

Risk Management of Student-Run Small Satellite Programs

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ABSTRACT: This paper proposes a risk management approach for university-affiliated, small satellite programs. These small programs have a unique set of risks because of a typically inexperienced workforce, limited corporate knowledge, occasional distributed tasking among universities, and a high student turnover rate. Only those risks unique to small, student-run satellite programs are presented. Additionally, several risk management strategies are explored, and the advantages and disadvantages of these risk-related tools and techniques are examined. To aid the process of risk identification in these particular programs, a Master Logic Diagram (MLD) for small satellites was created to help identify potential initiating events that could lead to failures during the mission. To validate the MLD, a case study is presented and analyzed. This Master Logic Diagram approach is shown to provide an effective method that can be easily adapted for risk identification in small, student-run satellite programs.

OVERVIEW OF RISK MANAGEMENT

A risk is “a factor, thing, element, or course involving uncertain danger; a hazard.”¹ Risk management is the process of identifying issues that may be potential pitfalls to the success of a program and then creating and implementing a plan to mitigate those risks. A risk management plan first requires understanding and identifying risks. Then, it is necessary to analyze the probability, impact, severity, and urgency of the failure modes. Next, a mitigation strategy is developed to reduce risks, and decision points are identified to test whether failures have been eradicated. All risks, including ones that have been mitigated, are then monitored and updated throughout a project’s lifecycle.²

Why Use Risk Management?

Risk management procedures are used to help programs focus on mission success and safety. Keeping the program’s objectives in mind, this process can help identify what might affect the outcome of the project in a negative manner. By identifying potential problems early, design changes can be made to prevent them, or resources can be allocated to them.

Without keeping track of and mitigating the effects of risks that threaten the mission, there is little hope of maintaining both a schedule and a budget; a management plan helps allocate both in the risk reduction process. To reduce the negative effects of risks, the risk management plan should be started at the beginning of the design.

A risk plan brings together all levels of engineers with the project management team. Making all personnel aware of failure modes throughout the program (and not just the dangers within their own work) can help to ensure the success of the mission as a whole. In addition, continually monitoring risks and updating the team members on the status of the risks can help to keep the project on track.

Student projects are mainly tools for teaching various types of engineering, and risk management is an important aspect of all engineering jobs. Since these projects are valuable learning experiences that help prepare students to work in the industry, the team members should learn risk management practices. In addition, the students can also learn to resolve technical and managerial problems that they may face while working on a project.

PROGRAMMATIC DIFFERENCES

In general, the fundamental elements of commercial businesses or government programs are similar to those found at universities. The biggest differences lie in the fact that universities normally have “less” of all major resources, which leads to many risks for small satellite programs.

In student-run programs, the monetary consequences of failure are lower; therefore, risk is perceived differently. While the student engineers working on a project are motivated by a desire to see the program succeed, the loss of the satellite is not as large of a financial burden as it would be for a satellite produced in industry. However, losing a satellite could be detrimental to the long-term success of a school’s

program, and risk should be taken seriously. Risk poses different threats to university-based programs than to industry projects, and, therefore, university programs have unique requirements, varying acceptable levels of risk, and different mitigation strategies.

In university-based satellite programs, the total number of people working on the program is less, so in turn, the subsystem teams consist of fewer people. Smaller teams lead to shorter lines of communication, meaning risk mitigation should be implemented more quickly. However, many universities tend to have a lax risk policy, which allows risk management to be conducted in an ad hoc and informal basis.

Since university teams are made up of mostly students, one major difference between university and industry programs is that a student's primary focus is academic. He/She must split his/her time between class, homework, extracurricular activities, research, and possibly work. With all of these activities (of which classes are usually the most important), research programs often do not receive the attention they need from students.

RISK ITEMS UNIQUE TO SMALL, STUDENT-RUN SATELLITE PROGRAMS

While all satellite programs have threatening risks, small, student-run satellite programs have a unique set of risks associated with them. This has many causes, including funding, experience, staff, schedule, follow-through, and turnover.

Funding and Competition

Obtaining financial support can be difficult for universities. In some cases, this means that at the beginning of a project, there is little to no money to pay either students or professors. For staffing purposes, funding is especially critical to attract graduate students. Funding also effects design decisions, testing procedures, schedule, and nearly every other aspect of designing and building a satellite. Trade studies should be performed to look at the cost-benefit analysis of what types of risk mitigation solutions (e.g. redundancy) should be utilized.

Some student-run satellites must compete against non-universities for funding. In this type of competition, the schools must convince the funding source that sufficient risk mitigation strategies are in place to give better-than-expected results. The combination of this acceptable level of risk and lower cost could comprise a good deal for the funding agency. Competition against non-universities for funding is difficult for schools both

with and without prior satellite design work, but it is even more difficult for the latter. Creating and implementing a satellite program at a university takes great effort and expense, which increases the risks associated with their program.

On the other hand, some funding competitions are solely focused on small satellites at universities, and these provide funding for a limited number of schools to conduct their work. The risk of not receiving funding is easy to identify, but its mitigation can be complicated and depends on the specific resources and design strategies.

The lack of funding affects other aspects of the mission, including the schedule. The small size of university satellites, as well as the prohibitive cost of being the primary satellite in a launch, leads many university satellites to be secondary payloads on a launch vehicle. Opportunities to be a secondary payload may not be identified until relatively close to the launch, making it difficult for the secondary payload team to plan their design schedule. This ties the development of the student project to that of the available primary object launches, making the spacecraft development fit a (potentially) tight schedule and, therefore, increasing technical risk.

Experience

Students lack the experience to identify risk and suggest mitigation strategies. Since students, especially undergraduates, work the most with the subsystems, they are best positioned to make observations about risk, but they often have little formal training or guidance. A method such as a risk template (see MLD section) is useful as both a teaching aid and a design tool.

The lack of experience is compounded by the short period that students usually participate in a satellite project. When students join a project, both their general subject knowledge and familiarity with the project are usually minimal. The learning curve to get general knowledge and become familiar with a project uses a large portion of the time a student has to work on the program. Students join projects later in their undergraduate career to minimize this learning curve, but it can take up to one year to fully catch up, depending on the progress of the project. Students have the advantage of being highly motivated and energetic, driven by the enthusiasm of being part of a space project. The desire to learn and master the material helps mitigate the negative effects that lack of experience brings to the project.

Staff

There are five main components to the staff that work on university satellites – undergraduate students, graduate students, university staff (such as technicians), professors, and industry professionals. These groups differ in responsibilities and size, but most programs are set up so that a large number of undergraduates work on specific tasks within subsystems. Graduate students act as subsystem leaders and managers, bringing the different teams together. Technicians can be employed to fabricate equipment, run tests and experiments, and, in general, help the students throughout the design and development phase. The professor(s) and industry counterparts oversee the project from a systems-level perspective.

One of the largest problems for these programs is the fact that a student must focus on classes, which can make it difficult to devote enough time to the satellite project. Without a set of dedicated students or funding available to pay personnel, it can be hard to guarantee that the project will have people with all the required skills. In addition, much of the work being done on the development of a small satellite is focused on design and fabrication, which would not be suitable for doctoral research. Therefore, it may be difficult to find PhD students to work on small satellite projects.

Turnover and losing students after graduation also makes it difficult to keep stability in a project. By the time a student has enough knowledge to be fully productive in a satellite program, they are approaching graduation. This is also a problem since students, especially undergraduates, are inexperienced and bring few previously-acquired skills to the project.

Many tasks have only one person assigned to them. These single-string workers pose a serious problem to any project because if that one person becomes too busy or leaves the project suddenly, the job they were assigned may be delayed while a new worker is found and trained. Having single-string workers also requires a large learning curve/hand-off time when the next person comes in.

Projects that occur in a class instead of as an extracurricular activity have even more challenges than the ones listed above. These classes have from one to, at most, three semesters to work on the project before it must be completed or handed over. These timeframes lead to either short development and production time or a project that will most likely be given to an entirely new workforce, incurring learning curves for a whole team. These classes do have the advantage that the students' grades are tied to their work on the project;

ensuring most of the students are devoted to its mission for a specified number of hours per week.

Schedule

As mentioned previously, schedules are tied closely with money, personnel, and available resources. At a school, setting a schedule can be difficult because the number of hours per week that students have available to work varies each week. Especially with new programs, it is difficult to determine how long it will take to complete a certain task. Companies have experience with similar projects, making the projections of how many person-hours should be devoted to each assignment easier. Without this knowledge, it is harder for student projects to determine how long a task will require and how many jobs will be completed in a given amount of time.

Small satellites are often subject to fast-paced development, and not all risk management techniques are applicable to these projects. Both assistance in identifying risk and streamlined methods to analyze a satellite's risks are needed to better study small, student-run projects.

Follow-Through

Since students often enter and leave a program in two years or less, a major risk is the handover of information to other team members. It is difficult to find time in a student's schedule to follow through with the required knowledge transfer. Improper documentation is a risk area because, without proper records, there is a high likelihood of losing valuable research and information.

In addition, students need to take ownership of the entire project in order to effectively mitigate risk now as well as pass on information to future team members. Students do not have an all-encompassing view of the risks of a program and are often unaware of the managerial risks associated with the project. Without a firm grasp on the severity of these risks and how they impact the technical risks, the students lack sufficient understanding of the risks and how to mitigate them.

CURRENT RISK MANAGEMENT METHODS AT UNIVERSITIES

At universities around the world, different risk management programs are being used. In general, risk assessment is done at a systems level with the team leaders. Often, the outcome of the analysis is informally documented, if at all. Risk mitigation tends to be completed through discussion of the risks and

modes of operation, making design decisions with these risks in mind. Frequent peer reviews, with periodic industry reviews, helps to focus on minimizing risk.

In rare cases, the risk management process is more developed, and the major risks are more formally identified and then traded as design choices. Projects with more defined risk management tend to track their risks and document their decisions better. In addition, programs with more guidance from an outside source (e.g. the United States Air Force) have a more defined and regular risk management plan. More formal guidance and regular reviews with an experienced adviser can lead to a better managed and less risky mission.

Team Review

At Stanford University³, students assess risk by brainstorming the possible failure modes for the part of the satellite for which they are responsible. To control the risks, the faults are categorized as to whether they need large, minor, or no changes. The students also list the ways in which they can eliminate, reduce, or live with the risk. The lists are collected from the team members, and the system leads and mentors review them and try to incorporate the mitigation strategies into the design.

Throughout the project lifecycle, risks are re-reviewed to determine the current level of risk and the progress that has been made with the mitigation plans. To review overall program risks, the whole team is used (including students, faculty, mentors, and former students).

A team review allows every student to be involved in the risk management process. This approach engages students in the awareness of and mitigation of risks while keeping the project leaders in charge of the risk management process and decisions.

Two-Phased Approach

Cornell University⁴ has a risk plan that uses two different approaches – one for the conceptual and requirements-allocation period and one for the detailed-design phase. At the beginning of the design cycle, while in the conceptual phase, the subsystem functional leads help to identify the likelihood and severity of risks. This assessment decreases risk by identifying areas in which money and time should be invested. Failure modes at the highest level are given a risk assessment score, which is the product of the probability of the risk occurring and a measure of its consequence. Next, the leads look at cost-benefit

analyses of the mitigation plans to find the strategy with the lowest combined risk and cost numbers.

When the team reaches the detailed-design phase, the major risks have been identified, so they use a fault tree analysis to continue to assess risk. A fault tree shows how initiating events can lead to functional failures of a design, such as a spacecraft.⁵ From this analysis, a system-level probability of failure can be calculated to prove that the reliability requirement has been met at various phases throughout the mission. It is only necessary to perform the entire process once, and then the fault tree should be updated and monitored as the project progresses.

A two-phased approach is very useful because it recognizes the need for different risk management strategies at various stages in the design. At the beginning of a project, the subsystem leads use the identified risks to make informed design decisions, and in later phases, the program management can monitor and control risks.

Extensive Testing

A large number of schools rely on extensive testing to reduce risk in a program. Since many schools use commercial off the shelf (COTS) products, one large concern is the effect of the space environment on these components.

Rather than spending time on computational analysis, many teams build components and then test them. Even though some money will be spent on parts that will be wasted, it is easier and cheaper to do testing rather than spending significant time and money analyzing the design. An additional benefit from this procedure is that students have the opportunity to learn both from the construction and manufacturing of the system and from the testing and analysis performed.

Both the amount of funding and the level of experience affect hardware acquisition – whether the project will choose to make or buy some components. By fabricating some parts of the satellite, a school can reduce costs while providing hands-on experience to the students. However, until a team has sufficient experience with building the component, fabricating elements of the satellite in-house increases risk greatly, so the decision is very situation-dependent.

California Polytechnic State University, San Luis Obispo⁴ (Cal Poly) combines risk assessment and testing with their approach. The Cal Poly team looks at failure modes to identify potential points of failure and critical functions and then focuses the testing on those

areas. This combination of extensive testing with risk management saves critical time and money.

Industry-guided Program

Many academic programs use industry professionals for advice on subsystems, program reviews, or software and hardware resources. One of the main advantages of partnering with industry is to lessen the risk that students have less experience. While professors are often focused on managing the project in addition to providing guidance, industry representatives can be there solely to question and challenge students.

Companies that offer help to university programs should be un-biased toward the project, but the companies also get some benefit in return. Most industry professionals donate their time to the university, but their time can be tax-deductible for the company. In turn, the company may receive advertisement, use of company logos, science return, or anything else that a unique small satellite program has to offer its contributors.

Industry representatives have varied roles and guidance between programs, but the Queensland University of Technology⁷ (QUT) uses these professionals as leaders in the risk management program. Industry partners can help to train students in risk management while handing over ownership of the risks to the student team. Business personnel are involved in identifying and reviewing risks, and Queensland University of Technology uses industry help in brainstorming, workshops, and reviews.

After each major milestone in QUT's programs, a brainstorming session is held to identify all the ways in which the satellite can fail. To best capture all the risks, the university team works with an experienced engineer from industry. The attendees can use the work breakdown structure, operational concept, or subsystem items and then try to "break" the satellite. It is important to also study the failure modes of project management and organizational issues in these brainstorming sessions. Once these sessions have been completed, the knowledge must be included in the risk management process by identifying mitigation actions and following through with those steps.

Another approach to include industry help is in risk identification during workshops, which are a more focused discussion of a risk topic. These sessions have a smaller scope and a fewer number of people. This meeting can be led by an industry representative, but the students set the agenda with guidance from the professors and industry representatives. This way,

students receive answers to their questions while getting feedback and focus from experienced engineers or scientists.

Industry reviews are one of the most-used tools to get feedback from sources outside a university. The review board may consist of professors from other schools, representatives of sponsoring companies or organizations, and un-biased industry personnel. The main purpose of these reviews is to analyze the design of the entire project; risk is only a small subset of the work covered. In addition, these reviews occur at the end of a student's work term or before a break from school, so the faults identified are left for the subsequent team. This can be a real problem if the risk items are not documented properly or are not transferred to the next students. Due to both the content covered by the board and improper timing, review boards are often not as useful as the previous two methods in terms of identifying and managing risk.

Of course, variations on these three methods would also be useful techniques to apply. Some examples include setting up a review board specifically for risk, employing a professor or experienced student to focus on risk, or holding review board sessions during work terms and not at the end.

Student programs should take advantage of the valuable insight offered by industry professionals. Through the various techniques mentioned, the expertise of business representatives can help guide a program through the risk management process, and they can help minimize the risk associated with the fact that students have little technical experience.

Intense Guidance

The University of Toronto⁸ (UofT) is developing Canada's first microsatellite and space telescope. Its success is critical to the nation's space program. UofT uses a full-time staff of professionals (five to six people) due to the program's low risk tolerance. This staff manages the risk issues, creates mitigation strategies, and carries out those plans. To identify risk, systems engineers on the professional staff review the system and subsystem level design, and their work is reviewed by the rest of the team. The staff continues to assess and monitor risk throughout the development process.

Intensely guided programs can be a good risk management learning experience for the students, but the students in these projects generally participate only in the discussions – the experienced engineers provide the risk analysis.

SUGGESTIONS FOR IMPROVEMENT OF UNIVERSITY RISK MANAGEMENT

Risk management at universities has been shown to be inconsistent and in need of improvement. Some very basic strategies can be used to reduce overall risk of mission failure. Consistent application of well-defined procedures, guidelines, and documentation can help to minimize careless errors while maintaining knowledge transfer. Configuration management, in which revision control, change control, and release control are regulated, can address many common problems before they escalate.

Personnel management is another area in which consistency will lower risk. Student-led programs should continually train and recruit new members, especially younger undergraduates that have the potential to be involved for many years. Another option is to hire a small number of necessary people to ensure the most important work is being completed. By tying the staff's work to a salary, they are more likely to work a set number of hours per week, and there will be more consistency in the program.

Retaining students as they transition from undergraduate to graduate school is a great advantage for a satellite program. Many schools encourage students to stay for their graduate work, but this cannot be guaranteed. Therefore, it is imperative that the universities have a good method for transferring information from one year to the next as students graduate. This knowledge transfer can be better controlled using consistent documentation and knowledge-management tools throughout the program.

When working with students, there are times in the semester when workload is lower, and more time and energy can be devoted to extra-curricular activities such as satellite programs. During these times, the projects should focus on critical items such as risk mitigation. After student breaks and at the start of a semester are ideal times to review risk and ensure that students are staying focused on risk management.

Reducing the risk of an overall mission can be accomplished by allowing significant risk only in new research areas. Risk can be minimized elsewhere by using hardware with flight-heritage as well as standard algorithms and processes. In cases where the risks are inherent to the mission, the program should maximize the satellite's value for the sponsor.

A de-scope plan can be used in conjunction with a risk management program to lower risk. De-scope options are technical areas of the satellite that be changed to

reduce cost, mass, power, etc. Even though de-scope options reduce performance of the mission, it is important to identify elements that can be de-scoped while still maintaining the baseline mission. A large area of risk is the underestimation of schedule or money, and having viable de-scope options can help keep the satellite within its allocations.

The strict deadlines imposed by an immovable launch date can lead to poor and hasty fixes of a student-satellite design. One solution to this problem is to implement a tiered design. By using spiral requirements, the team can do multiple releases of the satellite based on the tiered requirements, but every release can fly. This approach can be done for each subsystem or for the system as a whole. This staged release approach can be a hard method to implement for teams with little experience and low funding.

Programs that are similar at a large number of schools (e.g. CubeSat) have a unique ability to reduce risk. The teams should share information on lessons learned, probabilities of failure, high risk areas, etc. Many people may have thoughts on their own failures or suggestions for other schools, but they have not translated these into a resource for other programs to use, or if they have, they have not publicly shared them. By distributing this information, schools are less likely to make the same mistake, saving time, money, and frustration. An infrastructure, which could be hosted on a common website, is needed for universities to actively carry out this plan.

NASA Langley Research Center suggests that small satellite programs should focus on risks preventing the completion of a milestone. Instead of focusing on the risks that threaten individual technological advancements, the team should examine what the risks are that must be overcome to reach program milestone completion. The resources can be reallocated to better ensure that the next objective is reached.⁹

Finally, to reduce the risk that students have less experience, it is necessary to train people working directly with the subsystems to identify risk. Application-based training or academic classes are one option, but this might be too difficult to implement in a small program. A different option is to create a database of failures that can serve as a reference for students who must identify risk. By building a template of risk failures, students have a list from which to work. This idea will be discussed further below.

MASTER LOGIC DIAGRAM (MLD)

Many tools exist for the multiple stages of risk management; different techniques can be used to perform a combination of risk identification, assessment, control, or monitoring. Some common techniques include event tree analysis, fault tree analysis, probabilistic risk assessment, and master logic diagrams. The master logic diagram (MLD) will be discussed in more detail here.

A master logic diagram can be considered to be a high-level fault tree; it helps identify the initiating events that can lead to critical accidents or mission failure. An MLD is started by identifying critical end states (such as human loss, loss of all data, etc.), and then failures leading to those causes are found. MLDs are traditionally used in probabilistic risk assessments to identify the risk initiators and affected assets in a systematic and complete way.⁵

The top level of an MLD identifies faults of the system, while the intermediate levels are subsystem failures, and the lower levels identify component errors and the initiating events. While master logic diagrams can be done at different levels of detail, an MLD is considered complete when breaking down a component leads to the same response as the next higher level.⁵

Development of a Master Logic Diagram for Small Satellites

Small satellite programs that are run by students require guidance that the standard risk management approaches cannot provide. It is necessary to have a tool more applicable to these programs, which can help guide the users to identify risks. For this reason, a master logic diagram framework that outlines all risks relating to small satellites is useful to help identify pertinent risks.

This risk template can be used in many ways. When beginning a design, students can see the types of risks

associated with each subsystem, and they can identify where most of the risk falls in order to plan their resources accordingly. In addition, when working with a design, students can apply this framework to their project to recognize risks in their program. The whole diagram is not applicable to every satellite. Students can choose what parts of the diagram are needed based on the design of their satellite, and they are left with an MLD for their project. This method is intended to help give guidelines to students and to help them brainstorm risk modes, but they will still need to tailor the MLD to their own project.

To create the MLD, major end states must be identified first. Asking “What could be observed?” causes of the failures could be added to the MLD with minimum redundancy. For example, if a bad end state is “No data from the satellite”, one observable reason for this might be that there is no communication signal. The reasons for lack of communication are outlined at the next level, and this process is continued, expanding the tree until basic failures are identified. Figure 1 shows part of a tree when the failure is no communication signal.

Risk Mitigation Using the MLD

This MLD framework reduces much of the risk associated with university-run satellite programs. While not all the risks detailed in previous sections will be mitigated, the MLD does reduce risks associated with programmatic differences, funding, schedule, experience, and follow-through.

Since many universities have informal risk management programs, the MLD is useful because it provides a structured risk identification format. The schools will then have to create risk mitigation plans and implement those in conjunction with updating the MLD as the project progresses.

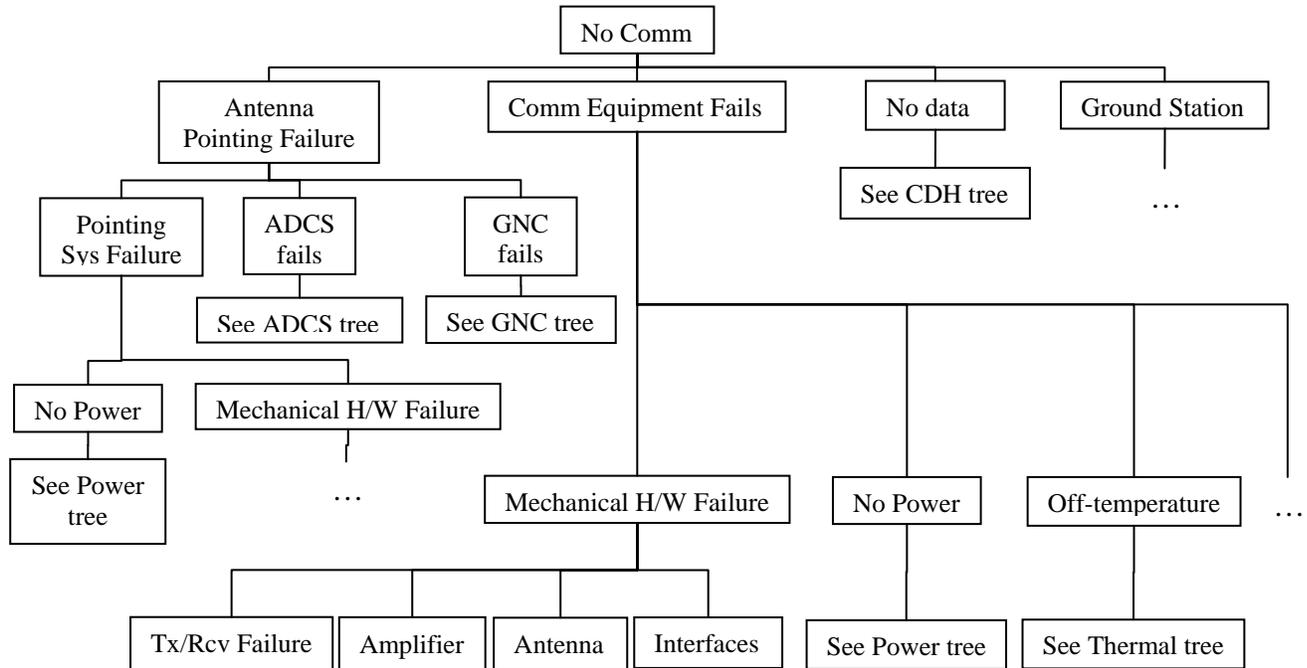


Figure 1. Section of a Master Logic Diagram for Small Satellites

While the MLD template does not directly help a project receive funding, risk management is a necessary part of a program review. When university programs are applying for funding, the source will likely require the program to identify risks, and the MLD will help to perform that task. In addition, when programs are deciding where to allocate funding, risky areas should receive more money than other less-risky components. By using the MLD, high-risk areas can be identified and given more resources in terms of funding and schedule.

Utilizing the MLD reduces the risk associated with the fact that students have less experience and are not sure of the potential failure modes. Students can better make observations about risk on their subsystems if they have a template from which to work. The MLD also provides a bigger picture of the risks facing the satellite, which decreases the students' learning curve and increases their knowledge of the entire system. With this broad view of all the failure modes, the students can better determine how risk mitigation techniques affect the whole project.

Documentation is a fundamental part of transferring knowledge from one team to the next. Using an MLD such as this provides a better way to document risk so that communicating failure modes to future members is easier. By providing a template for the

identification of risks, the reporting of risks will have a consistent format across the program. In addition, if schools want to share information, lessons learned, current risks to subsystems, etc., they can do so more easily with a consistent layout.

APPLICATION OF THE MLD TO THE MARS GRAVITY BIOSATELLITE

The Mars Gravity Biosatellite is a project run jointly between the Massachusetts Institute of Technology and the Georgia Institute of Technology. Its goal is to send 15 mice into low earth orbit, spin the spacecraft to simulate the gravity of Mars, and then bring the mice back to study the effects of partial gravity on their physiology.

One catastrophic end state would be to have no response from the satellite, particularly at the beginning of the mission. This failure would lead to complete science data loss and potential reentry problems because of the lack of communication. The MLD was applied to the Mars Gravity project in the area of power to show how part of the MLD would be expanded for a real application. Figure 2 displays the final MLD for the Mars Gravity satellite losing power (the higher level "No Power" is not displayed).

Solar panels fail	Mechanical H/W failure	Solar cells		
		Insulation between array and structure fails		
		Concentrator fails		
		Diodes fail		
		Radiation damage		
	Off-temperature			
	Panels not deployed	Structures	Unable to withstand torques	
			Unable to maintain stiffness	Off-nominal temperature
			Cannot withstand launch	See Structures
			Space environment	
		C&DH fails	See C&DH	
	Interfaces	Electrical		
		Mechanical		
	Panels not pointed to sun	ADCS fails	See ADCS	
		Structures fail	See Structures	
		Backup power fails	See Power	
		C&DH fails	See C&DH	
	Not enough power	BOL sizing incorrect		
		EOL sizing incorrect	Degradation	Space environment degradation
				Cell or array degradation
		Peak-power tracker fails		
		Shadowing on panels		
		Off-nominal satellite conditions		
		Off-nominal ground conditions		
Primary batteries fail	Mechanical H/W Failure			
	Off-nominal temp	See Thermal		
	Electrical			
	Sizing incorrect			
Secondary batteries fail	Physical	Charging fails	Loses charge	
			Fails to recharge	
		Mechanical H/W failure		
		Off-temperature		
	Electrical			
	Sizing incorrect			
Power not controlled/regulated	Mechanical H/W Failure	Controller fails		
		Converter fails		
		Regulator fails		
		Power amplifier fails		
	Off-temperature	See Thermal		
	C&DH fails	See C&DH		
Power not distributed	Wiring fails			
	Fault protection fails			
	Mechanical H/W Failure	Switching gear fails		

Figure 2. “No Power” branch of the MLD for the Mars Gravity Biosatellite

Figure 2 only shows a few levels of detail, but additions could easily be made to make the MLD more in depth. For example, under the row for degradation due to the space environment, additional rows could be added for materials, lubricant, coating, thermal expansion, and space debris. With this additional information, students are better aware of the specific threats within more general categories. However, an MLD is supposed to be a high-level fault tree, so a program can determine how much detail is needed.

In contrast, Figure 3 shows the risks associated with no power in a preliminary brainstorm for the Mars Gravity Biosatellite, where no formal technique was used to identify risks.

No power	All solar panels fail to deploy	C&DH fails
		Structures fail
	Rechargeable batteries fail	Lost charge
		Bad connection
		One battery fails
	Converter fails	
Less than max power	Fewer than all panels deploy	Structures fail
	A few panels fail	
	Voltage from panels < bus voltage	
		No info on eclipse & sun times
	GNC fails	
No power during eclipse	Batteries don't recharge	Solar panels don't deploy
		Bad connection

Figure 3. Preliminary Risk Brainstorm for Power Failures

Impact of the MLD on the Mars Gravity Biosatellite

To see the utility of the MLD, one can compare Figure 3 and Figure 2; the master logic diagram returns considerably more data on the risks relevant to the satellite. The MLD is better able to capture a complete set of risks by providing a consistent and comprehensive framework for identifying risks. Conversely, a simple brainstorming activity might be incomplete and biased toward the experiences of the people identifying the risks.

Another difference between the two risk identification methods is that the MLD follows a

logical path from the end state to the initiating events. In the brainstorming session shown in Figure 3, there is less utility for the risk list created because there is no unifying factor, such as a detrimental end state, motivating the assessment.

As with the identification of risks in any technique, the risks and their mitigation strategies will have an effect on the design of the satellite. The MLD ensures that risks over the entire satellite are noted, which is important information to have when considering design choices that affect an entire satellite.

The MLD is able to better capture a complete set of risks than other techniques, such as brainstorming, for a satellite project. While the Mars Gravity Biosatellite has not yet flown, this case study proves that a general yet adaptable tool such as a master logic diagram is needed for student-run satellite programs.

Future Plans

To best utilize this risk template and to share information between schools, the MLD will be put online to be reviewed and used by other universities. Receiving feedback from other satellite programs will help to make this tool more comprehensive and helpful, and newer versions can be shared with the entire small satellite community.

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