

# A Innovative Simple Lab Facility to Teach High Speed Jet Characteristics to Aerospace Engineering Students

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**Abstract :** In a laboratory environment a comprehensive discussion about the jet characteristics where students can visualize the characteristics, pattern of the jet flow. A project-based learning approach is adopted to make students understanding better about the jet phenomenon. A novel experiment set up is established. Hydraulic analogy concept is adapted in the experimental procedures. A detailed time chart and critical examination of results are presented in this paper. The method of evaluation is presented with results. The discussed learning methodology seems to be very effective and significantly increases the understanding level.

**Keywords:** Jets, Project Based Learning, Higher Level Competency, Project Study

## 1. Introduction

This paper discuss the effective tools for teaching jet studies to the undergraduate aerospace students in a simple way. The method includes design of low-cost experimental setup for demonstration purpose. This paper also discusses the attainment of knowledge by the student in the proposed area with adequate measuring techniques. In this work students are involved in the task through project-based learning (PBL). The learning method involves students directly. Students' problem-solving skills will be honed through this learning approach. PBL requires students to collaborate with others while also considering what they have learnt. Additionally, by honing their practical thinking abilities, students can participate actively in the search and decision-making process. Learning that is more focused on the student is called project-based learning. One of the educational methods that help students overcome challenges is project-based learning. PBL also helps students improve their knowledge of scientific methodology. As a result, students who master the scientific method come up with solutions to their problems by posing inquiries, exchanging viewpoints, forming hypotheses, performing experiments, and gathering and analyzing data.

The proposed work is based on simulating supersonic speed jet in a water jet facility using different nozzles. A jet is defined as a small pressure

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disturbance subjected to fluctuations. Studying a jet flow is important as it is responsible for acoustic noise generator in aircraft engine, also impinging a jet is important for engine cooling at the rocket base. So a propulsion stream oriented B.Tech Aerospace engineering student must aware of phenomenon called "JET". Understanding a jet characteristic is quite complex for a undergraduate student since it requires either a computational facility or a highly sophisticated measurement techniques. The observations on high-speed jet are time consuming and highly skill orientated. For instant, developing algorithms in OPENFOM, simulating the jet in ANSYS using pre-defined tools in the software requires expertise or complete understanding of the fundamentals is must. In other ways, flow visualization tools such as schlieren mirrors, shadow graph cost heavily which cannot be affordable for a self-financing institution. The mirror image techniques also required skilled workforce to get a proper image of the jet. In addition to the above said problems, charging the tank to get a Mach jet of 2 requires minimum 20 liters with a charging time of 45 minutes.

To avoid all those difficulties, we have developed a novel device in such a way that anybody can easily visualize a jet pattern emanating from any type of nozzle. The present research focused on developing a low-cost setup to impart knowledge on jet characteristics to the aerospace graduate at university level. Focus group talks and a survey were done to gain input from the project group, and the results are reported. We questioned them regarding the effect that the project experience had on their practical knowledge and whether it affected how well they learned.

## 2. Background

To meet up the specific task we have adopted project-, such as the B.Tech in Aeronautical Engineering based learning (PBL) approach [1]. The guiding learning outcomes serve as the overall basis for the creation of four-year programmes degree at the school of aeronautical engineering, Bharath Institute of Higher Education and Research (BIHER) Chennai, India.

1. Express the method of achieving perfection in project implementation and completion
2. Build the skills, competencies and point of view of

designed concepts.

3. Replicate professional skills in Presentation, Technical report writing, critical thinking and decision making

The first step in a project work is choosing a subject that will make students to identify a problem/issue. Of which these issues/problem is amenable to experimentation or observational solutions. Each person or group starts looking at knowledge on a specific subject (Kizapan & Bektas, 2016) [8]. As a result, students submit solutions to issues; at schools, these solutions are referred to as "Project Plans." Next, each person or group gathers the data and papers required to support or prove the thesis.

**Table 1 : Assigned Roles to the team members**

Sl.no	Roles	Assigned to
1	Team Lead & Computer Aided Design	Student 1
2	Simulation of Jet characteristics	Student 2
3	Camera handling techniques	Student 3

Usually, jet studies are carried out in a high speed jet apparatus which consists of a large storage tank, blower and automated traverse mechanism. At BIHER existing jet facility comprises (as shown in Fig.1) of 20litres capacity storage tank and automated traverse mechanism to measure pressure of the jets. The equipment cost around 25Lakhs, further minimum of 120 minutes required to charge the tank through 50Hp motor for a running time of less than 80seconds. So it is obvious that high standard safety measures are required to maintain during the process of experimentation. Hence most of the time the facility is not utilized for B.tech project fearing about the cost of fabricating a MS nozzle (almost Rs.10000 per piece) and over consumption of electricity, adequate maintenance. During the time of the project work the above said facility is kept under maintenance. Hence the project group and project supervisor are forced to look for alternate testing facility.

The original problem statement is to calculate the potential core length from a rhombus shaped nozzle for a Mach number of 1.5. The student group is expected to deliver a solution within a span of ninety days. The project group and the project mentor



**Fig. 1 : Existing High Speed Jet Facility at BIHER**

identified analogy method as the potential method to propose the solution to the problem. The past works of Mach [2], Von Karmen [3] gives the fundamentals of compressible flow analogy. This methodology is widely used in the research of Matthews [4] for education purpose. By using hydraulic analogy Linke et al.[5] developed a course on aerodynamic shapes at university of California. A unique and first of its kind lab facility is developed by E.RathaKrishnan [6] at Aerospace Engineering Department, IIT Kanpur, India. The formulation of mathematical equations for this analogy is presented to the student and skipped as it is not deemed to fit under the scope of this article. The project plan is devised in such a way that using hydraulic analogy concept a novel low cost experimental test is intended to develop instead of using the existing jet facility (which is under maintenance) at BIHER.

**Table2: work flow chart**

Weekly activities	Work Details
1	Formation of Objective
2	Literature Review
3	Literature Review
4	Design of Water Channel
5	Fabrication of Water channel
6	Fabrication of 3D printed nozzle
7	Trail runs in water channel
8	Trail runs in low speed jet facility
9	Image processing
10	Report Preparation
11	Internal Evaluation
12	External Evaluation

### A. Work Methodology and Activity Chart

The work is designed in such a way that the periodic review and examination of the results are matching with the final year eight credit project work course code titled BAN8P1. The work schedule is framed as presented in table. 1

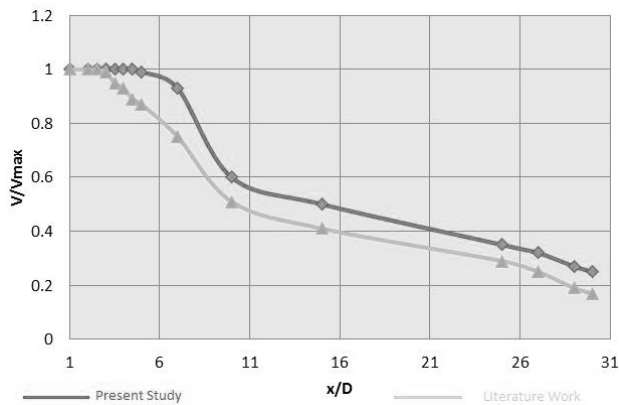
### B. Design of Water Channel

The experiment set up is made using glass slabs of 8mm thickness with dimensions of 914.40mm length, 609.60mm width, and 457.2mm height. With an inlet of radius 12.70mm. A cylindrical storage is fabricated using cast iron with the dimensions of 1000mm length, inner diameter of 165mm, and outer diameter of 175 mm with an outlet of diameter 25.40mm. Stand is fabricated using cast iron, A nozzles of rhombus exit geometry is fabricated and attached at the inlet of the test section, Both storage tank and test section tank are placed on stand as shown in figure 4.6. a tube connects the bottom outlet of the storage tank with the inlet of the test section with a valve at the outlet of the storage tank. The valve is used to control the flow. And the nozzles are connected to the inlet of the test section.

The experimental facility (figure 2) consists of two tanks, namely, a cylindrical storage tank having dimensions 1000mm height 165mm diameter, a test sections tank having dimensions of 914mm 609mm 450mm. The storage tank is placed at a higher hydraulic gradient level to ensure gravity-fed jet flow, and a control valve is placed to adjust the flow rate. In this study, the nozzle is placed at the centre of wall of the ambient tank. Flow visualization studies are carried out using a potassium permanent component as the dyeing agent. Jet experiments are carried out at five different Reynolds numbers with respect to five



**Fig. 2: Innovative inhouse jet facility**



**Fig. 3 : Comparing the effectiveness of the present study with the literature**

different nozzles, as shown in Table 1. The footage of the jet released to the ambient tank is recorded using the 12MP camera at 60 frames per second at a resolution of 1080 \* 1920 pixels as the jet stabilises. The photos are then analysed to identify the jet flow parameters using the ImageJ open-source software. The photographs are calibrated by utilising a known physical dimension in the image, and then the pixels are transformed to the standard units. For added brightness, LED lights are mounted on the ambient tank's exterior walls.

### C. Project Evaluation and Feedback

The students exhibited their model in two sets of experimental facility, which was evaluated by the project supervisor. The criteria of evaluation of the project were design, analysis and comparison of potential core length. Qualitative and quantitative analysis of the effect of understanding the jet by the student was done on the basis of the following parameters:

- Feedback on the experience of working on the project (10 marks)
- Two Internal evaluation by project supervisor and separate evaluation by project coordinator (10 marks each).
- The oral defense to the project external examiner (10 marks)

## 3. Results And Discussion

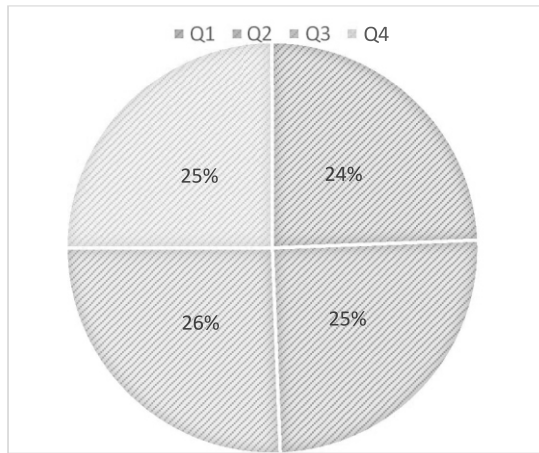
The project is carried out by experimenting a Rhombus shaped nozzle in low-speed jet facility at the propulsion laboratory of School of Aeronautical

Engineering, BIHER. The set up is run for Mach number of 0.4 and the potential core length is plotted. Later the same nozzle is kept in the water channel for Reynolds number equivalent to  $M=0.5$ . The Jet emanating from the nozzle is captured using high speed camera; then by post processing the image through photoshop, the potential core length for the given jet is plotted. The comparison of potential core length in both studies is carried out.

The outcome of the present study is scientifically evaluated as follows. Almost thirty literatures are studied relevant to jet studies. Out of which almost all the studies concentrated on studying the potential core length, half width and spread rate of a jet. Hence it was decided to study the same parameters in the present study too. An image processing code is developed to analyze the photographic images taken out of the experiment. The results are successfully matched with the literature [12]. In their study the potential core length of a circular jet was observed as 4.8 times of the exit diameter of the nozzle, whereas in the present work a potential core length of 5.3 times of the exit diameter achieved. In fig.3 the x- axis represents the any location of the jet (x) divided by the diameter of the nozzle (D), Y-axis represents the velocity (V) at station x divided by the maximum exit velocity ( $V_{max}$ ). By using the image processing tool and the present experimental set up it is possible to study the mixing characteristics in a better manner than the conventional flow visualization tools.

The feedback (fig.4) on the experience of the project work is assessed by the set of questionnaires given to the research group by the department head. The survey questions are devised into three categories such as: knowledge, skills and values. The direct knowledge presented in formal project discussions with the supervisor is referred and regarded as being within the knowledge category. With some help from the tutors and lecturers, the student applies their expertise to tackle the specific product design problem under the skills area. The values speak about the knowledge or the expertise that the industry can apply.

1. Can the stated problem/ issue be handled with the information and engineering skills provided by the PBL method?
2. Does the PBL allow you to analyses and define the design problem, as well as identify the criteria for reaching an acceptable solution?

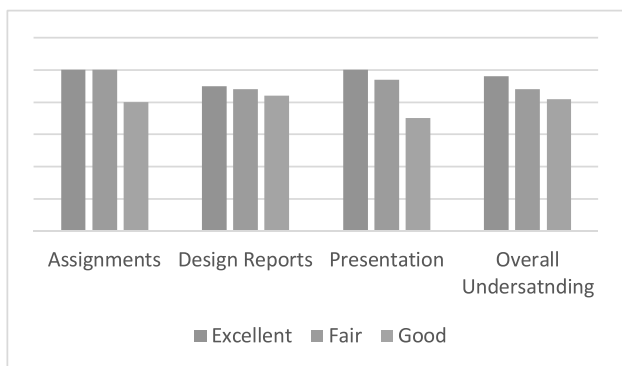


**Fig. 4 : Feedback about the project work**

3. Does the technical staff, lecturers, or supervisors cover how to do a literature or patent search using a scientific search engine?
4. Does the PBL instructional approach allow you to critically question preconceptions and welcome new ideas?

The first set of internal evaluation carried out by the project supervisor (fig.5) to capture the effort put forth by the students in understanding the design of the experiment. The evaluation is carried out on the oral presentation of the team followed by assessing the skill of individuals. From the evaluation it was found that the student displayed a better understanding of jet (almost 95%). It is observed that the student showcased fair computability in understanding the basis of potential core decay and half width. The questions posed under each category are presented in the table.3.

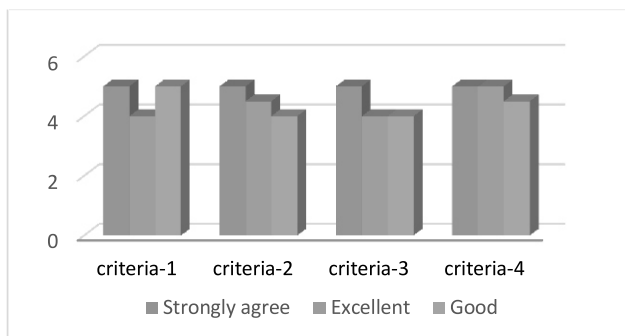
The internal evaluation carried out by the supervisor on four categories to test the students domain knowledge. based on the previously given



**Fig.5 : Internal Evaluation by research supervisor**

**Table 3: Components of Internal evaluation by supervisor**

Category	Tasks	Inference
Assignments	The student has been asked individually to prepare a graphical abstract of the work carried out by Prof.E.Rathakrishnan in the past ( 5 works per person)	The student displayed the graphical abstracts and compared the each other work on the day of discussion with supervisor.
	Individually, student has given a problem to process a shadow graph images (existing in the department) through Image J software.	Response is very good. This gives them the confidence of handling the image processing software.
Design Reports	To design a CD nozzle using a) method of characteristics b) MATLAB coding	The design reports evaluated were satisfactory and proceeded further for fabrication of scaled down model
Presentations	Presentations need to be given by individual students on weekly basis. The presentation was evaluated based on i) content, ii) comprehension iii)style of the presentation	The student’s presentation skills has remarkably enhanced from third week onwards. The usage of power point tools and animated tools has also considerably increased.
Overall Understanding	The overall understanding of the project is evaluated by two factors 1. Knowledge based test 2. One to one discussion	The knowledge-based test is based on 5 point Likert scale.



**Fig. 6 : Supervisor Evaluation by Students**

criteria that were adopted from Brown's (2001) [9] i.e., Imitative, Intensive, Responsive, Interactive: Intrapersonal, Interactive: Interpersonal, Extensive. The supervisor role in shaping the project is very vital and hence his effectiveness is also assessed by the student by giving set of questionnaires to them.

It was a pleasing one that all the students has given a commendable feedback about the research supervisor because this is the first time the supervisor is carrying out a innovative research project (fig.6). The supervisor effectiveness is presented in fig.4 out of 5 points. The questionnaire includes

Criteria 1: how effective the supervisor in demonstrating the concepts,

Criteria 2: how clear with his ideas and meetings

Criteria 3: how was he is influential in stimulating the research interest

Criteria 4: how he was available for discussion in time of project work.

The students expected the supervisor to be more precise in scheduling the meetings. The second set of internal evaluation by the project coordinator was carried out in assessing the learning outcomes of the

**Table.4 Project Supervisor- Rubrics for Evaluation**

Sl.no	Rubrics	Weightage (%)
1	recognizing the project's goal and the core issue	10
2	study of the literature	20
3	Design and execution of experiments	20
4	Results interpretation and discussion	30
5	Preparation of reports	20

project through rubrics (80% due weightage) as follows in Table.4. (Selvin P. Thomas et al. 2019 [10])

Followed by questionnaires given to students on 5 point lickert scale. The questions are designed to gauge respondents' impressions of the advantages of PBL and psychological functioning like as skills, engagement, and artwork performance. Table.5 represents the questionnaires by the project supervisor to the students (20% weightage). The internal marks awarded by the project coordinator is the summation of supervisor marks (50% weightage) and the project coordinator evaluation (50% weightage).

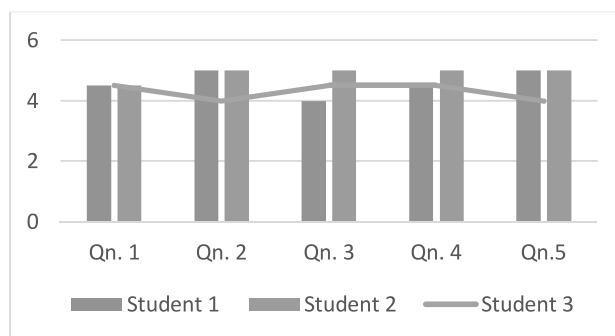
**Table.5 : Questionaries by Project Supervisor**

Q.no	Questions
1	The Project helped me in learning the Jet characteristics
2	Personally analyzing, fabricating and seeing the Jet flow was better than conventional experiment by the instructor.
3	The project helped me prepare for my personal interview
4	The Project gave me an experience of project management.
5	The Project increased my overall interest in the course

The response to the question is recorded out of 5-point scale and presented in the fig.7. The students felt that because of project based learning a thorough understanding of jets was possible.

The final evaluation is carried out by the external expert. The students were asked to present the work in front of the examiner, evaluation was carried out by the examiner. The rubrics for the oral defense were

C1. Detailed and extensive explanation of the purpose and need of the project.



**Fig.7 : Response to the evaluation by project coordinator**

**Table.6: Grades of the students**

Grade	Excellent	Very Good	Fair	Satisfactory	Repeat
	A+	A	B	C	RA
Student 1	A+				
Student 2	A+				
Student 3		A			

- C2. Appropriate design methodology and properly justification
- C3. Contents of presentations are appropriate and well delivered
- C4. Complete explanation of the key concepts and strong description of the technical requirements of the project
- C5. Extensive knowledge and awareness related to the project. The response to the questions were recorded with a relative grades from A+ to RA.

The grades obtained by the students witnessed the effectiveness of the project-based learning approach. The method is encouraging and result oriented in nature. The present study is compared for its effectiveness with other peer project groups. Out of 20 project works carried out by the final year students the present study has been appreciated in the poster presentation conducted by the department. Overall, they had the chance to evaluate the outcomes, put their knowledge into practice, and translate it into efficient comprehension and learning. In conclusion, taking into account all crucial elements of jet studies, the provided project was a better option for the students to assist them in learning the processes at the laboratory size and the methodologies utilized to scale up the results. A number of the student outcomes outlined by accreditation institutions like ABET in their criteria for engineering degree accreditation are helped by such projects for graduating students [10]. In order to figure out the development in competencies required for an engineering student to graduate, similar studies have been published in the literature. After adopting the project-based learning tactics employed in a particular course, Prussian Kumar et al. [11] reported the perceptions and attitudes of the mechanical engineering students. The authors came to the

conclusion that the students learned both interdisciplinary and cross-disciplinary information, a wide range of engineering skills, and both interpersonal and technical communication abilities. For an engineering graduate to be encouraged to pursue lifelong learning, it is essential that the students' mindsets, the supervisors' expertise, and the learning process be appropriate. In this regard, the project's objectives were met, and students left with the skills necessary to deal effectively with difficulties in the actual world. The experimental setup developed in the present study is alternate to a high cost jet facility. It is widely recognized by the neighboring institutions and the information's are disseminated to them to build a similar low cost setup.

The overall effectiveness of the present study is summarized as follows.

1. Out of 20 batches, the students involved in the current work learnt a new image processing tool successfully. This is considered to be one of the promising aspects of lifelong learning.
2. The experimental study is compared with the notable works [12] and found to be satisfactory. This ensures the credibility of the scientific results.
3. The students developed a low cost experimental setup which can be used by future students for studying jet studies, hydraulic analogy concepts. Thereby this work encouraged the critical thinking capabilities of the students.
4. The students performed well in end semester examination as well as in poster presentation competitions with impressive grades and appreciation respectively. Hence this attributes the learning and soft skills of them to a greater extent.

The present study carried out through project based learning has given an opportunity to study to enhance their knowledge, self-efficacy and learning skills positively.

#### 4. Conclusion

The students' grasp of the subject is improved via project-based learning. This is seen by their improvement in exam performance. It exposes students to teamwork and develops their project management abilities. Their technical and analytical abilities are enhanced, which increases their

employability. It has helped the student's personality to develop in general. Compared to the conventional classroom teaching method, the methodology may be utilized to raise the interest and excitement of the students to study a fundamental subject. Additionally, the department has benefited from having functional prototypes to show other student cohorts. The present study can be further extending to larger number of project groups in future and the effectiveness can be studied in detail.

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