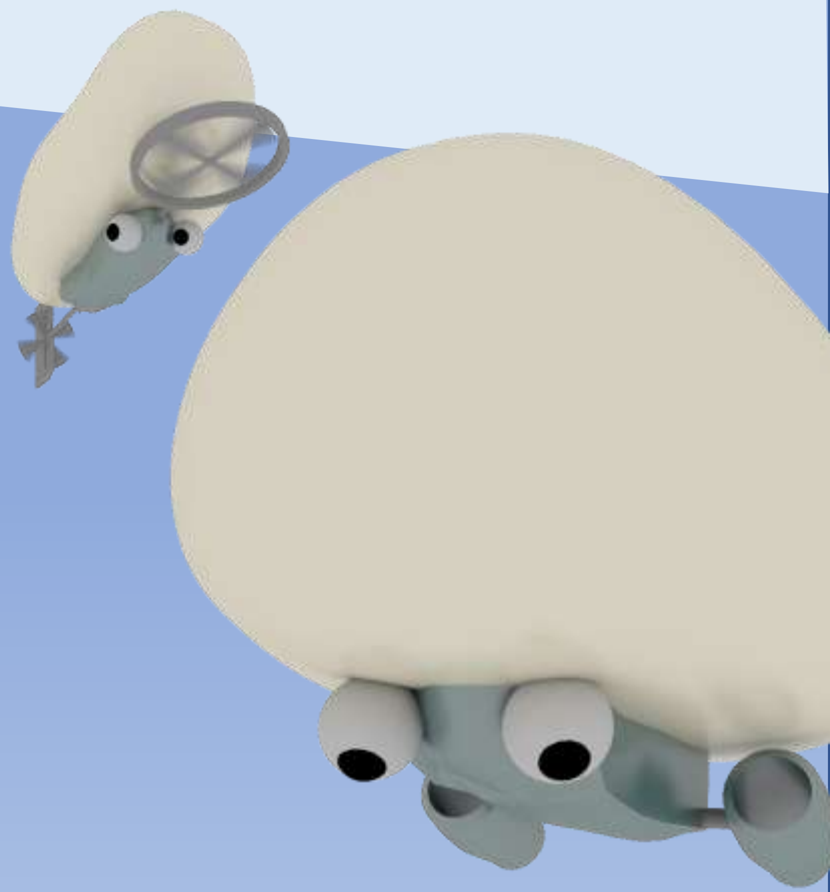
is in partnership with



Navigate To The Line

Teacher Guide 1.0

Contents

Overview

Navigate To The Line' involves students in the design of a remote controlled, micro:bit enabled aerostat - a 'lighter than air' craft. Aviation is going through a period of intense innovation with new materials, alternative power sources and autonomous operation all being part of the future of aviation technology and science for today's young engineers. The competition allows students to explore this future in a practical, fun and engaging way.

'Drones' and related technologies are becoming more popular devices in schools but how do they work? How does pressing a button or lever in one place, change how something moves somewhere else? The competition asks students to develop their technical skills and understanding by creating a flying craft from scratch that they can bring under remote control and use to complete challenges. As teams progress through the competition, they will equip their craft with sensors, to finally make an autonomous aerial vehicle.

How does the challenge work?

Using two 900mm (3 foot) helium balloons on a spar which can lift approx. 300g of mass, teams of 6 to 8 students must develop their own design approaches to mount up to four small electric drone motors to enable their lighter than air craft to steer and change altitude. Using microbit radio communications and a competition PCB that enables multiple micro motors and servos to be controlled by simple code blocks, students must tackle a series of challenges at an in-school competition to accrue points to progress towards regional and national finals.

The competition activities can be carried out in a school sports hall in an arena about the size of a badminton court. Activities and Challenges can include:

- *Air Race* – using the rules laid down by the FIA for drone racing, teams must compete to complete three laps of a figure of eight race course in the fastest time.

- *Target Lander* – teams must land and take off their craft closest to the centre of ten targets on the ground in the shortest possible time

- *Assault Course* – over and under bars between badminton net posts and through hoops for points – it's just like a dog agility show but in slow motion!

- *Air Battle* – with a felt tip pen mounted in front and an A4 piece of paper suspended from the back, the first craft to mark their opponent's paper, wins!

Later stages will introduce new challenges that need to be solved for the day!

Suggested team sizes and student roles

Competition resource kits are organised around balloon gas cylinder capacity. The cylinder of balloon gas proposed for the pilot is enough for 10 teams to build and test at least 10 craft through a school stage.

We recommend **team sizes of between 6 and 10 students**. A single kit could support 60-100 students in two/three classes.

The main roles for students in the team are:

Aero engineers – tackling the construction, ballasting and balancing of the craft considering all the factors such as density and strength of materials and the orientation and position of propellers to control motion.

Avionics engineers – responsible for programming the motor and servo controls and developing wireless communication for remote control of the craft using micro:bit radio messages. At later stages they will need to integrate sensors.

Pilots and ground crew – pilots remotely fly the craft and conduct test flights to provide detailed feedback to the aero and avionics engineers on handling and operation.

Ground crew – The ground crew are responsible for the precision ballasting of the aircraft and in competitions act as spotters to assist the pilots in navigating the courses and challenges. They are also responsible for handling and securing the craft when on the ground.

Students may have more than one role on the team.

The basic kit and tools required

A basic kit will be provided with parts enough to lift and power 5 craft.

Additional parts to complete the craft can be sourced easily from scrap plastics, light woods, and card.

What the competition will provide

The competition kit comprises of:

- 5 pairs of 3'/1m diameter latex balloons + spares. (One pair/team)
- 5 micro:bit motor/servo controller boards
- 20 micro drone motors + propellers (four per/team)
- 10 servos
- 5x AAA battery packs
- A bottle of Hi-Float latex treatment to preserve gas
- Game Controller adaptors for micro:bit

What the school will need to provide

The parts to complete the craft can be readily found by schools/students:

- A lightweight 1m beam/spar for each team – this can be a length of 1cm x1cm balsa or a spar made from a dowel rod, glass fibre tubes from old kites, old arrow shafts, etc.
- Card, foam or plastic trays to make gondolas, etc. These can easily be recycled from food packaging, etc.
- Motor mounts and ducts. Kebab skewers, balsa strips or plastic straws can all be used to make mounts and arms to hold motors. Plastic drinking cups can make ideal ducts to direct and accelerate the air moved by the propellers.
- Thin electrical hook up wire
- Fishing line can be used for tethers and suspending parts (cable stayed)

Schools may also want to provide additional micro:bits – one for the onboard control system and the other to provide a remote-control transmitter. Six micro:bits are provided in each kit to allow

Tools required by teams

Scissors, knives, small saws, wire cutters and terminal screw drivers are the types of tools needed to complete a craft. Most D&T departments will have these. Glue guns and tapes and various adhesives are all suitable to connect parts.

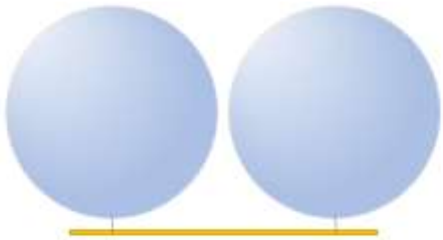
Teams may also need access to a soldering iron suitable for small electronics to make extensions to cables with good electrical properties.

There are no restrictions on teams using laser cutters, 3D printers or vacuum formers to create parts for their craft. Schools should encourage innovation and inventiveness by the teams. The most critical factor is the mass of the parts they add, and complex and exotic solutions may not be effective as something simple and cheap to make or adapt.

Designing the craft – features and requirements of competition designs

General requirements

- All team's competition craft **must use the 2 supplied latex balloons** inflated to no more than 1m diameter *(a hole in a large sheet of cardboard can be used to size balloons)*. Students **must use both of the 3'/1m latex balloons** and these can be connected to the ends of a **1m long spar**. Suspension points for the balloons can be simple fishing wire loops and paperclip hooks.



Essential design = two balloons and a 1m spar

- The craft **must carry the microbit PCB, a microbit, the battery pack and all the motors and servos** needed to make the craft move.

- Where loss of the balloon in a high space is possible, a low breaking strain fishing line can be used as a **safety tether**. This is for safety only and cannot be pulled to manoeuvre the craft in any competition stage.

- In competition, **control should be remote,** and no physical electrical connection can exist between the controller and the craft. Wireless control using micro:bit radio commands is recommended. Direct connection is permitted and encouraged in the early design and rapid prototyping stages.

- The only motors, battery packs and servos permitted are those supplied. **No craft can use more than four motors and two servos,**

Teams can use any materials they wish to construct the remainder of their craft and can place motors, servos, battery packs and electronics anywhere than want to.

Ballast may be required to stabilise the craft in the air. Plasticine is ideal. Moveable ballast enables the craft to be balanced.

Example designs:

There are many layouts and combinations of motors and servos that can control the aircraft.

Foamboard gondola suspended from a balsa spar. Three motors fixed in the X,Yand Z axes, control motion. No servos are used.

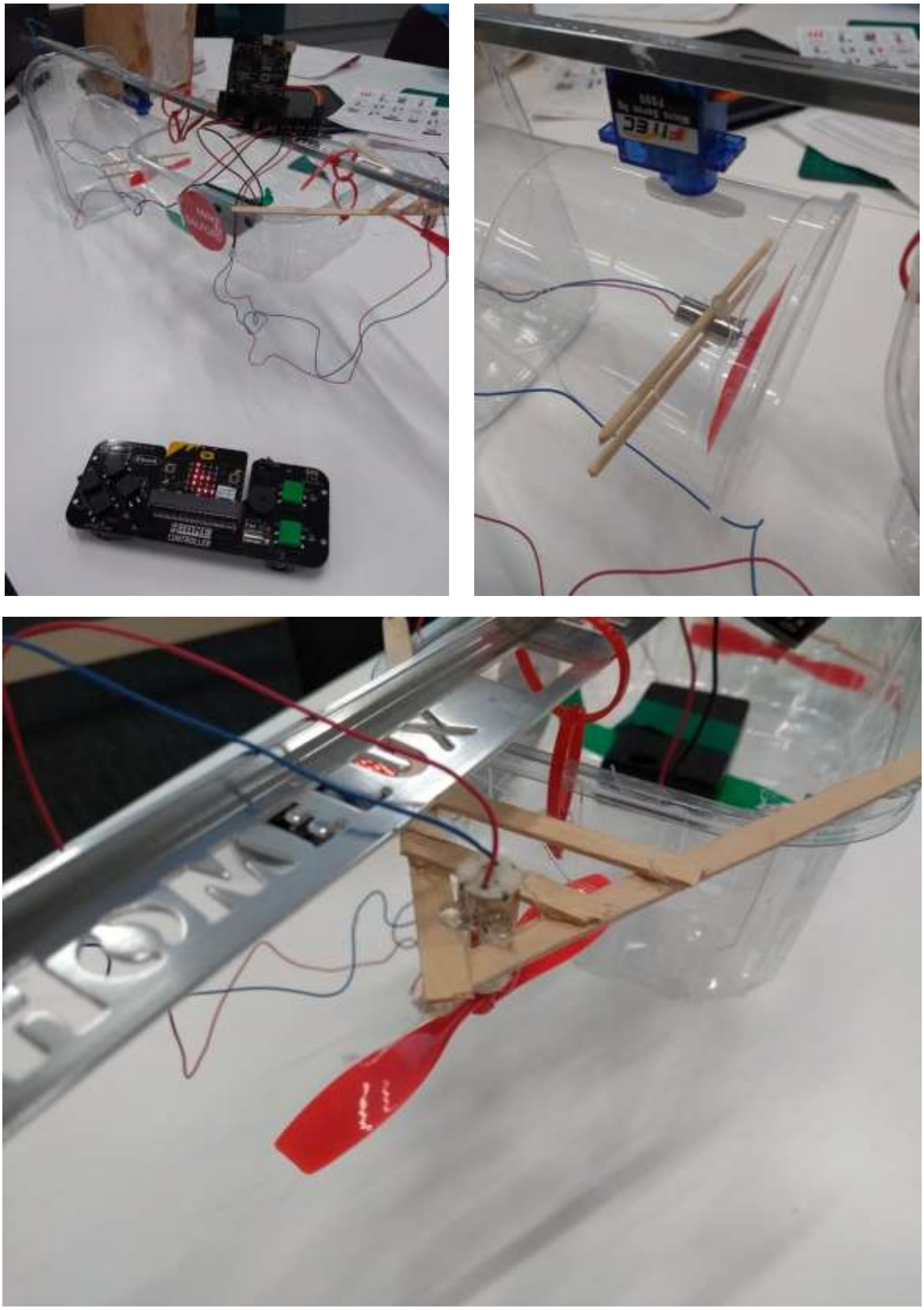
A plastic container on a balsa spar contains the electronics and a servo that can tilt the two independently controlled motors in their foam cup nacelles 180 degrees.

This configuration allows the aircraft to move forward, rotate and go up or down.

A cardboard box can be quickly recycled into a spacious gondola to contain the electronics and battery.

This design uses servos to 'vector the thrust' of motors in plastic cup nacelles.

This design uses 3 fixed nacelles to move the craft in the X, Y and Z axes.



Many readily available materials can be recycled into an aircraft.

Avoiding loss of the balloons in the environment

Tests and competitions should **always be held indoors**.

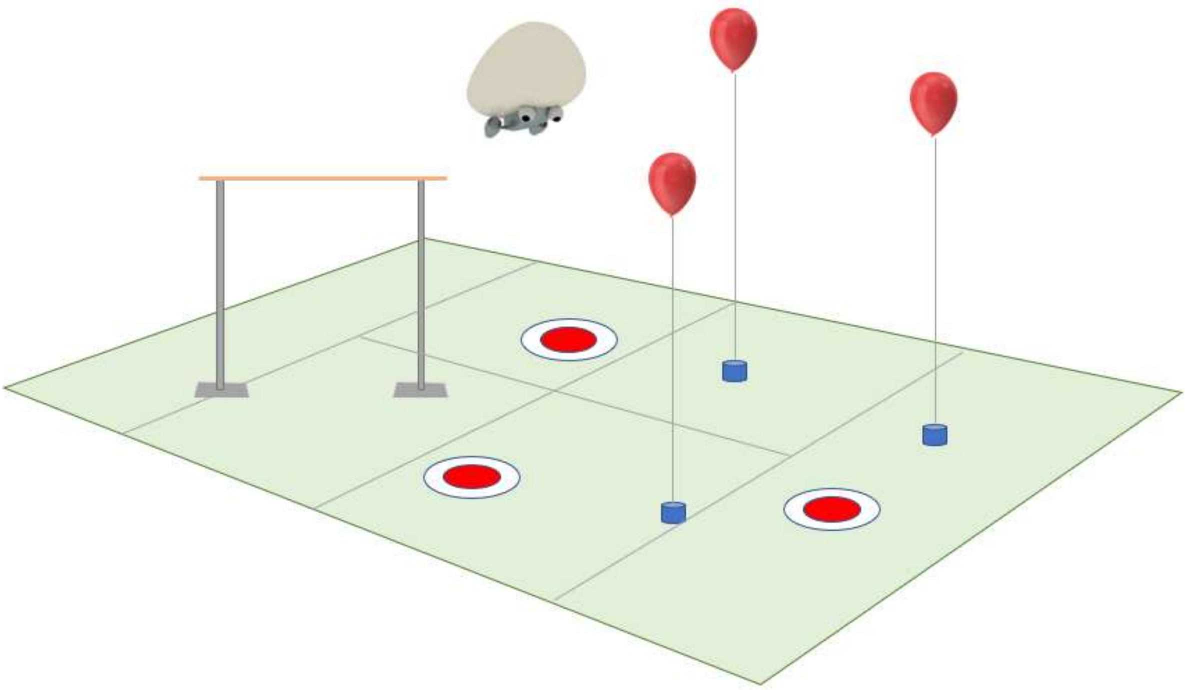
If a craft must be taken outside it should have extra ballast to keep it on the ground and at least two tethers.

Arena requirements

A **badminton court** area in a sports hall with at least 3+ metres of height is ideal for the competition.

Small balloons tied to weights can act as vertical markers to fly around and between and a line or pole between two badminton net posts can provide an 'over and under' challenge to test the ability to adjust altitude.

Floor markers made from card or paper can provide targets for testing landing and take-off accuracy.



Example arena

Invent a challenge!

Schools should encourage their teams to develop and test competition scenarios and ideas in the first season. The best ideas developed in the first season stages will make it into the national programme.

Notes on preserving the helium

The gas is expensive and not easy to store. It is highly recommended that teams avoid using lots of the helium gas in early stages. There is enough gas to fill balloons for eight teams at least once but not several times.

It is recommended that teams first understand the basic **helium lift equation** *i.e. how much lift does a litre of helium provide?* This can be an interesting question for an introductory lesson or activity.

Example activity: By making a helium filled party balloon float at a fixed height by adding mass (e.g. grains of rice) students can use the estimated volume of the balloon and the mass added to make it hover to calculate a lift value for helium.

Once the students have a figure for the amount of lift they can expect they can use volume of a sphere mathematics to predict the approximate lift they will have from a 1m diameter sphere.

Using this data, they can build designs without needing balloons and using force meters as suspension points to check the weight

** NOTE FOR TEACHERS:

You can expect around 1g of lift from every litre of Helium.

Two nearly fully inflated balloons will lift around 200-250 grammes. Students should be encouraged to minimise mass every way possible.

There is no requirement for teams to add the most amount of helium and there may be points to be gained by teams that use less gas (sustainability) in the competition through creating exceptionally lightweight designs.

Health and Safety

Helium is an odourless, colourless inert, safe gas.

As a general precaution the very high-pressure cylinder supplied should be stored in a locked location and only operated by teachers or technicians.

While the gas is non-toxic, there is a risk of suffocation if large volumes of Helium were to be released in a small room with poor ventilation. The helium should only be used in large, well ventilated rooms.

Wider Curriculum Opportunities

The Navigate To The Line competition lends itself to being approached as a cross-curricular STEM project.

Supporting Curriculum/Lesson ideas may include:

- "Archimedes principle" – designing airships – 'more boat than plane'
- "Vectored thrust" – manoeuvring a lighter than air craft by directing forces
- "Mass & lift" – maximising payloads and aerodynamic performance
- "Programming for control" – stability, autonomy vs manual
- "Navigation & dealing with the wind" – tip to tail vectors, etc.
- "Alternatives" – costs of fossil fuel-based transport and sustainable futures
- "The science of gases" - volume, density, noble gases, the periodic table, where does helium come from?

Season 1 schools are asked, where possible, to indicate lesson ideas or topics that the Navigate To The Line project can support or develop.

SUGGESTED ACTIVITY 1: Exploring aerostatic lift (1-2 hours)

Objectives:

- To understand how the low density of the balloon gas provides lift.
- Measure and estimate the amount of total lift that can be exploited in a Navigate To The Line craft.
- Explore ideas of neutral buoyancy, balancing and the role of ballast.
- (Optional) Explore the effects of temperature on lift

Resources needed:

- Balloon gas
- One 3'/1m latex balloon and/or pairs of party balloons and a kebab skewer and a plastic cup
- Weighing scales (optionally - a force-meter – 250-500g range)
- Plastic or paper cups, string, plasticine or rice.

Activity:

1) Weigh two party balloons, a kebab skewer and a plastic cup.
2) Inflate a pair of party balloons with helium and knot them and use the skewer to suspend a small plastic cup from the pair of balloons.
3) Use plasticine, rice or another material to make the craft neutrally buoyant and balance horizontally.
4) Weigh how much ballast & other materials was needed to counteract the total lifting force.
5) Estimate the volume of each balloon (*tip: combine sphere and cone volumes for a rough estimate*)
6) Work out how much lift / cm3 you can expect from helium.
7) (Optionally) Repeat with a 1m helium balloon treated with Hi-Float *(see appendix)*. You can use a force-meter to measure the lift of one balloon directly.

Taking things further:

It is useful to be able to predict the performance of the lifting balloons over time.

Attach the force-meter to a 1m balloon and take measurements over time (e.g. daily for a week or two) of the lift and the ambient temperature. Graph these.

Questions:

- What does the graph show? What does this mean?
- Does temperature effect lift and by how much?
- How long can a balloon treated with Hi-Float be usefully used for?

SUGGESTED ACTIVITY 2: Using the controller board, motors & servos (1 hour)

Objectives:

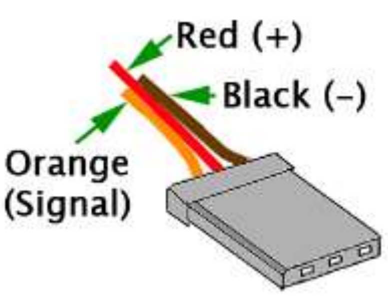
- Use the micro:bit makecode editor
- Install Kitronik extension blocks to enable unique functions
- Make servos and motors operate and change speed and/or direction under program control

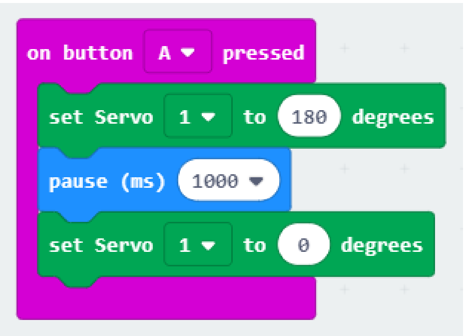
Resources needed:

- Laptops, computers, with internet access
- Robotics controller board
- Micro:bit
- USB synch cable
- 3x AAA Battery pack & batteries
- Up to four motors and two servos
- Terminal screwdriver

Activity:

1) Browse to https://makecode.microbit.org/ and choose *New Project*
2) Use the interface to locate the *Advanced > Extensions* option
3) Search for install the "*Kitronik Robotics Board*" blocks
4) Connect the AAA battery holder and one motor and one servo to the board. The orange cable on the servo is the signal wire.
5) Create code blocks to make a servo change angle on a button press





6) Download the program and copy the .hex file that has been created to the micro:bit using a USB connection and test the program
7) Make a program to set and return servo to a central position (e.g. 90º)

Taking things further:

- Combine motors and servos and have them change speed and direction several times
- Identify the lowest power/speed value that a motor will respond to.
- Combine the motor and propeller into a plastic cup or disposable coffee cup nacelle to explore the impact on airflow and thrust

SUGGESTED ACTIVITY 3: Using the micro:bit games controller and radio commands (2 hours)

Objectives:

- Set the radio channel and strength to enable remote control
- Make a button press transmit a number or string over radio
- Use the radio function in makecode to explore transmitting and receiving control commands between the micro:bit used in the controller and the micro:bit in the aircraft.
- Respond to and process a string or number message in order to control a motor or servo

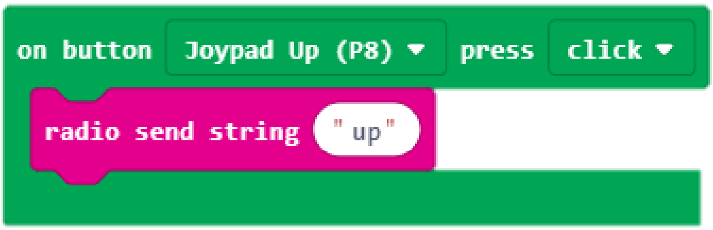
Resources needed:

- Laptops, computers, with internet access
- Robotics controller board
- 2x Micro:bit
- USB synch cables
- 3x AAA Battery pack & batteries for robotics board
- 2x AA batteries for controller
- Up to four motors and two servos
- Terminal screwdriver
- Kitronik Game Controller

Activity:

Making the transmitter/controller code:

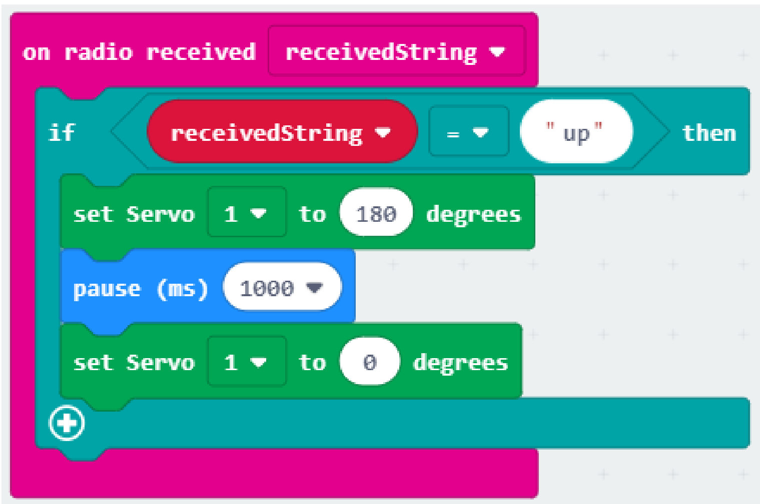
1) Browse to https://makecode.microbit.org/ and choose *New Project*
2) Use the interface to locate the *Advanced > Extensions* option
3) Search for and install the *Kitronik Controller* extension
4) Watch a video to see the controller in action https://www.youtube.com/watch?time_continue=133&v=eraedNuFyaY
5) Set the Radio group in makecode to a unique number for your team. Microbits that share the same radio group can share communication (*other teams can hack them too if they know your channel!*)
6) Set the radio strength to 7 by finding the block in the '…' extra section of the radio commands
7) Construct blocks to send a radio message (String or Number) in response to a press on the Kitronik Game Controller. Download the program to the micro:bit



Making the receiver code:

1) Browse to https://makecode.microbit.org/ and choose *New Project*
2) Set the Radio group in makecode to the unique number for your team.
3) Set the radio strength to 7 by finding the block in the '…' extra section of the radio commands
4) Use the Radio blocks to respond to the arrival of a new radio message (String or Number). NOTE: When a radio message is received the value (String or Number) is stored in a Variable called **receivedNumber** or **receivedString**
5) You can test that a number or string has been received by displaying it on the screen of the micro:bit when it arrives.

6) Download your test program to the receiver micro:bit, provide it with power and test to confirm that you can make radio messages pass between the two micro:bits.
7) Now that you can receive a command, lets link it to moving the servo.
8) Use the interface to locate the *Advanced > Extensions* option
9) Search for install the "*Kitronik Robotics Board*" blocks
10) Make sure you have a servo correctly connected to the robotic controller board and the micro:bit and a battery pack is installed.
11) Change the receiver code to move the servo when it receives a command. You can use the **Logic Comparison** blocks and an **If-Then** block to see what command has been received and act on it.
12) Download and test the new code and see if the radio instruction moves the servo.



This program moves the servo 180 degrees and then returns to 0 degrees after once second when the command string "up" is received.

Adding more commands:

1) Go back to your **transmitter code**.
2) Ensure the *Kitronik game controller extension* is installed.
3) Add additional commands to buttons such as "up", "down", "left", "right", "forward" & "back"

Example of multiple commands used on a transmitter

4) Download your new code to the transmitter micro:bit attached to the game controller.
5) Now go to your **receiver code**.
6) Attach more motors and servos
7) Use **If-Then-Else** checks to check each possible command in turn

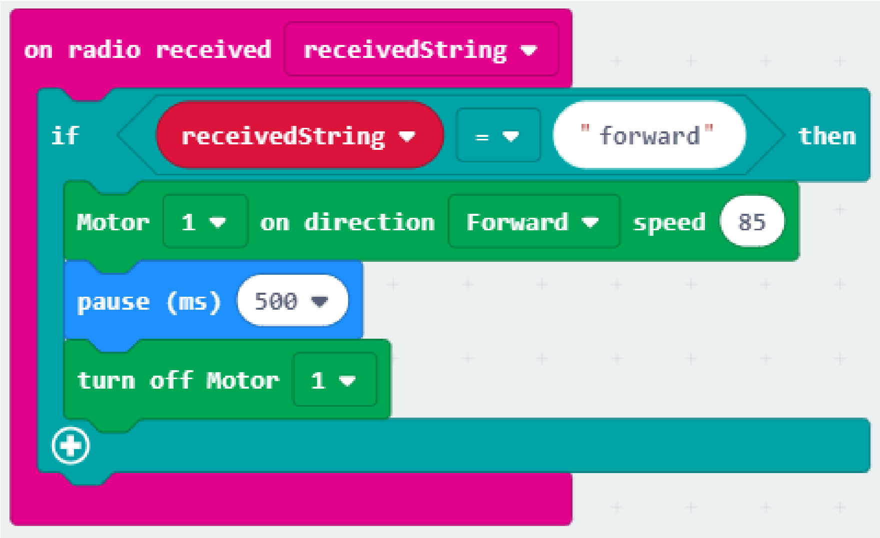
Example of four commands being checked on the receiver

8) Download and test your new code.

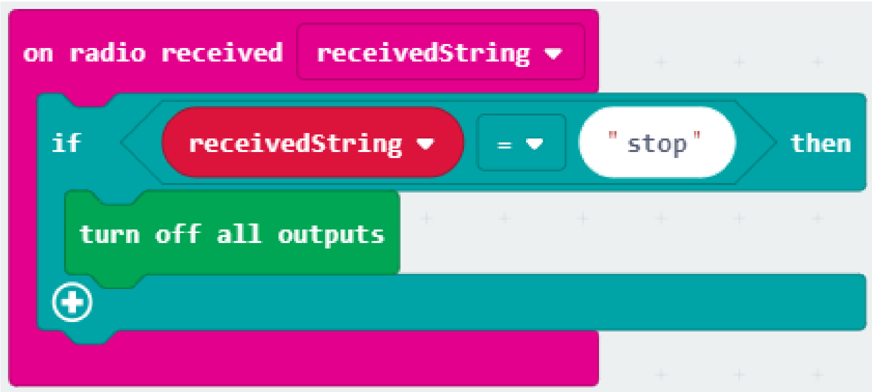
Taking things further:

Begin to consider the number and nature of commands likely to be needed to control the movement of a floating aircraft in three dimensions. Connect and test all *the parts (motors and servos) on a table top test rig.*

You may find that when a motor is activated it keeps working.   You may want to have the motor only switch on for a moment (e.g. half a second) when a command is received, or you can use a 'stop' command to stop and or all of the motors and servos moving.



Using a ***pause*** *block to make the motor switch off after half a second (500ms)*



Usina a stop command

NOTE: There are many other ways to develop code to process received messages

SUGGESTED ACTIVITY 4: Design your airship and the motor and servo layout (1 to 2 hours)

Objectives:

- Discuss and predict the effect of different combinations and orientations of motor and servo to achieve movement control in three dimensions – fixed motors, rudders and control surfaces or 'vectored thrust' using servo and motor combinations
- Design a control system 'protocol' – a plan showing which transmitted commands will result in which actions on the receiver
- Design and/or agree as a class, a method of attaching or sharing balloons between teams
- Consider how the aircraft will be 'ballasted' and balanced. How will these be able to be adjusted
- Work as a team to draft and sketch potential designs
- Identify and collect materials and tools needed to complete a craft

Resources needed:

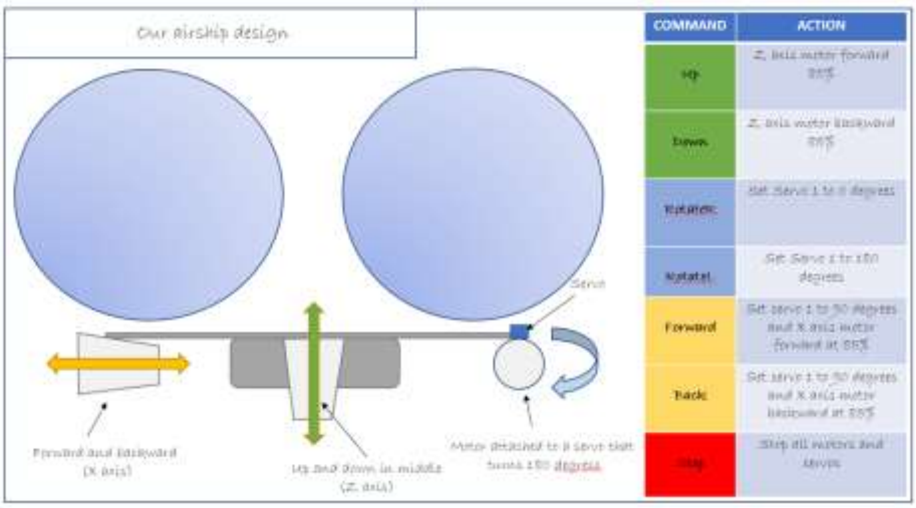
- Paper, pens, pencils and rulers
- Design sheets
- Assorted building resources – plastic containers, wood or balsa spars,
- Hot glue guns, tape, etc.

Activity:

Students should begin to construct a design sheet and plan for their aircraft, suggesting where key components will fit and how balloons will be shared

Discuss how micro:bits will remain accessible for programming or swapping

Develop a 'command and action' list to aid in the programming of the control communications – what action will result on receiving a command



Example design sheet with motor and servo layout and command/actions list

Taking things further:

Students can identify and assemble materials they will use to construct their craft

They may want to consider designing and assembling 3D printed clips or other mechanisms to avoid using glue on the motors

Examples of 3D printed quick release balloon connectors from Cardinal Langley RC High School

SUGGESTED ACTIVITY 5: Design a way to store you craft while it is being built (1-2 hours)

Objective:

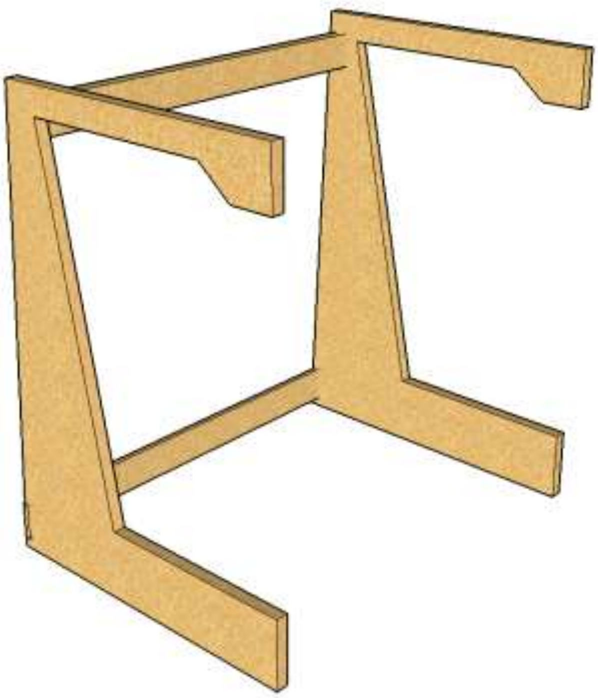
- Design a simple way to store an airship gondola
- Integrate a forcemeter system (if possible) to use the storage rig to calculate the mass of the suspended craft.

Resources needed:

Wood, cardboard, laser cut ply, paper clips, string, forcemeters (250-500g – optional)

Activity:

Conceive of a way to store the craft and prevent damage. A suspension system could enable the aircraft to be weighed during construction.



An example of something that could be made to store and weigh aircraft

Taking things further

Consider how you could safely carry a delicate aircraft to an event. Suspended in a box?

Could there be a system that hangs several designs from a roof beam?

SUGGESTED ACTIVITY 6: Building, testing and improving your craft (3 -5 hours)

Objectives:

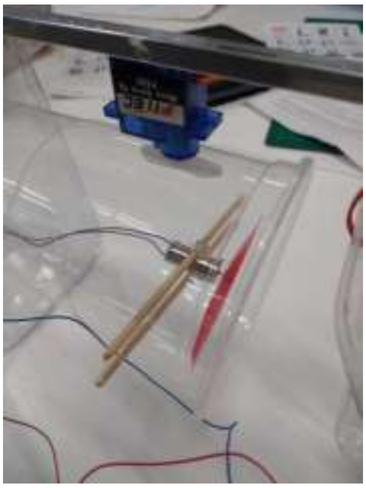
- Assemble the aircraft (*perhaps use the storage frame made before to assist*)
- Integrate the motors and servos (if used) and the battery and microbit robotics controller board in such a way that they are not damaged or inaccessible.
- Test that things work as expected various stages

Resources needed:

- Plastic cups of paper coffee cups to act as nacelles
- Assorted scrap materials for gondolas, wooden skewers and sticks. etc.
- Paper clips, wires, string, fishing line, hooks and eyes or other materials to make a balloon sharing solution
- Adhesives, glue guns, tape,
- Long lengths of wood, balsa, etc to act as a main spar
- Small cable ties or other fixings to hold the motors (they can be glued but this can damage a motor)

Activity:

Build the aircraft!



Taking things further:

Teams may want investigate 3D printing or laser cutting key components such as motor holders or propeller shields.

SUGGESTED ACTIVITY 7: Design a competition challenge

Objectives:

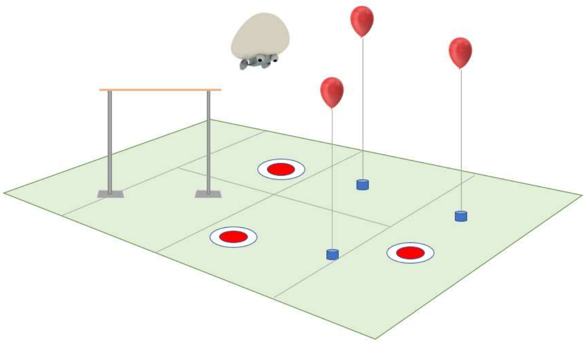
- Consider authentic problems and scenarios that can exploit and test their aircraft
- Design and test a challenge activity that could be specified for the national challenge or a competition stage

Resources needed:

- Arena
- Completed aircraft
- Imagination!

Activity:

Design and test a challenge idea that can work within a badminton court size arena.



Taking things further:

Explore lightweight sensors and cameras.

Can the aircraft collect and deposit a payload?

A first-person view (FPV) test using a micro wireless camera and headset at Cardinal Langley RC School