Practical Lecture, Research, and Projects Based Engineering Education

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Abstract

A lecture, research, and projects based course has stimulated student interest in aircraft aerodynamics, performance, and static stability and overwhelmingly enhanced preparation for the practical aircraft conceptual/preliminary capstone design course. This unique elective course titled "Aircraft Flight Mechanics and Performance" uses learning methods reinforced by application techniques to analyze actual aircraft performance. Semester lectures cover three topics in nearly equal segments: practical aerodynamics, total aircraft performance, and static stability derivatives. These lectures contain references from many authors/texts for researching and understanding various techniques to analyze aircraft characteristics in the three areas. Students apply the various techniques in five assigned projects. Each project is documented in a written technical report and the final project includes a presentation of the overall results. An outstanding motivational aspect of the current course is the ability to analyze the student data and compare to published results of existing aircraft. This paper demonstrates how team learning and applied research techniques for analyzing the performance and stability of actual aircraft can assist and motivate students in any aircraft project. The described approach could easily be successfully applied to projects in any engineering discipline.

Introduction

Many airplane design capstone courses in aeronautical and aerospace engineering programs in universities around the globe have adopted a purely theoretical approach to teaching design. This approach is characterized by assigning senior design students the task of re-designing a part of an existing airplane. Often this re-design requires utilizing a computer code or routine the students may or may not have written. The students may not be completely familiar with the boundary conditions or restrictive assumptions of the given routine. While this approach may mirror the tasking assigned a beginning engineer in industry, it seems to limit the scope of expertise and the effective areas for notable performance in an initial job. Industry representatives often express a preference for new graduates to possess a broader knowledge in the fundamentals rather than an in-depth background that could be achieved in a later graduate program. The Preliminary Airplane Design (AE 420) course at the Embry-Riddle Aeronautical University (ERAU), Prescott campus tasks the senior student groups to design an entire airplane given only performance requirements documents. The students must have design expertise in all areas including aerodynamics, propulsion, stability/control, weight/balance, structures, landing gear, and computer aided drawing/design techniques. If practical courses providing the fundamentals in these areas are not included in the pre-requisites, the students will enter the design sequence without the necessary basic skills to accomplish an entire aircraft design following basic established design methodology. After years of observing students struggle with the basics in the design course, it is apparent a course like the Aircraft Flight Mechanics and Performance (AE 395N) course is essential to develop a practical background before students entered the design sequence.

Course Overview and Motivation

The AE 395N course has been taught at ERAU in the fall semester for the last two years. This course was developed to provide practical instruction in three areas found to be necessary for design but not sufficiently covered in other courses. These three areas include: aerodynamics, performance, and aircraft static stability. The course is based on lectures, research, and projects to verify results. The projects are assigned during the semester to utilize each of these areas for problem solution and method verification. The research for each assignment usually reveals multiple methods advocated by different authors. The student group of two will research and evaluate each method, analyze the resulting data from each, and make a solution decision based on critical thinking and analysis. The results are documented in five reports and a final presentation. The first project is an individual effort to plot published airfoil lift and drag curves for a selected existing aircraft. The four remaining projects utilize groups to promote team dynamics and analyze/plot data for the aircraft. The second project expands the airfoil data into wing data including high-lift-devices. The third project completes the aerodynamic phase by including the fuselage and empennage. The fourth project evaluates performance of the entire aircraft and plots total thrust and drag data. Project five is the final project and includes thrust, drag, excess power, and flight envelope plots and also calculates take-off, range, endurance, and turning performance data.

Students learn more, quicker, and retain knowledge better when the subject is of high interest. Theoretical concepts in early undergraduate courses are sometimes difficult to comprehend when a student may not see a direct application of the material to a practical system. Early engineering students often have this problem with the required mathematics and physics due to few direct applications of the material until the upper-level courses in their engineering discipline. Engineering students enter their discipline because of a desire for knowledge in a certain area. Aerospace engineering students in the airplane track pursue this discipline because of their interest in airplanes. The first time the AE 395N course was taught, the solution techniques were applied to generic wings and aircraft with given dimensional and performance parameters. Feedback from students both currently in or already completed the design (AE 420) course indicate the AE 395N course was extremely helpful in preparing the students for all practical applications to design. However, it could always be improved. Therefore, the second version of AE 395N was modified to incorporate existing aircraft for the solutions and analysis. The student motivation for analyzing performance characteristics of these existing aircraft increased dramatically. The learning objectives were more thoroughly accomplished and the preparation for using the same research and analysis techniques in the follow-on design course was considered outstanding by the students.

Comparison and Results

In the first part of the AE 395N course, the course schedule is outlined and references for all research material are given. The students are also given a list of airplane dimensions and performance parameters for five different airplanes ranging from single engine general aviation to large jumbo jet. The students select the aircraft they wish to analyze and select partners for the group projects. The students use given aircraft dimensions and parameters to analyze the performance of the selected aircraft through a sequence of projects. Each project is assessed and corrected if necessary to ensure proper data for the following project. In assessing student performance for the course, all student data was realistic and encouraging when compared to actual aircraft data.

The sample student data presented here is for the T-38 Talon aircraft. This aircraft was selected due to the availability of actual aerodynamic and performance data plots for comparison. The student data are shown here in the course sequence as it was determined with descriptions of the analysis techniques and accompanying data plots. The calculated aerodynamics and performance characteristics, denoted as "AE395N" in the plots, were found using methods defined by Mattingly[1], Raymer[2], Yechout[3], and Nicolai[4]. The majority of the geometrical and propulsion data on the T-38 are listed in Yechout[3]. All analysis was accomplished assuming military thrust (i.e., full throttle, no afterburner). Some geometric and aircraft configuration data were approximated from three-view drawings of the aircraft. The calculated solutions are shown as dashed blue lines and the published T-38 data are shown as solid red lines.

The course initial solution project is to convert two-dimensional (2D) airfoil data to three-dimensional (3D) wing data. The airfoil data is taken from the experimental results published by Abbot and von Doenhoff[5]. The results of this conversion are shown in Figure 1.

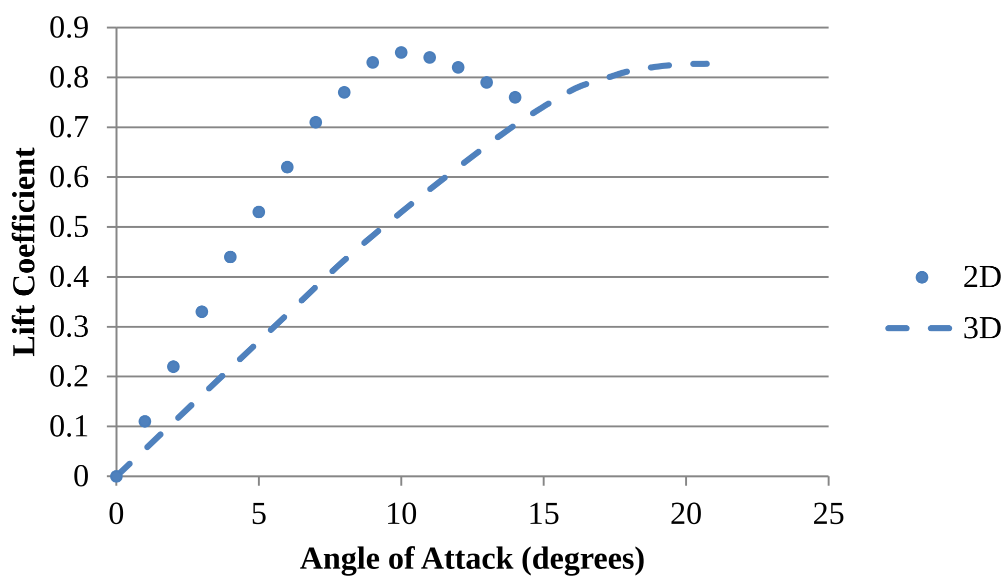

Figure 1: 2D and 3D Lift Data

The 2D to 3D conversion data follows general trends for aerodynamics. As expected, the maximum lift coefficient decreases and the stall angle of attack increases[4]. A similar analysis was accomplished on the horizontal tail of the aircraft.

The method of analyzing 3-D lifting surfaces as well as predicting stall characteristics uses both empirical relations and theoretical equations with corrections (e.g., for compressibility, wingtip vortices, etc.)[4]. After approximating the aircraft geometry (e.g., fuselage shape and location of lifting-surfaces), the overall aircraft lift curve can be determined. The Air Force Stability and Control DATCOM[8] was used to estimate the fuselage contribution to the lift curve. The published lift curve of the entire T-38 aircraft is shown in Figure 2 plotted with the calculated value.

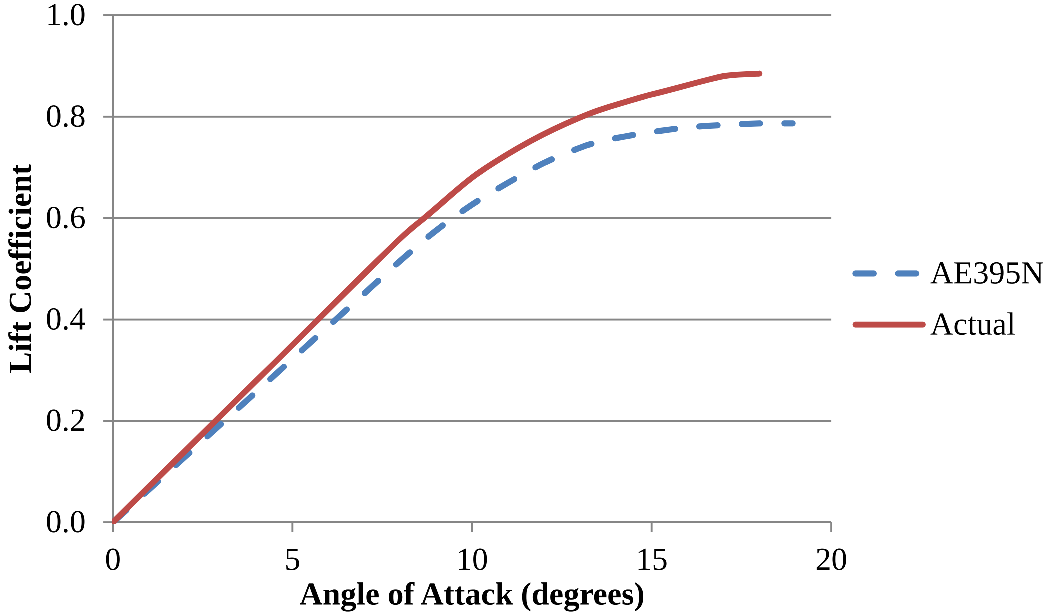

Figure 2: Aircraft Lift Curve

Figure 2 shows reasonable agreement between calculated and published data in aircraft lift-curve slope and stall characteristics. The calculations were accomplished using methods described in Raymer[4] and the DATCOM[8].

The aircraft lift curves with flaps deflected to 45 degrees are shown in Figure 3. The calculated values of lift-curve slope and maximum lift coefficient were obtained from methods outlined in Nicolai[6].

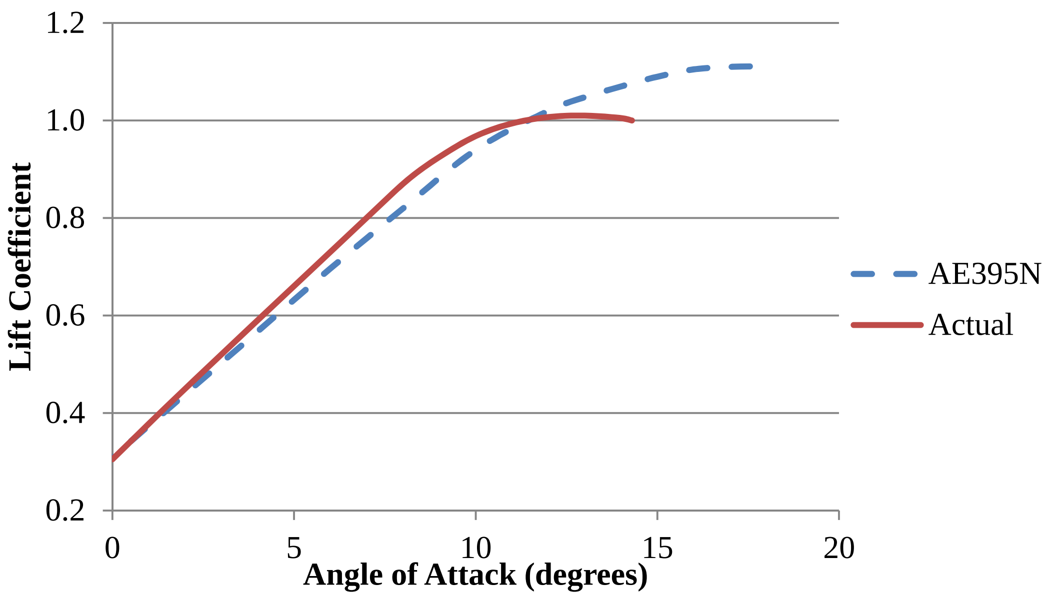

Figure 3: Aircraft Lift Curve with 45 degree Flap Deflection

The calculated lift-curve slope and zero-lift angle of attack show good agreement with the published data. The maximum lift coefficient and stall angle of attack are not coincident with the published due to the lack of accurate dimensions on the flap geometry in the published data.

The performance parameters of the aircraft were calculated utilizing values from the lift curves. The thrust required or drag was calculated for steady, level, unaccelerated flight. The thrust available was calculated using procedures found in Mattingly[1]. Parasite, induced, and wave drag were estimated utilizing a drag build-up method[2]. Since exact aircraft cross-sectional and wetted area dimensions were not available, the estimated parasite drag of the entire aircraft was based on assumptions that added error to the data. Using the installed military thrust of the T-38 engines at sea level, the effects of altitude change and Mach number were estimated using empirical relations based on engine performance analysis[1]. The results of the drag and thrust analysis at sea level and 20,000 feet are shown in Figure 4.

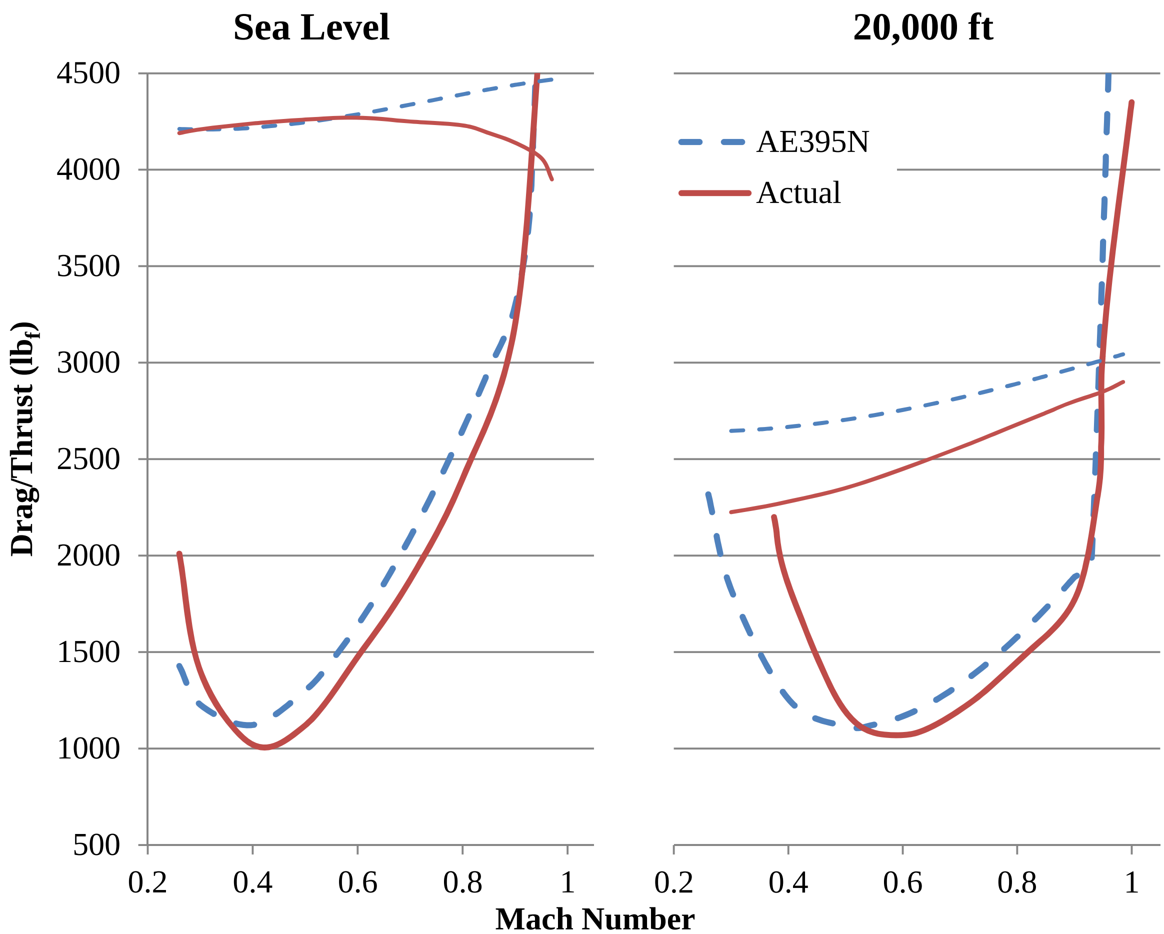

Figure 4: Thrust Available and Thrust Required

In Figure 4, the thinner lines represent the thrust available, and the thicker lines represent the thrust required. With the exception of lower Mach numbers at 20,000 feet, the thrust required analysis closely matched the actual drag behavior of the T-38. The calculated empirical relations were based on engine operation close to ideal operating conditions. This assumption caused variance in thrust available when flight conditions differed from ideal operating conditions.

The specific excess power was obtained from the thrust and drag analysis. These specific excess power curves at different altitudes are plotted verses Mach number and are shown in Figure 5.

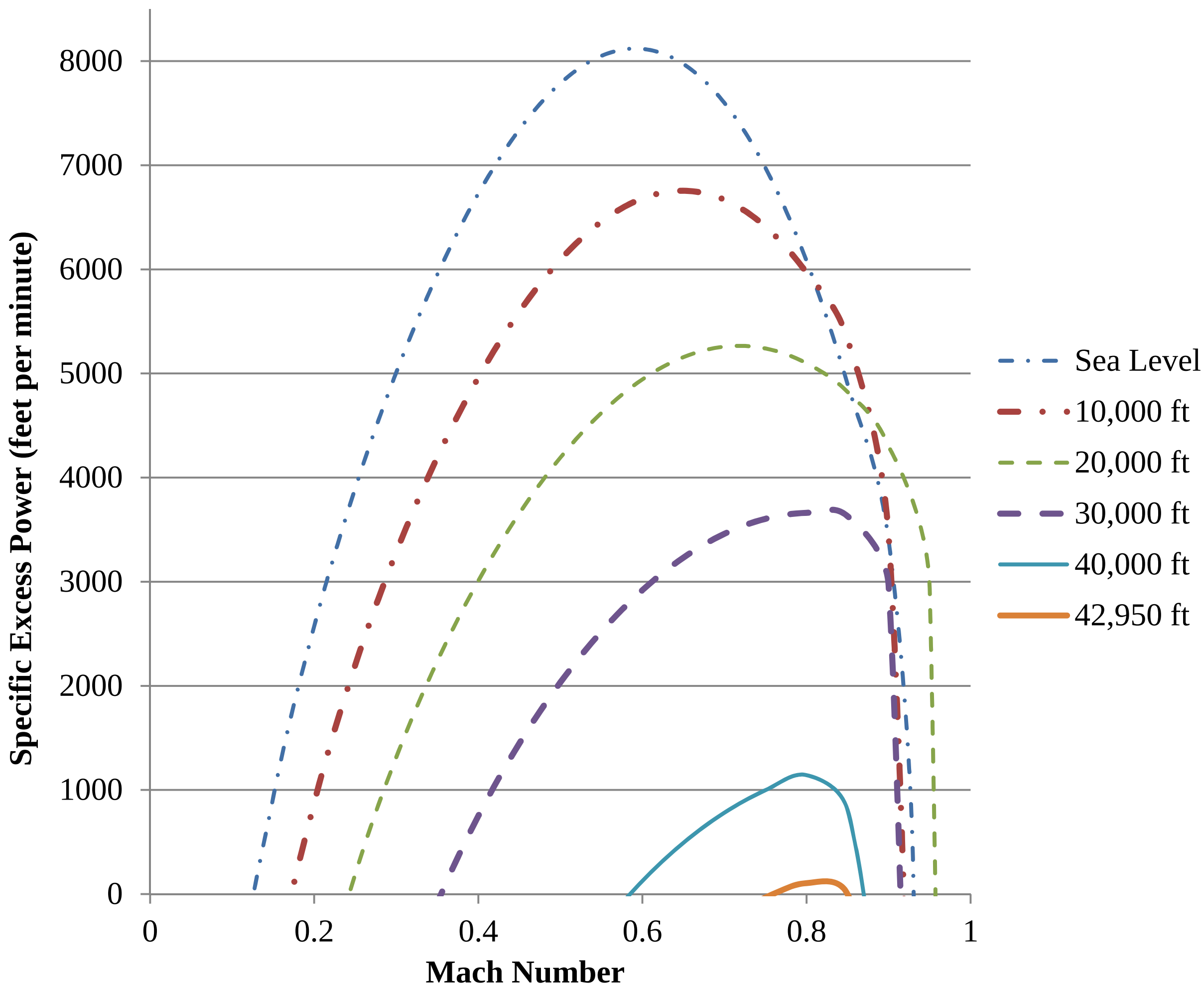

Figure 5: Specific Excess Power

Figure 5 shows the calculated specific excess power from sea level up to the service ceiling at 42,950 feet (i.e., when specific excess power equals 100 feet per minute).

A velocity versus load factor (V-n) diagram was constructed using the calculated stall velocity, given load limits[5], and the calculated dynamic pressure (q) limit. At sea level, the q limit is defined as the dynamic pressure corresponding to the maximum level velocity where thrust available equals the thrust required. This value of dynamic pressure is used at other altitudes and densities to solve for the corresponding Mach number. The data indicates a similar method was used to obtain the q limit of the published data. The calculated T-38 V-n diagrams for sea level and 15,000 feet are shown in Figure 6.

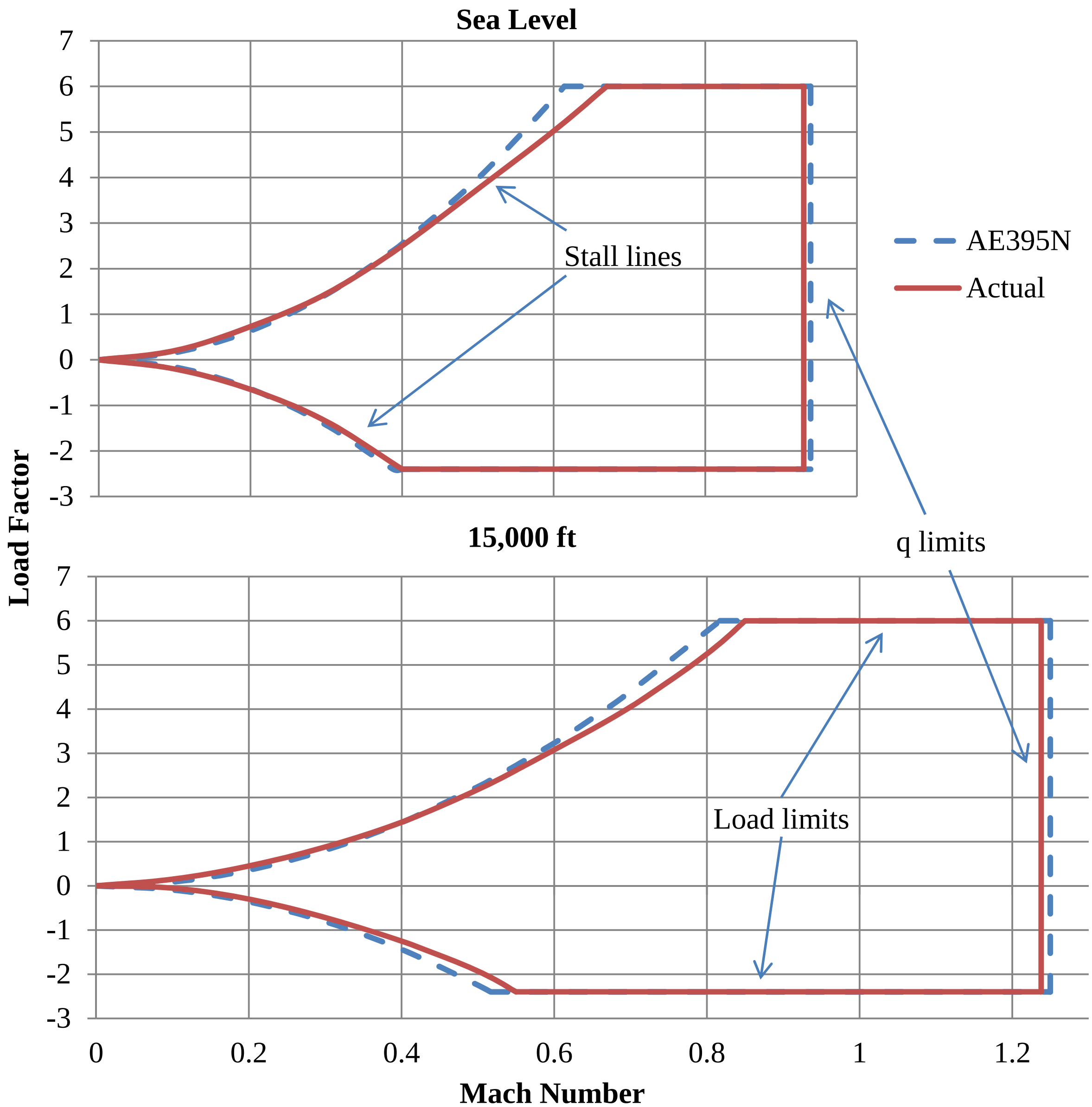

Figure 6: V-n Diagrams

Figure 6 demonstrates nearly identical stall and q limit lines when the calculated and published data are plotted. Slight deviances from the published V-n diagram occur on the stall lines at higher Mach numbers.

The T-38 was one of the aircraft analyzed in the AE395N course to obtain general aircraft performance characteristics. Lift curves, thrust available and thrust required curves, and V-n diagrams were used for the purpose of comparison. This course methodology employed techniques from multiple authors, data from published sources, and comparisons to actual flight test data to verify the course objectives and student outcomes.

Conclusions and Recommendations

Predicting actual full-scale aircraft performance throughout a variety of flight conditions using empirical techniques is very difficult. Many assumptions are made throughout the solution process and every aircraft variable affects all aspects of the overall performance. However, the student data plots show accurate performance trends and often very similar numerical results. The student T-38 solutions included here show good comparison to the published T-38 data verifying the student techniques and performance analysis methods. The aerodynamics and follow-on performance reflect valid techniques but seem limited by the dimensions and performance parameters given in the initial aircraft description. Some aircraft parameters were not available in published form before the course began so these were measured from aircraft drawings or assumed from similar aircraft. These assumptions in initial conditions and somewhat limited application to full-scale aircraft contributed to most of the differences in the data plots. However, the close agreement is very encouraging to the student groups and stimulates interest and understanding of the course material and follow-on design course.

In order to give the students the best possible chance at predicting aircraft performance, the instructor will contact aircraft companies for more specific dimensions, performance parameters, and data plots for comparison. More accurate industry-provided initial dimensions and parameters will improve student results and comparisons. Also, data for more aircraft will be requested so the students will have expanded variety in the aircraft selection and be able to analyze the type of aircraft they want to know more about.

This teaching method/technique is applicable to any engineering discipline. Nearly any engineering project can use basic techniques to analyze the performance of an existing system. In air-breathing propulsion class, the students could analyze an existing engine. In machine technology class, the students could use basic techniques to analyze the performance of an existing system. Often, in the current high speed environment, our students are assumed to be completely comfortable with the basics so course time is spent teaching favorite unique techniques or processes. Students may not fully understand these techniques nor really ever have the opportunity to use them. If students have the basic knowledge required by their discipline, there is no problem adapting to whatever specific environment encountered in initial job tasks as a beginning engineer. If new graduates have specifics without the basics, it will be difficult to adapt unless the initial tasks are exactly the same as their educational environment. So, to motivate our students and give them the best background possible, teach the basics through team/projects based delivery and comparison to real world systems.

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