FLIGHT TEST STEM PROJECT

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ABSTRACT

Science, Technology, Engineering and Math (STEM) is a curriculum concept that integrates these topics and provides students with not only the theory but the practice of science and math principles. Teachers utilize projects that allow students to explore, build and experiment with these concepts to provide a rich learning experience. Meaningful projects of this type can be difficult to conceive and require a considerable amount of work on the part of the teacher to develop. But when successful, students finish the project with a deeper understanding of the science principles and appreciate how math is used as a tool to solve technical problems. Engineers are a valuable resource to teachers as they can provide the context for the theory they are teaching.

This paper will describe one such project that engages students into meaningful flight testing using industry accepted practices on a desktop flight simulator that can be offered to junior high and high school teachers for incorporation into their classrooms.

For flight test engineers who have an interest in supporting their local teachers and schools with this flight test project, this paper will provide the background information for a teacher to create a classroom project suited to their student's needs and desires.

ABREVIATIONS

D, distance

V_f , final velocity

V_i , initial velocity

$V_{ave} = (V_f + V_i)/2$, average velocity

$D = V_{ave}*t$

a, Acceleration; $a = \Delta v/\Delta t$

t, time in seconds

$D = ½at^2$

$L = \frac{1}{2}\rho S V^2 C_L$, Lift equation

C_L, Coefficient of Lift

S, Wing area

ρ, air density

INTRODUCTION

Science teachers appreciate good STEM projects especially ones that have an authentic industry connection to add to their curriculum. As was mentioned in the referenced paper, 'STEM, Education Reform, SFTE and You' many engineers and scientists have a desire to assist teachers with STEM concepts from their practice but need a way to connect with educators. This paper can be thought of as an extension of the previous one, that will allow engineers to take the next step in providing teachers with a suitable aerospace STEM project.

This project uses the exciting field of aerospace and flight testing as a way to enthuse students about learning math and science principles. Students will explore the physics of flight through the study of aeronautical engineering and flight test using current industry practices using an engineering grade, desktop flight simulator. They will learn the forces of flight and how airplanes fly. Students will conduct airplane takeoff testing, varying variables such as flap setting and gross weight and then use kinematic equations to calculate runway takeoff distance, comparing their results with the simulator's values. They will make an assessment of the expected outcome, plan and conduct a test, collect and analyze data to determine if their hypothesis is proven correct or not. Conducting these flight tests using a flight simulator and analyzing data, allows students to visualize basic physics concepts within the context of aerospace and is done in a similar manner at typical flight test centers such as Edwards Air Force Base.

STEM PROJECT DESCRIPTION

This has been taught in various forms for seven years as a quarter long project primarily to high school freshmen, but also to junior high students. It uses a flight simulator to conduct a series of takeoff flight tests where students determine takeoff distance and correlate the results with different variables such as gross weight and flap setting. Advanced students can explore other independent variables such as temperature, altitude, winds and use kinematic equations to determine distance.

This project is expandable and as such can cover many concepts. For instance, although not required for the project, spreadsheet skills using Excel is helpful but not required and as such, using this project can be an opportunity to learn Excel.

The project can be scaled up or down as needed to fit an amount of time. It can range from three block periods, up to nine periods as outlined in the schedule further in this paper. The following are the topics that can be covered in the nine-session project.

- Anatomy of an airplane
- Reading flight instruments
- Airplane forces of flight
- Test planning
- Lift and the Lift equations
- Velocity equation
- Data analysis utilizing plotting tools
- Unit conversions
- Dimensional analysis
- Distance equations using either average velocity or acceleration

GRADE LEVEL AND SCALABILITY

This project can support a wide range of student levels and abilities starting in junior high. The determining factor being mostly math skills, but students from junior high through high school can benefit. Introducing Newton's laws, Lift equation, velocity and distance equations will require an understanding of basic algebra concepts.

The initial activity is for students to learn to fly and use the simulator. The simulator can determine the takeoff distance in the data output but introducing students to velocity, acceleration and the distance equation will allow them to independently calculate distance, validating their results with the simulators. After the initial activity extensions are provided suitable for high school students, for in-depth exploration into areas such as aerodynamics, air density and weather.

PROJECT OUTLINE

The basic three session schedule, primarily suited for junior high students, starts with a project introduction and a teacher led demonstration of Xplane, students then would be able to conduct their own flight tests on the third session.

For a more in-depth study of the different concepts, nine sessions as described below, would be as an example of a suitable class schedule.

Nine Session Schedule

Session	Presentation Topic	Activity	Lab Activity
1	Introduction to project and to flight testing	Flight test YouTube videos	Xplane Demo
2	Anatomy of an airplane	Explore parts of airplanes	Set up airplane, airport in Xplane
3	Flight Instruments	Explore Instrument panels	Instrument panels
4	Forces and Airplane Forces	Explore Newton's Law	Normal takeoff and How to fly
5	Lift and Lift Equation	Develop test plans	Airplane Configuration setup and data selection
6	Anatomy of a Takeoff	YouTube videos of typical airplane takeoffs.	Airplane takeoff testing
7	Velocity	Explore Velocity	Data reduction/Re-fly
8	Distance	Explore Distance	Data reduction and analysis
9	Test Results	Test Reporting	Summarizing

Additional extensions in the areas of exploring effects of temperature, altitude, wind, thrust and flaps on airplane takeoff performance can also be done.

LEARNING STANDARDS

Research into the Common Core Standards for math and science revealed a new series of standards adopted by Washington State for science called Next Generation Science Standards, NGSS. The following middle school science standard (MS-PS2-2) was addressed by the takeoff investigation of varying gross weight and flap setting to manually calculate takeoff distance and compare that with what the simulation determined. The math standard that follows (8EE.5) was demonstrated by the plotting of velocity and time, realizing that acceleration is the slope of the velocity. There may be other standards addressed by this project.

> *MS-PS2-2: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.*
>
> 8EE.5 *Understand the connections between proportional relationships, lines, and linear equations. Graph proportional relationships, interpreting the unit rate as the slope of the graph.*

MATH CONNECTION

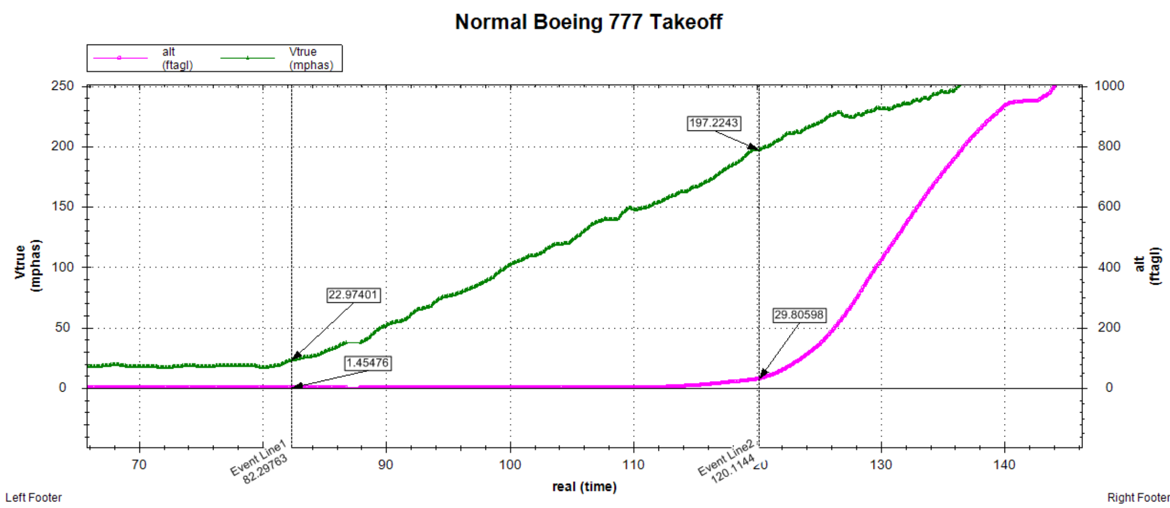
The connection to math concepts is important for several reasons, not only just for practice but primarily in the use of validating the test results against the theory. Manipulating one variable in a three variable equation such as the distance equation using average velocity, is something junior high students can understand. Here are some other specific examples;

- The concept of velocity is introduced and used as an important factor in determining takeoff distance and also in its effects on lift in the lift equation.
- The conversion of units, specifically miles per hour => feet per second is required to obtain the runway distance in the correct units of feet.
- Unit conversion can also be used as an opportunity to introduce students to dimensional analysis whereby doing the units conversion longhand, carrying all the units along with the numeric values in the equations and canceling 'like' units is a method to independently verify correct units at the end.
- Distance calculations can be made using average velocity where velocity can be assumed to be linear; distance equals average velocity multiplied by time: $D = V_{ave}*t$, where $V_{ave} = (V_f + V_i)/2$.
- Distance can also be arrived at by using acceleration: distance $D = ½at^2$, where acceleration is determined by: acceleration = $\Delta v/\Delta t$. Coupling this with another useful concept that the slope of the velocity plot equates to acceleration is another useful method to reinforce linear equation concepts.
- Introducing the lift equation, $L = \frac{1}{2}\rho S V^2 C_L$, is important in understanding the parameters that affect lift. For example, knowing that the lift generated by the wing must equal the weight of the airplane, will illustrate to students the need to increase some other variable in the equation to produce the extra needed lift. For example, increasing either velocity, wing area or the Coefficient of Lift, C_L will increase lift. For this example, adding flaps will increase both wing area, S, and C_L. Advanced students can explore how air density affects lift by testing airport

temperature or airport elevation. Other factors such as headwinds and thrust settings have a direct relationship to runway distance and test results readily illustrate that.

EXAMPLE CALCULATIONS

The example below demonstrates the steps in reducing the flight test data from the takeoff testing into runway distance. The example is a plot of just two variables, speed and altitude, against time (in seconds). From these two parameters, runway distance can be determined by selecting the times associated with the start and end of the takeoff, in this case the end was determined to be when the airplane reached an altitude of 30 feet. The example below used DatPlot as the charting software.



Example Steps:

1. Plot True Airspeed and Altitude above ground vs time in seconds
2. Obtain appropriate times for both start and end. Add Event Markers for the takeoff start and at 30 feet to obtain numeric values at these times.
3. Calculate acceleration as follows:
    a. Convert MPH to ft/s for the two speeds
        i. 197.2 MPH = 289.2 ft/s
        ii. 23.0 MPH = 33.7 ft/s
    b. Determine acceleration => $\Delta v/\Delta t$: (289.2-33.7)/(120.1-82.3) = 6.8 ft/sec^2
4. Calculate distance $D = ½at^2$ => ½* 6.8 * (120.1-82.3)^2 = 4858 ft.

These steps are repeated for the remaining test data and then summarized in charts. Such an example is the one below done in Excel by a ninth-grade student. Notice that the results fit nicely with the theory that the heavier the airplane, the more runway it requires to takeoff. Other important attributes of the data points are they being in tight patterns signifying consistent testing methods and results with no significant outliers.

Student Plot of B777 Takeoff Distance vs Gross Weight

HOW TO GET STARTED

For SFTE members and chapters who want to be involved, connect with a school, a teacher, a PTA, or a home school parent. Provide them with the Activity Planner in the Appendix A1. Offer to assist as either a guest speaker or as a project helper. Use the following references and links to discussion boards for reference material and to post questions.

SFTE Digital Notebook: https://www.sfte.org/members-only/community/sfte-forums/121-stems

Join the SFTE STEM Outreach LinkedIn Group: https://www.linkedin.com/groups/

SFTE Facebook page: https://www.facebook.com/groups/SFTE1/

Supplies Needed

The following equipment and supplies are needed for the project. All of the software can be downloaded for free.

- Xplane version 9 demo for free at http://www.x-plane.com/desktop/try-it/older/ Depending on internet connection it will take some time to download. This free demo version will stop running after 10 minutes and requires a program restart, but it runs long enough to conduct some testing. Version 9 is recommended if it is to be run on older, less powerful laptops, but still has all the functionality required.
- Alternatively, there is a commercial course called *Fly to Learn* that includes v9 Xplane software, lesson plans and other resources for both teachers and students to conduct the basic testing. The

cost to purchase Xplane Fly to Learn is approximately $24 per computer which eliminates the 10 minute restriction and can be found at http://flytolearn.com/ .

- Laptop (PC) or desktop computer with mouse.
- Excel spreadsheet software or graph paper to plot the data or a data plotting program such as DatPlot (http://www.datplot.com/)
- Online resources, *NASA Beginners Guide to Aeronautics* page https://www.grc.nasa.gov/WWW/k-12/airplane/index.html
- Online resources, *NASA What is Aeronautics* page https://www.grc.nasa.gov/WWW/k-12/UEET/StudentSite/aeronautics.html

CONCLUSION

For over the past seven years this project has been used for hundreds of students in ninth-grade science class and teachers, parents and participating SFTE members agree this is a meaningful demonstration of flight test engineering that can provide students with an authentic industry example.

REFERENCES

Hrehov, D. W. '*STEM, Education Reform, SFTE and You'*, 2013, 44th Annual SFTE Symposium, FT Worth, TX.

DatPlot web site: http://www.datplot.com /

X-plane Web site: http://www.x-plane.com/desktop/home/

Fly To Learn website http://flytolearn.com/

BIOGRAPHY

Dan Hrehov has over thirty-five years flight test experience in the Seattle area and has worked on most avionics systems on many Boeing Commercial Model types from the 727 to the 787. His primary work has been flight testing avionics and automatic flight controls systems as well as navigational and communication radios, and flight management computers.

Dan is a professional engineer and a Fellow in SFTE and has published several papers and conducted many symposium workshops on the subjects of FMC testing, Lightning, EMC, Data Systems Certification, and Safety of Instrumentation Installations. He also has a Master's in Teaching degree and holds a Washington State Teachers certificate for secondary education with a physics endorsement.
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