

# M&S-BASED SPACE REMOTE SENSOR DESIGN & ANALYSIS

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## ABSTRACT:

Space Remote Sensor (SRS) is a complicated system involving optics, mechanism, electric and thermal. Utilizing Modelling and Simulation (M&S) in the development of SRS can expedite the design process, reduce costs and minimize risks. This article first introduces the concept of Model Based System Engineering (MBSE), then expatiates the characteristics of VP. MBSE provides a methodology for complicated and large scale systems. VP can act as the connection between design, analysis and manufacture. After that, the article gives an example to illustrate how to utilize M&S in the development of SRS. The author first builds a simple virtual prototype (VP) of SRS. Then the performance change of SRS under sun radiation is analyzed by the VP. The simulation results show that the performance of SRS is not sensitive to radial temperature gradient

## 1. INTRODUCTION

SRS is a complicated system involving optics, mechanism, electric and thermal. The development of SRS is a process of high costs and risks because of the special working environment of SRS. Once the SRS is launched, it is very difficult to repair or update it. Constrained by time, finance, technical conditions and other factors, it is very difficult to use physical prototype to forecast the performance of SRS in space environment. Under such circumstances, simulation is a good choice. M&S can support the whole lifecycle of SRS from design to analysis and to manufacture. NASA's Next Generation Space Telescope (NGST) project is a good paradigm of utilizing M&S in the development of SRS (Gary Mosier, 2000; Olivier L. de Weck, 2000) and shows the merit of M&S.

The development of SRS can be considered as a flow of information between different departments. M&S can act as the connection between different development stages. In this article, MBSE (Jeff A. Estefan, 2007) and VP are introduced first. After that, the method to design and analysis SRS using VP is introduced by an example.

## 2. MBSE

MBSE is a new methodology based on modelling and simulation. The core idea of MBSE is to let model play the key role in the analysis, function decomposition, design, and development of systems. The main elements of MBSE are process, method and tool. MBSE is the combination of M&S and system engineering. MBSE represents the transition from the development pattern which focuses on documents to the one focus on models (Figure 1).

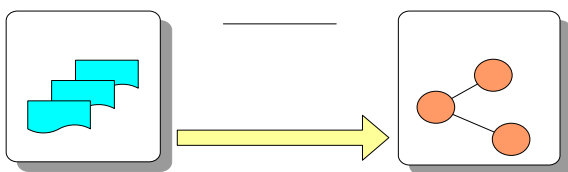


Figure 1. MBSE causes the change of development pattern

M&S can give support to the whole lifecycle of system development:

- 1) Model is the best media to record knowledge. In any organization, the most valuable thing is the accumulated knowledge. Model is the best media to record these knowledge with accurate syntax and semantics.
- 2) Models can foster intercommunications between stuffs. Every research domain has its own working language. Most of the languages are native languages and informal. Thus lead to the comprehension difficulty between different domain stuffs. Models are represented by some formal, accurate, universal modelling languages and are the best communication tools between people of different research domains.
- 3) M&S can be used to compare different design plans. Before the system is developed, even the users may not very clear about the detail of the system. Using M&S, developers can provide users a VP to help them realize the structures, behaviours and appearances of the system.
- 4) M&S can help to choose systemic parameters. The descriptions of systems are not complete at the beginning of design. Some systemic parameters can hardly be decided. M&S can help designers reduce the design space.
- 5) M&S is the core technology in the integration of design, analysis and manufacture. With the development of CAx, DFx and numeric manufacture, the integration of design, analysis and production is possible.

## 3. VIRTUAL PROTOTYPE

VP technology is an important part of M&S. VP model is an integration of different domain digital models. VP model contains the all primary characteristics of the real product. Compared with other simulation model, VP has the following specialties:

- 1) VP model targets certain product. There are strong heterogeneity and coupling between different sub-system models of different domains. Usually, these models are modeling with different tools.

2) VP model can simulate every main character of the product, including appearances, mechanical performances, thermal performances, etc.

VP model is based on models design with different domain modeling tools, such as CAD, CODE V, Pro/E, Protel and so on. Information of the product can be gained by simulation with VP. And these information can then be used to direct product design. VP-based simulation plays a very important role in the integration of design, analysis and manufacture.

One of the problems when using VP is the integration of heterogeneity models. Users must accomplish the mapping between different models and data. This can be achieved by special interface or universal platform (for example, HLA). Due to the bottle-neck of data transmission HLA is not suitable for analytical simulations (Rajive Joshi, 2003). The publication of OMG DDS provides a new method for model integration. DDS is a high efficient communication service. DDS allow user define the data format and support real time systems, thus is more suitable to be used as soft bus of simulation. MRA (Russell S.Peak, et al, 1998) provides a solution for the mapping between design model and analysis model. The other problem is about automation. Some of the simulation tasks can not be perform fully automatically. The flow-based simulation driving method provides a possible solution for this problem. It utilizes workflow technology to manage the simulation process which combined with automatic codes and human operations.

**4. SRS DESIGN AND ANALYSIS BY M&S**

Here is an example of how to use M&S in the design and analysis of SRS. When SRS exposed in space, the heating of the sun will deform the structure and then cause the performance change of SRS. First an VP of SRS is developed. Then analyses are carried out based on the VP.

The analysis of SRS performance can be organized in five steps(Figure 2):

- 1) Develop optical system model under the given system level parameters;
- 2) Develop structure system model on the optical system obtained by step1;
- 3) Analyze the temperature gradients of SRS under the heating of the sun.
- 4) Analyze the surface deformations of optical lens under the temperature gradients obtained by step 3;
- 5) Analyze the optical performance change due to the deformations obtained by step 4;

**4.1 The VP models of SRS**

To demonstrate the method but not deal with much details, the author uses a simple SRS model contains only optical and structure sub-systems. The optical sub-system is a Cassegrain Ritchey-Chretien reflecting telescope with f number 10. The optical system consists of three lens. The first and second lens are reflective and the surfaces are conicoid. The third lens is refractive and the surfaces are spherical. The surfaces can be represented with formula (1) and (2).

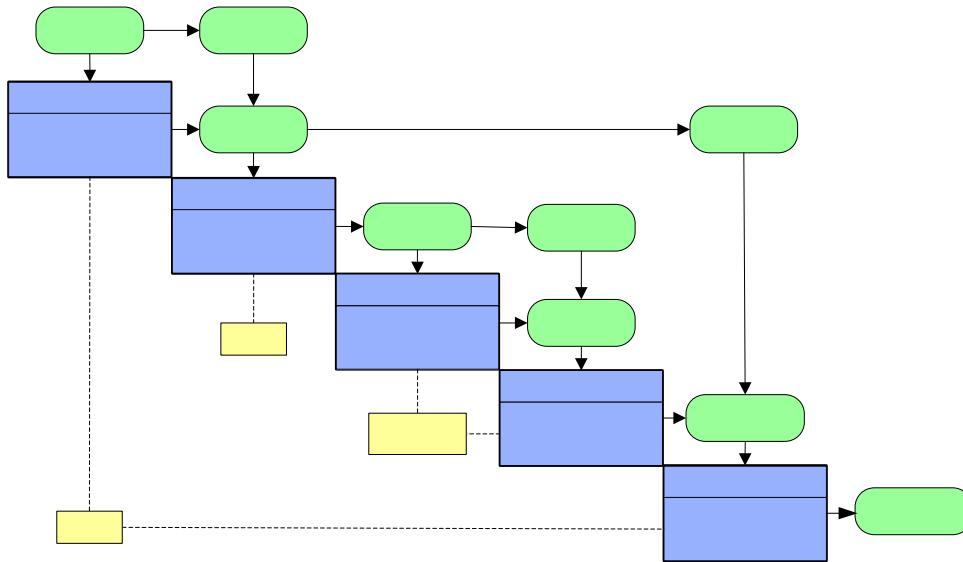


Figure 2. The N2 diagram of SRS modeling and analysis

Surface NO.	Surface Type	Curvature radius (mm)	Conicoid coefficient	Aperture (mm)	Thickness (mm)
1	Conicoid	-1271.941	-1.046	150.000	-445.179
2	Conicoid	-496.945	-2.915	45.000	807.687
3	Spherical	-94.566	1	29.053	12.841
4	Spherical	-202.896	1	30.938	

Table 1. Lens parameters

$$z = \frac{c(h^2)}{1 + \sqrt{1 - Kc^2h^2}} \quad (1)$$

$$h^2 = x^2 + y^2 \quad (2)$$

where  $c$  = curvature radius at the vertex  
 $k$  = conicoid coefficient

The origin is at the vertex of the surface. Axis Z is along the optical axis. Axis Y is upwards. Axis X is defined to create a right-hand coordinate system. The parameters of the three lens are shown in table 1. The optical system model (Figure 3) is created with CodeV 9.

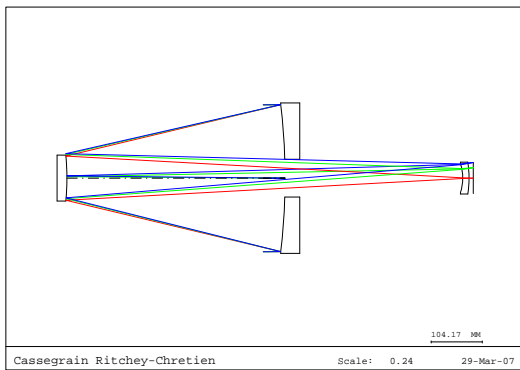


Figure 3. Optical sub-system model

The structure sub-system (Figure 4) includes the structures to mount optical lens, satellite platform and a sun shield cover. The structure sub-system model is created with Pro/E.

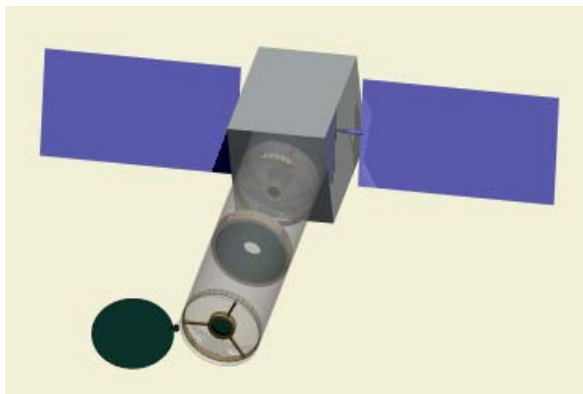


Figure4. Mechanical model

#### 4.2 Temperature gradients and surface deformations analysis

The sun radiant intensity near the earth's surface is 1395W/m<sup>2</sup>. The main exchange mode of heat is radiation and conduction. For the sake of simplicity, the initiative heat control system is

not considered here. The temperature gradients and lens surface deformations are analyzed with MSC/Nastran. The result shows that there is a maximum 29K temperature gradient over the lens (Figure 5). This is fairly large because we did not consider initiative heat control here. The surface deformations of lens are shown in Figure 6.

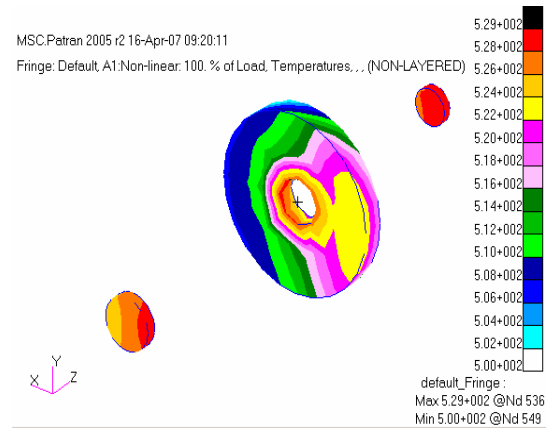


Figure 5. Temperature gradients of the lens

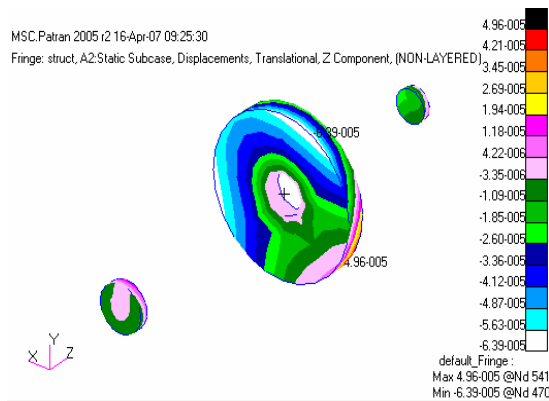


Figure 6. Lens surface deformations

#### 4.3 Optical performance analysis

The deformation data can not be used directly and must be imported into CodeV through polynomials. The author use 9 term Zernike polynomials (Max Born, Emil Wolf, 2006) to fit the surface deformations. The coefficients are shown in table 2. Write the coefficient in CodeV int file and add them to each surface. The MTF of the deformed lens is illustrated in figure 7. The comparison of ideal MTF and MTF with surface deformations is given in table 3. The results show that the optical performance of the SRS is not sensitive to the radial temperature gradients.

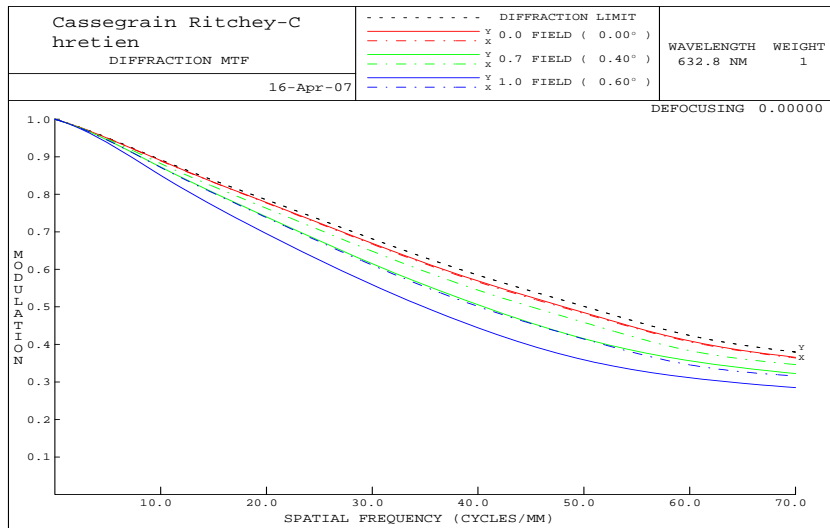


Figure 7. MTF with surface deformations

Term	Zernike polynomial	Main mirror	Second Mirror	Third mirror (Face 1)	Third mirror (Face 2)
1	1	-1.828E-3	3.880E-4	-2.518E-4	-4.333E-4
2	Rcos(A)	-1.093E-3	1.1572E-5	3.359E-5	-1.844E-4
3	Rsin(A)	-1.315E-3	6.130E-5	9.628E-4	-1.953E-4
4	R <sup>2</sup> cos(2A)	-1.283E-3	-1.425E-4	-5.922E-5	3.440E-5
5	2R <sup>2</sup> -1	-4.146E-3	-4.999E-5	2.9580E-5	-5.735E-5
6	R <sup>2</sup> -sin(2A)	1.122E-2	-1.790E-5	-4.771E-6	4.855E-6
7	R <sup>3</sup> cos(3A)	-2.366E-4	-3.349E-6	3.82389E-6	-8.961E-6
8	(3R <sup>3</sup> -2R)cos(A)	-2.932E-4	1.149E-5	8.963E-5	3.880E-5
9	(3R <sup>3</sup> -2R)sin(A)	6.528E-4	3.370E-5	5.192E-5	-2.518E-5

Table 2. Zernike polynomial coefficients

Space frequency (L/mm)	Ideal MTF		MTF with surface deform	
	Radial	Tangential	Radial	Tangential
0	0.999	0.999	0.999	0.999
10	0.891	0.889	0.889	0.890
20	0.782	0.777	0.777	0.778
30	0.676	0.667	0.667	0.669
40	0.578	0.566	0.566	0.569
50	0.495	0.482	0.482	0.485
60	0.419	0.407	0.407	0.409
70	0.375	0.364	0.364	0.366
80	0.344	0.332	0.332	0.334
90	0.311	0.300	0.300	0.302
100	0.262	0.252	0.252	0.254

Table 3. Comparison of ideal MTF and MTF with deformation

5. CONCLUSIONS

The development of SRS is a complicated system engineering process. M&S can be very useful in this process. MBSE and VP is the new evolution of M&S technology. MBSE provides a methodology for complicated and large scale systems. VP can act as the connection between design, analysis and production. Through the simple example of an optical SRS, the author illustrates how to apply M&S in the design and analysis of SRS. Utilizing M&S in the design and analysis of SRS can help a lot to expedite the design process, reduce costs and minish risks.

REFERENCE

Gary Mosier, Keith Parrish, et al, 2000. Performance Analysis Using Integrated Modeling. NGST Monograph No.6, NGST Project Study Office, Goddard Space Flight Center, USA.

Jeff A. Estefan, et al. Survey of Model-Based Systems Engineering (MBSE) Methodologies. [http://syseng.omg.org/MBSE\\_Methodology\\_Survey\\_RevA.pdf](http://syseng.omg.org/MBSE_Methodology_Survey_RevA.pdf) (accessed June, 2007) .

Max Born, Emil Wolf, 2006. Principles of optics: electronic theory of propagation, interference and diffraction of light,

*seventh(expanded) edition*. Publishing house of electronics industry, Beijing, China, pp.433-438.

Olivier L. de Weck , David W. Miller, Gregory J. Mallory, Gary E. Mosier, 2000. Integrated modeling and dynamics simulation for the Next Generation Space Telescope. SPIE International. In: *Symposium on Astronomical Telescopes and Instrumentation 2000*. Proc. SPIE Vol. 4013, pp. 920-934.

Rajive Joshi, Gerardo-Pardo Castellote, 2003. A Comparison and Mapping of Data Distribution Service and High-Level Architecture. <http://www.rti.com/docs/Comparison-Mapping-DDS-HLA.pdf>.

Russell S. Peak, et al, 1998. Integrating Engineering Design and Analysis Using a Multi-Representation Approach. *Engineering with Computers*, 14(2), pp.93-114.

