The Guggenheim Schools of Aeronautics: Where are they today?

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Introduction

The purpose of this paper is to present a brief summary and history of the seven original Guggenheim schools. Between 1925 and 1930, the family of Daniel and Harry Guggenheim invested more than $2.6 million in aviation-related programs at Universities around the United States. During this period, funding was given to New York University, the California Institute of Technology, Stanford University, the University of Michigan, the Massachusetts Institute of Technology, the University of Washington and the Georgia School (later Institute) of Technology to establish Guggenheim schools of aeronautics. In addition, Harvard University, Syracuse University, Northwestern University, and the University of Akron were given funds to establish research centers. Of the original seven Guggenheim schools, all have active aeronautics programs except New York University, which dropped its aeronautics program in 1973. The remaining six generally rank as top aerospace programs in the country. This paper reviews the history of the Guggenheim schools and research centers, and discusses how the original contributions have led to the existing programs of today.

History of the Guggenheim Schools

Daniel Guggenheim[1,2] was the grandson of Jewish immigrants from Switzerland. Following his father Meyer, Daniel expanded the growing smelting and mining business into a global enterprise. By the turn of the 20th century, the Guggenheims were well established and wealthy. In 1923, the largest asset of Guggenheim Brothers was sold, leaving Daniel to explore philanthropic interests. Daniel's son Harry became interested in flight[3]. Recruiting a team of fellow Yale students, Harry set up a flight club. On Sept. 14, 1917, the Navy commissioned Harry as a Lieutenant, at first in navigation. Harry continued flying after the war. It was this interest in flying and a fledging program at New York University that led Daniel to set up what became known as the Guggenheim Schools of Aeronautics[4].

In the early 1920s only five schools offered courses in Aeronautics. The Massachusetts Institute of Technology (MIT), under the leadership of Jerome Hunsaker[5], and the University of Michigan, under Felix Pawloski, each had degree programs in aeronautical engineering. The California Institute of Technology (Caltech), University of Washington and Stanford University offered special courses in the new field. The courses at the University of Washington were offered in an agreement with William Boeing in exchange for donating a wind tunnel to the University.[6] At New York University in 1923, two mechanical engineering faculty, Prof. Collins Bliss and Prof. Alexander Klemin, who studied under Hunsaker at MIT, began offering students an

elementary aerodynamics class. In 1924 an experimental program was approved by the University. The program was a success and it was decided to make it permanent. However, to do so, external funding estimated at $500,000 was required. Harry worked with NYU Chancellor Elmer Ellsworth Brown to locate funds. Harry took a letter to present to his uncles, but showed it first to his father. Daniel's response was to fund the new program himself. On June 15, 1925, Daniel Guggenheim announced his gift of $500,000 to NYU for a laboratory building with a wind tunnel, a propeller laboratory and other labs, as well as hiring laboratory assistants. An oversight committee was formed by Chancellor Brown and Orville Wright was selected as its head. On October 23, 1925 ground was broken on the NYU Guggenheim School of Aeronautics, which opened a year later.

The Daniel Guggenheim Fund for the Promotion of Aeronautics, under Harry Guggenheim's direction, went forward with a plan to fund $2,500,000 in gifts to assist in aviation development[7]. Following the NYU gift, the plan was to expand into other universities. It was decided to focus on those universities that already had fledgling aeronautics programs[8]. The first endowments after NYU went to west coast schools, Stanford and Caltech. It was believed that assisting programs in the West would help foster aeronautical education in that region. The recent Nobel Laureate, Dr. Robert Millikan convinced Harry Guggenheim to fund Caltech because of its excellent reputation in physics and its proximity to some major aircraft companies, most notably the Douglas Aircraft Company. The Caltech proposal was for $500,000 but was funded at $305,000. One of the most notable accomplishments was luring Theodore Von Karman from Aachen, Germany to head the new Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT). (Note: in 1961 GALCIT was renamed the Graduate Aeronautical Laboratory, keeping the acronym intact.) Stanford's driving force in aeronautics research was Dr. William Durand. Durand managed to get Stanford to build a wind tunnel suitable for testing propellers. As a result, some of the most significant work for the NACA was being performed at Stanford. Stanford asked for $330,000 and received $195,000 which was funded simultaneously with Caltech so the schools would not compete for students if one received funds before the other.

The University of Michigan was selected because of its advanced program in aeronautics. Aeronautics was its own department in 1916 and they were the first to award degrees in Aeronautics. What Michigan wanted from the fund was research Professorships, research assistants and equipment. They were given a grant of $78,000.

At MIT[9], Prof. Charles Taylor, formerly the chief engineer at the Wright Aeronautical Corporation, and builder of the Wright 1903 engine, sought funds for engine research, specifically gas turbine research. But, what MIT eventually requested and received was $230,000 for a building to house classrooms and offices. However, a grant from General Motor's Alfred Sloan and Henry Crane added $85,000 for an engine laboratory. At this point, the Guggenheims realized that the Northwest and Southeast were lacking programs. The University of Washington had a small program started in 1916, but it hadn't caught on. Prof. Fredrick Kirsten revived interest and started teaching courses in aeronautics again. An agreement was worked out where the Guggenheim

funds would pay for construction of a new building if the State of Washington supplied the funds to equip the building. Thus, the University of Washington was given $290,000 for a new building that became the home of the Dean of Engineering, as well as several other departments, including Aeronautical Engineering.

Putting a Guggenheim school in the south was a little more difficult as no school was teaching aeronautics at the time. The two main choices were the University of Alabama and the Georgia School of Technology. Georgia Tech's record of training Army engineers and aviators since WWI was probably the deciding factor, and it was with the initiative of Army officers deputed to the Guggenheim Foundation, that the final school selection was made[10]. A grant of $300,000 was used to construct a building around a nine-foot wind tunnel and invest in bonds for the future. In the following sections more details on the evolution of each of the seven schools to their present state will be presented.

New York University

As mentioned in the introduction New York University (NYU) was the first Guggenheim School, and the recipient of the largest grant. NYU developed excellent facilities and was a renowned center for years. In the 1940's it was joined by its cross-town rival and collaborator the Polytechnic Institute of Brooklyn[11]. The collaborative relationship proved important, when in 1973, NYU decided to eliminate its engineering program. This decision was not a reflection on the programs in engineering, but rather a poorly conceived notion about the future of engineering in an economic downturn, by the University's administration. Most of the faculty and labs were transferred over to the Polytechnic Institute of Brooklyn and the name was changed to the Polytechnic Institute of New York (PINY). NYU, the first Guggenheim School, became the only program to fail to continue to the present day. However, a perceived need by NYU to reengage in engineering has led to the transferring of PINY to NYU being given the name Polytechnic Institute of New York University.

California Institute of Technology

The Guggenheim building at CalTech was completed in 1928, with a $305,000 grant from the Guggenheim Foundation for a graduate school and laboratory in aeronautics, built around a 10-foot low speed wind tunnel designed by Louis Klein[12]. Arthur Emmons Raymond, Chief Engineer of Douglas Aircraft from 1925 to 1960, joined in 1927 as an Assistant Professor of Aeronautics, started teaching a Saturday class on airplane design to a class including Theodore von Karman, Arthur Louis Klein, Bateman, Clark Millikan, Sechler and Merrill. Clark Blanchard Millikan, starting with a Physics PhD on steady viscous incompressible flow, developed the wind tunnel along with Klein. Early work studied the effect of turbulence on lift, similarity in turbulent boundary layers and pipe flows, propeller slipstream effects, and the development of multi-engine high-altitude airplanes. GALCIT was rebuilt after WWII. Theodore von Karman[13], originally invited to review plans for the wind tunnel, joined as a research associate in 1929, and served as Professor of Aeronautics and the first Director of GALCIT from 1930 to 1949. In 1936, a GALCIT team carried out rocket tests, and were called the "Suicide Squad". Their work led to the establishment of the Jet Propulsion Laboratory later. The GALCIT approach to

teaching and research has been described by Professor Y.-C. Fung as "finding a simpler way to deal with complex problems, guided and checked by experiment rather than theory alone"[14].

The 2.5 inch supersonic tunnel designed by Tsien and Serrurier opened in 1941 and became the first continuously operated American tunnel to exceed Mach 4. "GALCIT Project No. 1" developed Jet Assisted Takeoff, using rockets to reduce aircraft takeoff distances by up to 50%, and led to von Karman establishing Aerojet Corporation to manufacture JATO devices for the Air Force. Frank Joseph Malina gave the first theoretical demonstration that long-duration solid rocket propulsion was possible, and became the first director of the Jet Propulsion Laboratory, leading the effort to build the WAC Corporal rocket. In 1949, Clark Millikan became the second Director of GALCIT, and the Daniel and Florence Guggenheim Jet Propulsion Center was established, with Robert H. Goddard Professor Hsue-shen Tsien, a 1939 PhD from von Karman's group, as first director. A 5 x 5 inch hypersonic tunnel reaching Mach 11 was set up as an extension to the Guggenheim building, and operated until 1970. Among his many significant accomplishments at GALCIT, Professor Tsien discovered similarity laws on supersonic and hypersonic flows, designed the first GALCIT supersonic tunnel (2.5 inch, 1941), and was a valued advisor to the US military in WWII. The McCarthy Hearings in 1955 forced him to leave the US and settle in China, where he pioneered the missile and space program. The Karman Laboratory of Fluid Mechanics and Jet Propulsion was dedicated in 1961 with funding from Aerojet Corporation, which was established by Theodore von Karman to manufacture JATO kits for the Air Force. In 1961, the California Institute of Technology renamed its Guggenheim School of Aeronautics to the Graduate School of Aeronautics, keeping its acronym GALCIT. It is still housed in Guggenheim Hall. In 2002, The John Lucas Adaptive Wall Wind Tunnel replaced the 10-foot wind tunnel. In 2001, an 8x8 in Ludwieg Tube capable of Mach 2.3 was commissioned. The Less-Kubota Lecture Hall replaced the old Guggenheim Aeronautics Library.

Recent research at GALCIT has focused on the structural mechanics of low-mass structures for space applications and stratospheric balloons, photonic crystals, nanomaterial characterization of carbon in sedimentary rocks, transport, phase change and wave phenomena in thin films, microfluidic devices, morphing surfaces, and bio-inspired propulsion. The Keck 40-Meter Flume was renovated in 2007. The Small-Particle Hypervelocity Impact Facility was established in 2005, capable of studying impact at 2 to 10 km/s. On September 25-28, GALCIT celebrated their 80th birthday. The Guggenheim building was re-opened on September 26th after a second phase of renovation, that created new lab space for research and education. In keeping with the "GALCIT" tradition, CalTech does not have an aerospace engineering undergraduate program.

Stanford University

The founding of Stanford's Aeronautics program was mostly due to the efforts of William F. Durand[15]. Durand was a hydraulics engineer who was largely responsible for the design of the water supply to much of the west. Durand had an interest in flight and, in 1915, offered the second aeronautics course in the nation, following MIT. He was then

recruited to be the first civilian chairman of the NACA. In 1917, Durand served as a military attaché in Paris and befriended Harry Guggenheim. This connection led to the appointment as a Trustee of the Daniel Guggenheim Fund for the Promotion of Aeronautics. Durand teamed with another Stanford engineer, Everett Parker Lesley, to research aircraft propellers. With a $4000 NACA grant, Durand and Lesley build a wind tunnel and created an extensive data base of propeller performance.

In 1927, Stanford submitted a proposal to the Guggenheim Foundation. This actually became an awkward moment for the new Foundation. It was decided to support a West Coast school and Caltech, with the draw of Dr. Robert Milliken, whose son, Clark, had pursued the study of aeronautics, was to be the new site. But, with Durand as a Trustee of the Fund, and the now renowned propeller work, Stanford put in a strong proposal. The Foundation decided to fund the two schools simultaneously. In addition to building a laboratory, Stanford hired two faculty with the Guggenheim support. They were Elliot Reid, recruited from NACA Langley, an expert in aerodynamics and airplane design, and Alfred Niles, recruited from Hope Field, OH, a structures expert.

Over the years Stanford built a strong reputation in all areas of Aeronautics. In applied Mechanics Stanford recruited Stephen Timoshenko. Timoshenko, in turn, trained Nicholas Hoff, who went on to head the department at Brooklyn Polytechnic before being recruited to return to head a revitalization of the Aeronautics program at Stanford after the original members of the Guggenheim era had past on. This revitalization resulted in the formation of the Division of Aeronautics, in 1957, which, in 1959, became the Department of Aeronautics, and, in 1961 added Astronautics to its name. The Department had a graduate student-only focus. Hoff brought in leading people from industry and the NACA's new Ames facility to grow programs in aerodynamics and gas dynamics. He also created a link with Prof. Hans Leipmann at Caltech, hiring three of his former students. In controls, Hoff brought in Robert Cannon from MIT, who eventually brought in a world leading team in controls.

By 1970 the Department of Aeronautics and Astronautics had moved into the new Durand building. By this time, Stanford was out-producing even MIT with Ph.D.s in aeronautics and astronautics. Stanford has never awarded undergraduate degrees in Aeronautics and Astronautics. Undergraduates can minor in Aero/Astro, or receive a BS in Engineering with an interdisciplinary major in Aero/Astro. The MS program at Stanford requires 45 credits, which is a full load for three quarters, or one academic year, and a no thesis requirement. This degree format is very attractive to industry, where an employee can take a 9 month leave and obtain an MS degree. Industry supports a fair number of the Master's students as a result. The close proximity to NASA Ames fosters an interaction that helps Ph.D. candidates have access to some of the best resources in the world. Stanford's reputation is outstanding, usually ranking in the top 3-5 Aeronautics and Astronautics Departments. In an amusing twist, Stanford has been ranked as high as 5th in undergraduate Aero/Astro education despite not having an undergraduate program.

University of Michigan

Michigan claims the nation's first college program in aeronautics, begun in 1914 by Professor Felix Pavlowski, who joined in 1913, and Professor Herbert Sadler who had started the Michigan Aero Club. The early culture was one of flight experimentation with balloons, gliders and powered craft. The Guggenheim Foundation made a $78,000 grant to University of Michigan to establish an 8-ft wind tunnel and a Chair of Aeronautics on October 1, 1926. The original wind tunnel had an 8 ft test section[16]. Today the largest of the 10 wind tunnels operated by the Gas Dynamics Laboratory is the 5' x 7' Low Turbulence tunnel, built in a joint effort with the Air Force in 1956. There are also a 4" x 4" variable Mach number tunnel and a 2' x 2' open-circuit low speed tunnel. A major recent addition is the Francois-Xavier Bagnoud Building, a 90,000 square-foot complex of classrooms and instructional laboratories, including supersonic and subsonic tunnels, composites laboratory, scientific visualization computing facilities and a large vacuum chamber. Four hardened, blast-resistant rooms follow the school's long tradition of research on explosion and combustion phenomena. Other traditional strengths of the School have been in basic fluid dynamics, structures and materials, controls, and electric propulsion. Today Michigan is usually ranked in the top 2 or 3 aerospace undergraduate engineering programs in the US by the US News and World Report annual rankings.

Perhaps it is an indicator of the School's dedication to basic research that the University purchased Willow Run airfield complex, from where B-24 bombers fresh off the production line lifted off, from the Federal government in 1946 for $1, and then sold it to Wayne County in 1977, also for $1, to become the busy cargo airport it is today. University of Michigan aerospace faculty have also become successful textbook authors, a relative rarity in aerospace engineering research universities with large undergraduate enrollments.

Massachusetts Institute of Technology

MIT offered the first aeronautical engineering courses in 1914. That same year, Jerome Hunsaker, along with an assistant Donald Douglas, built a wind tunnel on the new Cambridge campus of MIT. The undergraduate degree program began in 1926 as an offshoot of the Mechanical Engineering department. The Guggenheim grant supported the construction of a new building to house the program, known to MIT students as "Building 33," but having the formal name Daniel Guggenheim Aeronautical Laboratory.

A decade after completion of Building 33, the Wright Brothers wind tunnel began operation. The wind tunnel was pressurized and was very active during WWII. The following year, in 1939, the aeronautics program became a separate department. During the 1930's Charles Stark Draper developed course in instrumentation. This laboratory "would become the world's foremost academic center for inertial guidance research and development." During WWII, MIT trained officers for the Army and Navy, like many other schools at the time. After the war, MIT was the largest non-industrial defense contractor, with much of the work of the aeronautics department supporting the military. Labs that grew post WWII were the Gas Turbine Lab, the Aeroelastic and Structures Lab

and the Naval Supersonics Lab, which housed a Mach 2+ continuous wind tunnel. In 1959, two years after Sputnik, the department added Astronautics to its name.

A major educational innovation at MIT came in the early 1970s with "Unified Engineering." This course was a two-semester, 24 credit course that covered statics, dynamics, thermodynamics, solid mechanics, fluids, and propulsion in a single course. The concept was to combine the material to emphasize the systems nature of aerospace engineering. With this integrated approach to presenting the material, it became a natural fit for the ABET 2000 requirements on social impact, ethics and economics. In response to industry concerns that engineering students were becoming applied physicists instead of engineers, MIT revamped its undergraduate curriculum. The result of a two-year overhaul was the Conceive-Design-Implement-Operate (CDIO) educational initiative. Emphasis is towards hands-on learning. Unified Engineering is still a key part of the curriculum, but most core classes have added hands-on labs. Through the years, MIT has maintained a top ranking in Aeronautics and Astronautics with graduates populating many faculty positions across the world.

University of Washington

In 1917, a year after William Boeing incorporated his new airplane company, Boeing approached the University of Washington with a proposal. Boeing wanted trained engineers in this new field, and in exchange of courses taught at the University of Washington, he would fund the construction of a wind tunnel[6]. The Boeing Wind Tunnel would be the first large wind tunnel on the west coast dedicated to aeronautics. It had a 3x3 foot test section, which put it in the class of three east coast tunnels operated by government labs. The UW offered courses for several years, but problems retaining faculty who had many other opportunities, resulted in courses being taught less than anticipated.

The catalyst that changed this pattern was an electrical engineering professor, Fredrick Kirsten. Kirsten was an inventor who developed an interest in aerodynamics. He invented the "cycloidal propeller" which he thought would revolutionize flight. It never worked for airplanes but is used today to propel tugboats in the Puget Sound. Kirsten, with the help of a new University President, Matthew Spencer, wrote a proposal to the Guggenheim Foundation for $450000 in 1927. The following year a more organized proposal was submitted for $290000, which included a new building while the State of Washington would equip the building. Perhaps it helped that Professor John Miller had served as Secretary of the Guggenheim Fund Board of Trustees.

With the Guggenheim support in hand, the UW Department of Aeronautics was established as a separate department in 1929 with the Guggenheim building opening a year later. By Spring of 1930, UW was graduating its first graduates with degrees in Aeronautics and research was growing, especially Kirsten's "Cycloplane". Kirsten needed a large wind tunnel to test his cycloplane and the old Boeing wind tunnel was too small. He obtained a quote from Caltech at $200 a day, which he felt was outrageous. There is speculation that there was no love lost between Kirsten and Von Karman, who knew each other professionally. So, Kirsten put together a proposal for a wind tunnel

which was later named the Kirsten Wind Tunnel as part of the University of Washington Aeronautical Laboratory (UWAL). Completion of the facility just prior to WWII resulted in continual use and an expansion of the department. From the beginning students were hired as crew members, which provided a great hands-on educational opportunity, plus the early networking with industry engineers testing at UWAL.

With the proximity to Boeing, it is no surprise that many UW graduates worked their way up to important positions at Boeing. During the 40's and 50's there was a symbiotic relationship between the two organizations. The University of Washington College of Engineering was not a major research University at this time. A Master's degree was not available until 1948 and the Ph.D. degree was first offered in the 1959-1960 academic year. Then, in the 1960s, as with many Aero departments, the era after Sputnik ushered in a huge expansion and the addition of Astronautics to the name.

The expansion made the UW Aero/Astro department the premiere research department in UW's College of Engineering. The Chair, John Bollard, managed to recruit Abe Hertzberg from the Cornell Aeronautical Laboratory, who was already internationally recognized in high-energy gas dynamics. With the addition of Hertzberg and the efforts of Prof. Victor Ganzer, a new building was funded and built called the Aerospace Research Lab (later changed to the Aerospace and Engineering Research building (AERB). The Aero/Astro department still uses the four buildings funded for aerospace research: the Boeing Wind Tunnel Building (which is on the Historic Register), The Guggenheim Building, The Kirsten Wind Tunnel Building and AERB.

The Aero/Astro program is an upper division program, with the first two years being used for fundamental math and engineering courses. A hallmark of the program through the 1970's and 1980's was the Junior Lab, which was a three-quarter laboratory sequence required of all juniors. Budget cuts and faculty changes in the early 1990s reduced this hands-on research-oriented program to more canned experiments. However, with increased funding, and a concerted effort to tie the labs into the classes has made the class an important part of the curriculum again.

As a state-funded institution, UW is not immune to the ideas emanating from the state legislature. A threat to cut funding if four-year graduation rates did not increase led to a scramble of reductions in requirements for degree majors. The Aero/Astro Department, however, took a different track. Studying the cause for 5th year completions it was found that many students were taking sophomore-level classes after completing the Aero/Astro courses. But, these same students struggled during the early Aero/Astro courses by not having proper background. Rather then decreasing graduation requirements the Department tightened its prerequisites. The consequence was that the Aero/Astro department has the most prerequisites in the University, but the four-year graduation rate is near the top and fewer students are dropping out.

With the coming or ABET 2000, hands-on learning was reintroduced in many courses. Combined with the integration of Junior Lab (now called Aerospace Lab), and building, testing and flying hardware for their capstone design class, undergraduate

students are getting the balance of the fundamentals, with the experience of working in teams.

Figure 1: Guggenheim Building, Georgia Institute of Technology. Published by permission.

Georgia Institute of Technology

The last grant of the Foundation, $300,000, went to the Georgia School of Technology where Army personnel had been instructed in aviation matters since 1917. The Daniel Guggenheim School of Aeronautics was established on March 3, 1930. The building and facilities cost $91,088, of which $41,829 went towards equipment and maintenance, and $150,213 went into an endowment generating $6000 per year of income to be spent on research. It appears that the grant was accompanied by pledges of annual grants from the State, City, County and the Institute of $9000 each. Accounts vary on how much of the pledges came through during the Depression, but this appears to have served as an early lesson in how to increase research funding to survive and succeed through lean times.

Construction of the 9-foot low speed wind tunnel commenced in 1929, with the Guggenheim building constructed above the tunnel. The building was originally an integrated design/analysis/prototyping and testing facility with 12,900 sq.ft of floor space. It had the tunnel and a machine shop in the basement, two classrooms on the first floor, staff offices and a design hall on the 4th floor, and a 2.5 foot instruction wind tunnel with a 6-component balance and two conference/classrooms on the 3rd floor around the removable model access hatch of the 9-foot tunnel test section. Montgomery Knight, an MIT graduate and helicopter pioneer, was the first Director, recruited from NACA. A donated PCA-2 300 HP autogiro was received for flight research. The building was dedicated in June 8, 1931. The School's mandate was to place roughly equal emphasis on undergraduate education and research, a tradition that has been continued through the decades.

During and after WWII, the wind tunnel saw heavy use in bomber development, much of it in support of the activities of the Lockheed plant located in Marietta, Georgia. On July 1, 1962, the name was changed to Aerospace Engineering. The Montgomery Knight Building was completed in 1968, joined to the Guggenheim Building, and housed high-bay areas and laboratories in addition to a library and offices, but no new classrooms. Three other buildings came up in the 1960s: The Space Sciences and

Technology building and the Weber building across the street from the Knight building, and a Combustion laboratory with reinforced walls, a blow-off roof, and a seismic mass floor, located at the (then) far edge of the campus next to a (rumored) nuclear waste dump known as Crenshaw's Folly. The post-Apollo/Vietnam aerospace recession saw undergraduate enrollment plunge from the high 600s to the low 200s, and the viability of an aerospace school in Atlanta appeared dim. The SST / Weber buildings were taken over by Mechanical Engineering.

A strong emphasis on sponsored research led by Director Arnold Ducoffe brought the School out of that situation to become a leader in research activity at the Institute. Several new faculty from East and West coast schools and the MidWest, and a policy of recruiting students from all over the world, bold at the time for the area, boosted the School's research reputation. The Combustion trio of Warren Strahle, Ben Zinn and Edward Price built up experimental facilities in the 1970s, related first to the problems of solid and liquid rocket motor instabilities, and then to aeroacoustic phenomena, while Robin Gray continued the Montgomery Knight tradition of rotorcraft research. The defense buildup of the early 1980s sent enrollment soaring again along with the research program. In 1982, Georgia Tech won the largest of the 3 grants under the Army's Center of Excellence program in rotorcraft technology, one that continues today as the NASA/Army National Rotorcraft Center's Vertical Lift Center of Excellence. Jim Hubbartt and Howard McMahon turned the 9 foot wind tunnel into a 7' x 9' rotorcraft forward flight facility, and Narayanan Komerath set up signal processing and laser-based visualization and velocimetry. The tunnel was named the John Harper Wind Tunnel upon Professor Harper's retirement in 1986 after 40 years at the School. The Computational Aerodynamics program started by James Wu expanded with Spiro Lekoudis, and later with Lakshmi Sankar's prolific generation of PhDs, along with the School's strong programs in structural dynamics, aeroelasticity and composite structures. Following an ABET review in the mid-1980s, the Institute provided resources to modernize the undergraduate laboratories, renovate the curriculum, and to establish a strong program in Flight Dynamics and Controls. Arnold Ducoffe served as Director until he passed away in 1986.

With a string of national rotorcraft design competition victories, Daniel Schrage established a PhD program in Aerospace Design. Dimitris Mavris, one of the first batch of Rotorcraft Center Fellows and a PhD alumnus of the Komerath - McMahon research team who helped crack the rotor-airframe interactional aerodynamics problem, joined Schrage's rotorcraft design / flight simulation team in 1989. James Craig, with his vision for expanding the aerospace industry's efforts in computer-aided design into an ambitious multidisciplinary design effort, joined Schrage and Mavris to set up the Aerospace Systems Design Laboratory (ASDL), accurately recognizing the burgeoning demand from government and industry organizations for "systems" engineers.

From 1993 to 2008, Professor Robert Loewy served as School Chair. This period saw seen rapid growth in research dollars as well as in student enrollment. In 1994, the Guggenheim Building was renovated with funding from the alumni and from NSF, maintaining much of its external architectural aesthetics. The wind tunnel offices and

control room and model shop were reconfigured into an integrated hands-on learning environment, the third floor was renovated with modern computational laboratories, and the4th floor was expanded with an 80-seat auditorium. The ASDL grew into the biggest of its kind in the world. The Combustion Laboratory, with very strong institutional support matching its sponsored programs, moved into a new facility in the late 1990s, and became the Ben Zinn Combustion Laboratory in the mid-2000s. New programs in Air Traffic Management and Human Factors have been established. A growing program in Space Systems education and research led to the establishment of 3 tracks in the undergraduate program, differing by a couple of electives, and in the choice of the two-semester senior design: fixed-wing aircraft, rotorcraft, and space systems. In 2007, the School of AE had 696 undergraduate students[17], 477 graduate students, 38 academic faculty and 45 research faculty, with nearly $23M/yr in research funding and $7.7M in state funded support. It is consistently ranked in the top 3 in undergraduate and graduate programs.

The School's tradition of having all courses taught by full-time academic faculty continued through these periods of intense research and enrollment growth, and is still largely maintained in most discipline areas. In 2005 the faculty finally approved appointment of a full-time professional undergraduate course selection advisor, delegating the more routine parts of the undergraduate advising function that had been held by the academic faculty through the decades.

In the 1970s, Don Giddens, an alumnus of the AE undergraduate program, switched emphasis from rarefied gas dynamics research to studying turbulence generation in pulsatile flows, motivated by the issues of diagnosing cardiac problems. This effort grew into a research program in biofluid dynamics in collaboration with Emory University's School of Medicine. Professor Giddens moved to Mechanical Engineering, but returned to AE as Director from 1987 to 1992. The large and well-known School of Bioengineering is curiously a joint venture of state-affiliated G.I.T. and private Emory University, a marriage of cultures between Georgia Tech's engineering and Emory's medical school.

The Evolution of Education at the Guggenheim Schools: An Opinion

There are several papers that document the tremendous vision and impact of the Guggenheims[18,19], an important and lasting part of which is seen in these original Guggenheim Schools. Beyond the events reported in terms of buildings, facilities, forceful personalities, political networking, and amounts of funding, it should be remembered that the real "force-multiplier" contributions of the schools are in the ceaseless work of educating those who go there to learn, and in continuously improving that education and the learning environment as much as possible. We briefly discuss what we have seen at a couple of these schools, of how engineering education has evolved. Global and national megatrends and the natural flow of information would drive similar changes at many institutions, but the differences in paths taken by the two that we discuss show that such generalization is limited in its validity.

University of Washington

During the pre-Sputnik years, the Department of Aeronautics at the University of Washington had very strong ties to Boeing. Between WWII and 1960, several faculty served time on Boeing's engineering staff before teaching. While some graduates went on to distinguished careers in other companies, Boeing management and engineering staff was littered with UW graduates who came through the program during this period. All of these graduates remember their time in Guggenheim Hall.

The Kirsten wind tunnel provided a means for collaborative work with Boeing, and a conduit for trained engineers. The wind tunnel was Boeing's primary low-speed testing facility from roughly 1950 to the mid 1980's. It also brought recognition and stability to the department during these years. It could be argued that the Kirsten wind tunnel may not have been possible without the Guggenheim grant. Although technically unrelated, the presence of the Guggenheim building and the support of an established aeronautics program probably made it easier to raise funds from the State and Federal Governments to pay for the largest share of the construction. With Boeing's loan against future testing finishing off the funding, the wind tunnel was built.

The 1960's to 70's was a transition period for engineering at UW. Prior to this time the focus was entirely on teaching. The research being performed by aeronautics faculty was not the norm in the College. When the College of Engineering at UW decided to take the role of the premier engineering research school in the Pacific Northwest, the already established aeronautics was thus its shining star. With the post-Sputnik research funding, the renamed Aero/Astro department was able to continue to be the leader in the College. Geography helped since UW had the only Aerospace Department in a region covering almost a third of the United States (which includes service to Alaska).

Several times during this period, the University looked to remodeling Guggenheim Hall. In probably what was the right thing to do for the long-term, faculty resisted remodeling attempts due to poor building strategies of the time. Their biggest complaint was the standard size office, which during the 1970's was very small. By the 1990's preservation of architectural beauty gained importance. The building was finally renovated in 2006-2007 and the character of the building was able to be maintained.

Unfortunately, the collapse of the aerospace industry in the early 1970's led to two lasting changes in the Aero/Astro program. The first was the wholesale cutting of non-tenured faculty. The result was that carefully recruited junior-faculty, who have since had stellar careers (names withheld by request), were abandoned by the University. Not only were good people and career investment lost, but a damaging reputation made recruitment difficult for a while.

The other lasting change was a shift from a tight relationship with Boeing to a view towards the "other Washington" for research funds. National recognition was the theme and support from Boeing was not seen to support this cause. Simultaneous to this,

Boeing's growth as a global enterprise has led it to become geography-blind. Between Boeing's move beyond its backyard and the UW's desire for visibility on the national scale there has been an erosion of the once symbiotic relationship.

During the period from the late-1970's to roughly the mid 1990's the emphasis on nationally-recognized research had some payoff. The department's stature remained high, and its undergraduate program was pretty much on cruise control. Abe Hertzberg's model of recruiting research faculty who could build careers under his guidance, led to a renowned program in gas physics. Many of these research faculty went on to become tenured faculty in the department. However, the undergraduate program on cruise control was starting to show some wear.

In the late 1990's a major effort was made to update the undergraduate program. Under the leadership of the Chairs, Walter Christiansen and Adam Bruckner, and Undergraduate Faculty Advisors Bruckner and Eberhardt, the program was significantly revamped. Individual faculty efforts also helped in moving towards hands-on education. Labs were integrated better into classes, students were given opportunities to pilot airplanes, build UAV's, instrument and perform flight tests, perform full stability-and-control tests on a business jet and UAV's in the wind tunnel, and tinker with robotic control.

One of the most important results of the revamping of the undergraduate program was an affirmation and tightening of prerequisites. For decades it had been possible for students to leave some important introductory classes until after completing the specific department requirements. This led to students entering with unequal preparation. While it was feared that tightening prerequisites would lead to reduced enrollment, the enrollment has basically remained at capacity and there are many fewer dropouts and stragglers (those who take more then four years to complete their degree). It is interesting to note that at the same time the Aero/Astro program at UW as tightening its prerequisites, other departments in the College of Engineering were loosening theirs. Reducing prerequisites was seen as a means to recruit more students.

During the late 1990's the Aero/Astro faculty sponsored teaching and learning workshops and held informal "brown-bag" best-practices teaching tutorials. The Department was hailed as an innovator in teaching by a College that took upon itself to become a national leader in engineering education. Unfortunately, this proved difficult to maintain during the high faculty turn-over in the early 2000's. Within a two-year period, roughly one-third of the faculty were new. The new faculty were not beneficiaries of the teaching and learning workshops and had to emphasize their research programs. While the young faculty worked independently, and as a team, to become good educators, the peak of the Department's leadership in this area has waned.

As we move into the 21st-century, the turnover in faculty has allowed the Aero/Astro department to remain competitive in research. However, the loss of leaders such as Hertzberg and John Bollard, has left voids that are difficult to fill. In many respects the current period may be characterized as an exciting transitional period, in hindsight.

Geography still has its role in shaping the Aero/Astro Department. UW still has the premier (and only) Aerospace program in the Pacific Northwest. But, with the research emphasis on national funding sources, and the center of those sources in Washington DC, there is an element of remoteness to UW. A trip to sponsors requires a minimum of a grueling two-day trip.

Georgia Institute of Technology

Unlike the University of Washington's Aerospace school, and despite the proximity and excellent synergy of a large aircraft manufacturer (Lockheed Georgia), Georgia Tech's aerospace evolution has not been particularly tied to any single corporate entity. This is partly attributable to the school's historical association with the training of military engineers, continued and expanded through the years in programs driven by the Army and Air Force. As recently as the late 1990s, up to a third of the School's undergraduates were in the Reserve Officers Training Corps (ROTC), which paid for their education as part of their commitment to national service. In the 1980s for instance, curricula were laid out by academic advisors to allow those students to accommodate the ROTC courses, leaving little time for these students to enlist in other electives. A large part of the graduate student cohort in rotorcraft engineering were also Army officers. Some went on to national visibility as West Point faculty or as astronauts, many just became excellent military officers, and all the faculty know at least as few submariners, Navy or Air Force pilots, or Army helicopter pilots. The first hours of any war reminded us that those in the first waves into danger included those smiling undergraduates of not so long ago. So the Guggenheims' tradition has been upheld in that respect as well. Others went into government and industry research laboratories. In a significant disagreement with "traditional metrics", it was not a high priority to try to turn our students into professional clones of ourselves as faculty at other institutions.

A quote from Georgia Tech's 1888 prospectus says[20]: *"The time and attention of students will be duly proportioned between scholastic and mechanical pursuits, and special prominence will be given to the element of practice in every department"*. Early photographs show the Tech Tower and a large Shop building. The original Guggenheim grant's vision of a school that weighs instruction and research equally, has survived at Georgia Tech through the decades. Faculty in the 1950s had 6 to 9 hours per week of teaching and most were expected to be involved in creative thinking[21], though they were not very prolific in journal publications. In the 1960s, as major research activity and undergraduate enrollment both rose sharply, this led to the usual dichotomy between faculty who were heavily involved in undergraduate instruction, and those who taught at most one graduate course per academic year and "bought out" the rest of their time on research. This became necessary for the school to survive through the deep aerospace recession of 1970 – 76.

Continuing the trend started with MIT-trained Montgomery Knight, the School's faculty came from across the nation, with several faculty trained in northeastern and west coast engineering schools. In the 1970s, as peer-reviewed single-investigator basic research

grants became a nationwide funding medium through government agencies, Aerospace Engineering became the first on this Deep South campus to recruit graduate students worldwide, using the Graduate Record Examination as a powerful metric. This led to a United Nations-like environment and global perspectives that now appear quite commonplace across US universities, but was rare then in the South. What did not change was the strong emphasis on excellence in courses, with a tradition of having all classroom instruction and grading of tests done by full-time academic faculty. In fact, until very recently, Teaching Assistants were hardly seen except in laboratory courses. Several graduate courses of the time boasted of grading practices where at most one, and usually no, A grade was awarded, but these Continental practices disappeared with ever-rising quality of student achievement and a growing PhD program.

The new generation of faculty hired from the 1980s onwards, were involved very strongly in undergraduate instruction and advising, but also had strong research funding, graduate advising and publication activity. As a result, the distinction between "instructional" and "research" faculty blurred, and once again, nearly everyone on the faculty was strongly involved in both teaching and research. This was formalized in school policy in the late 1980s, with teaching assignments that were independent of research involvement. Until it was replaced with the Institute-wide (now nationwide) "Course-Instructor Opinion Survey" designed by psychology experts, the School used a thoughtful and brief "Student survey" of learning, administered in every course.

In the early 1990s, under Dean of Engineering John White, a professor of Industrial and Systems Engineering, Georgia Tech became a leader in the Total Quality movement. Strong links with NSF and ASEE developed, leading to the large NSF-funded SUCCEED (Southeastern University and College Coalition for Engineering Education, one of 4 or 5 Coalitions across the nation). This was the leading edge of a campaign to bring NSF funding for undergraduate education improvement efforts to a level comparable to that for government basic university research funding. Tenure-track faculty participants in SUCCEED raised serious concerns about how their involvement in educational improvement, as opposed to industry or military research, would be regarded in the faculty evaluation process (in other words, whether they should expect to be kicked out for caring how their students learned). Perhaps responding to these concerns, there were strong top-down influences on the faculty and on College-wide committees to "not use a cookie cutter" and to seriously consider teaching and undergraduate guidance metrics in promotion/tenure deliberations. The instruction to consider diverse approaches to faculty careers was strongly conveyed, and actually practiced up to the top levels in the Institute. Given the independence of faculty opinions, no claim can be made that it was accepted throughout or outside the College of Engineering at every level.

Undergraduate research participation gradually changed from being something that had to be protected from attacks by those who asked why we were wasting time that should be spent on PhD programs, to something that went into School reports to the Institute. Attending ASEE conferences became a realistic possibility even for non-administrator faculty, being a requirement of several NSF grants. For the first time in many years, it became possible to conceive of assistant professors whose primary contributions were in

teaching, getting promoted without having to be shifted to full-time administrative positions. With teaching involvement and research funding decoupled, the Aerospace School's strategic plan moved towards a model where all faculty would be fully funded through the academic year on state funds, so that sponsored research funding was to be used primarily on graduate students, post-doctoral researchers, and the expenses associated with facilities and research. This also implied large uncertainty for post-doctoral and other full-time researchers, as they could not be paid from state funds, nor be classroom teachers, but rising research funding minimized this problem.

By the mid-2000s, NSF funding in engineering education had once again become channeled into research on educational assessment and psychology. Institutional processes, though much improved in mechanics, appear to have shifted once again to the early 1960s models that are described as "publish or perish" or "grantsmanship" immortalized in the Chronicles of Professor Grant Swinger, with increasingly narrow (and accordingly random) definitions of what actually constitutes "top quality" (ASEE publications, reviewed by peer groups including Deans and School Chairs, are often disdained as not being in "top quality publications" since the disdainers rarely spend time on revising their courses or thinking about what they should teach).

With huge personnel cutbacks in government laboratories and basic research funding agencies associated with the Peace Dividend of the 1990s, the Quality movement appears to have taken a sharp turn into "Focused" or "Relevant" research. This meant that single-investigator basic research grants were increasingly drowned out by massive Centers involving multiple investigators, colleges, universities, states and even nations. One result is a huge increase in the magnitude and the annual rate of increase of the Funding Per Faculty Per Year expectation. Research faculty appointments were heavily leveraged in selected areas designated as "steeples of excellence" where the institution's administrators and their networks wished to make large investments. The policy of all classes being taught by full-time academic faculty changed to a tradition with exceptions, in the face of student enrollment rising beyond precedent at both the undergraduate and graduate levels.

Some of the results of these pressures, in terms of undergraduate instruction and teaching metrics, are best left to the imagination and experience of readers. However, some excellent changes have also occurred. Undergraduate research participation is very strong, and actually funded by Institutional and school initiatives, rather than having to be paid entirely out of graduate-level sponsored research as in the 1980s and early 1990s. Participation of student teams in competitions is very strong, starting with the freshman level. The School has a Freshman course on Introduction to Aerospace Engineering, so that even students in their first week of college can learn from senior faculty in the discipline. In its original version[22,23], this course uses Conceptual Design of flight vehicles to get students oriented quickly to the culture and thought processes of aerospace engineering. One hopes that the effort of breaking through superstition and other barriers of the academic culture involved in achieving these positives, remains permanent in its effectiveness.

The sudden change in the economic climate since 2007 brings the possibility of sharp changes. On the one hand, the dangers in uncontrolled leveraging and expansion (as in the case of real estate mortgages and derivative instruments), and in being pressured to relax standards of evaluation and certification (as in the case of the top Credit Rating agencies and banks) are all too visible. These should perhaps have tempering effects that lead to positive change. On the other hand, the short-term effect is a rush towards "shovel-ready" projects for short-term federal economic recovery funding. This, coupled with the "steeples of excellence" practice, has the potential to aggravate problems, or achieve tremendous results, depending on one's point of view.

Concluding Remarks

There is little question of the value of the Daniel Guggenheim foundation that funded seven Universities in the 1920's and 30's. In this paper a brief history of the program was covered and some discussion of the more recent histories is included. For the University of Washington and Georgia Tech, the authors have delved a bit deeper, offering personal insights.

It would be hard to imagine aerospace education without the six remaining Guggenheim schools. Each has played a prominent role in the growth of aerospace education in their region and nationally. All are still leaders in aerospace engineering educatgion today.

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