National Aeronautics and Space Administration

STEM LEARNING:

X-57 Scratch Coding Activity

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OVERVIEW

In this activity, students use Scratch, Snap!, or another programming language to create a working model of NASA's X-57 aircraft multiple propeller design, or distributed electric propulsion system. The activity engages students in computational thinking, problem-solving, and real-world applications of mathematics.

Grade Level: 6th-12th

Suggested Time: 1–1½ hours

Standards

CCS.MATH.CONTENT.7.EE.B.4: Use variables to represent quantities in a real-world or mathematical problem and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Next Generation Science Standards

Science and Engineering Practices

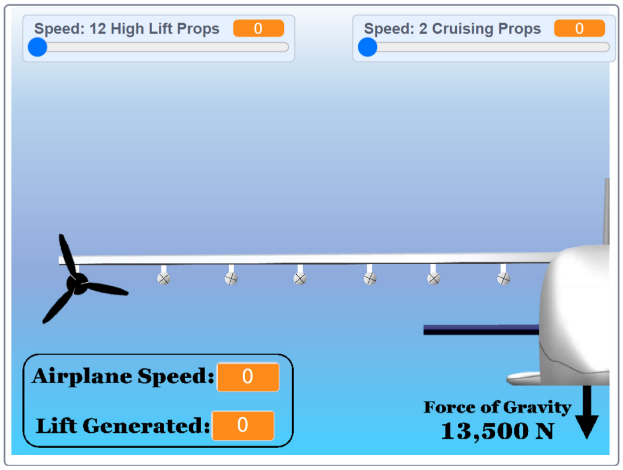
- Developing and using models
- Using mathematical and computational thinking

Crosscutting Concepts

- Scale, proportion, and quantity

Materials

- Computer or tablet with internet access (or download all content to run locally)
- X-57 Stage – *Download JPG* (51 KB)
- Cruising Propeller Sprite — *Download PNG* (12 KB)
- High Lift Propeller Folded Sprite — *Download PNG* (14 KB)
- High Lift Propeller Unfolded Sprite — *Download PNG* (16 KB)
- Programming language of your choice
    - Free Scratch account at: *http://scratch.mit.edu*
    - Free Snap account at: *https://snap.berkeley.edu*



Speed: 12 High Lift Props 0

Speed: 2 Cruising Props 0

Airplane Speed: 0

Lift Generated: 0

Force of Gravity
13,500 N

Management

1. This activity can be used to introduce students to coding or as an enrichment activity after students have learned about the various coding blocks.
2. This guide takes students through the process of modelling the propeller system of the X-57 airplane using simple drag-and-drop programs such as Scratch. It also introduces students to simple animation and the use of mathematical formulas in coding. Students can also complete the activity using other programs such as Snap!.
3. This tutorial style activity is appropriate for students with any level of programming experience. Once students get their program running, encourage them to experiment with modifying the code to see what it does. This helps students "see" what various commands and variables do by seeing how they affect the program's performance.
4. As students write their programs, they should beta test with the help of another student. Beta testers should look for errors in the program's execution and provide constructive feedback to the programmer.
5. If students complete the task with time remaining, they can be assigned additional higher-level requirements to challenge them. Several suggestions can be found in the "Extension Ideas" section of this guide. Optionally, students can come up with their own requirements and change their code to meet these new requirements.

Background Information

NASA's X-57 Maxwell is a small, experimental aircraft powered completely by batteries. It is NASA's first full-sized all-electric experimental aircraft, or X-plane. Compared to standard fuel-powered airplanes, the X-57 is designed to have increased high-speed cruise efficiency, zero in-flight carbon emissions, and flight that is much quieter for the community on the ground.

One of the primary goals of the X-57 project is to develop all-electric technology that will make flying cleaner, quieter, and more sustainable. The technologies and verification and testing processes created for the X-57 will be an important part of future projects that work towards more sustainable aviation.

Because the X-57 has wings that are narrower from front to back than standard airplanes, it is important to get as much air flowing over the wings as possible.

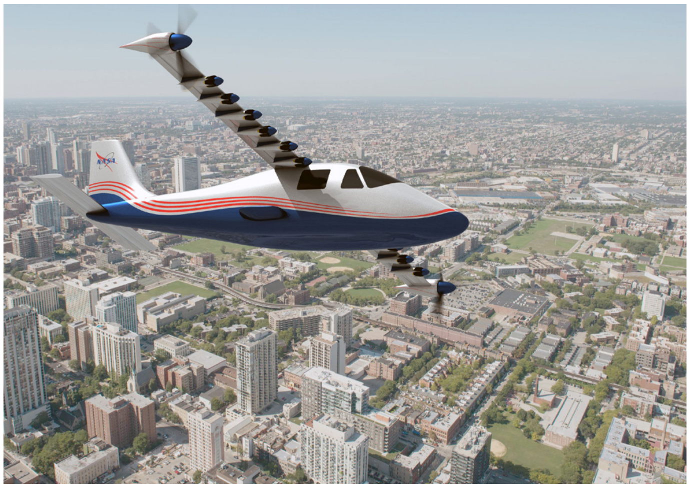


Figure 1. This artist's concept of NASA's X-57 Maxwell aircraft shows the plane's specially designed wing and 14 electric motors. Credit: NASA Graphic / NASA Langley / Advanced Concepts Lab, AMA, Inc.

To increase airflow, NASA engineers developed multiple designs, including a system of 14 propellers. In this design, two large cruising motors with propellers have been designed to be used throughout the plane's flight while 12 smaller, high-lift motors with retractable propellers are to be used during takeoff and landing. And while flying the X-57 will be a major milestone, it is important to note that the process of modifying the aircraft, along with building, testing, and validating the new technologies have already made important contributions to future aviation innovations. These results will be shared with other aircraft designers, who can use NASA's designs to help with their own developments.

FILES TO DOWNLOAD

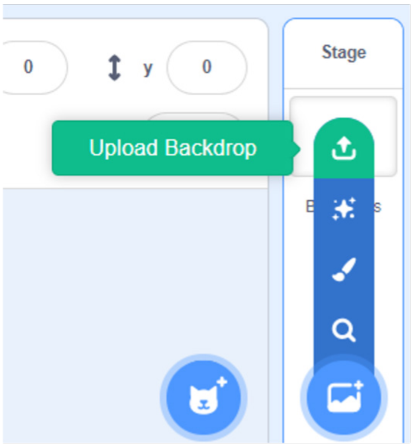
The following files need to be downloaded and saved on the device being used for the coding activity. Make sure to keep track of where these files are saved so they can be brought into the program.

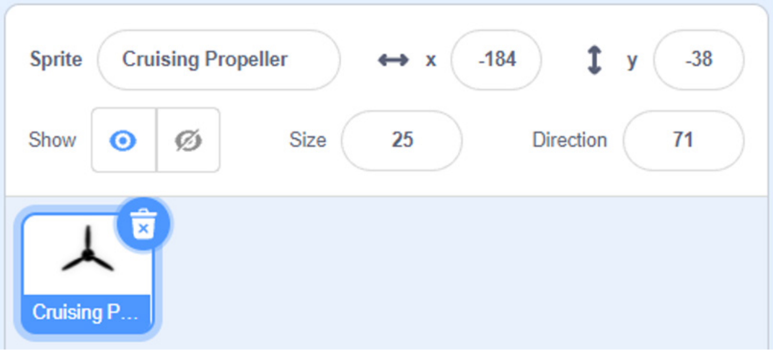
- X-57 Stage – *Download JPG* (51 KB)
- Cruising Propeller Sprite – *Download PNG* (12 KB)
- High Lift Propeller Folded Sprite – *Download PNG* (14 KB)
- High Lift Propeller Unfolded Sprite– *Download PNG* (16 KB)

PART 1 – SETTING UP THE GRAPHICS

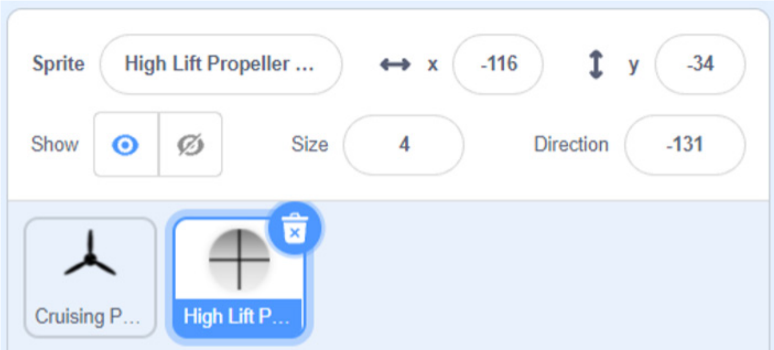
Graphics are the pictures in a program that make it easier for a user to interact with the program. The following instructions use Scratch (follow similar steps if using other programs).

1. On the Scratch website (*https://scratch.mit.edu/*), sign in and click "Create" to create a new project. Scratch can also be downloaded and run locally, removing the need for an active internet connection while working with Scratch.
2. In the "Stage" box in the lower right of the screen, place the mouse cursor over the blue button and select "Upload Backdrop." Select the file "X-57 Stage.jpg" that you downloaded.
3. Next to the "Stage" box on the screen, there is a box for sprites. There should be a sprite of a cat there by default. Click on the trash can attached to the cat to remove it since you won't need it for this activity.
4. Place the mouse cursor over the blue button in the "Sprite" box and select "Upload Sprite." Then select the file "Cruising Propeller Sprite.png" you already downloaded.
5. Move this sprite to the correct location. To do this, change the "x" and "y" values in the "Sprite" box in the lower left portion of the screen. The values should be as shown in the picture below. You also need to adjust the size by changing the value in the "Size" box as shown below.




Sprite: Cruising Propeller
x: -184
y: -38
Show
Size: 25
Direction: 71

6. Next, bring in the sprite for the first high lift propeller. Place the mouse cursor over the blue button in the “Sprite” box and select “Upload Sprite.” Select the file “High Lift Propeller Folded Sprite.png” that you downloaded.



Sprite: High Lift Propeller ... x: -116 y: -34

Show Size: 4 Direction: -131

7. Change the location of this sprite so that its X -value is -116 and its Y value is -34. The size needs to be adjusted to 4.

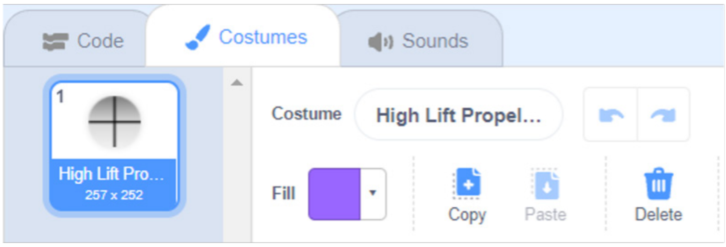
8. Since the plane has 6 high lift propellers on the wing, you need to repeat steps 6 and 7 five more times. Each propeller must be set to the same size (4), but each will be at a different location. The table below shows the X and Y values for each propeller.

High Lift Propeller	X value	Y value	Size
1	-116	-34	4
2	-63	-34	4
3	-9	-34	4
4	46	-34	4
5	96	-34	4
6	151	-34	4

9. The graphics that you added for the high lift propellers show the propellers when they are folded back. In this configuration, they do not act as propellers. On the X-57, these propellers can be deployed when needed, which is during takeoff and landing. So, you need to add the graphics that will show these propellers unfolded.

10. To do this, you will need to add another “Costume” for each of the high lift propeller sprites. In Scratch, a costume is an alternate form, or picture, for a sprite.

11. Select the first high lift propeller in the “Sprite” box located in the lower left corner of the screen. Once you have done this, click on the “Costumes” tab near the top of the screen.

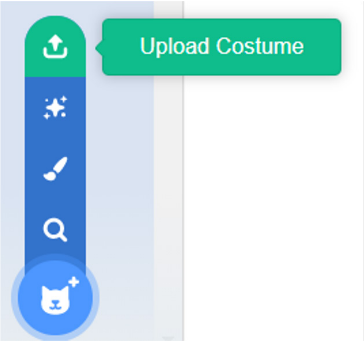


Costume: High Lift Propel...

12. Hover over the blue button at the bottom of the "Costume" box on the screen, then select "Upload Costume." You need to upload the file "High Lift Propeller Unfolded Sprite.png" that you downloaded.

13. In the "Sprite" box, change the size of this sprite to 20.

14. You need to also upload and change the size of this costume for each of the other high lift propeller sprites.



PART 2 – DEFINING THE VARIABLES

Variables are used in programs to store values that the program will use. They can be changed at different points throughout the program.

1. For this activity, you will need 5 different variables.

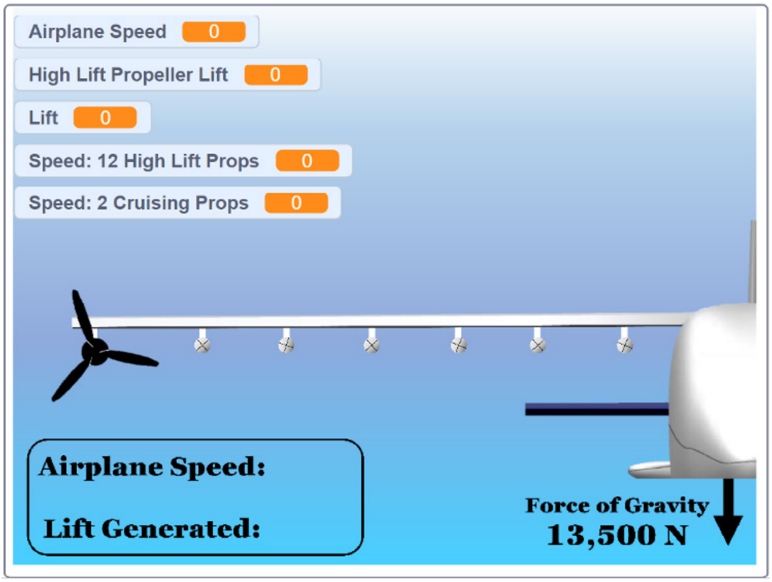
2. Click on the "Code" tab near the top of the screen. Then select the orange "Variables" button near the bottom of the left side of the screen.

3. Select the "Make a Variable" button. This will cause another window to pop up which allows you to define a new variable.

4. Type in "Airplane Speed" for the name of this variable. The "For all sprites" option should be selected by default. If not, select that option before clicking "OK."

5. Repeat these steps to create 4 more variables named "High Lift Propeller Lift", "Lift", "Speed: 12 High Lift Props", and "Speed: 2 Cruising Props".

6. All the variables will now be on the stage as shown in the picture below. You need to move them and change how they are displayed.


Airplane Speed 0

High Lift Propeller Lift 0

Lift 0

Speed: 12 High Lift Props 0

Speed: 2 Cruising Props 0

7. You need to make the variable “High Lift Propeller Lift” not display on the stage. In the “Variable” box, you will see a box next to this variable that is checked. Uncheck this box and the variable will no longer be displayed.

8. For the variables “Airplane Speed” and “Lift”, right click on the variable and select “large readout” before dragging them down next to the words “Airplane Speed” and “Lift Generated” at the bottom right of the stage.

9. For the other 2 variables, right click on them and select “slider” before moving them into the top corners of the stage.

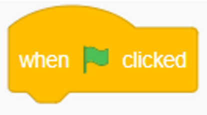
PART 3 – PROGRAMMING

A program is a set of instructions that is followed to accomplish a task. In Scratch, you can have different programs attached to the various sprites that you use.

Programming the Cruising Propeller Sprite

1. Select the “Cruising Propeller” sprite from the “Sprite” box. Then, select the “Code” tab.

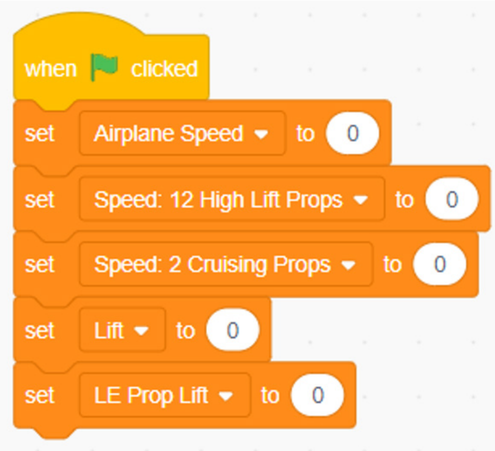
2. On the left side of the screen, click on the yellow “Events” button. Then, drag the “when clicked” block into the coding section of the screen.



```
when 🏴 clicked
```

3. This first program will simply reset all the variables when the program begins.

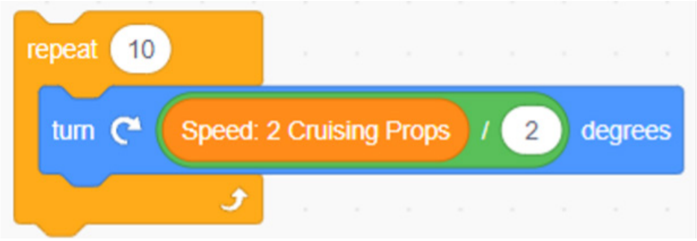
4. Click on the orange “Variables” button on the left side of the screen and drag the “set Airplane Speed to 0” so it attaches to the “when clicked” block. You need to do this 5 times. Then, change the name of the variable in each block so it looks like the following:



```
when 🏴 clicked
set Airplane Speed ▾ to 0
set Speed: 12 High Lift Props ▾ to 0
set Speed: 2 Cruising Props ▾ to 0
set Lift ▾ to 0
set LE Prop Lift ▾ to 0
```

5. The second program attached to this sprite is designed to animate the cruising propeller and adjust the airplane’s speed and the lift created. You need to drag a second “when clicked” block into the coding section of the screen.

6. The propeller is animated by rotating the sprite on the screen. How fast it turns depends on the speed that the user selects. In this program, each turn will be the speed of the cruising propellers (0-100) divided by 2, and it will do this turn 10 times. To accomplish this, the second program will have the following blocks of code.



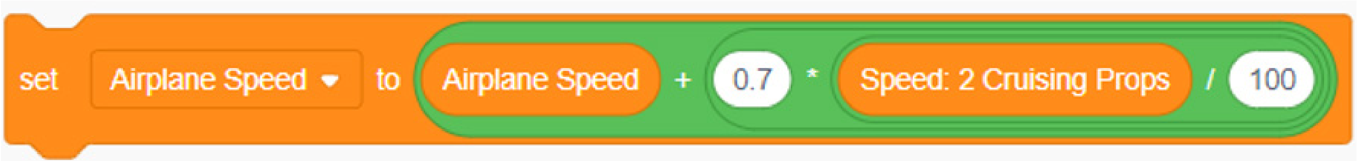
```
repeat 10
    turn ↻ (Speed: 2 Cruising Props / 2) degrees
```

7. As the propeller spins, the airplane's speed increases. In the model you are creating, the speed of the cruising propellers will determine how much the airplane's speed increases. For each percentage of speed for the propellers, the speed increases 0.7 miles per hour.

   The formula for this would be:

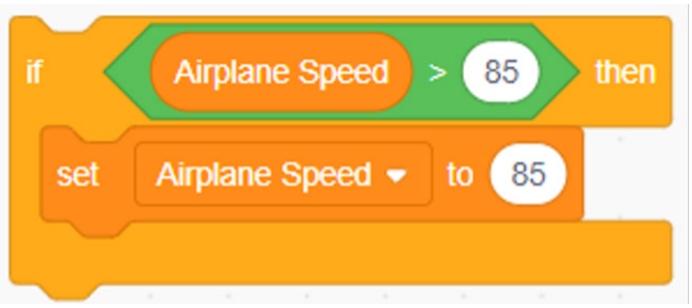
   Airplane Speed = Airplane Speed + ((0.7) * (Cruising Propeller Speed/100))

   To code this, you would use the following blocks of code.



```
set Airplane Speed ▾ to (Airplane Speed + (0.7 * (Speed: 2 Cruising Props / 100)))
```

8. The plane's maximum speed needs to be set to 85 miles per hour. So, you need to include code to check if the speed has gone over 85 miles per hour. If so, the speed needs to be reset down to 85. This is done using the following blocks of code.

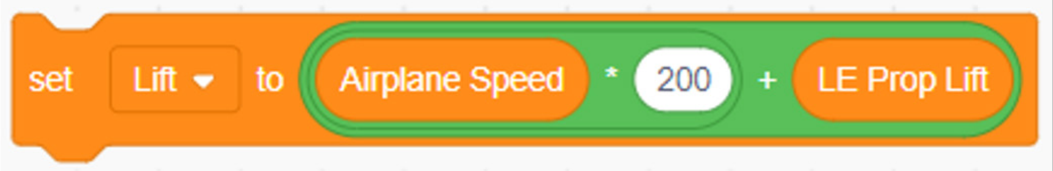


```
if <Airplane Speed > 85> then
    set Airplane Speed ▾ to 85
```

9. As the plane speeds up, it generates more lift, which is the force that pushes the airplane upward. For this model, 200 Newtons (N) of lift are generated for each mile per hour of speed that the plane moves.

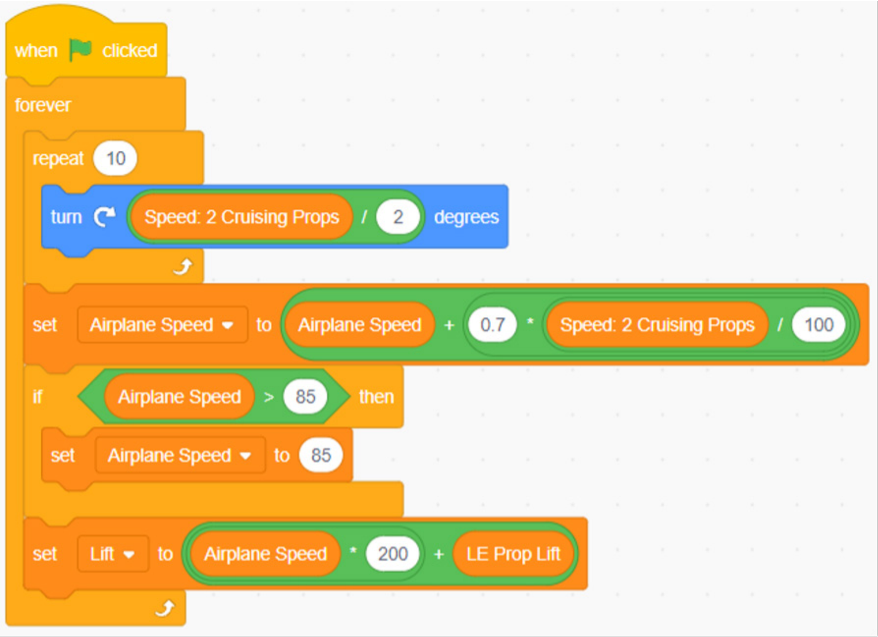
   Additionally, the high lift propellers generate lift by pushing air over the wing. The amount of lift generated by the high lift propellers will be calculated in the code for the first high lift propeller sprite and stored in the variable “High Lift Propeller Lift”. This amount of lift needs to be added to the lift generated because of the plane’s speed.

   In reality, the formula for calculating lift is much more complicated, so this program only provides an approximation of the lift generated. The following code will accomplish this.



```
set Lift ▾ to ((Airplane Speed) * (200)) + (LE Prop Lift)
```

10. Putting all these pieces together, your code for this program should look like the following.

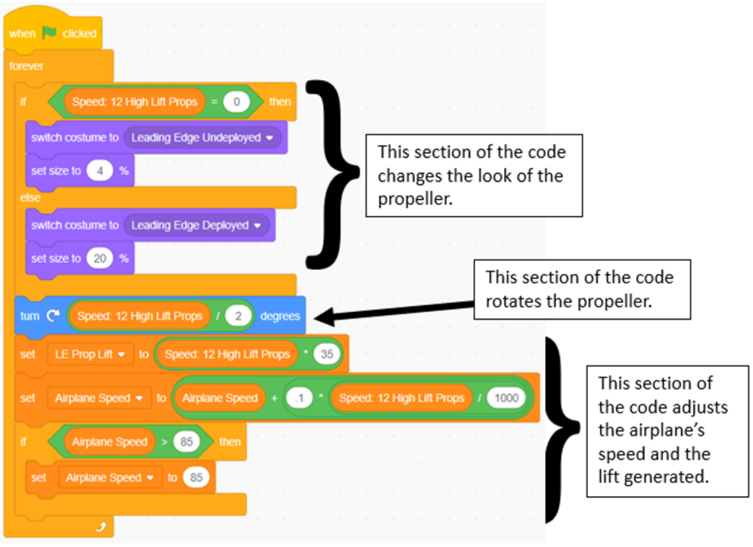


```
when 🏴 clicked
forever
  repeat 10
    turn ↻ ((Speed: 2 Cruising Props) / (2)) degrees
  ⤴
  set Airplane Speed ▾ to ((Airplane Speed) + ((0.7) * ((Speed: 2 Cruising Props) / (100))))
  if <(Airplane Speed) > (85)> then
    set Airplane Speed ▾ to 85
  set Lift ▾ to (((Airplane Speed) * (200)) + (LE Prop Lift))
⤴
```

Programming the First High Lift Propeller Sprite

The code for the first high lift propeller needs to do three things: change the costume when necessary, rotate the propeller, and adjust the airplane's speed and lift generated.

To do this, enter the code below. NOTE: the comments on the right side of the code will not be entered, it is there to show what the different parts of the code does.



```
when ⚑ clicked
forever
    if Speed: 12 High Lift Props = 0 then
        switch costume to Leading Edge Undeployed ▾
        set size to 4 %
    else
        switch costume to Leading Edge Deployed ▾
        set size to 20 %
    turn ↻ Speed: 12 High Lift Props / 2 degrees
    set LE Prop Lift ▾ to Speed: 12 High Lift Props * 35
    set Airplane Speed ▾ to Airplane Speed + .1 * Speed: 12 High Lift Props / 1000
    if Airplane Speed > 85 then
        set Airplane Speed ▾ to 85
```

This section of the code changes the look of the propeller.

This section of the code rotates the propeller.

This section of the code adjusts the airplane's speed and the lift generated.

Programming the Other 5 High Lift Propellers

Each of the other 5 high lift propeller sprites will have much of the same code, and this code will be the first portion of the code you just created. For each of the other 5, you need to enter the code that you created for the first high lift propeller. Do not, however, include the section of the code that adjusts the airplane's speed and lift generated. So, do not enter any of the code block below the "turn Speed: 12 High Lift Props / 2 degrees".

PART 4 – TESTING THE CODE

1. To run your program, click on the green flag located just above the stage.

2. Writing code can be difficult and the code often does not work properly the first time you try it. If your program does not work properly, go back through the directions to see if you can debug the code. It is also a very good idea to have someone else try your program to help find any errors. NASA uses inspectors to test the products they make as a measure of quality assurance. Having a classmate test your program is a great way to employ them as your inspector.

3. Once your program is running properly, try it out to see how having the extra propellers along the front of the wing helps the plane take off at lower speeds.

4. Restart your program and turn on only the cruising propellers. Note at what speed it generates enough lift for the plane to take off. Remember that the lift needs to be greater than the force of gravity pulling the plane down. For the X-57, the force of gravity is 13,500 Newtons (N).

5. Next, restart the program again and power up all the propellers. You should see that it generates enough lift to take off at a different speed.

EXTENSION IDEAS

Once you have your program running properly, you can do more with it. The following list contains some ideas for ways to expand this program. You might also be able to come up with some ideas of your own.

- Have a message pop up on the screen that tells the user when the plane has enough lift to take off. It has enough lift when the lift generated is greater than the force of gravity pulling the plane downward (13,500 Newtons).
- Make the propellers gradually speed up and slow down rather than just jumping to a certain speed.
- Make the airplane’s speed slow down if none of the propellers are spinning.
- Change the graphics. Can you add a window to the front of the X-57? Or can you change it so the wing has more or fewer propellers?

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