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Mechanical Engineering Design Experience for Hispanic and Low Income Students

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Abstract

In 2011, California State University, Northridge (CSUN) received a grant from the Department of Education's Hispanic-Serving Institutions STEM program to boost the number of students who transfer from a community college and graduate with degrees in engineering and computer science.

The program, known as the AIMS^2 (Attract, Inspire, Mentor, and Support Students) student support program, has three main objectives: (1) To increase the number of Hispanic and low income students who transfer from junior colleges (2) To increase the number of Hispanic and low income students who join the university as upper division transfers, and obtain degrees in a reasonable timeframe (3) To develop a sustainable model, for others to follow, that will result in a transfer program to service the students mentioned above [1].

In order for this program to succeed, it is necessary for articulation agreements to exist between universities and the junior colleges (JCs) that feed students to it. For students to transfer as upper division, freshman and sophomore classes must exist to allow for transfer in a reasonable time period, while meeting the strict requirements set forth by universities. With respect to Mechanical Engineering (ME), this includes a design component as each class within its design sequence now contains some level of design methodology.

Because of the time needed to complete articulation, students currently in the support program who are ME students did not receive the necessary design component in certain classes taken at junior colleges. In order to make up for this deficiency, a summer-long design clinic was held for those students, and provided the necessary information required for complete integration into the ME design stem.

This paper discusses the design experience. More specifically: Under the supervision of the support program advisor, a group of students was given the task of designing and manufacturing an intake manifold for an internal combustion engine. The students followed the standard design protocol of conceptual, preliminary, and critical design and presented their design through the review process. Upon completion, a wax-impregnated model was created using a Zcorp® rapid printer, from which a mold was made using the lost wax process. After burnout, an aluminum casting was poured with the result being a manifold in the as-cast form. Numerous machining operations followed which included complicated fourth-axis machining of various surfaces, as the manifold is a very complicated part. Ultimately, the students performed flow analysis on the

manifold which demonstrated an improved design, and provided their findings in final report form.

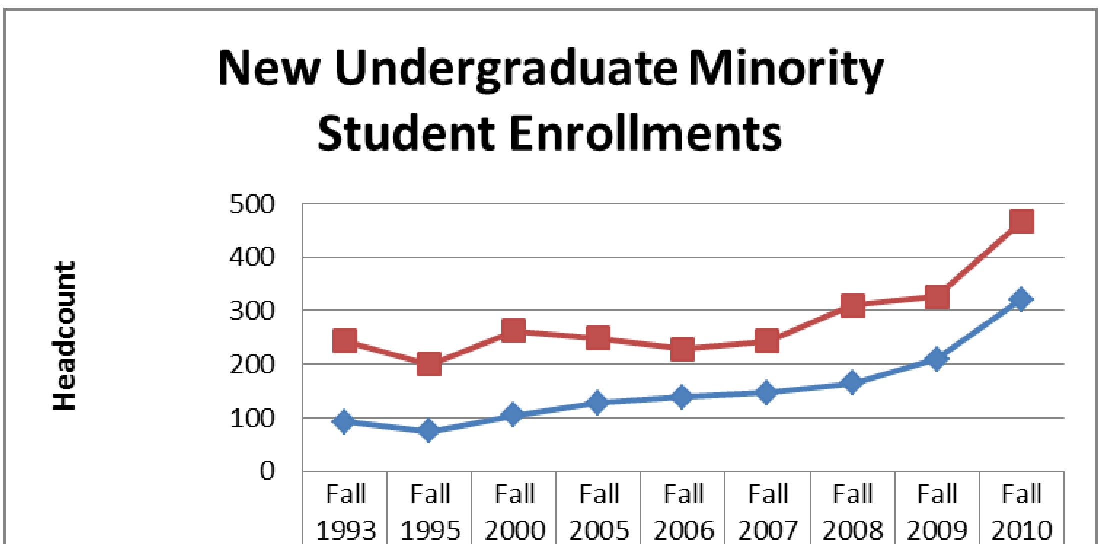
Introduction

In 2011, California State University, Northridge (CSUN) received a federal grant to increase the number of minority students studying engineering and computer science. CSUN qualifies as a Hispanic Serving Institution (HSI), and created the Attract, Inspire, Mentor, and Support Students (AIMS^2) program to meet the needs of underrepresented and low-income students entering into Science, Technology, Engineering, and Mathematics (STEM) programs [1].

CSUN chose to work directly with two local junior colleges in order to perform the study. Students meeting the qualifications were identified with the intent of following their progress from junior college transfer to graduation. The cohort would receive tutoring, mentoring, stipends, and career advice each semester and would be supervised directly by a faculty mentor. Students who demonstrated skills in the area of research were given the opportunity to perform such paid activities in summer.

While the primary goal of the study was to increase the number of minority students entering STEM at CSUN, goals also included increasing this student base who transfer from JCs , monitoring their progress and ensuring they graduate in a timely manner, and creating a template, or model for other institutions to use in the future.

As shown in figure 1, the number of minority students at CSUN, and in particular Hispanic students, is increasing. These students enter CSUN (1) as freshman (2) as upper division transfers from JCs.



	Fall 1993	Fall 1995	Fall 2000	Fall 2005	Fall 2006	Fall 2007	Fall 2008	Fall 2009	Fall 2010
Latino/a	92	75	105	128	138	147	164	210	321
All Minorities	243	200	263	249	228	244	310	327	467

Figure 1. Minority enrollment at CSUN.

Figure 2 shows that six-year as well as overall graduation rates are much lower for the underserved student population when compared with the better served. Reasons for this dichotomy are under debate, but may include poor K-12 preparation, advisement, study habits, workload, and more.

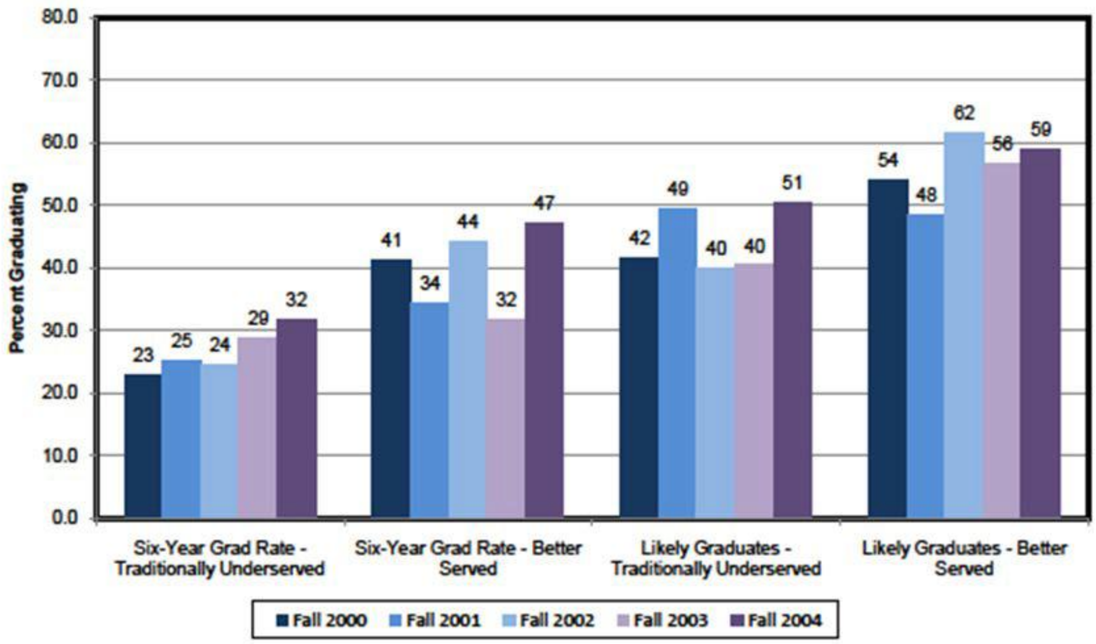


Figure 2. CSUN graduation Rates for different years.

As an example to explain the attrition, the Mechanical Engineering (ME) department at CSUN currently requires one-hundred and twenty-six units for graduation with a Bachelor's of Science in Mechanical Engineering (BSME). Ninety-nine must come from within the major, while twenty-seven are general electives (GE) [3].

CSUN requires all beginning students to take the Entry Level Mathematics Exam (ELM) and the English Placement Test (EPT), or obtain an exception through equivalent testing. CSUN also requires the Mathematics Placement Test (MPT) prior to enrollment in Mach 150A (Calculus I) as well as the Chemistry Placement Test (CPT) prior to enrolling in Chemistry 101 (required chemistry), all requiring appropriate scores [4].

Students meeting all the above requirements would require in excess of four years to graduate with a BSME, assuming a semester load of fifteen units. Students not meeting the requirements may take much longer, and those who work excessively or fail multiple classes may drop out altogether. Thus, the attrition rates shown in figure 2 are explainable.

Identifying the Problem

A large number of students enter the CECS from JCs, and institutions, whether two or four-year, have different curriculum requirements. However, CSUN has articulation agreements with certain local JCs and maintaining/improving these agreements is paramount in reducing the number of duplicate courses required when transferring from one institution to another.

Part of the AIMS2 mission was to work with local JCs to update the articulation agreements and reduce the overall time spent at CSUN prior to graduation. In order to satisfy ABET requirements, the ME department modified freshman and sophomore level mechanical design classes to include a hands-on design experience as well as design methodology. Local JCs have modified their ME classes accordingly and articulation agreements have been updated, but the AIMS2 students already in the pipeline and now attending CSUN did not obtain the modified design experience; more specifically, they lack the proper design experience in terms of design methodology, solid modeling, and design for manufacturing.

With the problem now identified, the AIMS2 students (four students, one advisor) were enrolled in an eight-week summer design activity with the intent being to follow a strict design protocol and design, fabricate, and test a product.

Design Problem

More specifically, the students were given the task of designing an intake manifold for a two cylinder motorcycle engine, with the goal being enhancement of per-cylinder flow characteristics while maintaining the total flow capability of the manifold. The current design is a "common" style, meaning the two intake tracks lead into a common, or single shared throttle. A dual track style has completely separate intake tracks and throttles. Theoretically, cylinder-to-cylinder variations should be reduced, but performance may be affected because of packaging issues and could cost more. These, and other issues, are captured in the following conceptual design statement:

Figure 3. Commercial Common Intake Manifold Design.

Design an intake manifold for a two cylinder motorcycle engine. The design should be cost effective, easy to manufacture, and have comparable maximum flow characteristics when compared to the standard design, while enhancing/decreasing the cylinder-to-cylinder variations.

As shown in figure 3, the standard design is of the common type, and requires a separate throttle to be attached to it. It is a cost effective design and is simple from a manufacturing standpoint. However, it suffers from cylinder-to-cylinder variations (verified by taking data while engine running).

Engineering Design Process

The engineering design process begins with an identified need and is completed when the resulting prototype is properly tested and qualified [5]. In this particular case, the recognition of need and conceptualization were completed (by the faculty advisor) prior to the design problem being given to the students. The students were required to perform a standard design study including preliminary, critical and design for manufacturing. Ultimately, they were required to produce the actual part based on their design decisions.

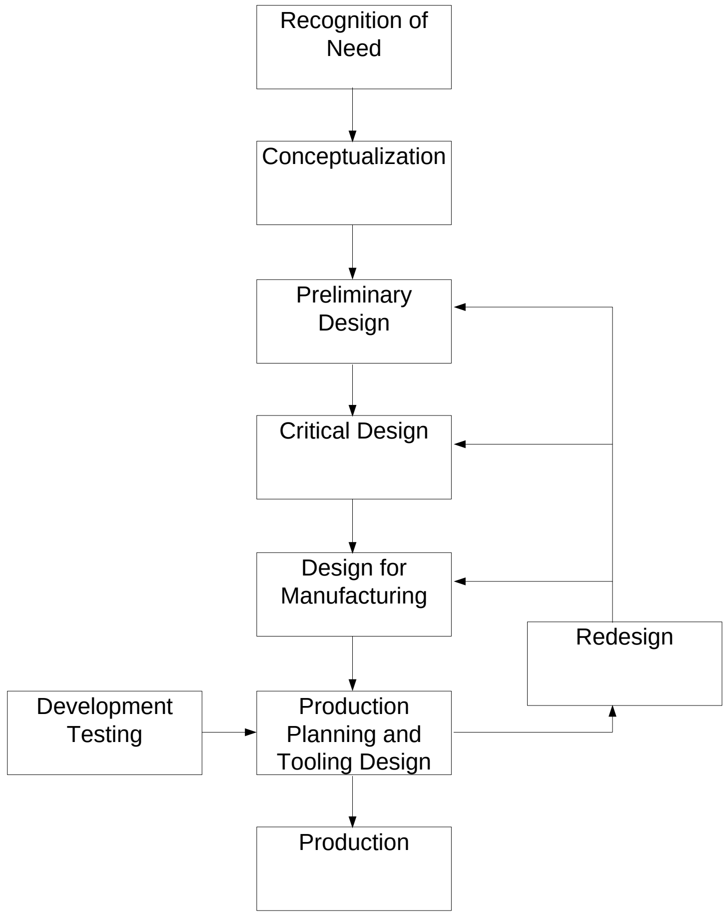


Figure 4. Engineering Design Flowchart.

Preliminary Design

The preliminary design phase of the design process bridges the gap between the conceptual and critical phases. It involves the evaluation of several different design configurations based on design criteria, and utilizes the design matrix. The design matrix numerically predicts a superior design by the use of design criteria, criteria weighting, and design rating. By summing the rating times weighting scores for each design criteria, a numerical score for each design can be obtained [6].

The design statement determines the design criteria (cost, durability, manufacturing, performance) for the design matrix, while the students as a group applied their own weighting scheme. Each student presented a unique preliminary design, with the intent being the design should be unique.

Design I	ABS rapid prototype, one piece throttle and intake
Design II	Billet machined, separate throttle and intake

Design III Cast and machined one piece throttle and intake

Design IV Split added to commercial intake, separate throttle

Table 1. Design Matrix.

Design Criteria	**Weighting**		**DESIGN 1**	**DESIGN 2**	**DESIGN 3**	**DESIGN 4**
COST	30		5	1	6	10
R x W			150	30	180	300
DURABILITY	20		1	10	10	10
R x W			20	200	200	200
MANUFACTURING	20		10	2	6	8
R x W			200	40	120	160
PERFORMANCE	30		10	10	8	2
R x W			300	300	240	60
Total			**670**	**570**	**740**	**720**

When comparing the different designs the following observations were made:

- Design 1 uses a rapid prototype to create the manifold by additive manufacturing. The resulting part is accurate dimensionally, and requires little time to make. However, the process is expensive, and it was determined that ABS would not meet the heat requirements of the engine under load.
- Design 2 requires advanced machining capability as the part must be machined completely from billet aluminum. Difficult from a manufacturing prospective, and costly.
- Design 3 requires the ability to cast the part. There will be some machining required. Cost is average, and the part will be comparable to designs 1 and 2 in terms of performance.
- Design 4 modifies the existing manifold and simply splits it in half. Cost, manufacturing, and durability are low, but it is not possible to meet the performance criteria.

After several iterations, the students finally chose design 3. It is not significantly better in any one area, however the results of the design matrix show the highest score. It should be noted the instructor tried to convince the students of the true complexity of this design, but as this was an academic exercise, the students went forward with design 3.

Critical Design

The intent of the detailed design phase is to develop a system of solid models and drawings that describe a part or assembly so that it can be manufactured [7]. This implies the design has been fully analyzed, by whatever means necessary. Analysis proved to be very difficult as the cohort lacked the necessary engineering skills to perform a thorough analysis from an engineering perspective.

Using a previously created solid model of the intake manifold as a starting point, the cohort generated various models that met the intent of design 4. Many iterations were necessary to produce a manifold that maintained the flow capability of the original while addressing the cylinder variation issue. Two graduate students helped the cohort with computational flow simulation. Eventually a solution was agreed upon, as shown in figure 5.

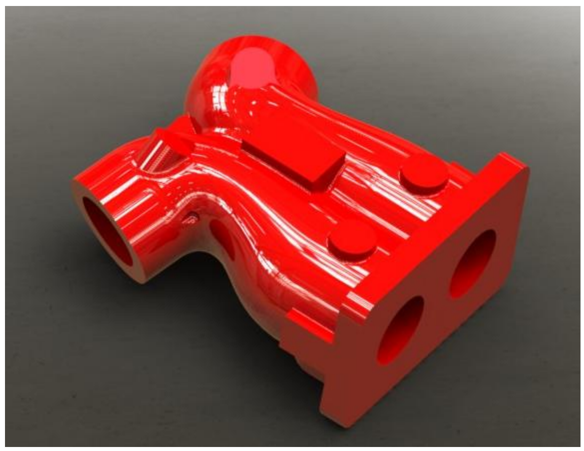


Figure 5. Solid Model Rendering of Manifold.

Design for Manufacture and Assembly

Manufacturing Processes

As discussed in the preliminary phase, the intent from a manufacturing perspective was to cast and machine the manifold. Upon further investigation several other steps were identified:

- A rapid prototype pattern of the manifold would be created out of starch.
- The pattern/gating system would be coated with a casting slurry (ten coats) in preparation for casting [8].
- The investment casting technique would be used to create the casting.
- The casting would be de-molded and machined.

Creating the Pattern and Mold

CSUN's ME department has a variety of rapid prototypers, including a Zcorp 310 printer, capable of created a starch based rapid prototype. By infusing the starch pattern with wax, the part takes on the form of a wax pattern, similar to those used in lost wax, or investment casting. The wax pattern was then coated with a casting slurry and silica sand, repeatedly, until a one-quarter inch this mold was created. Figure 6 shows the completed shell mold.

Figure 6. Hardened slurry on pattern.

Casting

Using the ME foundry, the part was cast using 356 aluminum casting alloy. Figure 7 shows the de-molding process. First, the main parts of the shell are removed manually. Any remaining parts of the shell can be removed using a vibration table.

Figure 7. De-molding manifold.

The gating system was removed manually using a band saw. After proper cleaning, the part was ready for machining.

Machining

This was by far the most complicated part of the manufacturing process. The manifold has many compound angles. Care was taken during the design for manufacturing phase to reduce the number of machining setups needed, but ultimately a CNC mill with fourth axis capability was utilized.

First, the manifold was secured in the mill in order to machine three datum planes, all orthogonal to each other. Fixture plates were then created to constrain the manifold in different alignments in order to complete the machining operations. A total of eight different setups were needed.

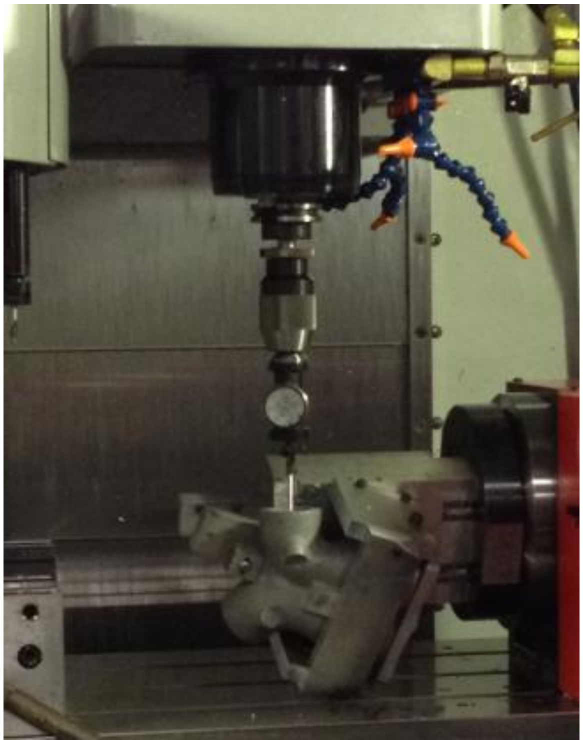


Figure 8. Machining manifold on Haas VF4 with HRT210 4th Axis

Final Assembly

Figure 9 shows the completed intake manifold and throttle. On the right is the AIMS2 manifold, on the left is the commercial manifold and throttle.

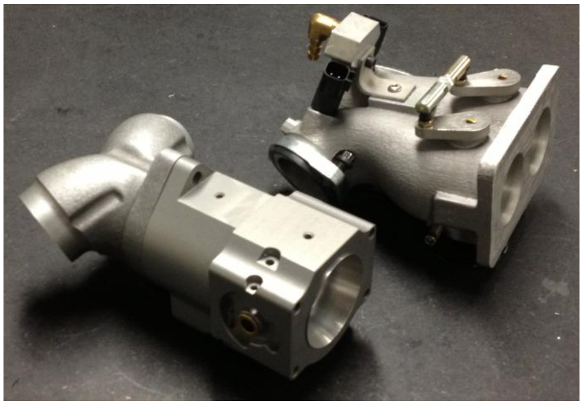


Figure 9 Intake manifolds, commercial on left, AIMS2 on right.

The AIMS2 manifold, which when fully machined and assembled, was virtually equal in weight, and size when compared to the commercial one. Both were made from cast aluminum and finish machined. Per cylinder throttle size was the same. Both fit on the engine.

Testing

In order to validate the design, all design criteria must be met. Cost and manufacturing were comparable as both designs were cast and machined, and both were made from aluminum. A performance comparison was accomplished by testing both manifolds on a flow bench.

As shown in figure 10, a test fixture was created to test both modes of performance: (1) cross flow (2) mass flow as a function of pressure drop, for different throttle positions.

Cross Flow: For the commercial manifold, any flow across orifice 1 was immediately measures across orifice 2, as they were commonly linked. For the AIMS2 manifold, there was no cross flow measured as the intake tracks were completely separate. Thus, the AIMS2 manifold was superior in that respect.

Mass Flow: Both intake manifolds were placed on the flow bench and tested by constraining throttle position and allowing the pressure drop across the manifold to vary from four to sixteen inches of water. Using a calibrated electronic throttle position sensor, throttle angle was varied from zero to one-hundred percent open opening. When looking at the results, the AIMS2 manifold was comparable until ninety percent opening, at which the commercial manifold showed a seven percent increase.

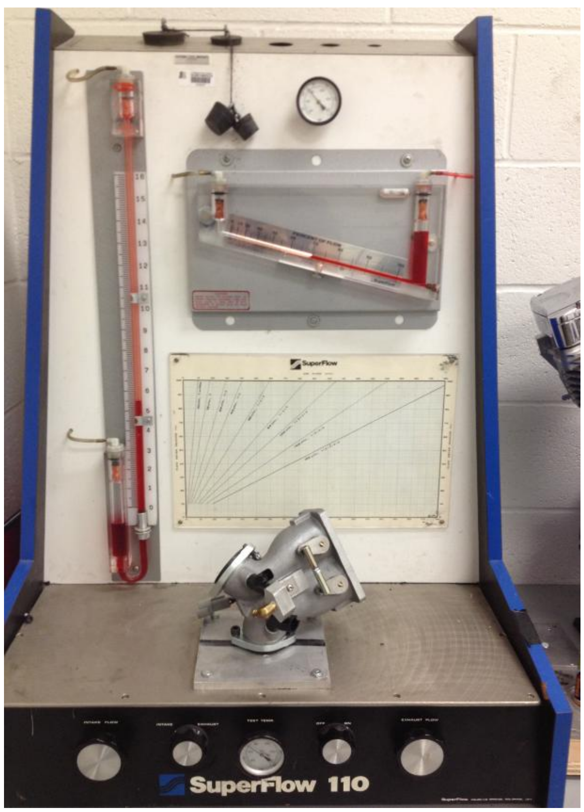


Figure 10. SF 110 flow bench test.

A significant amount of time was spent by the students trying to interpret the results. As the throttle openings were the same on both throttles, and as the geometry was similar, the manifold itself was not the problem. Upon further inspection, it was determined the throttle shaft on the commercial unit was not circular in cross section (as was the AIMS2 manifold) and was machined with “flats” on each side further reducing the silhouette area at wide open throttle.

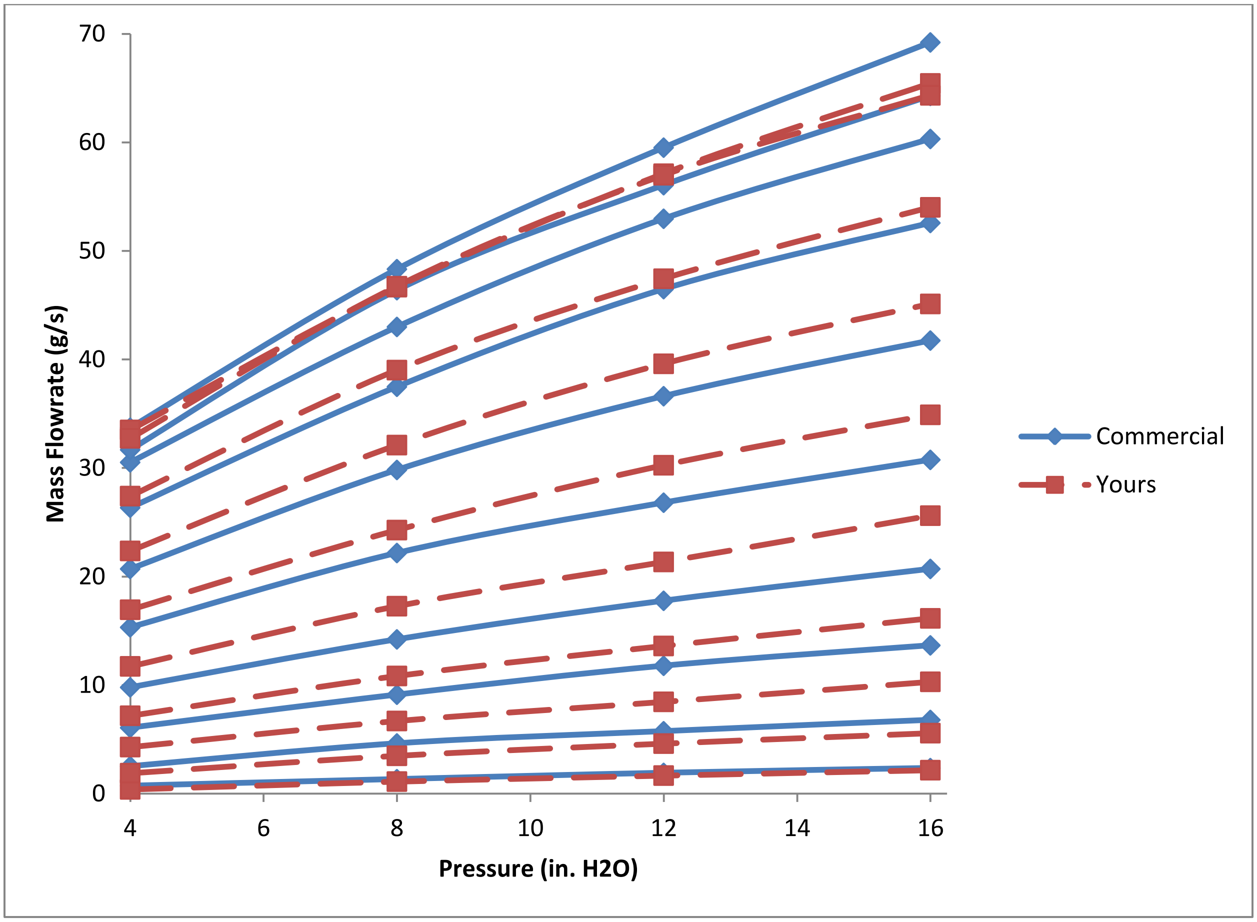


Figure 11. Mass flow vs pressure drop, constant throttle position lines.

Conclusions and Recommendations

The purpose of the AIMS2 program at CSUN is to increase the number of Hispanic and minority students entering the engineering curriculum, and to mentor those students once they have been accepted into the program. Underrepresented minorities typically take longer to graduate and attrition rates are higher when compared to traditional students.

For those students who transfer from JCs, class overlap can be reduced by articulation agreements between colleges and universities. However, these classes should not simply be "equivalent" but must include articulated content, especially in the area of design, as the ME department at CSUN as incorporated a strict design protocol into the curriculum. Those students who do not have the proper design experience should enroll in a summer design clinic in order to receive that skill set.

The AIMS2 summer design clinic was a success. The students were able to take a conceptual design and follow the standard design protocol in order to produce an intake manifold for a motorcycle engine. Steps included solid modeling, casting, machining, assembly, and testing, plus a final report. Although the students themselves did not perform all tasks individually, they were involved in all phases as a group, and experienced the entire process.

Testing of the intake manifolds yielded interesting results. Testing of both throttles and manifolds showed similar flow results, but the commercial unit flowed seven percent greater at wide open throttle. Further inspection determined the throttle shaft to be the greatest inhibitor to flow at wide open throttle, an issue to be corrected at a later date. Cross flow was nonexistent with the AIMS2 manifold, but was a significant problem with the commercial one.

In an exit interview, the students were asked to discuss the experience. All four had similar responses: (1) none had been exposed to any sort of hands-on design experience prior to entering college (2) their respective junior college classes did not prepare them for a hands-on design experience (3) they all felt the experience would help them in future engineering classes.

In the Fall of 2012, the four students involved in the design clinic enrolled in ME 286 (Design and Manufacturing). The four students passed the class with grades that were equal to, or exceeded other students' grades. The group expressed interest in helping with next year's design clinic that will be sponsored by $AIMS^2$.

In terms of future work and recommendations, it can be said that underrepresented students do not have the same design experiences in K-12 or even at JCs when compared to traditional students. With the incorporation of design experiences throughout the curriculum, these deficiencies can be overcome. This particular design experience was well-funded and had significant faculty support, but simpler design experience could be just as effective. For instance, a much simpler design concept could have been used while still allowing the students to experience the entire design process, and time/costs could be lower.

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