1) Good morning/afternoon, my name is Pilot Officer McKee and I am to present my thesis project

The design of a small satellite UHF radio beacon for identification, telemetry, tracking and control.

2) The Space Works market forecast estimates up to 2400 satellites will require launch into the Low Earth Orbit over the next 5 years.

This is due to a significant decrease in design, manufacture and launch costs.

3) A large portion of small satellites in the LEO environment are operated by organizations with little to no space experience

This has resulted in a mission failure rate of 55% for academic institutions and 23% for commercial enterprises.

4) The previous two conditions outlined has produced additional challenges for space monitoring and operations due to the increased number of satellites and space debris in the LEO environment

The initial research has identified three problems to be addressed:

1. The increased demand on resource expensive space monitoring equipment to maintain Space Situational Awareness
2. The large failure rate of small satellites leading to an increase in space debris objects, with the cause of failure being unable to be determined
3. The increased difficulties in identifying an object in the LEO environment

5) To address the identified problems, the design of a satellite UHF radio beacon system is proposed to provide:

1. A cost-effective system that can track active, End of Life and failed satellites
2. A better technique of uniquely identifying an object in LEO
3. A method of obtaining satellite telemetry or health data irrespective of a failure in any other satellite system
4. An alternative communications pathway for satellite control

6) The Satellite UHF radio beacon system will be separated into 3 components:

1. **The satellite radio beacon** – That is a self-sustained UHF communication system that can operate independently of all other satellite systems
2. **The communications link** – that supports the reliable transfer of data for a slant range of 2000kms
3. **The ground receiving station** – which can capture the transmitted data, recording the precise time of arrival of the RF signals and passing data to a peripheral device for processing.

7) The satellite beacon is linked with the other satellite systems to collect telemetry data and contains a unique 16-Bit address that is placed into data packets and periodically transmitted from the beacon’s UHF radio at 437MHz. This is followed by a short period of time where command data can be received by the radio.

The transmitted data from the satellite beacon is collected with the RF signals precise time of arrival at multiple graphically dispersed ground stations.

This data is then passed along to a peripheral device where the calculation of the satellites estimated position can be determined using the time difference of arrival between three ground stations

8) The satellite UHF radio beacon must be self-sustaining and independent of all other satellite systems

To achieve these aims the beacon must contain its own:

* **Processor** – which is based on the Arduino Pro Mini (APM) module
* **Radio Transceiver** – that utilises a RFM96 LoRa radio module
* **Power Generation, storage and regulation** – which contains silicon solar panels, a super-capacitor storage system and a buck converter for power regulation

9) The software cycle for the radio beacon was developed to comply with the following requirements:

* The beacon is required to maintain radio silence for 30 minutes after release from the launch vehicle
* The radio must have a receive period in which the radio can receive a command to cease radio transmissions
* The software cycle must contain a variable time period for the power down phase to prevent synchronisation of transmissions

10) The aim of the satellite radio beacon design is to minimise Size, Weight and Power (SWaP) of the system, with minimising the current consumption of each component being the focus of testing. The tests presented on the slide were carried out in a sequential order to determine the hardware and software configuration for the initial design of the satellite radio beacon

11) **The testing found the following methods to minimise the total beacon system current consumption:**

* Placing the LoRa module into sleep mode and the processor into low power mode where possible
* Minimizing the *receive* and *transmit* phase in the beacon software cycle
* Reducing the TX power and data packet size to as small as possible

**Some additional observations were made during the testing of the satellite beacon:**

* one solar panel could not support the beacon operation without an additional power source with a TX power greater than 10dBm
* The super-capacitors introduce an 8 minute and 20 second delay to the system initialisation which can be utilised in the launch phase of the cycle
* Several radio packets were observed to be transmitted but not received by the LoRa module (which is investigated in the communications link)

12) The ground testing has shown that the satellite UHF radio beacon can self-sustain operation using a single silicon solar panel with the power storage system providing 74 minutes of operation when no power is being generated.

There is a combination of analogue, digital and serial connections remaining to collect telemetry data from other satellite systems with most system memory remaining for the data collection and command receive software program development

Investigation into creating a PCB design and electrical component selection for space operations is required before proceeding to mission-readiness testing

13) The parameters for the communications link testing are based upon a satellite in a sun-synchronous LEO orbit with a 600kms height and a 98° inclination. These parameters result in the communications link have a maximum slant range of 2000km which equates to a 151.3dB Free-space path loss

14) The first investigation carried out was to determine why the LoRa radio module was not receiving the transmitted data packets. The testing carried out was unable to determine the reason because of the proprietary nature of the LoRa software and no methods could be found to bypass the LoRa receive process.

The high packet error rate of the LoRa module found during testing caused a change in the data transmission method in which the information will be split into 4 sequential identification packets followed by a separate telemetry data packet

15) The next step in the testing procedure was to verify the reliable transfer of data over the UHF communications link and determine the LoRa radio module settings and TX power

The receiver sensitivity was firstly estimated using the LoRa modem calculator tool followed by hand calculating the communications link budget. The calculations were then verified with the results of the ground-based testing

16) This slide presents the simplified equations used for the link budget calculation which were repeated for the 0, 2 and 3 default radio settings with various TX powers.

17) The ground-based testing was carried out by physically connecting two LoRa modules using a set of coaxial cables and attenuators.

The total attenuation was slowly increased until the receiver stops collecting consistent data which represents the maximum value of FSPL for which reliable data is received

18) The results of the link budget calculations and ground testing show that a reliable communications link can be supported if the LoRa module uses the RadioHead (2) default settings with a 15dBm TX power. This results in a 2000km communications link budget having an Eb/No of 14.38 which allows a margin for unaccounted and future losses.

19)

24) The aim of this project was to produce an initial prototype design for a self-contained and independent radio beacon that can transfer data from a small satellite in a low earth orbit. The project was extended to include a prototype design for a ground receiving station with a tracking function.

The satellite radio beacon prototype design has been tested and verified to be capable of

* Operating with no input from any other satellite system
* Collecting telemetry data from other satellite systems
* Sustaining beacon operation using a singular solar panel
* Executing a command received from a ground station
* Reliably transferring data for distance of 2000km

25) The ground receiving station protype design was capable of transmitting command data to the satellite beacon and receiving the transmitted identification and telemetry data. The testing carried out indicated that the time difference of arrival calculation of the satellites position had an uncertainty of 1.5kms but the final verification testing revealed an uncertainty of 450-510kms.

The initial design for the small satellite UHF radio beacon system has proven the concept for the small satellite Identification, Telemetry and Control but further investigation of the ground receiving station is required to obtain a reliable and accurate tracking function

27) It is suspected that the implementation of the processor clock counting method in the ground station software causes the large increase in time measurement uncertainty leading to the sizeable uncertainty in position estimation.

If the uncertainty of the satellites position can be reduced to an acceptable level, then development of the system can be continued to:

* Implement a TDOA algorithm that calculates estimated position based on Latitude/Longitude position
* Develop a user interface program for the ground receiving station
* Develop a server system for the collection and processing of ground station gathered data
* Produce a satellite radio beacon design ready for space operation testing