ADATS TECHNICAL BRANCH TECHNICAL REPORT

Report Ref: 1630/09
Issue: 3
Date: 06th October 2009

Title: WR 80026.054
INVESTIGATION INTO THE INTERFERENCE EFFECTS OF WIND TURBINES ON THE PAR SYSTEM

Defence Equipment & Support

MINISTRY OF DEFENCE

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EXECUTIVE SUMMARY

This report details the investigation of the interference effects of the Rothes wind turbine development on the PAR at RAF Lossiemouth.

The investigation demonstrated that within the arc of PAR coverage, the impact of the wind turbine development can be described by a volume of airspace bound by 4° left and right of the wind turbine development centroid and between the slant ranges of 9.4nmi to 10.7nmi up to FL020.

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LIST OF ABBREVIATIONS

ac	aircraft
ADATS DT	Air Defence Air Traffic Systems Delivery Team
AGL	Above Ground Level
Air C2 OEU	Air Command and Control Operational Evaluation Unit
AMSL	Above Mean Sea Level
ATC	Air Traffic Control
ATS	Air Traffic Services
CSSR	Cardion Secondary Surveillance Radar
dBi	Isotropic Gain in decibels
dBm	Power Ratio in decibels measured with respect to 1 milli-watt
dBsm	Radar Cross Section with respect to a $1m^2$ sized target
dBW	Transmission Power in decibels with respect to 1 watt
EGN	East of Grid North
km	kilo meter
kts	knots measured in nautical miles per hour
LoS	Line of Sight
MDS	Minimum Discernable Signal
MoD	Ministry of Defence
MSSR	Monopulse Secondary Surveillance Radar
nmi	Nautical Mile
PAR	Precision Approach Radar
RPAR	Replacement Precision Approach Radar (Original MoD designation for the PAR).
RAF	Royal Air Force
RCS	Radar Cross Section
MSSR	Monopulse Secondary Surveillance Radar
TB	Technical Branch
WGS	World Geodetic System
WR	Work Request

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REFERENCES

A. Flight Check Instruction 3, Issue 3 May 06

B. Priority Flight Check Directive - 27/05/2009

C. ITT RPAR Specification – February 2001 (Subject to US ITAR Regulations)

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1 Introduction

1.1 The MoD wishes to further develop an understanding of the effects of wind turbines on the Precision Approach Radar (PAR). Previous trials and observations on a number of radar types, including the PAR, have shown wind turbines will interfere with the performance of the radar, however little is known about the scope of effects on the PAR.

1.2 This office was tasked with investigating the effects of a wind turbine development on a PAR system. In its normal operational configuration, the PAR at RAF Lossiemouth has no wind turbines with in its arc of coverage. It can however, be configured to have direct Line of Site (LoS) with the Rothes wind turbine development. An informal investigation utilising passing traffic was carried out on the 26/11/2008. This showed that the performance of the PAR was severely affected when a local aircraft over-flew the wind turbine development. There was a loss of detection above and around the wind turbines.

2 Investigation Objective

2.1 The objective of this investigation is to find the boundary of the effects of a large cluster of wind turbines on a PAR system.

3 Investigation Conduct

3.1 This office contacted the operator of the Rothes wind turbine development to find details of the turbines and their layout. In order to have an aim-point for the investigation it was assumed that the middle of the wind turbine development would be where the effects of interference would be most severe.

3.2 Using the Eastings and Northings of each turbine it was possible to calculate a centroidial location for the Rothes wind turbine development. The source data derived centroidial location and subsequent turbine layout can be found in Annex A. The wind turbine development's centroid is 186.77° East of Grid North (EGN). It has a slant range of 10.21 nautical mile (nmi) and the tip height is 1470ft AMSL, resulting in a tip elevation of 1.23° above the horizontal from the PAR.

3.3 ADATS TB3 carried out a coverage assessment of the turbines and a CAP764 technical impact assessment using the parameters and antenna patterns of the PAR. The details of this assessment can also be found in Annex A. In summary, these two assessments demonstrate that the RAF Lossiemouth PAR will have 100% visibility of Rothes wind turbine development centroid and both the static and dynamic components will produce returns greater than the radar's detection threshold.

3.4 This office produced a flight check directive based around the commissioning flight check instruction detailed in Reference A. The resulting flight check directive can be found at Reference B. Due to the uncertain nature of this investigation it was anticipated that there would be a need to select elements of the directive as the understanding of the interference developed.

3.5 The investigation was timed so that it followed a small modification to the PAR feeder cables and the subsequent priority flight trial. The trial proved that the PAR was working correctly and that it met its operational requirement. The flight inspector's recommendation was that the PAR could be used out to a range of 19nmi.

3.6 The PAR would be normally expected to detect to 20nmi. This restriction has no operational impact and has been in place since the radar was first commissioned and flight checked. The Cobham Flight Inspection report can be found in Annex B. It concludes that the RAF Lossiemouth PAR was fully serviceable.

3.7 The PAR wind turbine development investigation took place on the 02-03/06/2009. Throughout the trial, the face of the turbines were presented to the PAR. This is often referred to as 0° yaw. There was also sufficient wind to ensure that the turbines were generating electricity.

3.8 The flight check aircraft was a two engine King Air B-200 with the designation of FPL-B. This aircraft is consistent with the ICAO Annex 10 description of a two engine light aircraft (ac). The ICAO Annex 10 provides the guidance that such a target has the X Band Radar Cross Section (RCS) of ≈10-15m², (10-12 dBsm).

3.9 To ensure that both operational and technical points of view were covered, a team with relevant expertise was formed to ensure the smooth running of the investigation. Those involved in the investigation are listed in Annex C.

3.10 The trial consisted of four sorties[1] lasting approximately 3 to 4 hours each. The first two of sorties enabled the team to develop a coarse appreciation of the wind turbine development's impact. The third sortie was designed to provide comprehensive proof of interference and the fourth sortie was used to complete the investigation and record illustrative scenarios.

3.11 Throughout the investigation image recordings were taken of each individual run to illustrate the effects of the wind turbines on the PAR. An investigation narrative and data inventory can be found in Annex D.

3.12 Certain runs denoted by the suffix A were recorded as the aircraft flew away from the PAR. The results from these runs were ignored as they did not fit the general pattern of the investigation and little is known about the backward RCS of the King Air B-200.

[1] For the purpose of this report, the British definition for sortie has been used. A sortie is defined as an operational flight by a single aircraft. Each sortie is comprised of any number of individual flight runs.

4 Investigation Results

4.1 The effects are summarised below:

4.1.1 **Azimuth:** It was observed that if the ac passed within the slant ranges of 9.4 to 10.7 nmi and 4° either side of the centroid there was a high probability of the PAR losing the target and track seduction occurring. The ac then had to be clear of these boundaries before the PAR was capable of re-identifying the target. The operation procedures for the PAR require the operator to break off the precision approach once the ac is missed for more than 3 seconds[2]. When the ac entered the boundaries the ac disappeared from the display, in some cases for a time period of greater than 25 seconds[3]. The effects observed were consistent across the azimuth envelope of system.

4.1.2 The limits of these boundaries are illustrated in Figure 1.

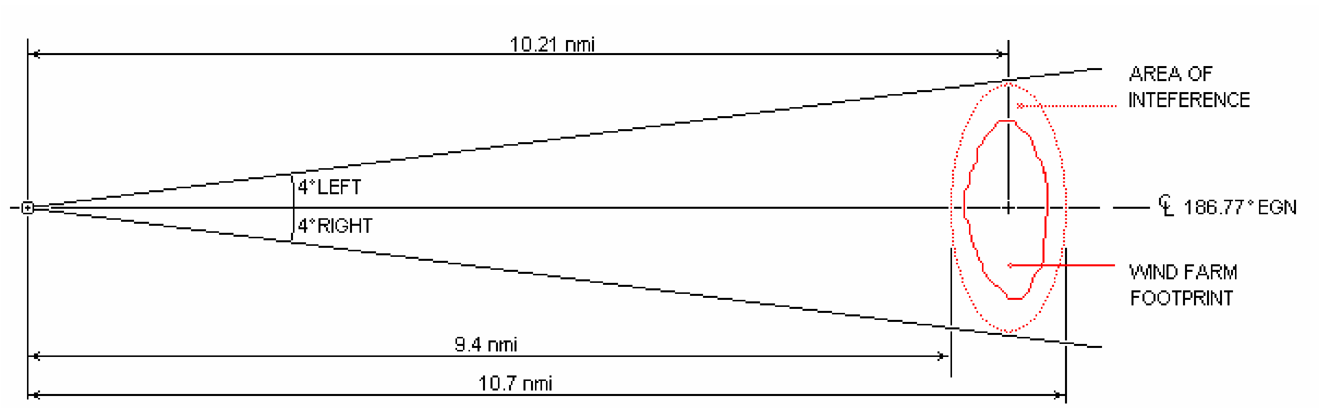

Figure 1 – Azimuth Boundary Limits (Not to Scale)

[2] JSP 552.402.137.15
[3] For a fast jet making an approach to the runway at high speed (e.g. 200knts) 25 seconds equates to travelled distance of approximately 1.38nmi.

4.1.3 **Elevation:** It was observed that the elevation return suffered occasional seduction towards the wind turbines. However, this only occurred at levels which were below the 3° glide path. Effects were observed at FL020, but none at a higher level. It should also be noted that the Rothes turbines were on a high elevation with the tip height for the centroid turbine being 1.23°.

4.1.4 The limits of this boundary are summarised in Figure 2.

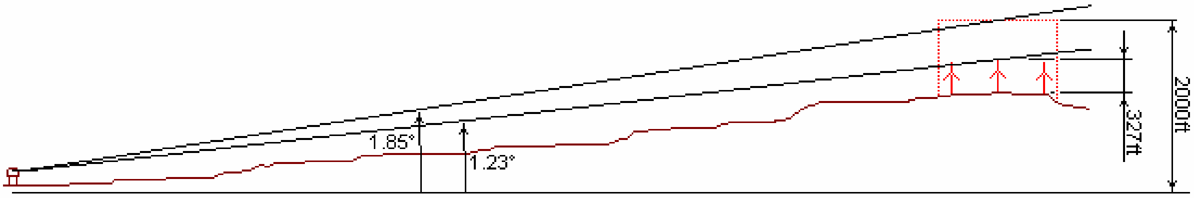

Figure 2 – Elevation Boundary Limits (Not to Scale)

4.1.5 **Tracker:** The tracker is used by the air traffic control operator to identify the ac under control. The tracker appears both in azimuth and elevation. If the tracker looses the ac for more than 3 seconds on either azimuth and elevation plots then the controller must terminate the approach. Observations made during the investigation indicated that the tracker was effective at continuing to track the ac in the elevation beam when the return was lost in the azimuth beam. However, it took greater than 3 seconds for the tracker to reacquire the ac as it reappeared in the azimuth beam after it emerged from the wind turbine development boundary. As a result, the total time of the loss of radar contact was greater than the time limit permitted for the operator to maintain a safe precision approach service[4].

[4] JSP 552, 405.137.15

5 Summary

5.1 The investigation demonstrated that a cluster of wind turbines has a significant effect on the azimuth element on the PAR system and a lesser effect on the elevation element.

6 Other Observations

6.1 At Reference C, the PAR is specified to be able to resolve two targets, one of these targets having a small RCS and the other a medium RCS[5]. However, as the maximum RCS of each of the Rothes wind turbines is an estimated 477m² it would indicate that the PAR can not cope with targets of this magnitude.

6.2 **Future work:** As the Rothes wind turbine development has a medium to large sized foot print and is at a relatively high elevation with respect to the PAR, it would be prudent to investigate the effects that smaller wind turbine developments have on the PAR.

7 Conclusions

7.1 The trial shows that a PAR system is incapable of resolving an ac with X Band RCS of 10-15m² and wind turbines in the same volume of space. However, the effect of the interference is localised.

8 Recommendations

8.1 Further investigation should be carried out to assess the effects of smaller wind turbine developments in order to gauge the scale of the interference caused by these developments.

[5] RCS values have not been included due to US ITAR Regulations.

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ANNEX A to
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Annex A – CAP764 Technical Assessment of Rothes Wind Farm on RAF Lossiemouth PAR

Table 1 – Wind Farm Position Information

Label	Grid Reference	Hub Height (m)	Tip Height (m)
RothesT01	NJ1860650394	58.00	99.75
RothesT02	NJ1856351060	58.00	99.75
RothesT03	NJ1861750721	58.00	99.75
RothesT04	NJ1831450852	58.00	99.75
RothesT05	NJ1828351153	58.00	99.75
RothesT06	NJ1818551486	58.00	99.75
RothesT07	NJ1793051303	58.00	99.75
RothesT08	NJ1772751011	58.00	99.75
RothesT09	NJ1772850692	58.00	99.75
RothesT10	NJ1803950999	58.00	99.75
RothesT11	NJ1805050685	58.00	99.75
RothesT12	NJ1827150454	58.00	99.75
RothesT13	NJ1839250167	58.00	99.75
RothesT14	NJ1787750398	58.00	99.75
RothesT15	NJ1808050170	58.00	99.75
RothesT16	NJ1859649906	58.00	99.75
RothesT17	NJ1827549871	58.00	99.75
RothesT18	NJ1789649854	58.00	99.75
RothesT19	NJ1757949981	58.00	99.75
RothesT20	NJ1879850146	58.00	99.75
RothesT21	NJ1892349840	58.00	99.75
RothesT22	NJ1867149572	58.00	99.75
Centroid	NJ1824550487	58.00	99.75

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Figure 1 – Layout of Rothes Wind Farm

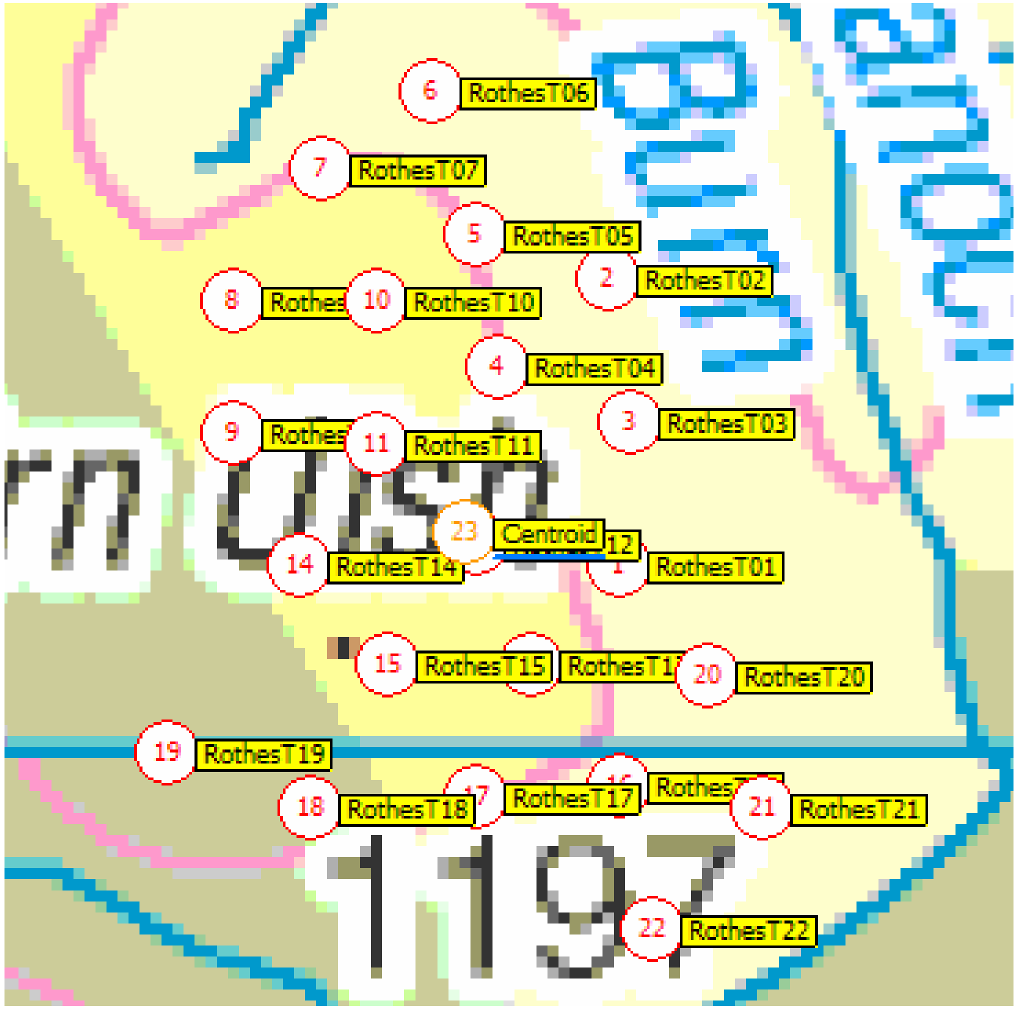

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Figure 2 – RAF Lossiemouth PAR 460m² Coverage at 100m AGL

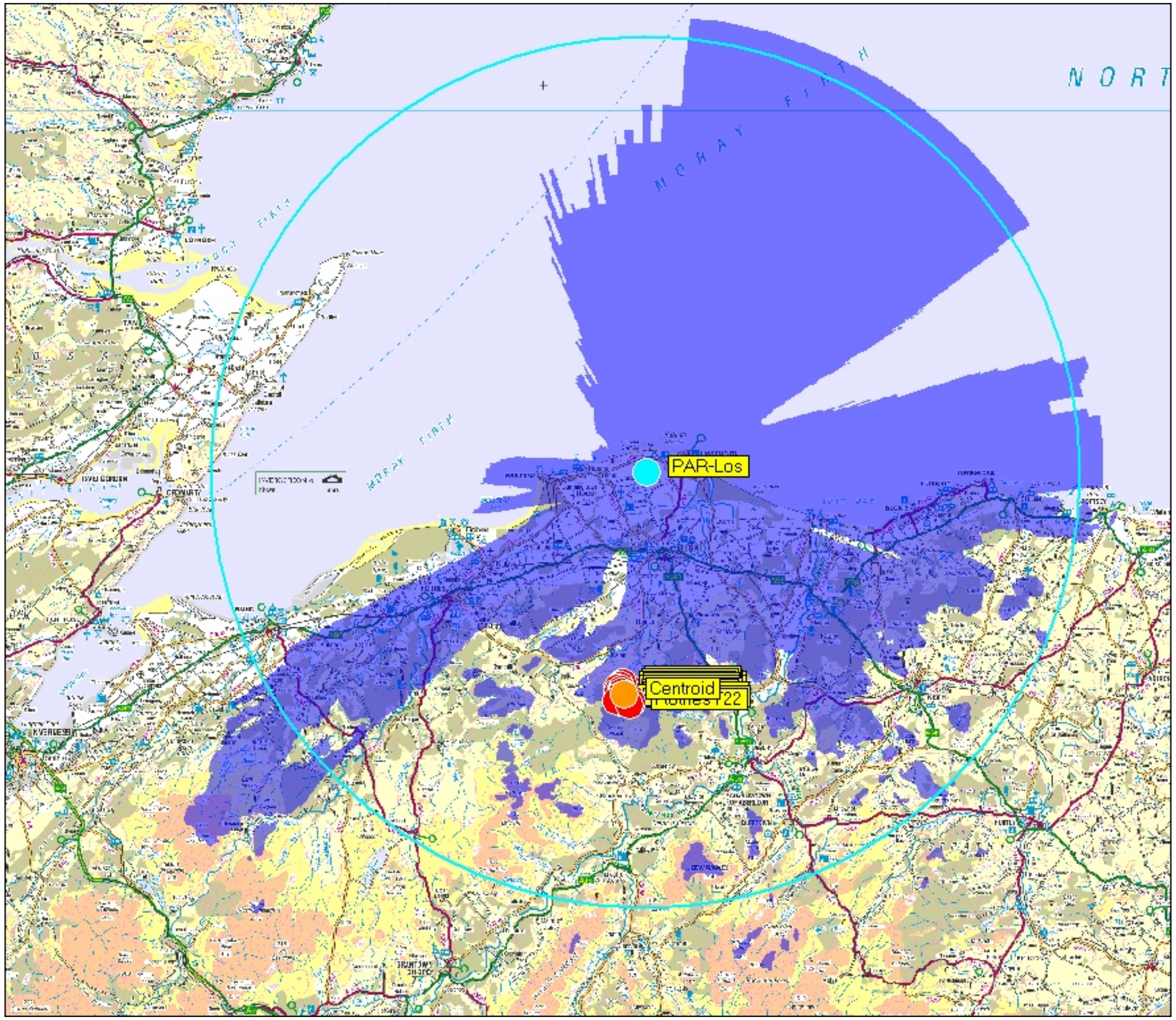

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Figure 3 – Visibility of Rothes Wind Farm Centroid from RAF Lossiemouth PAR

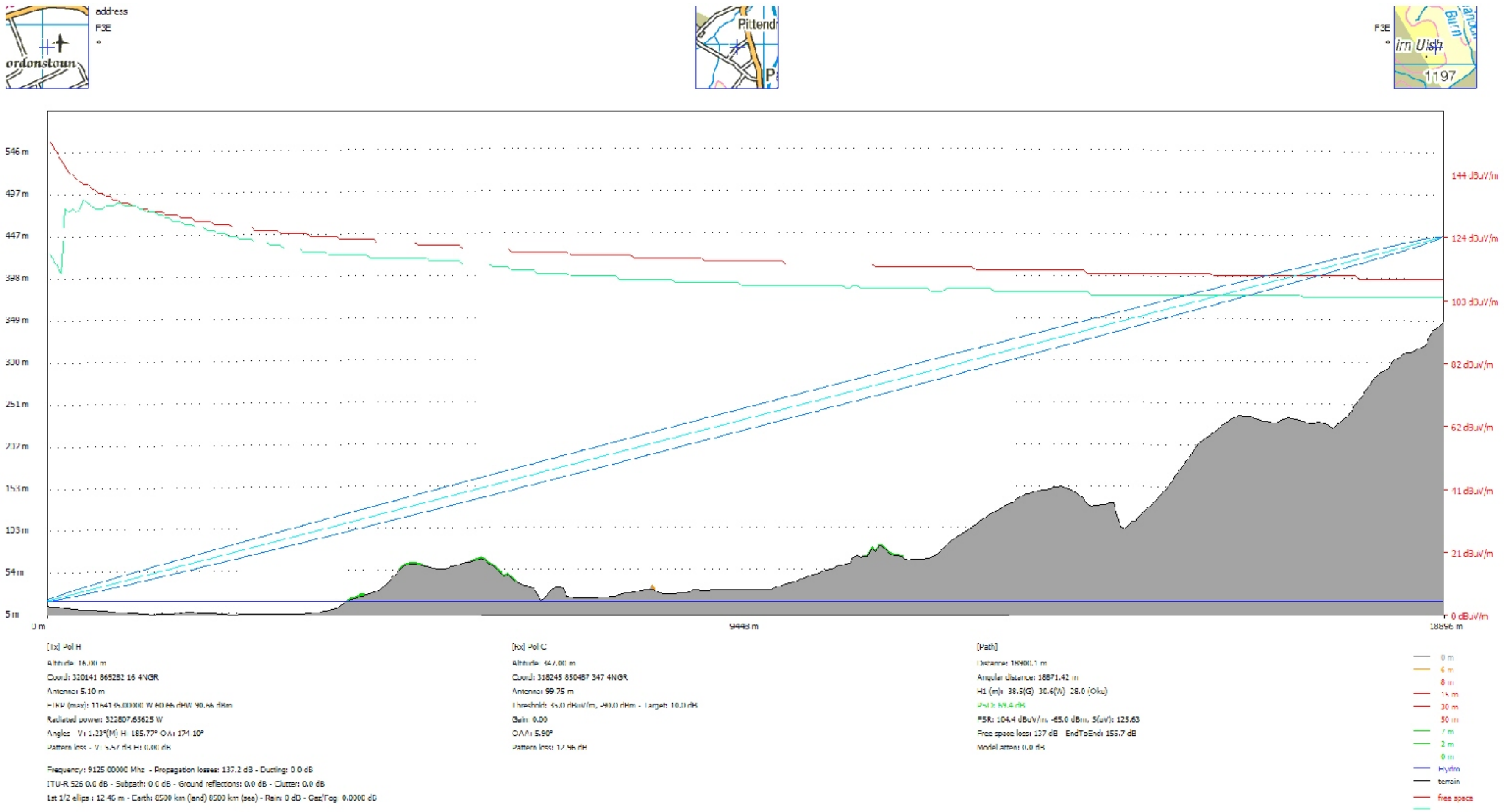

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Table 2: Rothes Wind Farm Centroid CAP 764 - Issue 1 Input and Output Values

	10	20	30	40	50	60	70	80	90	100	Mid Angle (deg)	Fixed RCS (m²)	Single Blade RCS (m²)	Reflected Energy Fixed dBm	Reflected Energy Moving dBm	Visibility (m)
Lossiemouth																
Centroid path loss figures (dB)	137.2	137.2	137.2	137.2	137.2	137.2	137.2	137.2	137.2	137.2		432.77	70.19	-77.56	-80.80	99.75
Sightline angle (deg)	0.95	0.99	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.23	1.08					

Table 3: Summary of CAP764 Centroid Turbine Analysis

RAF Lossiemouth RPAR				
	Static Predicated Signal Strength (dBm)	**Above MDS**	**Moving Predicated Signal Strength (dBm)**	**Above MDS**
Centroid	-77.56	**YES**	-80.80	**YES**

Annex B - Priority Flight Check Report from Cobham Flight Inspection

COBHAM

Checked 7/6/09 VB.

Station	Designator	Date of Report	RPAR ROUTINE FLIGHT CHECK REPORT	
Lossiemouth	EGQS	2 Jun 2009		
Runways	**Radar Type**		**Task No**	
05/23/28	RPAR		5268	
Next Routine Inspection Circa	**Date of Check**	**Wind Conditions**	**Executive Flight Inspector (R)**	**Aircraft Captain**
29-Nov-09	1-Jun-09	030° / 8kts	W Blackledge	Turner
	2-Jun-09	010° / 6kts	**Flight Inspector (R)**	**First Officer**
			B Foster	White
Aircraft Registration	**Aircraft Type**	**Software Version**	**ADFIS S. No.(s)**	
G-FPLB	B200	7.01_07_9b	3	

STATUS **RESTRICTED**

Standing restrictions apply.

ELEVATION WIDTH CHECK — **RUNWAY 05**

CLEAR MODE
Radar cover at 5° left of Centreline. 90% form 19.5nm. No significant losses from 19.5nm. Max Drift 1.9°R.

RAIN MODE
Radar cover at 5° left of Centreline. Solid from 15nm. Max Drift 1.7°R.

CLEAR MODE
Radar cover at 5° right of Centreline. 90% from 18.9nm. No significant losses from 18.9nm. Max Drift 2.5°R.

RAIN MODE
Radar cover at 5° right of Centreline. Solid from 15nm. Max Drift 3.2°R.

RANGE RUN CHECK — **RUNWAY 05**

The range run was flown at 3500ft (QFE) and from 20nm through to touchdown, with Glidepath intercept at approximately 12.9nm. A presentation rate of better than 90% was observed from 19.4nm. Max drift during procedure 3°R.

ELEVATION WIDTH CHECK - REFERENCE OR SECOND RUNWAY — **N/A**

CLEAR MODE
Radar cover at 5° left of Centreline. Max Drift °.

RAIN MODE
Radar cover at 5° left of Centreline. Max Drift °.

CLEAR MODE
Radar cover at 5° right of Centreline. Max Drift °.

RAIN MODE
Radar cover at 5° right of Centreline. Max Drift °.

RANGE RUN CHECK - REFERENCE OR SECOND RUNWAY — **N/A**

The range run was flown at ft (QFE) and from nm through to touchdown, with Glidepath intercept at approximately nm. A presentation rate of better than 90% was observed from nm. Max drift during procedure °.

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RUNWAY | **05** | *Glidepath 2.5 °*

MTI MARKER

AGGREGATED AZIMUTH RESULT	-0.03°	Elevation Range -0.1nm.
AGGREGATED ELEVATION RESULT	-0.04°	Glidepath Deviation 40ft
MINIMUM RADAR COVERAGE	-0.1nm	Azimuth Range -0.1nm.
		Centreline Deviation -462ft

RUNWAY | **23** | *Glidepath 2.5 °*

MTI MARKER

AGGREGATED AZIMUTH RESULT	0.02°	Elevation Range -0.1nm.
AGGREGATED ELEVATION RESULT	0.04°	Glidepath Deviation 30ft
MINIMUM RADAR COVERAGE	-0.2nm	Azimuth Range -0.1nm.
		Centreline Deviation 480ft

RUNWAY | **28** | *Glidepath 2.5 °*

MTI MARKER

AGGREGATED AZIMUTH RESULT	-0.01°	Elevation Range -0.3nm.
AGGREGATED ELEVATION RESULT	0.06°	Glidepath Deviation 84ft
MINIMUM RADAR COVERAGE	-0.5nm	Azimuth Range -0.3nm.
		Centreline Deviation -286ft

RUNWAY | **00**

MTI MARKER

AGGREGATED AZIMUTH RESULT
AGGREGATED ELEVATION RESULT
MINIMUM RADAR COVERAGE

RUNWAY | **00**

MTI MARKER

AGGREGATED AZIMUTH RESULT
AGGREGATED ELEVATION RESULT
MINIMUM RADAR COVERAGE

RUNWAY | **00**

MTI MARKER

AGGREGATED AZIMUTH RESULT
AGGREGATED ELEVATION RESULT
MINIMUM RADAR COVERAGE

NARRATIVE:

This was a priority flight check of the PAR at Lossiemouth following an upgrade modification by ITT. The antennae were calibrated as part of the upgrade so performance checks were only flown on runway 05, the runway used to provide reference information at this location. Prior to this flight check a new survey of the site was carried out by CAvS in order to site the tracker point close to the RPAR instead of at the old TACAN site as had been the case in the past.

Two sighting accuracy runs were carried out, one to each of runways 05 and 23, but the data that was gathered was difficult to decipher, a taste of what was to come, and further three runs were carried out before enough reliable information was gathered to give confidence that the adjustments that would be carried out would be appropriate. A -0.04° ARP change was made and accuracy runs to runway 23 carried out immediately following the adjustment. Runs 6 - 9 were not acceptable both because the radar was indicating larger than expected results and, there were not enough hits recorded in too many segments to be able to make these runs valid. The ITT engineer put forward a theory that the poor results may be, in part, because of the new tracker point - he voiced reservations about changing such a vital element of the check prior to a calibration of the antennae and suggested that this might not provide the most stable set of results. Also, the question was raised as to whether the pilot was actually taking the turns that were requested by the FI(R) - this proved to be a valid question as later in the check the Captain admitted that he was avoiding making changes because, from his perspective, even a slight change of aspect of the aircraft would elicit a command from the FI(R) to turn the aircraft back to where it had come from. *A phenomenon known about and discussed in JSP 552(405.135.2).* From the point of view of the ITT engineer the pilots should have been turning in accord with the instructions from the FI(R) so that the correct error profiles could be considered rather than have the pilot deciding what the best solution was. From the position of the FIs on the ground, the radar appeared to be unstable; there were occasions where the pilots gave their assurance that the flying course was reasonably stable, remaining visually on one side of the true runway centreline and varying only a few feet from it but, at the same time, the radar indicated the aircraft moving to the opposite side of the centreline by some distance - certainly enough, and probably more than would normally elicit a turn instruction to correct from the FI(R). Such a turn would undoubtedly have moved the aircraft away from the runway centreline, in the wrong direction, and probably then away from the PAR course line, rapidly and in the wrong direction. The pilot's were asked to always take the corrections requested by the FI(R) but admittedly did not always do so. Checking of runway 23 was put on hold and runway 05 accuracy runs attempted.

Using the new tracker point, the azimuth and elevation runs on runway 05 were completed satisfactorily then the azimuth accuracy runs on runway 23 were tried again. Three unsuccessful runs were attempted before the FI(R) decided to observe the radar without offering any corrections - the pilots followed the FIS guidance. Results were inconclusive so the elevation accuracy runs on runway 23 were attempted and completed. Another, single azimuth run on runway 23 was tried but without success for the same reasons as outlined above. The flying crew indicated very clearly that they had no wish to continue and the ITT engineer petitioned for a move of tracker point back to the old position at the TACAN. Flying stopped for the day. The LFI(R), one of the FIs on this task, was very content that the new tracker point seemed to be working well and the pilots were able to validate the FIS in a general sense by confirming that the FIS was indicating "on course" for the visual extended centreline from several miles to the point where the run was completed at 0.5nm. Whilst happy to oblige the ITT engineer with a change of tracker position, the LFI(R) was not convinced that the root cause of the problem lay with the CAvS Survey/Tracker/FIS systems.

The following day flying recommenced with the tracker at the tracking position at the old TACAN site. The angular results of runs 30 and 31 were acceptable but the results were still marred by a lack of hits in some segments - the pilots were still complaining that tiny movements on their part caused immediate reversal corrections from the ground and once again they admitted to not taking the corrections that were requested because of this. Throughout, the results achieved within the segment 1nm - 0.5nm were the ones that gave most concern. Up to this point the FI(R) had been "tagging" the aircraft return as per normal ATC procedure (JSP 552 405.135.4 - copy attached) but at this point the LFI(R) decided not to tag the aircraft return; this was done because the deviation figures indicated on the label were distracting. The other FI(R) present and ITT engineer agreed that it would be an acceptable way of continuing with the check. Without the distraction of the label's deviation from centreline information and using only the radar return (white dot) the perception of the LFI(R) was that radar seemed much more stable, especially towards the end of the run where we had previously had problems. Three runs with good angular averages and a goodly number of hits were completed in short order. None of the instability associated with the previous runs (especially in the last half mile) was experienced. TB3b was contacted and after a short explanation he was happy to allow the results achieved to be used. Runway 23 azimuth and both azimuth and elevation accuracy runs on runway 28 were completed without drama although the elevation results on runway 28 were slightly high. *(To avoid unnecessary flying an adjustment was not considered appropriate here at this time because the results were within the allowable tolerances and on the safe side. At the next flight check, if the results are similar an adjustment should be considered.)*

To try to examine whether the use of the new tracker point had an effect on the results, a single tracked azimuth accuracy run on both runways 23 and 28 was carried out once the remainder of the Priority check was complete and the tracker was positioned back at the RPAR tracking position. Using the "label off" method the results were good and not dissimilar to those achieved using the tracker point at the old TACAN site. Results of these runs can be seen as runs A1 and A2.

Performance checks were carried out and, fortunately, were as expected. Two part orbits and an elevation coverage check were carried out to give base line information in preparation for the RPAR trial that was to follow the Priority check. Results of both of these checks were satisfactory.

This flight check has thrown up several questions that will need to be answered after all of the facts have been considered. The Cobham LFI(R) will write to ADATS DT separately to explain his actions and considerations. All future PAR flight checks at Lossiemouth are expected to use the tracking position at the RPAR for all runways.

Flight Inspector: W Blackledge/ B Foster

The Flight Check of the above facility was carried out in accordance with procedure CFI.P.09-12a.

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ANNEX C to
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Annex C - Investigation Team Personnel

Name	Post & Company	Experience
Mr. Jonathan Cashmore	TB3c, ADATS DT, MoD	≈5 years flight trials and radars systems experience including wind farm assessments and mitigations.
Mr. Lee Ashton	Radar Systems Subject matter expert with Mepward Ltd.	30 years experience in ATC radar system and flight trials. Mr Ashton is retained by the ADATS DT to provide specialist advice on radar systems and is considered an expert in the field.
Flt. Lt. Daniel Gill	ASM Team Leader, Operational Evaluation Unit, 56 Sqn(R)	Flt. Lt. Gill is Air Traffic Control Officer (ATCO) with 10 years experience in military air traffic services and is currently qualified on all ATC equipments. He is currently carrying out a tour in the RAF's Operational Evaluation Unit. He has held the position of both Local Examining Officer and DSATCO on his last tour.
Mr. Gary Gibb	ITT Defence Ltd, Senior Contractor Logistical Support/Field Service Engineer	Mr Gibb has spent 6 years working for ITT in his current position, preceded by 2 years with BAES and 14 years as a radar technician with the RAF
Mr. Benjamin Patterson	Apprentice, MoD	None

Mr Bill Blackledge	Senior Flight Inspector, Cobham Flight Inspection	Mr. Blackledge has worked for Cobham Flight Inspection since 1997 and has been a Senior Flight Inspector for the past 5-6 years. Before joining Cobham Mr. Blackledge was ATCO with the RAF.
Mr Barry Foster	Flight Inspector, Cobham Flight Inspection	Mr Foster is a former ATCO with 32 years experience in Air Traffic Control. In 2004, Mr. Foster left the RAF to join Cobham as a flight inspector.

Annex D - Investigation Narrative & Data Inventory

Nomenclature:

El is Elevation
Az is Azimuth
NI is No Information presented to the user.
WFC is Wind Farm Centre, (bearing 186.77° (GRID)).
TS is Track Seduction
TL is Target Loss
TOO Target of Opportunity

Sortie 1 - 02/06/2009

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
1	1	FL 030 Coverage	El: None, Az: 10.6-9.5nmi	TL	20090602-Run1-Serial1.avi
2	3	FL 050 Coverage	El: None, Az: 10.5-9.4nmi	TS & TL	20090602-Run2-Serial3.avi
3	4	FL 070 Coverage	El: None, Az: 10.5-9.6nmi	TS & TL.	20090602-Run3-Serial4.avi
4	9	2.5° Approach	El: None, Az: 10.5-9.8nmi	TS & TL.	20090602-Run4-Serial9.avi

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Sortie 2 - 02/06/2009

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
5	2	FL 020	El: 10.8-10.0nmi, Az: 10.6-9.6nmi	TS, TS & TL	20090602-Run5-Serial2.avi
6	5	Part Orbit @ 10.1, CCW	El: NI Az: -2.5° to +6°	No elevation information. TL and it took 3 seconds to reinitiate a track	20090602-Run6-Serial5.avi
7	6	Part Orbit @ 10.1, CW	El: NI Az: +2.5° to -16°	No elevation information. TL and it took 3 seconds to reinitiate a track	20090602-Run7-Serial6.avi
8	7	Part Orbit @ 13.2, CCW	El: NI Az: No Effect	-	20090602-Run8-Serial7.avi
9	8	Part Orbit @ 13.1, CW	El: NI Az: No Effect	-	20090602-Run9-Serial8.avi
10	10	5° LEFT	El: No Effect, Az: No Effect	-	20090602-Run10-Serial10.avi
11	11	5° LEFT	El: No Effect, Az: No Effect	-	20090602-Run11-Serial11.avi
12	12	5° RIGHT	El: No Effect, Az: No Effect	-	20090602-Run12-Serial12.avi

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
13	13	5° RIGHT	El: No Effect, Az: No Effect	-	20090602-Run13-Serial13.avi
14	14	FL 020	El: No Effect, Az: 10.5-9.6nmi	-	20090602-Run14-Serial14.avi
15	15	2.4° West of WFC @ FL020	El: No Effect, Az: 10.5-10.0nmi	TS	20090602-Run15-2.4degree west-Serial15.avi
16	15	2.4° West of WFC @ FL020	El: 10.4-9.7 Az: 9.8-9.4nmi	TS	20090602-Run16-1.6degree west-Serial15.avi
17	15	2.4° West of WFC @ FL020	El: 10.2-9.6, Az: 10.5-9.6nmi	TS & TL	20090602-Run17-1.6degree east-Serial15.avi
18	15	2.4° East of WFC @ FL020	El: 10.1-10.3nmi, Az: 10.5-9.8nmi	TS & TL	20090602-Run18-2.4degree east-Serial15.avi

Observations after completion of Sortie 1 & 2

- It would appear that effects are symmetrical so repeating measurements both right and left of the centre line is nugatory.
- There is no effect outside of ±5° of the centre line of the wind turbine development.
- The radial effects seem to be between 10.7 and 9.4nmi.
- The elevation effects are not as pronounced as the azimuth effects.

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Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
19	16	2.5° Glide Slope	El: None, Az: 10.6-9.5nmi	TS & TL	20090603-Run19-Serial16.avi
20	16	2.5° Glide Slope	El: None, Az: 10.5-9.7nmi	TS & TL	20090603-Run20-Serial16.avi
21	16	2.5° Glide Slope	El: None, Az: 10.4-9.6nmi	TS & TL	20090603-Run21-Serial16.avi
22	17	3.0° Glide Slope	El: None, Az: 10.5-9.5nmi	TS & TL	20090603-Run22-Serial17.avi
23	17	3.0° Glide Slope	El: None, Az: 10.7-9.7nmi	TS & TL	20090603-Run23-Serial17.avi

PAR aligned to have a +2° Offset from WFC

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
24	18	2.5° Glide Slope, Fly Offset	El: None, Az: 10.4-9.5nmi	TS	20090603-Run24-Serial18-2degree offset.avi
25	18	2.5° Glide Slope, Fly Offset	El: None, Az: 10.4-9.5nmi	TS & TL	20090603-Run25-Serial18-2degree offset.avi
26	19	3.0° Glide Slope, Fly Offset	El: None, Az: 10.6-9.9nmi	TS & TL	20090603-Run26-Serial19-2degree offset.avi
27	19	3.0° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.5-9.5nmi	TS & TL	20090603-Run27-Serial19-2degree offset.avi

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
28	20	2.5° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.5-9.6nmi	TS & TL	20090603-Run28-Serial20-2degree offset.avi
29	20	2.5° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.7-9.5nmi	TS & TL	20090603-Run29-Serial20-2degree offset.avi
30	21	3.0° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.4-9.9nmi	TS & TL	20090603-Run30-Serial21-2degree offset.avi
31	21	3.0° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.4-9.5nmi	TS & TL	20090603-Run31-Serial21-2degree offset.avi

PAR aligned to have a +4° Offset from WFC

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
32	22	2.5° Glide Slope, Fly Offset	El: None, Az: 10.5-9.5nmi	TS & TL	20090603-Run32-Serial22-4degree offset.avi
33	22	2.5° Glide Slope, Fly Offset	El: None, Az: 10.6-9.5nmi	TS & TL	20090603-Run33-Serial22-4degree offset.avi
34	23	3.0° Glide Slope, Fly Offset	El: None, Az: 10.7-9.6nmi	TS & TL	20090603-Run34-Serial23-4degree offset.avi

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Run	Serial	Description	Interference Effects	Comments	Associated AVI File
35	23	3.0° Glide Slope, Fly Offset	El: None, Az: 10.7-9.3nmi	TS & TL	20090603-Run35-Serial23-4degree offset.avi
36	24	2.5° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.3-10.1nmi	TS & TL	20090603-Run36-Serial24-4degree offset.avi
37	24	2.5° Glide Slope, Fly PAR Centre Line	El: None, Az: None	TS & TL	20090603-Run37-Serial24-4degree offset.avi
38A	TOO	Over-fly right edge of wind farm	El: 10.5-11.1nmi, Az: 9.5-11.5nmi	TL & TS Anomalous result. IGNORE. King Air rear RCS may be smaller.	20090603-Run38A-extra run east edge.avi
38	24	2.5° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.6-10.4nmi	TS & TL	20090603-Run38-Serial24-4degree offset.avi
39A	TOO	Over-fly left edge of wind farm	El: 9.6-10.7nmi, Az: 9.5-10.7nmi	TL & TS Anomalous result. IGNORE. King Air rear RCS may be smaller.	20090603-Run39A-extra run west edge.avi
39	25	3.0° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.4-10.0nmi	TS & TL	20090603-Run39-Serial25-4degree offset.avi

40	25	3.0° Glide Slope, Fly PAR Centre Line	El: None, Az: 10.4-10.0nmi	TS & TL	20090603-Run40-Serial25-4degree offset.avi

PAR aligned to WFC

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
41	26	Part orbit @ 9.5, CCW	El: NI, Az: None.		20090603-Run41-Serial26.avi
42	27	Part orbit @ 9.5, CW	El: NI, Az: None.		20090603-Run42-Serial27.avi
43	28	Part orbit @ 9.75, CCW	El: NI, Az: -3900-+7500ft.	TS & TL	20090603-Run43-Serial28.avi
44	29	Part orbit @ 9.75, CW	El: NI, Az: +0000—4000ft.	TS & TL	20090603-Run44-Serial29.avi
45	30	Part orbit @ 10.25, CCW	El: NI, Az: -1000-+5000ft.	TS & TL	20090603-Run45-Serial30.avi
46	31	Part orbit @ 10.25, CW	El: NI, Az: +2000->8000ft.	TS & TL	20090603-Run46-Serial31.avi
47	32	Part orbit @ 10.5, CCW	El: NI, Az: -3400ft-6000ft.	TS & TL	20090603-Run47-Serial32.avi
48	33	Part orbit @ 10.5, CW	El: NI, Az: +5000--4000ft.	TS & TL	20090603-Run48-Serial33.avi
49	32	Part orbit @ 10.5, CCW	El: NI, Az: -3000ft +6000ft.	TS & TL	20090603-Run49-Serial32.avi
50	33	Part orbit @ 10.5, CW	El: NI, Az: +4200ft - -3000ft.	TS & TL	20090603-Run50-Serial33.avi
51	34	Slow Tangent	El: NI, Az: -2500ft - +6000ft.	TS & TL	20090603-Run51-Serial34.avi
52	35	Fast Tangent	El: NI, Az: -2500ft to +6000ft.	TS & TL	20090603-Run52-Serial35.avi

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PAR in Rain Mode (Runs 53-60)

Run	Serial	Description	Beam Interference Effects	Comments	Associated AVI File
53	36	2.5° Glide Slope	El: None, Az: 10.5 to 9.5nmi	TS & TL	20090603-Run53-Serial36.avi
54	36	2.5° Glide Slope	El: None, Az: 10.6 to 9.7nmi	TS & TL	20090603-Run54-Serial36.avi
55	37	3.0° Glide Slope	El: None, Az: 10.6 to 9.6nmi	TS & TL	20090603-Run55-Serial37.avi
56	37	3.0° Glide Slope	El: None, Az: 10.5 to 9.4nmi	TS & TL	20090603-Run56-Serial37.avi
57	38	Part Orbit @ 9.75, CCW	El: NI, Az: -2500ft - +6000ft.	TS & TL	20090603-Run57-Serial38.avi
58	39	Part Orbit @ 9.75, CW	El: NI, Az: -2500ft - +6000ft.	TS & TL	20090603-Run58-Serial39.avi
59	40	Slow Tangent	El: NI, Az: -2500ft - +6000ft.	TS & TL	20090603-Run59-Serial40.avi
60	41	Fast Tangent	El: NI, Az: -2500ft - +6000ft.	TS & TL	20090603-Run60-Serial41.avi

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Illustrative Demos

Run	**Serial**	**Description**	**Beam Interference Effects**	**Comments**	**Associated AVI File**
61	Scenario 1	Target flies wide of wind farm when funnelling onto glide slope	None	TS & TL	20090603-Run61-Senario1.avi
62	Scenario 2	Target flies close to but not over of wind farm when funnelling onto glide slope	None	TS & TL	20090603-Run62-Senario2.avi
63	Scenario 2	Target flies close to but not over of wind farm when funnelling onto glide slope	None	TS & TL	20090603-Run63-Senario2.avi
64	Scenario 3	Target flies too close to wind farm when funnelling onto glide slope	El: None, Az: 10.5-9.5nmi	TS & TL	20090603-Run64-Senario3.avi