Design, Construction, and Testing of a Prototype Test Unit for "Impact of a Jet" Experiment through Senior Design at Southern Arkansas University

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Abstract

"Impact of a Jet" experiment is a commonly offered laboratory exercise in most undergraduate engineering programs. The equipment available in the market for this experiment can be expensive despite the fact that no sophisticated technologies are involved. This paper presents an attempt to develop a low cost prototype equipment for "Impact of a Jet" experiment through senior design course at Southern Arkansas University.

Introduction

"Impact of a Jet" is a common laboratory exercise offered by most undergraduate engineering programs. The purpose of this exercise is to demonstrate the relationship between force and rate of change of momentum. In an undergraduate fluid mechanics course, theoretical equations for rate of change of momentum are usually derived from the Reynolds transport theorem.

Almost all technical teaching equipment companies such as TQ equipment, EDIBON, and US Didactic produce and market an apparatus for the measurement of force on solid surfaces due to the impact of a water jet. Most designs use a vertical jet as shown in Figures 1-4. The apparatuses produced by those vendors can be expensive despite the fact that they are not based on sophisticated designs.

Developing laboratory facilities in an engineering program is a major challenge due to financial constraints. Many engineering programs adopt various approaches to reduce the cost associated with laboratory classes. Douglas and Holdhusen (2013) reported the development of hands-on lab experiments for an online course in mechanics of materials. Torick and Budny (2009) developed a fluid mechanics lab under six thousand US dollars.

The engineering program at Southern Arkansas University(SAU) is a new program that started in 2014. As the case may be with many engineering programs, the Engineering and Physics department at SAU will strive to develop laboratory facilities with a mixture of purchased

equipment and in-house built apparatuses. This approach will help reduce the cost to some extent but will not compromise on the quality of laboratory exercises.

The Senior Design course is the perfect avenue to build in-house equipment because students can get extremely valuable design experience with hands-on work.

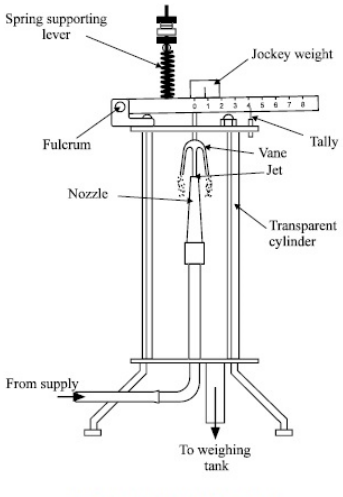

Figure 1. Configuration of an impact of a jet test unit

Figure 2. Impact of a jet experiment unit from TQ equipment

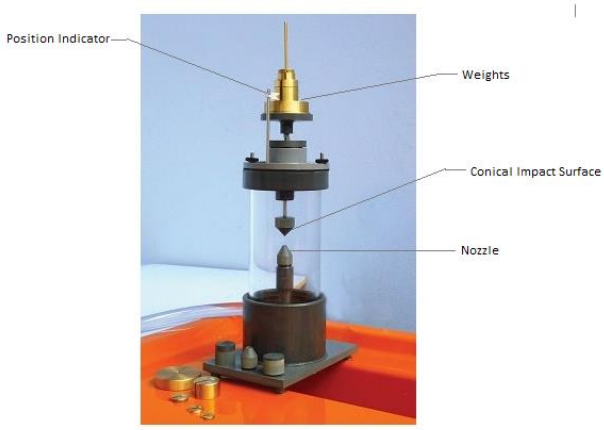

Figure 3. Impact of a jet experiment test unit with a base for load mounting

Figure 4. Apparatus for impact of a jet experiment from EDIBON Co.

Ahmed et al. (2015) first reported the beginning of constructing lab equipment in-house at the Engineering and Physics department at SAU. This current paper reports the continuation of the effort made earlier and discusses the building of an equipment in-house for the "Impact of a Jet" experiment.

Design and Construction of the Lab Equipment

The equipment was designed, constructed, and tested in a senior design project undertaken by three senior students Joseph Lonigro, John Hauver, and Allan Derrickson in spring 2017. They underwent a complete design experience in the process. The design team researched existing designs, developed engineering design specifications, produced a project management plan, evaluated several concept designs using the Weighted Rated method, selected the final design, completed engineering calculations, produced engineering drawings, prototyped the selected design, and carried out test trials. They also made two presentations and produced a final comprehensive report. In developing the equipment, the major objective was to produce a low cost, easy to build and maintain, and effective set up to be used in the Thermal Science laboratory at SAU. Figures 5 and 6 show the final configuration of the equipment and completely assembled set up.

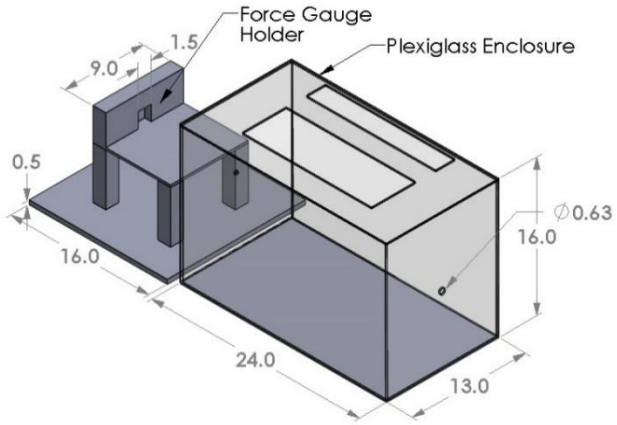

Figure 5. Tank and the force sensor support

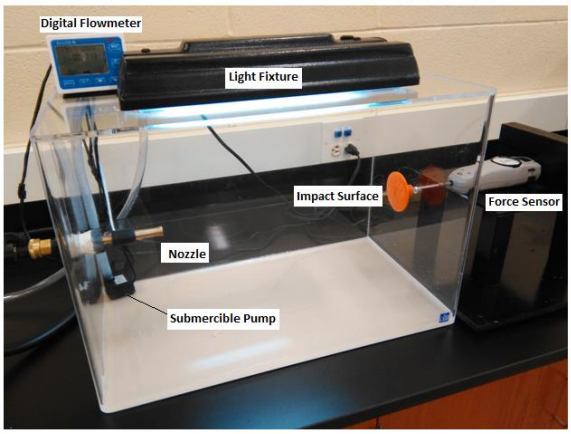

Figure 6. Assembled setup

The experimental set up consists of a transparent rectangular tank, a nozzle, a digital flow meter with water temperature sensing capability, a force sensor, a submersible water pump, a light fixture mounted on top of the tank, 3D printed impact surfaces, and plastic hoses connected to a water faucet. The approximate cost of each component is given in Table 1. The total cost was $910.

Table 1. Approximate cost of the equipment

Component	Cost ($)
Tank	175.00
Digital Flow Meter	90.00
Omega Force Sensor	570.00
Submersible Pump	10.00
Nozzles	20.00
Shut off Valve	10.00
3d Printed Impact Surfaces	25.00
Plastic Hoses	10.00
Total	910.00

Evaluation of the Equipment, Results, and Discussion

Several test trials were completed with a circular vertical impact surface at different flow rates, and the corresponding force sensor readings were recorded. It was ensured at each flow rate that the water jet remains horizontal to minimize the gravity effects. The flow meter can read one hundredth of liters per minute while the force sensor can read from 0 – 5 kgf with an accuracy of 0.025 kgf. In laboratory trials, volume flow rate was adjusted to read an accurate force reading on the sensor. Theoretical impact force was calculated using the equation $F = -\rho A V^2$ where F is the horizontal force, ρ is the fluid density, A is the cross sectional area of jet stream, and V is the jet stream horizontal velocity. This equation can be derived using the Reynolds transport theorem applied to a fixed control volume. The negative sign indicates that a force similar to the impact force should be applied in opposite direction to hold the vertical surface stationary.

Table 2 presents the computed force, theoretical force, and the percentage error for each flow rate for a circular vertical impact surface. Each data point is the average of five trials. Raw data of each trial is presented in the appendix.

It can be seen from Table 2 that the percentage error is positive, and the equipment tends to overestimate the impact force. Even though the maximum error is around 20%, the percentage error is below 15% at most flow rates. In these lab trials, water jet showed the formation of bubbles before impacting the surface. This bubble formation may have contributed to the error. However, the formation of bubbles before the impact can be removed by moving the nozzle closer to the impact surface. We intend to modify the equipment by introducing a movable jet so that the impact force can be determined accurately. This modification will also minimize any errors caused by gravity effects.

Table 2. Comparison of theoretical force and experimental force in "Impact of a Jet" experiment with a circular vertical flat surface

Volume Flow Rate (L/m)	Volume Flow Rate (m^3/s)	Experimental Force (N)	Theoretical Force(N)	Percentage Error (%)
5.43	91×10^{-6}	1.32	1.16	14.2
6.45	108×10^{-6}	1.96	1.63	19.9
7.48	125×10^{-6}	2.45	2.20	11.5
8.16	136×10^{-6}	2.79	2.61	6.8
8.64	144×10^{-6}	3.28	2.93	12.0

Figure 7 shows the variation of impact force with the rate of delivery of momentum. The relationship between the impact force on the vertical surface and the rate of delivery of fluid momentum is linear as expected. Ideally, as reported in the TQ equipment technical data sheet, the graph depicting the impact force and rate of delivery of fluid momentum for a vertical surface should be a straight line going through the origin. Experimental data presented in Figure 7 shows a similar trend with a slight error.

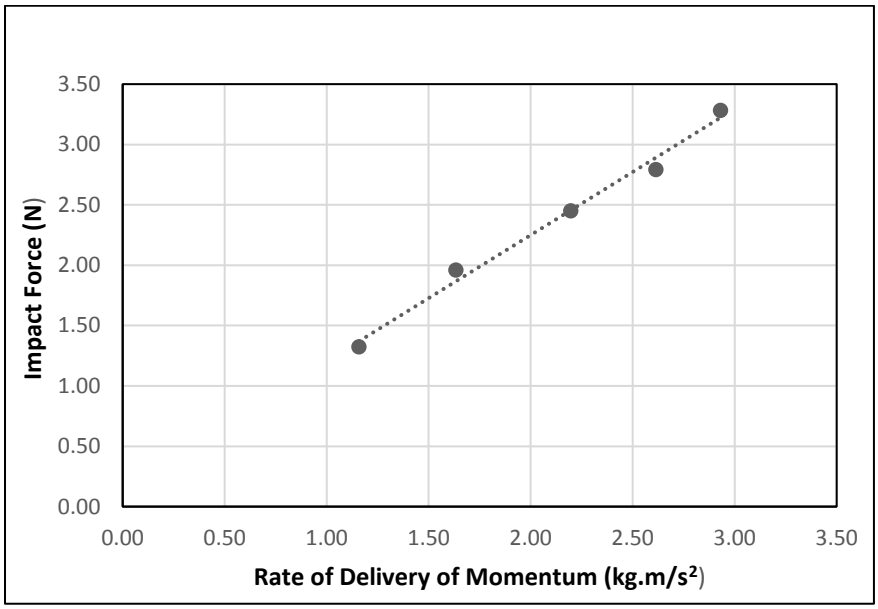

Figure 7. Variation of impact force with rate of delivery of momentum for a vertical flat plate.

Conclusion

The work presented in this paper shows that an equipment based on a horizontal water jet can be successfully used in an "Impact of a Jet" fluid mechanics laboratory experiment. The reported error is under 15% in most cases and can be reduced further with some improvements to the equipment. The cost of equipment available in the market for "Impact of a Jet" experiment is several times higher than the cost of the equipment presented in this work. Therefore, developing laboratory equipment in –house whenever sophisticated technology is not required is a worthwhile consideration for any engineering program.

References

1. Ahmed, Mahbub., Hewavitharana, Lionel., McKay, Scott., Ahmed, Kendra (2015). *"Development of Low-Cost Laboratory Experiments for Southern Arkansas University's Engineering Program"*, ASEE Zone III, Springfield, Missouri
2. Douglas, Jamie., Holdhusen, Mark (2013). *"Development of Low-Cost, Hands-On Lab Experiments for an Online Mechanics of Materials Course"*, 120th ASEE Annual Conference & Exposition.
3. Torick, David., Budny, Dan (2009)."*Adjusting the Curriculum in the Fluid Mechanics Course by Modifying the Laboratory Setting"*, American Society for Engineering Education, AC 2009-1159.
4. White, Frank(2008). *Fluid Mechanics*, Sixth Edition, Chapter 3, Integral Relations for a Control Volume, PP. 137-192, McGraw-Hill Publishers.
5. Technical Data Sheet-Impact of a Jet –QT Equipment
6. Technical Data Sheet – Impact of a Jet – EDIBON Educational Equipment

Lionel Hewavitharana, Ph.D.

Dr. Lionel Hewavitharana is an Associate Professor at Southern Arkansas University(SAU). He obtained his BS degree in Mechanical Engineering from the University of Peradeniya, Sri Lanka, and the Ph.D. from Louisiana Tech University. Dr. Hewavitharana came to SAU from the University of Central Florida(UCF) where he was with the Mechanical and Aerospace Engineering(MAE) department from 2012 to 2015. At UCF, he was the lead instructor of the MAE department's Capstone Design course.

Mahbub Ahmed Ph.D., P.E.

Dr. Mahbub Ahmed is an Associate Professor at Southern Arkansas University(SAU). He obtained his BS degree in Mechanical Engineering from the Bangladesh University of Engineering and Technology. In 2008, he obtained his Ph.D. in Materials Science and Engineering with an emphasis in Mechanical Engineering. Dr. Ahmed came to SAU from Georgia Southern University where he was a Lecturer and a Visiting Assistant Professor.

John Hauver
John Hauver is a senior student majoring in Engineering and Engineering Physics at Southern Arkansas University(SAU). He is on track to graduate in August 2017.

Joseph Lonigro
Joseph Lonigro was an engineering student at Southern Arkansas University(SAU). He graduated with BS in Engineering in May 2017.

Allan Derrickson
Allan Derrickson was an engineering student at Southern Arkansas University(SAU). He graduated with BS in Engineering in May 2017.

Appendix

Table 3. Lab trials for force measurement in “Impact of a Jet” experiment – vertical surface

Trial#1		Trial#2		Trial#3		Trial#4		Trial#5	
Flow Rate (L/min)	Exp. Force (kgf)	Flow Rate (L/min)	Exp. Force (kgf)	Flow Rate (L/min)	Exp. Force (kgf)	Flow Rate (L/min)	Exp. Force (kgf)	Flow Rate (L/min)	Exp. Force (kgf)
5.72	0.15	5.73	0.15	4.68	0.10	4.84	0.10	6.18	0.18
6.43	0.20	6.78	0.23	6.04	0.18	6.30	0.18	6.70	0.20
7.44	0.25	7.03	0.25	7.20	0.25	7.24	0.25	7.70	0.25
8.30	0.30	8.0	0.28	7.98	0.28	8.13	0.30	8.00	0.28
8.70	0.35	8.5	0.35	8.62	0.35	8.5	0.43	8.57	0.33