SAE TECHNICAL PAPER SERIES

2012-36-0482
E

THE PHASES OF SYSTEMS ENGINEERING AT INPE

MARIO CELSO PADOVAN DE ALMEIDA
MARCELO LOPES DE OLIVEIRA E SOUZA

SAE BRASIL

AFFILIATED TO
SAE International

Congresso 2012
SAE BRASIL

21th SAE BRASIL International Congress and Exhibition
São Paulo, Brasil
October, 2nd to 4th

AV. PAULISTA, 2073 - HORSA II - CJ. 1003 - CEP 01311-940 - SÃO PAULO – SP

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database.

ISSN 0148-7191

SAE International

2012-36-0482

The Phases of Systems Engineering at INPE

Mario Celso Padovan de Almeida
Marcelo Lopes de Oliveira e Souza
National Institute for Space Research - INPE

ABSTRACT

Since its introduction at INPE, in the late 1960s, Systems Engineering has passed through phases of greater and lesser importance. Three different phases are clearly recognized. The first two phases are closely associated with efforts to develop space systems. The third and present phase is associated to the recent growth in the importance of Systems Engineering to the development of the contemporary large and complex systems. This paper is a summary review of the history of Systems Engineering at INPE from its inception to the present.

INTRODUCTION

Since its introduction, the use of Systems Engineering (SysE) at INPE has passed through phases of greater and lesser importance. Those phases have occurred by influence of external forces and events, such as the variation in the importance given to Systems Engineering at world level, and by internal forces and events such as the recognition of its importance in the government administration by a farsighted individual and by the necessity of use of its processes and tools as aids in the management of space projects.

Three phases of Systems Engineering at INPE can be recognized during the 50 years of INPE's history. The first phase starts in the middle of 1960's with the inception of Systems Engineering at INPE, as a universal tool to projects administration. This phase ends with the abrupt discontinuation of a prospective satellite project in the middle of 1970's. The second phase starts with the reintroduction of Systems Engineering at INPE in the middle 1980's, associated with the start of the project of the first satellite to be built and launched by Brazil. This time, Systems Engineering has a strong tendency to Space Systems hardware development. This phase has not finished yet, but it will be assumed that it ended when the third phase started in 1997. The third phase was influenced by the recent growth in the interest in Systems Engineering at world level due to its great importance to the successful development of the contemporary extremely large and complex systems in a global economy.

FIRST PHASE: THE INTRODUCTION OF SYSTEMS ENGINEERING AT INPE AND THE SACI PROJECT

During the last decades of the XIX century and the first decades of XX century many new areas of science, technology and engineering emerged and developed. The capability of using this new knowledge in the creation of systems that integrated many of the new engineering technologies was hampered by the lack of engineering management techniques and tools appropriate to such developments. Most representatives of those developments of early 1900's were the weapon systems developed before and during the WWII. Those difficulties were more visible during the development of long range ballistic missiles because they integrated many of the new engineering technologies of the time and their development were inherently difficult and complex and carried much more risk. The development of those complex weapons led, during the development of the Intercontinental Ballistic Missiles (ICBMs), to the development of extremely rigorous engineering management techniques that received the names of Systems Management, Systems Engineering Management, and was finally crystallized with the name of Systems Engineering.

When Dr. Fernando de Mendonça took the office of general director of INPE in 1963, he strived to bring to INPE the most modern technologies to accelerate the national development. Besides bringing the most modern space technologies for weather forecast, natural resources development, communications and education, he also struggled to bring the most advanced management technologies to the institute under his responsibility. He made effort to bring to INPE the management technologies that had been introduced at the NASA by the military that developed the ICBMs. He strived to use the management technologies to be used to manage thousands of contractors and almost half a million workers in the NASA's Apollo project. The enormous success of the Apollo project had also led the US and many other nations' government to try to use Systems Engineering management techniques to the solution of social problems; problems like, illiteracy, unemployment, crime, etc.. This same view of Systems Engineering as a universal administration aid was shared by Dr. Fernando de Mendonça.

According to its policy of using the most advanced technologies, INPE tried to convince the Brazilian government of the necessity of a telecommunications satellite to help reduce the high illiteracy of the Brazilian population. As a first step to demonstrate the utility of a satellite to help solve this problem, INPE strived to get involved in the tests of the ATS-F satellite; a NASA advanced experimental communications satellite with direct broadcast capability. In order to be accepted in the tests of the ATS-F satellite, INPE needed to demonstrate its capability in the management of a complex engineering project. For that purpose, INPE obtained training in Systems Engineering and Project Management from several companies, particularly from General Electric Space Division. INPE succeeded in being approved by NASA to participate , in the tests of the ATS-F satellite together with India and NASA itself. INPE then created the SACI project, an educational project using the ATS-F satellite to transmit television programs to isolated schools in rural areas of Brazil. The SACI project was structured as a matrix project and was managed using a Systems Engineering approach, methodologies and tools.

INPE had a large team working in the SACI project and there was an intense exchange of specialists in Systems Analysis and Education between INPE, the RAND Corporation, and American universities. Many RAND and university researchers took part in studies and courses at INPE. As a byproduct of those courses, a group of INPE students published their master thesis in the form of books entitled "Engenharia de Sistemas - Planejamento e Controle de Projetos", publised in 1972, and "Engenharia de Sistemas - Uma Abordagem Prática", published in 1980. Those two books still are the only books in Portuguese language dedicated to Systems Engineering.

In order to be known and to obtain support and funds for its projects, during many years INPE transmitted Systems Engineering knowledge through many dozens of seminaries directed to other Brazilian government organizations and industries that could profit from the use of Systems Engineering. Due to the nature of the target audience to those seminaries, they were not focused in technical systems but in social and administrative systems.

INPE also made efforts to create a center named “Centro Nacional de Análise de Sistemas”, to make studies and analysis to help the Brazilian government in its administration, in a similar fashion to what the RAND Corporation did to the US government. The creation of this center did not succeed for lack of interest and support from the Brazilian government.

Due to government reorientation and political competition between different ministries, the SACI project was abruptly interrupted and Dr. Fernando de Mendonça, the main advocate of Systems Analysis and System Engineering, was replaced in the office of INPE's general director. Most of the SACI project team quit INPE with the interruption of the project. Only a few members of the SACI project team remained at INPE after the end of the project.

Simultaneously, at world level, failures of projects applying Systems Engineering to social problems caused the reduction of interest in Systems Engineering; and, for more than a decade, the use of Systems Engineering was limited to only large military and space projects.

SECOND PHASE: THE MECB AND CBERS SATELLITE DEVELOPMENT PROJECTS

THE MECB PROGRAM

The program named “Missão Espacial Completa Brasileira” (MECB), commissioned to execute a Brazilian complete space mission (launcher; space, ground and data segments), was approved by the Brazilian government in the end of 1979, after two years of discussions of a possible cooperation mission with France.

The MECB was a space mission to be carried-out together by INPE and the Brazilian Air Force (FAB). INPE's share in the MECB was the space, ground and data segments. The Brazilian Air Force was responsible for the launch vehicle, the satellite launch center and the launch operations.

To be able to fulfill its assignment in the MECB, INPE needed training in the many specific areas of the satellite subsystems engineering and in the management of a complex engineering project. Training in the specific satellite engineering areas was carried-out mostly at CNES, AEROESPATIALE and SPAR during the early part of the 1980's.

By the middle of the 1980's, when the MECB acquired momentum, only two engineers with previous formal training and working experience in Systems Engineering, from having worked in the SACI project, were still working at INPE. Besides those two engineers, only one INPE engineer received practical training in Systems Engineering at CNES when working in the engineering management team developing the SPOT satellite. This training at CNES was completed by a master thesis with the title "Estruturação Lógica para a Gestão de Projetos Espaciais". This thesis, published in 1987, summarized the Systems Engineering methodologies to be implemented for the development of the INPE's part of the MECB.

Those few engineers implemented at INPE a modern and rigorous Systems Engineering system, similar to the one used at the SPOT project. Because of its focus on spacecraft hardware development, there was some difference from the previous experience with Systems Engineering that occurred during the SACI project. This time, extreme attention was paid to configuration control, product assurance, reliability, and risk management.

Many INPE's workers that did not have a chance to have a formal training in Systems Engineering learned its practical operating principle "on the flight" during the development of the MECB. Since this learning was only practical, they lacked the fundamentals of Systems Engineering, its history and the reasons for its existence.

During the MECB, besides using Systems Engineering internally, INPE again disseminated Systems Engineering knowledge when it forced its contractors to use engineering management techniques similar to the ones used at INPE. This caused that its contractors had to learn, at least partially, some of Systems Engineering.

THE CBERS PROGRAM

When the program named “China-Brazil Earth Resources Satellite” (CBERS) begun, the MECB Systems Engineering was almost fully established, and, for lack of personnel, a large part of the MECB project team had to be shifted to work for the CBERS satellite project.

At that time, due to China's isolation from the rest of the world, the approach of our partner in the project, the Chinese Academy of Spacecraft Technology (CAST), to a spacecraft design was very different from our Systems Engineering approach. This led to some misunderstandings in the beginning but, in the end, CAST accepted and used our approach. During CBERS satellite development, INPE again disseminated Systems Engineering knowledge because its contractors were again forced to use engineering management techniques similar to the ones used at INPE.

The success of CBERS, with three satellites successfully launched and operated, demonstrated that success can be achieved in the complex area of spacecraft technology if proper engineering management techniques are used. In this case even for two developing countries, with very different cultures, located almost 20.000 km and a 40 hour trip apart, with 11 hours time different, speaking different languages and using English as the project language when just a handful of people in either side could speak it fluently, using only telephone, telefax and telex for communications, and meeting only a couple of times in a year.

During the time CBERS was developed, many of the INPE's workers with experience in Systems Engineering have left INPE. Some left INPE to work as contractors for the CBERS project, but the most experienced workers left INPE due to retirement and other reasons. None of the workers that remained at INPE during the latter part of CBERS project had a formal training in Systems Engineering. What they had was the experience of having worked in the MECB and CBERS projects using Systems Engineering. Due to the loss of the more experienced personnel and to the always dwindling personnel working in the project, those that remained did not have time to pay attention to the improvement of INPE's Systems Engineering methodologies and the introduction and use of the many new Systems Engineering automation tools.

The best that could be done was to continue using the methodologies, processes and tools already established. Since INPE's international relations in Space Engineering during the last 20 years were mostly limited to CAST, that had learned Systems Engineering from INPE, and INPE's new employees had to learn Systems Engineering with those without a formal training, with the passing of the time, occurred a degradation of the rigorous methodologies implemented during the MECB program.

THIRD PHASE: THE RE-EMERGENCE OF SYSTEMS ENGINEERING AT WORLD LEVEL AND AT INPE

During the last two decades many events have caused the reemergence of the importance of Systems Engineering at world level. The main events that have caused the recent increased importance of Systems Engineering are the applicability and generality of its methods to develop many of the contemporary extremely large and complex systems. The current scope of Systems Engineering has also broadened to large civil engineering projects, complex commercial products and has teamed with new related disciplines as Requirements Engineering (RE), Verification, Validation and Accreditation (VVA) Engineering, Project Management (PM), etc., and the computational automation tools created by the recently developed Software Engineering (SE).

The recognition of the present importance of Systems Engineering and the demands by the Brazilian industry of personnel with formal training in Systems Engineering led to the creation, since 1997, of 9 new disciplines related to Systems Engineering in the Option Space Mechanics and Control - CMC of the Graduate Course in Space Engineering and Technology – ETE of INPE. In the end of 2007, these 9 disciplines were moved and complemented by others to form the Option Space Systems Engineering and Management – CSE of the Graduate Course in Space Engineering and Technology – ETE. Many of the INPE's employees with only practical experience in Systems Engineering now had a chance of having a formal learning of Systems Engineering and related disciplines, and, at same time, of obtaining an academic degree in the area. Several papers, dissertations and theses on Systems Engineering and related disciplines have been recently published by INPE employees and students; and many more are expected in the future.

Other recent actions to introduce new methodologies and tools of Systems Engineering were: 1) the creation in 2002 of the Laboratory for Environments, Systems, and Controls - LabSystems at the Division of Space Mechanics and Control – DMC of INPE; and 2) the formation in 2011 of a team of specialists as the LabSys facility at the Integration and Tests Laboratory - LIT of INPE with the mission of learning and disseminating the new techniques and tools using real systems currently in development at INPE.

Another action involving Systems Engineering at INPE was that many of INPE's employees, together with colleagues from other institutions, struggled to constitute a Brazilian chapter of the International Council of Systems Engineering (INCOSE). Many meetings have occurred, with the participation of many international members of INCOSE before the installation of the chapter in Brazil has finally occurred in 2011.

A related action using the Systems Thinking approach was the creation of the Graduate Course of Science of the Terrestrial System – CST at INPE in the end of 2009.

SUMMARY/CONCLUSIONS

This paper presented a summary review of the introduction and use of Systems Engineering at INPE during a period of almost 50 years. The use of Systems Engineering at INPE during this period was characterized by three very distinct phases due to influence of both external and internal events:

In the first phase, Systems Engineering was introduced at INPE thanks to the foresight of INPE's general director with the scope of using Systems Engineering in the organization of INPE's projects, and as a general tool to help solve many Brazilian social and administrative problems. During that phase the primary use of Systems Engineering was in the development of a satellite based educational project. Two books on Systems Engineering were published by INPE during that phase.

In the second phase, Systems Engineering was reintroduced at INPE with a distinctive space engineering bias. The use of the Systems Engineering rigorous techniques and efficient tools permitted the successful development of the MECB and CBERS satellites missions. One Master Thesis on Space Systems Engineering was published by INPE during that phase.

In the third and current phase, the update of Systems Engineering at INPE was caused by the reemergence of general interest in System Engineering at world level due to the necessity of use of its methodologies and tools in the development of the contemporary large and complex projects in a global economy. So far, this phase is characterized by the efforts to train people in Systems Engineering, its related disciplines and its automation tools. There are many recent publications by INPE on Systems Engineering and related disciplines.

We expect that the third phase continues to unfold itself further for the benefit of INPE and its activities.

REFERENCES

1. ALMEIDA, M. C. and SOUZA, M.L.O., "The Introduction of Systems Engineering into Brazil," SAE Technical Paper 2011-36-0183, São Paulo, SP, 2011, doi:10.4271/2011-36-0183.
2. ALMEIDA, M. C. P. Proposta de Adoção de um Processo de Captura e Rastreamento de Requisitos Baseada num Estudo de Caso e num Histórico das Fases da Engenharia de Sistemas no INPE. 2011. 222 p. (sid.inpe.br/mtc-m19/2011/11.17.19.31-TDI). Dissertação (Mestrado em Engenharia e Gerenciamento de Sistemas Espaciais) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2011.

CONTACT INFORMATION

Mario C. P. Almeida

National Institute for Space Research

Integration and Tests Laboratory

Av. dos Astronautas, 1758

12227-010 - São José dos Campos - SP - Brazil

Phone: 55-12-3208-6303

Email: mcelso@lit.inpe.br

Marcelo L. O. Souza,

Professor and Senior Researcher

National Institute for Space Research - INPE

Division of Space Mechanics and Control - DMC

Room 27 - Satellite Building,

Av. dos Astronautas, 1758

12227-010 - São José dos Campos - SP - Brazil

Phone: 55-12-3208-6198

Email: marcelo@dem.inpe.br

ACKNOWLEDGMENTS

Both authors thank the National Institute for Space Research - INPE of Brazil, the Laboratory for Integration and Tests - LIT, the Coordination of Space Engineering and Technology - ETE, and the Division of Space Mechanics and Control-DMC for supporting them during the writing of this paper. We also thank very much Dr. Fernando de Mendonça for conceding us

a long interview with invaluable information summarized in this paper and detailed in the references.