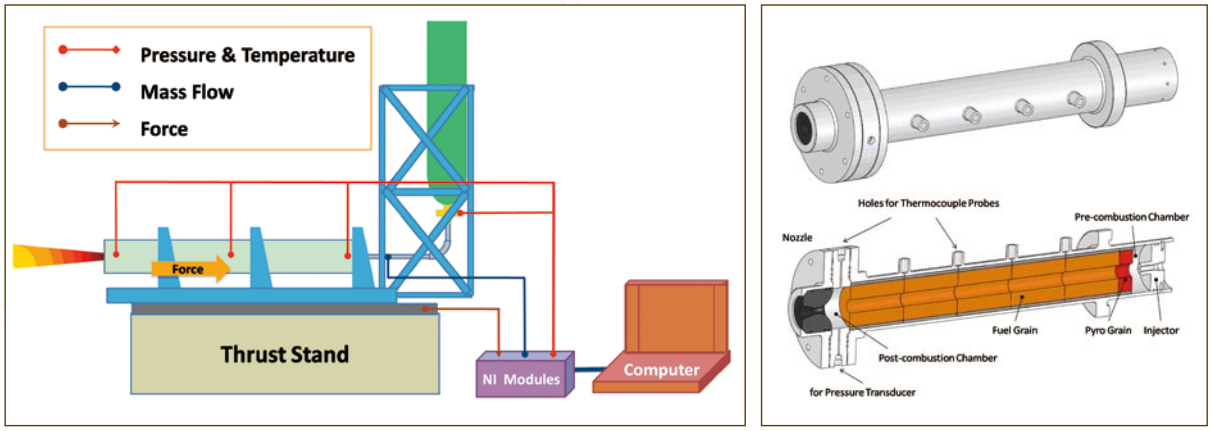

Fig. 2 地面測試規劃。
(Ground Test Configuration)

Hybrid Sounding Rocket Technology Development

To establish university research and development capabilities in relation to performing sounding rocket experiments (Fig. 1), NSPO initiated research programs with domestic universities based on hybrid rocket technologies and designed to achieve 200kgf thrust and convey a 3kg payload to an altitude of over 20km in a flight test campaign. Based on the use of liquid oxidizer separated from the solid fuel, this research is characterized by safe manufacturing, simple configuration, multiple re-ignition capability, and good performance. The on-going preliminary feasibility study includes system integration, aerodynamics, flight environment, propulsion system, structure and heat transfer, combustion and insulation, launch support equipment, design analyses, simulations, etc.

The preliminary development phase of the hybrid rocket, using N2O as an oxidizer and HTPB as a fuel, focuses on computer simulation and ground testing as a means of reducing the development costs. The research team has developed a single 6-DOF simulink as well as other mission analytic software. Furthermore, the Hardware-In-The Loop (HITL) was performed using the developed software to demonstrate 6-DOF flight simulations and the temperature profile of the combustion chamber. After completing the laboratory, test stand and data acquisition systems (Fig.2), several ground tests were performed and thrust curves were measured (Fig.3). The main accomplishments during the current phase include demonstrating rocket performance, technology readiness and filing a patent application for an invention that significantly boosts the thrust performance of a hybrid rocket.

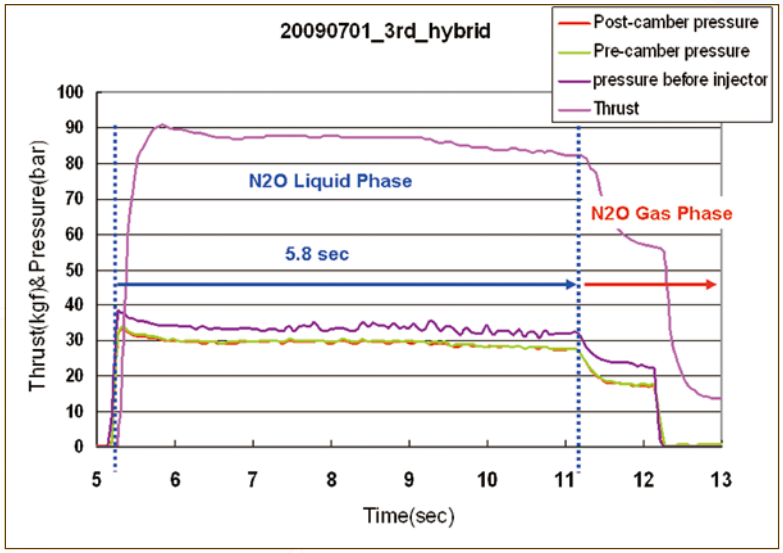

Fig. 3 推力與燃燒室各區域壓力曲線圖。
(Thrust And Pressure Curves at Various Locations in Combustion Chamber)

記憶體模組

指令與資料管理單元（CDMU）為衛星資料處理與控制中心，衛星資料包括：衛星健康狀態資料與科學酬載的科學資料。當衛星在軌道上運作執行任務時，若發生異常狀況，地面操作人員與工程人員必須依靠著衛星下傳的健康狀態資料執行分析，並依分析結果處理以恢復衛星正常運作。另外，衛星收集的科學資料為科學家分析太空科學實驗的依據，必須正確可靠，任務才能成功，因此提供正確可靠的衛星資料為CDMU設計的重要需求。

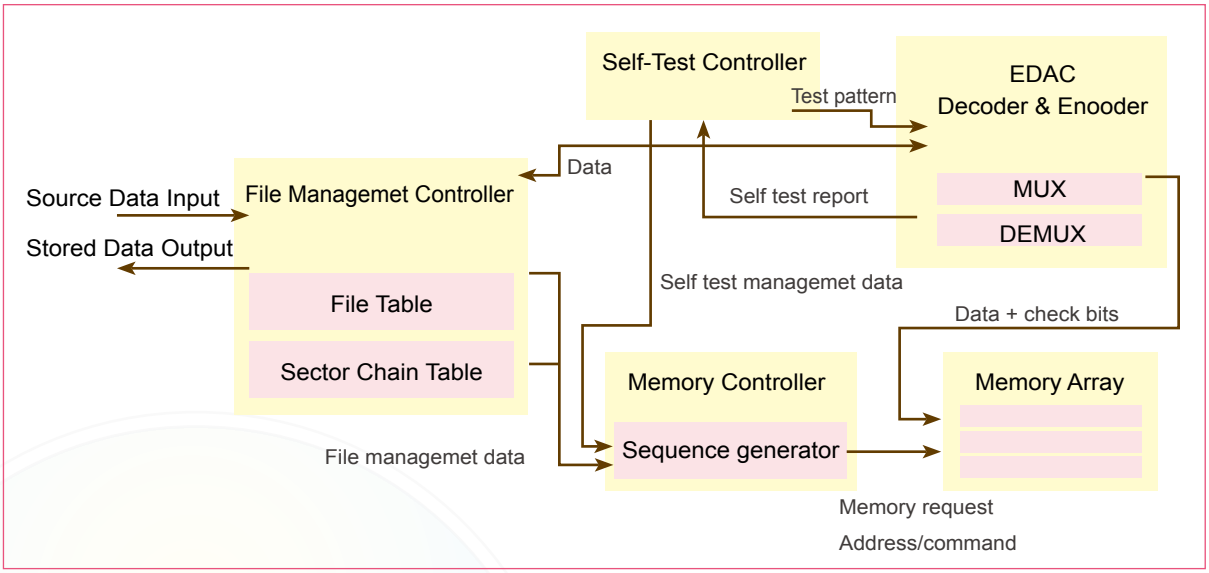

Fig. 1 高可靠度之記憶模組架構。
(Architecture for High Reliability File System Memory)

國家太空中心衛星電機組在CDMU發展計畫中，完成了高可靠度記憶體模組架構設計（見Fig.1），於2008年獲得台灣新型專利，專利編號M339758。此記憶體模組架構具備兩個特色，第一個特色為記憶體損壞偵測與隔離功能，利用自我測試機制確認記憶體區段是否有損壞，如測試結果顯示記憶體區段有損壞，此一機制可進行記憶體區段標記，資料存取時可依照區段鏈結表的紀錄，跳過被標記的損壞區段，而其它未損壞的記憶體則可使用於資料的儲存，達到有效運用記憶體的目標。第二個特色為因太空輻射造成單一事件擾動（Single Event Upset，SEU）的保護機制，當資料寫入記憶體時需先經錯誤偵測與校正（EDAC）編譯器，產生對應資料的錯誤偵測與校正碼，一同存入記憶體，當資料讀取時，亦需經EDAC解譯器，進行資料錯誤偵測與校正，以確保資料的正確性與完整性，並提高其可靠度。

今（2009）年以來衛星電機組持續進行技術精進，完成了更先進的記憶體模組架構設計，將原來以現場可程式化閘陣列（FPGA）實現的檔案管理改以軟體實現，使得設計或修改較為彈性與簡單。在衛星整合測試時若仍需要修改設計，可以上傳更改過的軟體以取代原有的軟體，而不需變更硬體設計，因而可大大的減少設計修改時間。另外在設計上更模組化，可依需求擴充或減少記憶體，而不需作任何設計修改，使得在應用上更具彈性。

File System Memory Architecture for Ensuring High Reliability

The Command and Data Management Unit (CDMU) represents the data management and control center for satellite data, including the state of health (SOH) data of the bus and the scientific data gathered via the science payload. In the case of satellite, the ground operation staff and engineers must perform extensive analysis using the downloaded SOH data and restore the satellite to its normal operating mode after reaching a conclusion. Furthermore, for a successful mission, all collected scientific data must be accurate and reliable. Consequently, providing accurate and reliable satellite data is crucial in CDMU design.

The EE division delivers a highly reliable memory module structure design in the CDMU development plan, and in 2008 was granted a Taiwan patent for this design (Patent number:M339758). Two features distinguish this memory module from others: the first feature is its memory damage detection and isolation capabilities, which utilize a self-detection mechanism to detect memory section damage. The damaged memory section is then marked in the record of the section link table and skipped according to the table during data storage and retrieval. This procedure for skipping damaged sections further enhances memory utilization efficiency. The second feature is the mechanism for protection against Single Event Upsets caused by space high energy particles. Data included in the memory must proceed through an Error Detection and Correction (EDAC) encoder in which a corresponding error detection and correction code is produced and stored along with the data onto the memory. When data is retrieved from the memory they must employ an EDAC decoder for error detection and correction to ensure the data accuracy and integrity, and thus enhance its reliability.

On top of this accomplishment, this year the EE division revealed another advanced version of memory module structure: this structure converts FPGA-implemented file management to software-implemented management, increasing the ease and flexibility of design and modification. New software can be uploaded to the spacecraft without changing the hardware design in response to design modifications during the I&T phase, significantly accelerating the design modification process. Furthermore, the design is more modularized and the memory can be easily expanded or reduced.

磁矩校準方法

衛星部分元件因為材料的原因通常會伴隨一定大小的殘餘磁矩，這些殘餘磁矩可分為永久磁矩（或稱硬磁矩），被環境磁場激發的磁矩（或稱軟磁矩），以及電流迴路所引發的磁矩。這些磁矩在與地球磁場交互作用下，會對衛星姿態控制系統造成干擾，進而衝擊姿態控制系統的性能或準確度。

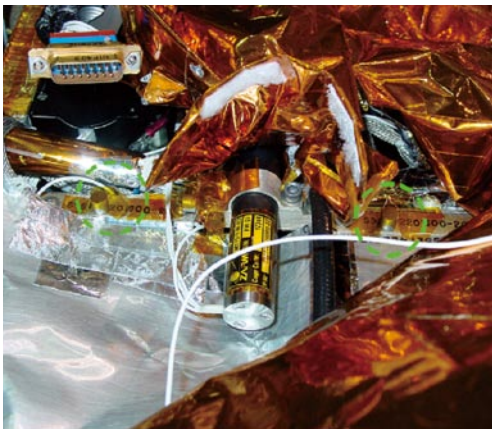

Fig. 1 裝置於福衛三號微衛星上的補償磁鐵。(Compensation Magnet Installed on FORMOSAT-3 Spacecraft)

這些殘餘磁矩中較可能被降低的就是藉由裝置補償磁鐵（如Fig.1所示）而降低的永久磁矩。在以往對於衛星中如何適當地利用安裝補償磁鐵以降低永久磁矩的方法，許多人是使用「試誤法」的方式來處理此一問題，但這個方法往往無法很快達成目標，以致於常常造成測試資源浪費進而使得計畫時程延宕。上述問題在內部空間狹小的微衛星上更是嚴重，因為所裝置的補償磁鐵往往會引起其他額外而無法預期的磁矩，使得校準工作更加複雜。例如福衛三號微衛星星系在進行磁矩校準測試時，由於一天中可測試的時間受限於環境磁場變化僅限於半夜，因此福衛三號中第2顆衛星就用了將近6個工作天，才將殘餘磁矩校正到允許範圍內。

為解決此一困擾多時的衛星整合測試問題，福衛三號磁力校正團隊於2005年發展出一套全新的補償磁鐵計算及選擇方法（如Fig. 2所示），可一併解決補償磁鐵裝置位置受限與耗時昂貴「試誤法」等問題。這個創新的方法是假設補償磁鐵激發出的磁矩落在某一線性範圍內，因此所激出的磁矩與置入的磁矩可以由一個3乘3的張量來描述。每次在其中一軸置入磁鐵就可測試出3個張量中的係數。因此，完整的張量可經3次測試獲得，而第4次則用於驗證所計算及置入磁矩的正確性。

藉由所提出的測試方法、包含補償磁鐵的計算方式，福衛三號衛星工程師僅需3次量測就可成功地將福衛三號星系中後五顆衛星殘餘硬磁矩降低至規範的範圍內（如Fig. 3所示），降低了不少衛星整測的成本。這個創新方法已於2009年獲得台灣發明專利，專利編號095147594號。

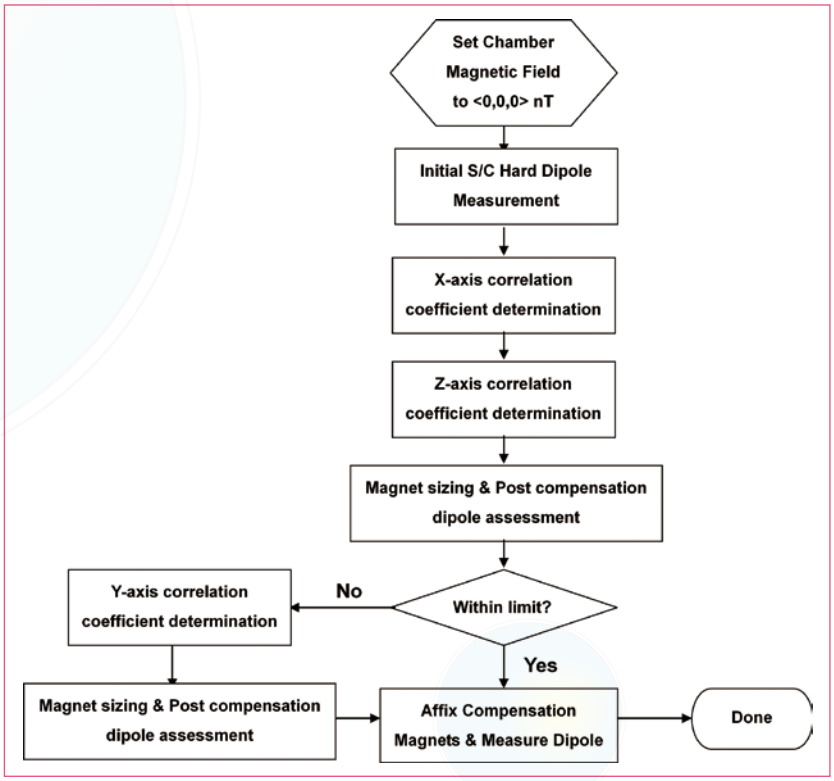

Fig. 2 補償磁鐵計算及選擇方法。(A New Hard Dipole Compensation Procedure)

Residual Magnetic Dipole Compensation under the Presence of Induced Magnetism

Spacecraft components usually come with certain residual magnetic dipoles. Those residual dipoles can be categorized into permanent magnets (hard dipoles), magnetism induced by magnetic field (soft dipoles), and current loops. Through interaction with the magnetic field of the earth, those residual dipoles turn into disturbance torque that degrades the performance of attitude control system.

The only feasible method of controlling residual magnetic dipoles on spacecraft is placing compensated magnets (see Fig. 1) to achieve permanent dipole control. However, this approach faces issues such as disturbing unexpected magnetic dipoles, especially in the case of small micro-satellites with limited internal space. Many practitioners in the field try to solve these issues via a trial-and-error approach, potentially leading to wastage of test resources and unexpected schedule delays. The try-and-error approach created serious issues for the FORMOST-3 program since the FORMOST-3 constellation comprises six spacecraft and the time available for performing calibration is limited to midnight to avoid causing magnetic disturbances. Thus it took nearly six working days to achieve a satisfactory outcome when performing calibration on the second satellite Formosat-3 satellite.

In 2005, the FORMOSAT-3 magnetic calibration team developed a methodology for compensation magnet calculation and selection designed to both release the constraints on magnet affixing location and eliminate the costly trial-and-error compensation process. Assuming that the induced magnetic dipole is within linear range, the level of induced magnetism can easily be found via a 3-by-3 tensor with constant coefficients. Installing a magnet along just one axis at a time, it then becomes possible to derive three of the tensor coefficients. Consequently, the full tensor coefficients can be found after three attempts and the accuracy of installed compensation magnets can be verified after four measurements.

The proposed methodology was tested on the last five of the six FORMOSAT-3 spacecraft, where residual permanent magnetic dipoles were successfully reduced to satisfactory levels (see Fig. 1). This unique magnetic compensation and calibration approach was awarded an invention patent (No. 095147594) by the Intellectual Property Office of Taiwan in 2009.

Fig. 3 福衛三號微衛星磁矩校正作業。
(Magnetic Characteristic Calibration Test Campaign of FORMOSAT-3 Spacecraft)

一種熱源在上方位置的板式熱管結構

近年來在高性能、高效率與輕薄短小趨勢的訴求下，電子元件散熱問題，無論是在太空領域或民生應用產品上均成為一項重要課題，由於熱管具有高熱傳能力、重量輕、無可動元件與結構簡單等特性，已經廣泛地使用於人造衛星上。國家太空中心歷經福衛一號、二號與三號計畫已掌握了衛星熱控的研發能力，為了未來高性能遙測衛星與微衛星的發展需求，提供一省電、質輕、可靠且高效能的散熱模組，因此國家太空中心開始進行高性能太空級熱管研製工作。

本項專利的概念源自於技術研發過程中進行熱管性能實測所發現的現象。一般商業產品，如筆記型電腦，因內部空間配置緣故，其熱源常位於熱管或板式熱管的上方，然而從經驗得知，在重力場影響下，從熱管上方加熱時，熱管導熱效能並不能充分發揮。我們利用熱管中一導熱件與特殊熱流設計，如Fig. 1所示，來提升熱傳效果以解決這個從熱管上方加熱的議題進而有效提升其熱傳效果，熱模擬分析結果，如Fig. 2所示。國家太空中心已於今（2009）年10月正式取得台灣發明專利，專利編號為I 316127號。

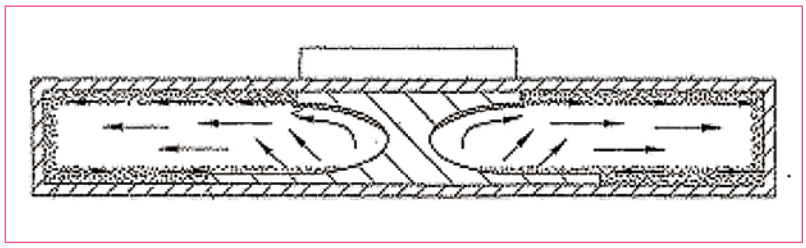

Fig. 1 專利板式熱管。
(Patented Vapor Chamber / Flat Plate Heat Pipe)

Flat Plate Heat Pipe Design for Top Mounted Heat Source

The characteristics of heat pipe include high thermal conductivity, instantaneous response, no moving parts, simple structure, compact size and light weight. Heat pipe thus thus has long been used in satellite manufacture. Recently, thermal management of commercial products such as notebook computer and camcorder have required a combination of high thermal performance/efficiency, compact size and light weight, making heat pipe popular in consumer applications in addition to satellite applications. NSPO has developed thermal design and analysis capabilities though the development of the Formosat series of satellites (Formosat1, 2, 3, etc). Further development of remote sensing satellite and micro satellites requires the development of a power-saving, light weight, reliable, and high thermal performance thermal module, thus making domestic development of space heat pipe and vapor chamber a key area of research.

This idea is to improve the thermal performance of heat pipe via a series of experiments and thermal performance tests. The heat source of commercial products such as notebook computers is generally located on top of the heat pipe (or vapor chamber) owing to space constraints. However, experience suggests that it would be better for the heat source to be located underneath the heat pipe. The performance/efficiency of the thermal module may be reduced when heat source is located above the heat pipe. Locating the heat source beneath the heat pipe can resolve issues of thermal module performance/efficiency and improve the thermal performance of the heat pipe. This invention includes the thermal conductive component connecting the top and bottom walls, unique internal thermal insulation, and customized design to improve the thermal performance of the heat pipe and spread the heat of the hot spot on top of the heat pipe. Figure 1 (sketches) heat pipe internal configuration. Meanwhile, Fig. 2 shows the results of thermal analysis. The National Space Organization patented this innovation in 2009.

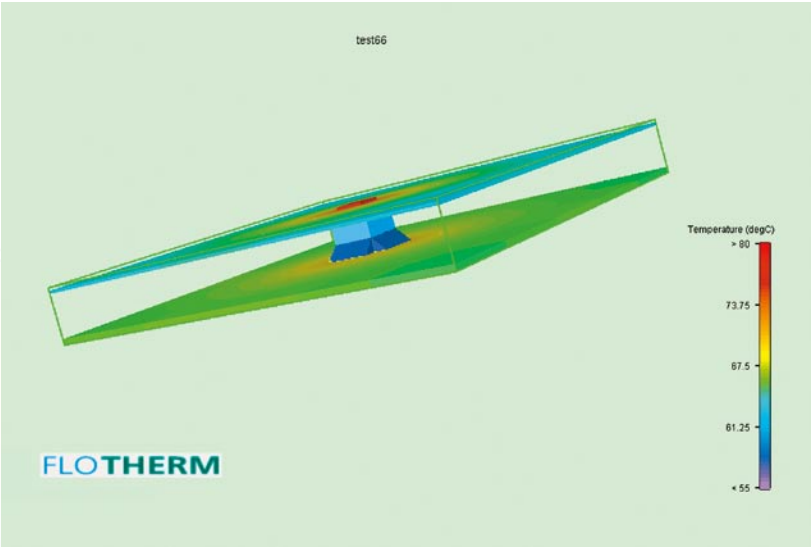

Fig. 2 熱模擬分析結果。
(Thermal Analysis Result)

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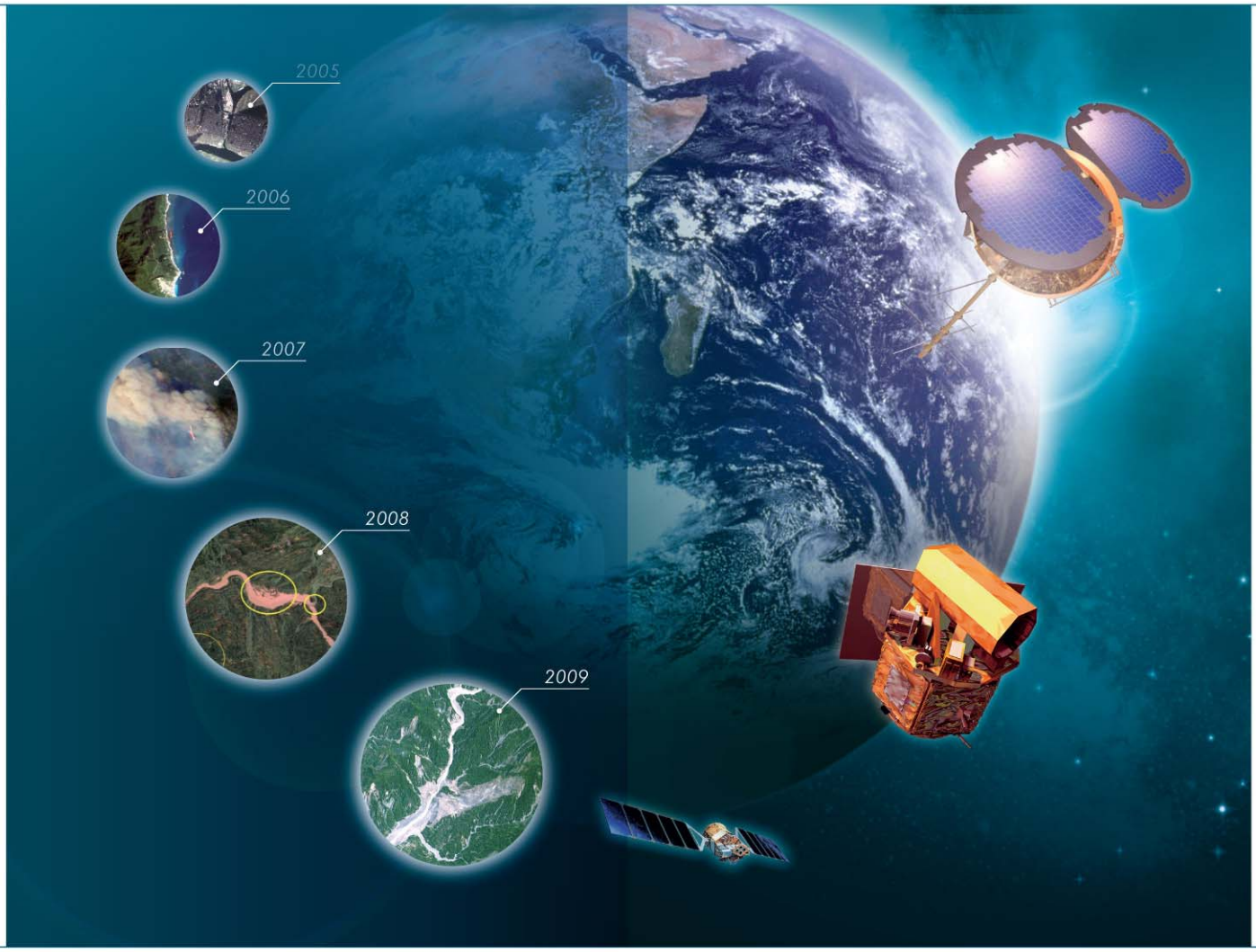

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