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Joseph F. Ware, Jr. Advanced Engineering Lab

Annual Report
2018-19

Executive Summary

This annual report summarizes activities at Virginia Tech's *Joseph F. Ware, Jr. Advanced Engineering Lab* housed in the College of Engineering for academic year 2018-19. The report includes sections on project budgets, team competitions, outreach activities, and student demographics.

This year over 450 Virginia Tech students completed the general use survey with a third of these working in the lab on a regular basis. *Formula SAE* utilized the lab 35% of the time, followed by BOLT, Baja SAE, and HEVT at 15% each. *Formula SAE, Hybrid Electrical Vehicle, and SailBOT* placed in the top 15 percentile at national competitions with rankings of 14/120, 2/12, and 2/12, respectively. Machining and welding expenditures equaled $28,400 and truck and trailer maintenance totaled $23,200. Competition fuel costs totaled $11,900 with ten teams traveling over 29,000 miles utilizing our GMC Sierra and Ford F350 trucks!

In-kind and monetary team sponsorship included contributions of over $603,000, ($4500 from Ware Lab stipends) while costs to design, manufacture and compete project deliverables totaled $329,000. Ware Lab tours totaled 2100 persons from K-12, industry, and higher-ed. Over 50 students received specialized machine shop training with five receiving advanced Hurco VM20i training. 24 Ware Lab students received training on truck/trailer equipment necessary for safe travel to competition events.

Appendix A contains a report completed by senior design students in Virginia Tech's Industrial System Engineering department. The report is an in-depth study of developing methods of lab space utilization and safety training. A proposal for future lab expansion is include.

The following report has additional detailed information on demographics, outreach, budget, and competition related items. Additional details are available from the Ware Lab manager, Dewey Spangler (spanger@vt.edu).

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Introduction

The Joseph F Ware, Jr. Advanced Engineering Lab at Virginia Tech (aka *Ware Lab*) is an undergraduate design facility housed within Virginia Tech's College of Engineering in Military Building 203 on the main campus. The facility is home to ten undergraduate teams from various departments within the college. Ware Lab staff consists of:

- Dr. Bev Watford, PE - Director
- Dewey Spangler, MS, PE - Manager
- Phil Ratcliff - Assistant Manager

The Ware Lab facility spans over of 10,000 square feet of space divided into four main areas. Each area requires varying levels of safety certification as specified in the *Ware Lab General* and *Machine/Weld Policy Manuals*. These areas include:

1. General Areas
    a) First floor – (Room 100, 104, 106 through 114, 117) – Fig. 1.
    b) Basement – (Room 18) – Fig. 2.
2. Machine Shop – (Room 101) – Fig. 1.
3. Welding Shop – (Room 102) – Fig. 1.
4. Administrative Areas – (Room 101A, 101AA, 103, 105) - Fig. 1

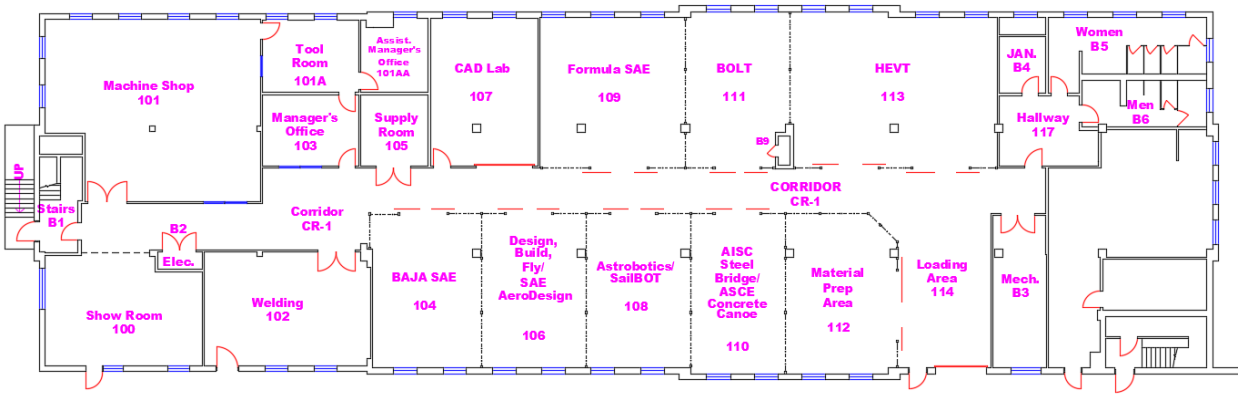

Figure 1 – Ware Lab Main Floor

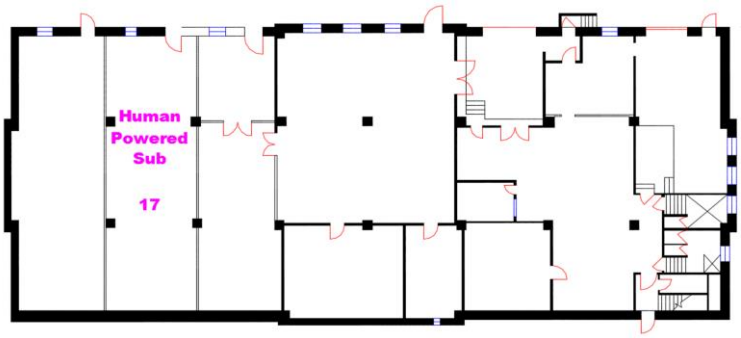

Figure 2 – Ware Lab Basement

New Ware Lab Equipment

This year Ware Lab purchased a 2019 Ford F350 truck with dually transmission for use by teams traveling to competitions throughout the United States. The total cost of the vehicle was $64,300 with $20,000 funded by the College of Engineering. The balance was provided by Somic America, Inc. and the following private contributors:

- Marvin and Sue Johnson,
- John and Elizabeth Donehower, and
- Dale and Deborah Hamilton.

Figure 3 – 2019 FORD F350 truck with dually suspension.

Figure 4 – FORD F350 with Ware Lab logo, team list and sponsorship logos.

The new truck will be used in addition to our 2007 GMC Sierra, providing teams traveling long distances with safe and reliable transportation.

Lab Improvements

Each summer floors in Ware Lab are painted to maintain bays in a clean and manageable state. In 2019 *HEVT (CAD lab side)* and *Design Build Fly* bay floors were painted with a concrete stain having a high gloss finish. Total cost for painting both areas was $5,200. Also, a framed photo of all teams participating in the 1989 Formula SAE event was added to the lab's main hallway. As Figure 5 illustrates, the event was well attended and indicates the level of dedication and longevity of our Virginia Tech Motorsport program.

Figure 5 – Formula SAE participation photo at 1989 event.

In addition, a new wrap was added to the 36' goose neck trailer, as shown in Figures 7, 8 and 9. The design includes our new Ware Lab logo, team list, and sponsorship list. Costs for the new wrap totaled $6000 and was paid for via a *Big Contribution* grant from the Student Engineer's Council (SEC).

Figure 6 – Original trailer layout.

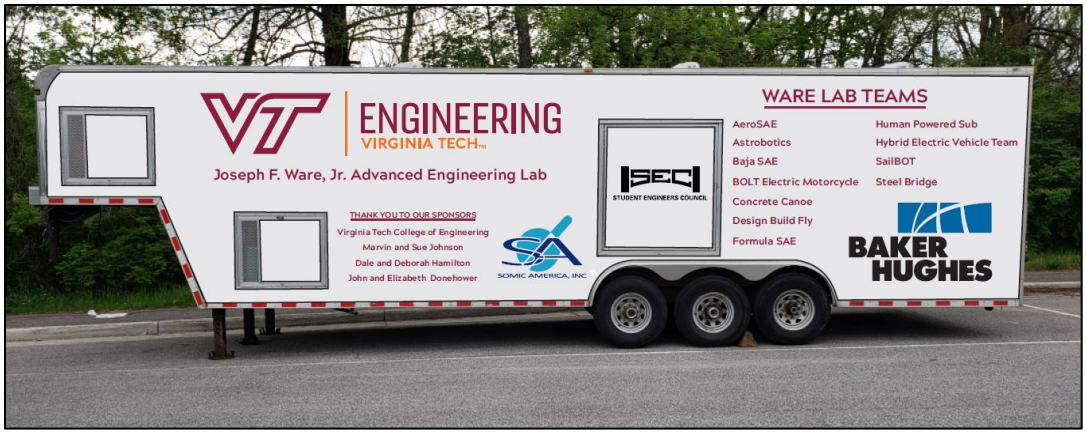

Figure 7 – New trailer design with lab logo, team list and sponsorship logos.

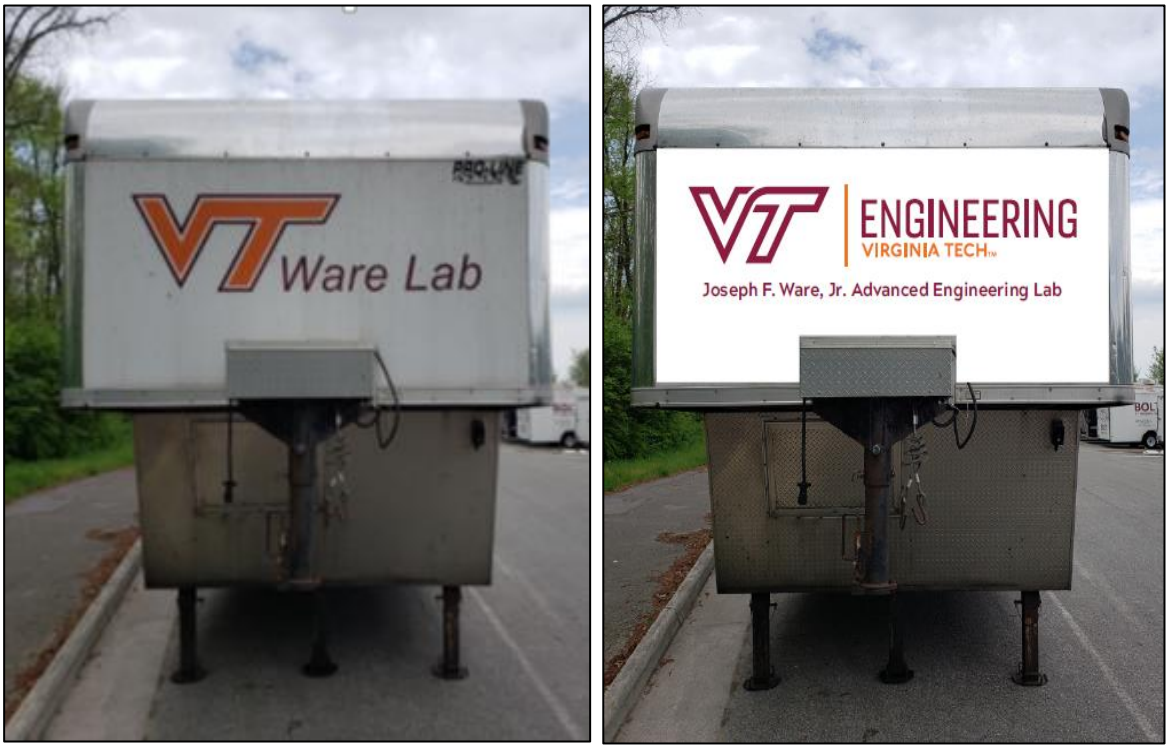

Figure 8 – Original (left) and new (right) front trailer design.

Figure 9 – Original (left) and new (right) back trailer design.

Special Events

20th Anniversary Celebration

On September 6th, 2018, Ware Lab observed twenty years of continuous operation on the Virginia Tech campus with a lab open-house celebration. In attendance for this event was General Motors vice president Bill Verner, and College Dean Dr. Julia Ross. Visitors and students were treaded to lunch and signed a display banner, celebrating this important lab milestone.

Figure 10 – Bill Venner, with GM, (left) and Dean Ross (right) during Ware Lab's 20th anniversary.

Figure 11 – Ware Lab students having lunch during the 20th anniversary open-house (left). Signed event banner (right).

Ut Prosim Luncheon

Members of Virginia Tech's Ut Prosim *President's Circle* visited Ware Lab on April 27th, 2019 for a luncheon and in-depth discussion with student team members. In attendance were President Tim Sands, Dean Julia Ross, and Provost Cyril Clarke. Genevieve Gural, who served as Baja SAE's team lead in 2017-18, also spoke to the assembled crowd.

The Ut Prosim Society (https://give.vt.edu/giving-societies/ut-prosim-society.html) is comprised of individuals who epitomize the motto: *That I May Serve,* through engagement, leadership, and extraordinary generosity. The society is instrumental in helping sustain many areas of university operations, including Ware Lab.

Figure 12 – Provost Cyril Clarke speaking with the Human Powered Sub Team (left). Ware Lab students at the catered event (right).

Figure 13 – President Sands (left), Dean Ross (center), and Genevieve Gural (right) speaking at the recent *Ut Prosim* event.

Fusion 360 Workshop

On July 18th Ware Lab hosted participants from industry and academia for a FUSION 360 CAD/CAM workshop. The event included an in-depth course on AutoDESK's Fusion 360 and concluded with part production using the Hurco VM20i mill. Those in attendance were:

- Jim Swain, Synergis
- Kevin Lee, Peloton Group
- David Taylor, Synergis
- Jason Miles, Applied Software
- Nick Narzinski, D3 Technologies
- Dave Lapthorne, D3 Technologies
- Jim Logue MESA
- Steve Olson, Mesa
- Caleb Funk, Imagine
- Ron Richard, Autodesk
- Jason Roth, Autodesk
- John Peros, Autodesk (Instructor)

Fusion 360 is used to produce CAD engineering drawing and convert computer models to CNC (computer numeric control) necessary for automated subtractive manufacturing. Ware Lab plans to hold an introduction class in Fusion 360 during the early fall semester of 2019 for students and faculty working in the lab.

Figure 14 – John Peros with Autodesk instructs participants on Fusion 360 (left). Part production on the Hurco VM20i (right).

Team Competitions

Ware Lab teams compete in regional and international competitions across the United States each year. Our top performing teams included *HEVT* (2/12 – EcoCAR Mobility Challenge, Year 1), *SailBOT* (2/12 - International Robotic Sailing Regatta), and *Formula SAE* (14/120 – Michigan, 7/70 – Nebraska). See Table 1 for a complete listing of competition results for this year.

Figure 15 – Formula EV and ICE (left). FSAE ICE earned 3rd in *Endurance*, 2nd in *Fuel Efficiency* and 7/70 overall at Lincoln, Nebraska. The team also earned 2nd place in *Fuel Efficiency* and 13/120 overall at the Michigan event (right).

Figure 16 – Virginia Tech's Hybrid Electric Vehicle Team earned 2nd place at Year 1 of the EcoCAR Mobility Challenge in Atlanta Georgia, on May 22 (left). 2019 Chevy Blazer donated to Virginia Tech (right).

SailBOT

Congrats to the 2019 SailBOT team on their 2nd place finish at the International Robotic Sailing Regatta! The 13th International Robotic Sailing Regatta was hosted by Worcester Polytechnic Institute June 3-7, 2019 on Lake Quinsigamond in Massachusetts.

Teams were judged on presentations, fleet races to demonstrate the remote control system and the boat's performance, a long distance/endurance event, and challenges in station keeping and transporting payloads.

Virginia Tech brought home second place honors and looks forward to improving on their design for 2020!

Figure 17 – *SailBOT* feature in recent AOE alumni newsletter.

Human Powered Submarine

The Human Powered Submarine team recently competed at the 15th International Submarine Races at NSWC Carderock in Bethesda, Maryland. The Hokies last participated in this competition two years ago, and failed to place in any of the categories. This year, HPS returned to Carderock with a revamped version of their Phantom series submarine and added a second submarine (Trident), making them the only college team with two boats in the competition.

HPS completely changed their management systems, resulting in a great improvement in race performance. Their testing plans included a bollard pull test, which was a submarine race first.

Bringing two vessels to the competition proved beneficial for VT. Phantom 8 required the team's attention for adjustments during much of the competition, but Trident completed several successful runs.

Trident was awarded second honorable mention for the Innovation Award, which recognizes the submarine team from any design category that incorporates the most innovative design, construction and/or performance. Congratulations to the HPS team!

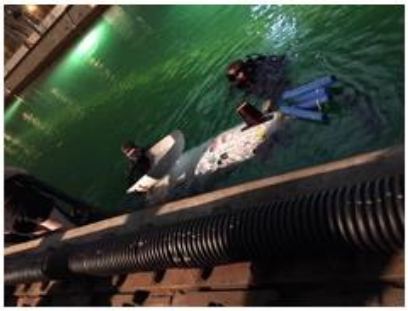

Figure 18 – *Human Powered Sub* feature in recent AOE alumni newsletter.

Table 1 – Ware Lab Team Competition Results

Team	Competition	Location	Ranking
DBF	AIAA DEF Competition	Tucson, Arizona	24/113
SBT	ASCE Virginias Regional	George Mason University, Washington DC	Disqualified
CCT	ASCE Virginias Regional	Catholic University, DC	Did not report
Astrobotics	NASA Robotic Mining Competition	University of Alabama, Tuscaloosa	Did not report
Baja	Baja SAE Tennessee Tech	Cookeville, Tennessee	37/96
Baja	Baja SAE California	Gorman, California	39/100
Baja	Baja SAE Rochester	Rochester, New York	46/100
BOLT	AHRMA eMoto Varsity Challenge	Millville, New Jersey	Did not compete
Formula SAE	Formula SAE Michigan (IC)	Brooklyn, Michigan	14/120
Formula SAE	Formula SAE Lincoln (IC)	Lincoln, Nebraska	7/70
Formula SAE	Formula SAE Lincoln (EV)	Lincoln, Nebraska	Disqualified
HEVT	EcoCAR Mobility Challenge - Year 1	Atlanta, Georgia	2/12
HPS	Human Powered Submarine	David Taylor Model Basin, Bethesda MD	7/21
SailBOT	International Robotic Sailing Regatta	Worcester, Massachusetts	2/12

Lab Operational Budget and Expenditures

Ware Lab funds are provided by the College of Engineering and several endowment accounts, as shown in Table 2. Tables 3 and 4 include machine/weld shop and truck/trailer expenditures. Table 5 lists competition fuel expenses per team. During 2018-19 the Ware Lab GMC Sierra and Ford F360 trucks traveled over 29,000 miles to various competition events.

Support from the Student Engineer's Council totaling $6000 was used to offset the cost of new logos for the Ware Lab goose-neck trailer. $20,000 was received from the college of engineering to support the purchase of our 2019 Ford F350 truck. Also, Ware Lab made a final payment of $10,000 to the College of Engineering for the Hurco VM20i four axis mill, effectively retiring this debt. Ware Lab continues to be financially sound as we enter the 2019-20 academic year.

Table 2 – Ware Lab Accounts

Account Name	Balance
Ware Laboratory - Operational	$173,000
Endowment Funds	
Marvin and Sue Johnson	$56,691
John and Elizabeth Donehower	$43,900
Bare Family Competitive Engineering Income	$27,320
Somic America, Inc.	13,950
Income Funds	
Ware Lab Students Projects	$9993
Joseph Ware Mechanical Engineering Fund	$63,626
Design Space of the Future	$8,856
Alumni Donations	$325
Ware Lab Unrestricted	$53,070
Total	**$437,000**

Table 3 – Machine/Weld Shop Expenditures

Company	Totals (2017-18)	Totals (2018-19)
Airgas	$7	$0
Alro Steel	$0	$280
Amazon.com	$0	$1,115
ARC3	$2,473	$2,100
Barrows	$3,612	$911
Batteries Plus, LLC	$0	$120
Blacksburg Auto Parts	$52	$0
CSE Inc.	$0	$4,670
Crotts & Saunders	$743	$5,012
Dominion Air & Machinery	$942	$2,320
DTS Reprographics	$0	$250
Ferguson	$14	$0
Grainger	$264	$0
Guy Brown Products	$484	$496

Homestead Material Handling	$0	$1,863
Lowes	$0	$152
McMaster-Carr	$372	$308
Mitchell Instrument Company Inc.	$180	$0
MSC	$2,459	$7,552
National Auto Fleet Group*	$0	**$64,279**
The Supply Room Companies	$11,432	$97
Today's Classroom LLC	$0	$1,185
Total	**$23,034**	**$92,710**

*For the purchase of Ford F350 heavy duty truck. Total expenditures for 2018-19 = $28,430 for all other items indicated.

Table 4 – Truck and Trailer Expenses (miscellaneous)

Company	Vehicle	Totals
Pro-Line Trailer Sales (tires)	CEE Trailer	$350
Pro-Line Trailer Sales (maintenance)	CEE Trailer	$240
Auto Experts (oil change)	Ford F350	$509
Fuel	Ford F350	$5,490
Pro-Line Trailer Sales (maintenance)	Ford F350	$300
Auto Experts (new radiator)	GMC Sierra	$1,844
Firestone Complete Auto Care (new radiator)	GMC Sierra	$1,702
Fuel	GMC Sierra	$5,425
Harvey Chevrolet (rear-end repairs)	GMC Sierra	$5,360
Auto Experts (tires)	Goose Neck Trailer	$446
Fuel	Goose Neck Trailer	$53
Pro-Line Trailer Sales (maintenance)	Goose Neck Trailer	$635
Pro-Line Trailer Sales (generator repair)	Goose Neck Trailer	$497
U-Haul	Rental	$307
		$23,158

Table 5 – Competition Travel Fuel Expenses

Purpose	Vehicle	Cost
Astrobotics trip to Alabama	GMC Sierra	$212
Astrobotics trip to Alabama	Ford F350	$253
Baja SAE trip to California	Ford F350	$2,067
Baja SAE trip to Kentucky	GMC Sierra	$130
Baja SAE trip to New York	Ford F350	$340
Baja SAE trip to Tennessee	Ford F350	$260
Concrete Canoe trip to DC	GMC Sierra	$144
DBF trip to Arizona*	GMC Sierra	$4,834
Formula SAE trip to Michigan	Ford F350	$123
Formula SAE trip to Nebraska	Ford and GMC	$1,112
Formula SAE trip to South Carolina	Ford F350	$220

HEV trip to Charlottesville, VA	GMC Sierra	$105
SailBOT trip to Massachusetts	GMC Sierra	$1,800
SailBOT trip to Massachusetts	U-Haul Rental	$307
Total		**$11,907**

*Includes repair of GMC radiator.

Ware Lab Demographics

Gender, race, and student transfer information is gathered each year when students complete the general admissions survey. Based on collected data, trends in these areas are shown in Tables 6 and 7 and Figures 19 and 20. Table 8 lists ideas as to how Ware Lab can be improved overall. As in previous years, additional team space was indicated as the top concern by students working in the lab.

Table 6 – Ware Lab Population by Gender

Team	Number of Females	% Female	Number of Males	% Male
Astrobotics	8	2%	20	4%
Baja	10	2%	78	16%
BOLT	3	1%	51	10%
DBF	3	1%	52	11%
FSAE	15	3%	115	24%
HEV	4	1%	29	6%
HPS	2	0%	27	6%
SailBOT	2	0%	27	6%
SBT	8	2%	32	7%
Total	**55**	**11%**	**431**	**89%**

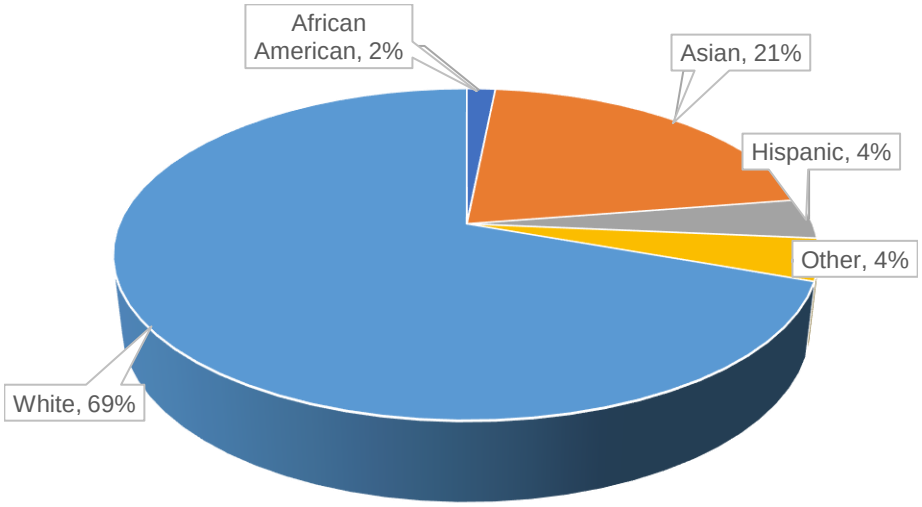

Figure 19 – Ware Lab population based on ethnicity.

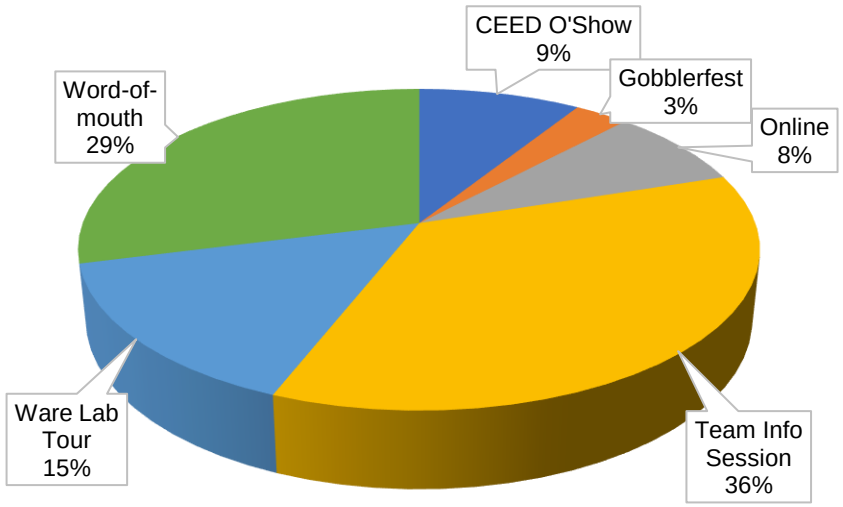

Figure 20 – "How did you learn about Ware Lab?"

Table 7 – Transfer-Student Population

Transfer College	How did you find out about Ware Lab?	Major	Team
Central Virginia CC	word-of-mouth	AOE	HPS
Danville CC	team info session	ME	BOLT
Danville CC	team info session	ECE	Formula SAE
Germanna CC	team info session	ECE	DBF
Germanna CC	team info session	AOE	DBF
James Madison University	word-of-mouth	ENGE	HPS
John Tyler CC	team info session	ENGE	BOLT
Lord Fairfax CC	word-of-mouth	ISE	SBT
Lord Fairfax CC	word-of-mouth	CEE	SBT
Manipal University, India	word-of-mouth	ECE	SailBOT
Mountain Empire CC	team info session	ENGE	BOLT
Mountain Empire CC	team info session	CS	Formula SAE
Northern Virginia CC	word-of-mouth	AOE	HEV
Northern Virginia CC	word-of-mouth	ME	HEV
NVCC	online	ME	Baja SAE
NVCC	word-of-mouth	ME	SailBOT
NVCC	word-of-mouth	ME	SBT
Piedmont Virginia CC	Other	ECE	BOLT
Piedmont Virginia cc	Ware Lab tour	ME	Formula SAE
Piedmont Virginia CC	word-of-mouth	AOE	HPS
University of Illinois	team info session	ME	DBF
University of Illinois	team info session		DBF
University of Kansas	team info session		Formula SAE
University of Kansas	team info session	ME	Formula SAE
VCU	word-of-mouth	ME	HEV
VCU	word-of-mouth	AOE	SBT
Virginia Western CC	team info session	ME	BOLT

Table 8 – "How can Ware Lab be improved?" (from the Ware Lab general survey)

Larger CAD lab.
Better Baja bay organization.
Better space allocation. Teams shouldn't have to share bays; there should be a process which allows them to apply for a private bay or move to a new bay.
Continuous updates on PPE ordering and safety related equipment.
Every time there is a hard rain the HEVT, BOLT, and Formula bays are heavily flooded.
Formula needs new drills. We have 10 but only 2 work.
We need a conference room for Ware Lab related meetings.
Teams should not have items littering the hallways and other bays.
More airlines for the composites bay.
More soap in women's room.
More space for carbon lay-up related work.
More space in the welding class.
More storage.
Space is limited in bay since we are building two cars now.
Team storage space outside the bays to allow for a more organized, cleaner, and safer work environment.
The basement leaks when it rains hard.
The FSAE bay is small considering the size of the team.
The HVAC duct in the HEV bay is too low, and we will need more space to raise our competition vehicle.
When it rains heavily, the basement floods. This is not good for materials that we need stored.

Project Team Demographics

Students working in the Ware Lab must pass all required OSHA safety classes, sign a lab waiver form, and complete an on-line survey. Table 9 is a list of teams currently serving at the Ware Lab along with department affiliation, and faculty advisor. Team advisors provide continuity and invaluable assistance to students throughout the year. Tables 10 through 14 indicate other relevant Ware Lab team demographics such as stipend amounts, individual team sponsorship, and project bay square footage.

Table 9 – Ware Lab Teams

Team	Department(s)	Faculty Advisor
AIAA Design Build Fly (DBF)	Aerospace and Ocean	Rakesh Kapania
AISC Steel Bridge (SBT)	Civil and Environmental	Matt Hebdon
ASCE Concrete Canoe (CCT)	Civil and Environmental	David Mokarem
Astrobotics	Mechanical	Alex Leonessa
SailBOT	Aerospace and Ocean	Stefano Brizzolara
Baja SAE	Mechanical	John Ferris
Formula SAE (FSAE)	Mechanical	Matt Rice
Human Powered Submarine (HPS)	Aerospace and Ocean	Christine Gilbert
Hybrid Electric Vehicle (HEV)	Mechanical	Doug Nelson
Battery Operated Land Transportation (BOLT)	Mechanical	Richard Clark

Table 10 – Ware Lab Team Stipends

Team	Amount	Department
Steel Bridge	$500	CEE
Astrobotics	$500	AOE
Baja SAE	$500	ME
BOLT	$500	ME
Design Build Fly	$500	AOE
Formula SAE	$500	ME
Hybrid Electric Vehicle	$500	ME
Human Powered Sub	$500	AOE
SailBOT	$500	AOE
Total	**$4500**	

Table 11 – Team Sponsorship/Expenditures

Team	Corporate	Private	Virginia Tech	Total	Expenditures	Net
Astrobotics	$6,500	$0	$7,670	$14,170	$11,900	$2,270
Baja SAE	$35,000	$250	$6,220	$41,470	$3,900	$37,570
BOLT	$53,500	$2,000	$16,770	$72,270	$64,710	$7,560
DBF	$6,500	$0	$19,700	$26,200	$17,600	$8,600
Formula SAE	$220,000	$10,000	$10,500	$240,500	$64,000	$176,500
HEV	$148,800	$1,000	$22,500	$172,300	$148,445	$23,855

HPS	$16,500	$0	$8,600	$25,100	$11,750	$13,350
SailBOT	$0	$900	$5,920	$6,820	$4,450	$2,370
Steel Bridge	$3,200	$0	$500	$3,700	$2,500	$1,200
Total	**$490,000**	**$14,150**	**$98,380**	**$602,530**	**$329,255**	**$273,275**

Table 12 – Major vs. Academic Level

Major	Freshmen	Sophomore	Junior	Senior	Graduate	Total	%
AOE	10	29	25	18	1	**83**	**17%**
BEAM	0	0	0	1	0	**1**	**< 1%**
BSE	0	1	0	0	0	**1**	**< 1%**
Business	0	1	2	3	0	**6**	**1%**
CEE	2	16	4	10	1	**33**	**7%**
ChE	0	0	1	0	0	**1**	**< 1%**
Communications	0	0	1	0	0	**1**	**< 1%**
CS	1	9	3	0	0	**13**	**3%**
ECE	13	18	18	22	3	**74**	**15%**
ENGE	73	2	2	0	0	**77**	**16%**
Industrial Design	0	0	1	2	0	**3**	**< 1%**
ISE	0	1	4	9	0	**14**	**3%**
ME	25	31	71	31	5	**163**	**34%**
Nanoscience	0	2	0	0	0	**2**	**< 1%**
MSE	1	2	4	0	2	**9**	**2%**
Other	2	1	0	1	0	**4**	**1%**
University Studies	0	1	0	0	0	**1**	**< 1%**
Total	**127**	**114**	**136**	**97**	**12**	**486**	**100%**
%	**26%**	**23%**	**28%**	**20%**	**2%**	**100%**	

Table 13 – Team vs. Academic Level

Ware Lab Team	Freshmen	Sophomore	Junior	Senior	Graduate	Total	%
Astrobotics	4	9	7	7	0	**27**	**5%**
Baja	20	23	24	17	3	**87**	**18%**
BOLT	18	13	11	6	3	**51**	**10%**
CCT	1	1	0	0	0	**2**	**0%**
DBF	14	10	14	15	0	**53**	**11%**
FSAE	29	29	27	33	1	**119**	**24%**
HEV	20	8	17	7	5	**57**	**12%**
HPS	7	9	10	3	0	**29**	**6%**
SailBOT	6	9	7	6	0	**28**	**6%**
SBT	7	11	17	3	0	**38**	**8%**

Table 14 – Lab Area Square Footage

Bay/Area	Sq. Ft.	Student Number	Sq. Ft. per Student
Astrobotics/SailBOT	480	55	9
Baja	550	87	6
BOLT	490	51	10
DBF	250	53	5
FSAE	680	119	6
HPS	1200	29	41
HEV	980	57	17
SBT	470	38	12
Machine Shop*	1150	54	21
Weld Shop*	560	10	56
Offices	800	N/A	N/A
CAD lab*	500	20	25
Hallways/Loading Area	2000	N/A	N/A
Total	**10,110**		

*Denotes common-use area.

Ware Lab Outreach

In 2018-19, Over 2000 people visited Ware Lab from K-12 groups, universities, corporations, and Virginia Tech student families. Approximately 200 people attended our 20th anniversary and Ut Prosim events. Ware Lab students continue to serve as tour guide volunteers throughout the academic year with visitors are always being impressed with the caliber of work occurring in the lab.

Table 15 – Ware Lab Tours

Group	Quantity
VT Corps of Cadets	20
CEED	60
Committee of 100	90
Galipatia Outreach Committee	100
K-12	1040
Kids to College Program	75
Perspective Students	161
The Language and Culture Institute	20
Virginia Cooperative Extension (4-H)	100
Virginia Tech Alumni Reunion Weekend	20
VT Friends of Fulbright Argentina	23
VT Global Education Office	15
VTNETS Program	25
Ware Lab Open House	150
Ware Lab 20th Anniversary Event	150
Ut Prosim President's Circle Event	50
Total	**2100**

In addition to continuing to provide facility tours, Ware lab plans to participate in the upcoming STEAM (*Science, Technology, Engineering, Arts,* and *Math*) event on November 8, 2019 in Roanoke, Virginia. Figure 21 shows display-banners for the event which will host multiple K-12 public and home-schooled students from Roanoke and surrounding areas.

Figure 21 – Ware Lab banners for upcoming STEAM event in Roanoke, Virginia.

Machine/Weld Shop Statistics

Each year, the assistant lab manager provides comprehensive training for all Ware Lab teams. Training consists of a three hour secession within the machine and weld shop bays. Truck and trailer training is necessary due to the complexity of pulling a 35 foot goose-neck trailer, used by teams for transportation to competition. Tables 16 and 17 show the number of students trained in these areas.

Table 16 – Machine Shop/Hurco Training

Ware Lab Team	Machine Shop	Advanced Hurco
Astrobotics	4	0
Baja SAE	16	3
BOLT	10	0
Formula SAE	17	2
HEVT	4	0
HPS	2	0
Steel Bridge	1	0
Total	**54**	**5**

Table 17 – Truck/Trailer Training

Ware Lab Team	Number
SailBOT	3
Baja SAE	3
BOLT	3
HPS	3
DBF	3
Formula SAE	6
HEV	3
Total	**24**

Team Lab Access

Students have access to the general areas and machine shop after hours via a card swipe system. Figures 22 and 23 provide a summary of student access to these areas based a team breakdown, providing an indicator of how lab space is utilized. During operating hours the showroom door is unlocked and students can gain access without using their Hokie passport card. Formula SAE utilized the Ware Lab the most at 34% based on data provided by Virginia Tech Hokie Passport Services.

Table 18 – Team Access to General Lab Area (number of Hokie Card swipes per team)

Month-year	Astrobotics	Baja	BOLT	DBF	FSAE	HEV	HPS	SailBOT	SBT	Total
Aug-18	0	42	74	2	74	41	5	0	5	**243**
Sep-18	0	136	95	36	237	136	9	0	6	**655**
Oct-18	32	126	104	37	231	142	4	1	0	**677**
Nov-18	21	87	117	40	231	98	11	1	1	**607**
Dec-18	31	75	38	16	102	26	8	3	0	**299**
Jan-19	15	53	69	81	109	79	14	1	5	**426**
Feb-19	34	88	121	64	270	82	27	8	27	**721**
Mar-19	58	60	161	85	183	62	11	3	38	**661**
Apr-19	25	57	52	28	123	69	8	5	1	**368**
May-19	9	68	58	5	109	32	15	12		**308**
Jun-19	36	0	6	0	41	4	9	0	0	**96**
Jul-19	0	29	0	6	42	0	0	0	0	**77**
Total	**261**	**821**	**895**	**400**	**1752**	**771**	**121**	**34**	**83**	**5138**

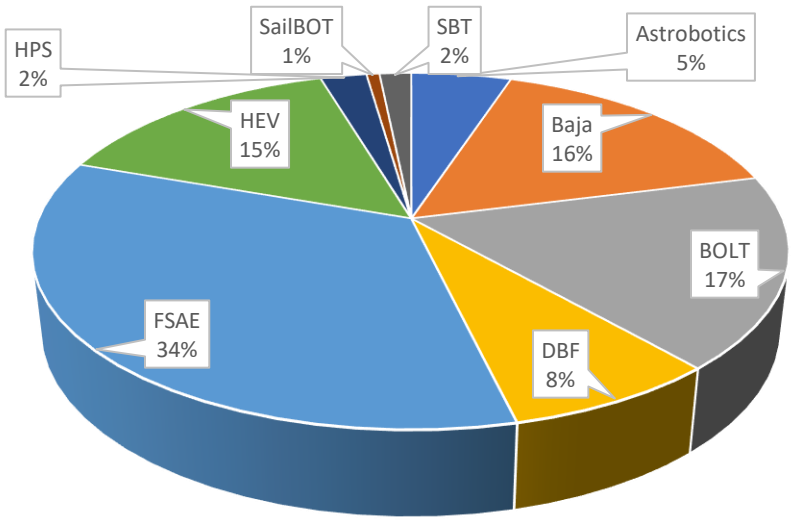

Figure 22 – Team access to general lab areas.

Table 19 – Team Access to Machine Shop
(number of Hokie Card swipes per team)

Month-year	Astrobotics	Baja	BOLT	FSAE	Total
Aug-18	0	23	2	11	**36**
Sep-18	0	117	18	193	**328**
Oct-18	0	79	3	202	**284**
Nov-18	4	12	35	439	**490**
Dec-19	1	3	20	264	**288**
Jan-19	1	71	25	357	**454**
Feb-19	23	120	31	588	**800**
Mar-19	65	126	65	281	**537**
Apr-19	10	77	11	134	**232**
May-19	1	53	5	144	**203**
Jun-19	0	98	0	94	**192**
Total	**105**	**779**	**215**	**2707**	**3844**

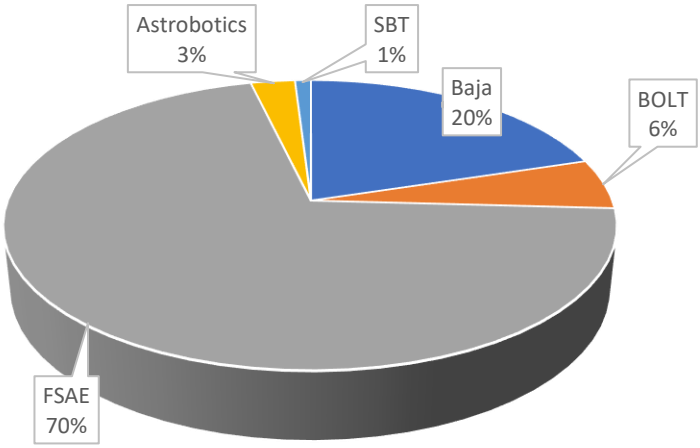

Figure 23 – Team access to machine shop.

Demographic Trends

Since 2012, students using the Ware Lab have completed a survey indicating major, academic level, and team affiliation. Based on collected data, trends in these areas are shown in Figures 24 through 26. Figures 27 and 28 show trends for Ware Lab gender and ethnicity, staring in 2014-15.

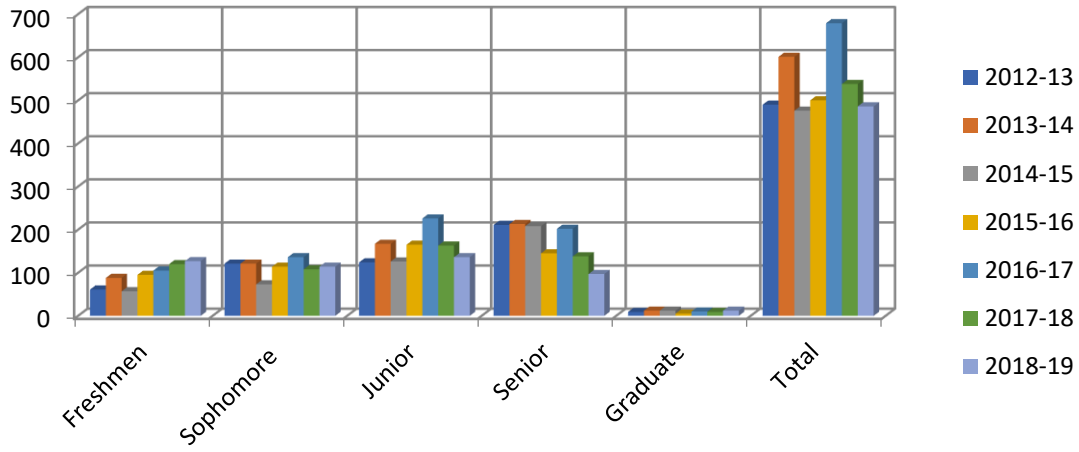

Figure 24 – Academic Levels (number of students).

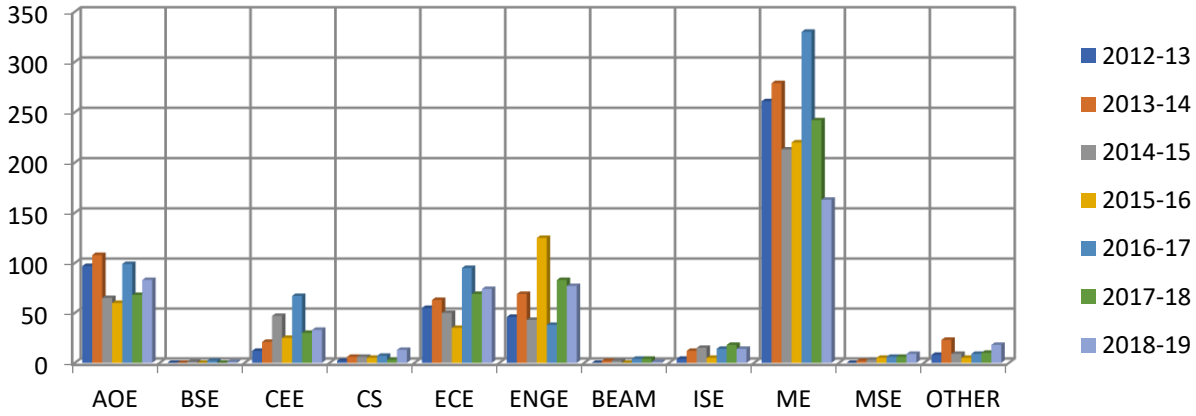

Figure 25 – Academic Majors (number of students).

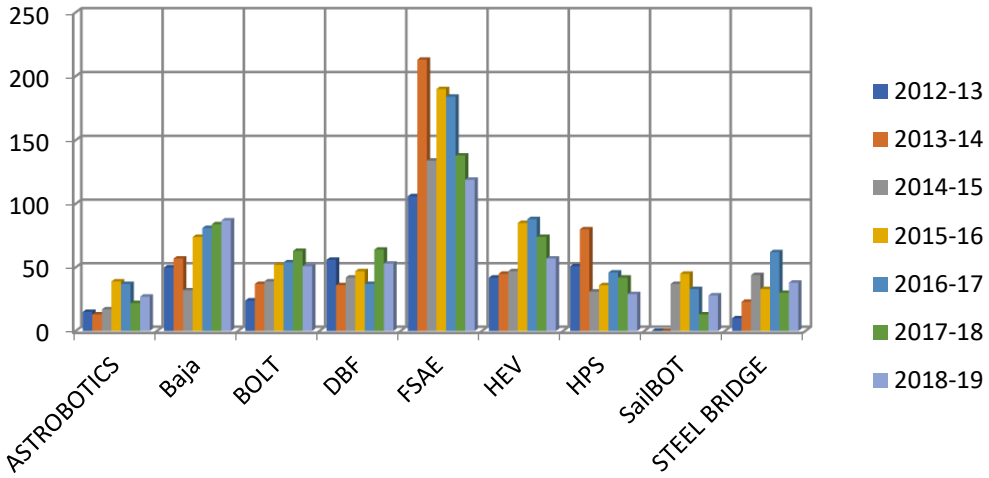

Figure 26 – Teams (number of students).

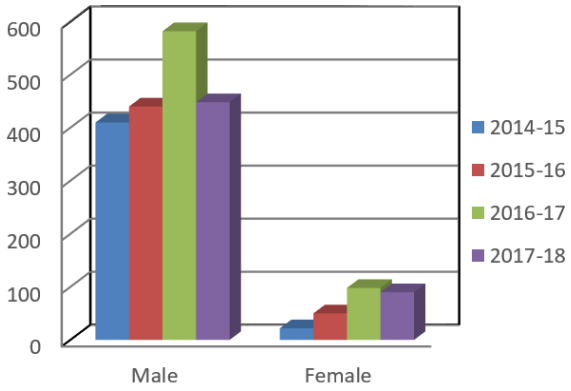

Figure 27 – Gender (number of students).

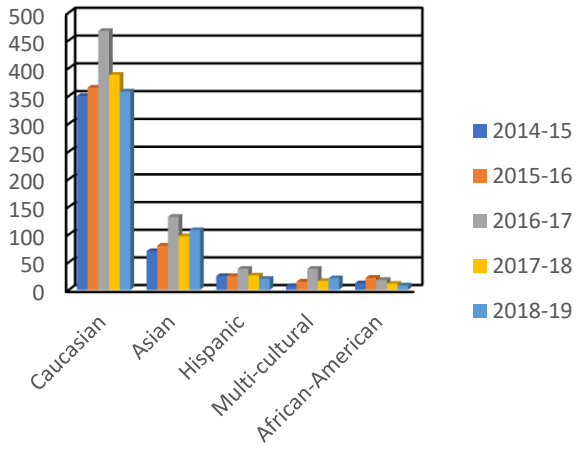

Figure 28 – Ethnicity (number of students).

Conclusion

This comprehensive 2018-19 annual report discusses sponsorship, project, and outreach related topics for the Ware Advanced Engineering Lab. Undergraduate students from multiple engineering majors comprise the teams who participate in designing, manufacturing and competing top tier projects. In addition to participating in regional and international events, Ware Lab teams take part in multiple outreach venues giving corporations, K-12 groups, universities, and the general public a chance to experience the outstanding work performed by our students.

Formula SAE, Hybrid Electrical Vehicle, and SailBOT teams earned in the top 15% at national competitions and outreach in the form of lab tours totaled over 2000 people from various educational, government and private sector venues. In total, teams traveled over 29,000 miles to multiple regional and international competition events throughout the United States. The Joseph F. Ware, Jr. Advanced Engineering Lab continues to be the main focal point of undergraduate engineering competition teams for Virginia Tech's College of Engineering.

Appendix A: Virginia Tech Ware Lab 2019 ISE Senior Design Project

In 2018-19 a team of senior design students from the *Industrial Systems and Engineering* department performed a comprehensive study to develop a lab expansion plan and determine if changes were necessary with regards to safety requirements and space utilization. The report concluded that the necessity of all Ware Lab team members taking the *EHS Hazard Assessment* course was not warranted. The report also provided two proposals of future lab expansion. One plan specifies expansion into the second floor of the Military Building and the other, more ambitious, plan specifies inclusion of "Ware Lab" type space in the basement of the new Randolph Hall once it is constructed. The report, as submitted to the Ware Lab director and manager, is contained in this appendix.

Virginia Tech Ware Lab
2019 ISE Senior Design Project

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(Virginia Tech Ware Lab)
(Dewey Spangler)

(Dr. Lance Franklin & Robin Miller)

Abstract - **The Ware Lab currently has approximately 10,000 square feet of space on campus here at Virginia Tech. In previous years, this has been plenty of space for the design teams, but more recently, with a growing undergraduate student population, the Ware Lab has been forced to turn away multiple new project teams. In addition, the Ware Lab has experienced a few near misses with regards to safety, which led to the implementation of additional safety training as well as bottlenecks in the machine shop. This team has been tasked with the objectives of developing an expansion plan for the Ware Lab, determining if any changes need to be made with regards to the safety requirements in the lab, and looking into the addition of another machine in the machine shop. The project stakeholders include: Dr. Bev Watford - Director of the Ware Lab, Dr. Ed Nelson – Associate Dean for the College of Engineering Administration and Chief of Staff, and Dr. Julia Ross - Dean of Engineering. The Ware Lab consists of 450 undergraduate students split among 11 design teams that compete in yearly competitions. The Ware Lab is an essential resource in acquiring potential students. In order to remain relevant, the Ware Lab should be expanded not only to give the current teams more space, but also to create space for new and innovative teams. Additionally, research has been conducted on the Ware Lab's peer schools to assist with the expansion plan to make the Ware Lab more comparable in size and features.**

Index Terms - Expansion Plan, Safety Training, Space Utilization

INTRODUCTION

In 1998, the Virginia Tech Ware Lab was founded by Dr. Joseph Ware Jr. and his wife, Jenna. Their vision for the Ware Lab was for undergraduate students to be involved on campus, collaborate in a team, and apply concepts learned in class to real world scenarios. Since 1998, the Ware Lab has grown significantly in size. The lab is now home to 11 undergraduate student-run design teams and over 450 students in a variety of majors. Each design team participates in national competitions with the goal of bringing home first place and sponsorships. As the number of undergraduate students at Virginia Tech increases, so does the involvement in the Ware Lab.

PROBLEM STATEMENT

The Ware Lab is comprised of approximately 10,000 square feet of space, which includes project bays for each team as well as a welding shop, a machine shop, a material processing bay, and a computer design (CAD) lab. In recent years, the number of undergraduate admissions has increased and is expected to continue to rise, specifically for engineering. The design teams located inside the Ware Lab began from an undergraduate student's idea. Every year, hopeful students submit new team ideas to the manager of the Ware Lab to receive a project bay within the Ware Lab. Unfortunately, most teams are turned away due to a lack of space in the current layout. Since space is a premium in the Ware Lab, the 11 teams constantly fight for space and time in the machine shop and the CAD computer lab. As technology continues to advance, students come up with design teams to join future competitions. However, the fact remains that the limited size of the Ware Lab is fixed and will not be able to accommodate for this growth. Without any growth to compete with design labs at peer universities, the Ware Lab will fall behind. The resulting consequences are teams losing out on sponsorship opportunities and Virginia Tech failing to attract prospective high school students since showcasing the Ware Lab attracts students interested in engineering. Therefore, the senior design team will ensure the current facility layout has optimal space utilization and determine an expansion space to aid in the development of new design teams while providing the current teams in the Ware Lab to space to grow.

Another part to the problem is safety. Currently, every member of the Ware Lab must take seven safety training courses in order to gain access and work on a design team in the lab. Additional training is required if a student wants access to work in the machine shop and/or welding shop. Recently, one of the seven courses was added due to two isolated safety incidents. The senior design team is tasked to decide whether or not the new hazard assessment training

should be required for all members of the lab, or for only specific members on each project team such as the team leaders and safety officers.

DESIGN METHODOLOGY, SOLUTION ALTERNATIVES, AND SELECTED APPROACH

We adjusted the IDOV method to IDDOV, which is Identify, Design, Do, Observe and Optimize, and Verify. Our method added the "Do" section in order to complement our goals for this project. This methodology is appropriate for the project because the goal is to make process improvements to the current lab safety requirements, to optimize the machine shop space utilization, and to develop an optimal expansion plan. The safety improvements require the team to determine if the safety training assessments and quizzes are value added for every member of the Ware Lab. Regarding the current space utilization of the machine shop, the team will determine if the current layout is optimal or if it needs improvements. Based on this analysis, space utilization recommendations will be provided. The expansion plan will be developed based on client information and feedback from Ware Lab team members. After taking the feedback and criticism into consideration, the layout will be optimized to ensure all the needs of the lab are met.

The solution alternatives for the safety trainings are to keep the seven safety trainings mandatory for every team member or to make the Hazard Assessment Training mandatory for team leads and safety officers and optional for all other members. For the machine shop, the alternatives are to leave the machine shop as is, replace outdated machinery with new machines, or to reconfigure the layout to make room for additional machines. For the expansion plan, the team investigated two location options: the second floor of the Military Building and the proposed Randolph Hall basement.

The selected solution approach for the safety trainings was to only make the Hazard Assessment Training mandatory for team leads and safety officers. Based on feedback from the team members, the faculty advisors, and the client as well as our personal analysis while completing the assessment, the team determined this was the appropriate solution to pursue. The client, several survey respondents, and the team noted that the Hazard Assessment Training only really needed to be completed by the team leads and safety officers since they would be the individuals actually completing the Hazard Assessment for the teams. For the general members who would not be completing the assessment, their time could be spent more efficiently by beginning work on the projects. However, several respondents did note that they still wanted everyone to complete the Hazard Assessment Training since safety is everyone's concern, which is why the team added that the other members could be assigned the training course if the team leads and/or faculty advisors believe it is necessary for their project and project role; it will just no longer be a requirement for everyone to obtain their badges.

In order to discover the machine shop needs of the lab, the team sent surveys to the members as well as faculty advisors for each of the 11 undergraduate project teams to gain insight into the general amount of time spent utilizing the machines in the machine shop. After gathering and analyzing all the survey data, the team realized there was a strong need for at least one new machine in the machine shop to reduce the bottlenecks that become especially apparent during competition season. Most teams noted waiting upwards of five hours to use the lathes, the mills, and the Hurco. After discussions with the client, it was made clear the next step should be to determine the current space utilization of the machine shop. The team took measurements of the shop and created a layout in AutoCAD, which helped to determine the space utilization. The team decided in order to improve the space utilization and make room for an additional machine, some of the machines and miscellaneous items in the shop would need to be moved around or repurposed in a different area of the Ware Lab. The team determined that adding two machines instead of leaving the layout as is or replacing the older machines would be the best solution because entirely adding the machines resulted in the greatest increase in machine capacity. Using AutoCAD, the team was able to test multiple layouts and discover one that improved the space utilization as well as made room for two additional machines. The machines to be added to the layout are one CNC lathe and one CNC mill. This decision was made in order to reduce the average wait time for lathes and mills. The team then calculated the space utilization of the new potential layout to compare it to the original in order to notice any improvements.

The selected solution approach for the expansion plan was to plan for and pursue both locations. The primary plan was to move into the upstairs of the Military Building, and the secondary plan was to move to the proposed Randolph Hall basement. To determine the specifics for these expansion plans, the team first surveyed Ware Lab team members to better understand their spatial needs as well as discussed the lab's needs with the client. Almost every team noted that they needed or would soon need additional space. Baja SAE provided one example of why they need space, stating how they can barely simulate competition activities with just one car in the bay, but there are times where they need two cars in the bay. Another example from Bolt is that their project requires high voltage work, and while the danger zone to safely complete this work increases, the rest of their workspace decreases. From this feedback, the team was able to begin developing floor plans for these potential locations. When developing the expansion plan layout for the Military Building, the team took inspiration from the layout the client had previously provided. The layout for the Randolph Hall basement was made entirely from scratch. The new layout incorporates a U-line configuration in order to improve flow and space in the layout. The Ware Lab does many tours all throughout the year. The U-line design helps to ensure multiple tours have enough space to not run into each other.

Additionally, in order to determine a baseline for the Ware Lab, the team was given a list of peer schools who also have a Ware Lab like space. The average amount of machines at the peer schools is 23 while the Ware Lab only has 12. To

stay competitive with peer schools, the square footage of the machine shop needs to at least double. This is the reason the machine shop in the Randolph Hall basement is over 2,000 square feet, which is over double the size of the current machine shop. With this increase in square footage, it is expected that the new machine shop will be able to house at least 24 machines, which exceeds the average machine count in the peer schools' labs.

RESULTS

The team chose to make the Hazard Assessment Training mandatory for the team leads and safety officers. This specific training is made optional, and up to the discretion of each design team's faculty advisor and team leads to the remaining team members. This change will need to be implemented through the Hokie Passport Services, so that team members can retrieve their badge from the office without needed to complete the Hazard Assessment Training.

We also improved space utilization in the machine shop by utilizing more of the wall spaces and removing some of the tables from the shop. With that being said, the team found valuable space that the Ware Lab could add additional machinery. A CAD drawing of the proposed new layout can be found in the Appendix. The graph below in Figure I compares the number of machines in the current layout to the number of machines in our proposed solution.

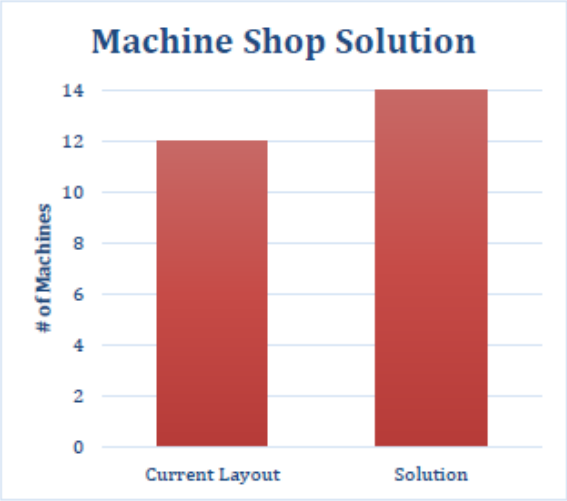

FIGURE I
NUMBER OF MACHINES IN THE MACHINE SHOP LAYOUTS

Lastly, the team wrote a comprehensive expansion plan proposal that contains both solutions. The first solution is to expand into the second floor of the military building, currently occupied by the Virginia Tech Corps of Cadets (VTCC) and Army and Air Force ROTC programs. A CAD drawing of the proposed layout can be found in the Appendix. This expansion solution will double the size of the current Ware Lab. Table I found below compares the square footage of the current bay dimensions and the proposed bay dimensions for the automotive teams to highlight a few of the major changes in square footage. However, in order for this proposal to be taken into effect, the VTCC and ROTC departments must move into their own designated military science building, which has yet to start construction. Alas, the implementation of the team's proposal may take several years once the upstairs occupants are officially moved out. The second solution is for the Ware Lab to move into the basement floor of a proposed new Randolph Hall. A CAD drawing of the proposed layout can be found in the Appendix. This solution is much more lucrative as the space of the entire building is set to be 280,000 square feet. An assumption made is that there will be five total floors with equal square footage, one of which is the basement. If the Ware Lab is given just 20,000 square feet of the estimated 56,000 square foot basement, the Ware Lab will look aesthetically pleasing and will have adequate room for additional machinery and a high-bay capacity. Table II found below highlights some of the major changes in square footage between the current layout and this solution with regards to the automotive teams, the machine shop, and the welding shop. The new Randolph Hall is set to open between 2025-2026. In both designs, there is more space for design teams, offices, a conference room for team meetings and/or professional meetings with sponsors, and an innovative space that will feature state of the art equipment, such as 3-D printing. The total square footage in the current facility layout and both solution layouts is compared in the graph in Figure II below.

TABLE I
PROJECT BAY DIMENSIONS BEFORE AND AFTER EXPANSION INTO THE SECOND FLOOR OF THE MILITARY BUILDING

Team	Current Sq. Ft.	Solution Sq. Ft.
Bolt	490	680
HEVT	990	1480
Formula SAE	680	1025
Baja SAE	525	975

TABLE II
PROJECT BAY DIMENSIONS BEFORE AND AFTER EXPANSION INTO THE RANDOLPH HALL BASEMENT

Team/Item	Current Sq. Ft.	Solution Sq. Ft.
Bolt	490	830
HEVT	990	1120
Formula SAE	680	1120
Baja SAE	525	1120
Machine Shop	1150	2200
Welding Shop	586	915

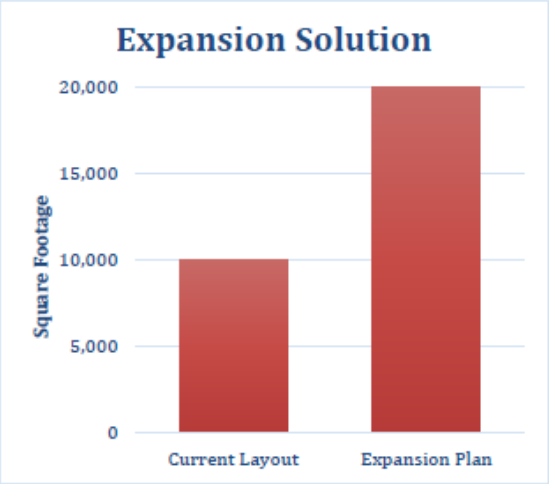

FIGURE II
WARE LAB SQUARE FOOTAGE

IMPACT

The project impacts safety procedures to obtain a Ware Lab and the current and future design of the Virginia Tech Ware Lab. The process to obtain a Ware Lab badge is a long, and arduous process. There are seven training assessments that must be taken, and to fully complete these training assessments take up to six hours per student. In previous years, there were only six training assessments, but as a result of a near miss in the Ware Lab, steps were taken to improve safety by adding a hazardous object training assessment. As a result, another assessment was added that increased the time and energy to obtain a Ware Lab badge. After deliberation with the Ware Lab team members, faculty members, and our client, it is recommended that the Hazardous assessment training is made optional, and up to the discretion of each design team's faculty advisor and team leads. With this decision, it will allow each team to demonstrate more responsibility, and freedom to decide, collectively as a whole, on what to do with the assessment, and also reduce the amount of time it takes to complete training assessments for a Ware Lab access by about 14%.

The machine shop will feature a change in machine placement to improve space utilization. By rearranging the room to make use of the wall spaces, and taking tables out, the space utilization will increase by 3% while the machine capacity increases by 17%. In implementing the solution to the current Ware Lab machine shop layout, an extra lathe and mill can be added. As a result, it will be a financial cost of about $60,000 for each machine. One cost consideration that is not taken into account is the labor hours that would be required to rearrange the room to fit the machine.

The renovation of the Ware Lab includes drawings of the top floor of the military building when the Corps of Cadets and ROTC programs transitions out of the building. In the design there is more space for design teams, offices, a conference room for team meetings and/or professional meetings with sponsors, and an open innovative space that will feature state of the art equipment such as 3-D printing.

The projected impact is expected to increase undergraduate student involvement in the Ware Lab by over 100 students. It is also expected to attract over 400 students to the College of Engineering at Virginia Tech. The K-12 STEM Outreach Program is essential to introducing the world of engineering to kids of all ages. By increasing the square footage of the Ware Lab, the involvement in the lab should increase by approximately 1,500 individuals. In addition to an increase in the involvement, sponsorships should increase by nearly $100,000, and the Ware Lab's outreach with other universities should increase by approximately 150 individuals.

Additionally, the expansion of the Ware Lab into the Randolph Hall basement will feature key changes to the machine shop. One of these changes includes a new hire for an additional assistant manager in the expanded Ware Lab. This role will be similar to the current assistant manager. The main responsibility of this new position will be managing the machine shop area(s). The estimated cost of this position is an annual salary between $50,000 and $60,000.

Another key change to address the bottlenecks in the current machine shop are having more machines in the new machine shop located in the Randolph Hall basement. An increased total space of 20,000 square feet will allow more room for a larger machine shop. This expansion will increase the capacity and decrease the waiting time for these machines by at least 50% (five hours reduced to to two and a half hours) for the students during competition season to manufacture their parts. The larger machine shop will now feature at least six lathes, two Hurcos, and six mills as well as the other miscellaneous machines currently in the machine shop. Also, the new CAD lab will more than double in size to 20 computer stations, which will be fully equipped for the students to use for their CAD work and other project simulations.

The main goal of the Ware Lab when it first opened 20 years ago was to provide undergraduate students a space to engage and gain valuable experience in real-life engineering problems that will build a strong foundation for students' successes in the real-world. Ultimately, these changes to the Ware Lab will improve Virginia Tech, and act as a method to recruit prospective students to the program. Therefore, as a major draw to prospective students to see an innovative, and practical space, it will recruit more students to the college of engineering. As a result, the school will gain more students that will be qualified, and build upon the reputation and prestige of having an engineering degree from Virginia Tech, and also practice the school's motto Ut Prism. In addition, it will draw more students to join the Ware lab with more available teams. As a result, there is a possibility for more corporate sponsorships to fund projects, and continued success will build an even greater engineering program that will be highly regarded among the world.

CONCLUSION

The team took on an approach of Identify, Design, Do, Observe and Optimize, and Verify since our objective was to make process improvements to safety, space utilization, and to develop an optimal expansion plan.

We determined if the safety training assessments and quizzes were value added for each member of the Ware Lab. We recommended that the Hazardous assessment training is made optional, and up to the discretion of each design team's faculty advisor and team leads. This will allow each team to demonstrate more responsibility and reduce the amount of time it takes to complete training assessments for Ware Lab access by about 14%. This change will need to be implemented through the Hokie Passport Services.

We also determined if the machine shop utilization was optimal. Based upon this analysis, we then provided space utilization recommendations with the addition of client information and feedback. The team rearranged the machine shop by utilizing more wall spaces, and taking tables out. We then proceeded to write a written expansion proposal for two solutions: expanding into the second floor of the Military Building and the moving into the basement of the proposed new Randolph Hall.

The design for each of the two solutions guaranteed more space for design teams, offices, a conference room for team meetings and/or professional meetings with sponsors, and an open innovative space that will feature state of the art equipment such as 3-D printing.

However, the implementation of the expansion portion of this project hinges on the successful construction of buildings, the new military science building or the new Randolph Hall. With that being said, future work for senior design teams may involve them having to monitor the status of the construction of these buildings. Since the construction of buildings is a long and arduous feat, the Ware Lab will have to continue to operate on the limited space that they have now. It will take several years for their expansion to come to fruition.

ACKNOWLEDGMENT

Natalie Cherbaka, Industrial and Systems Engineering Professor, for assisting the team with facilities matters

Robin Miller, Occupational Safety Program Manager, for offering guidance throughout the project

Dewey Spangler, Ware Lab Manager, for working with the team and providing great feedback

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[2] D. Spangler, "Joseph F. Ware, Jr. Advanced Engineering Lab Annual Report," rep., 2018.

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APPENDIX

FIGURE III
CURRENT MACHINE SHOP LAYOUT AND FUTURE MACHINE SHOP LAYOUT

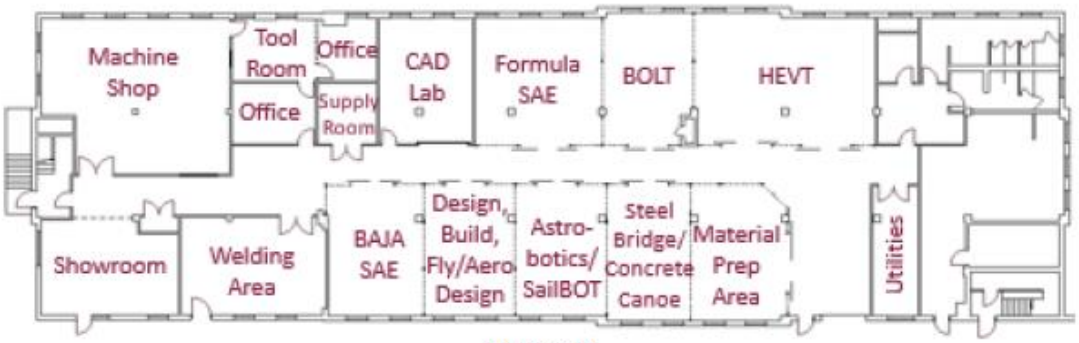

FIGURE IV
CURRENT WARE LAB LAYOUT

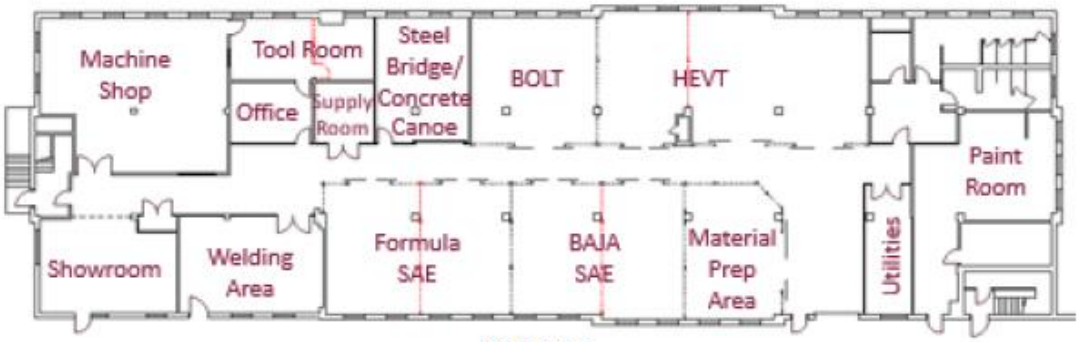

FIGURE V
FIRST FLOOR OF THE MILITARY BUILDING EXPANSION SOLUTION

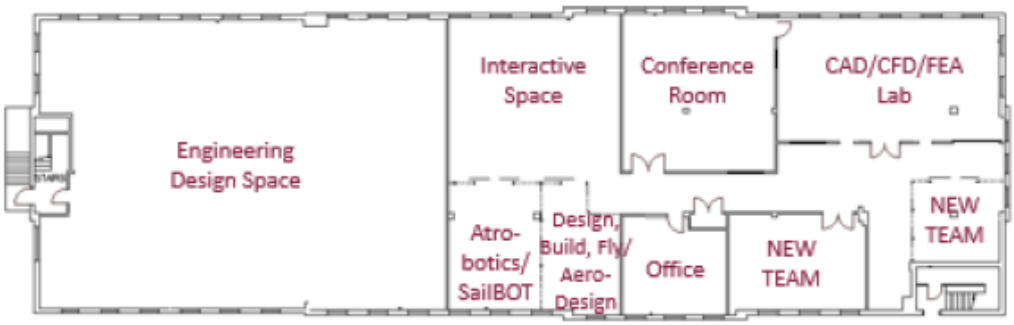

FIGURE VI
SECOND FLOOR OF THE MILITARY BUILDING EXPANSION SOLUTION

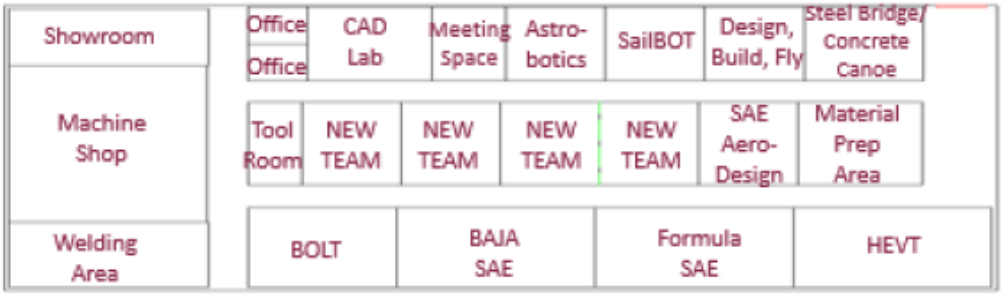

FIGURE VII
RANDOLPH HALL BASEMENT EXPANSION SOLUTION