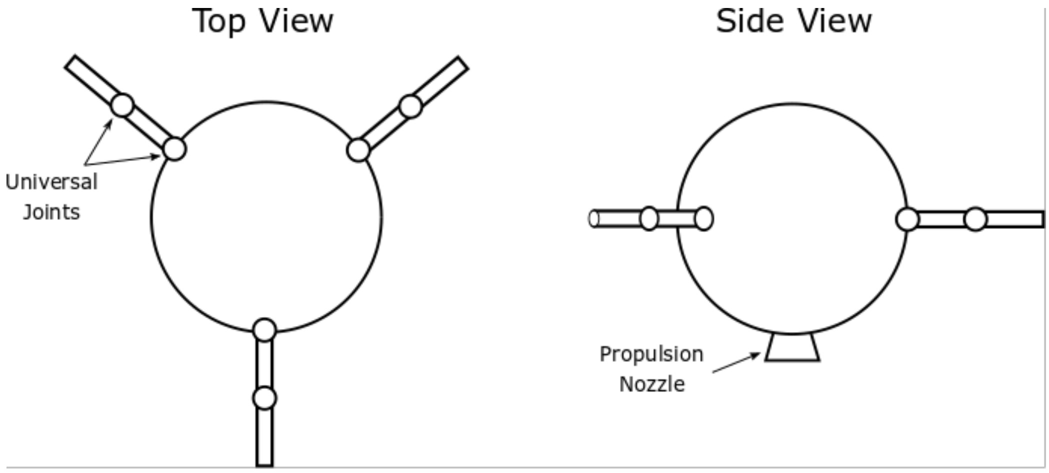
ICA Design

At the centre of the squid-inspired ICA concept is the use of multiple, movable arms for directional control of this small space vehicle. The primary function of the arms is to control the pointing direction of ICA. Uniquely, the arms also provide the potential to perform other functions.

The main function of ICA is to inspect the outside of spacecraft for signs of damage. ICA will therefore need to carry appropriate sensors, probably including visual and infrared cameras. These would probably need to look out through the top of the main body to avoid any blockage by the arms.

During the short duration of the challenge, Team Squid, developed 2 design options.

DESIGN OPTION 1



OPTION 1, the first ICA design shown above, uses three 2-part arms. Each arm is made up of two segments with controllable universal joints at the attachment to ICA's body and between the two segments. The arms are attached half way along ICA's main body.

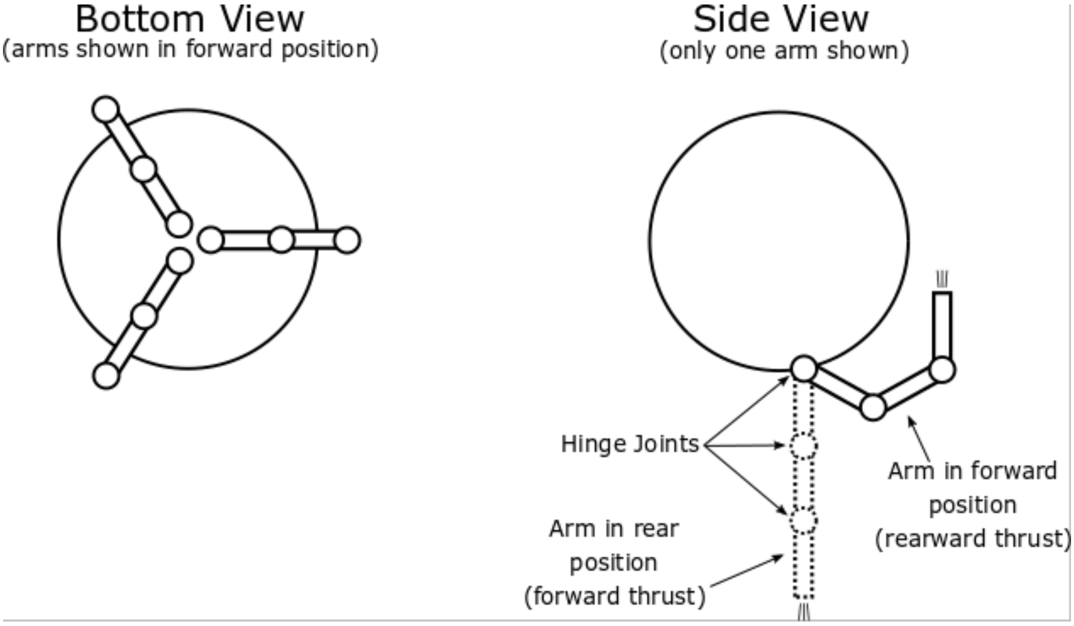
The arms achieve direction control using the principles of equal and opposite reaction and conservation of momentum. The trick is that each of the arms has mass and inertia.

Each arm is controlled by applying turning forces to each joint. This not only turns the arm, but due to equal and opposite reactions, also turns the rest of the ICA craft in the opposite direction.

Conservation of angular momentum is also a major factor in the control process. Changing the position of ICA's arms also changes the overall moment of inertia (the spinning inertia) of the craft. Due to conservation of momentum, changing the moment of inertia changes the craft's spin rate. A well known example of this effect is the greatly increased spin rate an ice skater can achieve by pulling their arms in close to their body.

For simplicity, propulsion would probably be provided using a single fixed nozzle gas ejection motor and would only apply force along ICA's longitudinal axis. The craft is therefore rotated first to move in the desired direction.

DESIGN OPTION 2



OPTION 2, the second ICA design shown above, also has three steerable arms, but the arms are hollow. Each arm is made of 3 segments, connected by hinge joints with 60 degrees of movement. This gives sufficient range of movement for each arm to point anywhere from straight behind ICA to straight ahead.

The exhaust gases from the propulsion system are directed through each of the hollow arms to provide fully steerable thrust. Varying the amount and direction of thrust from each arm controls both the direction of movement and the pointing direction of ICA.

Unfortunately, this does not provide any control about ICA’s longitudinal axis (roll). This could be overcome by modifying one or more of the joints in each arm to provide some out of plane movement of the exit nozzle. An alternative would be to include a controllable vane in the exit nozzle of each arm to deflect the propulsion gases to the side.

In the design shown above the three arms are all attached at the base of ICA’s body. This is intended to allow shared use of a single propulsion unit, thereby saving overall weight.

As in OPTION 1 the movement of the arms also affects ICA’s pointing direction. Thus the overall control strategy for OPTION 2 would need to be a hybrid of steered thrust and arm inertia effects.

Review of the ICA Design Options

The OPTION 1 ICA design is the simpler of the 2 options and as such represents a significantly lower development risk. The design and control of the arms are the most novel features. OPTION 1 could probably draw significantly on propulsion technologies already developed, or currently under development for micro-satellite applications.

We used the OPTION 1 design to demonstrate that machine learning can be used to achieve a viable control solution.

The OPTION 2 design is significantly more complex with additional challenges in the design of the propulsion system and arms capable of steering the propulsion jets. Control is also significantly more complex, requiring the integration of steered propulsion jets and the steering due to physical movement of the arms.

The physical ICA model we used in the simulation of flight around the International Space Station is based on the OPTION 2 design.

Future Development

The two design options we developed are intended to provide a starting point to indicate what a squid-inspired, small, multi-arm space vehicle could achieve.

We chose a simple spherical body shape with a small number of arms and links for the designs. This allowed us demonstrate in a very short timescale that a control scheme can be developed for an OPTION 1 design concept with multi-link arms.

The ICA design could also incorporate a repair module for mending minor damage to the outside of the spacecraft. This might include sealing small holes produced by micro-meteorite impact. In this application, the arms in the OPTION 1 design could provide a method of attaching ICA to the spacecraft during the repair.

Overall, the OPTION 1 design concept appears to be the more practical solution.

Clearly a practical implemention of the ICA concept will require a different body shape to package all the necessary sub-systems. There are also many possible options for the number of arms and type of arm structure.

We believe we have shown that the ICA OPTION 1 design concept is viable and we invite others to develop the concept further.