Ministry of Defence

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Our Ref: FOI2017/07160

[redacted]

28 July 2017

Dear [redacted]

Thank you for your email of 18 July 2017 requesting a copy of the trial report of Trial Bellowing Denims Stage 2.

I am treating your correspondence as a request for information under the Freedom of Information Act 2000 (FOIA).

I am writing to confirm that MOD holds the information on the subject you have requested. A copy of the report you requested is attached.

Under Section 16 of the Act (Advice and Assistance) you may find it helpful to note that the acronym TMO used in the report stands for Trials Management Officer.

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Yours sincerely

[redacted]
Air Command Secretariat

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Published by

Development Division

TRIAL REPORT
TRIAL BELLOWING DENIMS
STAGE 2

Air Warfare Centre

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TRIAL REPORT

TRIAL BELLOWING DENIMS STAGE 2

An assessment to provide evidence of the impact of Wind Farms (WF) on the performance of the RAF Spadeadam Electronic Warfare (EW) threat radars.

EXECUTIVE SUMMARY

1. **Background.** The AWC conducted Trial BELLOWING DENIMS (BD) Stage 2 in order to gain further evidence as to the effects of WF on representative threat radars operated by RAF Spadeadam's EW Training Facility (EWTF). The extent of obscuration of ac tgts, variation in impact for representative ac and operator workload were assessed to provide guidance to HQ AIR EW Trg.

2. **Trial details.** The Trial was conducted by 56(R) Sqn personnel using deployed EW threat radars from RAF Spadeadam; Lynx, Hawk, and Andover ac were flown over the Robin Rigg WF in support of the Trial.

3. **Trial results.** The presence of the WF caused acquisition or tracking loss during 88% of the runs. During only 6% of sortie runs was it possible to maintain acquisition or tracking over the WF. During the remaining 6% of runs, losses were non-WF attributable. The presence of the WF not only caused a reduction in the ability of Spadeadam threat systems to acquire and lock onto tgts in the airspace above the WF, but also impacted the performance of trialled threat systems beyond the WF boundary. Furthermore, once tgts had been lost, reacquisition or lock onto an emerging tgt could require distances in excess of 19 km from the WF boundary. Performance of the radars against the different types of ac used varied; performance against low Radar Cross Section (RCS) and high-speed tgts was the most significantly degraded. Operator workload increased when the ac were in the vicinity of the WF and mitigation techniques were not sufficient to overcome the effects of the presence of the WF.

4. **Conclusions and recommendations.** The trial objectives were fully satisfied. The presence of Robin Rigg WF significantly reduced the ability of representative EW radars to acquire, establish and maintain lock on tgts operating in the airspace above and adjacent to the WF. As there is no clear evidence of a change in performance when the tgt height varied, further work would be required to assess the impact on ac operating above 1200 ft. Profiles used during this Trial were predictable and repetitive; it is assessed that the performance of the radars would further deteriorate in the presence of manoeuvring ac. On the basis of these results, it is recommended that, until mitigation can be identified, HQ AIR EW Trg should consider the implications of these results on EW trg when framing their response to future WF planning applications.

TRIAL REPORT

TRIAL BELLOWING DENIMS STAGE 2

Introduction

5. **Background.** HQ AIR EW Trg, tasked the AWC[1] to conduct a follow-on task from Trial BD Stage 1 in order to gather further evidence as to the effects of WF on representative threat radars operated by RAF Spadeadam's EWTF. 56(R) Sqn's Air Battlespace Management Test and Evaluation Flight undertook Trial BD Stage 2 in accordance with the TI[2] over the period 27 Jun – 1 Jul 11 at RAF Spadeadam, Robin Rigg WF and 2 coastal deployed locations that were situated within 20 km of the WF.

6. **Aim.** The aim of Trial BD Stage 2 was to assess the effect of WF on representative threat radars operated by RAF Spadeadam.

7. **Objectives.** The objectives of Trial BD Stage 2 were as follows:

a. **Objective 1.** For each threat radar provided, observe and determine the effects that WF have in terms of: the extent of obscuration of tgts, increase in workload of the radar operator(s) and variation in impact on representative ac.

b. **Objective 2.** To provide guidance to HQ AIR EW Trg on the impact of WF on selected threat radars used at RAF Spadeadam.

Trial conduct

8. **Eqpt under test.** EWTF Spadeadam uses a variety of eqpt to provide aircrew with a realistic hostile electronic environment, including Surface to Air Missile (SAM) systems, emulators and simulators. The threat systems chosen for the Trial, selected to represent eqpt that is frequently utilised at the EWTF, were as follows:

a. SA-6 'Gainful' medium to high altitude SAM system which incorporates the 'Straight Flush' radar and command guidance system.

b. SA-8 'Gecko' low to medium level SAM system which incorporates the 'Land Roll' radar and guidance system.

c. The T43 v4 emulator which provides signals that emulate the SA-8.

d. The Oerlikon Skyguard system.

9. **Radars under test.** For each participating threat system, the following elements were tested:

a. Target Acquisition Radar (TAR) of the SA-6 'Straight Flush', SA-8 'Land Roll' and Oerlikon Skyguard[3].

b. Target Tracking Radar (TTR) of the SA-6 'Straight Flush', SA-8 'Land Roll', Oerlikon Skyguard and T43 v4 Emulator.

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[1] 20110503-BD2_TIF-U (I 076/11).
[2] 20110616-BELLOWING_DENIMS_St2_TI-R.
[3] Skyguard TAR and TTR operate concurrently. For the purposes of this Trial, tgt acquisition and tracking were effectively simultaneous.

10. **Trial method.** Following recommendations from Trial BD Stage 1[4], this Trial was designed as follows:

a. **Eqpt configuration.** The threat radars were configured for normal daily use, with onward data transmission into the Spadeadam Integrated Command, Control and Communications System (SPICCCS) enabled.

b. **Eqpt and WF locations.** Robin Rigg WF, located in the Solway Firth, consists of 60 wind turbines and was chosen for Trial BD Stage 2 due to low levels of terrain clutter in its vicinity. The threat systems were deployed to 2 coastal farmland sites with direct line of sight to the Robin Rigg WF, as shown in Figure 1. Exact locations of the turbines are illustrated at Annex A.

c. **Participating ac.** A single 667(Development and Test) Sqn Army Air Corps Lynx, a 100 Sqn Hawk and a 206(Reserve) Sqn Andover were selected to provide a broad spectrum of representative tgt types varying in both speed and RCS. The TMO conducted face-to-face briefings with the crews of all 3 ac types prior to the start of the Trial. Sorties were flown over the period 28-30 Jun 11.

d. **Data recording.** The TMO was located at Range Control, RAF Spadeadam. Other trial personnel were located in each of the trialled threat systems to ensure that the following data was collected:

(1) **Radar and optical displays.** TAR (where applicable) and TTR data was recorded by videoing the Plan Position Indicator and A-trace displays respectively.

(2) **Automatic data gathering.** Tracking data from the Skyguard together with threat scenario and Secondary Surveillance Radar (SSR) data from SPICCCS were recorded on organic data recorders.

(3) **Voice recording.** Microphones on the video cameras were used to record voice communications between operators throughout the Trial.

(4) **Manual data recording.** Trial personnel maintained a written log of events throughout the Trial and ensured that, after each run, questionnaires were completed in consultation with the eqpt operators.

(5) **Recording synchronisation.** Each threat system was fitted with a GPS timing device to enable recording synchronisation to be achieved during post trial analysis.

e. **Sortie profiles.** Sortie profiles were designed to ensure that acquisition, lock and loss of lock data could be gathered. The heights of the profiles were based on theoretical analysis of the emitters' capabilities and the results of previous trials that investigated the impact of WF on the performance of air defence radars. The lengths of the profiles were designed to allow 1 min of flight in airspace clear of the WF at the beginning and end of each run. This 1 min period ensured that operators were given sufficient time to lock on to the ac before it entered the airspace above the WF.

(1) Reference runs for the Lynx were conducted on a bearing of 050°/230° overhead the WF and between 700 ft and 2000 ft. These runs were designed to gather data to confirm that main trial runs had been set at appropriate heights.

[4] 20101118-BELLOWING DENIMS AL1 TR-U.

(2) Reference runs for the Hawk and Andover ac were conducted in clear airspace in between the WF and the threat system locations and provided control data. These reference runs were conducted on a bearing of 040°/220°.

(3) The main trial runs are considered as those runs that took place overhead the WF and in the airspace directly adjacent to the WF. These runs were flown on a bearing of 070°/250° and at heights of 700 ft, 950 ft and 1200 ft.

(4) The first leg of a main trial run (flown on a bearing of 250°) is considered as the outbound leg. The second leg of a main trial run (flown on a bearing of 070°) is considered as the inbound leg.

Details of sortie profiles, including heights, can be found at Annex B.

11. **Trial constraints.** The following constraints were experienced during the Trial:

a. **Timing.** GPS clocks were used in each system to provide a common time reference to allow data from all systems to be directly compared. Due to the light conditions in the eqpt, the GPS clock screens were not always clearly displayed on the video recordings. Whilst some data was unrecoverable, post event analysis was able to extrapolate timing information from known points in time and thus, despite some information being lost, this was not considered to be detrimental to the overall trial results.

b. **Health and safety restrictions.** Due to the excessive noise and vibrations that personnel are exposed to within the trialled threat systems, it is regulated that no individual can spend more than one hour at a time within the eqpt. That individual must then have a minimum of one hour away from that environment before being allowed entry again. This regulation imposed strict limitations on the design and conduct of the Trial.

Trial results

12. **Sorties flown.** Each ac type flew 3 serials as directed in the TI[5]; however, during several sorties it was apparent that the ac would not be able to complete the planned number of legs within the ground eqpts' rigid 1 hr health and safety time window. The TMO therefore authorised a reduction in the number of legs as appropriate. Additionally, the TMO authorised a change in the levels at which the legs were conducted iaw the TI.

13. **Weather conditions.** Weather conditions throughout the Trial were favourable with light winds and no low-level cloud. A summary of the met data gathered from the Dundrennan weather station throughout the Trial is at Annex C.

14. **Turbine serviceability.** Visual observations of the WF using the threat system optics and by trial ac crews confirmed that typically 6-7 turbines were stationary during the trial sorties. This figure was deemed to not have a significant impact on the outcome of the Trial, as over 50 turbines were typically active.

15. **Eqpt serviceability.** The threat radar systems under test generally maintained a high level of serviceability. The following discrepancies were noted during the Trial:

a. The SA-6 TTR was not operational for any of the serials flown by the Andover.

[5] 20110616-BELLOWING_DENIMS_St2_TI-R.

b. Throughout the Trial, several other pieces of eqpt suffered from short periods of unserviceability. This included visual and sound recording eqpt, radar processing functionality and threat system optical equipment (cameras).

c. SPICCCS is used by the eqpt operators as an aid to locating tgts through the use of SSR data. The availability of SPICCCS data to the SA-6 and SA-8 was reduced during several serials. This impeded both the ability of the operators to detect tgts (due to lack of cueing from SSR positional data) and prevented the electronic logging of events. However, the lack of SPICCCS data did not prevent operators from acquiring or tracking tgts, nor did it prevent manual event logging.

16. **Methods of analysis.** Data from video, audio, manual and automatic recordings was collated. The times at which tracking and acquisition were lost and subsequently regained were extracted and cross-referenced with GPS data for each sortie. The reason for loss of lock was further broken down into WF and non-WF related losses. It was therefore possible to produce graphical illustrations of how the acquisition and lock performance for each system was impacted in the vicinity of the WF. When eqpt was unserviceable, or it was not possible to accurately correlate video, audio, manual and automatic recordings, data was not included in the analysis. 21% of main trial runs were affected by data loss, however it is assessed that this had no detrimental effect on the overall findings of the Trial.

17. The area of the WF was taken as the geographical area formed by a line between the centre point of each of the outer-most turbines, illustrated at Annex A. As it was not possible to ensure that each ac entered the WF overhead at exactly the same point on each run, the distance at which acquisition or lock was lost or regained was calculated relative to the distance from the nominal outer boundary of the WF. Where eqpt maintained lock throughout a run, no plot was recorded and the run was recorded as 'lock maintained over WF'. Figure 1 illustrates the geographical area covered by Robin Rigg WF with the ac route overlaid, (as recorded by GPS, taken from the first Hawk serial), together with the threat system locations.

Figure 1 - Geographical overview of BD Stage 2 Trial area[6]

[6] Red arcs indicate the approximate constant range rings from the two threat system locations to the far boundary of the WF.

Results

18. Table 1 contains a summary of the trial results, which are presented in more detail at Annex D. Figure 2 sets out trial data in a graphical format and shows the distance from the boundary of the WF at which loss of lock and subsequent reacquisition or lock was achieved. Analysis of this data has shown that the presence of the WF caused acquisition or tracking to be lost during 88% of the legs flown. Only during 6% of the legs was it possible to maintain acquisition or tracking over the WF and the remaining 6% of losses were attributed to non-WF reasons, including terrain masking, surface clutter and range from the eqpt.

19. The presence of the WF caused a reduction in the ability of the threat radars to acquire and track tgts in the immediate vicinity of the wind turbines (onset of loss occurred from up to 2 km outside the WF boundary). Additionally, once tgts had been lost, the reacquisition or lock of a tgt emerging from the WF could require distances in excess of 19 km from the boundary of the WF.

A/C	System	Target lost to WF	Maintained over WF	Non-WF losses	Distance acquired/ locked onto from WF boundary (km)			Acquired by end of inbound leg
		%	%	%	Min	Median	Max	%
Lynx	SA6 TAR	76%	24%	-	-1.3	0.0	1.3	100%
	SA6 TTR	91%	-	9%	0.8	2.0	6.8	100%
	SA8 TAR	88%	-	13%	0.6	2.0	3.6	100%
	SA8 TTR	86%	-	12%	1.0	1.8	5.5	100%
	T43	100%	-	-	-0.6	1.2	6.6	100%
	Skyguard	90	-	10%	1.3	1.6	2.9	100%
Hawk	SA6 TAR	94%	3%	3%	0.2	1.2	13.5	100%
	SA6 TTR	96%	-	4%	2.8	4.9	13.5	100%
	SA8 TAR	90%	-	10%	1.9	6.1	18.6	100%
	SA8 TTR	88%	-	13%	7.8	11.8	>19.1[7]	89%
	T43	92%	-	7%	1.1	5.1	17.5	100%
	Skyguard	68%	-	32%	0.7	1.7	2.8	100%
Andover	SA6 TAR	94%	6%	-	-0.3	0.7	4.3	100%
	SA6 TTR[8]	-	-	-	-	-	-	-
	SA8 TAR	64%	30%	4%	-0.4	1.7	8.8	100%
	SA8 TTR	78%	22%	-	1.3	2.3	8.8	100%
	T43	100%	-	-	0.7	1.8	10.1	100%
	Skyguard	83%	-	17%	0.2	0.7	1.9	100%
Overall		88%	6%	6%	-1.3	1.6	>19.1	99.5%

Table 1 - Summary trial data

Results by ac type

20. Ac types for the Trial were chosen to be representative of the ac types that routinely use RAF Spadeadam's EWTF. During the main trial runs, the ability of all systems to acquire, lock onto and maintain lock on tgts was reduced in the area surrounding and overhead the WF, irrespective of ac type.

[7] For 1 return leg the SA8 TTR did not lock onto the tgt prior to the end of the run.
[8] No SA-6 TTR data was available for the Andover runs due to eqpt unserviceability.

21. When loss of lock is considered (Figure 2, left hand side charts), it can be seen that all systems experienced WF related losses when the ac was in the vicinity of the WF boundary. The Lynx and Hawk runs indicated that when loss of lock occurred, it did so overhead the wind turbines. For the Andover, the length of time that the ac could be tracked when entering the WF environment increased. This can be directly attributed to the larger RCS of the Andover when compared to both other trial ac and this is further illustrated by the fact that on 15 occasions the SA-6 and SA-8 were able to maintain acquisition or lock throughout a leg. When loss of lock did occur, it did so up to 4.5 km inside the boundary of the WF.

22. The variety of ac type also resulted in a difference in the ability of individual systems to acquire and/or lock onto targets. From Figure 2 (right hand side charts) it is clear that the ability of a system to acquire and track a relatively fast (360 kts) and small RCS (approx 1 m^2) Hawk ac was significantly reduced when compared with the Andover and Lynx. The only exception to this was the Skyguard, which was consistently able to relock onto targets within 3 km from the exit boundary of the WF. Once the tgt had been lost, acquisition or lock of a tgt emerging from the WF could require much larger distances; for the T43, SA-8 and SA-6 systems it took between 13 km and 19 km for the Hawk to be locked onto once the ac had left the airspace over the WF. This compares with maximum distances of between 5.5 km and 7 km for the Lynx and 8.5 km and 10 km for the Andover[9].

[9] No SA-6 TTR data was available for the Andover runs due to eqpt unserviceability.

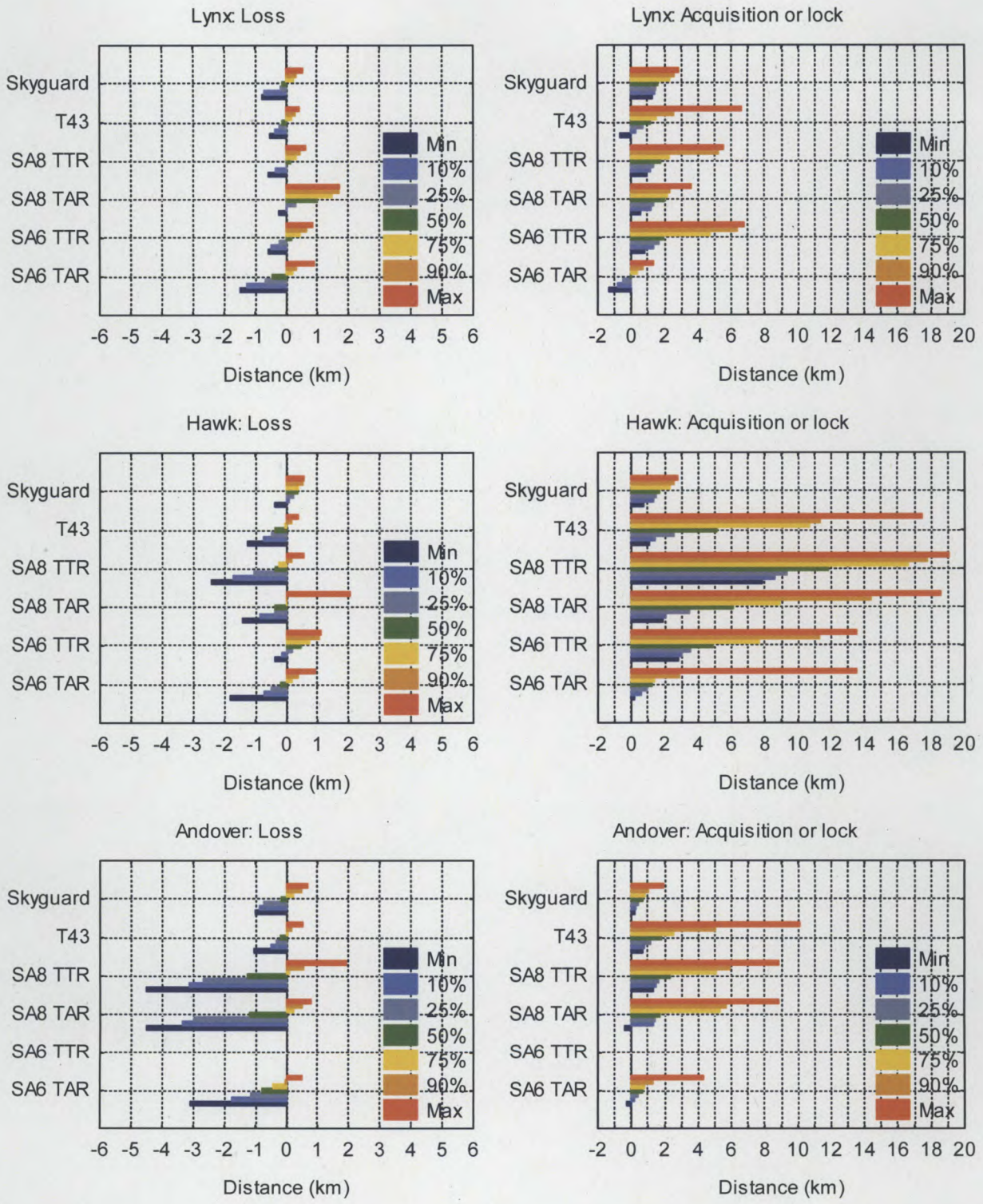

Figure 2 - Summary data for loss and subsequent reacquisition or lock during main trial runs[10]

[10] For all graphs, negative data points indicate that the event took place within the boundary of the WF, positive data points indicated that the event took place outside the boundary of the WF.

23. **Summary.** These results show that the presence of Robin Rigg WF reduced the performance of the threat systems against all trial ac. It is therefore assessed that, unless suitable mitigation can be identified, there will be a reduction in the effectiveness of the threat radars against all ac in the vicinity of WF and an associated degradation in the ability of RAF Spadeadam EWTF to provide effective and realistic EW trg.

Results by threat system

Skyguard

24. **General.** The Skyguard system acquires and locks onto a tgt almost simultaneously[11], thus system data is not broken down into TAR and TTR components (data downloaded from the Skyguard relates to TTR only). The Skyguard was the only system that was limited by range for both reference and main trial runs; the maximum operational range of the system is approx 16 km, which falls inside the bounds of Robin Rigg WF. Data gathering was therefore limited to losses on the entry to and exit from the WF at the eastern boundary. During the reference runs that took place in the airspace in between the WF and the threat system locations, the Skyguard was able to observe, lock onto and track the ac until it was beyond the range of the system.

25. **System performance.** During the main trial runs, loss of lock was either attributed to range or directly to the presence of the wind turbines. An example of a screenshot from the Skyguard is at Figure 3, showing an ac being tracked during a reference run; illustrations of loss due to range and the presence of wind turbines are at Figure 4 and Figure 5 respectively. It should be noted that figures 4 and 5 are not snapshots from the Skyguard but post-analysis amalgamation of GPS ac plots and tracking data taken directly from the Skyguard system.

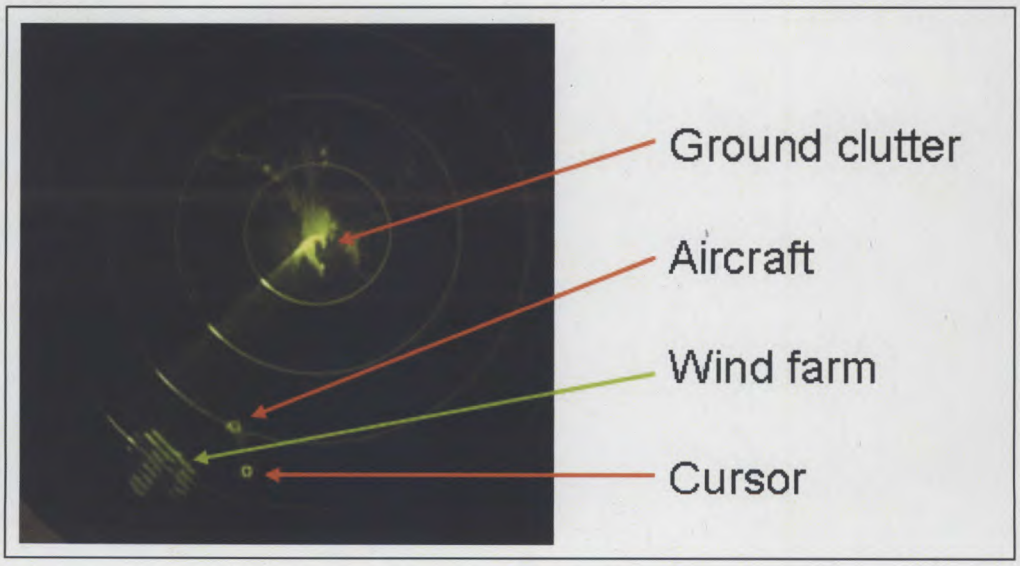

Figure 3 - Screenshot from Skyguard

[11] The operator is required to select 'track' when the system has acquired the tgt. This typically occurs within 1 second of tgt acquisition.

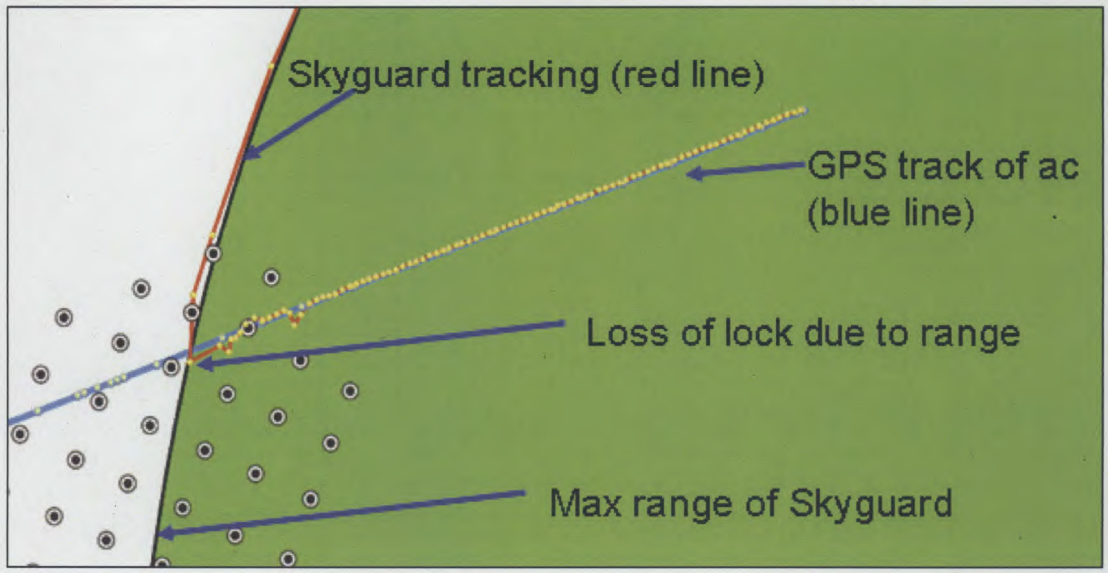

Figure 4 - Loss of lock due to range (Skyguard)

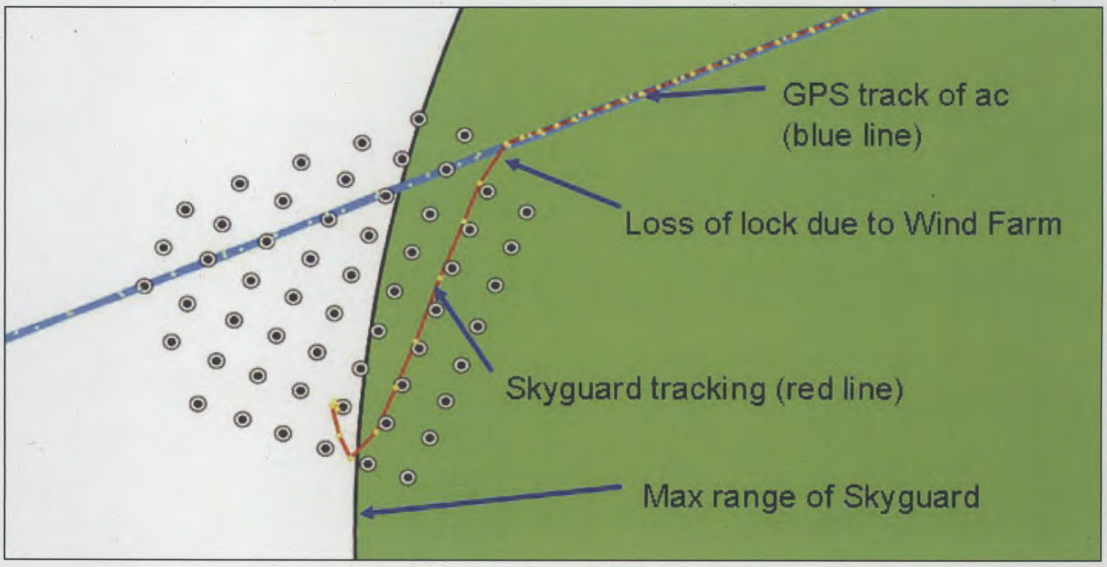

Figure 5 - Loss of lock due to WF (Skyguard)

26. Analysis of the Skyguard data shows that loss of lock occurred within 700 m of entering the airspace above the WF; on 10 out of 37 occasions loss was attributable to ac flying beyond the range of the system, all the remaining 27 losses were attributable to the presence of the WF. Once lock was lost in the area of the WF, the ac could not be distinguished from the turbine returns. The Skyguard was only able to regain lock on the ac once it had exited the WF on the inbound leg; all recorded occurrences of lock were achieved within 2.9 km of the WF boundary. This ability to regain lock within a relatively short distance is considered to be due to the relative ability of the Skyguard to resolve tgts in comparison to the other systems trialled, resulting in a clear paint from the tgt as it exited the WF. Furthermore, as the Skyguard was limited by range, and the ac were flying predictable and repetitive profiles, the operator was able to optimise the radar to detect the ac in the shortest time possible. Annex E graphically illustrates the plan position and range where lock was lost and subsequently regained for each data run.

T43

27. **General.** The T43 emulates the performance characteristics of a SA-8 TTR. However, results from BD Stage 2 have been examined and there is no apparent direct correlation in this environment between its performance and that of the SA-8 TTR. Data from the T43 emulator was analysed and during those reference runs that took place in front of the WF, lock was maintained until the western extreme of the outbound leg when terrain masking resulted in a loss of lock.

28. **System performance.** During the main data runs, it was demonstrated that loss of lock was directly attributable to interference caused by the presence of the WF on 76 out of 78 occasions. Only on 2 legs was loss of lock attributable to non-WF reasons. Once lock had been lost from the ac, the system would jump from the weak ac return to the stronger wind turbine returns and maintain steady lock on this until the operator disengaged "autotrack". Figure 6 is a screenshot from the T43 emulator showing that, upon entering the WF, the system maintained lock, albeit for a very short period of time, before it was lost due to wind turbines.

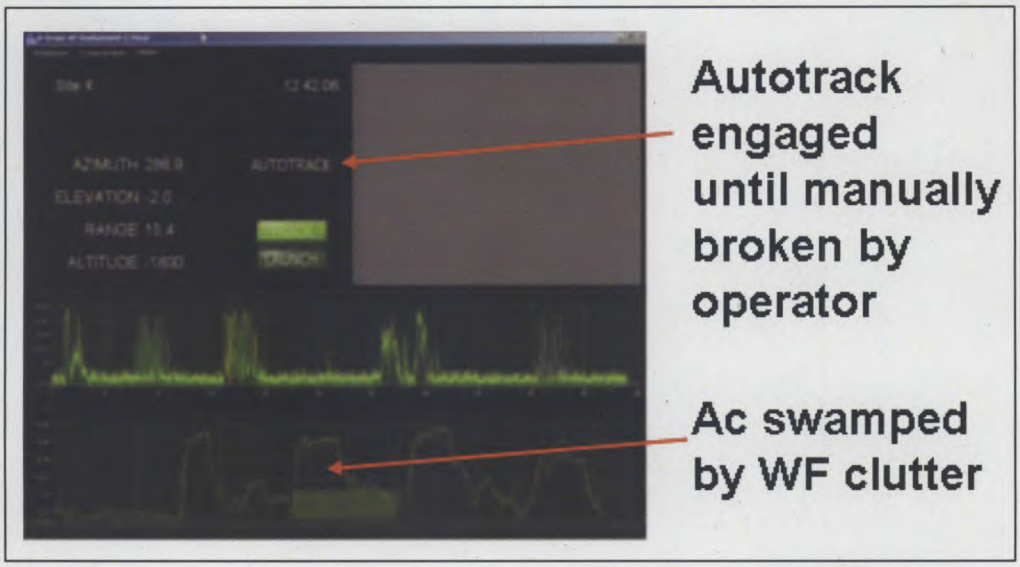

Figure 6 - T43 tracking of Lynx in WF clutter

Once lock on the ac had been lost, it was impossible to discern the tgt from the mass of clutter created by the WF, making even manual tracking of the ac unviable. When the ac exited the western boundary of the WF at the end of the outbound leg, the T43 was able to regain lock onto the tgt prior to the inbound leg on 70% of occasions. Once lock was lost (outbound and inbound legs), the system was able to regain lock in 100% of recorded occurrences within 17.5 km from the boundary of the WF. Annex F graphically illustrates the plan position and distance from the WF boundary where lock was lost and subsequently regained for each data run.

SA-8

29. **General.** The results from the SA-8 TAR and TTR were analysed separately. During the reference runs that took place in the airspace in between the WF and the threat system locations, when acquisition or lock was lost, the loss was attributable to non-WF related reasons such as range, terrain masking or weather. Both the TAR and TTR performed in accordance with the eqpt specification; i.e. when lock was lost on an ac, the TAR was required to reacquire the tgt before the TTR was able to relock the tgt.

30. **TTR.** The performance of the SA-8 TTR was greatly reduced in the vicinity of the WF. When lock was lost, it was not possible to regain stable lock until the ac was clear of the WF. Loss of lock was directly attributable to the interference caused by the presence of the WF on 47 out of 57 occasions, with lock maintained over the WF on 6 legs. During the remaining 4 legs, loss of lock was attributed to non-WF reasons. Annex G provides data from the TTR illustrating the position of loss of lock and subsequent relock relative to the position of the WF. Figure 7 is a screen shot from the SA-8 showing a tgt being tracked prior to its entry into the airspace overhead the WF. Figure 8 shows a screen shot where it was not possible to track the tgt once it had exited the WF

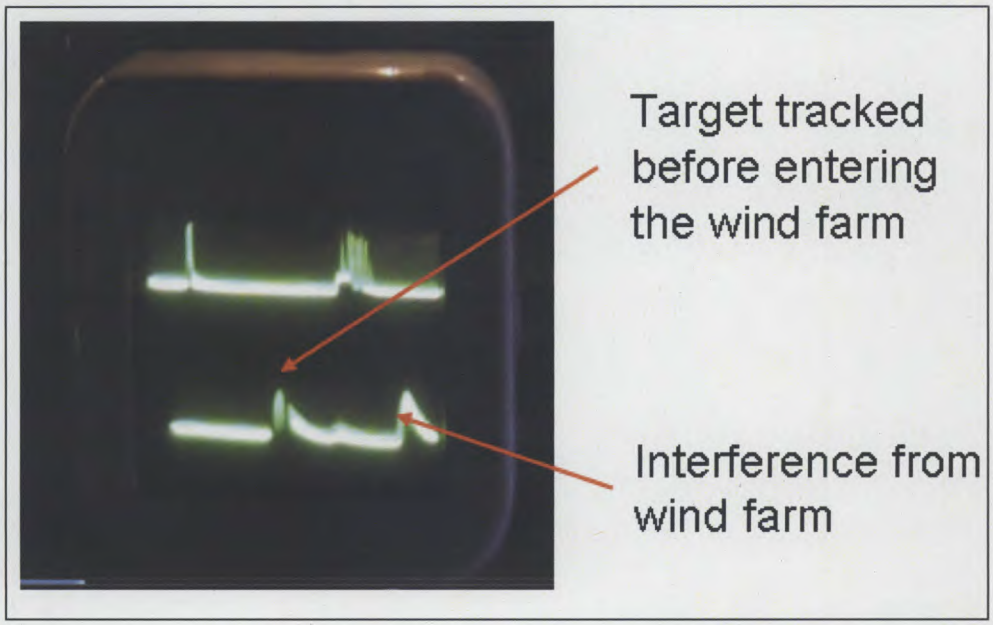

Figure 7 - Screen shot from SA-8 TTR

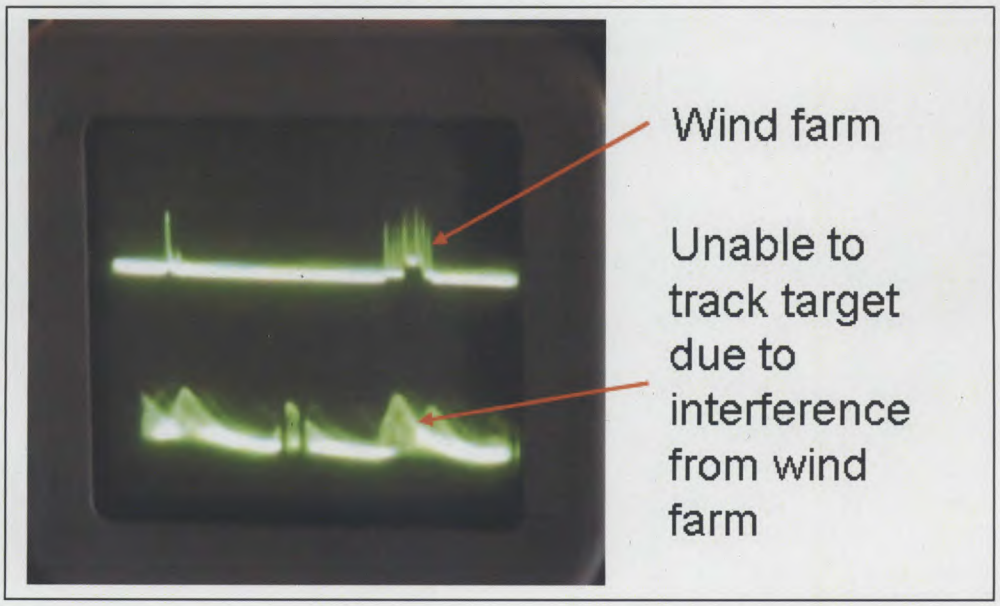

Figure 8 - Screen shot from SA-8 TTR

at the western boundary.

31. It should be noted that when a tgt was reacquired after it had exited the WF at the western extreme of the outbound run, the presence of the WF still caused interference on the TTR, increasing the difficulty and, therefore, the time taken to lock onto the tgt. Figure 9 shows a screen shot from the SA-8 TTR where the system has reacquired a tgt on the far side of the WF in spite of interference from the WF. The maximum distance required for reacquiring tgt lock was in excess of 19.1 km, as lock was not achieved by the end of one return leg.

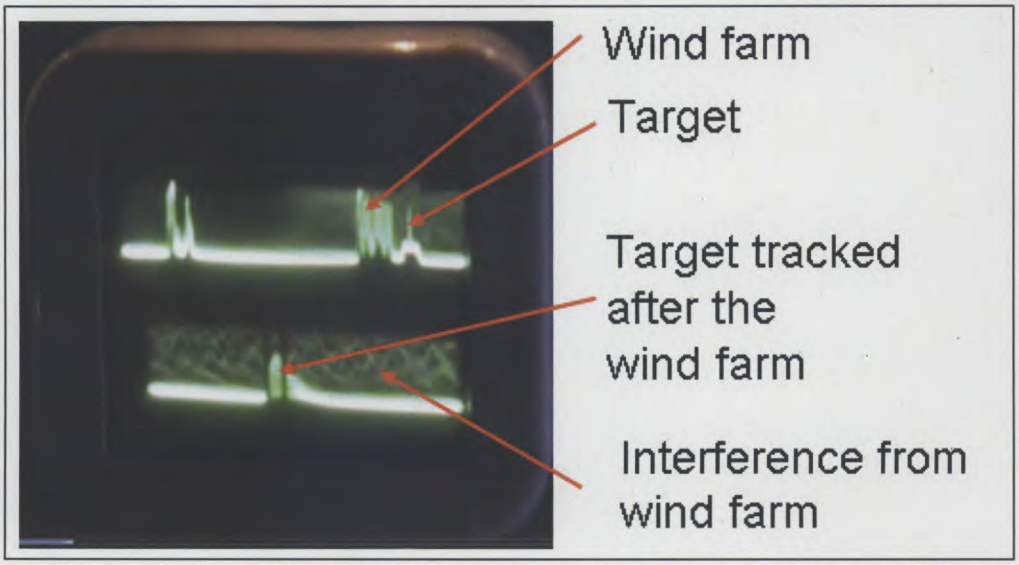

Figure 9 - Screen shot from SA-8 TTR

32. **TAR.** Results from the SA-8 TAR illustrate that the loss of acquisition was directly attributable to the interference caused by the WF on 47 out of 59 occasions and acquisition was maintained over the WF on 7 occasions. During the remaining 5 legs, loss of acquisition was attributed to non-WF reasons. Annex H provides data from the TAR, illustrating the plan position and distance at which loss of acquisition and subsequent reacquisition from the WF boundary took place. Figure 10 shows an SA-8 TAR screen shot when a tgt had been acquired; Figure 11 shows how interference from the WF prevented acquisition of a tgt when exiting the WF at the western boundary, providing evidence of an area behind the WF where an apparent shadow effect of the WF reduced the ability of the TAR to acquire a tgt in what may normally be considered clear airspace.

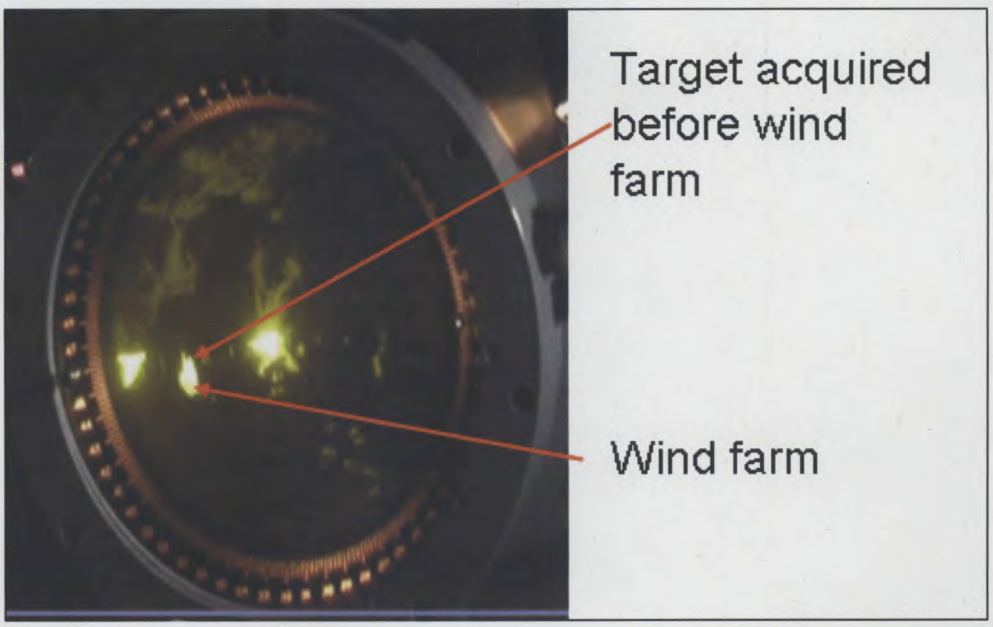

Figure 10 - Screen shot from SA-8 TAR

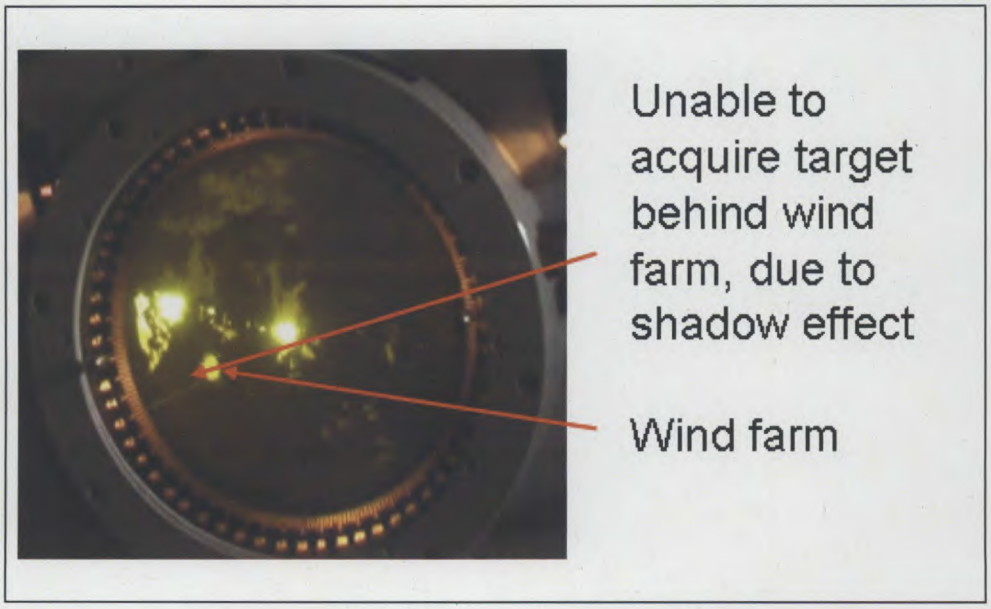

Figure 11 - Screen shot from SA-8 TAR

SA-6

33. **General.** The ability of the SA-6 to acquire and maintain lock onto a tgt has been assessed separately through analysis of data from the TAR and TTR. In line with the standard performance of the SA-6, it is necessary to acquire the tgt before lock is achieved. This behaviour was demonstrated during those reference runs that took place in the airspace in between the WF and the threat system locations. During these reference runs, when lock was lost it could be attributed to terrain masking when the ac was at the western extreme of the outbound leg.

34. **TTR.** Due to eqpt unserviceability, it was not possible to record TTR data for the Andover runs; consequently only data from the Hawk and Lynx has been analysed. On no occasion was the SA-6 TTR able to maintain lock on an ac for a complete leg. Loss of lock could be attributed to the presence of the WF in 32 out of 34 occasions, with 50% of the loss of locks occurring prior to the ac entering the WF; it was not possible to regain lock until the ac had exited the WF. The ability of the TTR to achieve lock once the ac was outside the boundary of the WF was significantly reduced compared to the TAR, taking up to 13.5 km for all recorded locks to be achieved. Annex I illustrates the plan position and range at which loss of lock and subsequent re-lock took place, relative to the WF boundary.

35. Figure 12 shows a screen shot from the SA-6 TTR, demonstrating how it was not possible to identify the ac return when the system was swamped by interference caused by the WF. Figure 13 illustrates the display when an ac had been reacquired in airspace clear of the WF.

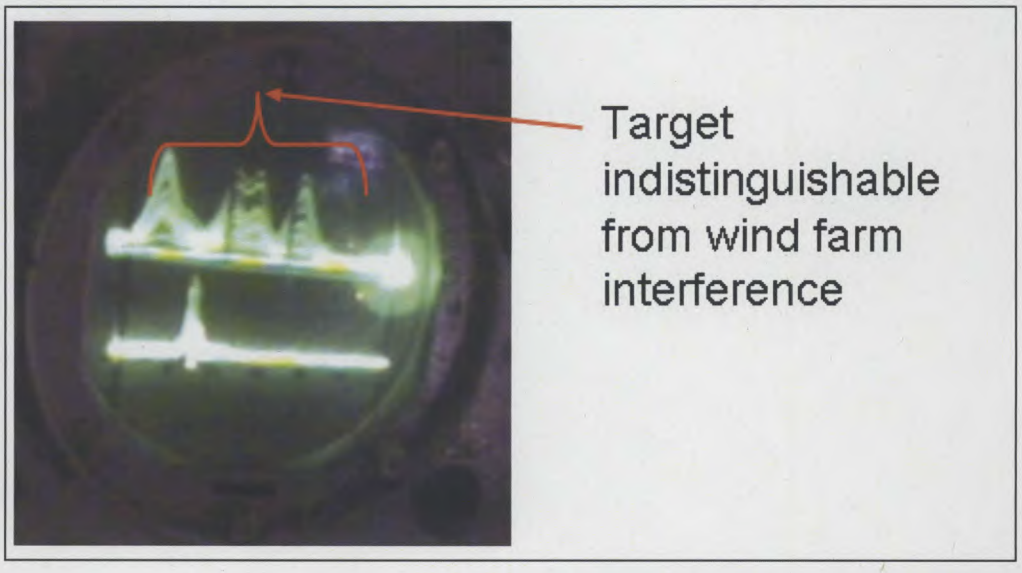

Figure 12 - Screen shot from SA-6 TTR

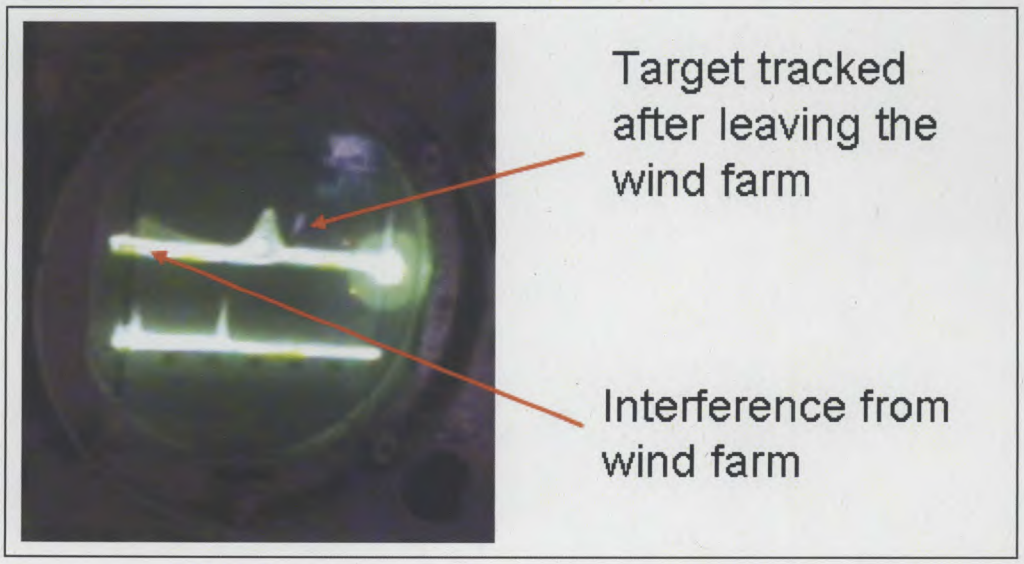

Figure 13 - Screen shot from SA-6 TTR

36. **TAR.** During the main trial runs, the TAR was able to maintain acquisition on a tgt throughout the leg on 8 out of 92 occasions. However as illustrated at Annex J, loss of acquisition was observed both prior to or overhead the WF for the majority of trial runs (83 occasions with 1 occasion when acquisition was lost due to non-WF related reasons). When exiting the WF, it was then possible to reacquire the tgt. All of these acquisitions took place within 13.5 km of the WF boundary.

Threat system performance summary

37. Data analysis has shown that in the vicinity of the WF, the ability of each system to acquire, establish and maintain lock on a tgt was significantly reduced. Reference runs provided control evidence that the individual systems can acquire and maintain lock on ac operating in airspace clear of Robin Rigg WF. Each system showed clear evidence that in the presence of the WF, lock was lost and it was not possible to re-establish a stable lock until the ac was clear of the WF. Without lock, a tgt cannot be engaged and the training benefit for ac operating within the RAF Spadeadam EWTF would be drastically reduced. The ability of the Skyguard to regain lock on a tgt within 3 km of the boundary of the WF highlights it as the best performing system of those tested. However, it is considered that none of the systems tested could provide meaningful EW training for ac operating in the vicinity of this WF. All were adversely affected with some tgts taking in excess of 19 km to reacquire and overall, lock was only maintained during 6% of the main runs.

38. In addition, given that the trial profiles were repeated and predictable, any unpredictability in ac track (e.g. manoeuvring) is likely to further increase the amount of time taken to track an ac within, or emerging from the WF. It is therefore assessed that, unless suitable mitigation can be achieved, there would be an additional reduction in the training effectiveness of EW threat radars operating against manoeuvring ac in the vicinity of WF.

Results by height

39. Runs were conducted at 3 distinct heights: 700 ft, 950 ft and 1200 ft amsl. Following analysis of the data from all systems, as presented in Figure 2 of Annexes E to J, it was evident that there was no clear correlation between the run height and the ability of the TAR and TTR to acquire, establish and maintain lock on the tgt. **It is recommended that should the need arise to assess the impact of WF on the performance of EW threat radars against ac operating above 1,200 ft, a further trial should be conducted.**

Operator workload

40. In order to achieve lock on a tgt, operators need to manually manipulate the eqpt to acquire the tgt and then subsequently to achieve lock. In areas of increased clutter, including weather, surface returns and WF, it is increasingly difficult to achieve lock. This increase in difficulty is illustrated by Figure 14 and Figure 15. Figure 14 shows a screen shot of an ac being tracked in clear airspace, prior to flying over the WF, with a low level of background clutter. Figure 15 shows a screen shot of WF clutter preventing the ac from being tracked.

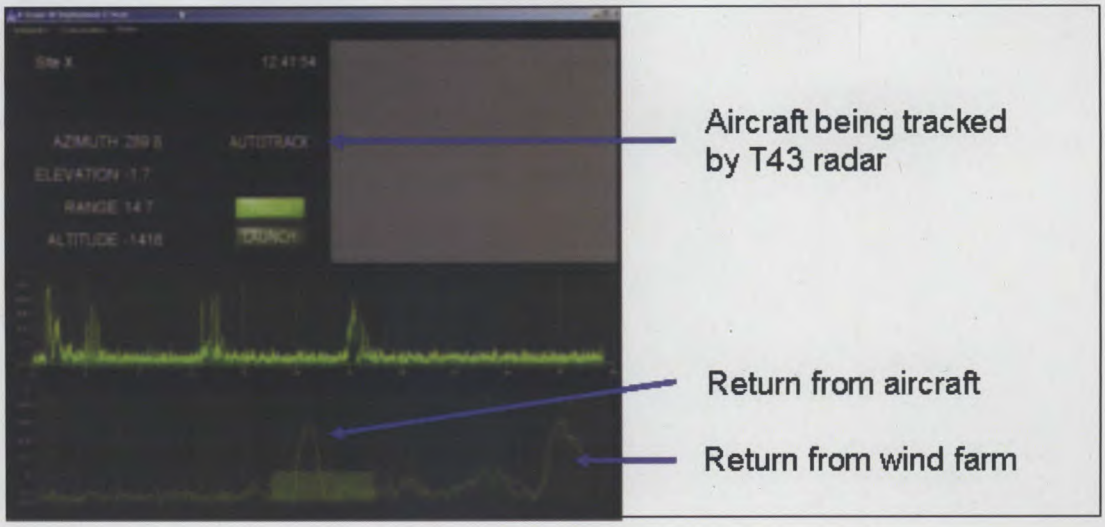

Figure 14 - Ac approaching the WF (T43 emulator)

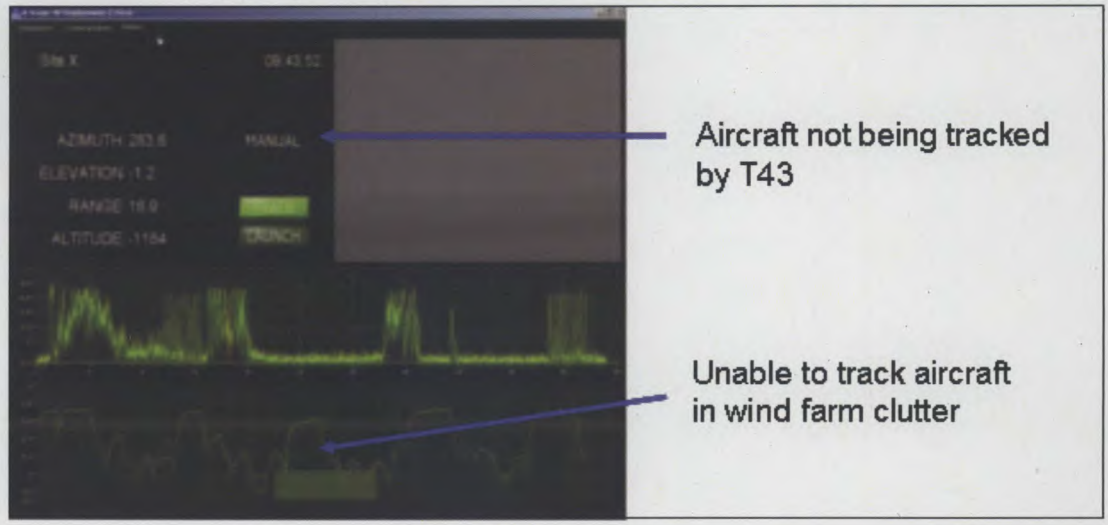

Figure 15 - Ac not being tracked due to WF clutter (T43 emulator)

41. During this Trial, the presence of wind turbines increased the level of clutter and therefore noise in the region of the WF. This higher level of clutter dramatically added to operator workload when attempting to gain lock. Due to the high speeds of the Hawk ac, the response time available to the operator to combat the WF interference was greatly reduced. The improved performance of the radars against the Andover was not only due to the larger RCS, but also due to the tgt's slow speed, which allowed the operator more time to combat the WF interference.

42. Advanced processing techniques such as Moving Target Indicator (MTI) and Wind Compensation (WC) were available to assist tracking in areas of increased clutter. During the Trial, the SA-6 operators were able to use both of these techniques to maintain tracking of the tgt ac. MTI and WC could be applied separately or together. MTI reduced stationary clutter, (ground clutter and clutter from the stationary part of the wind turbine) but allowed weather clutter to be displayed, resulting in large areas of the display being obscured as shown in Figure 16.

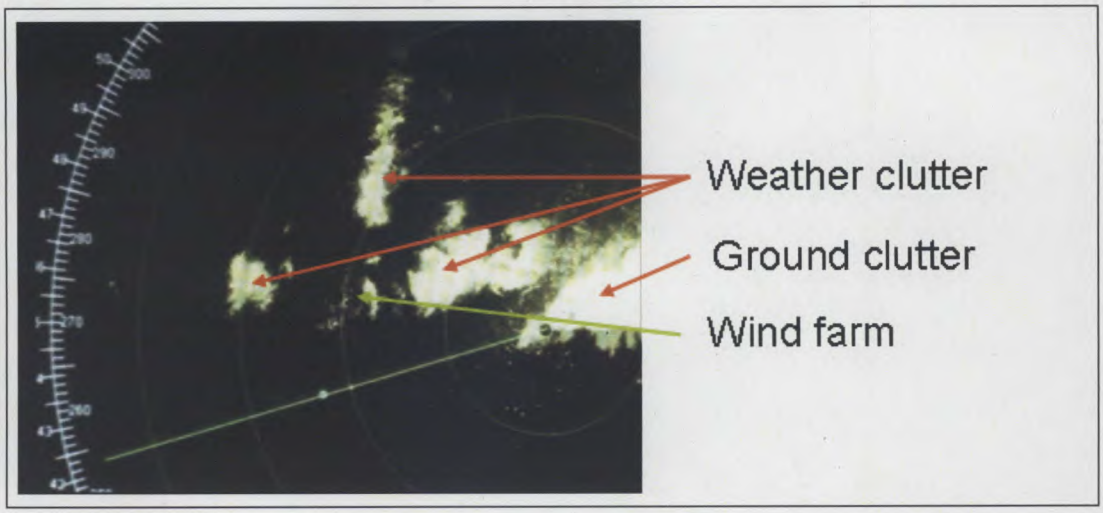

Figure 16 - MTI applied to SA-6 TAR

43. Figure 17 shows a screen shot from the SA-6 TAR when WC only had been applied. WC reduced weather clutter almost completely in the vicinity of the WF however, ground clutter 'bloomed'.

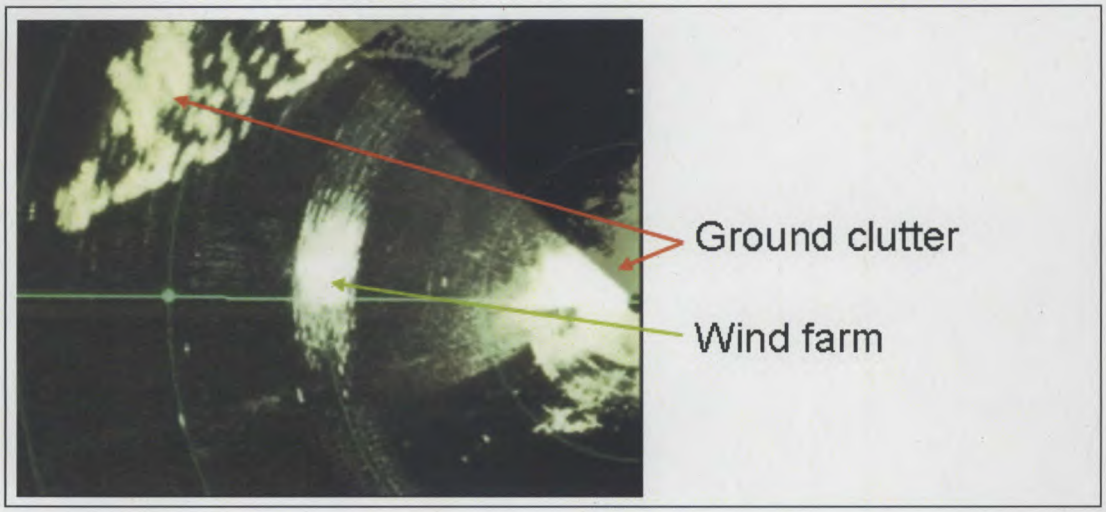

Figure 17 - WC applied to SA-6 TAR

44. When both MTI and WC were applied simultaneously, clutter from the ground, weather and WF remained present as shown in Figure 18. Operators reported that the method that provided the greatest assistance to tracking a tgt was through the application of MTI and WC separately as the tgt transited the distinct clutter areas.

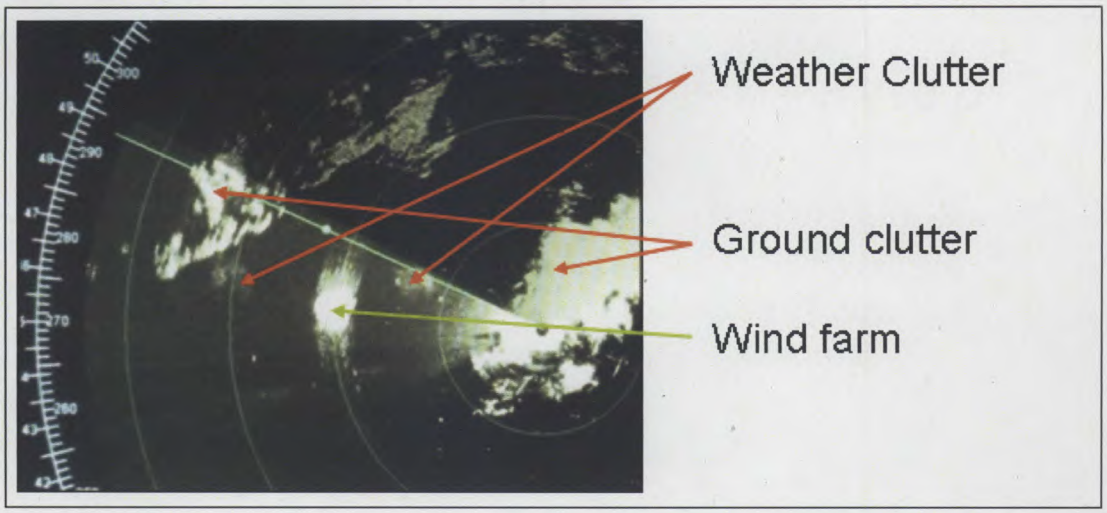

Figure 18 - MTI and WC applied to SA-6 TAR

45. The use of advanced processing techniques can aid the detection of ac in areas of high clutter; however these techniques were not sufficient to overcome the returns caused by the presence of the Robin Rigg WF and resulted in a significant increase in the operator's workload.

46. Trial BD Stage 2 did not consider the ability of operators to acquire and maintain lock on a manoeuvring tgt. It is evident that the ability of the operator to provide an effective trg event in the presence of a WF is reduced even when the position of the tgt ac is predictable. Any reduction in the predictability of the ac position (through manoeuvring or evasion) in close proximity to a WF is likely to only further degrade the ability of the operator to undertake their task.

Trial objectives satisfied

47. **Objective 1.** For each of the threat radars provided, observe and determine the effects that WF have in terms of; the extent of obscuration of tgts, increase in workload of the radar operator(s) and variation in impact on representative ac tgts.

Objective fully satisfied

48. **Objective 2.** To provide guidance to HQ AIR EW Trg on the impact of WF on selected threat radars used at RAF Spadeadam.

Objective fully satisfied

Conclusions

49. Trial BD Stage 2 was undertaken to assess the effect of WF on representative threat radars operated by RAF Spadeadam. In order to achieve this, the extent of obscuration of tgts, variation in impact on representative ac and increase in workload were determined in order to provide guidance to HQ AIR EW Trg.

50. It has been shown that the Skyguard, T43, SA-8 and SA-6 can successfully engage and track ac in clear airspace in between Robin Rigg WF and the deployed coastal sites. During the main trial runs, it is assessed that the presence of the Robin Rigg WF significantly reduced the ability of the EW threat systems to acquire and track all tgt ac operating in the airspace above and adjacent to the WF; on 88% of runs, acquisition and tracking were lost due to the presence of the WF. The presence of the WF not only caused reduced performance against all tgts in the airspace

above the WF, but also impacted the performance of the trialled threat systems beyond the WF boundary. Furthermore, once tgts had been lost, reacquisition or lock onto an emerging tgt could require distances of in excess of 19 km from the WF boundary. Unless suitable mitigation can be identified, there will be a significant reduction in the training effectiveness of EW threat radars operating against ac in the vicinity of WF. The performance of the radars against the different types of ac used varied; the degradation against low RCS and high-speed tgts was the most significant. As there is no clear evidence of a change in performance of the threat radars at the ac heights trialled, further work would be required to assess the impact to ac operating above 1200 ft. Whilst advanced processing techniques such as MTI and WC improve the operator's ability to detect tgts in the presence of high levels of clutter, these techniques were not sufficient to overcome the clutter created by the presence of Robin Rigg WF. Profiles used during this Trial were predictable and repetitive; it is assessed that tracking problems are likely to be exacerbated if the systems operated against manoeuvring ac in the vicinity of WF. Given the impact on threat system performance demonstrated during Trial BD Stage 2, **it is recommended that HQ EW Trg consider the implications of the trial results on EW Trg when determining their response to future WF planning applications.**

Recommendations

51. It is recommended that should the need arise to assess the impact of WF on the performance of EW threat radars against ac operating above 1200 ft, a further trial should be conducted. (Para 39). **(HQ Air EW Trg).**

52. It is recommended that HQ Air EW Trg consider the implications of the trial results on EW Trg when determining their response to future WF planning applications. (Para 50). **(HQ Air EW Trg).**

Responses

53. The Sponsor is requested to inform the TMO of actions or intentions resulting from this TR. If required, responses may also be forwarded to HQ AWC by e-mail to PCC Spt or hard copied to PCC Spt, HQ AWC, Thomson Building, RAF Waddington, Lincoln, LN5 9WA.

[redacted]

S C Evans
Air Cdre
Cmdt AWC

16 Jan 12

Annexes:

A. Wind turbine locations.
B. Sortie profiles summary.
C. Dundrennan weather observations.
D. Summary trial data.
E. Skyguard performance.
F. T43 results.
G. SA-8 TTR results.
H. SA-8 TAR results.
I. SA-6 TTR results.
J. SA-6 TAR results.

Distribution:

HQ AIR	AIR A3 EW SO1*
AWC, 56(R)Sqn	TMO*
	AWC-Ops & Dev Sec Spt*
AAC Middle Wallop	OC 667(T&D) Sqn8
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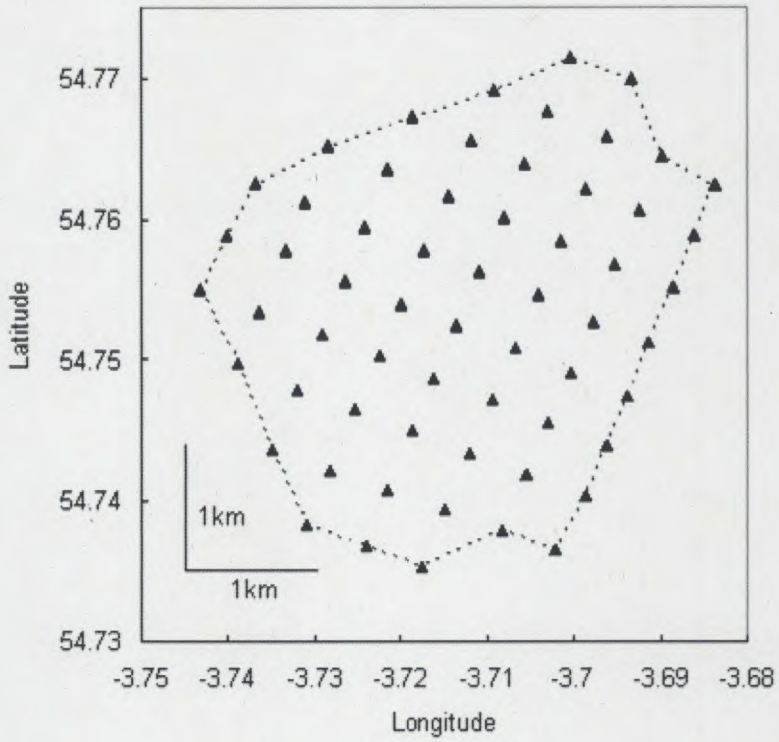
* = Electronically distributed.

Annex A to
20120105 BD2 TR-U
Dated 16 Jan 12

WIND TURBINE LOCATIONS



WF Turbine locations and WF boundary

Annex B to
20120105 BD2 TR-U
Dated 16 Jan 12

SORTIE PROFILES SUMMARY

A/C	Serial	Run	Height ft	Serial	Run	Height ft	Serial	Run	Height ft
Lynx	1	1a	2000-700	2	1a	2000-700	3	1a	2000-700
Lynx	1	1b	2000-700	2	1b	2000-700	3	1b	2000-700
Lynx	1	2a	2000-700	2	2a	2000-700	3	2a	2000-700
Lynx	1	2b	2000-700	2	2b	2000-700	3	2b	2000-700
Lynx	1	3a	2000-700	2	3a	2000-700			
Lynx	1	3b	2000-700	2	3b	2000-700			
Lynx	1	4a	700	2	4a	700	3	4a	700
Lynx	1	4b	700	2	4b	700	3	4b	700
Lynx	1	5a	1200	2	5a	950	3	5a	1200
Lynx	1	5b	1200	2	5b	950	3	5b	1200
Lynx	1	6a	950	2	6a	700	3	6a	1200
Lynx	1	6b	950	2	6b	700	3	6b	1200
Lynx	1	7a	700				3	7a	700
Lynx	1	7b	700				3	7b	700
Lynx	1	8a							
Lynx	1	8b							

A/C	Serial	Run	Height ft	Serial	Run	Height ft	Serial	Run	Height ft
Hawk	1	1a	700	2	1a	700	3	1a	700
Hawk	1	1b	700	2	1b	700	3	1b	700
Hawk	1	2a	700	2	2a	950	3	2a	950
Hawk	1	2b	700	2	2b	950	3	2b	950
Hawk	1	3a	950	2	3a	700	3	3a	700
Hawk	1	3b	950	2	3b	700	3	3b	700
Hawk	1	4a	700	2	4a	1200	3	4a	700
Hawk	1	4b	700	2	4b	1200	3	4b	700
Hawk	1	5a	1200	2	5a	950	3	5a	1200
Hawk	1	5b	1200	2	5b	950	3	5b	1200
Hawk	1	6a	950	2	6a	700	3	6a	1200
Hawk	1	6b	950	2	6b	700	3	6b	1200
Hawk	1	7a	700	2	7a	1200	3	7a	700
Hawk	1	7b	700	2	7b	1200	3	7b	700
Hawk	1	8a	1200						
Hawk	1	8b	1200						

A/C	Serial	Run	Height ft	Serial	Run	Height ft	Serial	Run	Height ft
Andover	1	1a	700	2	1a	700	3	1a	700
Andover	1	1b	700	2	1b	700	3	1b	700
Andover	1	2a	700	2	2a	1200	3	2a	1200
Andover	1	2b	700	2	2b	1200	3	2b	1200
Andover	1	3a	950	2	3a	700	3	3a	700
Andover	1	3b	950	2	3b	700	3	3b	700
Andover	1	4a	700	2	4a	1200	3	4a	700
Andover	1	4b	700	2	4b	1200	3	4b	700
Andover	1	5a	1200	2	5a	950	3	5a	1200
Andover	1	5b	1200	2	5b	950	3	5b	1200
Andover	1	6a	950	2	6a	700	3	6a	700
Andover	1			2	6b	700	3	6b	700
Andover	1	7a	700	2	7a	700	3	7a	950
Andover	1	7b	700	2	7b	700	3	7b	950
Andover									
Andover									

Annex C to
20120105 BD2 TR-U
Dated 16 Jan 12

DUNDRENNAN WEATHER OBSERVATIONS

BST	Z	Weather	Temperature (°C)	Direction (16 points)	Speed (mph)	Visibility (km)
28/06/2011 08:00	0700		11	NW	3	
28/06/2011 09:00	0800		11.8	WNW	5	
28/06/2011 10:00	0900		13.2	WNW	10	
28/06/2011 11:00	1000		13.1	WNW	9	
28/06/2011 12:00	1100		14.4	SW	11	
28/06/2011 13:00	1200		15	SW	14	
28/06/2011 14:00	1300		14.7		16	
28/06/2011 15:00	1400		15.3		16	40
28/06/2011 16:00	1500		15.3		17	20
28/06/2011 17:00	1600		15.2		18	50
29/06/2011 08:00	0700	Medium Level Cloud	10.7	W	9	30
29/06/2011 09:00	0800	Medium Level Cloud	11.3	W	8	30
29/06/2011 10:00	0900	Medium Level Cloud	12.2	W	9	40
29/06/2011 11:00	1000	Light Rain Shower	12.5	WSW	8	9
29/06/2011 12:00	1100	Heavy Rain	11.5	WSW	10	11
29/06/2011 13:00	1200	Light Rain Shower	12.5	SW	11	10
29/06/2011 14:00	1300	Heavy Rain	11.7	WSW	10	12
29/06/2011 15:00	1400		13.9	SW	11	18
30/06/2011 09:00	0800		11.6	W	10	35
30/06/2011 10:00	0900		12.2	WNW	9	29
30/06/2011 11:00	1000		12.5	W	14	22
30/06/2011 12:00	1100		13.3	W	15	45
30/06/2011 13:00	1200		14.7	W	15	35
30/06/2011 14:00	1300		14.1	W	15	45
30/06/2011 15:00	1400		14.5	W	15	50

Latitude: 54.8N; Longitude: 04.0W.
Altitude: 113 m above mean sea level.

Annex D to
20120105 BD2 TR-U
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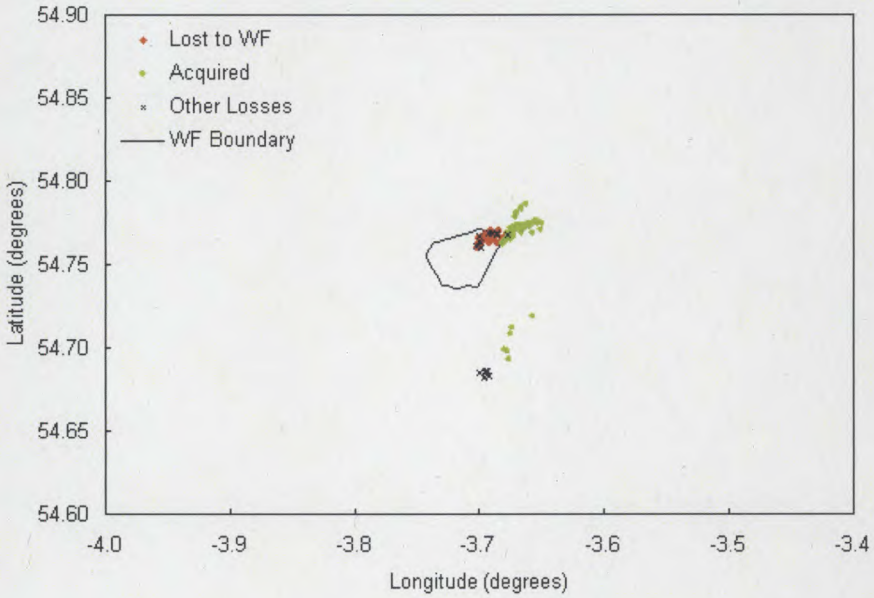
SUMMARY TRIAL DATA

A/C	System	Number of runs[1]	Lost outbound to WF		Maintained outbound over WF[2]		Non-WF loss[3]		Missing outbound data[7]	Acquired beyond WF		Lost inbound to WF		Maintained inbound over WF[2]		Non-WF loss[3]		Recorded as acquired on inbound leg		Missing inbound data[7]
			Count	%[4]	Count	%[4]	Count	%[4]	Count	Count	%[5]	Count	%[6]	Count	%[6]	Count	%[6]	Count	%[4, 8]	Count
Lynx	SA6_TAR	11	10	91%	1	9%	-	-	-	10	91%	6	60%	4	40%	-	-	6	100%	1
	SA6_TTR	11	7	100%	-	-	-	-	4	4	36%	3	75%	-	-	1	25%	7	100%	4
	SA8_TAR	11	10	100%	-	-	-	-	1	6	55%	4	67%	-	-	2	33%	8	100%	3
	SA8_TTR	11	8	89%	-	-	1	11%	2	8	73%	4	80%	-	-	1	20%	7	100%	4
	Skyguard	11	9	90%	-	-	1	10%	1	-	-	-	-	-	-	-	-	10	100%	1
	T43	11	10	100%	-	-	-	-	1	10	91%	9	100%	-	-	-	-	11	100%	-
Hawk	SA6_TAR	19	18	100%	-	-	-	-	1	18	95%	16	89%	1	6%	1	6%	17	100%	1
	SA6_TTR	19	13	100%	-	-	-	-	6	12	63%	11	92%	-	-	1	8%	11	100%	8
	SA8_TAR	19	14	93%	-	-	1	7%	4	6	32%	5	83%	-	-	1	17%	14	100%	5
	SA8_TTR	19	10	91%	-	-	1	9%	8	5	26%	4	80%	-	-	1	20%	8	89%	10
	Skyguard	19	13	68%	-	-	6	32%	-	-	-	-	-	-	-	-	-	19	100%	-
	T43	19	18	100%	-	-	-	-	1	9	47%	6	75%	-	-	2	25%	16	100%	3
Andover[9]	SA6_TAR	18 (17)[9]	18	100%	-	-	-	-	-	18	100%	15	88%	2	12%	-	-	15	100%	-
	SA6_TTR	18 (17)[9]	-	-	-	-	-		18	-	-	-	-	-	-	-	-	-	-	17
	SA8_TAR	18 (17)[9]	13	81%	3	19%	-	-	2	7	39%	1	17%	4	67%	1	17%	9	100%	4
	SA8_TTR	18 (17)[9]	14	93%	1	7%	-	-	3	12	67%	7	58%	5	42%	-	-	9	100%	3
	Skyguard	18 (17)[9]	15	83%	-	-	3	17%	-	-	-	-	-	-	-	-	-	17	100%	-
	T43	18 (17)[9]	18	100%	-	-	-	-	-	15	83%	15	100%	-	-	-	-	11	100%	6
Overall		288	218	92%	5	2%	13	6%	52	140	49%	106	76%	16	11%	11	8%	195	99.5%	70

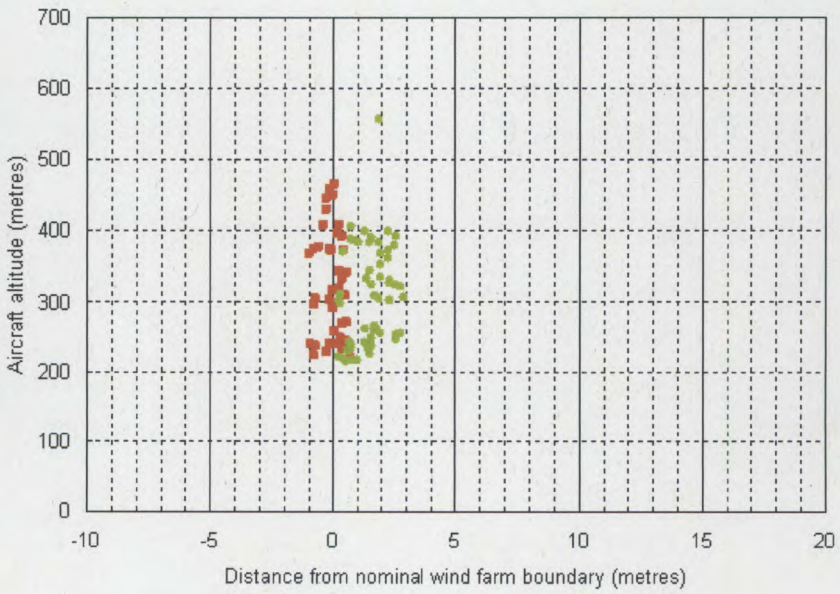
Notes:
1. Reference runs excluded from table; 8 return runs descending across WF by Lynx and 3 return runs not crossing the WF each by Hawk and Andover.
2. Ac track maintained either continuously or with intermittent breaks.
3. Runs where tgt was lost to other causes, e.g. range or weather, precluding subsequent loss to the WF.
4. As a proportion of the number of runs for which data successfully recorded.
5. As a proportion of the total number of runs completed.
6. As a proportion of the number of runs for which data successfully recorded when tgt had been acquired beyond WF.
7. For reasons including: system unserviceable, loss of communications, failure to successfully lay onto tgt, or recording faults.
8. Proportion includes runs where tgt was maintained inbound over WF.
9. Only 17 inbound legs were completed by the Andover.

Annex E to
20120105 BD2 TR-U
Dated 16 Jan 12

SKYGUARD PERFORMANCE

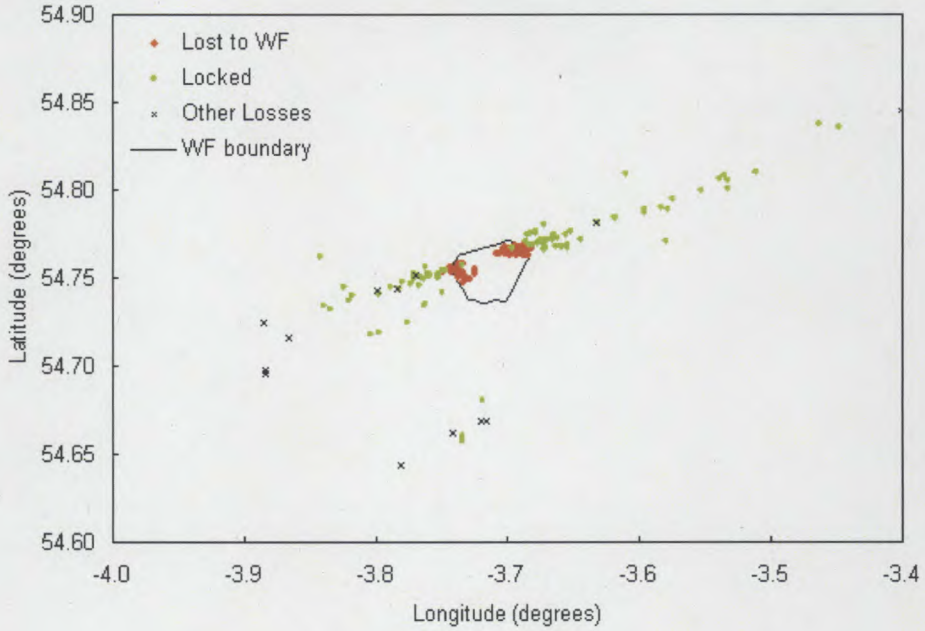


Plan position of loss of lock and acquisition

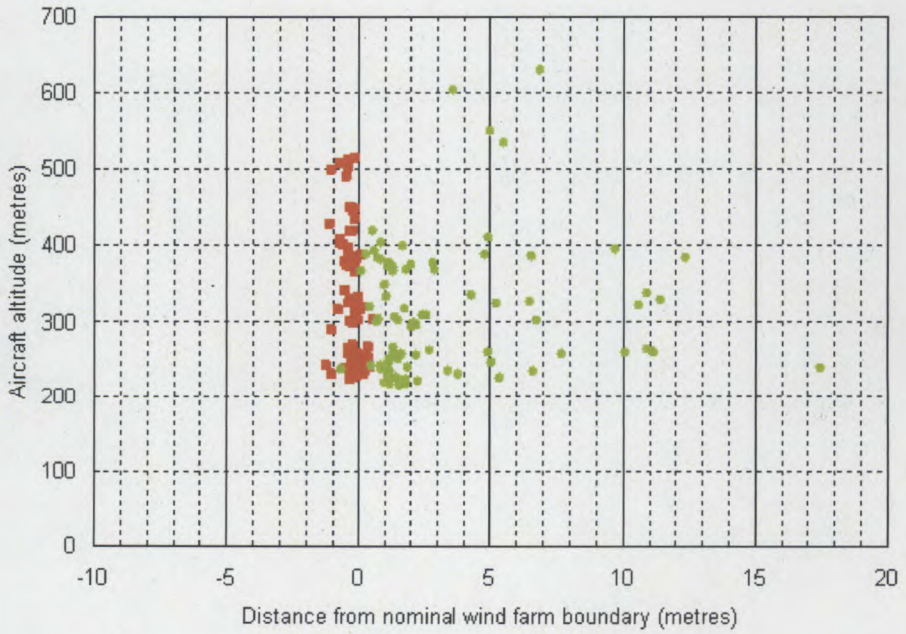


Distance from WF boundary at which loss of lock and acquisition occurred

T43 RESULTS



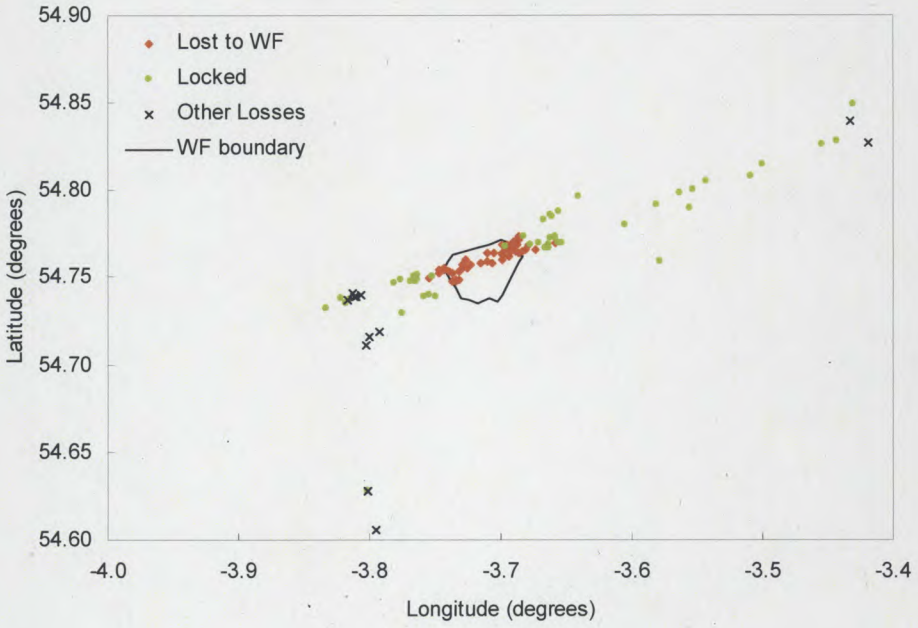
Plan position of loss of lock and acquisition



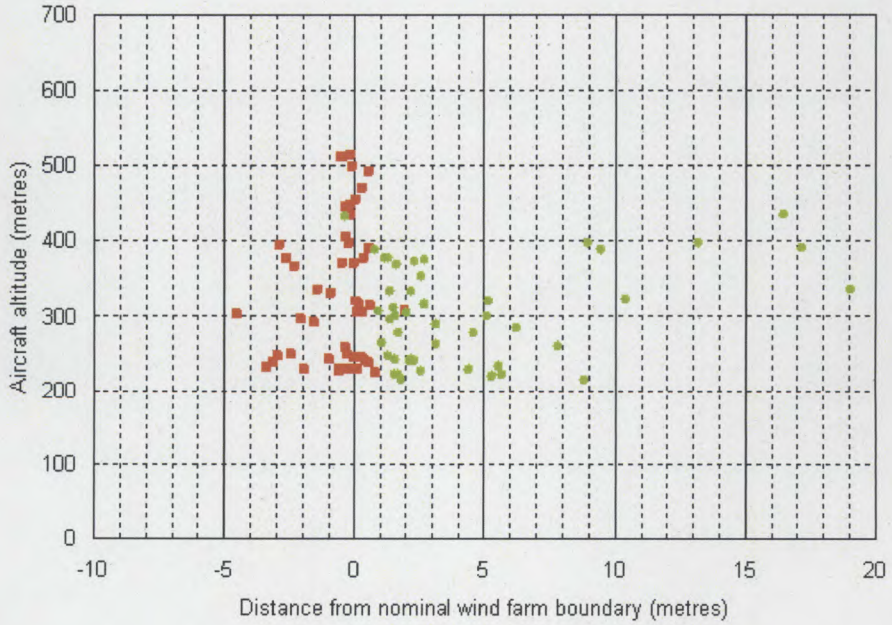
Distance from WF boundary at which loss of lock and acquisition occurred

Annex G to
20120105 BD2 TR-U
Dated 16 Jan 12

SA-8 TTR RESULTS



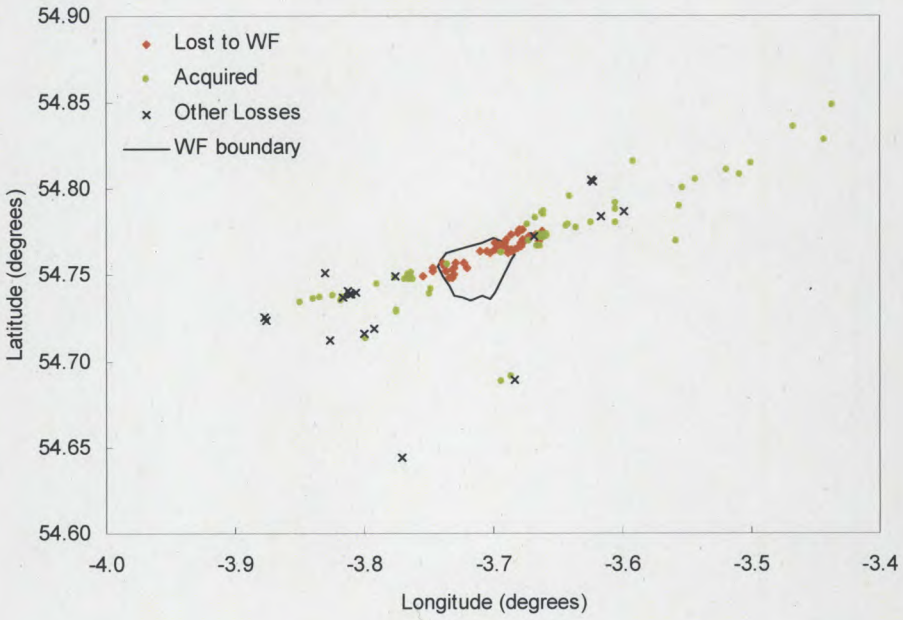
Plan position of lock and loss of lock



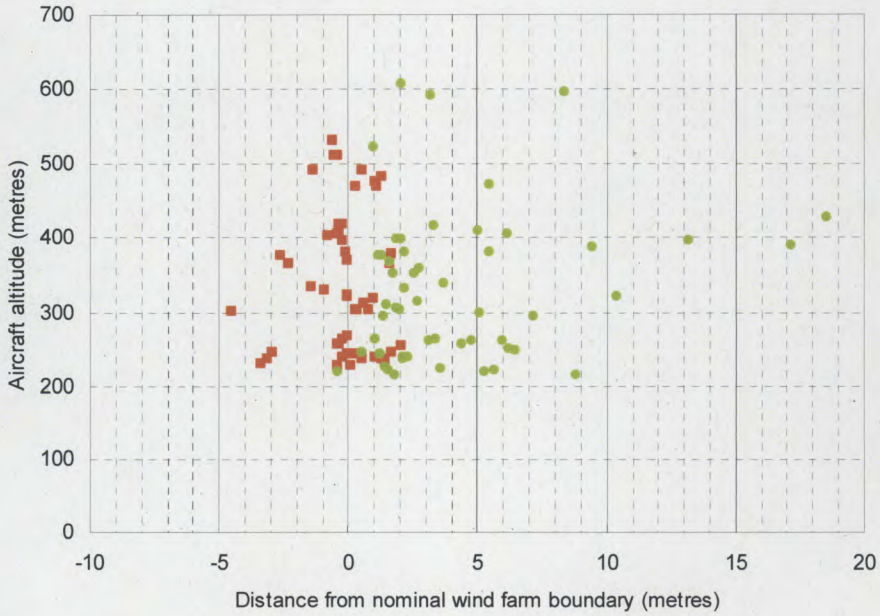
Distance from WF boundary at which lock and loss of lock occurred

Annex H to
20120105 BD2 TR-U
Dated 16 Jan 12

SA-8 TAR RESULTS



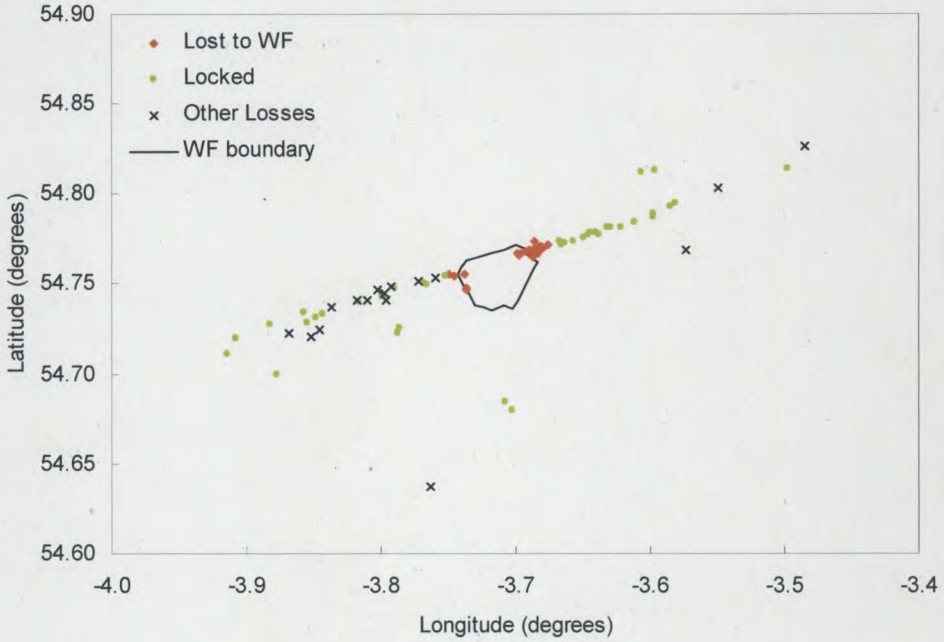
Plan position of acquisition and loss of acquisition



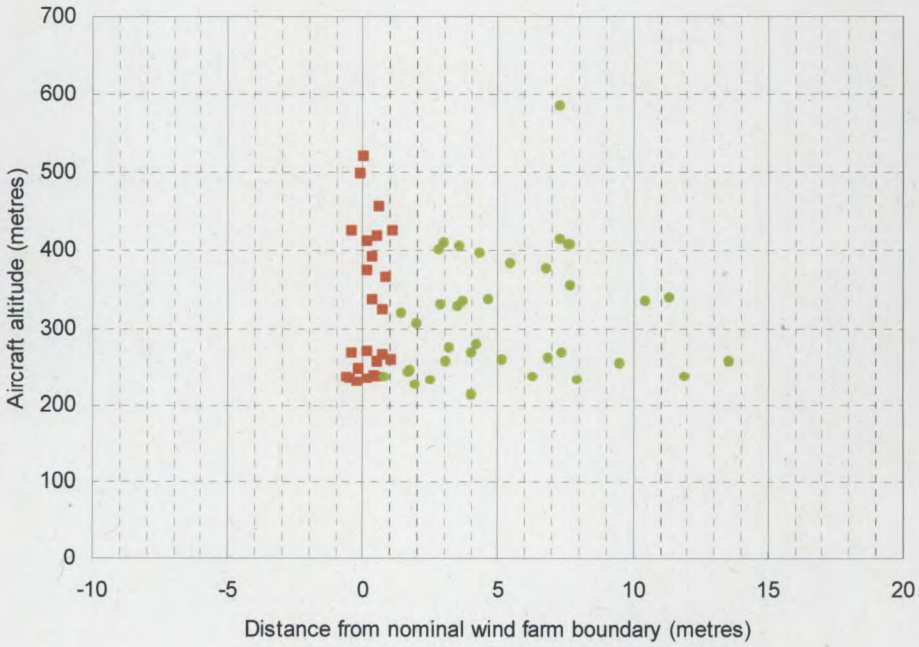
Distance from WF boundary at which acquisition and loss of acquisition occurred

Annex I to
20120105 BD2 TR-U
Dated 16 Jan 12

SA-6 TTR RESULTS



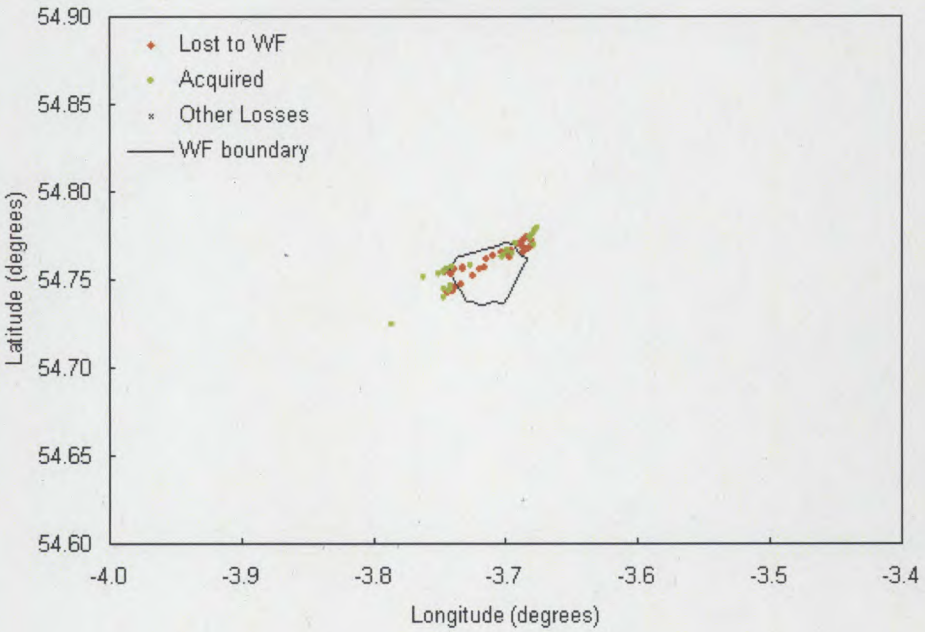
Plan position of lock and loss of lock



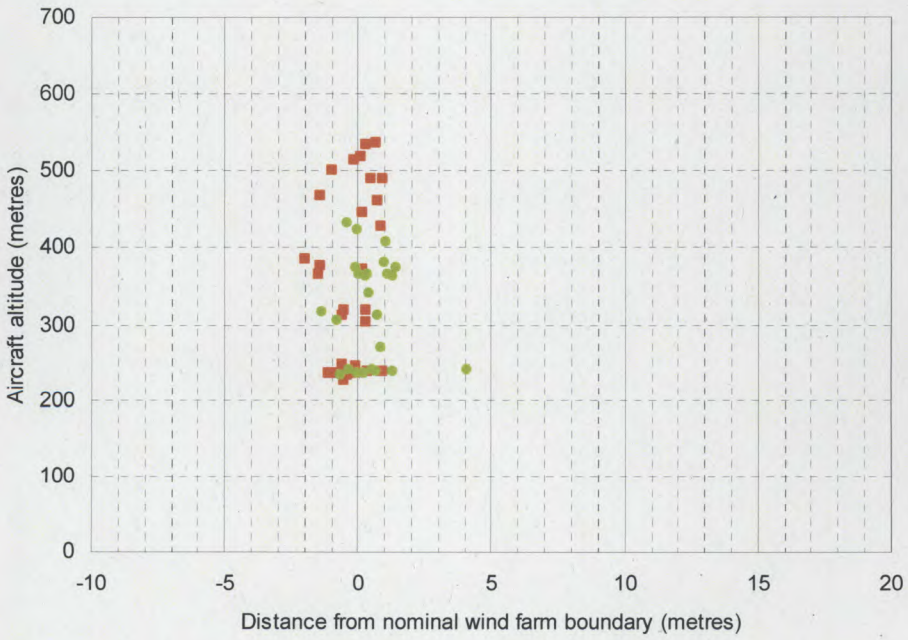
Distance from WF boundary at which lock and loss of lock occurred

Annex J to
20120105 BD2 TR-U
Dated 16 Jan 12

SA-6 TAR RESULTS



Plan position of acquisition and loss of acquisition



Distance from WF boundary at which acquisition and loss of acquisition occurred