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Propulsion Research and Academic Programs at the University of Alabama in Huntsville - 30th Anniversary Summary

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The UAH Propulsion Research Center (PRC) is in its 30th year at the University of Alabama in Huntsville (UAH). The mission of the Propulsion Research Center is to provide an environment that connects the academic research community with the needs and concerns of the propulsion community while promoting an interdisciplinary approach to solving propulsion problems. This paper summarizes recent metrics from academic and research programs. The emphasis this year is highlighting the production of close to 500 refereed publications over the past 30 years and highlighting the growth of the Mechanical and Aerospace Engineering program at UAH during that same time. The PRC continues to be a resource to perform both fundamental and applied research. It is also a significant contributor to workforce development in the propulsion and energy fields.

I. Introduction

The Propulsion Research Center (PRC) marked its 30th year as a University of Alabama in Huntsville (UAH) research organization in 2021. This paper is part of a series of annual updates about PRC strategic goals, research activities, research capabilities, and history. The past PRC overview papers include a summary of the first 13 years of operations in 2004 [1], a 25th anniversary review in 2016[2], an overview of nine technical research areas in 2017[3], a description of fifteen laboratories in 2018[4], our recent strategic plan in 2019[5], and a review of 29 years of graduate student production in 2020[6]. This paper highlights PRC faculty and student refereed publication production covering the last 30 years. For this paper, the works are cross-referenced by the faculty or staff authors of those publications. This paper also summarizes recent PRC research metrics and academic programs at the Mechanical and Aerospace Engineering Department at UAH.

A. PRC Mission and Strategy

The mission of the PRC is to provide an environment that connects the academic research community with the needs and concerns of the propulsion community, while promoting an interdisciplinary approach to solving propulsion problems. Individuals and groups within the university collaborate to achieve the PRC's research goals. Researchers from government laboratories, other universities, small businesses, and the aerospace industry also collaborate with the PRC. This environment produces leading-edge research results and scholarly activity leading to new discoveries and significant workforce development.

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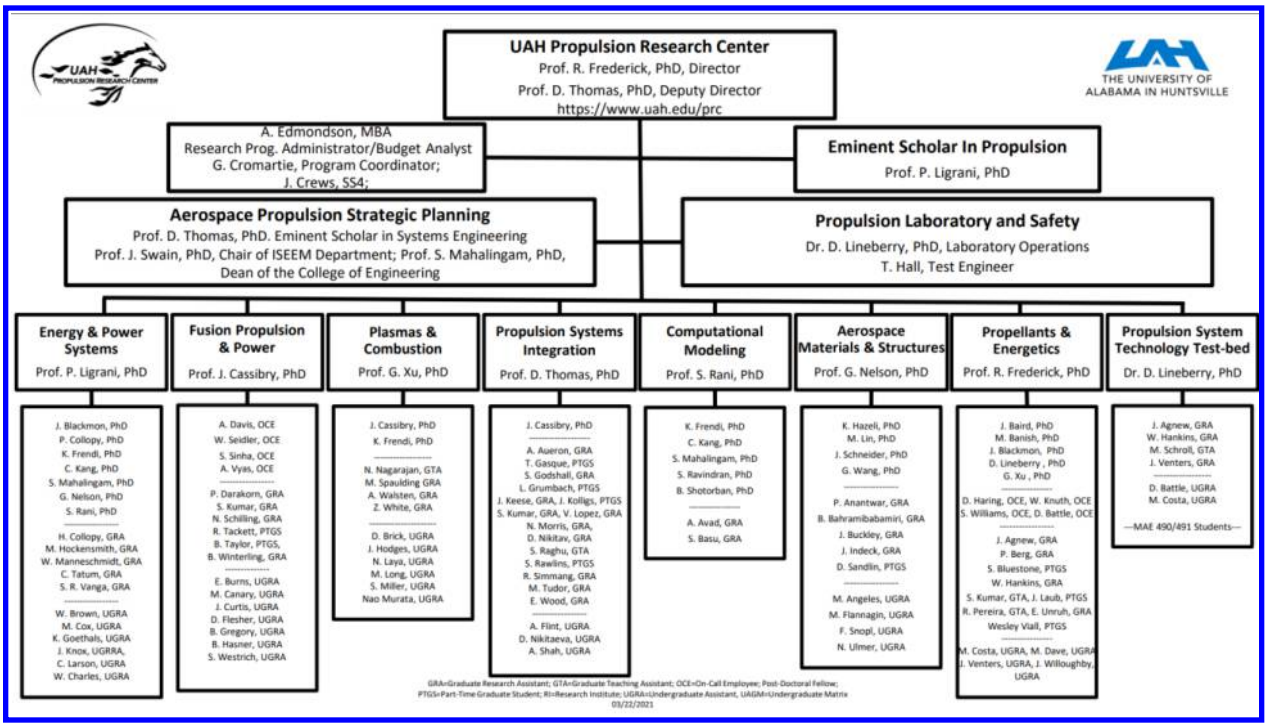

Fig. 1. The 2021 PRC Organization Chart.

Figure 1 shows the current PRC Organization Chart. Research centers at UAH are interdisciplinary business units that focus on specific technical disciplined areas. The Propulsion Research Center is an assembly of faculty, students, and support staff who work in research teams on projects related to propulsion and energy topics. Each box in Figure 1 represents a research topic area in the organization. Currently, there are over one hundred faculty, staff, and students associated with PRC research activities.

The PRC Director, Dr. Robert Frederick, oversees all operations and leads a research group in Propellants and Energetics. The PRC Deputy Director, Dr. L. Dale Thomas, advises in strategic planning and is the Eminent Scholar in Industrial and Systems Engineering, the Director of the Alabama Space Grant Consortiums, and the leader of his own Propulsion Systems Integration research team. The Eminent Scholar in Propulsion, Dr. Phillip Ligrani, holds a named chair that resides in the Department of Mechanical and Aerospace Engineering. As the Eminent Scholar, he leads his own world-class research team in Energy and Power Systems and promotes the overall academic quality of research in the center.

The PRC staff includes Program Administrators/Budget Analysts who manage administrative/fiscal items, a Senior Researcher, Dr. David Lineberry, who directs Laboratory Projects, Safety, and Testing, and a Test Engineer, Mr. Anthony Hall, who oversees laboratory operations at the UAH Johnson Research Center. Figure 1 also shows eight technical topic areas ranging from Energy and Power Systems to Propulsion Systems Technology Test-bed. Each of these eight areas has a lead person/principal investigator, in most cases a faculty member, identified as a point of contact. Participating faculty principal investigators, staff, graduate students, and undergraduate students who are active in projects or in independent research are shown in each area. The research areas emphasize the participation of graduate and undergraduate research assistants.

B. PRC Graduate Student Production Summary

The first overall metric presented is graduate student production. Figure 2 shows the cumulative production of Master's and PhD. degrees supported by the UAH Propulsion Research Center. To date there are 71 Ph.D.'s and 216 Master's degrees accumulated, totaling 287 since 1991. Table 1 shows the citations for the most recent Master's Theses and Ph.D. Dissertations. Most of the students who receive advanced degrees are in the UAH School of Mechanical and Aerospace Engineering. A compilation of the theses and dissertations for the first 29 years was presented in reference [6].

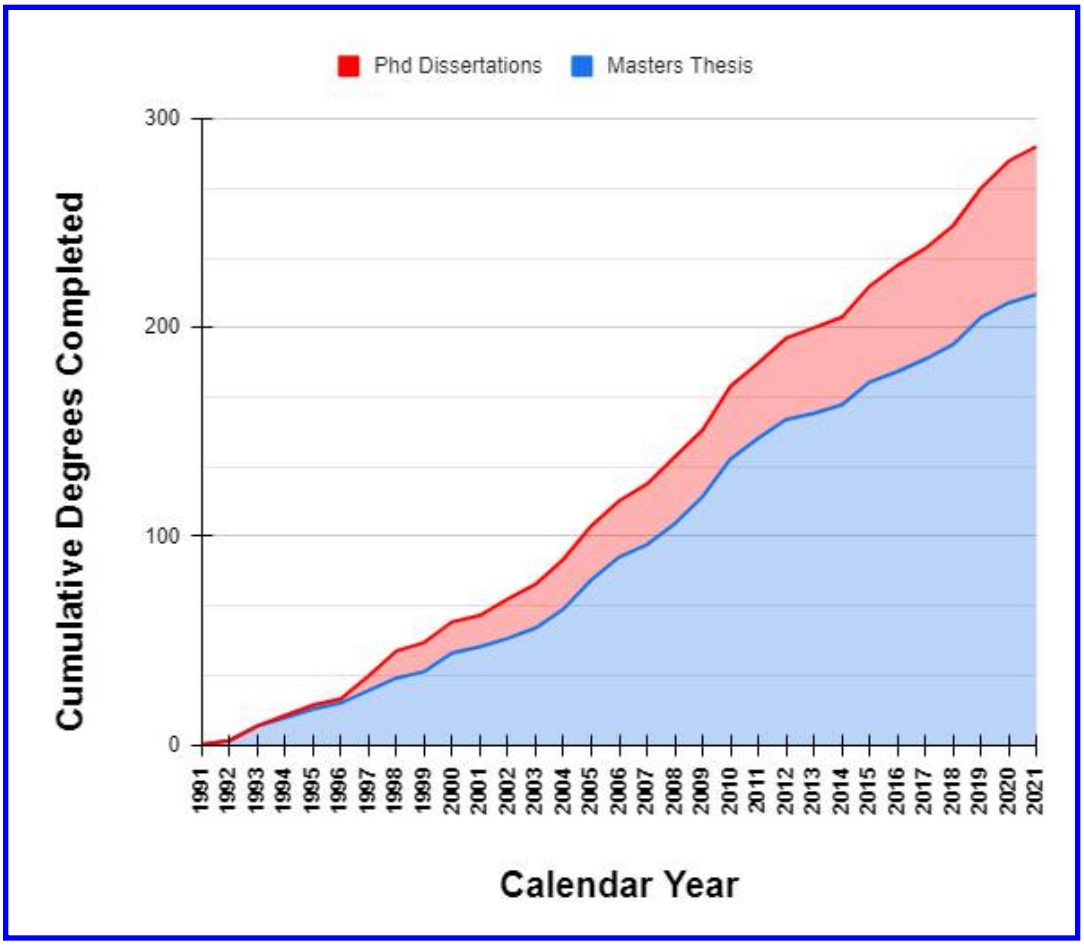

Fig. 2. Cumulative number of master's and Ph.D. degrees completed.

Table 1 - Recent theses and dissertations by calendar year.

Thesis and Dissertations for 2020 and 2021

Area	Citations
Master's Thesis 2020	[7–13]
Master's Thesis 2021	[14–17]
Dissertations 2020	[18–23]
Dissertations 2021	[24–27]

C. PRC Research Expenditure History

Figure 2 shows the annual research expenditures from external sources for the UAH Propulsion Research Center since its inception in FY 1991 through a projection of FY 2021. The average annual expenditure level of the entire period is $1.6 million dollars per year [not accounting for inflation]. The periodic "surges" in funding generally represent the growth and completion of significant research programs or with a particular major sponsor. FY 20 saw a 33% increase in research expenditures. FY 21 anticipates a slight decrease in the current year, with a projection of $3,000,000. The overall research portfolio has increased by 282% since FY 2008. The research expenditure numbers do not include cost shares, internal university research funds, state provided operating funds, or UAH Foundation investments into the PRC.

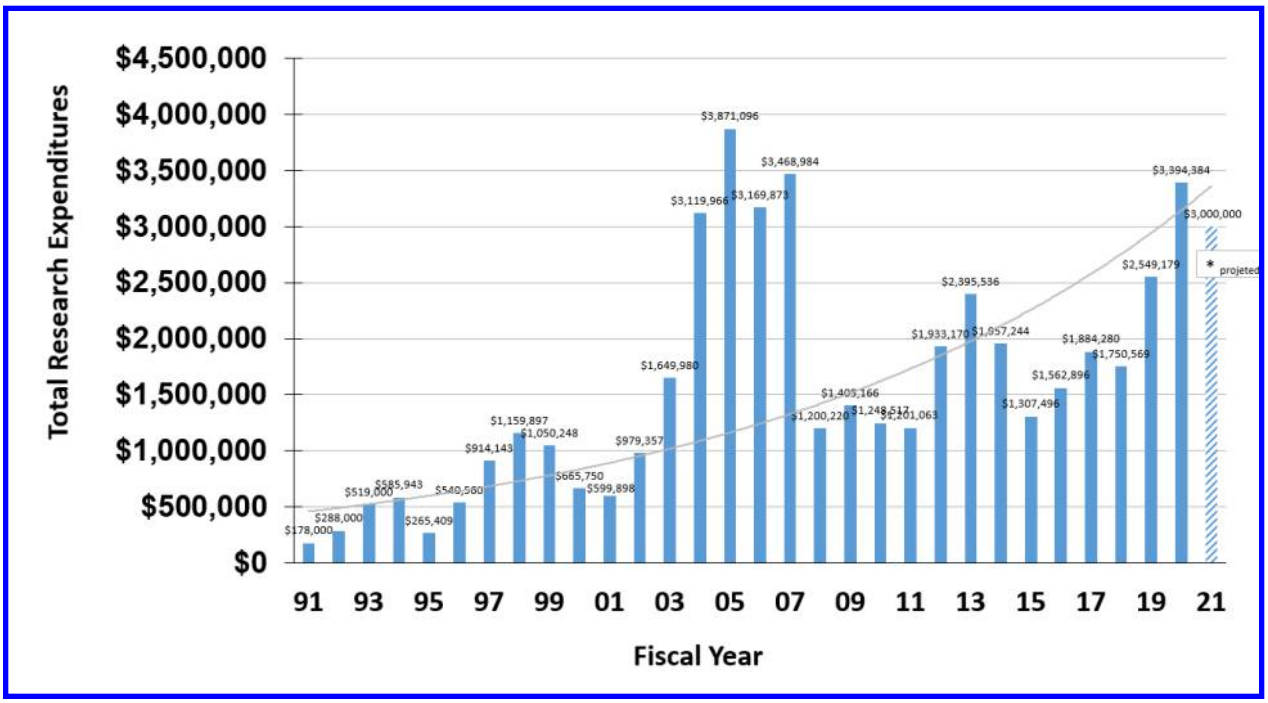

Fig. 2. Research expenditures distribution by FY.

D. PRC Refereed Publication History

This year, the PRC started compiling the 30-year history of refereed publications associated with PRC researchers. The PRC team gathered the propulsion-related refereed publications, patents, and book chapters of the various researchers who have brought their expertise to the center over the past 30 years. Table 3 shows the results.

Because of time limitations, the results this year are presented without further analysis or technical discussion. The initial search produced 422 refereed publications, patents, or book/book chapters. In some of the earlier cases, the compilation of works is still in progress. Although the results presented span 30years, the tenure of individual researchers working at UAH varies from person to person. The PRC will update this list next year and provide some discussion of the various technical areas covered.

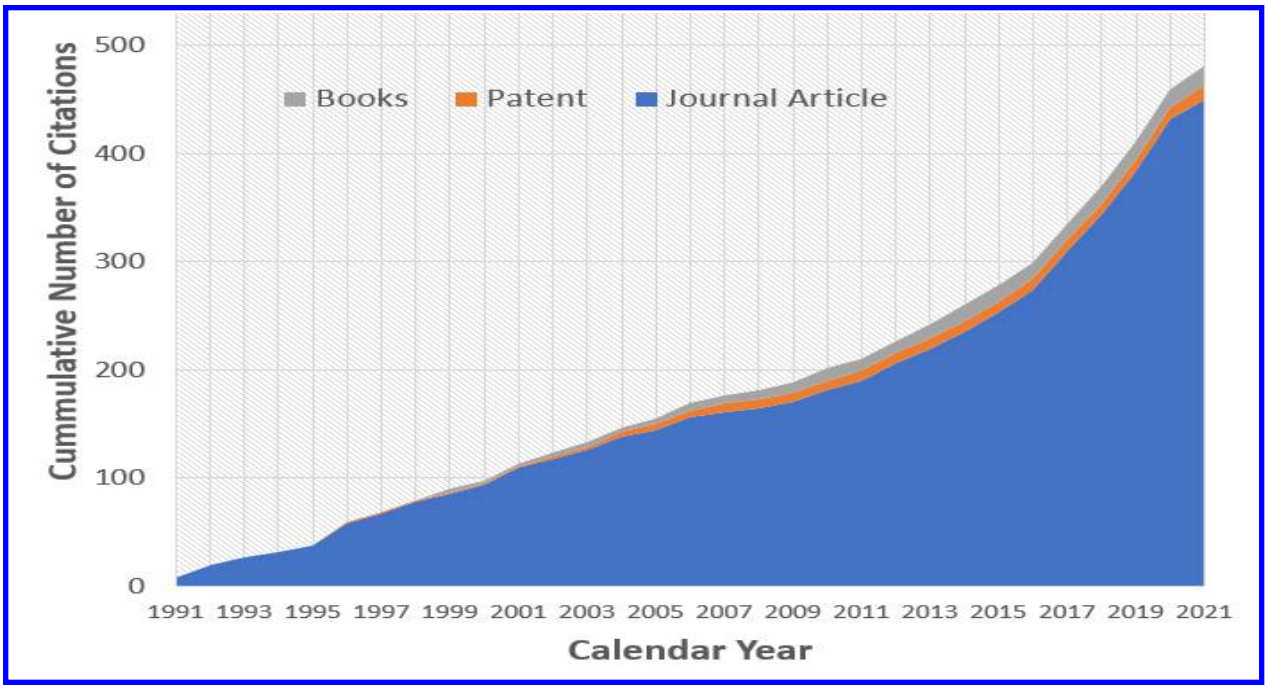

Fig. 3. Cumulative Refereed Publications for the UAH Propulsion Research Center

Table 2. PRC Refereed Publications indexed by faculty or staff researcher (1991 -2021)

PRC Affiliated Researcher	Archival Propulsion-Related Publications
Dr. James Baird	[28–40]
Dr. Mike Banish	[41–47]
Dr. James Blackmon	[48–63]
Dr. Jason Cassibry	[64–100]
Dr. C. P. Chen	[30,64,74,101–114]
Dr. Coleman	[115–132,132–200]
Dr. Robert Frederick	[32–34,36,38–40,144,145,169,171,179,199,201,201–227,227–232]
Dr. Kader Frendi	[233–259]
Dr. Clark Hawk	[142,164,185,260–272]
Dr. Kavan Hazeli	[103,273–284]
Dr. Keith Hollingsworth	[285–287]
Dr. C-K Kang	[288–292]
Dr. D. Brian Landrum	[109,156,266,271,289–291,293–303]
Dr. Phillip Ligrani	[285,286,304–356]
Dr. David Lineberry	[109,153,182,187,201,201,209,216,227,227,357]
Dr. Marlow D. Moser	[71,83,179,206,213,217,222,232,263,358–361]
Dr. George Nelson	[83,113,362–373]
Dr. Sarma Rani	[201,201,227,227,245,259,374–401]
Dr. Judy Schneider	[95,111,359,402–412]
Dr. L. Dale Thomas	[29,74,85,93,247,267,287,303,413–426]
Dr. Gang Wang	[28,113,427–436,239,437–444,248,250,257,277,305,418,424]

II. Academic Infrastructure

A. Mechanical & Aerospace Engineering Enrollment

The MAE undergraduate programs currently consist of accredited Bachelor of Science degrees in Mechanical Engineering (BSME) and Aerospace Engineering (BSAE). Figure 4 shows the evolution of student enrollment in these degree programs since the inception of the Propulsion Research Center. During the decade of the 1990's, the Alabama Commission on Higher Education (ACHE) collectively designated the UAH College of Engineering (COE) degrees as a Bachelor of Science in Engineering (BSE) with concentrations in specific majors such as Mechanical Engineering or Electrical Engineering. However, each of the degree majors were also nationally ABET accredited. In 1993, an Aerospace Engineering option under the BSE ME concentration was authorized by ACHE. This program option was required to meet the ABET standards for both ME and AE and was often identified as the "MAE degree." The new AE option spurred a modest 2% average yearly growth rate in undergraduate enrollment during this time period with a 13% increase in total BSE ME (including the AE option) degree enrollment.

In response to recommendations from the 1995 Base Realignment and Closure Commission (BRAC), Army Aviation research and development personnel were moved from St. Louis and combined with Army Missile Command (MICOM) personnel to form the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) in 2000. Between 2004 and early 2010, Marshall Space Flight Center was responsible for developing the propulsion systems for the Ares I crew launch and Ares V heavy-lift launch vehicles as part of the Constellation Program. These and other events and activities produced numerous aerospace employment opportunities. These are reflected in a yearly MAE undergraduate enrollment growth of ≈ 10% and a total enrollment increase of 129% during the decade of 2000 to 2010. Figure 4 shows this period of significant enrollment growth plateau around 2010 which correlates with a drop in aerospace employment as a result of the Great Recession of 2007 to 2009.

Undergraduate MAE enrollment has undergone an even more exponential growth during the decade of 2011 to 2020. As Fig. 4 shows, the ME cohort has grown steadily at ≈ 2.5% per year. A significant event occurred in 2014 when the Aerospace Engineering program was designated as an independent BSAE degree by ACHE and received its first independent accreditation by ABET. Since 2014, the AE undergraduate enrollment has experienced an average yearly growth of 19% and a total enrollment growth of over 200%. The growth in BSAE students, starting in 2014, has reshaped our undergraduate profile. The BSAE student enrollment of 772 and BSME enrollment of 695 combined for a total MAE undergraduate student enrollment of 1467 in fall 2020. The UAH BSAE and BSME programs are, respectively, the largest and third-largest undergraduate programs on campus, and the MAE department makes up 15% of the total UAH student population.

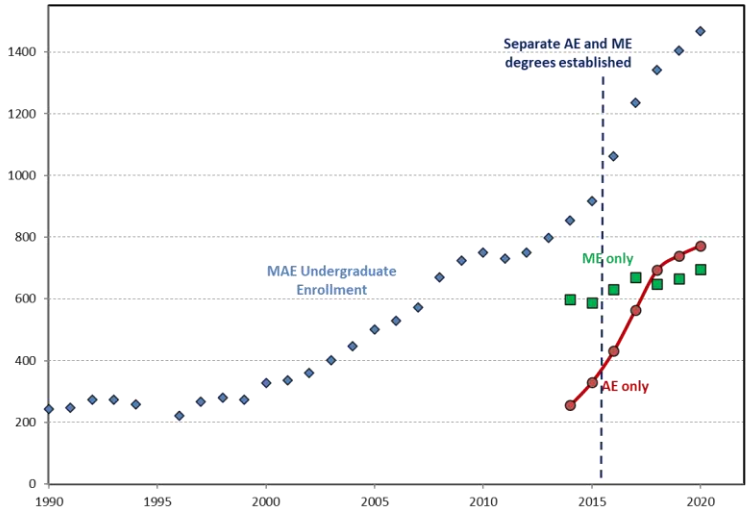

Fig. 4 Undergraduate student enrollment in the AUH Department of Mechanical and Aerospace Engineering between 1990 and 2020. MAE is total enrollment. Beginning in 2014, ME and AE are separate degree programs.

The MAE graduate enrollment growth between 1990 and 2020 is shown in Fig 5. Periods of significantly increasing and decreasing enrollment are shown. Unlike undergraduate enrollment, declines in graduate enrolment are often linked to periods of high employment which reduce the interest in graduate education. For example, the significant decrease in MAE graduate enrollment during 1991 to 1995 is possibly due to stable employment opportunities. Conversely, there was a significant increase in MAE graduate enrollment during the Great Recession of 2007 – 2009 when aerospace related jobs in Huntsville and nationally were in decline. Other factors have also impacted graduate enrollment. Between 2008 and 2011, MAE offered specialty MSE AE degree programs emphasizing rotorcraft and tactical missile design for AMRDEC sponsored employees. These programs contributed to the growth in AE graduate enrollment during this time period. The MAE graduate student population still consists of a majority of part-time MSE students. The decreases in graduate AE and ME enrollments beginning around 2013 appear to be correlated to local aerospace employers (commercial and government) reducing tuition assistance benefits for advanced degrees.

In 1990, the MAE department offered a Master's of Science in Engineering in Mechanical Engineering (MSE ME) degree and a Doctor of Philosophy in Mechanical Engineering (PhD ME) degree. With the increased emphasis on aerospace propulsion and an influx of new aerospace-related faculty in the MAE department, a Master's of Science in Aerospace Engineering (MSE AE) degree was established in 1992. A Master's of Science in Aerospace Systems Engineering (MS ASE) was established in 2011. A Doctor of Philosophy in Aerospace Systems Engineering (PhD ASE) was also established in 2011, the first time an aerospace related doctoral degree was offered at UAH. The recent trend has been toward more graduate students in the Aerospace Systems Engineering program and fewer in the Mechanical Engineering program. This is a reversal of the opposite trend that was in place from 2008 to 2015. However, the ME graduate enrollment has also began to rebound in 2018. Much of this increased interest in ASE and ME related graduate degrees, as well as undergraduate enrollment, can be attributed to the high-profile growth of the commercial space industry. As of 2020, the MAE Graduate Student enrollment was 199 with 119 ASE students and 80 ME students. As the MAE research activity grows, the proportion of the graduate student population has also shifted more to full-time research-active students.

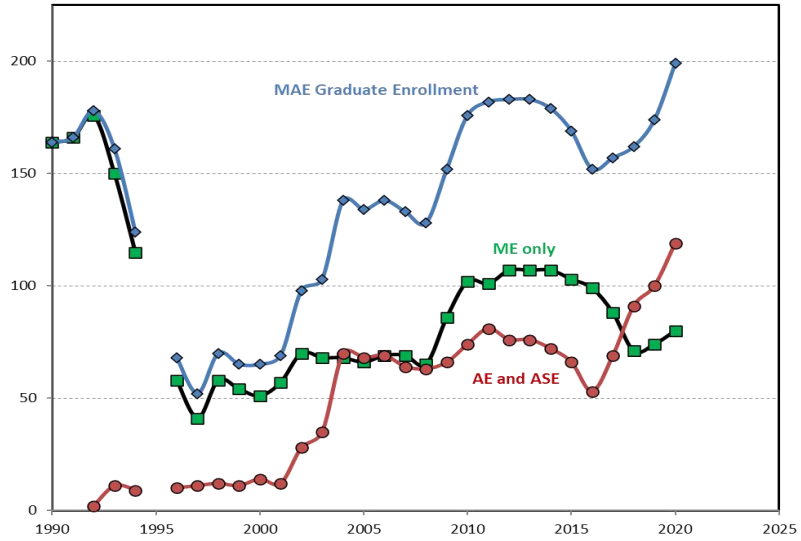

Fig. 5 Graduate student enrollment evolution in the UAH Department of Mechanical and Aerospace Engineering between 1990 and 2020.

The MAE full-time faculty count now stands at 25. Nineteen are tenure-track; two are non-tenured Clinical Associate Professors, and four are full-time lecturers. MAE also employs around eight adjunct instructors each term from the Huntsville engineering and research community. In fall of 2019, a new junior faculty member joined MAE in the area of control of autonomous flying vehicles, and a new full-time lecturer joined in fall 2020. However, one Clinical Assistant Professor retired in spring 2021 and a tenured professor is leaving for another university position this summer. The COVID-19 pandemic has affected the Department in several ways. Hiring of two Assistant Professors was cancelled in spring 2020. Although the MAE undergraduate enrollment actually grew 4.51% between fall 2019 and 2020, the fall 2021 undergraduate enrollment is expected to decrease several percent from fall 2020. This will be a deviation from the rapid growth experienced in the last six years.

A. UAH Rocket Propulsion Course Enrollment

The University of Alabama in Huntsville (UAH) has a rich rocket propulsion heritage. Dr. Werner Von Braun and other community leaders facilitated state funding for the expansion of The University of Alabama in Huntsville to attract and further develop the workforce for the U.S. Space program. On June 20, 1961, Dr. Von Braun remarked, "It's not water, or real estate, or labor, or cheap taxes that bring industry to a state or city. It's brainpower." Over the past 30 years since the founding the UAH Propulsion Research Center, MAE 440/540 (Rocket Propulsion I) and MAE 640 (Rocket Propulsion II) in various forms have supported undergraduate and graduate degree programs in what is now The Department of Mechanical and Aerospace Engineering at the University of Alabama in Huntsville. In fact, as shown below, "Applied Aerodynamics and Propulsion," was in the 1968 UAH Course Catalogue.

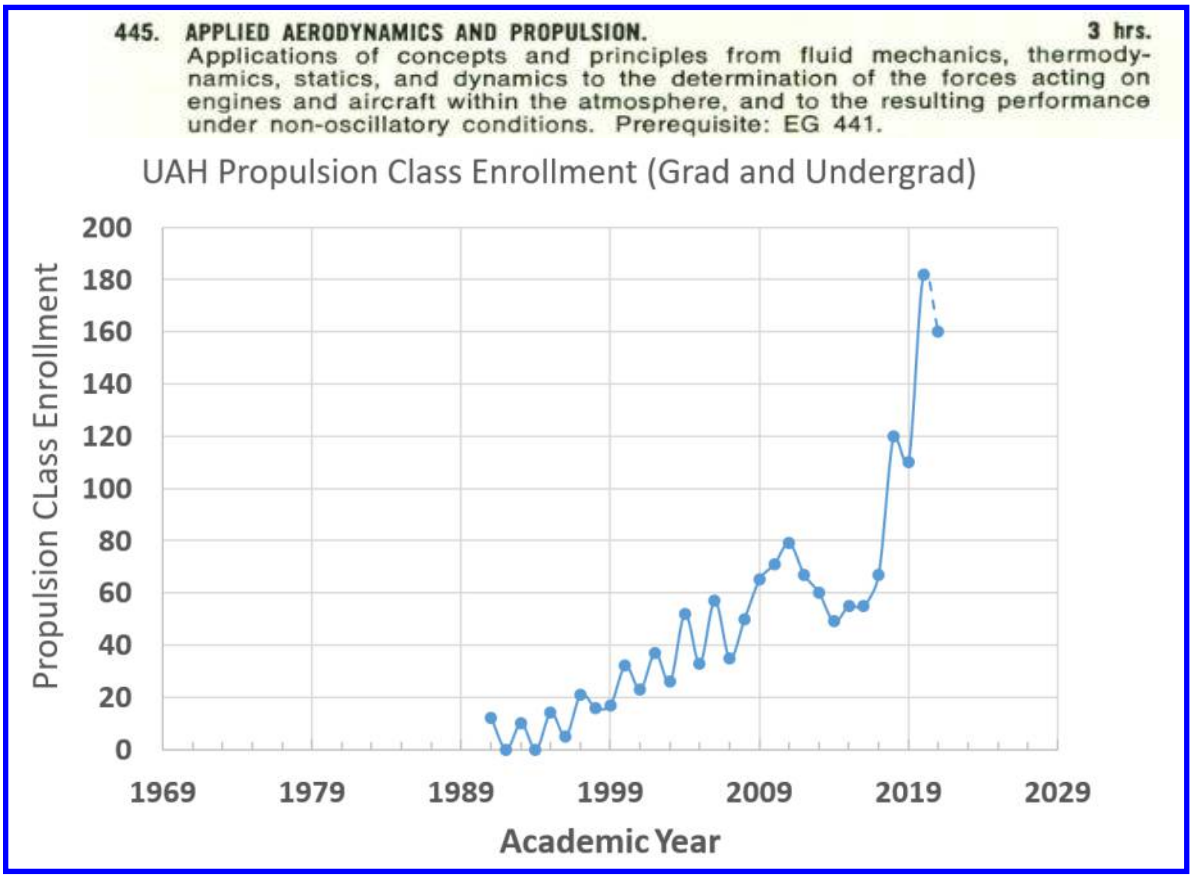

Fig. 4. Enrollment trends for The UAH Department of Mechanical and Aerospace Engineering.

Dr. Robert Frederick and several others have taught propulsion courses for the past 30 years (with many before them) using various textbooks and instructional modes. The 3-hour Rocket Propulsion II, (Currently MAE 640) course has grown from 12 students in academic year (AY) 91-92 to 51 students in AY20-21. The 3-hour undergraduate propulsion course with an associated 1-hour laboratory started in AY95-96 with two students in each as the department transitioned from Mechanical Engineering (ME) to Mechanical and Aerospace Engineering (MAE) in scope. The initial 3-hour undergraduate propulsion course covered both rocket and air-breathing propulsion using textbooks first by Hill and Peterson and then Archer. The one-hour Propulsion Laboratory was a co-requisite to provide hands-on experiences. The propulsion laboratory was phased out in AY08-09 when enrollment reached 45 students in the lab. The growing overall enrollment in the MAE department and the aerospace concentration made it impractical to staff.

As the aerospace concentration grew, the undergraduate course was then divided into a separate 3-hour rocket and a 3-hour air-breathing propulsion course in AY06-07. The rocket course was renamed MAE 440/540 adding a 500-level graduate student version. This dual-level approach allowed both the undergraduates and graduate students to attend the same lectures with the graduate students having extra material to fulfill their course requirements. The

subsequent undergraduate and graduate rocket courses eventually used the current editions of Sutton et al. as the textbook.

In AY06-07, the MAE 540 section of the course also added a distance learning section. Students enrolled in distance learning received videos of the classroom lectures, submitted work remotely using online tools, and had options to take proctored exams remotely. The distance-learning students received a recorded version of the in-class lecture to allow remote access to the course without substantial course design revisions for the online instruction. Enrollment in the undergraduate course and subsequently the dual-level course has grown from 2 students in AY95-96 to a projected enrollment of 160 students for AY21-22 as the Mechanical and Aerospace Engineering Department (now with an accredited aerospace degree) has also grown at UAH.

III. Final Remarks

The UAH PRC stands poised to build upon a rich legacy of research advances in propulsion. One of our original strategies was to pursue funding support for projects that would support students. The faculty associated with the PRC have followed that vision are anticipated to produce 300 graduates with advanced degrees on propulsion topics in the first 30 years. If we also project 30 years of total expenditures at $50 million, that averages to about $170,000 per degree. The strategy forward will focus on continuing a legacy of excellence in traditional student production in the propulsion arena, equipping the future workforce for success in their future careers.

Acknowledgments

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