Systems Engineering in Industry Internship and Academic Projects

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Abstract - *Large complex Industrial projects most often are interdisciplinary and require a complex systems engineering approach to guarantee success. In this paper we present a successful implementation of a true systems engineering approach to a summer internship program in industry. We exported the methods and lessons learned to an academic environment. For each project a group of six to fifteen students were selected to solve a practical industry problem and produce a detailed design for a specified project. Different aspects of the project plan were assigned to members of each group who were the most qualified or who expressed interest in a specific area of specialization. Three industrial and one academic implementation of this method are explained in this paper.*

Keywords: Systems engineering, interdisciplinary, industrial projects, systems engineering in academic environment.

1 Introduction

For three years we had the pleasure of leading as academic and industry mentors, groups of eight to fifteen of the brightest students from across the country in a summer internship program at the Jet Propulsion laboratory in Pasadena CA. This team approach to internships provided a unique opportunity to expose each team of students (comprised of undergrad and graduate students) to a novel true systems engineering approach to design a complex mission to Mars.

During spring semester of 2014 this novel systems engineering approach was implemented for senior design projects using a team of six interdisciplinary students at Western New England University (WNE). This paper presents the systems engineering approach used for these complex systems in an industrial environment and migration of these methods to academic environment.

2 Mars student projects

The goal of each student team was to produce a mission design for a mission to Mars targeting a specific launch time. Different aspects of the mission plan were assigned to members of each group who were most qualified or interested in a specific area of specialization. Advanced technologies and design paradigms were used in groups when formulating the project.

2.1 EMPHASIS Mission

Exploration of Mars for Preparation of Human Arrival with Science Done In Situ (EMPHASIS) was a mission design based on the premise of the "Safe on Mars" study by the National Academy of Sciences. The mission would serve as a precursor mission to manned Martian exploration [1,2,3,4].

The EMPHASIS mission design offers a unique approach to the challenge of characterizing hazards in the Martian environment. Through the utilization of emerging technology and the heritage of the Phoenix mission, the EMPHASIS mission aims to further explore Mars and serve as the foundation for future manned expeditions.

NASA has outlined the manned exploration of Mars as one of the agency's future objectives. However, human understanding of the Martian environment is limited, especially in terms of potential hazards to a human expedition. In order to safely design and execute a manned mission to Mars, a robotic mission must take science measurements on the Martian surface. The environmental parameters of particular interest are radiation levels, soil toxicity, dust properties and climate characteristics.

Through in situ measurements, EMPHASIS will be able to provide detailed hazard measurements of three distinct landing sites on Mars. The Landers will therefore extensively characterize each of these sites as candidate sites for future manned mission exploration.

The mission would measure and characterize the key hazards on the Martian surface that may jeopardize the safety and success of a human expedition to Mars. EMPHASIS was a robotic mission and the mission architecture was comprised of three identical Landers, all launched as a single launch vehicle payload and equipped with their own aeroshells and carriers. The Lander payload

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is supported and connected via three Launch Vehicle Adaptors (LVA). The design aims to utilize forward-looking technologies in its implementation. The EMPHASIS mission would be analyzing radiation, toxicity, dust and climate characteristics on the Martian surface. The science lifetime of the mission was designed to be one Martian year, approximately two Earth years. At the end of the mission, the science gathered would allow scientists and engineers to better understand and design for the hazards associated with a manned Martian mission.

2.2 Inspiration mission

The Inspiration Mission (Mars Student Climate Lander, MSCL) Proposal was sponsored by NASA's Jet Propulsion Laboratory (JPL) and the National Space Grant Student Satellite Program. Eleven students from universities across America, representing seven Space Grant Consortia, worked at JPL during the summer to begin the development of this mission; a stand-alone Martian science payload. The payload would accompany the Mars Astrobiology Field Laboratory (AFL) rover to the Martian surface. This mission intends to be the first student-designed and student-built mission to perform in-situ science on the surface of another planetary body [5,6,7,8].

JPL's Mars Program Office provided the constraints to this payload. Specifically, the payload must possess a mass of 25 kg or less, remain within the volume envelope determined by the JPL's AFL rover team, and must be as self-sufficient as possible to minimize the impact to the host vehicle. The Program Office left the specific objectives and purpose of the mission for the students to determine.

Using carefully selected weighted metrics, the team iteratively narrowed its focus to a small subset of feasible objectives, given the requirements of our mission. JPL Mars science experts were routinely consulted as part of the mission objectives development. Our selected mission characterizes both the daily and seasonal cycles of Martian global weather throughout one Martian year. Primary measurements include surface temperature, pressure, lower boundary layer (<1 km) wind velocities and dust concentrations. Secondary measurements map the seasonal changes in subsurface thermal inertia by measuring the subsurface temperature profile over one Martian year and also to monitor the ultraviolet and cosmic radiation environment on the Martian surface.

2.3 SEISMOS mission

The Student Seismic Discovery Mission (SSDM) concept is supported by the Jet Propulsion Laboratory (JPL) and Space Grant. An eight student multidisciplinary team was assembled that was comprised of students with an assortment of experience levels, from all over the United States. The students spent 10 weeks at JPL designing a small, low mass, self-sufficient and self-contained Martian lander concept. The primary objective of the summer mission study was to educate and inspire the student participants by offering a challenging summer internship experience, rich with interaction with JPL professionals and NASA design procedures. In addition, the students developed a unique Mars lander concept that JPL or future students can develop further.

For the purpose of simplifying the scope of the summer concept study, the concept of a carrier vehicle was introduced at the beginning of the project. The carrier vehicle will provide transportation to Mars and will deploy the Student Seismic Discovery Lander (SSDL) on the Martian surface. The vehicle selected for this purpose is the Astrobiology Field Laboratory (AFL).

SSDM's science objectives were derived from recommendations by JPL mentors and science objectives deemed to be priorities by the Mars Exploration Program Analysis Group (MEPAG). The science objectives of the Student Seismic Discovery Lander (Seismos) mission were to observe and characterize the Martian interior, seismic activity and sources of the Martin climate at the landing site of the Astrobiology Field Laboratory [9,10,11].

The primary science objective of the mission was to observe the state of seismic activity caused by tectonics, impact events and volcanism. This would provide invaluable information for future planning of a network seismic mission. Included in the primary objective was the investigation of the crust, mantle and core. Such knowledge will provide fundamental insight into the formation and evolution of Mars and terrestrial planets in general.

The secondary science objective was to measure nominal weather conditions from a unique location, investigate extreme weather events, and contribute constraint conditions to boundary layer mixing process theories.

The science instrumentation package consists of a seismometer and basic meteorology package, including anemometer, thermocouples, humidity sensor and an optical depth sensor.

3 Systems engineering

Using carefully selected weighted metrics, each team iteratively narrowed its focus to a small subset of feasible objectives, given the requirements of our mission.

One main challenge of each group was to design several different mission concepts which will be reviewed in a week and eventually turned into a final mission plan. To accomplish these tasks, each team brainstormed collectively a list of possible mission concepts. From this list, primary concepts were chosen to research further.

Then each group was split up into sections, each with the task of researching one of the mission concepts. Emerging from this process was the need for each member of the group to have a different area of specialization. Each member of the group had expressed an interest in one of the following areas where they will be researching aspects of mission concepts: C&DH, Orbit/Mission Design, Telecommunications, Navigation, Entry, Decent, and Landing, Power, Structures, Materials, Mechanical, Robotics, Thermal, Propulsion, Science and Instrument team, and Costing as show in Figure 1.0.

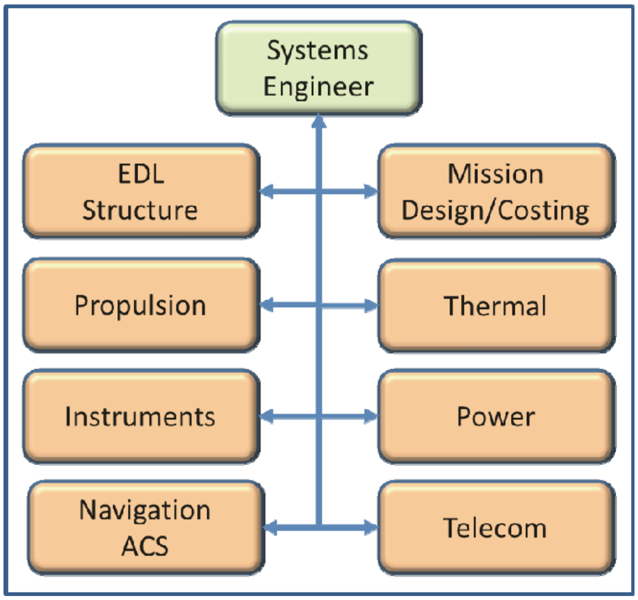

Figure 1. Subsystems Titles

A couple of weeks into the project each team selects one or two of the team members to take the role of project systems engineering coordinator. The complexity and interaction between these subsystems are briefly explained in the following subsections

3.1 C&DH Subsystem

Figure 2.0 shows how the C&DH subsystem interfaces with the rest of MSCL. C&DH interfaces with 10 science instrument packages, the communication system, the housekeeping (or telemetry) sensors and the deployment mechanisms.

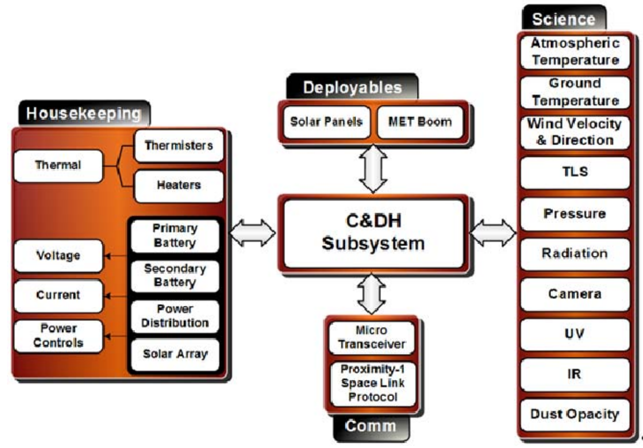

Figure 2.0 MSCL C&DH Subsystem

3.2 MSCL Power and C&DH Subsystems

Figure 3.0 shows how the MSCL C&DH system interacts with the power system and science payload. There are nine science packages external to the warm electronics box (WEB). There are thermal monitoring sensors within the WEB, and also near the external RHU container. All science data goes through a data conversion process controlled by the control circuits. The storage, memory, and read-only memory are all discrete ICs which interface to the CPU via the control circuits. The power system is monitoring various voltage and current sources. C&DH controls how the power is distributed throughout the system. The amount of solar energy entering the system is monitored. If the situation arises where the secondary batteries are fully charged, the energy is diverted to the shunt radiator.

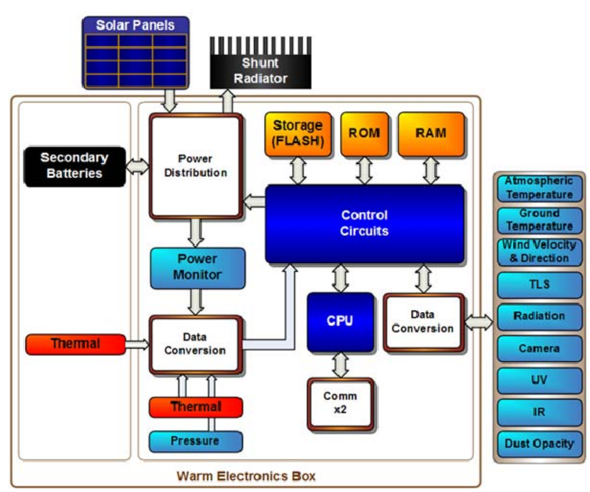

Figure 3.0 MSCL power and C&DH interaction

4 Systems engineering in academia

Mentoring students at JPL for several years and observing the growth and development of engineering skills of the students was the main motivation to create this multidisciplinary environment at Western New England University (WNE). All senior students are required to take a senior project capstone course at WNE. An opportunity arose during academic year 2013-2014 to conduct a multidisciplinary project collaborating with Firestar Technologies Company.

Firestar Technologies is an aerospace company that specializes in the development and commercialization of technologies for advanced chemical propulsion (mono-propellant regenerative gas cooled rocket engine) and power systems as well as related diagnostic instrumentation. Firestar Technologies™ is one of a consortium of companies located at the Mojave Air and Spaceport

The project was to design and develop a high efficiency Thermal Engine with Metastable Power Extraction Step (TEMPES) for high efficiency, low temperature heat recovery [12,13,14,15].

TEMPES is a closed cylinder 2-cycle engine which is designed to illustrate energy recovery from low grade industrial wasted heat. The basic operating principle of the TEMPES engine is a closed cylinder piston assembly that converts heat energy in a working fluid to mechanical energy using innovative chemical processes to extract greater than 50% more energy from a thermal energy source relative to traditional heat engines restricted to bulk thermodynamic equilibrium processes. I designed and developed a motion controls system that guides the TEMPES engine through an unconventional cam profile.

The purpose of this Phase of project was to demonstrate, for the very first time, the TEMPES power cycle in an actual closed thermodynamic cycle operation.

For this development effort of TEMPES engine, as a preliminary proof-of-concept testbed, we utilized a single cylinder piston engine with its output shaft coupled to a state-of-the-art high speed, high torque electric industrial servomotor in order to allow us to feedback control and backdrive the piston motion to any kinematic trajectory we defined. This system will allow kinematic motion control changes via software rather than hardware (e.g. through modified cam profiles). Ultimately, once an optimal trajectory is “tuned” with such an experimental set-up, a near constant rpm engine can be designed with mechanical camming and hardware in order to not necessarily require a backdriven electric motor.

4.1 TEMPES Subsystems

Six Engineering students, four electrical and two mechanical participated in this project to create a true systems engineering approach to contribute in design and development of this project. Three weeks into the project, students selected one student to be the lead systems engineer for coordinating all efforts. Figure 4.0 show the systems engineering structure for this project

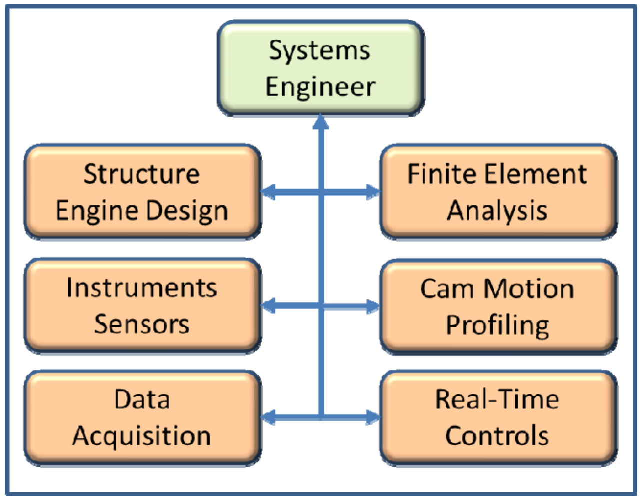

Figure 4.0 TEMPES Team Structure

4.2 Sample of subsystems results

In this section we present sample results of different TEMPES subsystems working in a systems engineering structure as show in Figure 4.0.

Figure 5.0 shows a typical crankshaft sinusoidal profile (blue trace), the theoretical TEMPES profile (red) and the designed camp profile (green) that had to be generated by a cam motion profiling group in collaboration with a real time controls system group.

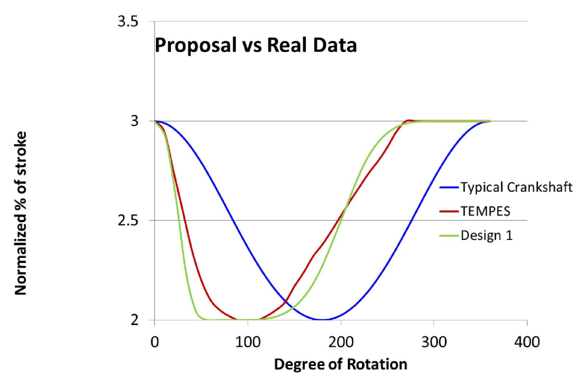

Figure 5.0 TEMPES required piston profile

Figure 6.0 shows the front panel of the data acquisition software. These subsystem results are generated by a data acquisition group in collaboration with systems sensors and a real-time controls group.

The LabVIEW program front panel as shown in Figure 6.0 takes the input locations of the DAQ for all measurement devices as well as the file paths for the saved data as controls.

Once the temperature indicator reaches a steady state the OK button is pressed to begin recording data.

The data is also displayed in the graphs on the right after it has been taken. The data is then sent to an Excel file for analysis.

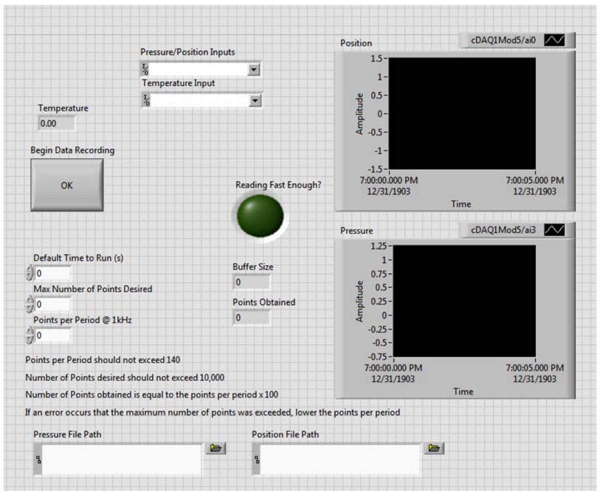

Figure 6.0 LabView DAQ front panel

Figures 7.0 and 8.0 results are from a structural engine design and finite element analysis subsystems. Students from these subsystems were required to collaborate very closely with instruments sensors selection and data acquisition subsystems to allow proper collection of critical TEMPES engine parameters data such as piston pressure and temperature.

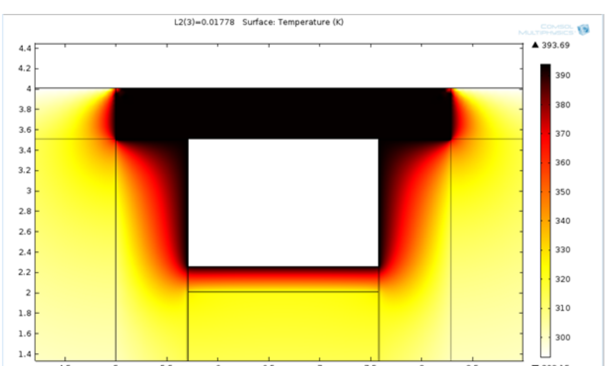

Figure 7.0 TEMPES engine temperature distribution

The above image (Figure 7.0) represents the temperature distribution with a ceramic wall thickness of 0.7".

Figure 8.0 shows mating all of the components to each other on the final product. This final assembly can be viewed as well as an exploded image of the entire assembly in Figure 8.0.

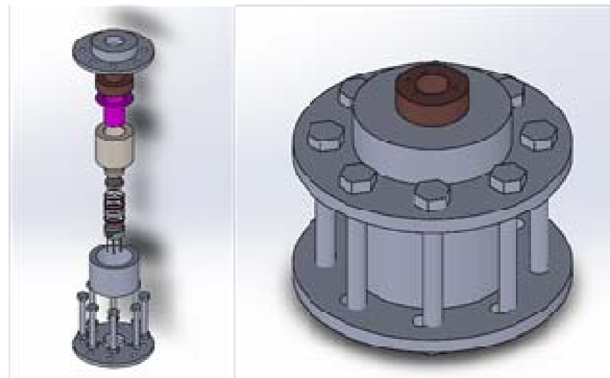

Figure 8.0 Completed assembly of piston cylinder

5 Conclusions

Western New England University requires all engineering students to participate in a capstone project during the senior year of their education. Rahnamai, one of the authors of this paper has been an academic educator in the engineering discipline for more than twenty seven years. He has conducted hundreds of industry sponsored projects throughout his tenure at WNE but always strived to incorporate the systems engineering concepts that he learned at a JPL engineering curriculum.

Although an academic environment is not best suited to implement a small to medium sized systems engineering structure in a curriculum, the rewards of allowing students to gain such experience are valuable and rewarding from an educator's perspective.

In this paper we presented how an interdisciplinary team industrial summer internship project can be implemented using a true industrial systems engineering method. Students learn and contribute in an interdisciplinary structure which prepares them for large scale complex industrial projects. We also showed that these methods can be implemented in academic environment.

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