Session 2625

# Using Computer-Aided Design to Enhance Undergraduate Engineering Education

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Abstract

This paper describes the local development and use of a Computer-Aided Design (CAD) software program as an enhancement to an undergraduate engineering design project. The program was used in the helicopter aeronautics course at the United States Military Academy. The motivation behind the development of this program was the desire to provide students with a useful, visually driven design tool that would allow them to see and increase their understanding of the effects of different design parameters on a conceptual rotor design. The time required for in-depth study and modeling of these parameters was beyond that currently available in the course. The program was successfully utilized and student and instructor feedback gathered for future improvements.

## I. Purpose

The ***WEST POINT ROTOR DESIGNER*** was written to supplement the design instruction at the United States Military Academy in the Department of Civil and Mechanical Engineering's Helicopter Aeronautics course. The course is an introduction to basic aerodynamic theory applied to a rotating wing. Mid-way through the course, students are given an open-ended, mini-design in which they must design a rotor system to support a given load in a hover configuration and perform a cursory, forward-flight performance analysis.

Using the blade element approach, the students can easily devise a spreadsheet or write a program to design for fundamental rotor system parameters such as number of blades, rotor diameter, blade chord, root cutout and tip speed. Students were allowed to do this using a spreadsheet or by writing an iterative program. Given only five lessons, the students can easily reach the point of diminishing returns when they attempt to modify their simple programs to consider the effects of blade taper and aerodynamic and geometric twist. The ***WEST POINT ROTOR DESIGNER*** was written to bridge this gap and allow students to see the effects of minute changes to their designs without spending an undue amount of time affecting those changes.

## II. The Design Problem

The design problem covered five out of 40 course lessons and spanned a period of 19 days. The problem posed to the students consisted of a fictional scenario in which the U.S. Army had decided to retrofit the UH-1 helicopter. All design teams were notionally in place except the rotor design team. The students were organized in 2-3 person teams and given the task of proposing a conceptual rotor design for the new aircraft.

They were given a parametric set of weight and cost equations and the constraints listed in Table 1.

| **Design Parameter** | **Range of Values** |
|---|---|
| Rotor Tip Speed | 400 ft/sec< $V_T$ < 760 ft/sec |
| Maximum Forward Speed | 130 knots < V < 205 knots |
| Minimum Hover Ceiling | 4,000 DA at 95° F |
| Maximum Disk Loading | 15 lbf/ft$^2$ |
| Maximum Rotor Diameter | 44 ft |
| Maximum Number of Blades | 7 |
| Root Cutout | 1.8 ft |
| Maximum Twist | -12° |
| Maximum Blade Ratio (Radius/Chord) | 20 |
| Maximum Induced Velocity | 50 ft/sec |
| Download | 3.5 % of Main Rotor Thrust |
| Equivalent Flat Plate Area | 20.00 ft$^2$ |
| NACA Airfoils Available for Use | 0006<br>0009<br>0012<br>2412<br>23012<br>23015 |

Table 1. Design Constraint Information

The teams were also given the following, *notional*, program manager guidance:

*Our design approach will be to fit the UH-1 with the T-800-LHT-801 engine that has been developed for the Comanche. We will limit the drive train to 1350 hp. I want the maximum gross weight on the final aircraft to fall between 10,500 lbf and 11,500 lbf. As part of your presentation and report, I want to see two tables summarizing the key parameters for your rotor and aircraft. Since we are in the conceptual phase of design, I want you to define your rotor in terms of ten, equally spaced, blade elements. Specify the following parameters in your tables:*

- *Table 1:*
  - *Rotor Diameter (ft)*
  - *Root Cutout (ft)*
  - *Gross Weight (lbf)*
  - *Collective Pitch Angle for Hover (deg)*
  - *Rotor Speed (RPM)*
  - *Number of Rotor Blades*
- *Table 2 (for each blade element):*
  - *NACA Airfoil*
  - *Chord (ft)*
  - *Twist (deg from root)*

Armed with this information, the students approached their project. They were required to develop their own computer model and propose an initial design solution during an In Progress Review (IPR) with the instructor no later than the end of the third lesson in the design sequence. This occurred on day eleven of the design sequence (there were two weekends, a holiday and a flight lab during this period). Upon successful completion of the IPR, the students were given the CAD program to 'fine tune' and complete their design for formal presentation and competition during lesson five in the sequence. While graded separately, the designs were compared according to the criteria in Table 2. Winners in each category and the overall winner were awarded certificates in order to inject some additional excitement into the process. A full, written design report was due at the lesson following the design presentations.

| Points / Place | Rotor Diameter | Forward Velocity | Aircraft Cost | Hover Power | Payload/ Gross Weight |
|---|---|---|---|---|---|
| 1 | 10 | 10 | 20 | 35 | 40 |
| 2 | 8 | 8 | 16 | 28 | 32 |
| 3 | 6 | 6 | 12 | 21 | 24 |
| 4 | 4 | 4 | 8 | 14 | 16 |
| 5 | 2 | 2 | 4 | 7 | 8 |
| 6 | 0 | 0 | 0 | 0 | 0 |

Table 2. Judging Criteria

## III. The Model

The model used in the CAD program allowed for hovering analysis only. It was a combined momentum/blade element code, using ten elements for modeling the blade. While a higher number of elements would have increased the fidelity of the results and would have been easy to accomplish, the code would have become cumbersome from an interactive viewpoint. The ultimate goal was for the student to be able to quickly and easily run a large number of cases.

A non-uniform inflow distribution, based on momentum theory, as presented in *Gessow and Meyers*[1] was used. The program allowed the students to incorporate both aerodynamic and geometric twist as well as blade taper. Aerodynamic twist was modified by designating/changing NACA airfoils for each blade element. For each NACA airfoil, the CAD program would assign distinct values for lift curve slope, zero-lift angle of attack, stall angle, and the drag polars. No attempt was made in this version of the model to account for mach effects along the blade span. Geometric twist was set for each blade element with the root being considered the zero reference point and the downward pitch of an element's leading edge being considered negative in sign convention. The taper of the blade was modeled by assigning an average value of the chord for each blade element.

## IV. The Software

The software for this program was written using Microsoft Visual Basic 4.0. It runs on IBM compatible computers with at least a 486 micro-processor and running Microsoft Windows 3.1 or better. The user interface consisted of five input windows and an analysis window. The students used check boxes and scroll bars to input their data.  After each test run, the students could go back to any window, change one or more design parameters and run another test.

For those familiar with basic rotary wing aerodynamics and blade element theory, the CAD program was intuitive, quick and easy to use.  There was no required instruction or train-up required in order for students to use the program.  Two typical input windows are shown in figures 1 and 2.  In addition to the parameters shown in these windows, students were able to input the following information:

- Air Pressure
- Temperature
- Helicopter Gross Weight
- Rotor RPM
- Rotor Tip Loss Factor
- Installed Power
- Download (as a percentage of Gross Weight)

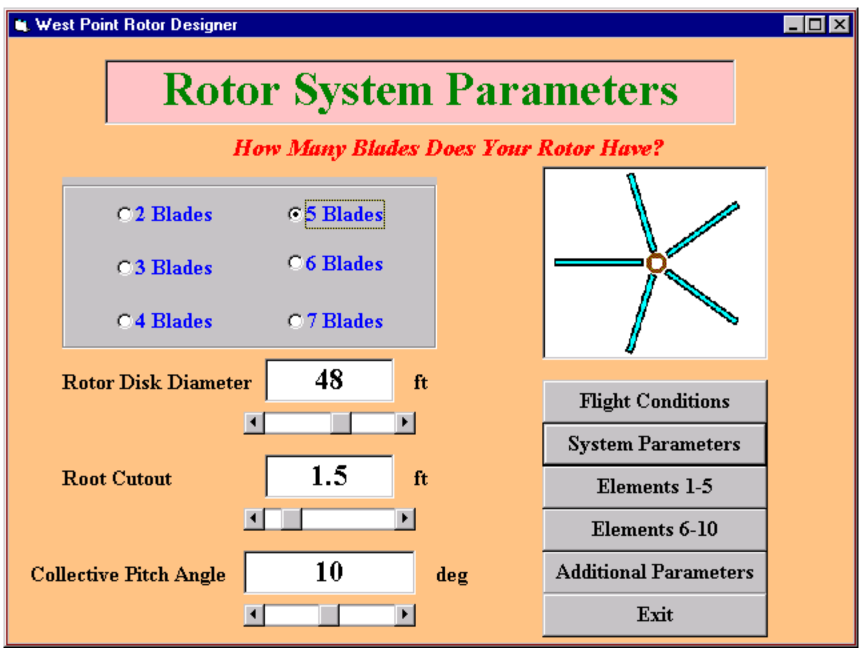


Figure 1.  'Rotor System Parameters' Input Window

V.  Student Feedback

Thirteen students utilized the CAD program and completed a survey administered at the end of the design block of instruction.  The number-one comment was that the user should be able to type-in the input values to speed use.  The students also wanted a forward flight analysis capability added to the program.  Additional modifications requested by the students were:

- Ask if the user is sure he/she wants to exit after checking the exit control

- One window containing all of the design information
- Ability to save the data for each design and recall it later for further work
- Ability to print a summary of the design parameters
- Instructions and tips

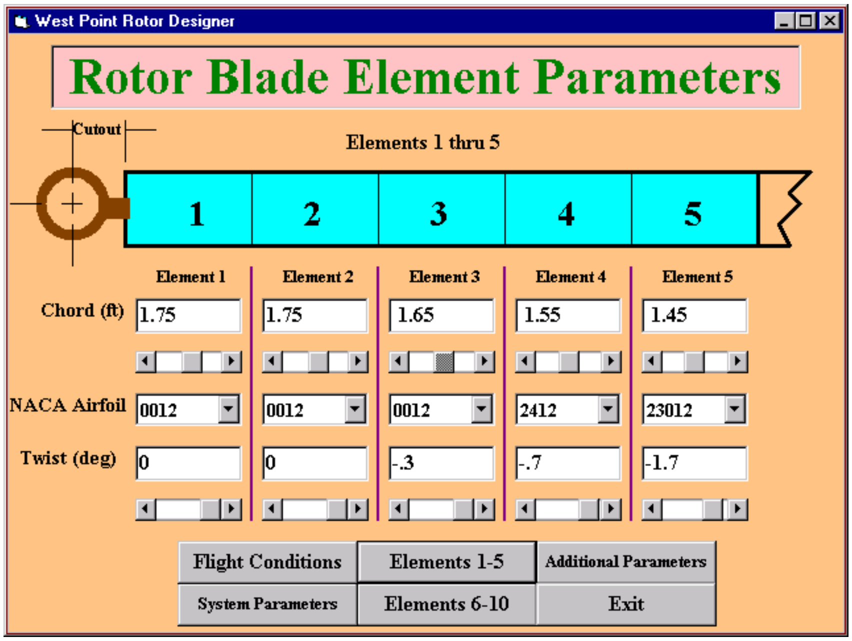


Figure 2. 'Rotor Blade Element Parameters' Input Window

VI. Refinements

In response to student feedback, version 2.0 of the ***WEST POINT ROTOR DESIGNER*** is under development. It will include:

- Keyboard input by the user
- Forward flight analysis
- Single window design board
- Data storage/recall/print capabilities

The updated, design board/user interface appears below in figure 3.

VII. Conclusions

The ***WEST POINT ROTOR DESIGNER*** has been an effective enhancement to the design portion of West Point's introductory helicopter aeronautics course. It provides a graphic design tool, which aids in visualizing the effects of design changes. This has enabled the instructor to impart a greater understanding of the relationships between the various physical equations developed in the course and their application to the art of design. The student recommended enhancements of version 2.0 promise to be of even greater benefit.

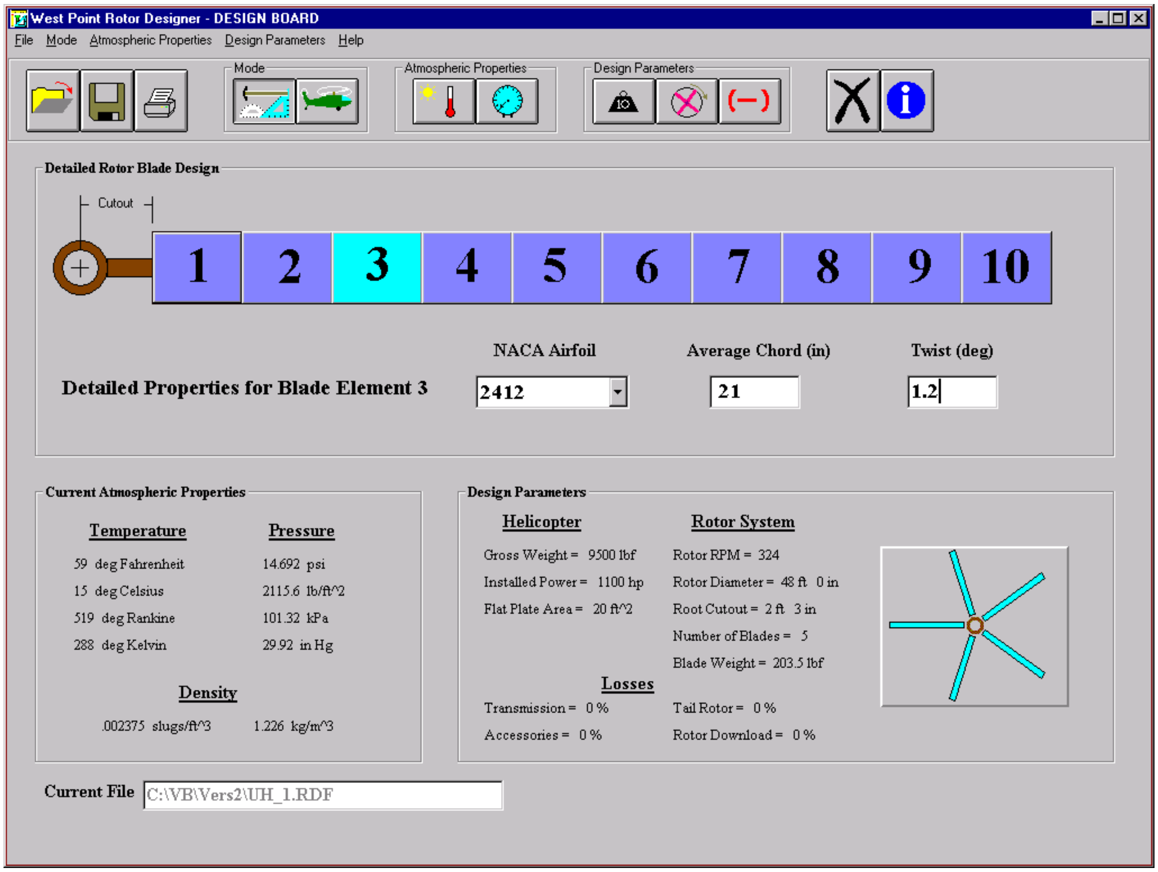


Figure 3. Improved User Interface

Bibliography

1. Alfred Gessow and Garry C. Meyers Jr., *Aerodynamics of the Helicopter*, College Park Press, 1985.

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