There are many small details to this build, particularly in the electronics and first-time code setup, so please follow these steps very, very carefully—and make sure you are testing as you go! Give these instructions a read through first before jumping into it. There may be some steps where you wish you knew what part was eventually going where. Have fun!

- *Nick*

## 3D PRINTING INSTRUCTIONS:

.STLs are included in the 'Files' section of the Hackaday page—print 1 of each with solid infill on a printer with at least a 300mm x 300mm bed. Print 2 of the side panel pieces. PLA, PETG, or ABS plastic will work just fine. Some supports will help. Be sure to remove the built-in skirts with a sharp knife after printing. These were included on the design to assist with bed adhesion.

## HARDWARE ASSEMBLY INSTRUCTIONS:

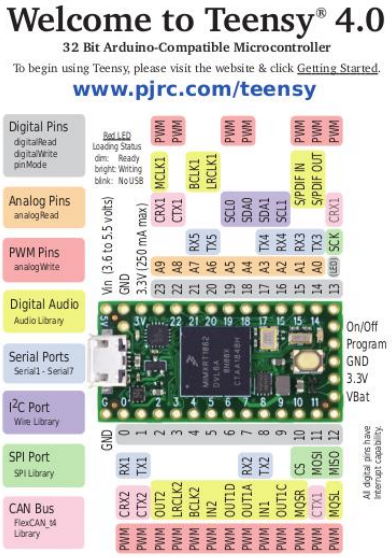
1. **Heat Set Inserts:**
    - Use a soldering iron to melt the M3 heat set inserts into the bottom airframe piece. These will be used to mount the electronics stack later.

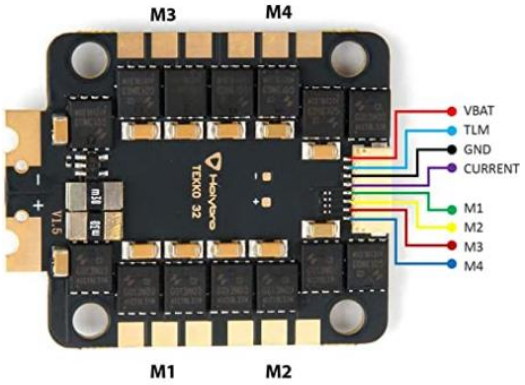
2. **Soldering the electronics stack:**
    - The electronics stack consists of the 4-in-1 ESC, FPV video transmitter, Teensy 4.0 microcontroller, and MPU6050 IMU. These will

ultimately be stacked on top of each other in this order, so keep that in mind when cutting wires to length.

- Solder an XT-60 connector to ~1.5" of ~14AWG wire (usually included with the ESC), and solder those leads to the battery input terminals on the ESC.
- Solder the ground wire from the ESC's input wires to any GND pin on the Teensy using 24AWG wire.
- Solder the ESC's input wires to the following pins on the Teensy using 24AWG wire:

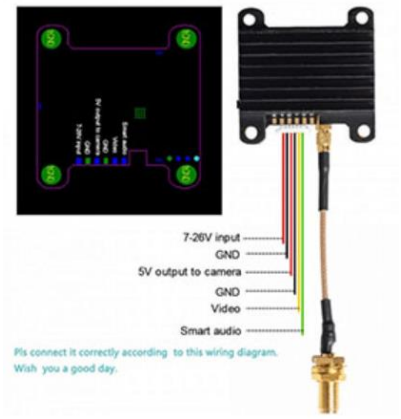
| Teensy Pin # | ESC Wire |
|---|---|
| 0 | M1 |
| 1 | M2 |
| 2 | M3 |
| 3 | M4 |




- Solder the FPV VTX cable to the cable provided with the camera:

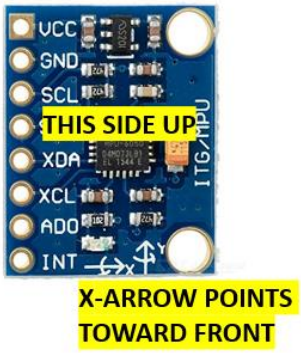
| Camera | VTX |
|---|---|
| 5-36V | 5V output to camera |
| GND | GND |
| Video | Video |

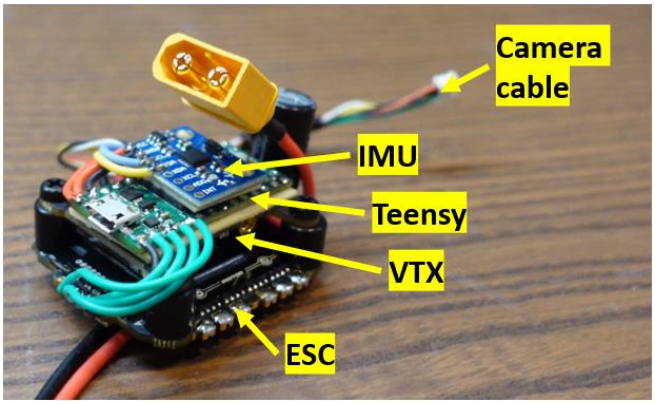




- Solder the FPV VTX “7-26V input” wire and the other “GND” wire to the battery input terminals on the 4-in-1 ESC. This will provide power to the VTX and camera. We will also use the VTX’s 5v output to power the flight controller and other electronics.
- Splice the “5v output to camera” wire on the FPV VTX so we can use that source to power the electronics. You can do this by simply burning a bit of the wire’s outer coating off with your soldering iron, and then soldering on another 24AWG wire to the exposed part. Then use shrink tubing or electrical tape to cover the exposed wire. Solder the new wire to the “Vin” pin on the Teensy. Note that you don’t need to solder another ground wire to the Teensy, since the VTX is already grounded to the ESC, and the ESC is grounded to the Teensy (check for yourself!)
- Solder the IMU to the following pins on the Teensy with 24AWG wire:

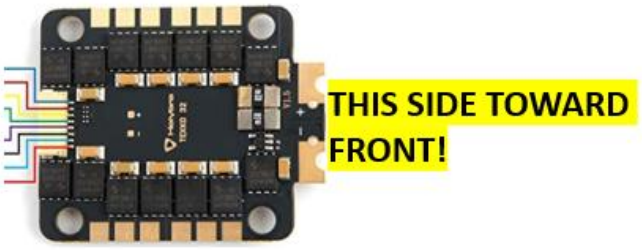
| **Teensy Pin** | **IMU** |
|---|---|
| Vin | VCC |
| Any GND | GND |
| 19 | SCL |
| 18 | SDA |

- You may notice we are now soldering multiple components to the Vin and GND pins on the Teensy—don’t worry, there will be more. It might be a good idea to solder a small header pin to these pins so that there is more surface area for you to solder more stuff to, since there are still more components that need to be powered.
- The basic electronics stack is now done! There are still some other electronics to solder to the Teensy, but we can go ahead and ‘stack’ the electronics stack now. ESC on the bottom, then VTX, then you can use some double-sided foam tape to mount the Teensy on top of the VTX, and more tape to mount the IMU on the Teensy. Be sure to mount the IMU in this orientation:




- Use some M3 bolts and maybe some spacers to mount the electronics stack on the bottom piece of the 3d printed airframe. Make sure the IMU is facing the correct direction, and also make sure your ESC is facing this way:

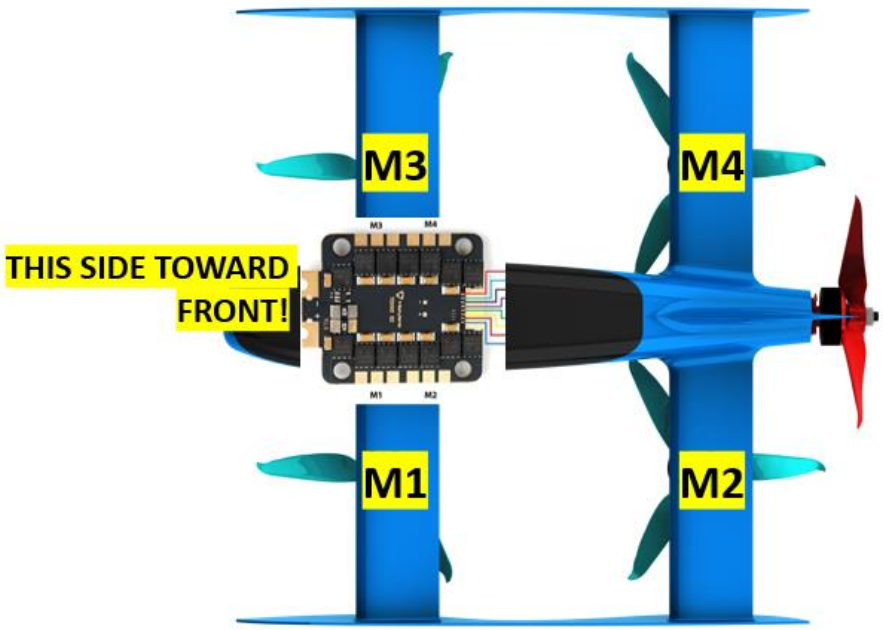



- Just kidding! Don't mount the electronics stack yet, it will be easier to solder the motors and other electronics without it bolted down. But it was good to check the fit, wasn't it?
- Also, make sure that the Teensy is mounted in an orientation where you can plug in the micro USB cable to program it later. I chose to mount my Teensy with the USB port facing the rear of the drone.

**3. Soldering the lift motors:**

- Extend the rear lift motors' wires by a few inches with 18AWG wire.
- Run the wires through the holes in the mounting arms on the lower piece of the airframe. Cut the wires to length so you can solder them to the pads on the ESC.

| Motor Position | ESC Label |
|---|---|
| Front Left | M1 |
| Rear Left | M2 |
| Front Right | M3 |
| Rear Right | M4 |




- Solder all the motors to the ESC—don't worry about individual motor wire order, we will check this later and come back to swap wires to reverse motor direction if needed.

4. **Installing the Lidar:**
   - Solder the Lidar wires to the Teensy:

| Teensy Pin | Lidar Wire |
|---|---|
| Vin | Red |
| Any GND | Black |
| 16 | Green/Blue |
| 17 | White |

   - Mount the Lidar with double sided foam tape to the cutout area on the front side of the lower airframe piece. Be sure that it is mounted flush with the underside surface.

5. **Installing the Receiver:**
   - Use two spare servo extension plugs to plug into the receiver: one that plugs into the "BATT" port, and one that plugs across the signal pins for steering, throttle, and aux1:

- The receiver will mount in the back end of the airframe behind the battery, so make sure these wires are long enough. Solder them to the Teensy:

| Teensy Pin | Receiver Pin |
|---|---|
| Vin | BATT + |
| Any GND | BATT - |
| 21 | STR |
| 22 | THR |
| 23 | AUX1 |

6. **Soldering the Pusher Motor:**
    - The pusher motor ESC will mount in the back by the receiver. Push the motor wires through the hole on the back motor mounting face of the top airframe piece. Cut them down to about ~2in and solder them to the motor terminals on the ESC. The order of the wires does not matter at all.
    - Run the ESC signal and ground wires up to the Teensy and solder the ground to any Teensy GND, and the signal to pin 4 on the Teensy.
    - Also, run the ESC battery power and ground wires up to the 4-in-1 ESC and solder those to its battery input terminal so that the standalone ESC also receives battery power. You may need to extend these wires with some 18AWG wire.

7. **The Top Cover:**
    - Press fit a magnet into the top cover piece, and another to the top airframe piece. Snap them together and awe at how satisfying it is.
    - This step you may want to come back to once the electronics and the top airframe piece are fully mounted and cleaned up: Drill a hole in the top cover piece to accept the FPV transmitter antenna. A good place I found was just behind the electronics stack, and just in front of where the battery will go—that way the stiff antenna wire on the inside has some room. Once the antenna is mounted, push the antenna's pigtail into the connector on the FPV VTX.

8. **Pulling It All Together:**
    - Once you're happy with the wiring, you're ready to mount the motors and get the top airframe piece on.
    - It may be a good idea to tape down the wires running from the back to the front with some tape along the bottom. Also, now is the time to mount that electronics stack for real using some M3 hardware and spacers.
    - If you haven't already, hot glue the camera to the front so that the lens is just shy of the front face but not too recessed, and then plug it in to the VTX.

- Lay the top airframe piece on top of the bottom with all the electronics. Mount the motors. It may help to tape down the motor wires in the arm channels to prevent them from getting stuck as you lay the top airframe piece down.
- Mount the rear motor: this part is tricky. It may help to screw it into the top piece with two bolts prior to laying the top piece down. Then with a long screwdriver, try your best to get the other two screws in. If you can only get one more, that's fine. Don't give up, you're almost done!
- Use some CA glue to glue the additional side panel pieces on the sides of the frame. If you have some epoxy and fiberglass/carbon fiber laying around, that would be a great way to reinforce these panels too. They will definitely take a beating on hard landings.
- Use a Velcro strap around the two small cutouts in the lower airframe piece to mount the battery. Check the fit.
- Run the receiver antenna out the back and up the tail. I found that a paperclip bent to shape and taped to the tail helped guide the antenna over the pusher prop.

# FIRST TIME CODE SETUP INSTRUCTIONS:

We are using a slightly modified version of my flight controller code, dRehmFlight. You can find that code here: https://github.com/nickrehm/dRehmFlight-LandSpeeder

You will not have to write ANY code to get this project flying. The code linked above has all of the changes I added for this particular project. You will, however, need to go through some important first-time setup steps to get everything calibrated and ready for your first flight. Just to give some context, I highly recommend watching my video series on this flight controller. Do not follow any steps from that series; the purpose of this section is to very clearly lay out the steps you need to take to get the flight controller set up. There are deviations from the "default" dRehmFlight tutorials that we need to do in order to correctly set this project up. So again, I highly recommend watching the tutorial videos for more context, but do not go thinking that you can get this project flying by only watching them and not following the steps outlined below.

Tutorial videos: https://www.youtube.com/playlist?list=PLTSCOv-lGtMax-oA4Pnq8OTxd4fTucrjQ

***DO NOT INSTALL PROPELLERS UNTIL THE VERY END OF THIS PROCESS!!!***

1. **Download the Software & Code:**
    - Download and install the Arduino IDE: https://www.arduino.cc/en/software
    - Download and install Teensyduino: https://www.pjrc.com/teensy/td_download.html
    - Download the modified dRehmFlight code (the entire folder): https://github.com/nickrehm/dRehmFlight-LandSpeeder

2. **IMU calibration:**
    - Open the “dRehmFlight_Teensy_BETA_1.3_Speeer.ino” file in Arduino. Plug the USB cable into the Teensy and into your computer. Go to Tools > Board > Teensyduino > Teensy 4.0.
    - Go to Tools > Port, and select the COM port corresponding to your Teensy. It may even say something like “Teensy Serial”.
    - Upload the code to the board by pressing the “Upload” button on the top left. Make sure your drone is on a flat surface, and the IMU is mounted and level prior to uploading. Do not touch the drone as you upload the code. The IMU is calibrating.
    - Open the Serial Monitor by going to Tools > Serial Monitor. You should see some values printed to the screen. These are the IMU calibration values. If they are not there, try uploading the code again.
    - Copy these values and go to line 171 in the code. Paste the new calibration values you just copied here.
    - Go to line 381 in the code. Comment out this line of code by putting “//” in front of it. This was the code that ran and printed the calibration values. Now that we’ve saved them, we do not need this code to run ever again.

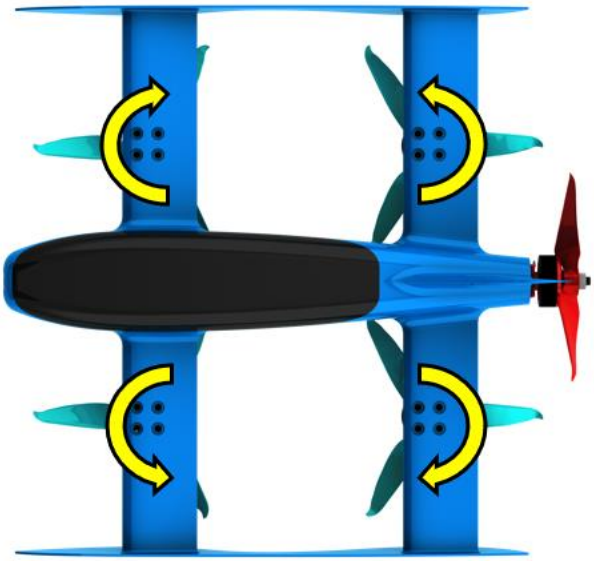
3. **Radio Setup:**
    - Bind your receiver to your transmitter. If you are using the transmitter I use and recommended, you can read the manual to learn how to do this: https://www.astramodel.cz/manualy/spektrum/SPM2340-Manual-EN.pdf
    - Go to line 429 in the code. Uncomment this line by removing the “//” in front of that line. This code will now run when you upload it and print the radio data to the screen.
    - Upload the code and open the Serial Monitor. You should see radio data printing to the screen. We are only concerned with channel 1 (throttle), channel 2 (steering), and channel 5 (arm).
    - Check to see that each is responding to your input.
    - We need to make sure that the channels have the correct direction, centering, and endpoints. Consult your radio’s manual to achieve the following:
        - The throttle channel (1) should be centered at 1500 when your finger is off the trigger. When you pull the trigger to go forward, the throttle channel should increase to 2000. When you push the trigger to brake/reverse, the throttle channel should decrease to 1000. Within 3-5 units of these values will be fine.
        - The steering channel (2) should be centered at 1500 when your hand is off the steering wheel. When you turn to the right, the steering channel should increase to 2000. When you turn to the

left, the steering channel should decrease to 1000. Within 3-5 units of these values will be fine.
    - The arming channel (5) should be configured such that it has a high (above 1500) and low (below 1500) state. There should only be two discrete states. You want the transmitter to power up and always be in the HIGH state; this is the disarmed vehicle state. TEST THIS!!! Power off the transmitter and power it back on—what is the value of channel 5 and why is it not above 1500? Make sure that you can toggle the third channel on your transmitter and visually see that channel 5 on the serial monitor is definitively above and below 1500 (1800 and 1200 are very safe values to shoot for).
- Once you are happy with the radio calibration, go back to line 429 in the code and comment this line back out by putting "//" in front of it.

**4. ESC Calibration and Motor Direction Verification:**

- Go to line 394 in the code. Uncomment this line by removing the "//" in front of that line. This line of code will now run when you upload it to the board. The purpose of this code is to allow you to calibrate the endpoints of your ESC so that it will arm correctly.
- Upload the code to the Teensy. Unplug the Teensy from the computer.
- ENSURE THAT YOUR PROPS ARE OFF ALL OF THE MOTORS!!!
- While holding the throttle trigger to the maximum throttle position, plug in the flight battery to the drone.
- The ESCs will beep: "beep-beep-beep". There will be a short pause and it will sing a more intricate beep sequence to you and then pause again. At this point, reverse the direction of the throttle trigger to the maximum reverse/brake position and hold it there. The ESCs will beep a song at you again, and then shut up. Keep holding the throttle trigger in the maximum reverse position.
- As you ease off of the throttle trigger, all of the motors will spool up at once. If any of them don't, it's a good time to start troubleshooting your wiring connections to the motors. Some common issues:
    - There was no beeping: ESC did not receive power. Check your wiring.
    - A motor jitters, but does not spin: Check that motor's solder connection to the ESC pads.
    - A motor does not spin at all: Check that motor's ESC signal connection to the Teensy.
- I apologize that you need to hold the trigger in the maximum braking position to keep the motors from spooling up for this part of the process, but that is unfortunately the way it has to be for now. Maybe get a friend (or duct tape, same thing) to hold the trigger for you while you complete the next steps:
- We need to verify motor rotation directions. Spool up the motors very slightly and observe their rotation. Some tape on the motor shafts can

help visualize the direction. Take note of any motors that do not spin in the following directions:



- Also take note of the direction of the pusher motor.
- Now unplug the battery and plug the Teensy back into the computer.
- Go back to line 394 in the code and comment this line back out by putting "//" in front of it. Upload this code to the board.
- If there were any motors that did not spin in the directions indicated in the figure above, you need to reverse these motors to spin in the correct direction. Do this by swapping any two motor wires into the ESC. Yes, you will have to un-mount the electronics stack in order to be able to re-solder these pads. No, you cannot skip this step—unless you want to have a really, really bad time.
- The rear motor direction does not matter, we just need to take a note of its direction so that we can put the correct prop on it later when we're ready to fly.

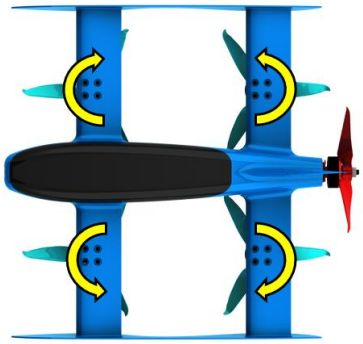
5. **Motor Response Test:**
    - If you made it to this step, the IMU, radio, and ESCs are all calibrated and you should be ready to do a props-off arming test to see if the motors spin and try to stabilize correctly.
    - Make sure you have the code uploaded to the board with the line from the ESC calibration commented out. This is the final code that will fly the drone.
    - Unplug the Teensy from the USB.
    - ENSURE THAT YOUR PROPS ARE OFF ALL OF THE MOTORS!!!
    - Plug in the flight battery. The ESCs should beep and then stop beeping, indicating that they are armed. The little LED on the Teensy should blink once every ~2 seconds.

- While holding the whole vehicle above the ground, about 1 foot high, press the arming button that you configured on your transmitter. The lift motors should all slowly spool up over ~4 seconds.
- Raise the drone while holding it level to about 4 feet high. You should be able to hear all of the motors spool down. This is the altitude hold code lowering the throttle in response to the larger measured altitude. Raise and lower the drone, listening for this throttle change to validate that the lidar and altitude hold functionality is working correctly.
- Now, tilt the drone forward about 30 degrees. You should hear the front two motors spool up to try to counter the angle from level. Tilt the drone backward 30 degrees. The rear two motors should now spool up. Tilt the drone to the right 30 degrees. The right two motors should spool up. Finally, tilt the drone to the left 30 degrees. The left two motors should spool up.
- With the drone level, turn the steering wheel all the way to the right. You should feel the motor torque ever so slightly trying to yaw to the right. Repeat for the left.
- Squeeze the throttle trigger on the transmitter. The rear pusher motor should spool up. If the pusher motor is spinning with the throttle trigger at the center, adjust the trim in your radio to prevent this.
- Push the throttle trigger to the max reverse/braking position. The front two motors should spool up for the pitch-back-to-brake functionality.
- Push the disarm button. The motors should all spool down and stop after ~2seconds.
- Now unplug the flight battery. If all of this went well, you're just about ready to install the props and try for a first flight. If something didn't work, please go back through all of the steps outlined in this document and make sure you didn't:
    - Miss a step.
    - Skip a step.
    - Do a step wrong.
    - Proceed forward without convincing yourself that things were doing what they were supposed to.
- I would love to outline all of the potential problems you could encounter, but that would take me way too long to type up. So if you truly believe you are stuck at this point, send me an email and describe exactly what you did, what is not working, and up to which point in these instructions you made it to successfully and I'll do my best to personally help: NicholasRehmYT@gmail.com
    - If it is clear you did not read or follow these instructions as closely as possible, I probably will not respond—sorry :)

## FIRST FLIGHT:

Congrats! If you made it to this point after carefully following all of the directions above, you're ready to try for a maiden flight.

- Install all of the props on the vehicle. Remember that the motors are in the pusher configuration, and need to be spinning according to this diagram. This is known as the "tips-out" prop mounting layout:



- Also mount the rear prop. Pick the correct propeller rotation direction according to the rotation direction you noted in step 4 of the "First Time Code Setup Instructions" section.
- Turn on your transmitter and power up the flight battery. Make sure the top cover is on and there are no exposed wires that could get caught in the props. If the top cover is not fitting, use a Velcro strap to hold it down.
- In a large indoor or outdoor space, place the drone on a flat surface such as a large piece of cardboard.
- Stand back 8-10 feet and press the arm button on your transmitter. Be ready at any moment to press the button to disarm it. As the motors spool up, if it begins doing anything other than slowly rise vertically, **press the disarm button.** Pressing the disarm button will not immediately kill the motors, but fade them out over ~2 seconds so that the drone can have a soft landing during normal operation.
- The drone should rise to about 4 feet above the ground. If it continues going higher than 5 feet, **press the disarm button.**
- It may drift around slightly. Try using the forward/braking capability to prevent it front drifting. If this does not act as expected, **press the disarm button.**
- Try steering around. If this does not act as expected, for example if the turning is reversed, **press the disarm button.**
- If it hovers at a fixed altitude and responds to your control inputs, have fun! The battery will last about 4 minutes, so it's best to set a timer. Those will be the most fun 4 minutes of your RC flying career, I guarantee it.
- Go to my YouTube channel and **press the subscribe button:** https://www.youtube.com/@NicholasRehm