Analysis of Platform and Payload Integrated Design Technology for Optical Remote Sensing Satellites

Yanfeng Yao

Abstract Driven by the goal of high resolution, high agility and low cost, the integrated design technology of satellite platform and payload considering payload as center is an important trend in the development of advanced optical remote sensing satellites. The paper investigates the typical applications of integrated design technology in remote sensing satellites. The technical features of the technology, such as integrated satellite configuration, integrated thermal control, integrated electronic system and integrated micro-vibration suppression are also discussed. On this basis, it puts forward the development trends of the platform and payload integrated design technology, which include multidisciplinary design optimization taking into account structural-thermal-optical performance, integrated electronic system based on reconfigurable modules, focus on improving the ability of micro-vibration suppression and innovation of satellite development process.

Keywords Remote sensing satellite · Platform · Payload · Integrated design

1 Introduction

With the development of remote sensing satellite technology, space optical remote sensor payload is developing towards the direction of long focal length and large aperture. The traditional platform and payload subdivision design mode will lead to an increase in the volume, weight and inertia, which is difficult to meet the demands of high resolution, high agility and low cost of advanced remote sensing satellites. The integrated design of platform and payload considering payload as center can break through the limitations of traditional separate service and payload modules, realize the whole satellite design optimization from system level, and significantly reduce satellite weight and development costs. Platform and payload integrated

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design involves multiple disciplines, requires overall consideration of various factors such as optical, mechanical, electrical, thermal, etc. Configuration, layout and thermal control of satellite should be designed around remote sensing sensor tightly. Meanwhile, the electronic system also needs to be integrated designed, achieving the goal of unified scheduling and management of satellite resources.

The current advanced optical remote sensing satellites generally adopt the platform and payload integrated design concepts, such as Ikonos-2, WorldView, GeoEye-1 and Pleiades. The paper investigates the typical applications of integrated design technology in remote sensing satellites. Furthermore, the technical features of integrated design are also discussed from four aspects. Finally, it puts forward four trends of the platform and payload integrated design, which expects to provide a reference for the development of the technology.

2 Typical Satellites Applied Integrated Design

2.1 Ikonos-2

The Ikonos-2 satellite launched successfully in 1999 is the world's first 1 m-resolution commercial earth observation satellite, developed by Space Imaging Corporation [1]. The design idea of integration and high rigidity is adopted in the satellite. As shown in Fig. 1, the remote sensor is embedded in the platform, and the structure of the satellite is strengthened by using the plate and rod structure. Star tracker and gyro are directly mounted on the remote sensor to achieve high attitude accuracy. Other platform equipments are also installed on the remote sensor, saving the redundant structure of platform. The rigid fixed support solar arrays are designed to reduce the influence of the flexible appendages on the attitude maneuver. The surface of the remote sensor is coated with multi-layer thermal insulation materials to reduce the influence of the space environment on the temperature control, and a thermal door is installed on the top of the remote sensor to reduce the heat leakage.

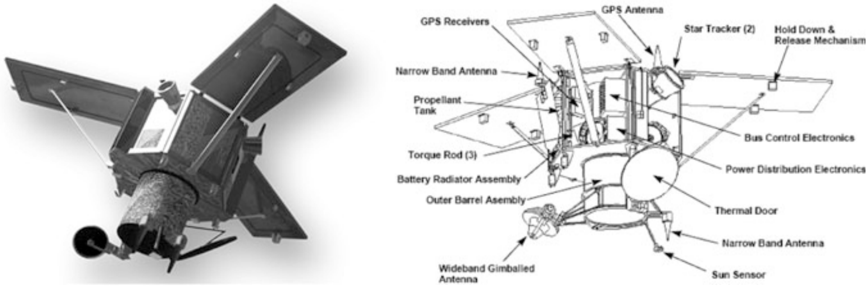

Fig. 1 Ikonos-2 satellite

2.2 WorldView Series

WorldView series satellites are developed by DigitalGlobe Inc. including WordView-1/2/3 on orbit. The design of WorldView satellites fully reflects the integrated idea of high stiffness and small inertia. As shown in Fig. 2, the composite structure of beam and plate is adopted to ensure the rigidity of the satellite. The electronic equipments are mounted on the outer surface of the platform. CMG module with vibration isolation devices is installed at the bottom of the hollow platform cabin, while the spherical tank and optical telescope are mounted successively on the top of the CMGs. The top of the telescope is also equipped with a thermal protection door, while special radiators are arranged for the high heat consumption equipments like focal plane unit, battery and solid state memory [2]. Another highlight of the satellite is the advanced integrated electronic systems [3].

2.3 Pleiades

Pleiades is the high resolution earth observation satellite developed by the CNES, including Pleiades-1A/1B, representing the most advanced technical level of France in the earth observation field. The focus of Pleiades design is the agile imaging and

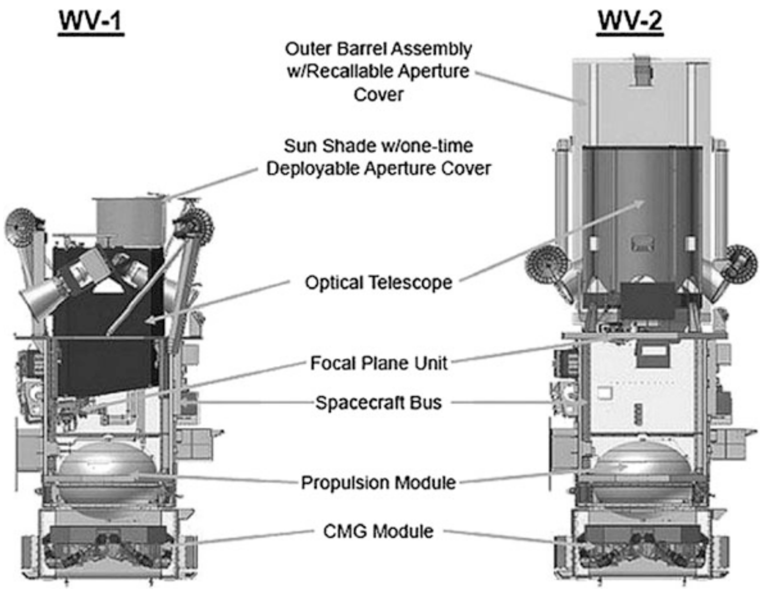

Fig. 2 WorldView-1/2 satellite

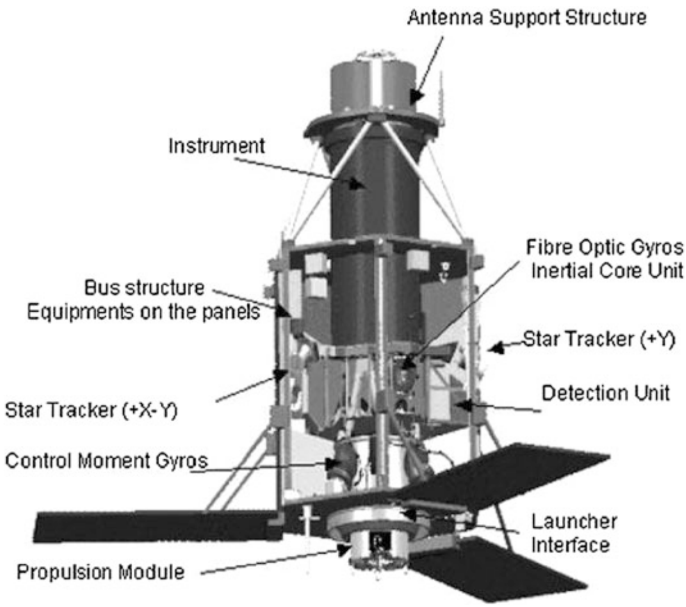

Fig. 3 Pleiades satellite

high positioning accuracy. As shown in Fig. 3, the satellite has adopted an integrated rigid structure similar to Ikonos-2. Meanwhile, latest technologies are introduced in the design of satellite including fiber optic gyro, star tracker, CMG and advanced navigation receiver. Pleiades uses the integrated design of electronic system, which can realize the scheduling and management of the whole satellite resources [4, 5].

3 Technical Features of Integrated Design

Through investigation and analysis, the ultimate goal of the integrated design of satellite platform and payload is to coordinate the design from the system level to achieve the maximum efficiency of the payload, which include configuration, layout, thermal control and electronic system design. In addition, the integrated design makes the satellite more compact, the influence of micro-vibration of reaction wheel, CMG, etc. on the imaging of remote sensor can't be ignored and micro-vibration suppression measures must be taken. In summary, the integrated design of platform and payload includes several aspects as follows: integrated configuration, integrated thermal control, integrated electronic system and integrated micro-vibration suppression.

3.1 Integrated Configuration Design

Integrated configuration is the foundation of the integrated design technology, which has a critical impact on the mechanical, electronic and thermal design. Integrated configuration design has the following features and advantages:

1. Light structural weight and excellent mechanical properties

The payload uses an embedded (Ikonos-2, Pleiades, WorldView-1) or fusion (EAROS-1A/B, GeoEye-1) installation, which can effectively lower the centre of gravity and improve the mechanical environment during launching stage. In addition, the main load-bearing structures of platform and payload are directly connected to each other, resulting in enhanced structure strength, excellent mechanical properties and lower structure weight. According to statistics, the structure weight of traditional remote sensing satellite is generally accounted for 15–20% of the whole satellite, while the data will drop below 7% using integrated design.

2. Small rational inertia

The rotational inertia of satellite is proportional to the square of the distance between the equipments and the rotating axis. The equipments of the integrated configuration satellite are arranged around the payload or even directly mounted on it, which are closer to the axis of the satellite, so it can significantly reduce the rational inertia and improve the agility of the satellite. Moreover, the satellite solar array usually adopts the rigid structure or parallel configuration to reduce the influence of flexible components on the attitude maneuver.

3. High image positioning accuracy

In the satellites with integrated configuration, the star trackers, gyros and other attitude sensors are generally installed directly on the payload (such as Ikonos-2, WorldView, Pleiades), which can maintain the stability of the high precision measurement datum and the optical axis of the remote sensor, avoid the adverse effects of the force and thermal deformations of the platform, and improve the positioning accuracy of the satellite image.

4. Saving development and launch costs

Remote sensing satellite with integrated configuration has more compact structure and smaller occupied space, which is more applicable to the flexible launch of low cost launch vehicles.

3.2 Integrated Thermal Control Design

With the increase of resolution, long focal length and large aperture remote sensor is more sensitive to platform and space environment temperature changes.

Therefore, the temperature field change has become an important factor affecting the quality of on-orbit imaging. The high performance remote sensing satellite with integrated design has the characteristics of high function density, multi imaging mode and long working time on orbit. The high function density causes limited heat radiation area and high temperature level. Multi imaging mode requires frequent satellite attitude maneuver, resulting in a large range of heat flux and temperature fluctuations. On-orbit long time imaging results in increased local high temperature and thermal noise. All these factors increase the difficulties of thermal control. Due to the heat transfer process of the platform and the payload are tightly coupled, we should give full play to the advantages of the whole satellite thermal control, and carry out the integrated thermal control design of the platform and the payload.

In order to meet the requirements of high performance imaging, a thermal control method based on integrated remote sensing satellite is proposed, which aims at the minimum occupancy rate of satellite resources [5]. To solve the problems of limited power and high power density and long working time of CCD, the following measures are taken: (1) Turning the waste of platform equipments into heating power of the payload. (2) Using phase change materials to increase the thermal inertia of CCD and extend the remote sensor time. The heat pipe and special radiating surface are connected to CCD to improve the radiating efficiency. Moreover, precision temperature control of radiating surface is adopted to reduce the temperature fluctuation.

3.3 Integrated Electronic System Design

With the development of remote sensing technology, the imaging modes of remote sensing satellites are becoming increasingly complex, requiring the satellite to have the capability of efficient and flexible task planning and self-management. In this context, the satellites adopting integrated design will be no longer only a collection of individual functions of devices, but an integrated system capable of unified scheduling and management of tasks, functions and resources.

Integrated electronic system is composed of hardware and software modules, which can complete the entire satellite management functions such as data management, management attitude and orbit control, satellite ground downlink data management, thermal control management, time management, power management, payload management, autonomous fault detection and security management of satellite. The essence of its function is the generation, processing, transmission and distribution of information flow. Integrated electronic system contains most of the electronic equipments of satellite, whose design standards determine the performance of the satellite to a large extent.

As shown in Fig. 4, WorldView satellites adopt advanced data system technology based on integrated electronics [6], which enable the satellites to have the

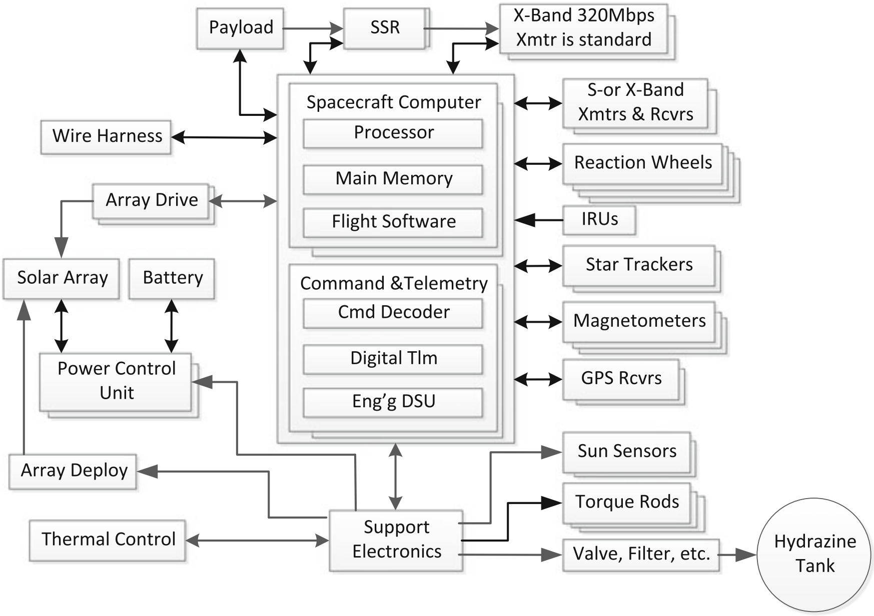

Fig. 4 Integrated electronic system of WorldView satellites

ability of task management, autonomous execution and autonomous fault processing, enhancing the ability of autonomous operation on orbit in full life cycle.

Pleiades satellites also use the integrated design concept of the whole satellite electronics system, taking the integrated management unit OBMU as the core [7], which can not only complete the routine satellite service management mission, but also fulfil the payload, attitude and orbit control, thermal control and power management as well as telemetry and telecontrol tasks.

3.4 Integrated Micro-vibration Suppression

As mentioned above, it is necessary to consider the influence of the micro-vibration in the integrated design of remote sensing satellite. For micro-vibration suppression, optimized layouts of vibration source and vibration isolation devices are mainly adopted to reduce the influence on payload imaging. First, the reaction wheel, CMG, solar array actuators and so on should be mounted as far away from the payload as possible, in order to increase the micro-vibration transfer path and attenuation (such as the CMG module mounted at the bottom of the platform in Fig. 2). Moreover, micro-vibration suppression devices are also frequently used,

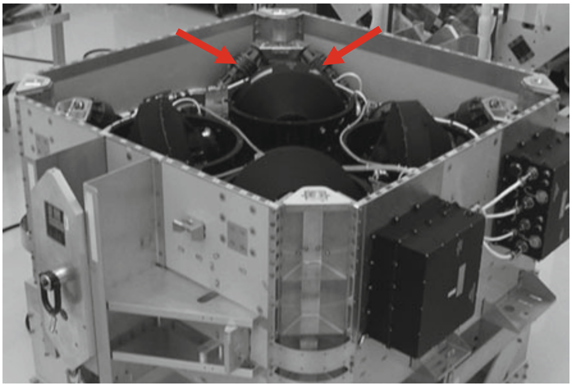

Fig. 5 WorldView vibration isolator

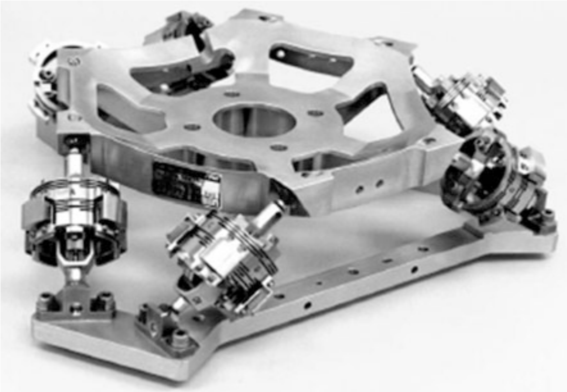

Fig. 6 Chandra X-ray vibration isolator

which consist of vibration source isolator, payload vibration isolator and flexible appendages damper, etc.

Vibration source isolators are installed between reaction wheels/CMGs and satellite structure to separate high frequency vibration transmitted to the satellite. For instance, an eight connecting rod isolation system was installed between the CMG mounting brackets and the main support beam of service module in WorldView; Chandra X-ray observer installed Stewart vibration isolation platform for each reaction wheel [8], as shown in Figs. 5 and 6.

The payload vibration isolators are installed between the imaging device and the satellite structure. Both WorldView-2 and GeoEye-1 used Bipod mechanisms [9] to realize the vibration isolation between payload and platform as well as optical components and remote sensor structure, as shown in Figs. 7 and 8.

Flexible accessory dampers are connected between the root of the flexible appendages and the structure of satellite to improve the damping parameter of the

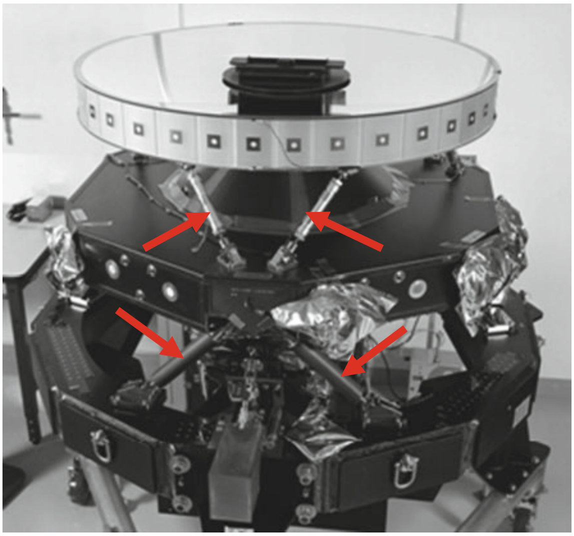

Fig. 7 GeoEye-1 vibration isolator

Fig. 8 WorldView-2 vibration isolator

flexible appendages. As shown in Fig. 9, a damper was used on the root of the solar array of the Hubble telescope, which effectively reduces the amplitude of sloshing and improve the attitude stability [10].

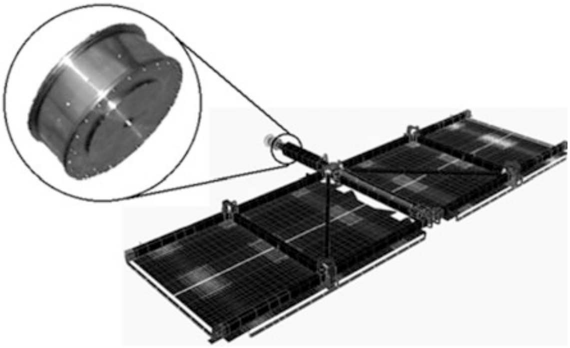

Fig. 9 HST solar array damper

4 Analysis of the Development Trends of Integrated Design Technology

4.1 Multidisciplinary Design Optimization of Remote Sensor Based on Structure-Thermal-Optics Performance

As the center of the integrated design of platform and payload, the space optical remote sensor has a complex coupling relationship with the external space environment and other satellite equipments. Therefore, it is necessary to carry out multidisciplinary design optimization considering optics, structure and thermotics, etc. For example, there are a number of connection points between the platform and payload structure under the integrated configuration. The deformation of the platform structure will directly affect the stability of payload. In addition, the heat radiation of the equipment of the platform will affect the thermal environment of the remote sensor, thereby affecting the imaging quality.

Traditional remote sensors are usually designed based on serial mode. After the optics, structure and electronics design is completed, the design thermal control system is carried out. The serial mode is easy to cause the design process repeatedly modified. Therefore, according to the platform and payload integrated design requirements, the development mode should be changed from traditional serial mode to STOP (Structural-Thermal-Optical Performance) multidisciplinary design optimization [11]. The flow of STOP is shown in Fig. 10. Firstly, thermal analysis model and structure analysis model are established based on the same remote sensor configuration, while the thermal analysis model contains the preliminary thermal control scheme. After solving the transient temperature field data of the remote sensor, the temperature field is mapped to the structural analysis model, and the calculation of the displacement field is completed. Then the optical component surface and position change data is extracted from the displacement field. After fitting the data into the optical analysis software, the assessment of the optical performance is completed. If the optical performance is not satisfied, the thermal

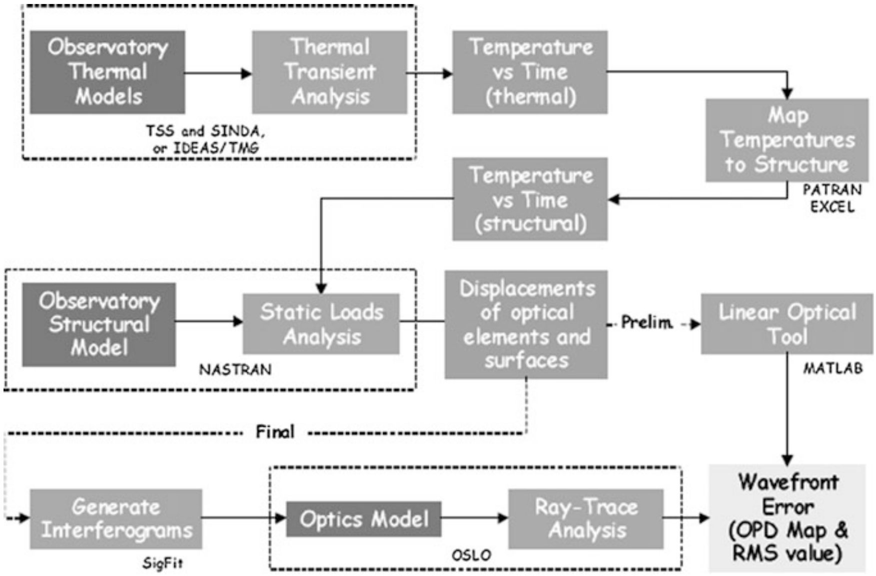

Fig. 10 STOP analysis process map

model (thermal control scheme) and structural model (structural design) should be improved iteratively until the final performance is satisfied.

The most striking feature of the STOP design mode is to achieve the multidisciplinary design optimization. Through a large number of data exchange based on temperature field, displacement field and optical surfaces, we can debug thermal, structure and optical design parameters repeatedly, which can fulfill real-time assessment for the optical performances of remote sensor and ultimately achieve overall optimization.

4.2 Development of Reconfigurable Integrated Electronic Technology

The integrated electronic system fulfils all the management functions of the satellite, which is the key to ensure the effectiveness of remote sensing satellite. The integration and miniaturization of the system have important influence on the integrated design of satellite. The spacecraft integrated electronic system has been developed to the fourth stage, the main development trends are from the special interface definition to the standard interface definition; from electronic equipments simple fusion to the top level system optimization and integration; from decentralized design to the top-down integrated design.

According to the above trends, the satellite integrated electronic system needs to be designed adopting top-down and integrated design methods. The hardware resources and software functions should be fully played to realize the unified application, deployment and operation of satellite resources. System should adopt the FDIR design and have strong autonomous fault detection and reconfiguration ability, which also has emergency hardware circuit and telemetry and telecontrol backup, in support of safe mode while fault occurs to ensure reliability and robustness of the satellite.

4.3 Focus on Improving the Ability of Micro-vibration Suppression

Under the integrated configuration, taking appropriate micro-vibration suppression measures to improve on-orbit dynamics environment of payload, is one of the key technologies in imaging quality assurance. Therefore, we should pay attention to the research of the mechanism and method of micro-vibration suppression. First, the disturbance source on-orbit should be determined. Perturbation amplitude and spectrum distribution must be identified by the vibration analysis and testing as a basis for micro vibration suppression design. Second, appropriate installation locations need to be selected for the vibration source and imaging equipments according to the mode of the whole satellite structure (avoiding the vibration antinodes, as close as possible to the node). Third, the micro-vibration transmitted to the satellite structure can be reduced by the micro-vibration source device optimization design (such as reducing static and dynamic unbalance amount of high speed rotor) and isolation (such as vibration isolator, flexible damper). Finally, it is one of the effective methods to solve the problem of micro-vibration by reducing the sensitivity of payload, which includes compensating the key sensitive components and taking the vibration reduction measures.

4.4 Innovation of Development Process

For traditional remote sensing satellite, the platform and the payload can be divided into separate modules for parallel development and production. After the platform structure and equipments are delivered, the AIT (Assembly Integration and Test) of the service module can be carried out first. Payload can be delivered at the late stage of the AIT of the platform. The integrated configuration satellite needs to use the payload structure as a support to complete the satellite equipments installation, so the payload delivery cycle needs to be advanced. Therefore, we should carry out AIT program research and process innovation for remote sensing satellite adopting integrated design to shorten the development and delivery cycle of satellite.

5 Conclusions

By investigating the typical applications of integrated design technology in remote sensing satellites, the technical features of the technology including integrated satellite configuration, integrated thermal control, integrated electronic system and integrated micro-vibration suppression are detailed summarized in this paper. Finally, four development trends of the platform and payload integrated design technology are proposed, which include multidisciplinary design optimization taking into account structural-thermal-optical performance, integrated electronic system based on reconfiguration modules, focus on improving the ability of micro-vibration suppression and innovation of satellite development process, which can provide a reference for the platform and payload integrated design of optical remote sensing satellite.

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