Radar Technical Safeguarding Assessment – St Annes Radar

Blackpool Council

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Executive Summary

A new B2 industrial unit is proposed on land 600m north of the runway at Blackpool Airport. NATS (En Route) [NERL] has objected to the development on the grounds of unacceptable operational impact on their St Annes radar facility, which lies to the east.

Blackpool Council (the Client) has engaged Cyrrus Limited to undertake a modelling study in order to assess the potential impact of the development on St Annes radar.

The main findings of the study are:

- The proposed building is clear of the St Annes Primary Surveillance Radar (PSR) and Monopulse Secondary Surveillance Radar (MSSR) sterile zones and will have no impact on radar performance;
- The maximum height of the B2 unit is below the PSR and MSSR antenna electrical centres, so it will have no impact on radar coverage;
- Reflections of radar signals from the vertical faces of the proposed building will be towards the ground where they will scatter and be absorbed. However, NERL are concerned that MSSR reflections from the building could be detected by aircraft;
- Calculations show that the radiated power of MSSR signals reflected from the building will be less than the control pulse radiated power, which will inhibit aircraft transponder replies;
- If an aircraft transponder still responds, the maximum range for an aircraft to detect the MSSR reflected signal is 16.8km from the building. A reply from such an aircraft subsequently reflected from the building is unlikely to be detected by the MSSR receiver due to Sensitivity Time Control (STC) reduction of receiver sensitivity to reduce overloading of the MSSR;
- In any case, Raytheon MSSRs have integrated processing features for dealing with reflecting surfaces. The self-adaptive reflector file in the MSSR processor dynamically calculates the location and orientation of reflectors from the geometry of real and false targets. If the proposed building is found to generate false targets its position will be stored in this file; and
- During periodic checks, NERL engineers will routinely update the permanent reflector file with data from the self-adaptive reflector file. This is an optimisation task that can be performed remotely.

Full details of the investigation and findings are contained within the body of this report.

Abbreviations

AGL	Above Ground Level
AOD	Above Ordnance Datum
DSM	Digital Surface Model
DTM	Digital Terrain Model
LIDAR	Light Detection and Ranging
MSSR	Monopulse Secondary Surveillance Radar
NERL	NATS (En Route)
PSR	Primary Surveillance Radar
RCS	Radar Cross Section
RLoS	Radar Line of Sight
STC	Sensitivity Time Control
TOPA	Technical and Operational Assessment

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1. Introduction

1.1. Background

1.1.1. A new B2 industrial unit development is proposed on land at Amy Johnson Way, Blackpool. The site is approximately 600m north of the runway at Blackpool Airport, and the intention is for Blackpool Council to develop and lease the site to an appropriate business to occupy.

1.1.2. Blackpool Council (the Client) has engaged Cyrrus Limited to undertake a radar modelling study in order to assess the potential impact of the proposed new development on the NATS (En Route) [NERL] radar facility at St Annes, which lies to the east of the development.

1.1.3. NERL has submitted a Technical and Operational Assessment (TOPA) Report[1] in which it objects to the development on the grounds of unacceptable reflections from the building resulting in false aircraft targets.

1.2. Scope

1.2.1. This study examines the way in which the proposed development may affect the performance of St Annes combined Primary Surveillance Radar (PSR) and Monopulse Secondary Surveillance Radar (MSSR). The extent of this assessment includes:

- Impact of proposed development on radar beam formation;
- Impact of potential coverage loss due to shadowing and obscuration;
- Impact of reflections of radar signals from the proposed development.

[1] NATS Technical and Operational Report ref: SG28301 Issue 1, March 2020

2. Evaluation Tools Used

2.1. Software

- ZWCAD+ 2015 SP2 Professional;
- Global Mapper v21.1.1.

2.2. Terrain data

- Light Detection and Ranging (LIDAR) composite 1m Digital Terrain Model (DTM);
- LIDAR composite 1m Digital Surface Model (DSM).

2.3. Data provided by Client

- SG28301_TOPA.pdf;
- 19_0391-PLANNING_STATEMENT-368312.pdf;
- 19_0391-PROPOSED_ELEVATIONS-368285.pdf;
- 19_0391-PROPOSED_INTERNAL_LAYOUT-368283.pdf;
- 19_0391-PROPOSED_SECTION_DRAWING-368284.pdf.

3. Development

3.1. Location

3.1.1. The site for the planned industrial unit is depicted in Figure 1 and Figure 2.

Image © 2020 Google & Europa Technologies

Figure 1: Development location

Image © 2020 Google, Landsat/Copernicus & Europa Technologies

Figure 2: 3D view of development location

3.1.2. Elevation images for the proposed development are shown in the following figures.

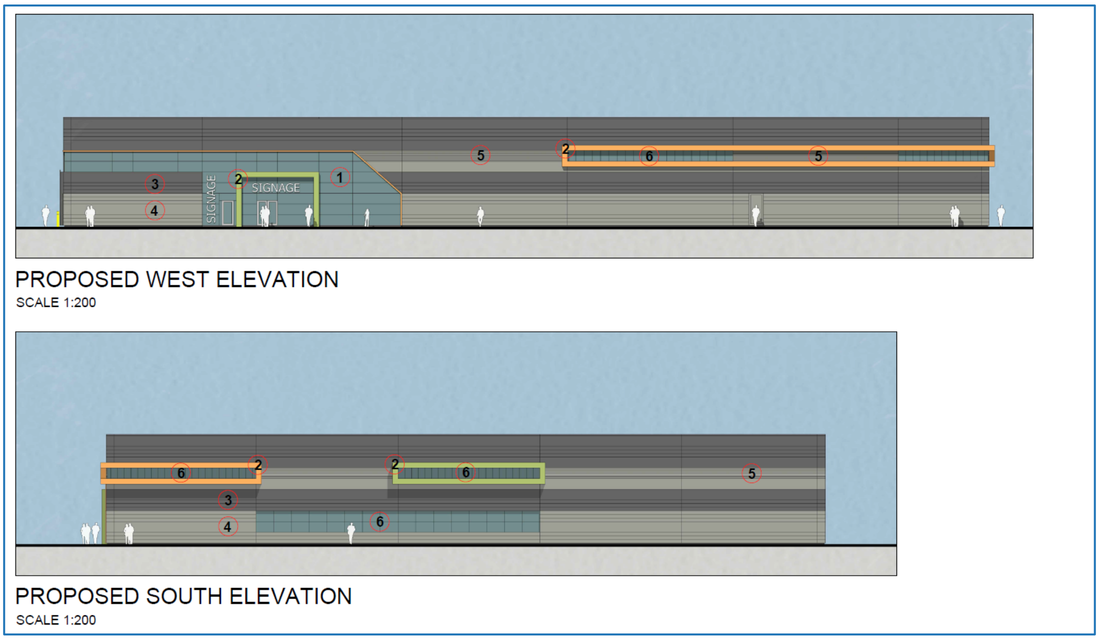

Figure 3: Proposed west and south elevations

Figure 4: Proposed east and north elevations

3.1.3. The proposed B2 unit has a maximum elevation of 9.3m Above Ground Level (AGL), as shown in the section drawing in Figure 5. The average site elevation is 7.8m Above Ordnance Datum (AOD)

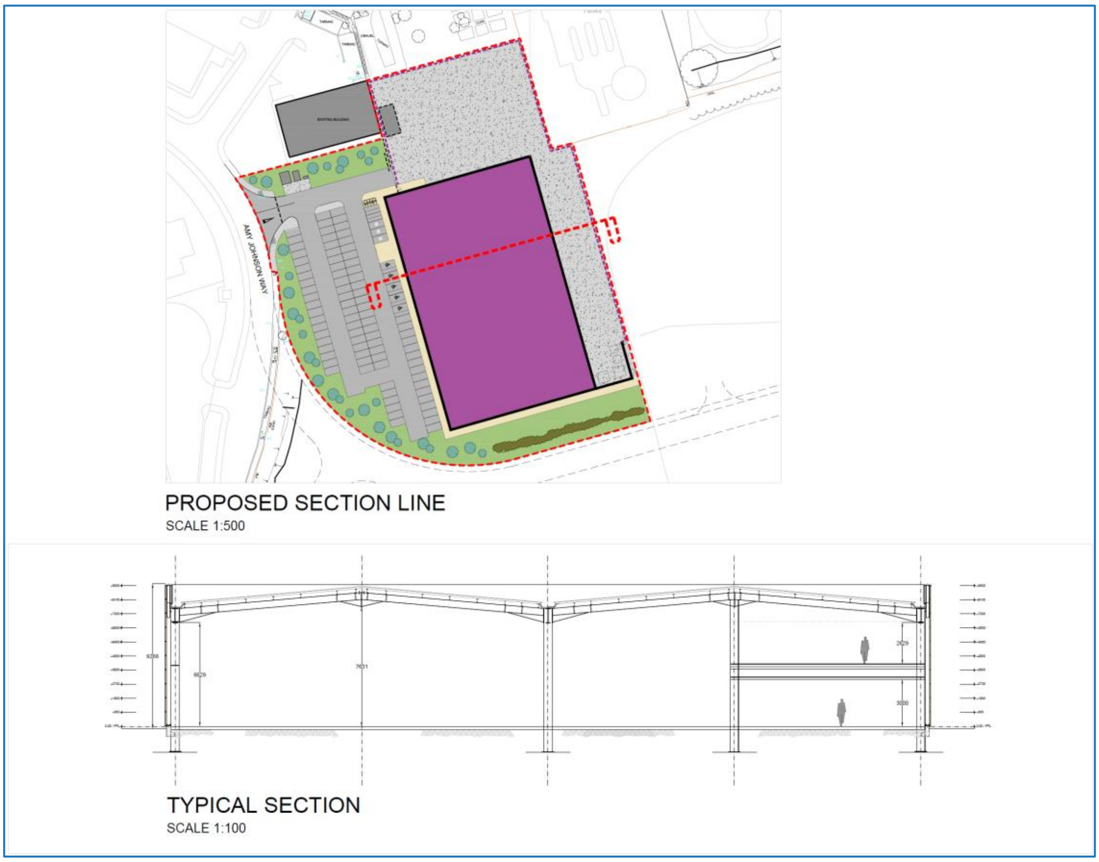

Figure 5: Proposed development section

3.1.4. Figure 6 shows the relative locations of the development and St Annes PSR/MSSR. At its closest point, the development is 2.35km from St Annes radar.

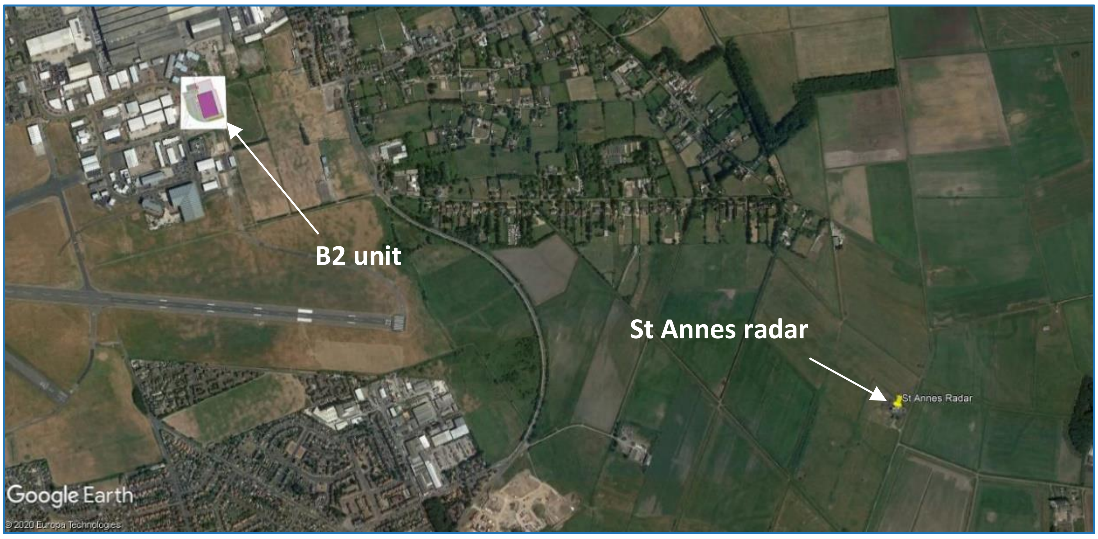

Image © 2020 Google & Europa Technologies

Figure 6: Relative locations of development and St Annes radar

4. Technical Data

4.1. St Annes Radar

- PSR/MSSR location (WGS84) – 53° 46’ 06.2’’ N, 002° 59’ 26.8’’ W;
- Equipment type – Raytheon S-Band ASR 10SS, co-mounted Mode S MSSR;
- PSR frequency – 2800MHz;
- PSR electrical centre – 29.2m AOD, 25.1m AGL;
- MSSR frequency – 1030MHz;
- MSSR electrical centre – 32.2m AOD,
- Other radar parameters used in the assessment have been taken from data held on file by Cyrrus.

4.1.1. The arrangement of the radar antennas is shown in Figure 7.

Figure 7: St Annes radar

4.2. B2 Unit details

- Maximum building elevation – 9.3m AGL;
- Average site elevation – 7.8m AOD.

5. Radar Analysis

5.1. Radar issues

5.1.1. Large structures can have three unwanted effects on both PSR and MSSR:

- **Beam forming** – Structures too close to the radar antenna can affect the formation of the radar beam, creating distortion of the beam structure;
- **Shadowing** – This is where the structure forms a physical obstruction causing a radar shadow behind the structure where coverage is impacted. This may result in the loss of radar detection of wanted targets in a particular volume of airspace;
- **Reflections** – Radar energy may be reflected from the faces of buildings which may result in the detection of false targets. PSR energy reflected from the roof of a structure can cause fading of targets over a particular azimuth sector.

5.1.2. The primary issue identified by NERL in their planning objection is reflections of MSSR energy from the surfaces of the proposed unit.

5.2. Modelling

5.2.1. A 3D CAD outline of the proposed development is constructed and imported into a Global Mapper software 3D model that also includes the radar, LIDAR 1m terrain and existing building data.

Figure 8: LIDAR 1m DSM data

5.2.2. A 3D view from the radar towards the development is shown in Figure 9.

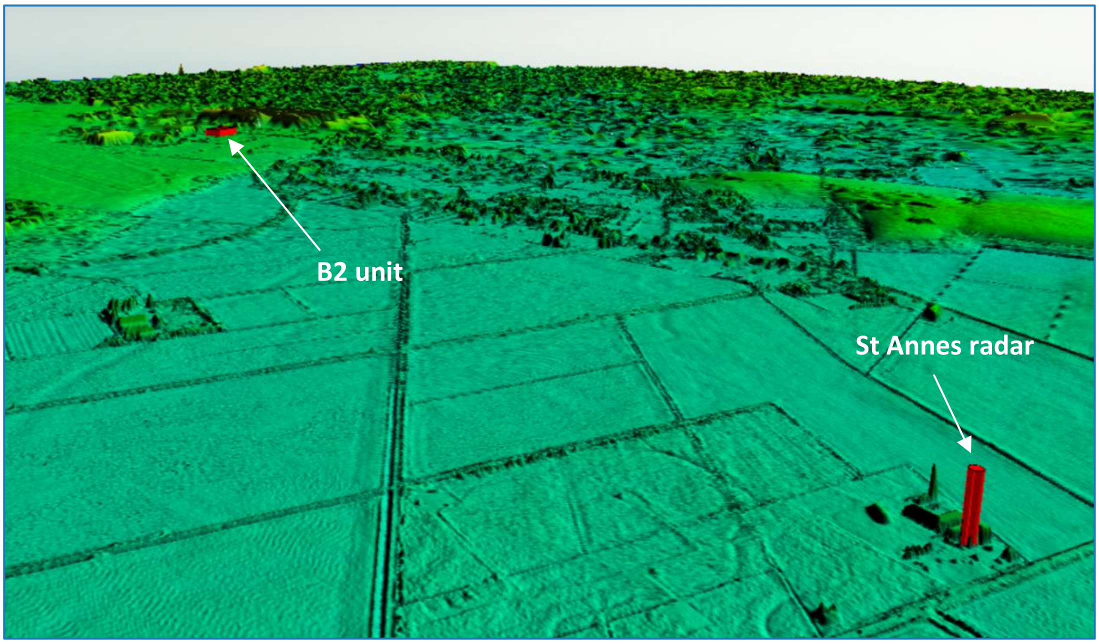

Figure 9: 3D view

5.2.3. The closest point of the proposed unit is 2350m from the radar, as shown in Figure 10.

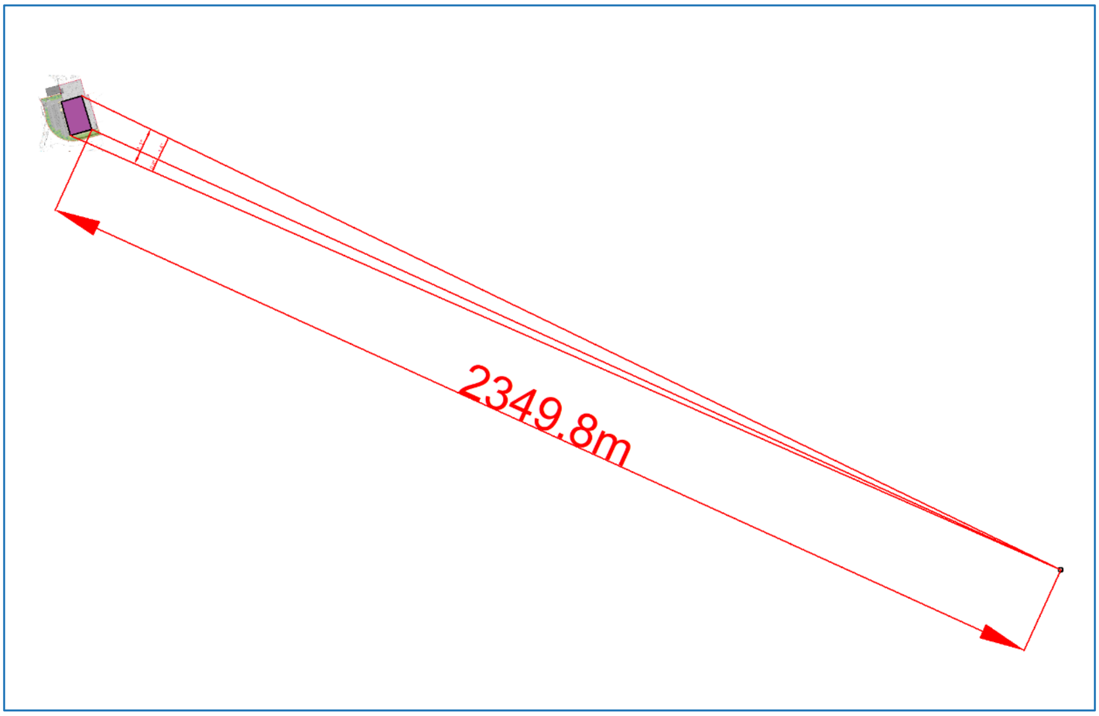

Figure 10: Range of unit from radar

5.2.4. The unit will occupy a sector of 2.14° from the radar, between 294°T and 296°T. This sector of potential radar shadowing is illustrated in Figure 11.

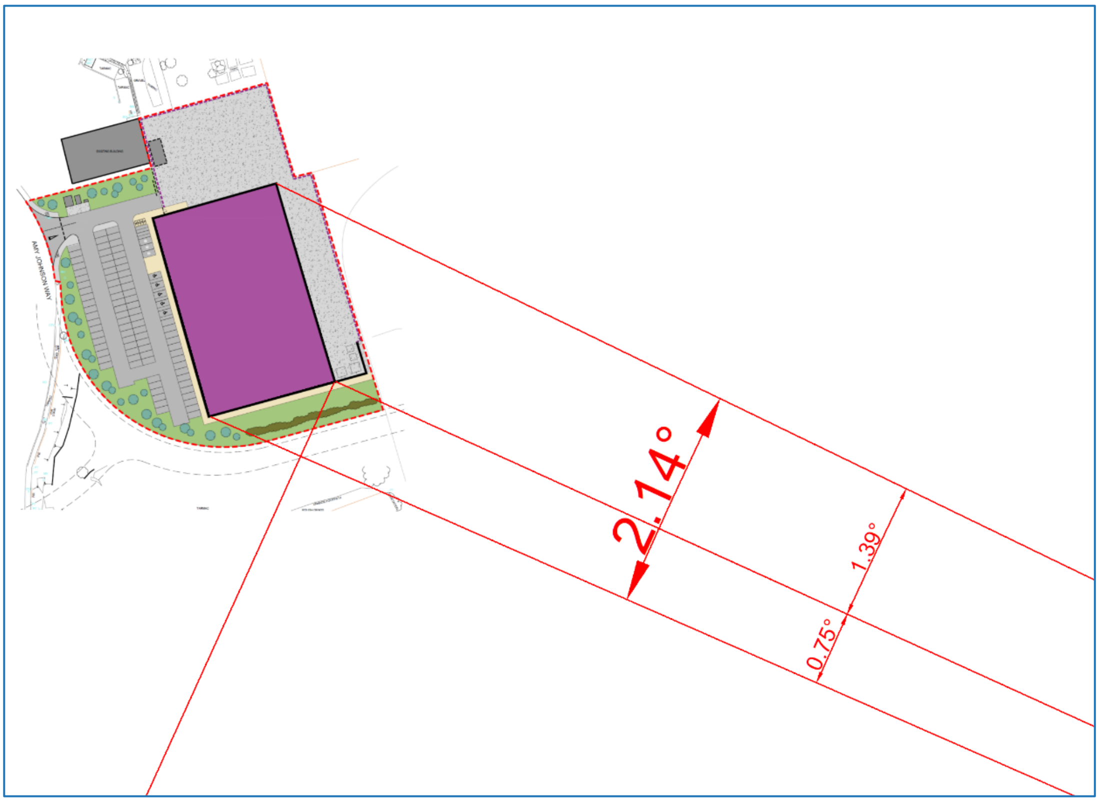

Figure 11: Radar sector occupied by B2 unit

5.3. Development visibility

5.3.1. Figure 12 shows the view from the MSSR antenna towards the proposed development, shaded in red.

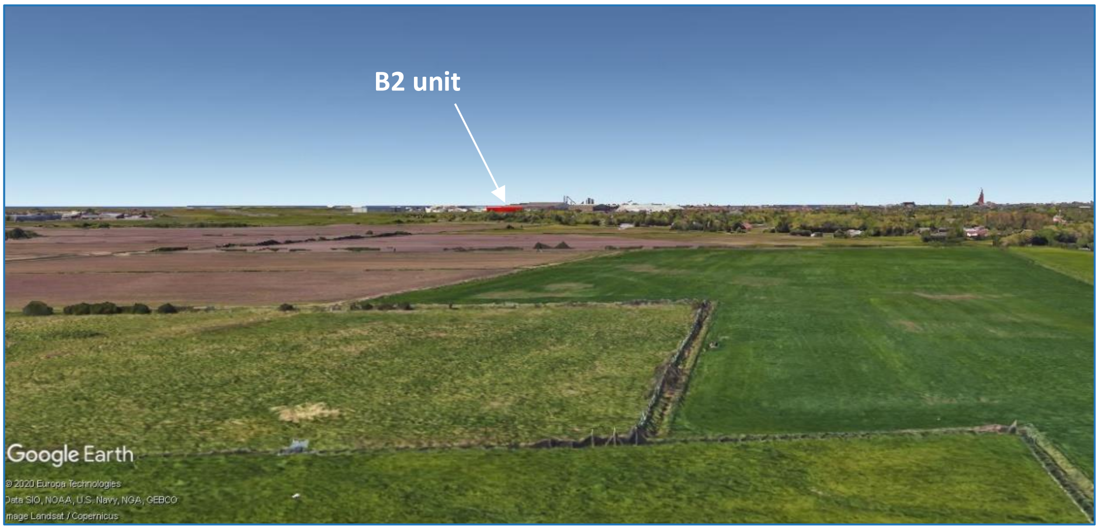

Image © 2020 Google, Landsat/Copernicus & Europa Technologies

Figure 12: View of B2 unit from MSSR

5.3.2. As can be seen, the proposed B2 unit is partially shielded by existing trees and buildings which may serve to reduce any possible shadowing or reflection effects. The building also lies below the horizon.

5.3.3. Radar Line of Sight (RLoS) modelling can be used to determine how much of the unit is visible to the radar.

5.3.4. Figure 13 shows RLoS from the MSSR antenna for targets at 1m AGL in a sector encompassing the proposed development and indicates that most of the northeast face and some of the southeast face will be visible at this height.

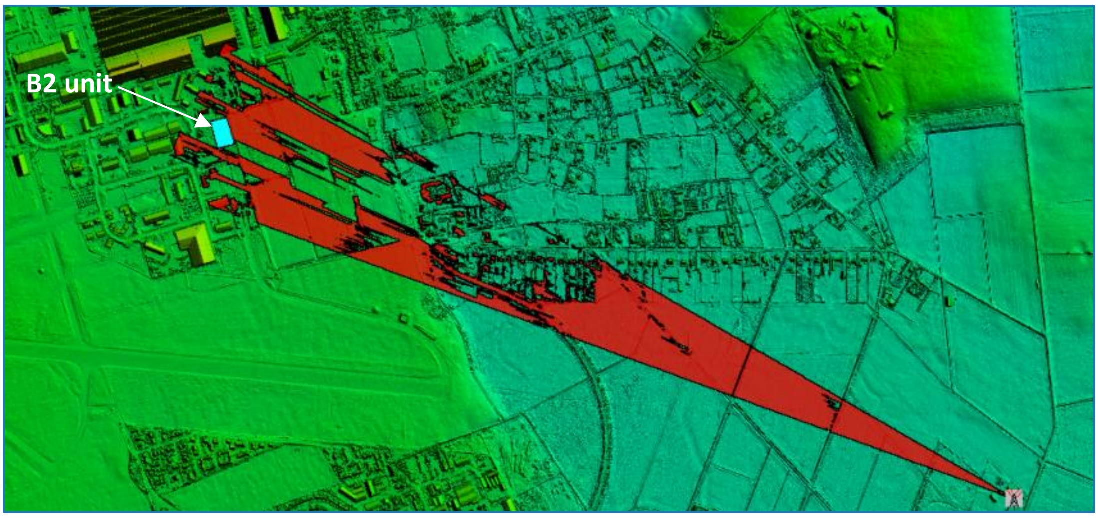

Figure 13: MSSR visibility of building at 1m AGL

5.3.5. At 4m AGL both the northeast and southeast faces are fully illuminated by the MSSR signal, as shown in Figure 14.

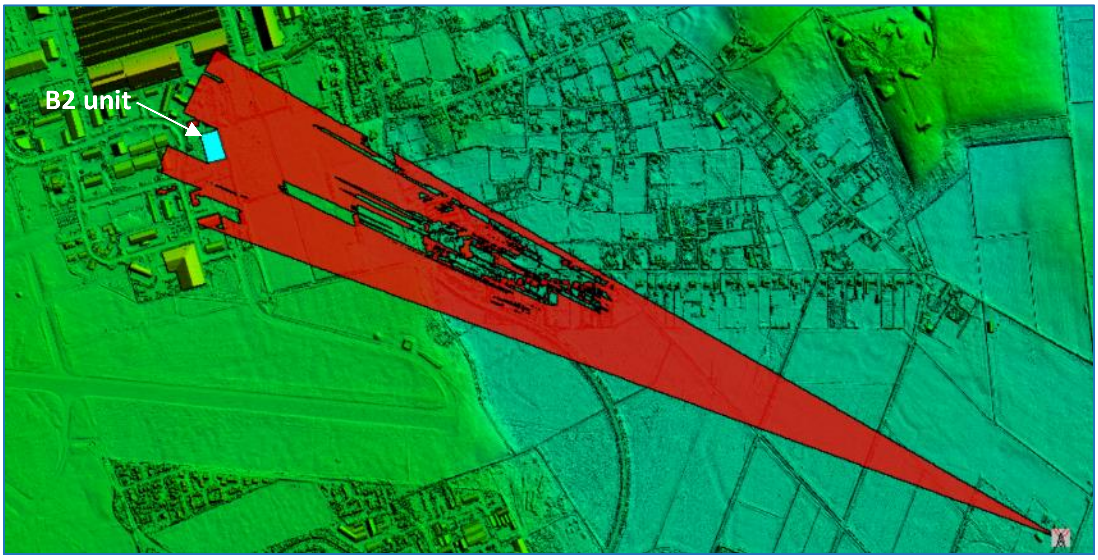

Figure 14: MSSR visibility of building at 4m AGL

5.4. Beam forming

5.4.1. Radar beam formation depends on various factors such as the antenna height, the dimensions of its reflector, and the signal wavelength. The volume in which the beam is progressively formed as it emits from the antenna is divided into the following three zones:

- Near field reactive zone, or Rayleigh zone;
- Near field radiating zone, or Fresnel zone; and
- Far field radiating zone, or Fraunhofer zone.

5.4.2. These zones are illustrated in Figure 15.

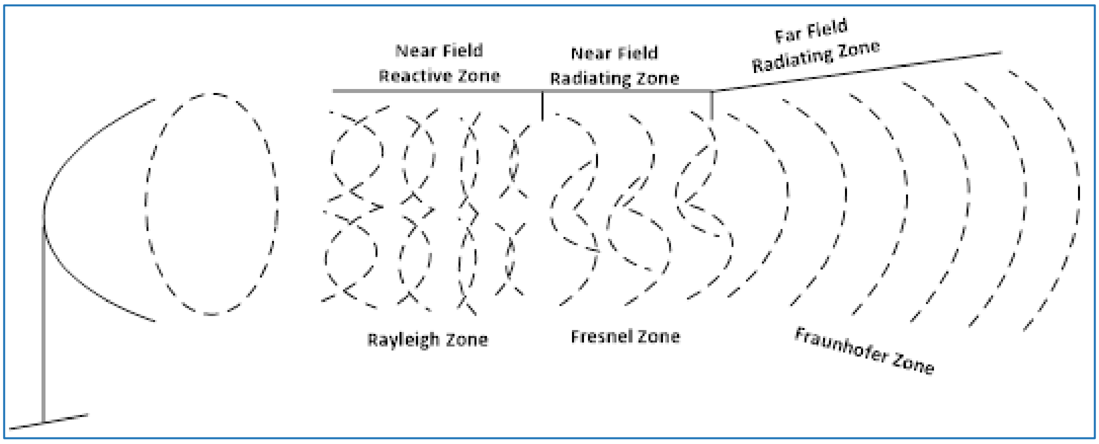

Figure 15: Antenna beam forming zones

5.4.3. The beam forming area needs to be free of structures which could negatively affect the formation of the radar beam. This area is referred to as the Sterile Zone.

5.4.4. Of the three zones, the far field region is considered the most important in terms of radar operation, as the radiating signal pattern is uniform and constant with distance. The relationship between the electronic and magnetic components of the emitted signal is more stable. The electrical field strength of the signal weakens over distance in this zone and energy propagates to infinite distance.

5.4.5. A radar beam can be considered to be fully formed at the distance where its gain becomes equal to its value at infinity. Most literature agrees that the beam is formed by more than 90% of its infinity value when it reaches the Fresnel zone and Fraunhofer zone boundary. The boundary distance is nominally considered to lie between D^2/λ (where gain reaches 94% of its infinity value) and $2D^2/\lambda$ (99% of its infinity value) from the radar, where D is the largest dimension of the reflector and λ is the wavelength[2].

5.4.6. If a linear progression of beam formation from 94% to 99% is assumed, then it could be argued that the beam will be completely formed by $2.2D^2/\lambda$.

[2] Merrill Skolnik – Introduction to Radar Systems, McGraw Hill, 1962

5.4.7. For St Annes PSR, $2.2D^2/\lambda$ corresponds to a distance of approximately 535m. Similarly, for the MSSR the beam is completely formed at a distance of approximately 485m.

5.4.8. At a minimum range of 2350m from the St Annes site, both the PSR and MSSR beams will be fully formed at least 1800m before reaching the development site. The proposed building lies significantly outside the radar sterile zones and performance of the PSR and MSSR will not be impacted.

5.5. Shadowing

5.5.1. The maximum height of the proposed unit is 7.8 + 9.3 = 17.1m AOD. The electrical centres of the PSR and MSSR antennas are 29.2m AOD and 32.2m AOD respectively. This means that shadowing and obscuration due to the building will only impact airborne targets below the height of the building.

5.5.2. Shadowing leading to loss of radar coverage will not be an issue.

5.6. Reflections

5.6.1. It has already been established that the maximum elevation of the proposed building is below the elevations of the radar antennas. Radar signals will illuminate the unit roof and the northeast and southeast vertical faces of the building.

5.6.2. Where the reflecting surface is horizontal or tilted perpendicular to the radar, for example a building roof, this can lead to a reflection which interferes with the direct radar signal, as shown in Figure 16.

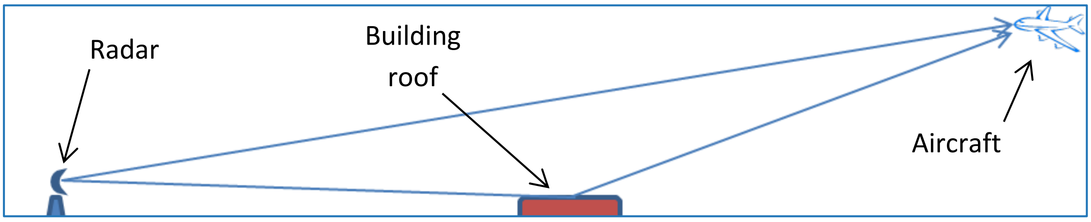

Figure 16: Reflection causing interference

5.6.3. The received radar signal is the sum of these two signals. Depending on the relative phases of the signals, this can either reinforce the signal or cancel the signal causing the target to fade from the display. For close-in targets, this can result in the radar seeing two targets on the same bearing closely separated in range. Any sideways slope to the roof results in a change in azimuth between the main and reflected signal, which can lead to azimuth errors in the reported positions of aircraft.

5.6.4. The roof areas of the proposed B2 building will act as reflectors of radar signals, with upward reflections slightly offset in azimuth due to the shallow pitch of the ridged roofs. This may potentially lead to targets having small azimuth errors, or duplicate targets being displayed.

5.6.5. The volume of airspace potentially affected is likely to only be a narrow band of shallow elevations within the azimuth sector shown in Figure 11. The NERL TOPA makes no reference to roof reflections from the proposed unit so it can be assumed that NERL do not regard this as a significant issue.

5.6.6. The mechanism for creating a false aircraft target, when radar energy is reflected from a vertical building face, is shown in Figure 17.

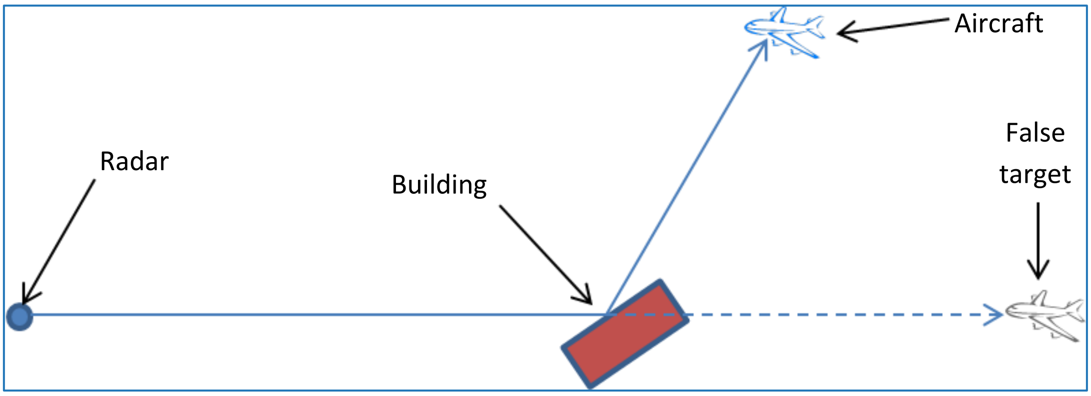

Figure 17: Generation of a false aircraft plot

5.6.7. False targets are caused by the radar signal being reflected to an actual target. The false target will appear on the bearing of the reflector from the radar, i.e. the real target is duplicated on the reflector bearing.

5.6.8. The maximum elevation of the proposed building is lower than both the PSR and MSSR antennas, thus any reflections from vertical building surfaces will be towards the ground where they will scatter and be absorbed.

5.6.9. The NERL TOPA suggests that MSSR reflections from the southern wall of the unit could generate reflections detectable by aircraft within the entire range of the radar. It is true that sidelobes of the reflected radar signals will be in multiple directions, but they will be of a magnitude several dBs below that of the main lobe which will be directed towards the ground.

5.7. Reflection probability – MSSR

5.7.1. The probability of a reflected signal presenting a false target depends on the reflected signal being of sufficient strength to be detected by the radar. Unlike PSR, MSSR operates by the radar interrogator transmitting a coded pulse sequence which is received and decoded by suitably equipped aircraft. The aircraft transponder replies with a coded pulse sequence on a different frequency which is received by the MSSR.

5.7.2. To determine if the reflected signal received at the aircraft from the MSSR will be detected, a simple calculation of radar path loss is made to determine the level of reflected signal at the aircraft.

5.7.3. The process is based on the MSSR performance specification and some generic assumptions and gives an indication of the magnitude of potential effects.

5.7.4. The process for the calculation is outlined in Table 1.

Parameter	Value
Transmitter Power	+dBm
- System losses	-dB
+ Antenna Gain	+dB
- Gain reduction	-dB
- Free space path loss to reflector	-dB
+ Radar Cross Section (RCS) gain of reflector	+dB
- Free space path loss to aircraft	-dB
= Power at receiver	dBm

Table 1: MSSR reflection calculation process

5.7.5. By populating Table 1 and adding the values together, the received signal level at the aircraft can be determined. This is compared with the minimum signal level required to trigger the transponder (-71dBm). A similar calculation can be undertaken for the signal between the aircraft, reflector and the radar. The return path of the replies to the interrogator also needs to factor in the Sensitivity Time Control (STC) gain curve. This serves to reduce the overloading of the MSSR from close in replies and is also a mechanism for reducing unwanted false replies from reflections and multipath.

5.7.6. This calculation assumes a direct reflection between the vertical faces of the proposed building and an aircraft, whereas the reflection main lobe will initially be directed towards the ground. There will therefore need to be a secondary reflection from the ground for both uplink and downlink paths. The attenuation caused by ground reflection of radar signals is dependent on various unknown variables such as surface irregularities, and the angle of incidence and so for this worst-case calculation it is ignored.

5.7.7. The Radar Cross Section (RCS) of the reflector (vertical building face) is not the physical size of the reflector, but the effective radiating area at the particular radar frequency. The physical area of the reflector for a plane surface cannot exceed the aperture of the smallest source and is equivalent to the area perpendicular to the signal path, not the area of the actual reflection plane. The aircraft antenna is very small and can be considered as a point source at distance. For the purposes of this evaluation, the flat plate reflector cannot exceed the dimensions of the MSSR antenna aperture (8.0m x 1.85m) which is equivalent to an RCS of 45dBm^2 or a maximum RCS gain of around 67dB at the MSSR frequencies.

5.7.8. A nominal peak power for the MSSR transmitter of 62dBm is assumed. The peak gain of the MSSR antenna is 27dB. At low elevations the gain is reduced and is usually 6dB below peak at 0° elevation. The proposed building is below the radar horizon so the antenna gain for MSSR signals illuminating the building will be no more than 21dB.

5.7.9. Table 2 shows a calculation for the equivalent reflected power from the proposed building. The additional path losses that must occur through ground reflection are ignored and a reflector perfectly aligned to reflect radar energy towards an aircraft is assumed, resulting in an equivalent radiated power that cannot exceed **+46.2dBm**.

Parameter	Value
Transmitter Power	+62dBm
- System losses	-3.5dB
+ Antenna Gain	+27dB
- Gain reduction	-6dB
= Equivalent radiated power	+79.5dBm
- Free space path loss to reflector	-100.1dB
+ Radar Cross Section (RCS) gain of reflector	+66.8dB
= Equivalent reflected power	**+46.2dBm**

Table 2: Calculation for equivalent reflected power (uplink)

5.7.10. The MSSR system radiates a control pulse to prevent aircraft from replying when out of coverage of the main beam. This is primarily to prevent the aircraft responding to interrogations from antenna sidelobes. The control pulse transmitter power can be a maximum of +62dBm but up to 15dB attenuation may be added for terminal operations. With system losses it is unlikely that the control pulse effective radiated power is less than +58.5dBm for an en-route radar. As this is higher than the expected reflected power of +46.2dBm an aircraft transponder should not respond to the reflected interrogation.

5.7.11. If it is assumed that the aircraft transponder still responds to the reflected interrogation, then the maximum range at which an aircraft will respond can be calculated. The aircraft transponder requires a minimum signal of -71dBm for detection, so the minimum path loss to drop the reflected signal below the detection threshold is:

- Minimum path loss drop = -71dBm – 46.2dBm = **-117.2dB**

5.7.12. 117.2dB of path loss in free space at the MSSR frequency is the equivalent of approximately **16.8km** in distance from the proposed building.

5.7.13. This defines the maximum range where a reflected MSSR interrogation is potentially of sufficient strength to be detected by an aircraft MSSR transponder.

5.7.14. Using a similar calculation to the process outlined in Table 1, the power of the reply signal received at the MSSR antenna from an aircraft at 16.8km can be determined.

5.7.15. For a Class 1 aircraft transponder a peak power of 500W or 57dBm is assumed.

5.7.16. Table 3 shows a calculation for the power received at the MSSR from an aircraft transponder reply at 16.8km via a reflection from the proposed building. A received power of **-75.5dBm** exceeds the MSSR receiver minimum sensitivity of -86dBm, but this does not consider the STC gain curve. For a total return path distance of 16.8 + 2.35 = 19.15km, the MSSR sensitivity is likely to be reduced to a value between approximately -65dBm and -71dBm. This means that the MSSR is unlikely to detect the reflected reply from the aircraft. Similarly, reflected replies from aircraft at ranges closer to the proposed building will not be detected due to STC reduction of receiver sensitivity.

Parameter	Value
Transponder Power	+57dBm
- Cable losses	-3.0dB
= Equivalent radiated power	+54.0dBm
- Free space path loss to reflector	-117.7dB
+ Radar Cross Section (RCS) gain of reflector	+67.8dB
- Free space path loss to MSSR	-100.6dB
+ Antenna gain	+27dB
- Gain reduction	-6dB
= Power received at MSSR antenna	**-75.5dBm**
MSSR receiver minimum sensitivity	-86dBm

Table 3: Calculation for signal power received by MSSR (downlink)

5.8. Mitigation

5.8.1. Notwithstanding the calculations in the previous section demonstrating the unlikelihood of the MSSR detecting false targets due to reflections from the proposed B2 unit, the Raytheon MSSR has integrated processing features for dealing with reflecting surfaces.

5.8.2. An inbuilt permanent reflector file in the MSSR processor contains the locations and orientations of fixed objects such as buildings which are known to produce reflections resulting in false targets. These reflector positions are effectively 'learnt' by the system during initial optimisation when the MSSR is commissioned.

5.8.3. The MSSR processor also has a self-adaptive reflector file for dynamic or new reflecting surfaces that may produce false targets. Self-adaptive processing calculates the location of reflectors by analysing the geometry of real and false targets and saves these reflectors in the self-adaptive file. Data in this file that is not accessed for a typical period of 2 hours is automatically cleared as these are likely temporary reflectors such as high-sided vehicles or mobile cranes, whereas the positions of new permanent reflectors, for example the proposed building, are retained.

5.8.4. During periodic checks of NERL MSSRs, engineers will routinely check the contents of the self-adaptive reflector file and clear the data. If on subsequent checks the same fixed reflectors are present in the file, the data is transferred to the permanent reflector file and an updated copy of the permanent reflector file is stored in the processor. This is a routine optimisation task that can be performed remotely.

6. Summary

6.1. The proposed building is clear of the St Annes PSR and MSSR sterile zones and will have no impact on radar performance.

6.2. The maximum height of the B2 unit is below the PSR and MSSR antenna electrical centres, so it will have no impact on radar coverage.

6.3. Reflections of radar signals from the vertical faces of the proposed building will be towards the ground where they will scatter and be absorbed. However, NERL are concerned that MSSR reflections from the building could be detected by aircraft.

6.4. Calculations show that the radiated power of MSSR signals reflected from the building will be less than the control pulse radiated power which will inhibit aircraft transponder replies.

6.5. If an aircraft transponder still responds, the maximum range for an aircraft to detect the MSSR reflected signal is 16.8km from the building. A reply from such an aircraft subsequently reflected from the building is unlikely to be detected by the MSSR receiver due to STC reduction of receiver sensitivity.

6.6. In any case, Raytheon MSSRs have integrated processing features for dealing with reflecting surfaces. The self-adaptive reflector file in the MSSR processor dynamically calculates the location and orientation of reflectors from the geometry of real and false targets. If the proposed building is found to generate false targets its position will be stored in this file.

6.7. During periodic checks, NERL engineers will routinely update the permanent reflector file with data from the self-adaptive reflector file. This is an optimisation task that can be performed remotely.

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