Aerodynamic Drag Reduction:  
A Design/Build/Test Experience for High School Students  

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Abstract  

For several years at Kansas State University, as part of the annual Engineering and Science Summer Institute (ESSI) Program, participating high school students have been assigned the task of designing, constructing and testing streamlined rocket models of their own design. The rocket models are constructed from readily available construction materials consisting of hardwood dowel rods for the rocket body and rectangular block balsa wood for the fins. Their assignment is to modify (streamline) and assemble their rocket in such a manner as to minimize the aerodynamic drag. They are not allowed to alter the overall length of the rocket body (rod), the front view profile area, or the planform area of the fins. The students work in teams of two and the first of two class periods is devoted to the design/construction phase of the assignment. They are given a “kit” consisting of an assortment of materials and “tools” to assist them in the streamlining and assembly task. During the second class period each design group is assigned the task of testing their design using the wind tunnel in the Mechanical and Nuclear Engineering Department. The rocket models are mounted on an electronic balance in the wind tunnel and the measured drag force for each of the designs is compared against a “poor” rocket design with virtually no streamlining, and against designs from the other competing design groups. This paper describes the authors’ experience with high school students involved in this hands-on design/build/test activity, as a means of introducing them to the principles of aerodynamic streamlining, along with a presentation of some of the typical quantitative results.  

I. Introduction  

The emphasis on design, as an integral part of Engineering Education, has been on the increase for more than a decade. In particular, considerable importance has been placed on the integration of design, and design principles, early in the Engineering Curriculum, in contrast to merely “exposing” students to design at the end of their senior year. In the Department of Mechanical & Nuclear Engineering at Kansas State University (KSU), students are introduced to the principles of design very early, within the first or second year of study. At this level they do not yet have the technical background to tackle a difficult design problem, but they can exercise a variety of other talents—including creativity. In contrast to a “token” design experience much later in their academic program, this early introduction of design provides a firm foundation in the area of design as an engineering tool. At the same time it provides motivation and justification for subsequent upper level engineering courses, which will eventually give the students greater technical tools for refining their design and analysis capabilities.  

In keeping with this basic philosophy, it would seem equally important to introduce some of these same concepts of design to students even before they formally enter the university
environment. The current paper presents the experience of this author with introducing the principles of aerodynamic design to high school students participating in the Engineering and Science Summer Institute (ESSI) at KSU. The ESSI Program is offered to high school students (and high school instructors) as an opportunity to learn about engineering, as well as physics, chemistry, biology and mathematics. Lectures and laboratory activities are given to illustrate important problems and challenges faced by society presently and into the future. The program is also designed to aid the students in determining their career interests. In addition, students are given opportunities for leadership activities and for learning about life on campus at a university. Further information about the ESSI Program can be obtained by contacting the College of Engineering at Kansas State University.

II. The Design/Build/Test (DBT) Problem

The DBT experience described in this paper is a hands-on laboratory activity, where the participating students are confronted with a design objective, and asked to formulate a solution, construct their proposed solution, and ultimately test their design in a wind tunnel facility. The approach is intuitive and experimentally based. At the same time, they are in friendly competition with their fellow students to achieve the best design. The students are assigned to work in teams of two (or at most three). Typical class size ranges from about six to about 15 students. Philosophically, the importance of the hands-on experimental approach is clear when one considers that the Wright brothers developed through experimentation and successfully flew the first aircraft in 1903, about a year before the theoretical principles of fluid mechanics were proposed.

The aerodynamic design problem is as follows:

The basic task is to modify a model rocket configuration to achieve the minimum total drag force. Figure 1 shows the typical materials used to construct the rocket model.

Rocket Body: 1.25 in. dia. x 18 in. long

Hardwood Dowel Rod

Fins (3 required):
3/16 in. x 2 in x 4 in long
Balsa (or equivalent)
The teams must assemble a complete rocket model (body and fins). They may rearrange the fin or rocket body materials in any way they choose, but they must use all of the materials provided. As design constraints, they must maintain the same frontal area (with minimal loss due to removal of material from the fins or rocket body for streamlining purposes). Each group is assigned a workbench and is given a Tool Kit Box, which contains an assortment of simple tools and hardware that they will need to complete the construction of their design. The items typically included in the toolbox are shown in Table 1.

| 1. | 1 oz bottle of Cyanoacrylate Extra Thick 10-25 second adhesive (Super Glue). |
| 4. | Sanding block (2 5/8” x 5” x 3/4”). |
| 5. | Sandpaper (Coarse, Medium, Fine grit) 8 1/2” x 11” sheet. |
| 6. | Plastic 12” ruler. |
| 7. | #2 pencil. |
| 9. | Large Cardboard box (for shavings). |

Table 1: Aerodynamic DBT Tool Kit

The overall DBT activity takes place over two days, in two separate time slots of approximately 2-hours duration. During the first day, students formulate their designs and begin their construction activity. If they do not complete the construction of their design by the end of the first period, they are allowed to take it back to their dorm room to finish it. Interestingly enough, this was not part of the original assigned requirements, but was requested by the students themselves—an indication of the degree of interest they exhibited in this activity. The use of high-tech Cyanoacrylate fast-drying adhesives greatly speeds up the construction process. It is also a simple matter to make on-the-spot repairs where necessary, to strengthen the models for the subsequent wind tunnel testing phase.

Figure 2: Poorly Designed Rocket Model
Each rocket body (dowel rod) comes pre-drilled with two clearance holes to facilitate mounting in the wind tunnel. The alignment of fins must take into account this mounting requirement so as not to obstruct any of the holes or interfere with the force balance mounting hardware. To give the students a “target” to improve upon, they are shown in advance the poorly designed rocket model given in Figure 2. They are allowed to carve, cut, rearrange, and sand streamlining features into their model as necessary to achieve the “best” design.

III. Test Facilities

Figure 3 shows the wind tunnel test facility used to conduct all experimental measurements of drag force. Each design team is allowed to conduct their own tests, subject to an evaluation by the instructor of the physical integrity of the design for safety reasons.

![Figure 3: Wind Tunnel Test Facility](image)

The wind tunnel is equipped with an electronic balance for measurement of the axial (drag) force. Prior to testing, the rocket models are mounted on the support balance (“sting”) and the axis of the rocket body is aligned with the direction (horizontal) of the airflow. The typical mounting of the rocket models is illustrated in Figure 4, where the “poor” design is shown mounted on the balance. For simplicity, the sting mount is fabricated very simply from a piece of hexagonal aluminum rod stock. This introduces some undesirable parasitic drag effects; however, since the ultimate goal is to compare results with the “poor” design, this parasitic drag is of no particular concern. More sophisticated mounting arrangements (which provide a more in-line mount with minimal parasitic drag) can also be implemented if desired; however, these will likely require more time to fabricate.
IV. Discussion of Results

Figure 5 shows a rocket model developed by one of the previous design groups. Typically, groups will modify the fins in a variety of ways, as well as making significant changes to the cylindrical rocket body. Their designs are for the most part intuitive, as they have not been instructed in aerodynamic design principles as yet. Yet past groups have demonstrated considerable creativity in their designs. Even with the relatively small number of modifications apparently possible with the simple materials used, there is an amazing diversity of designs.
On the second day, the students conduct their own tests of their design. Figure 6 shows this same typical group conducting tests using the wind tunnel.

![Figure 6: Design Group Conducting Wind Tunnel Tests](image)

Once their model is mounted, they operate the wind tunnel themselves and collect data manually by reading the axial (drag) force in lbf units directly from the digital display panel. The measurements are then directly logged into an adjacent PC for display to the entire class. Each team can then compare the performance of their design immediately with those of previous groups, and with the “poor” design, which has no attempt at streamlining. Some typical results are shown in tabular form in Table 2. The data shown is a sample of some actual data collected by the students. To obtain these results the students have to become acquainted with basic principles of measurement uncertainty in utilizing reasonable judgement of the fluctuating digital display output.

<table>
<thead>
<tr>
<th>Air Speed (mph)</th>
<th>Drag Force (lbf)</th>
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<tbody>
<tr>
<td></td>
<td>Poor Design</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
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<tr>
<td>20</td>
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<tr>
<td>80</td>
<td>0.33</td>
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</tbody>
</table>

Table 2: Typical Tabulated Test Results
The range of air speeds associated with the testing typically goes from 0 to about 100 mph, with drag forces ranging from 0 to a maximum of about 0.5 lbf. The results given in Table 2 are also shown graphically in Figure 7.

![Figure 7: Graphical Drag Reduction Results](image_url)

There are several useful observations that are apparent from the above graphical results. First of all, there is considerable improvement noted over the “poor” rocket design. Even modest attempts to streamline the rocket model result in as much as a factor of two reduction in the drag force for a given air speed. Secondly, the trends of the results strongly suggest some form of parabolic increase in the drag force as the air speed is increased, in contrast to a simple linear behavior.

In discussing the above results with the students, the different physical characteristics responsible for drag are brought out in the context of this simple rocket design problem. In particular, the differences between drag due to viscous shear, and so-called pressure drag (due to boundary layer separation) are noted. Previous groups have even made attempts, intuitively, to promote reduction of pressure drag by adding streamlining to the trailing edge as well as the leading edge. This effect can also be demonstrated quantitatively with the existing rocket models, by adding additional gently-tapered streamlined shapes to the trailing edge of the cylindrical rocket body. Interestingly enough, addition of a streamlined shape to the trailing edge reduces the resultant drag force, even though there is a significant increase in surface area—clear indication that pressure drag effects are at work.

The model rocketry DBT activity has been very well received by the students, and the level of enthusiasm demonstrated by the students is clear indication that they enjoy the project, as well as the competition. They clearly spend considerable time outside of class to refine their rocket designs for the competition, which takes place on the second day. The students also
enthusiastically support the hands-on work with the wind tunnel. They can easily operate the wind tunnel with minimal instruction. Of course, these activities are supervised by the instructor for safety reasons; however, the models are constructed well enough, and the drag forces are small enough, that accidental breakage of a given rocket model under test is very unlikely.

The basic results presented above can be extended with the additional calculation of a drag coefficient for the rocket models. This same basic model has also been used successfully in conjunction with an introductory aerodynamics class to illustrate the physical characteristics of drag, and the role of streamlining in drag reduction. Modest extensions of the basic approach are shown in Figure 8, where three “identical” rocket models have been constructed to allow discovery of the relative significance of altering the geometrical shape by carving and sanding, and the relative influence of surface finish by application of enamel.

![Figure 8: Comparison of Rocketry Streamlining Techniques](image)

This same simple model and setup has also proved to be a useful tool to illustrate streamlining principles to elementary students involved with 4H model rocketry. Students at this level also can develop an intuitive feel for the physical characteristics associated with aerodynamic drag reduction using this simple setup.

V. Summary and Conclusions

A simple tool for introducing high school students to the physical characteristic of aerodynamic drag, and the basis for drag reduction, has been presented. The model rocketry design/build/test activity has proven to be a very popular activity for high school students participating in the Engineering and Science Summer Institute at Kansas State University. They learn some of the basic principles of aerodynamics in a very non-threatening hands-on laboratory atmosphere. Their enthusiasm is quite notable, especially when it is taken into consideration that this lab activity is but one of many activities the students participate in as part of the ESSI Program.
same rocket model setup, on different levels of sophistication, has also been utilized in conjunction with an introductory undergraduate level aerodynamics class, as well as in conjunction with elementary school students involved with 4H model rocketry activities.

Bibliography
1. For further information about the ESSI Program at KSU, contact Dr. Tom Roberts, Director, Engineering and Science Summer Institute, Kansas State University, 142 Rathbone Hall, Manhattan, KS 66506-5201.

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Terry Beck is an Associate Professor of Mechanical and Nuclear Engineering at Kansas State University. He teaches courses in the fluid and thermal sciences, including Aerodynamics I, which is a senior level design/build/test elective course. He conducts research in the development and application of optical measurements, including laser velocimetry, and is the Director of the Non-Contact Precision Measurements (NCPM) Laboratory at Kansas State University. Dr. Beck received his B.S. (1971), M.S. (1974), and Ph.D. (1978) degrees in mechanical engineering from Oakland University.