SSC21-S1-42

Hot-Fire Thruster Testing Approach at University Level

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ABSTRACT

Technological advancements in chemical propulsion systems leading to increased interest and new applications for small satellites in recent years has created a need for additional testing resources and targeted workforce development. Generally, chemical propulsion testing requires interactions with hazardous materials and environments, which presents significant challenges in a university setting. The Center for Aerospace Exploration and Technology Research (cSETR) at the University of Texas at El Paso (UTEP) has developed a sustainable hot-fire testing program for chemical thrusters that is operated by undergraduate and graduate students. The program is managed analogous to testing programs in professional settings to enable reliable test results, ensure safety of all participants, and provide appropriate training to student engineers.

The day-to-day activities of the test program are managed entirely by the student team. A flow-down mentoring approach is used where graduate students with years of experience in the lab train new students joining the program. Tests are planned and executed using standard industry practices, including approved testing procedures, assigned participant roles, and test readiness reviews. The use of a standardized and systematic approach enhances the repeatability and validity of each test. Safety management is achieved using readily-available, low cost resources to maintain operation within a standard University budget. This program is presented as a working example for other University groups looking to establish or improve in-house chemical testing methods to enable expanded hot-fire chemical propulsion testing capabilities and workforce development.

INTRODUCTION

SmallSats have become an excellent resource for students to exercise a multidisciplinary approach for educational and commercial projects. With both industry and academia increasingly using SmallSats since 2012[1], an effort to expand their capabilities by adding chemical propulsion technologies is of interest. The implementation of chemical propulsion can expand the mission scope for many of these SmallSats by adding the ability to maintain orbit for longer periods, orbit injection, or even deep space exploration[2]. Development of chemical propulsion systems requires intensive testing to validate their use in SmallSats. This is an excellent opportunity to involve students in testing programs and provide experience while developing a product.

Some of the most common propellants used for SmallSat propulsion are Hydrazine, Green Monopropellants and Cold Gas (Table 1). Hydrazine has an extensive heritage of being a propellant for small scale propulsion, but it is also highly toxic and requires several layers of safety to use[4]. Developments of Green Monopropellants and Cold Gas have opened access to safer testing and handling of propellants, making them more accessible by universities.

Table 1: Various Propellants used in CubeSat Propulsion Systems[3]

Propulsion Type	Thrust	Specific Impulse (I_{sp})
Green Monopropellants	0.1-27 N	220-250 sec
Hydrazine	0.5-4 N	150-250 sec
Cold Gas	10 mN-10 N	65-70 sec

The Center for Aerospace and Technology Research (cSETR) at The University of Texas at El Paso has developed a sustainable hot-fire testing program for chemical thruster operated entirely by students. This program is managed in the same manner as in professional settings, allowing students to acquire experience and be exposed to the different aspects of planning a testing campaign. Being such a relevant topic of study, students are able to learn about the latest technologies involved in chemical propulsion, how to manage a testing campaign using low cost resources in a University budget, and interpreting the results obtained from the testing campaign.

HOT-FIRE TESTING PROGRAM

A hot-fire testing program provides students with the experience of planning, performing and interpreting data from the testing campaign. Many of these aspects require multiple iterations of testing procedures, which describe in detail the steps needed to initiate and perform a testing campaign.

Planning Testing

Planning a testing campaign starts by creating and approving of a testing procedure. This document details every measure related to the testing campaign. It starts with details such as original author and version numbers along with a description of changes made through the different versions. The bulk of the testing procedure includes nine sections. These sections are Scope, Test Article Description, Pressurization & Propellant Management, Reference Documents, Safety Precautions, Propellant Handling Procedures, Initial Set-Up and Check-Out Procedures, Test Procedures, and finally Emergency Procedures.

The Scope section describes the reason the testing campaigned is conducted, describes the facilities where the test is going to be performed, and the steps needed to take in case of a mishap occurs. This gives an overall sense of how the testing will proceed, where, and immediate steps in case of an accident.

In the Test Article Description everything known about the test article is stated. How the test article was made, the materials used, all the components of the test article, and performance characteristics.

The Pressurization & Propellant Management section describes the pressurization system. This system is used to pressurize the system to desired levels. Usually, schematics of the pressurization system and the propellant delivery system are shown here along with a component list to be able to refer to the specific instrumentation mentioned in the schematics. The instrumentation described includes thermocouples, pressure transducers, thrust balance (for measuring thrust) and flow meters if desired.

The Reference Documents section lists documents related to the testing campaign. Here documents such as Safety Data Sheets, Tests Plans, and Safety Assessments are listed. These documents are first created or obtained before completing the rest of the testing procedures.

The Safety Precautions section covers the type of Personal Protective Equipment required for the handling of chemicals and while performing the test. In case of injury, detailed guidance on how to proceed is in this section as well.

The Propellant Handling Procedures is the section where the components used to store and handle the propellant are described. In case of spills or need of first aid due to contact with the propellant, this section will contain the guidelines to safely contain the situation.

The Initial Set-Up and Check-Out Procedures are a set of instructions that are performed prior to testing. These instructions are listed in a way that when testing, these can be marked off and followed, ensuring that the instrumentation, the hardware, and other gas delivery systems are operational. Here one can find instructions on what to do if a leak is detected in the system and how to mitigate it.

The Test Procedure is then listed in the same manner. Actions are broken down step-by-step where the Conductor of the test can follow marking each step as they are performed. Once the test is complete, a set of instructions are also included on how to proceed to safely shutdown the testing facility and properly store or dispose of the remaining propellant.

At last, an Emergency Procedures section is placed at the end, where more specific scenarios are described and their respective instructions on how to proceed are listed. An example of this would be on how to proceed in case of a power loss occurs during testing.

Executing Test

Once the students finish creating the Testing Procedure, it is then reviewed by the center's safety engineer. Here the Testing Procedure undergoes several test readiness reviews until approved by the safety engineer. Once approved, testing can commence. This ensures the tests performed will provide reliable test results, ensure the safety of all participants, and provide enhanced repeatability by using the same parameters on the same type of tests.

Before starting the test, the test conductor assigns roles to the other participants. This distributes the responsibilities among all the participants which helps facilitate testing and gives the students the experience of relying on their teammates for vital steps. These roles can be interchanged between the students and provide a full experience between the whole team.

Once participant roles are assigned, the test can start following the Initial Set-Up and Check-Out Procedures and following through until testing has been completed.

Interpreting Data

Once testing has finalized, the data obtained is then gathered and analyzed. In case of any anomalies, it is possible to repeat part of the test matrix or repeat it fully and ensure the tests performed are repeatable, making the data more reliable.

KNOWLEDGE TRANSFER

Being in a university setting many times the retention of knowledge is a challenge due to the rotation of new and graduating students. This can be mitigated by a combination of two methods. The first helps pass down knowledge from graduate students to new students by serving as mentors and training the new students. This helps provide a pipeline of knowledge that can be retained by the new students when graduate students graduate from the program. Second, a knowledge repository can be maintained where every information used to proceed with the projects is stored. Here the key to success is the ability to organize the information in a manner where any file is easily accessible by any of the team members. These two methods greatly enhance the ability of testing programs such as these to continue to be entirely managed by a student team.

SUMMARY

The Center for Aerospace and Technology Research Center at the University of Texas at El Paso has developed a Hot-Fire Testing Program which is entirely run by a student team. This program is analogous to testing programs followed in professional settings and allow for reliable test results, training of students in testing habits, and ensures the safety of all participants. This testing program is performed following a Testing Procedure that is drafted by the students and approved by the center’s safety engineer. The test is then performed entirely by the students, where roles are assigned, maximizing the experience on all team members. This program also helps in establishing a pipeline of knowledge where graduate students pass down their knowledge to incoming students. This can then document their experience to maintain a permanent repository where any future student can access when in need.

By allowing students to fully take charge of testing programs such as this one, not only is their experience in this field enhanced but technical aspects such as safety considerations are challenged every time testing is required. Students will have a better understanding of the project at hand while being aware of constrains such as availability and cost of resources to be able to maintain a university budget. These practices will not only enhance the student’s experience in their team but will also develop a student that will be better prepared to enter the workforce.

References

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