Vertical Flight Society White Paper
On
Vertical Lift Workforce: Graduate Research and Education

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ISSUE: A review of the Army Vertical Lift Technology, Mission & Management in the early 1980s led to the establishment of the Rotorcraft Centers of Excellence program in 1982. The program combines graduate education in vertical lift technologies at the centers with long-term research grants to effectively train the next generation of scientists and engineers for the vertical lift community. This has led to impressive expansion of multidisciplinary research and education in the vertical lift area. Today, under the Future Vertical Lift (FVL) program, the Department of Defense (DOD) is working towards development of the next generation of aircraft – manned and unmanned. This together with the emerging Electric-Vertical Take Off and Landing (Electric-VTOL or eVTOL) aircraft motivated by the Urban Air Mobility (UAM) industry, as well as unmanned aerial systems for package delivery, require a significant expansion in vertical lift technology workforce. The Vertical Flight Society (VFS) estimates a three- to four- fold increase in workforce to support FVL alone in the next five years, and a ten-fold increase to support both FVL and UAM over the next two decades. It is time to revitalize the centers of excellence by significantly expanding sustained, long-term research grants focused on vertical lift technology to proactively address the growing workforce requirement and ensure US competitive edge in the vertical lift industry.

BACKGROUND: Vertical lift – a special branch of aeronautics that deals with runway independent hover-capable rotary-wing aircraft – has long been a vital source of America's security. Its specialized workforce – highly-trained (primarily M.S. and Ph.D.), multi-disciplinary (aircraft and systems), engineering intensive (design and manufacturing-based), and mission-oriented (aligned with DOD and NASA) – has been key to the US dominance in vertical lift.

The existing Vertical Lift Research Centers of Excellence (VLRCOE) are key components of the critical vertical lift infrastructure. The program originated in 1982 as the Center for Education and Research in Rotary Wing Aviation Technology (CERWAT) to increase academia's contribution to the vertical lift technology by focusing on both academic research and graduate education in a number of multi-disciplinary research areas critical to vertical lift technology. In 1996, the program was re-named the Rotorcraft Center of Excellence (RCOE) program with added emphasis on collaborative research with the government and industry through another collaborative applied research component as follow-on to the RCOE basic research tasks. In 2006, the program was re-energized as the Vertical Lift Research Center of Excellence (VLRCOE) emphasizing inter-disciplinary multi-university teams to address multi-disciplinary technology barriers. This collaborative nature of the program led to the infusion of additional basic research funding from the Navy and NASA to supplement the Army funding. The sustained long-term focus on vertical lift that has been the primary driver for growth of the Centers, and has helped attract other support through short-term research grants such as MURI, NRA, and national scholarships and fellowships.

The current VLRCOE program comprises of three university centers led by the *Georgia Institute of Technology*, *The Pennsylvania State University*, and the *University of Maryland*. The centers have formed partnerships with outstanding universities across the United States to strengthen our technology base while germinating vertical lift research and education at these partner institutions. The partnerships have been key to the success of the program. Currently, there are 13 partners, including nominally HBCU/MI universities. These are the Ohio State University, Embrey Riddle Aeronautical University, Iowa State University, Purdue University, Rensselaer Polytechnique Institute, Texas A&M University, US Naval Academy, University of California-Davis, University of Michigan-Ann Arbor, University of Tennessee-Knoxville, University of Texas-Austin, University of Texas-Arlington, and University of Washington-St. Louis. All these schools provide generous cost share towards the VLRCOE program. The centers have provided competitive edge to US rotorcraft industry by generating innovative solutions of numerous technical barrier problems, introducing disruptive innovations in rotary-wing technologies and basic sciences, and transferring technology rapidly to industry and government laboratories. An important mechanism in technology transfer consisted of the highly trained graduate students, who were hired by industry, academia, and government laboratories. The program has retained the dual education-research focus, consistent with the original intent, providing an effective and exciting educational environment to train the next generation of scientists and engineers for the Army. The US Army and the rotorcraft industry consider this a model program. The vibrant nature of the program is ensured by the fact that these centers are competitively renewed at the end of each five-year period.

SOLUTION: Revitalize vertical lift research by significantly expanding long-term research grants combined with graduate education to train the next generation of scientists and engineers to retain US competitive edge in the vertical lift industry. This will increase the number of graduate students significantly, recruit and retain the best under-graduates, create new experimental facilities, modernize existing facilities, and ensure timely transition of disruptive innovations to US industry. Vertical lift technology is aligned with both DOD and NASA missions and will help support future workforce requirements for FVL and eVTOL/UAM research and education.

Recommendations on approaches to implement the solution are listed below.

RECOMMENDATIONS:

1. Expand VLRCOE for long-term sustained research:

The VLRCOE program is a long-term sustained research program. Therefore, the most efficient approach to revitalizing vertical lift research is to fortify and expand this program.

Currently the Army, the Navy and NASA collaboratively fund the VLRCOEs at nominally $23M over five years. The funding amount has decreased over the past 38 years both in actual and inflation-adjusted values. At the same time, the number of partner universities have increased to 16. Thus, the funding is already spread too thin. As a reference, the cost of supporting one graduate student (tuition, health, and a graduate stipend) in a state school is around $80-100K per year, depending on the location. The current funding level is barely enough to support today's graduate rate of approximately 20-30 M.S. students and 10-15 Ph.D. students every year. This is not even sufficient to fulfill today's workforce requirement, let alone the projected growth in future requirements. Proactively addressing these growing requirements will ensure US competitive edge in the vertical lift industry.

A large number of under-graduates are drawn to the vertical lift program from diverse backgrounds, including students from chemical, electrical, and mechanical engineering and computer science. They volunteer in rotorcraft labs and participate in graduate projects, but shortage of funds prevents their recruitment into the graduate program (which pays tuition, graduate stipend and health benefits). As undergraduate tuition varies from $40 – 60 K per year (depending on university), a majority of this talent pool, which would otherwise enter graduate school or join aerospace companies, are now lost to Google, Facebook, and Amazon. There are a few national fellowships (such as NSF and NDSEG) available to high caliber students, but these awards vary year to year, and while being an excellent supplement, cannot form the basis for long-term multi-disciplinary research and graduate education. As it is, the Fellowships mentioned above typically cover expenses over three years, not enough for a Ph.D. The US industry and government laboratories provide short term support through summer and pathway internships, but these form avenues for recruitment, rather than for academic research or education.

The VLRCOEs have an impressive track record in outreach to women and under-represented minorities – from local high-schools to community colleges. The best role models for outreach are the graduate students themselves who act as mentors and with whom they can work in the laboratories. Thus, a healthy and vibrant graduate student body has significant impact both up-stream (student recruitment) and down-stream (workforce deployment). Expanding VLRCOE should focus on expanding this student cohort.

Active participation of the US Air Force should be sought along with additional DOD resources to expand the scope of the VLRCOE program by enhancing the funding of the existing VLRCOE's as well as increasing the funding that is provided to the partner institutions. The emphasis should be on those institutions which have a strong aerospace program and by using the funding the number of faculty involved with the program, who are already in place, can be expanded. This will increase the number of graduates in a fairly rapid manner. A longer-term solution is to expand carefully the number of current lead institutions. The infusion of additional funds allows the establishment of additional centers when a new institution reaches a critical mass in multi-disciplinary VTOL research and has a comprehensive program available. An example is the Rensselaer Polytechnique Institute, where a vertical lift-focused center was established in October 2018.

Programs such as NRTC (National Rotorcraft Technology Center), now defunct, should be re-invented for timely transfer of VLRCOE-generated disruptive innovations to US industry. These can be follow-on programs to VLRCOE in direct partnership with companies and the US government. Several structural problems exist with current and former arrangements. DOD should study and remedy these problems. The view from academia is that limited short term 1-year statements of work with no option for continuation is essentially ineffective from a workforce development standpoint (an M.S. is a minimum 2-year program and it takes a year to train a student), let alone meaningful technology transfer. The view from industry was that the requirement to share knowledge with all their competitors (as mandated by the arrangement) meant no frontline barriers were in fact exposed, only unimportant and inconsequential ones for which 50% of IR&D cost-share could not be justified (also mandated by the arrangement). The view from government was that it ended up bearing the cost of the entire program indirectly. The requirement that the projects be led by industry resulted in large administrative costs and paperwork; administration by the Universities could be a more tractable alternative.

2. Invest in Equipment:

The vertical lift infrastructure is aging. The rotorcraft centers need many urgent upgrades and modernization of existing experimental facilities. New facilities must be developed for new and emerging disciplines related to electric-power, high-speed operation, low-noise, zero-emissions, all-weather operations, de-icing, air-launch systems, unmanned-systems, autonomy, and ship-board operations, among others. DURIPs offer intermittent relief for some experimental equipment, but are not sufficient to create long-term infrastructure to support national interests. A one-time investment in equipment can raise productivity for over two decades.

3. Create New eVTOL & UAM Initiatives for Near-term Disruptive Research:

New initiatives are needed to break the principal barriers of eVTOL, and generate the ten-fold increase in workforce over the next two decades. Currently, eVTOL and UAM research is carried out piecemeal across isolated institutions. Collaborative Technology Alliances (CTA) and Collaborative Research Agreements (CRA) are ideal instruments for multi-year coordinated research initiatives. The Army's CTA-MAST (Collaborative Technology Alliance-Micro Autonomous Systems and Technology, 2008-2017) was a model example. The DOD Multi-disciplinary University Research Initiative (MURI) is another instrument that can be utilized. MURI topics should emphasize areas of basic science that impact vertical lift.

Clean, quiet, and compact electric power is the principal enabler of eVTOL and also its principal barrier. A national initiative is required to address this barrier in a coordinated manner. Breakthroughs in aviation require different strategies compared to consumer electronics, power-grid, or surface transportation. Not only are the missions and storage requirements distinctly different – higher power densities, faster charging, unique cycles, shorter storage, and orders of magnitude greater safety and reliability – but power in aviation is integrated with the platform and cannot be pursued in isolation; isolated advances dropped-in from elsewhere, even if adequate for initial demonstration, is ultimately detrimental to the safety and integrity of aviation systems.

Vertical lift is unique. The principles that govern rotary-wing aircraft are different from principles that govern fixed-wing aircraft. Understanding these principles, their barriers, and innovations that conquer these barriers constitute basic research in vertical lift. Breakthroughs require in-depth understanding of these principles. The science of vertical lift impacts not only the eVTOL aircraft but all aspects of UAM, from platform to power to infrastructure. Isolated research oblivious to the principles of vertical lift will be impractical research, not basic research.

Power, platform and infrastructure are broadly the three cornerstones of eVTOL and UAM technical research. Power includes energy storage and the electric-drive. Platform includes vehicle aeromechanics, propulsion, structures, and operations. Infrastructure includes transportation, manufacturing, and grid-insertion. Electric-power is intimately tied to the platform, through propulsion. Power is also tied to infrastructure, through the grid. Infrastructure is intimately tied to the platform. Safety is tied to all. Cost impacts all. A number of emerging technologies disrupt these inter-dependencies, such as, fuel cells for power, autonomy and AI for airspace, proprotors for agility, shrouds for noise, additive manufacturing for large-scale production, psycho-acoustics for community impact, and multi-fidelity tool chains for design, synthesis, and full life-cycle assessment. These technologies should be advanced and expanded from the unique perspective of eVTOL and UAM applications.

<u>Basic research in aviation and all aviation-related systems should be directed by agencies with expertise in aeronautics</u> and which are direct stake holders in the research that is funded. Therefore, it is incumbent upon DOD and NASA to assume the leadership of this effort for rapid and effective progress.