The Objective and Strategy Behind the Liquid Propulsion Laboratory at the University of Southern California

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The history, objectives, strategy, collaboration, and technical projects of the student-run Liquid Propulsion Laboratory (LPL) at the Viterbi School of Engineering at The University of Southern California (USC) are presented. LPL designs, builds, and tests liquid-propellant rocket engines and integrates them with flight vehicles. LPL consists of mostly graduate level students and has a strong international presence both in the laboratory and through its partnership with the Kyushu Institute of Technology (Kyutech), Japan. This partnership is focused on developing a reusable, liquid engine powered launch vehicle. Kyutech is responsible for the airframe and overall control system, and LPL is responsible for developing the propulsion system. LPL is founded on the idea of providing students with hands-on industry tailored experiences in developing liquid rocket engines. The objective is achieved by establishing the following strategies: recruit like-minded individuals, create a motivational and competitive lab environment, develop training tools for incoming students, build a strong and interactive alumni network, and streamline the transition of leadership. Recent success in designing, building, and testing of a propulsion system validates LPL's philosophies and development strategies as feasible and promising options for student organizations across the country.

I. Introduction

Liquid-propulsion is a technical challenge in its own right which is why industry is heavily subsidized and features decades-long development programs. With greater aspirations ahead, future engineers will need to tackle and solve progressively more complex problems. A greater level of understanding will be required to make progress and must be done in an equivalent timeframe as previous generations. Student organizations give members familiarity and experience solving real world technical challenges at a younger age, which offers aid in workforce development. As well having to overcome technical challenges, student organizations also have to deal with program management, which is an obstacle that can impede any progress or the overall success. One aspect that makes the Liquid Propulsion Laboratory (LPL) unique is that it is completely student-run in all areas and only receives faculty oversight on safety, administration, and logistical support. Some challenges that come with this demanding but rewarding organization is a rapid turnover rate, steep learning curve, work-school balance, lack of resources and funding, and minimal experience and guidance. By researching practices of universities across the country and attempting various management styles, LPL has developed an overall philosophy and strategy to overcome these challenges and build towards a brighter future.

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II. Motivation and Challenges for Student Organizations

A. Motivation

Space and particularly rocket technology is quite complex and, to this point, features government-commercial partnerships to closely monitor and ensure safety and success. With rocketry containing millions of moving parts, attention to detail is critical, and failures along the way are a near guarantee. As programs come to completion, new documentation is recorded, superior protocols are adopted, and state-of-the-art methods are practiced. In order to develop such technology, a deep understanding of a wide array of disciplines is required. This includes but is not limited to fluid systems, thermal control, structures, material science, aerodynamics, guidance navigation and controls, electronics, and software. This means that companies seek to acquire top engineering talent that have a strong understanding of their field and the capability to recognize how their system fits and affects the overall system. Over time greater strides will be taken in this field which will require a great understanding by future engineers. The burden of this learning curve will be placed in the hands of the respective companies to train future engineers and have them continue to innovate and advance society.

For centuries, academia has succeeded in guiding students towards their career choice. For engineering degrees, theory is a heavy focus point and students are taught how to think. One area that sees occasional criticism is that academia lacks workforce development and training for the real world. In coursework, every problem has a solution, but this is almost never the case in reality. In academia, students are provided a problem statement to solve, whereas in the workforce engineers typically need to determine the question they should be asking. This results in many students leaving school unprepared and makes the transition difficult [1].

One feasible solution to this challenge for both industry and academia is through the adoption of student organizations that provide hands-on experience. As previously mentioned, a higher-level understanding is required for future generations, but they are ultimately given the same amount of time as previous generations. Through student organizations, members get initial exposure to industry practices and terminology prior to exiting academia. Students are provided the opportunity to use knowledge acquired in coursework and directly apply it to actual hardware. This experience allows students to try out various engineering roles, such as in design, development, manufacturing, test and operations, and ultimately determine where their interests lie. In addition, they are developing communication and teamwork skills which can be difficult to achieve through coursework. In return this hands-on experience helps provide intuition that will aid students in future courses and help universities educate students. Moreover, hands-on organizations are attractive to prospective students which helps the university to draw in the best talent. They are undoubtedly in the best interest of both universities and companies to adopt and support.

B. Challenges

As great as student organizations are at providing practical experiences, they have their deficiencies too. Rapid turnover rate, steep learning curve, work-school balance, lack of resources and funding, and minimal experience and guidance are all areas that need to be understood and addressed in order for a student organization to be self-sustaining and successful in developing engineers to enter the workforce. Ultimately, students are attempting to mimic the work done by a handful of experienced and accredited engineers do on a full-time basis but do so with the aforementioned deficiencies.

Another main challenge for students is time management. Students, especially those in a leadership position, are asked to lead a lab, deal with the bureaucracy that comes with a university, potentially work a part-time job to help sustain themselves, enroll in graduate level courses, all while trying to network and search for a career. All of these challenges make it difficult for organizations to keep a high morale and continue to deliver work that potential employers view as valuable.

These challenges are some of the underlying reasons why LPL has spent an ample amount of energy and time in leadership and management. Due to how demanding developing rocket technology can be, student organizations need to figure out an optimal way to both motivate and collaborate effectively. Unlike industry, student commitment is voluntary, and without an attempt at making this experience both a practical and useful one, students may believe their time is better off spent in other endeavors.

III. Commitment to Space Education at USC

The University of Southern California has shown its commitment to space education by establishing a specific department and housing multiple space related organizations. Over 14 years ago, this was not the case. Like most universities, the study of astronautics was embedded within the aeronautical department. Although, the two fields have many similarities, they carry many differences as well. The classic aeronautics curriculum features a heavy focus on atmospheric phenomena, such as lift and drag and also includes a heavy dose of fluid mechanics. Astronautical engineering on the other hand does not deal with atmospherics besides ascent and landing but orbital mechanics, attitude dynamics, and space environments, are crucial to success in this field. USC realized that in order to provide a world class educational experience in the field of space engineering, it had to form a purely space-focused department.

A. Astronautical Engineering Department at USC

The University of Southern California made a large stride to advance space education in 2004 by establishing a new department entirely focused on space engineering. The motive for independence was based on a slow and resistant attitude towards equal status of astronautics and aeronautics in the aerospace department. The 1950's is considered to be the birth of space engineering as this was the beginning of the "space race" where the initial space technologies were conceived and rapidly developed. Both military concerns and national pride resulted in space engineering being a popular and promising profession to pursue. The demand for space education found a home in the late 1950's as universities merged astronautics with the well-known aeronautics and formed the initial aerospace departments. Through the years, the equal status of the two disciplines has not materialized. The nature of faculty members wanting to maintain their area of research a focus of their university, has resulted in them hiring new faculty in their area of interest. USC Astronautical Engineering (ASTE) Department Chairman, Professor Mike Gruntman, has discussed that the separation of these two departments would result in the elimination of the competitive atmosphere, which benefits the industry [2].

The initial and primary focus of ASTE was to build and develop the Master's program. With a highly dynamic and advancing industry, space engineering continues to push the boundaries of science and engineering, which results in the industry preferring higher education. Obtaining a Master's degree in the field of STEM has become the new norm of the space industry. Many full-time engineers decide to further their education by enrolling in a university on a part-time basis to acquire more responsibility and opportunity in their career path. USC has been able to capitalize on this as the university has been a leader in online education through their Distance Education Network (DEN). Pursuing a Master's degree in astronautical engineering immediately became an ideal and feasible solution for aspiring engineers across the country. The location of USC has also played a critical role in its early success. Being located in Los Angeles, USC is at the heart of the aerospace industry. In 2008, the Aerospace Advisory Committee noted, "The space enterprise community alone, when extracted from the greater aerospace industry, impacts California's economy with a $31 billion in revenues generated by 71,000 direct jobs - which is a 21 percent share of the $146 billion global space marketplace.", [3]. California's dominance in space related jobs does not look to be slowing down in the near future. Space Exploration Technologies (SpaceX) has recently announced that Long Beach will be the location for the production of their new Mars rocket, the BFR [4].

The student body of ASTE is typically divided equally between part-time online students and full-time on-campus students. To help aid these full-time students and prepare them to become engineers, the astronautical engineering department has founded research centers and student-organizations to help maximize the student experience. From 2007 to 2008, the department founded the Viterbi School of Engineering's Space Engineering Research Center (SERC). SERC objectives feature student-centered projects and has been successful thus far with numerous contracts and CubeSats currently in orbit. For the growing Bachelor of Science program, undergraduate students receive practical extracurricular experience through the department's Rocket Propulsion Laboratory (RPL). This student-led, design-build-and-launch team has an ambitious goal to become the first university to design and build a rocket to reach the Von-Karman line, 100 km. Since 2005, USC's RPL has successfully developed undergraduate students by building amateur solid rockets and in turn has resulted in strong job placement within the industry and has also provided some students the foundation and ambition to start their own space companies. Utilizing a solid rocket motor and lessons learned over the past decade, RPL hopes to achieve its overall mission during the 2018-2019 school year. With success seen in both laboratories, the founding of USC's Liquid Propulsion Laboratory seems to be an ideal fit as its primary objective lines up with the beliefs and values of the department.

B. Liquid Propulsion Laboratory at USC

The founding of the Liquid Propulsion Laboratory was a product of a few graduate students interested in developing their own liquid rocket engine. In January 2014, two Master's students in the Astronautical Engineering Department, Juha Nieminen and Calvin Cheung, along with friend, Cris Mar, decided to design and develop a nitrous oxide-kerosene engine. Both the team and the engine can be seen in Fig. 1. This self-funded endeavor took over a year to complete. On April 4th, 2015 they witnessed a successful static fire with the nitrous oxide-kerosene producing 620 newtons of force during its 2.5 second burn.

a) b)

Figure 1. First successful engine firing. a) Rocket hobbyists Juha (left), Chris (middle), Calvin (right). b) Nitrous oxide-kerosene engine

A former RPL member and current NASA JPL engineer, Adarsh Rajguru, took note of this success story and envisioned a future for this project within the Astronautical Engineering Department. From his time at RPL, Rajguru was exposed to the success they had with job placement and believed that the Master's program could greatly benefit from a similar laboratory. Rajguru envisioned a laboratory that primarily housed students with a Master of Science in astronautical engineering and would be able to apply coursework to developing liquid propulsion systems. In the following months, Rajguru was able to pitch this success story to the department, and in the Fall 2015 semester the Liquid Propulsion Laboratory was founded. In addition to founding LPL, Rajguru reached out to an international university, Kyushu Institute of Technology (Kyutech), and from that LPL and Kyutech formed a partnership. This international partnership focuses on developing a state-of-the-art liquid propelled rocket. More details of this partnership will be discussed in the following section.

In its first few years, LPL tried to replicate a management style similar to that of RPL but quickly found that liquid engines are far more complex and require a strong foundation in fluid mechanics, thermodynamics, and a strong attention to detail. For LPL to see success by building increasingly more complex propulsion systems and in order to maintain support from the university, an identity with clear objectives and strategies needed to be adopted.

IV. Objectives of the Liquid Propulsion Laboratory

Space engineering is competitive and relatively small thus requiring students to show a well-rounded portfolio in order to get attention from companies for employment. But as students prepare to enter the workforce they run into a catch-22 situation: most companies want you to have multiple years of experience, but no one wants to give it to you. This is a major roadblock that can be stressful and concerning for students trying to get their foot in the door and start their careers. It is a day and age where just getting high marks in school is not sufficient. This issue is one that has personally affected the majority of students in LPL, and therefore solving this issue has become the fundamental value of LPL. The primary objective of LPL is to prepare students for the workforce through international collaboration.

A. Workforce Development

The overall mission statement is different from most university research laboratories as it is not product driven. Many student-run laboratories want to be the first university to reach the Karman line, have a lander touchdown on the surface of the moon, or even build the first additive manufactured engine. As common challenges previously outlined are certain to arise within a student organization, workforce development typically becomes an afterthought as organizations panic to keep their project from disaster. But in reality, student organizations at universities are one of the most ideal places to develop engineers as there is no product that must be delivered to an owner before a costly financial loss is inherited. The benefit of a student organization is that it builds familiarity with industry practices and a strong foundation through experience and collaboration. Not only does designing, building, and testing provide familiarity with the process, but more importantly, it allows individuals to build confidence while solving problems in a collaborative environment, which aids in the transition into the workforce. This will help as they can reduce the resources in training entry level engineers and delegate more responsibility to them. LPL practices an inward-out approach as they seek to find individuals that are hungry for self-growth, and it uses rocket technology as the aid to develop them.

Workforce development is achieved by providing students the opportunity to take knowledge acquired in coursework and apply it in a hands-on, extracurricular setting that replicates what is seen in the industry. This type of setting provides students an opportunity to experience "the internship before the real internship". This starts with the recruiting process and is implemented throughout the design, build, and testing phases, and presented with various types of deliverables. Recruiting is done by conducting interviews that feature similar questions to those seen in the workforce, such as behavioral questions, technical questions, and a technical riddle. The design phase has the students create, assemble, and maintain 3D models using Siemens NX as well as conduct analysis and verification of their design using a combination of hand calculations, developing programming scripts in-house, and utilizing the ANSYS software package. Samples of student design work can be seen in Fig. 2.

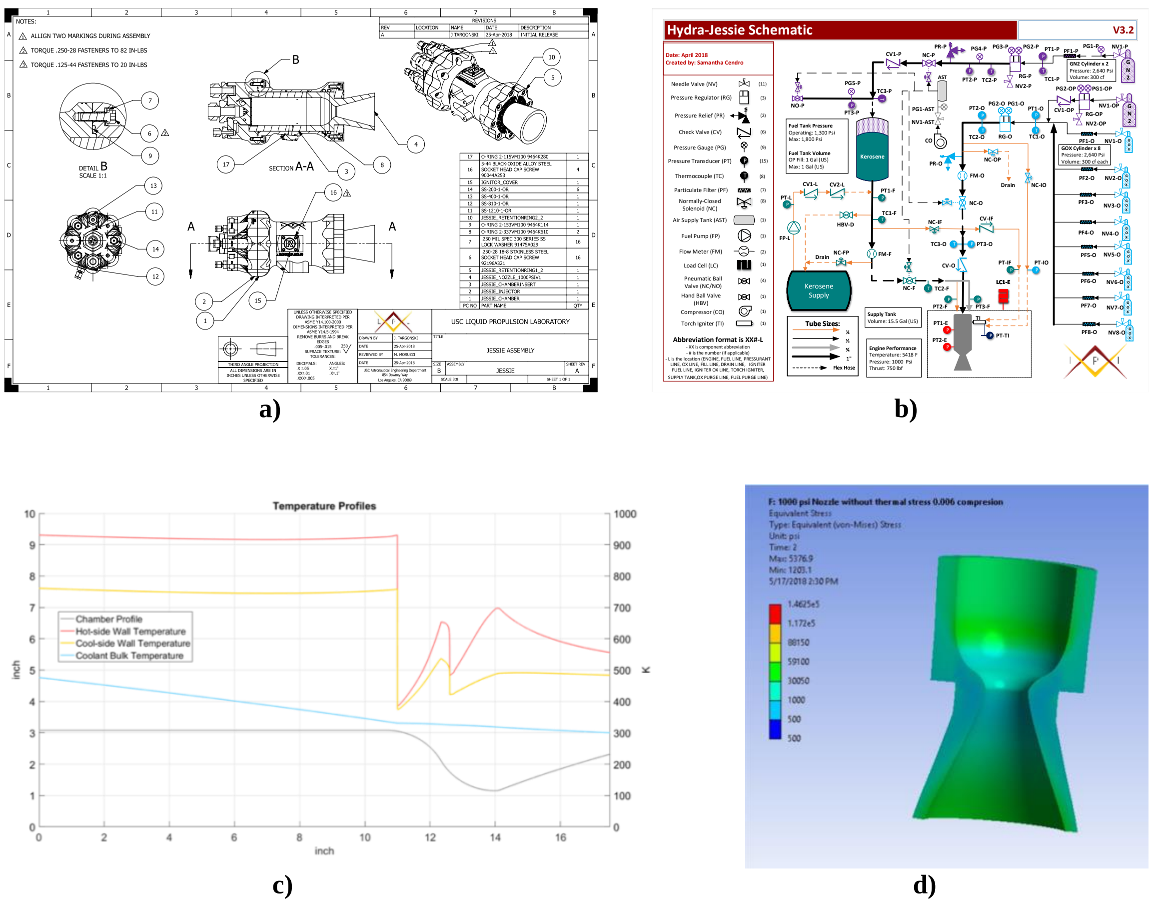


Figure 2. Student deliverables. a) Assembly drawing b) Schematic c) In-house code d) ANSYS simulation

During the build phase, students have the opportunity to take on the role of build and integration engineers by creating drawings that feature geometric dimensioning and tolerancing, procure all necessary materials within the budget and lead time constraints, and collaborate with various machine shops, suppliers, and additive manufacturing facilities. Testing includes component, subsystem, and system level testing, where students create and implement operating procedures, create various testing roles and training programs to develop and qualify peers, coordinate logistics with test facilities, and develop codes to aid in data post processing and analysis. LPL requires each lab member to provide deliverables to document decision making as well as the design itself. This provide the students with the opportunity to complete individual projects with portfolio worthy work. LPL creates documentation such as plumbing and instrumentation diagrams, bills of materials, master equipment lists, functional block diagrams, and prepares and presents various design reviews throughout each semester. For students, learning the process will provide a foundation that can be easily expanded on once students enter and contribute to the workforce.

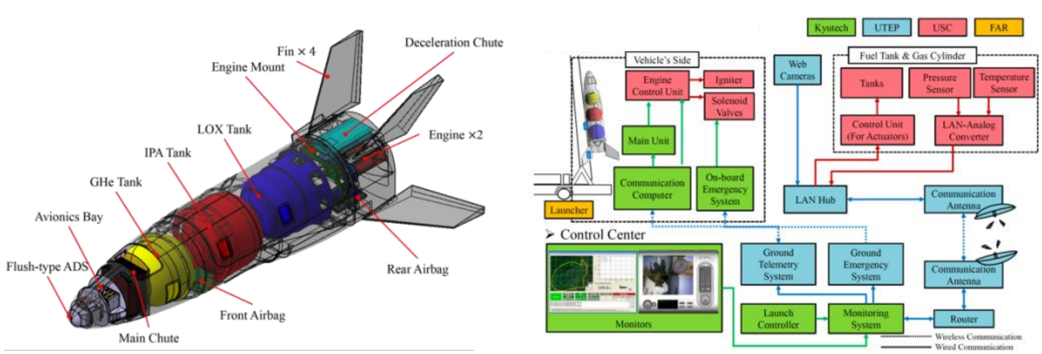
B. International Collaboration

The Liquid Propulsion Laboratory also has a strong attitude towards international collaboration. This is passed down by the university as USC consistently ranks at the top for housing a diverse student body. “USC continues to attract the most talented and creative students from all over the world — a point of tremendous pride for our community,” said USC President C. L. Max Nikias, [5]. Many students travel abroad to America in order to receive a college education with the hope of one day staying in the United States and living the “American Dream”. As mentioned earlier, students have a difficult time obtaining an internship or job in the space industry without prior experience, and for international students it is near impossible. The United States classifies military technology under International Traffic in Arms Regulation (ITAR), which is a regulation that acts to limit employment to US citizens and permeant residents. This automatically prohibits international students from working in the space industry within the US. The vision of LPL is to give all students the same opportunity during their time at a university with the hope of obtaining a career in the industry of their choice upon graduation regardless of location.

Throughout history, international talent and collaboration has helped accomplish some of the most iconic American achievements. Many of the brightest engineers in the space industry, both past and present, have come from abroad to pursue a career in the space industry. A few classic examples would be Wernher Von Braun and Elon Musk. Wernher Von Braun was a German aerospace engineer that eventually found his way to the US and became the leading figure for the United States’ rocket program during the Cold War. For NASA, Von Braun was the director for the Marshall Space Flight Center and was Chief Architect for the Saturn V “Moon” rocket. In today’s world, Elon Musk, an entrepreneur from South Africa, continues to push the limits of human capability with the founding and operation of his private company, SpaceX. At SpaceX, Musk serves as both the CEO and Lead Designer with the ambitious goal of making humankind a multiplanetary species and does so by making rockets a rapid and reusable technology. Lastly. the famous International Space Station was a collaboration of 15 countries [6]. This illustrates how some of America’s greatest accomplishments have been achieved with international talent and collaboration.

The product of collaborating with individuals from different backgrounds is innovation. Due to varying cultural influences, individuals of different nationalities bring a different perspective to help with problem solving. This is a great asset as the space industry will require solving more complicated problems in the years ahead. Unfortunately, many student organizations limit involvement to US citizens due to potential ITAR complications. This is not the case at USC because the school provides legal guidance in this manner and all projects to this date and moving forward will only be pursued if international participation is allowed.

LPL is currently partnered with Kyutech to develop a liquid-propellant rocket. The launch vehicle in development is the Winged Reusable Sounding Rocket (WIRES#13). The system architecture can be seen in Fig. 3. WIRES#13 has a length of 4.6 m, a wet mass of 900 kg, and will be flown to an altitude of 6 km. The purpose of this iteration is to develop and test both the recovery system and ground support equipment. LPL’s role in this partnership is to provide the propulsion system for the WIRES#13 vehicle. LPL is designing and integrating the propulsion feed system that will feed two of LPL’s regeneratively cooled liquid rocket engines. Each engine will produce 10 kN of thrust, utilizing kerosene and liquid oxygen as propellant, and will be additively manufactured out of Inconel-718. The engine development program will feature an iterative approach, which will be discussed in the following section. The development engine, Balerion, is currently scheduled to be tested during the 2018-2019 academic year, and the inaugural launch of WIRES#13 is tentatively scheduled for 2020. No part of the WIRES#13 project is ITAR restricted.



a) b)

Figure 3. WIRES#13 system architecture. a) 3D model b) Functional block diagram

V. Strategy of the Liquid Propulsion Laboratory

Through experience with different universities, laboratories, backgrounds, and through trial and error, LPL has developed a series of philosophies that aid in meeting the overall objective of developing students for the workforce. They can be broken down to the following: recruiting like-minded individuals, creating a motivational and competitive lab environment, practice developing propulsion systems iteratively, develop training tools to teach incoming members, build a strong and interactive alumni network, and have a strong and selfless transition of leadership. If these guiding principles are instilled, accepted, and practiced as a whole, team and personal development are bound to take place.

A. Recruit Like-Minded Individuals

To satisfy the objective of developing students to become ideal candidates in the workforce, LPL recruits like-minded students. These students demonstrate passion in their studies and show a desire to grow as individuals. Through experience, it has been found that individuals that begin their studies with the mindset of maximizing the universities resources are more likely to commit the time and energy required to grow, which in turn positively influences the lab. It would be hypocritical to solely recruit members with experience; experience is not required in order to join. Showing previous experience is still coveted and may result in joining the lab with an immediate leadership position instead of a general engineering position. Since students typically only spend two years in the Master's program, students are encouraged to immediately take on responsibilities if able. But regardless of past experience, each prospective member goes through the same recruitment process.

This process is a critical to maintaining the talent and values of the laboratory. LPL aims for quality over quantity. With other established organizations like RPL and SERC, every student has the chance to get valuable hands-on experience, which allows LPL to selectively recruit students they believe will excel and positively contribute to the lab culture and environment. This would not be the case for universities that only house one space engineering organization. LPL believes every student should get the opportunity to be involved in a student organization in some capacity.

A strong belief of LPL is that in order to build a strong, respectful, and family-like team, an onboarding routine needs to be practiced and maintained to ensure a rite of passage for incoming members. If anyone were given the opportunity to join, it would result in a lower talent pool and, more importantly, fail to provide incoming members that feeling of fulfillment one gets when accepted into an organization. This sort of philosophy is practiced all throughout society and may not even be noticed. Not every student that applies to college gets an acceptance letter, and not every job applicant receives the job offer. Life needs barriers in order to assemble a group of like-minded individuals and pursue a common goal.

In alignment with the lab's overall objective of workforce development, LPL's interview style is similar to that seen in the industry. The outline of the interview is as follows: a brief agenda, an introduction to LPL, interview questions, concluded with follow up questions. The introduction to LPL is a key part of the interview because potential members can get a feel for what the lab environment will be like and it allows the interviewee the chance to gauge if that sort of environment and objective is interesting to them. In addition to the current projects, the overall mission statement is discussed. Prospective members learn how they do not need any prior experience but will need to embrace the concept of "end-to-end ownership with minimal direction". This concept will be discussed in detail in the second philosophy of creating a motivating and competitive lab environment. Once these values are laid out, the actual interview process begins.

To start this part of the interview, an icebreaker in the form of a technical riddle is given. This riddle provides an impromptu setting to see how someone thinks through a problem. Solving the riddle is not a factor in deciding to bring a student onboard but the way they attempt to approach the riddle is considered. From there the interview continues with resume-focused and behavioral questions. These behavioral questions are aimed to see if the student has solved technical problems and to show off their resourcefulness. From here, the interview concludes with possible follow-up questions.

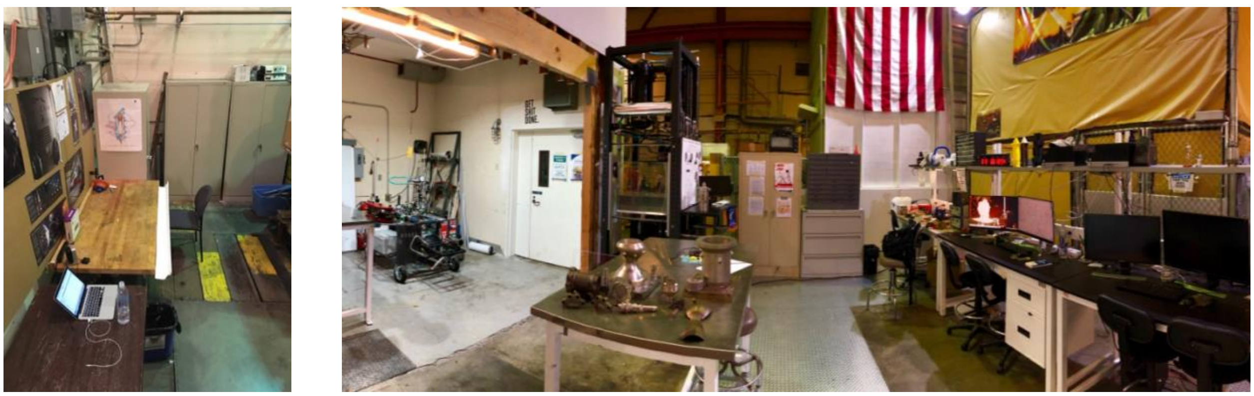
During and after the interview it is important to not show any sort of reaction to the interviewees performance. If this is shown, it can backfire. It is human nature for people to desire things they cannot have. If the interviewer shows that the interviewee did a perfect job with an interview, their interest in joining that organization will subconsciously drop. If they are unsure of their performance, the interviewee will desire that dopamine release of satisfaction, and will want to be accepted as part of that organization. This is the same phenomena seen with romantic relationships. If a person on a first date shows too much interest towards the other person, he or she will subconsciously be less attracted to that individual.

The main attributes looked for during this interview is likeability - no one likes to spend a large portion of their day with someone they don't get along with - passion through a previous project, potential in the desire to grow as an individual, and availability. To reiterate, technical skill is not focused on. One may argue that writing about the recruitment strategy in a published paper is not a great idea being that potential members can read this and get a "leg in" about what is looked for, but it is in here for a reason. If a potential member locates and reads this, they have already shown off their resourcefulness and therefore deserves the tip.

B. Create a Motivating and Competitive Lab Environment

Establishing a lab environment that is accepted as a whole is by far the most challenging aspect of leadership, but it is of most importance for a student organization to become both self-sustaining and practical. Having a leadership position is both physically and mentally exhausting as one needs to lead a group of people in an area he/she is not an expert in and do so while being a full-time student. Typically, leads are the more technically sound engineers. If a lab requires the lead to manage everyone, it loses one of its most valuable assets as the lead becomes a manager instead of an engineer. In addition, to require a lead to personally manage everyone and get stuck in the middle of every problem that arises is ineffective and ultimately unsustainable. In order to prevent this, it requires that some form of responsibility, ownership, and accountability be seen at all levels in the organization.

The strategy is to build an environment that motivates and challenges members to do their best. This all starts with the actual environment. It is important to strive for and maintain a lab people want to spend time in. Furthermore, having people regularly in the same place at given times allows for communication and routine; bonds will be formed, questions will be asked, and production will ensue. This environment is something that has become a staple in the tech hub of Silicon Valley. It is seen from Google and their slides and ball pits to Apple with their aesthetically pleasing spaceship building. Fig. 4 illustrates the investment LPL has made in recent years to improve the overall lab environment.



a) b)

Figure 4. Photographs of lab space. a) January 2017 b) June 2018

Motivation is achieved by keeping a high morale and making each member feel like a part of the laboratories success. When it comes to developing rocket engines, there will be down periods. Things will not go according to plan, and the lab will see major setbacks. One way to combat this is by developing a propulsion system that allows frequent static fire tests. There is something magical that results in experiencing a static fire or rocket launch: first comes a rush of euphoria, which is followed by a desire to experience a feeling like that again. LPL is currently developing a pair of relatively simple rocket engines, Jessie and James, that are not actively cooled and do not utilize cryogenic propellant. These engines in combination with a mobile test stand Hydra, will perform static fires multiple times a semester within short notice. This will motivate onboarding members and can help with morale in low periods. Besides the projects members work on, LPL has a unique way of creating that feeling of contribution. For example, on Hydra, flags of every members' nationality are featured on it. This helps illustrate the lab's commitment towards international collaboration as well as showing respect to everyone's background. As seen in Fig. 5, Jessie and James features every current member's name engraved. This may seem like a minor feature, but in terms of moral it goes a long way as members can point to their name and show participation.

In building a challenging lab environment, LPL encourages individuals to become self-learners through projects that feature end-to-end ownership, which allows individuals to see the complete product cycle with minimal direction. When a project or task is given, members need to know it is their responsibility to get that project done. Each project or task has an outcome that is desired, and it is up to that assigned member to find or make their path to achieve that outcome. This may require self-learning a new topic, becoming resourceful, and being aware of potential roadblocks before they happen. It is not important for members to just complete the task at hand because the majority of the time things do not go according to plan. Students need to have an understanding as to why their task is important and how it fits in the bigger picture. If this is understood, the lab will build an environment where members look out for each other and not just follow orders.

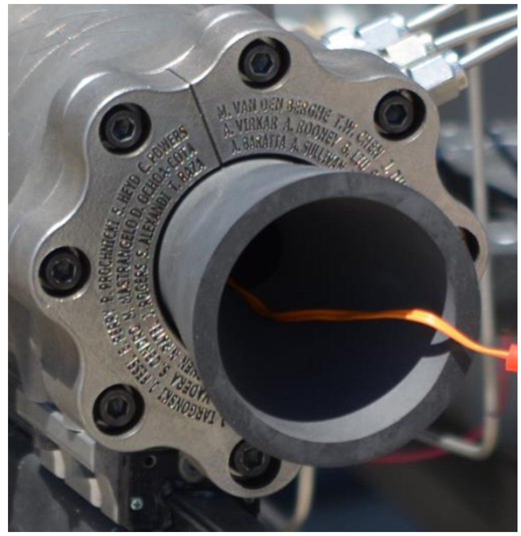


Figure 5. Jessie nozzle and retention ring.

The approach to achieve this type of environment comes down to grasping the current level of understanding of each member and getting everyone on an equal playing field. For new members with minimal experience, proper training in the beginning is essential. LPL has developed various systems that can serve as training tools. Once new members are familiar with common items such as terminology, overall subsystems, and how they depend on each other, an initial task is given. The task is for the most part not mission critical and is something along the lines of making a modification to a training tool. This ensures that if the new member ultimately feels that the laboratory is not compatible with their schedule, it will not negatively affect the progress of the main project. These tasks aim to show the full product cycle and will require new members to find time to contact older members. An example would be to modify Hydra to allow the capability of a dual engine firing. This project would require the new member to learn the current configuration of the test stand, learn how to use CAD software, learn both the terminology and procurement of fittings, as well as how to fabricate and install a feed system. If this is accomplished, the new member would get that dopamine release of satisfaction and would have learned valuable skills along the way. The individual’s level of commitment would be validated and he or she would be ready to move on to the lab’s main project, the Kyutech propulsion system.

For members with prior experience or members that have gained experience through their work in lab, the approach is to increase their level of responsibility. These members would be offered to take on a task that is critical to the labs success and see how he or she handles the new responsibility. These tasks would most likely be ones that require collaboration and work delegation. One example would be to do develop operating procedures to conduct a test with a newly designed ignitor. He or she would need to understand the functionality of the ignitor, be aware of safety precautions, and ultimately what type of tests need to be conducted in order to obtain the data the lab is interested in. This will require communication along multiple subsystems and a big picture understanding. If he or she succeeds in this responsibility, the current leadership may feel comfortable promoting this person to a leadership position either in that area or one that is similar.

This sort of strategy does require more time and energy for the leadership initially, but if this is accomplished with enough members, the lab will move to a level of self-sustainment. Members will build confidence and self-esteem, and if that is coupled with a passionate and persistent personality, people will look for future tasks and projects on their own. They will speak up when they believe a certain decision is not the right one and ultimately work together in a self-policing manner. This is similar to the kind of environment legendary enterpriser Steve Jobs talks about with his Macintosh team.

“It’s through the team, through that group of incredibly talented people, bumping up against each other, having arguments, having fights sometimes, making some noise, and working together they polish each other and they polish the ideas and what comes out are these really beautiful stones. It’s hard to explain and it’s certainly not the result of one person.

I’ve built a lot of my success off finding these truly gifted people and not settling for B and C players, but really going for the A players…I found that when you get enough A players together, when you go through the incredible work to find five of these A players, they really like working with each other. Because they’ve never had a chance to do that before. And they don't want to work with B and C players and so it becomes self-policing and they only want to hire more A players. And so, you build up these pockets of A players, and it propagates." [7]

The only difference at LPL is that people with potential are recruited and molded into an "A player" persona. Once this kind of working environment is instilled, the lab leadership can go out and fulfill the responsibilities that makes one a great lead: one that can articulate a clear vision, make the hard choices, motivate individuals to give their best, and ultimately will their team to success.

In order to maintain a level of accountability, this sometimes leaves leadership in a position where they need to decide to remove members from the roster. Typically, when a member is not pulling their own weight, a warning is issued, and a meeting is scheduled to discuss the member's role in the lab and if they want to continue. From here the member has an opportunity to improve on their involvement. If the level of commitment is still not on par with the rest of the laboratory the individual is dismissed. This is something that is not preferred, but it is necessary to maintain talent, hard work, and, more importantly, to be fair to the members that do commit and prioritize their time.

C. Develop Propulsion Systems Iteratively

Propulsion systems are developed in an iterative manner at LPL. Every major product is designed with the expectation that it would be iterated on again. This management style is similar to the "Spiral Model" that is used in the software industry. Since the lab is at a level of experience where learning is happening constantly, this iterative approach seems to be the obvious choice. For any program, by the time a product is developed the engineers close to the project will always be able to reflect and think "If I could do this again I would change x, y, and z." For a student lab, this happens frequently.

Figure 6. Balerion engine.

In addition, another challenge of a student organization is the frequent influx and outflux of students. With LPL featuring primarily graduate students, the turnover rate is only two years. This iterative approach can help combat this rapid turnover rate. This approach allows students the ability to go through the full product cycle of major products while they are enrolled in a university. For example, for the Kyutech partnership, the plan is to have an engine development program that features four engines. The engine development program will feature one development engine, one qualification engine, and two flight engines. The original development engine, Balerion as seen in Fig. 6, was started in the Fall of 2017, and the testing campaign is scheduled to be completed before the conclusion of the 2018-2019 academic school year. This will allow the incoming class to learn about Balerion during the entire school year, take the lessons learned from the graduating class, and start the design and development of the qualification engine.
Lower level systems like the injector are designed with an iterative mentality. The Balerion pintle injector is designed so you can try out different designs without fabricating an entire new engine. This is also the case with both the Jessie and James injectors. This will allow for research opportunities, especially with LPL's Water Flow Test Stand recently operational.

D. Develop Training Tools for Incoming Students

To progressively develop increasingly more complex systems, LPL's training program will need to be second to none. As time goes by, students will need to take in more information to make progress on future designs. This will need to be done in the same amount of time as their Master's program. To develop incoming members, training tools have been developed and will continue to be improved upon.

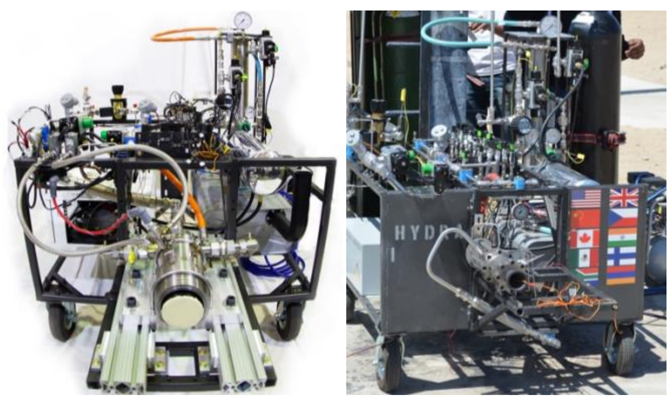
Figure 7. Jessie and James engines.

One tool to aid in training is the presentation of crash courses on topics of relevance and interest. Senior members or alumni would put together a presentation on a topic they are relatively knowledgeable in. This can range from a survey lecture in propulsion to how to size feed lines in a propulsion system. In addition to teaching incoming members, these lectures help improve the presentation skills of senior members, which both help achieve the labs objective of workforce development.

Likewise, hands-on training is conducted. This can be anywhere from how to cut, swage, flare, or bend a tube to a step-by-step walk through of a plumbing and instrumentation diagram.

The main tools that have had the largest impact on developing students are operating and conducting modifications on Hydra and the Jessie and James engines. As discussed earlier in this section, initial projects are given using these systems as baselines for modifications. They are less complex and are not critical to the Kyutech project. This gives incoming students the opportunity to go through full product cycle and to do so on a system that is a non-cryogenic or actively cooled. Working with cryogenic propellants or an actively cooled rocket engine raises the level of design considerations and safety precautions. By training on a simpler system, new members can contribute in a quicker timeframe. Once a project with these tools are complete, members should have the background and process in mind to start contributing on the lab's main project. Jessie and James, as seen in Fig. 7, have been designed as a pair so that LPL can overcome any technical challenges of dual engine firings prior to two flight engines are fabricated for the WIRES#13 vehicle. Another way that Jessie and James will serve as a training tool is that they feature a modular design. As seen in Fig. 8, Jessie will be capable of swapping out different injectors and nozzles. This will allow LPL to operate these engines at various conditions and try out various injector designs. Figure 9, illustrates modifications made on Hydra by incoming members.

Figure 8. Jessie modular design.



a) **b)**

Figure 9. Images of Hydra. a) November 2017 b) June 2018

E. Build a Strong and Interactive Alumni Network

Having a strong and interactive alumni network comes with countless benefits. Firstly, it is a great way to stay up to date with the latest practices used in the industry. The awareness of the current software that is used for CAD or the general outline for a fluid schematic is learned from interaction with alumni. In addition, they are the next level up in providing guidance. LPL holds multiple design reviews during a semester: preliminary design reviews, critical design reviews, and test readiness reviews. Since the majority of the alumni end up working in the Greater Los Angeles area, it is an easy commute and allows for great feedback.

Industry recruitment is another area that will be continued and built upon. Being that the lab is relatively new, the alumni network is small and still growing. It is common for members to stay active upon graduation, which reflects one of the main attributes recruited for: passion. International alumni have a higher inclination to collaborate as it is their sole opportunity to stay involved with space systems. The eventual goal is to have alumni located at all major companies and for those companies to use LPL as the first option for new hires. With a lab objective of workforce development and an alumni base that continually keeps the lab up to date with standard practices, it is possible to see this achieved.

Alumni are kept involved by featuring events like the annual homecoming tailgate and static fires. For testing campaigns, the lab treks out to the Mojave Desert. This makes it a convenient way for alumni to participate in these events. In addition to mingling events, alumni are routinely updated with emails, as well as through social media accounts.

F. Streamline the Transition of Leadership

To maintain consistency in the strategy of LPL, the process of leadership transition must be well accounted for. Once the current leaders have served their one-year term, they select two replacements that will best suit the future of the lab. New leads are selected one semester before the current leads graduate. Transition of leadership is facilitated by having the past leads guide and give insight on how to continue the vision of the lab. This helps to avoid any inconsistency arising within the lab. Also, this allows new leads a chance to learn from what past leads wish they had done, because each lead's duty is to leave the lab in better circumstances than when they began. This process is still in development. With every transition the process is becoming better as new suggestions are brought forward. The most important piece of this process is communication between the past and current leadership. It is crucial that both sides are able to converse over past experiences and lessons learned to improve the future leadership of LPL. This process leads to improving the effective working environment and helps leadership avoid repeated mistakes. There will be levels of discomfort occurring on both sides, but if the leaders are humble and have the lab as their main priority, this will be overcome.

Having two leads helps with dividing the workload, and LPL has found success in promoting two general lab leads. Every person has strengths and weaknesses. Having two leads helps fill these gaps. The leadership of LPL needs to take care of a range of tasks including managing subsystem leads, making technical decisions, recruiting new members, communicating with the university, and most importantly creating plans and budgets for the lab. It is not feasible for these tasks to be done just by one individual, especially with course workload during the semester. In the case of two leads, there is the possibility of splitting the responsibilities. For example, one lead can mainly be focusing on the vision of LPL, recruiting, and taking care about the budget. The second lead can oversee all of the projects and provide technical supervision. This enables efficiency and avoids burnout of the leadership because of workload. Consideration should be taken in deciding which two leads may complement each other the best to reap the most beneficial outcome.

VI. Recent Results from Strategy

A. Hydra Inaugural Firing

On December 2nd, 2017 LPL conducted its first successful static fire in Mojave, California. This was the inaugural test of the student designed and built mobile test stand Hydra, and student-built rocket engine Blue Steel 2.0. Blue Steel is a kerosene and gaseous oxygen rocket engine designed to produce a thrust of 4.5 kN. For a conservative initial test, the operating conditions were altered to aim for a thrust of 2.5 kN. The data concluded that it was 20% off nominal at 2 kN. Images for Hydra's inaugural static fire can be seen in Fig. 10. This project was intended to give the laboratory experience in the complete process of building a liquid-propellant engine and feed system. It allowed students to learn the fundamentals by taking on a lower risk and cost project, as the engine does not utilize cryogenic propellants and is not actively cooled. The future of this project is to teach incoming lab members the fundamentals about liquid propulsion systems prior to attempting a more challenging task for the WIRES#13 project. In addition, new ideas and projects will be tested utilizing Hydra.

a) b)

Figure 10. Images from Hydra's inaugural static fire. a) Blue Steel 2.0 firing b) LPL team

B. Base 11 Interns

LPL has and will continue to participate in the BASE 11 program where leads of LPL mentor students from community colleges, shown in Fig. 11. Base 11 offers students attending community colleges opportunities to conduct research with mentors at world-class institutions through academic year and summer internships. It has been one year since beginning the collaboration between LPL and BASE 11. Students from this program went through lecture series about all subsystems. Next, they moved towards a small hands-on project where they built actual hardware. Last step in their training was a design project to enable them to go through the entire process of design, procurement, assemble, and testing. For example, one project was to design plumbing to support dual engine firing. This has shown that with appropriate training even students who are still in their prerequisite courses are capable of finishing design projects for liquid propulsion technologies.

Figure 11. Base 11 interns at LPL.

C. Jessie Inaugural Firing

After the first static fire, Hydra has transitioned to serve as a training tool to help incoming members get over the learning curve. Numerous small modifications can be implemented which prepares new members for future more complex problems. Before the Jessie firing, a rigorous testing campaign was conducted to characterize the operational parameters needed from Hydra. These tests helped determine pressure drops, regulation pressures, and timing sequences. This testing campaign will be repeated for each subsequent engine firing. The testing phase is great for developing the understanding of the basics of rocketry in new members. Testing allows for hands-on learning that will accelerate progress up the learning curve associated with rocketry. In addition, performing tests on this simpler system will help teach LPL about anomalies using less critical and expensive hardware. The inaugural static fire of Jessie has taught LPL about the phenomena of hard-starts. This could have had severe financial consequences if learned while testing with Balerion. Images of both the testing campaign and set up at Mojave Desert can be seen in Fig. 12.

Figure 12. Preparation for Jessie inaugural static fire. a) Hydra timing test b) Test stand setup

D. Student Job Placement

Despite the fact that LPL has only existed for three years, it has already begun to grow a strong alumni network within the industry. LPL alumni are currently working for the following companies: The Aerospace Corporation, Firefly Aerospace, Generation Orbit, NASA JPL, Northrop Grumman, Orbital ATK, SpaceX, Vector Space Systems, and Virgin Hyperloop One. This validates the LPL strategy and environment; LPL prepares students to enter the industry and work on challenging projects in the aerospace field, but more importantly satisfies the laboratories primary objective of developing students for the workforce.

VII. Acknowledgments

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