

# A Basic Flight Simulator in Excel #4 – creating the initial, current and previous landscape matrices

- This section starts by correcting an error in the z-coordinate of the ground vertex array, after which is reviewing the top level functionality of the model and the needed arrays for creating the moving landscape effect in front of the virtual airplane.
- The tutorial then explains the allocations of the data and calculation matrices in a new worksheet.
- Finally the section explains several input parameter formulas (among which the roll rate, pitch rate, throttle control) and implements them in the worksheet together with several trigonometric functions needed for rotating the image of the landscape.

## [A correction to the Ground Vertex Array:](#)

- There was an error in the implementation of the z-coordinate of the Ground Vertex array.
- The problems lays in the fact that the *Ground Vertex* array has the x-y-z coordinates stacked vertically and it takes information from the *Landscape Elevation* array for the z-coordinate. The *Ground Vertex* array has of course the same number of columns but three times the number of rows as the *Landscape Elevation* array. By the way we built the *Ground Vertex* array by copying and pasting groups of cells (multiples of 3) we got the z-coordinate all messed up.
- The z-formula in the Ground Vertex array is contained in every third row and we need to do the following changes:

=> Cut range U81:U83 and paste it in range T81:T83

=> U83: "=0", U86: "=U83+1" then copy range U84:U86 in the range U87:U203

=> Change the content of V83 from "=\$V\$78+V211" to "=\$V\$78+OFFSET(V\$211,\$U83,0)"

=> Copy V83 to W83 then copy range V83:W83 to range V86:W86 then copy the same range to range V89:W89

=> Copy range V84:W89 to range V90:W203

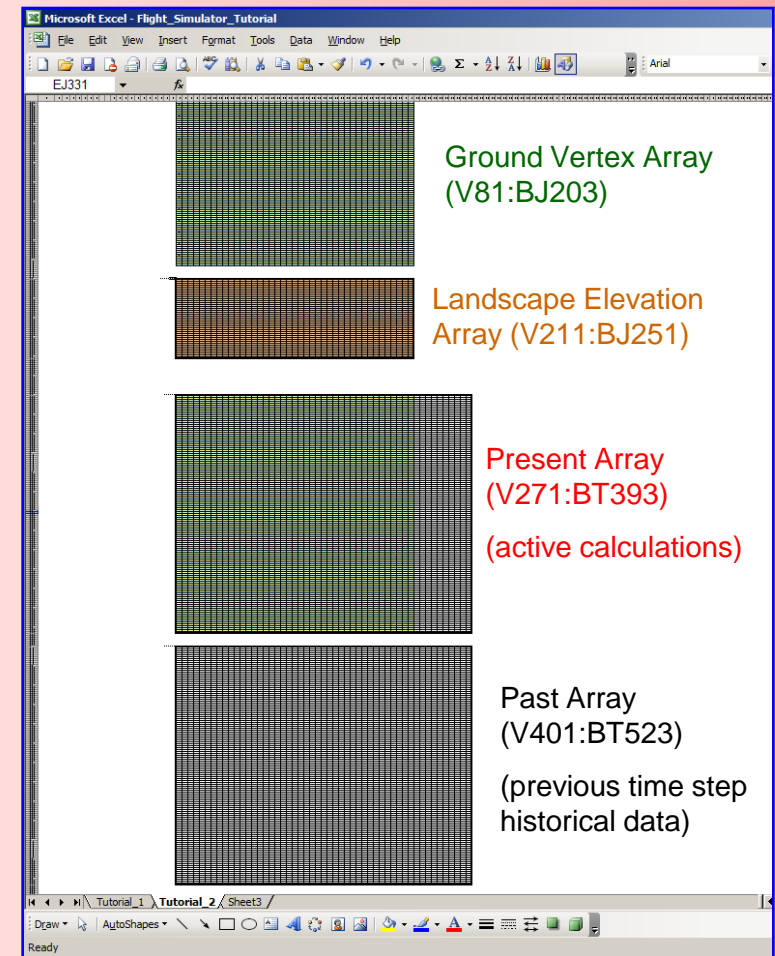
=> Copy range W81:W203 to the right up to range BJ81:BJ203 and we are done

The screenshot shows a Microsoft Excel spreadsheet with the following data structure:

| R   | S | T | U        | V        | W        | X        | Y        | Z        | AA       | AB       |
|-----|---|---|----------|----------|----------|----------|----------|----------|----------|----------|
| 72  |   |   |          |          |          |          |          |          |          |          |
| 73  |   |   | L        | 100      |          |          |          |          |          |          |
| 74  |   |   | h        | 86.60254 |          |          |          |          |          |          |
| 75  |   |   |          |          |          |          |          |          |          |          |
| 76  |   |   | Offset_x | 0        |          |          |          |          |          |          |
| 77  |   |   | Offset_y | 0        |          |          |          |          |          |          |
| 78  |   |   | Offset_z | 0        |          |          |          |          |          |          |
| 79  |   |   |          |          |          |          |          |          |          |          |
| 80  |   |   |          |          |          |          |          |          |          |          |
| 81  |   |   | Vertex_X | 0        | 100      | 200      | 300      | 400      | 500      | 600      |
| 82  |   |   | Vertex_Y | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 83  |   |   | Vertex_Z | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 84  |   |   |          | 50       | 150      | 250      | 350      | 450      | 550      | 650      |
| 85  |   |   |          | 86.60254 | 86.60254 | 86.60254 | 86.60254 | 86.60254 | 86.60254 | 86.60254 |
| 86  |   |   | 1        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 87  |   |   |          | 0        | 100      | 200      | 300      | 400      | 500      | 600      |
| 88  |   |   |          | 173.2051 | 173.2051 | 173.2051 | 173.2051 | 173.2051 | 173.2051 | 173.2051 |
| 89  |   |   | 2        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 90  |   |   |          | 50       | 150      | 250      | 350      | 450      | 550      | 650      |
| 91  |   |   |          | 259.8076 | 259.8076 | 259.8076 | 259.8076 | 259.8076 | 259.8076 | 259.8076 |
| 92  |   |   | 3        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 93  |   |   |          | 0        | 100      | 200      | 300      | 400      | 500      | 600      |
| 94  |   |   |          | 346.4102 | 346.4102 | 346.4102 | 346.4102 | 346.4102 | 346.4102 | 346.4102 |
| 95  |   |   | 4        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 96  |   |   |          | 50       | 150      | 250      | 350      | 450      | 550      | 650      |
| 97  |   |   |          | 433.0127 | 433.0127 | 433.0127 | 433.0127 | 433.0127 | 433.0127 | 433.0127 |
| 98  |   |   | 5        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 99  |   |   |          | 0        | 100      | 200      | 300      | 400      | 500      | 600      |
| 100 |   |   |          | 519.6152 | 519.6152 | 519.6152 | 519.6152 | 519.6152 | 519.6152 | 519.6152 |
| 101 |   |   | 6        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 102 |   |   |          | 50       | 150      | 250      | 350      | 450      | 550      | 650      |
| 103 |   |   |          | 606.2178 | 606.2178 | 606.2178 | 606.2178 | 606.2178 | 606.2178 | 606.2178 |
| 104 |   |   | 7        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 105 |   |   |          | 0        | 100      | 200      | 300      | 400      | 500      | 600      |
| 106 |   |   |          | 692.8203 | 692.8203 | 692.8203 | 692.8203 | 692.8203 | 692.8203 | 692.8203 |
| 107 |   |   | 8        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 108 |   |   |          | 50       | 150      | 250      | 350      | 450      | 550      | 650      |
| 109 |   |   |          | 779.4229 | 779.4229 | 779.4229 | 779.4229 | 779.4229 | 779.4229 | 779.4229 |
| 110 |   |   | 9        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| 111 |   |   |          | 0        | 100      | 200      | 300      | 400      | 500      | 600      |

## Array structure and top level functionality description:

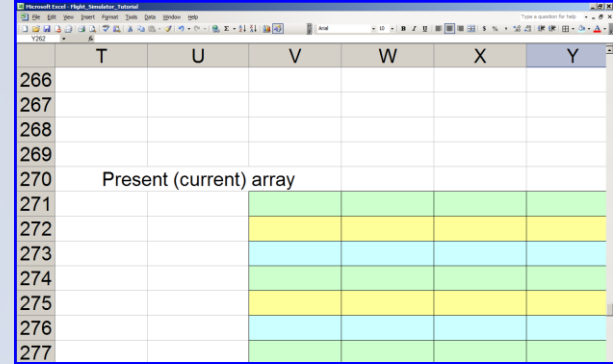
- We already have two arrays built in the worksheet: the *Ground Vertex* array and *Landscape Elevation* array.
- Next, we need two more arrays: the *Present* array (or *Current* array) and the *Past* array (or *Previous* array).
- The size of the *Ground Vertex* array is 123 x 41 (height x width) but we will choose the *Present* array larger since later we might want to add some more shapes on the ground (some buildings) and possibly some more shapes in the sky (clouds, sun, moon, maybe some stars etc).
- Let's choose the dimension of the *Present* array size to be 123 x 51 and place it in the range V271:BT393 (we can later increase or decrease its width).
- We will choose the *Past* array in the range V401:BT523 to be of the same size with the *Present* array size (123 x 51).
- Copy the first worksheet ("Tutorial\_1") and rename the second worksheet "Tutorial\_4".
- To the right there is a zoomed-out snapshot of the new worksheet with the all four arrays visible.
- There will be a **Reset** macro which, before the takeoff, will paste the *Ground Vertex* data into the *Past Array*. During the flight there will be a **Run-Pause** macro will operate the joystick but will also copy the data from the *Present* array into the *Past array* as a loop, emulating the passage of time.
- The change in perspective is done recursively in the *Present* array formulas during every loop cycle using data from the *Past* array and data from the control devices (joystick and throttle).



## Allocate and format the present and the past arrays:

### **The present array:**

- In range V271:BT393 will be the *Present* array containing the active calculations.
- Label the array in cell U270: “Present (current) array”
- Draw cell borders in range V271:BT393 and also use colors with a spatial period of three rows (green for x, yellow for y and blue for z).

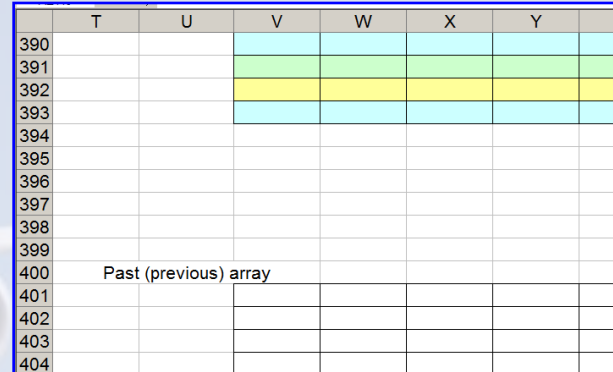


The screenshot shows an Excel spreadsheet with columns T through Y and rows 266 through 277. The label 'Present (current) array' is in cell U270. The data area is a 3D grid from V271 to BT393, with rows 271-277 visible. The grid is colored in a repeating pattern of green, yellow, and blue rows.

|     | T | U                       | V | W | X | Y |
|-----|---|-------------------------|---|---|---|---|
| 266 |   |                         |   |   |   |   |
| 267 |   |                         |   |   |   |   |
| 268 |   |                         |   |   |   |   |
| 269 |   |                         |   |   |   |   |
| 270 |   | Present (current) array |   |   |   |   |
| 271 |   |                         |   |   |   |   |
| 272 |   |                         |   |   |   |   |
| 273 |   |                         |   |   |   |   |
| 274 |   |                         |   |   |   |   |
| 275 |   |                         |   |   |   |   |
| 276 |   |                         |   |   |   |   |
| 277 |   |                         |   |   |   |   |

### **The past array:**

- In range V401:BT523 will be the *Past (previous)* array containing the active calculations.
- Label the array in cell U400: “Present (current) array”
- Draw cell borders in range V401:BT523 but we don't need to use any colors in this array. The content of this buffer array will be handled by macros so we don't need to worry about its formatting.

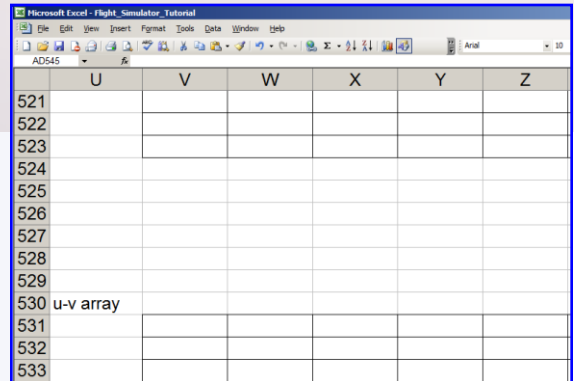


The screenshot shows an Excel spreadsheet with columns T through Y and rows 390 through 404. The label 'Past (previous) array' is in cell U400. The data area is a 3D grid from V401 to BT523, with rows 390-399 visible. The grid is colored in a repeating pattern of green, yellow, and blue rows.

|     | T | U                     | V | W | X | Y |
|-----|---|-----------------------|---|---|---|---|
| 390 |   |                       |   |   |   |   |
| 391 |   |                       |   |   |   |   |
| 392 |   |                       |   |   |   |   |
| 393 |   |                       |   |   |   |   |
| 394 |   |                       |   |   |   |   |
| 395 |   |                       |   |   |   |   |
| 396 |   |                       |   |   |   |   |
| 397 |   |                       |   |   |   |   |
| 398 |   |                       |   |   |   |   |
| 399 |   |                       |   |   |   |   |
| 400 |   | Past (previous) array |   |   |   |   |
| 401 |   |                       |   |   |   |   |
| 402 |   |                       |   |   |   |   |
| 403 |   |                       |   |   |   |   |
| 404 |   |                       |   |   |   |   |

### **The u-v array:**

- In range V531:BT653 will be the “u-v” array. This array wasn't previously mentioned but it will be containing the u-v coordinates after the 3D-2D perspective conversion plus a “vanishing variable” for each vertex (we need to put any triangle out of view if any of its vertices gets behind the observer otherwise we get image artifacts).
- Label the array in cell U530: “u-v array”
- Draw cell borders in range V531:BT653



The screenshot shows an Excel spreadsheet with columns U through Z and rows 521 through 533. The label 'u-v array' is in cell U530. The data area is a 3D grid from V531 to BT653, with rows 521-529 visible.

|     | U         | V | W | X | Y | Z |
|-----|-----------|---|---|---|---|---|
| 521 |           |   |   |   |   |   |
| 522 |           |   |   |   |   |   |
| 523 |           |   |   |   |   |   |
| 524 |           |   |   |   |   |   |
| 525 |           |   |   |   |   |   |
| 526 |           |   |   |   |   |   |
| 527 |           |   |   |   |   |   |
| 528 |           |   |   |   |   |   |
| 529 |           |   |   |   |   |   |
| 530 | u-v array |   |   |   |   |   |
| 531 |           |   |   |   |   |   |
| 532 |           |   |   |   |   |   |
| 533 |           |   |   |   |   |   |



## Adding several input parameters:

$$\left\{ \begin{array}{l} Rate_{pitch} = \frac{\Delta\alpha_{pitch}}{t_{step}} \\ Rate_{roll} = \frac{\Delta\alpha_{roll}}{t_{step}} \\ Speed_{plane} = \frac{\Delta y}{t_{step}} \end{array} \right.$$

In the previous section we defined the parameters to the left. Assuming the step time is equal to 1 we can rewrite:

$$\left\{ \begin{array}{l} Rate_{pitch} = \Delta\alpha_{pitch} \\ Rate_{roll} = \Delta\alpha_{roll} \\ Speed_{plane} = \Delta y \end{array} \right.$$

Which really means that we will replace the incremental values with their rates

- The roll and pitch rates will be controlled by the joystick and will be proportional to the displacement of the joystick from the neutral. The minus in the pitch rate formula comes from the fact that a positive plane pitch is achieved with a negative  $\Delta y$  of the joystick.

- We choose the sensitivity of the joystick to be a number from 1 to 10 and the throttle will be a number from 1 to 25 and both will be adjustable by the virtual pilot using spin buttons.

- By trying different settings I found out that a  $K_J$  of 1/300 and a  $K_T$  of 1 would be good numbers to start with. You can choose different values later.

- Joystick sensitivity and throttle will be later adjusted via spin buttons. For now choose the constant 5 for both of them.

- The index represents the number of iterations since the last reset (is a measure of the simulation progress).

- Name the following ranges: P74: "JoystickSensitivity", P77: "PitchRate", P80: "RollRate", P83: "Throttle", P86: "Index", B52: "JoystickX", C52: "JoystickY", V73: "SideTriangle"

$$Rate_{pitch} = -S_{Joystick} \cdot K_J \cdot \Delta y_{joystick}$$

$$Rate_{roll} = S_{Joystick} \cdot K_J \cdot \Delta x_{joystick}$$

$$\Delta y = Throttle \cdot K_T$$

|    | P                    | Q | R | S | T | U        | V           |
|----|----------------------|---|---|---|---|----------|-------------|
| 71 |                      |   |   |   |   |          |             |
| 72 |                      |   |   |   |   |          |             |
| 73 | Joystick Sensitivity |   |   |   |   | L        | 100         |
| 74 | 5                    |   |   |   |   | h        | 86.60254    |
| 75 |                      |   |   |   |   |          |             |
| 76 | Pitch Rate           |   |   |   |   | Offset_x | 0           |
| 77 | 0.05                 |   |   |   |   | Offset_y | 0           |
| 78 |                      |   |   |   |   | Offset_z | 0           |
| 79 | Roll Rate            |   |   |   |   |          |             |
| 80 | 0.05                 |   |   |   |   |          |             |
| 81 |                      |   |   |   |   | Vertex_X | 0           |
| 82 | Throttle             |   |   |   |   | Vertex_Y | 0           |
| 83 | 5                    |   |   |   |   | Vertex_Z | 0           |
| 84 |                      |   |   |   |   |          | 50          |
| 85 | Index                |   |   |   |   |          | 86.60254 86 |
| 86 | 0                    |   |   |   |   | 1        | 0           |
| 87 |                      |   |   |   |   |          | 0           |
| 88 |                      |   |   |   |   |          | 173.2051 17 |
| 89 |                      |   |   |   |   | 2        | 0           |
| 90 |                      |   |   |   |   |          | 50          |

You can see instructions about how to name cells and ranges in the following page.

- Introduce few more names for the trigonometric functions used in the scene rotation: R73: "cos(roll)", R74: "sin(roll)", R76: "cos(pitch)", R77: "sin(pitch)", R79: "cos(roll)\*cos(pitch)", R80: "cos(roll)\*sin(pitch)", R81: "sin(roll)\*cos(pitch)", R82: "sin(roll)\*sin(pitch)"

- Name the following ranges: S73: "cosR", S74: "sinR", S76: "cosP", S77: "sinP", S79: "cosRcosP", S80: "cosRsinP", S81: "sinRcosP", S82: "sinRsinP"

|    | Q | R                    | S |
|----|---|----------------------|---|
| 73 |   | cos(roll)            |   |
| 74 |   | sin(roll)            |   |
| 75 |   |                      |   |
| 76 |   | cos(pitch)           |   |
| 77 |   | sin(pitch)           |   |
| 78 |   |                      |   |
| 79 |   | cos(roll)*cos(pitch) |   |
| 80 |   | cos(roll)*sin(pitch) |   |
| 81 |   | sin(roll)*cos(pitch) |   |
| 82 |   | sin(roll)*sin(pitch) |   |

## A parenthesis – how to name cells or ranges in Excel:

You can create an Excel named range by typing in the Excel Name Box:

- Select the cell or a range to be named
- Click in the Excel Name box, to the left of the formula bar
- Type a one-word name for the list, and then press Enter.
- To delete a name: Insert => Name => Define => choose a name => Delete

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RollRate fx: 0.05

|    | P         | Q | R |
|----|-----------|---|---|
| 78 |           |   |   |
| 79 | Roll Rate |   |   |
| 80 | 0.05      |   |   |
| 81 |           |   |   |

## Adding several input parameters formulas:

Roll and pitch rate formulas => P77: "=-JoystickSensitivity\*Throttle\*JoystickY/300"  
=> P80: "=-JoystickSensitivity\*Throttle\*JoystickX/300"

*Both the roll and pitch rates will be adjustable from a spin button controlling joystick sensitivity. They also need to be proportional to the speed (throttle) of the airplane and of course they need to be controlled by joystick deviations.*

The trigonometric formulas: S73: "=-COS(2\*PI()\*RollRate/180)",  
S74: "=-SIN(2\*PI()\*RollRate/180)", S76: "=-COS(2\*PI()\*PitchRate/180)",  
S77: "=-SIN(2\*PI()\*PitchRate/180)", S79: "=-cosR\*cosP",  
S80: "=-cosR\*sinP", S81: "=-sinR\*cosP", S82: "=-sinR\*sinP"

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SUM X ✓ fx: =cosR\*cosP

|    | Q | R                    | S          | T        |
|----|---|----------------------|------------|----------|
| 71 |   |                      |            |          |
| 72 |   |                      |            |          |
| 73 |   | cos(roll)            | 0.86603    |          |
| 74 |   | sin(roll)            | -0.5       |          |
| 75 |   |                      |            |          |
| 76 |   | cos(pitch)           | 0.86603    |          |
| 77 |   | sin(pitch)           | -0.5       |          |
| 78 |   |                      |            |          |
| 79 |   | cos(roll)            | =cosR*cosP |          |
| 80 |   | cos(roll)*sin(pitch) | -0.43301   |          |
| 81 |   | sin(roll)*cos(pitch) | -0.43301   | Vertex_X |
| 82 |   | sin(roll)*sin(pitch) | 0.25       | Vertex_Y |
| 83 |   |                      |            | Vertex_Z |
| 84 |   |                      |            |          |

You can see that we converted the pitch and roll rates in radians!

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to be continued...