RAAF Williamtown Air Traffic Control and radar 1981

Background data, information and investigative findings assisting the search of aircraft VH-MDX

Version: 4th Edition, 2nd August 2015

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Distribution: Public

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Document Purpose

This document was drafted to support VH-MDX related operations of the author, Bushwalkers Wilderness Rescue Squad (BWRS) search operations and NSW Police Force Rescue and Bomb Disposal Unit (NSWPRBDU) Strike Force Wittenoom.

The contents of this document are purely intended to clarify accident events to the best of the author's ability to offer a solid base in determining the location of VH-MDX.

This document must not be used for any purpose other than to provide guidance in locating VH-MDX.

The information and data presented in this document must not be used for any legal purposes as the content may be inaccurate or subject to interpretation errors of the author.

This reference paper will be subject to change as new information and data is found or errors corrected; it is a 'living' document.

Amendments:

2nd Edition June 2014

- General expansion of referenced points
- More detailed radar fix analysis, in particular the 330___ call
- General grammatical corrections
- Addition of a more accurate magnetic variation determination for 1981
- C-210 aspect vs. paint: ATCO updated PSR target sizes
- Expansion of the 330°M call analysis
- Radar propagation
- Inclusion of Williamtown ATCO statement to NSW Police

3rd Edition August 2014

- Public release version
- SURAD head exact geographical position now confirmed (small change)
- ASIB final radar fix defined as a bearing/range from Williamtown: 326ºM/46.7NM
- ASIB final radar fix range error corrected from 1.4NM to 1.7NM
- ATC transponder Minimum Triggering Level (MTL) at antenna end nominally –71dBm but in a range of –69dBm to –77dBm as per TSO-C74c
- ATC transponder receiver sensitivity amended to 65 microvolts for -71dBm and 32 microvolts for -77dBm
- ATC transponder response reliability 90% as per TSO-C74c
- ATC transponder line losses 3dB as per TSO-C74c
- ATC transponder simple quarter wave antenna as per TSO-C74c (0 to 2dBi)
- Radio Mobile correctly referenced
- Clarification of VH-MDX SPI and mode A SSR symbols on Williamtown SURAD PPI at 0936UTC being observed as whole, suggesting a range of not more than 47NM and due to their location over permanent terrain clutter over the Barrington Tops to the north-west sector of the PPI, greater than 44NM (MTI boundary). This forms a gross error check that at 0936UTC MDX was roughly over the Barrington Tops between 44NM and 47NM from Williamtown.
- Clarification that the impression of a west to east track of VH-MDX made by the Williamtown ATCO in a statement to Police was not based on observation of radar paint persistence or collation of multiple paints
- Basic explanation of how PSR systems work
- Tidying up of ATCRBS overview
- Clarification that the ASIB/RCC final radar fix was determined by Sydney Rescue Coordination Centre (RCC) and not the DoT Officer who's name appears beneath one of the position entries

- Inclusion of a reference to the 0936UTC position being referred to as a final position by radar
- Addition of a gross error check of the 320˚M/45NM fix
- Clarification that PSR returns could not be seen amongst the Barrington Tops permanent echoes at the 320˚M/45NM fix
- Addition of SURAD panel photos depicting controls of interest
- Inclusion of transcript extracts direct from the BASI Accident Investigation Archives to better present arguments
- Inclusion of images to give examples of PSR and SSR paints on a SURAD PPI
- Radar fixes better illustrated with a better time line approach
- Addition of 320˚M/45NM track approach limits
- Evidence to suggest a +4/˚-2˚ tolerance for the 320˚M/45NM 0936:00UTC Williamtown radar fix based on a report from a person who discussed the VH-MDX accident with the Williamtown ATCO within a few weeks of the accident. ('Approximately' 324˚ was stated to have been suggested by the Williamtown ATCO)
- 'Radar pro-forma' changed to 'Radar plot sheet'
- Updated Round Mountain to ASIB/RCC final radar position propagation analysis at 8200'AMSL

4th Edition August 2015

- Addition of Sydney radar fade at approximately 330˚M/45NM Williamtown at 0939UTC
- Addition of various interpretations by Sydney ATS of the Williamtown 320˚M/45NM position (differing times)
- Corroborating evidence to suggest the 0936:00UTC Williamtown radar position was likely 323˚M-326˚M and 46NM-47NM from Williamtown
- Expanded discussion of the 330˚M call with a higher likeliness now that Sydney made the call
- Suggestion of how 0940UTC was arrived to for the ASIB/RCC final radar position

Abbreviations

ADATS	Australian Defence Air Traffic System
ADF	Automatic Direction Finder
AMSL	Above Mean Sea Level
AGD66	Australian Geodetic Datum 1966
AGL	Above Ground Level
AGRF	Australia Geomagnetic Reference Field
ARFOR	Area Forecast
ASIB	Air Safety Investigation Branch
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATS	Air Traffic Services
ATCO	Air Traffic Control Officer
BASI	Bureau of Air Safety Investigation
cm	Centimeter
CP	Circular Polarization
CRT	Cathode Ray Tube
DCA	Department of Civil Aviation
DoT	Department of Transport
FS	Flight Service
FSC	Flight Service Centre
FTC	Fast Time Constant
GHz	Gigahertz
GS	Ground Speed
m	Meters
MSL	Mean Sea Level
MHz	Megahertz
NM	Nautical Mile
MTI	Moving Target Indicator

IEEE	Institute for Electrical and Electronic Engineers
INCERFA	Uncertainty Phase of Search and Rescue Procedures
IAS	Indicated Air Speed
PPI	Plan Position Indicator
PSR	Primary Surveillance Radar
RAAF	Royal Australian Air Force
RCC	Recue Coordination Centre
RCS	Radar Cross Section
RF	Radio Frequency
RSR	Route Surveillance Radar
RPM	Revolutions Per Minute
SATCO	Senior Air Traffic Control Officer
SOC	Senior Operations Controller
SPI	Special Position Identification
SSR	Secondary Surveillance Radar
SURAD	Surveillance Radar
TAR	Terminal Approach Radar
TAS	True Air Speed
TMA	Terminal Area
UTC	Universal Time Coordinated
UHF	Ultra High Frequency
VHF	Very High Frequency
WGS	World Geodetic System

Executive Summary

The objective of this reference paper was to capture and record as much information and data as possible regarding the RAAF Williamtown Air Traffic Control (ATC) operation as it was during 1981. This consequently provides a robust reference for current but particularly, *future* work regarding VH-MDX.

Two air surveillance radars were located at Williamtown during 1981:

- An *Air Defence* radar used for controlling fighter intercepts and performing surveillance
- An *ATC* radar known as SURAD (Surveillance Radar) for traffic separation and airspace management.

The former was confirmed as *not* operating during the VH-MDX accident.

Available key personnel who were experienced in the use and maintenance of the SURAD radar system as installed at RAAF Williamtown were interviewed in detail or simple discussions carried out to gain the best understanding of this radar system and the human factors issues associated with its' use.

During the VH-MDX accident, only *one* Air Traffic Control Officer (ATCO) and at least one technical support member were present in the RAAF Williamtown ATC facilities. RAAF Williamtown at no stage communicated with VH-MDX directly but was communicating with Sydney Air Traffic Services (ATS) via an internal telephone type communications system.

SURAD was equipped with both Primary (PSR) and Secondary (SSR) type surveillance radar. Some useful SURAD specifications are included in figure 24 on page 46.

Many pragmatic traits of the SURAD radar were discovered. In particular, both Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR) coverage from SURAD were found to be reasonably good at low-level being primarily limited in coverage by intervening *terrain or obstacle*s.

SURAD *PSR* and SSR antennae were shown to incorporate designs giving significant vertical low-angle coverage. These are important findings that set the rules for radio propagation analysis.

Accordingly, it was concluded that valid propagation analysis of SURAD could be conducted with simple *line of sight assessments* taking into account effects of earth curvature, terrain and obstacles rather than antenna tilt values. More detailed analysis could be performed by propagation software accounting for diffraction around terrain and objects in marginal cases if required.

Procedural (non-radar) control was in-force at Williamtown during the VH-MDX accident. The SURAD radar was used only for situational awareness to support procedural control. There was no requirement to have the radar on or to use information from it to conduct procedural control.

The radar display was located a few sidesteps away from the procedural workstation making radar observations a conscious effort.

Regarding radar fixes of VH-MDX by Williamtown radar, it was found the only confirmed radar fix was the 320˚M/45NM fix at approximately 0936:00UTC. It was confirmed that the ATCO observed a SSR mode A symbol and a SSR SPI ident symbol from VH-MDX at this position making miss-identification unlikely.

The range of 45NM was shown to be within +2NM /-0NM and quite possibly VH-MDX was located at 46NM during this fix. It was shown how the actual bearing could have been 323˚M-326˚M.

A recorded call on the air traffic communications line revealed a bearing reference of 330˚M with no range when Sydney ATS requested Williamtown for a further VH-MDX fix at 0938:30UTC.

Although this call is attributed to the Williamtown ATCO in the ASIB (Air Safety Investigation Branch) communications transcripts, the Williamtown ATCO does not remember making this call. The ATCO also states if he did make this call that he would have observed the radar scope (PPI) for *precise* information.

It was also discussed how the 330˚M call may have been from Sydney ATC.

A map suggesting that VH-MDX radar returns disappeared in the Upper Williams River Valley at 0940UTC was found unlikely to be a radar *fade* position. This position was named the ASIB/RCC final position by Williamtown radar.

More robust alternatives are that the ASIB/RCC final position by radar is a composite of data for the only common radar position between Sydney and Williamtown: the 0936:00UTC 320˚M/45NM position or, derived by vectoring an aircraft to the 320˚M/45NM radar position and marking the location on the map.

There has been no bearing/range data found of the ASIB/RCC position that would have been *required* to plot the position on a topographical map.

It was shown that VH-MDX could have tracked through either the ASIB/RCC final radar position described or to the deposed Sydney final radar position at approximately 5NM west to north-west of Craven waypoint, and arrive at the 330˚ bearing from Williamtown within expected read-off tolerances and time frame recorded on communication transcripts.

Radar propagation analysis suggests that VH-MDX at the ASIB/RCC final radar position:

- Could *not* be interrogated by Sydney RSR below 10000' AMSL
- Probably could be interrogated by Round Mountain RSR at 6200' AMSL
- Could be interrogated by Williamtown ATC radar at 3500' AMSL

Radar propagation analysis combined with communications transcript timings and altitude calls suggest the ASIB/RCC position is not a radar fade position.

Research is ongoing and future findings will be included in this document.

Table of Contents

1. Introduction

1.1. Purpose

Understanding RAAF Williamtown Air Traffic Control (ATC) as it was during the VH-MDX accident in August 1981 is crucial in forming likely and defensible assumptions as to the location of the aircraft. Williamtown ATC was importantly involved in a number of ways with VH-MDX:

- Williamtown's radar was much *closer* to VH-MDX than Sydney's northern ATC radars (around half the distance)
- Potentially more accurate radar fixes than Sydney ATC radars (because of closer distance)
- Increased probability of radar detection (faster sweep and less terrain obstruction)
- Williamtown's ATC radar features in an intermediate fix and also in a suggested *final radar position* of VH-MDX.

The search for VH-MDX will likely continue for some time following the initial release of this reference guide. Without doubt, new opportunities for analysis will present themselves in the form of new people with alternative views and applicable technology that does not currently exist or, is cost prohibitive today.

Accordingly, as much detail as possible will be recorded in key interest areas and although possibly not of immediate use, will provide a solid base for future use.

Current areas of analysis in the VH-MDX accident involve topics such as human factors, radio and radar propagation analysis and radar fix errors. This document is drafted to support these tasks whilst also offering a long-term reference to minimise repetitive researching.

1.2. Methodology

Information and data will be sought from publications, reports and the like however the main source will be derived from RAAF Air Traffic Control Officers (ATCO), Radar Technicians and Radio Technicians.

The capture in particular of key personnel directly or closely involved with the VH-MDX accident is a focal point.

1.3. Acknowledgement

The support offered by many Air Traffic Control Officers (ATCO's) and Technicians in producing this document is greatly appreciated. Some have gone to great lengths to support this research.

1.4. Note on recent interviews and discussions

Interviewing key personnel over thirty years from an event can result in changed views compared to what was apparent at the time. The author has proceeded as carefully as possible to ensure capture of the most true-to form views of the event however, caution must be applied in using such information.

1.5. Legal disclaimer

The information and data presented in this document must not be used for any legal purpose, as the content may be inaccurate or subject to interpretation errors of the author.

2. RAAF Williamtown ATC

2.1. RAAF Williamtown

Williamtown Airport was in 1981 and remains to this day a Royal Australian Air Force (RAAF) base primarily the home of fighter aircraft. RAAF Williamtown 'owned' large volumes of airspace primarily over the sea but also areas surrounding the Terminal Area (TMA) immediately around the base itself.

Due to Williamtown's location on the coast in the middle of a busy aircraft transit route, light aircraft traffic had to make their way around or through Williamtown's airspace by a number of options:

- Obtain a clearance to track straight through Williamtown airspace
- Obtain a clearance to track along the coast at low altitude
- Track via an inland light aircraft lane at low altitude
- Depending on what airspace was active, track around the terminal airspace via Craven Waypoint or other alternative routes.

2.2. Personnel, procedures and equipment

The basic ATC installation at Williamtown consisted of a control tower, Approach Center and ATC radar. Various navigation aids were installed and separate Air Defence radar (non-ATC) was also installed to support fighter operations. Either procedural (non-radar) or radar based control could be in force.

Air Traffic Control Officers (ATCOs) were supported by Radio and Radar Technicians who maintained and calibrated ATC equipment. A single ATCO located in the control tower and at least one technician was on duty during the VH-MDX accident[4].

During the night of the VH-MDX accident, *procedural* control was in-force, which did *not* require the use of radar[4]. Regardless, the ATCO decided to turn on the ATC radar to give him better situational awareness[4].

2.3. Communications

Williamtown had VHF radio to communicate with civil aircraft and a landline based system to communicate with various Air Traffic Services (ATS) agencies such as Sydney Approach, Radar Sectors or Flight Information Service (FIS).

The sole ATCO on duty during the VH-MDX accident did *not* communicate with VH-MDX *at any stage* during the accident[7]. Sydney Flight Information Service 5 (FIS-5) was the only ATS agency in communications with VH-MDX during the period of interest from approximately 0850 UTC – 0940 UTC[7].

2.4. Airspace

Active Williamtown airspace during the time of the accident was[7]:

- Restricted Area 589 (12NM arc)
- Restricted Area 591B (25NM arc from approximately north to south-west)

Both areas were active to 10 000 feet[7] and are highlighted in figure 1 on the following page.

A clearance to enter Williamtown airspace <u>was</u> offered by the Williamtown ATCO but the clearance was held up by Sydney ATC for appropriate reasons[7]; this will be discussed later. Accordingly, the pilot of VH-MDX decided to track clear of the active airspace[7].

As VH-MDX was unpressurised, flight over the top of the active Williamtown airspace was not possible and was likely to be active Sydney Sector 2 airspace in any case. Using the low-level coastal or inland light aircraft lanes was also not possible as VH-MDX was flying at night (lowest safe altitude considerations).

Tracking via Craven waypoint was the logical choice.

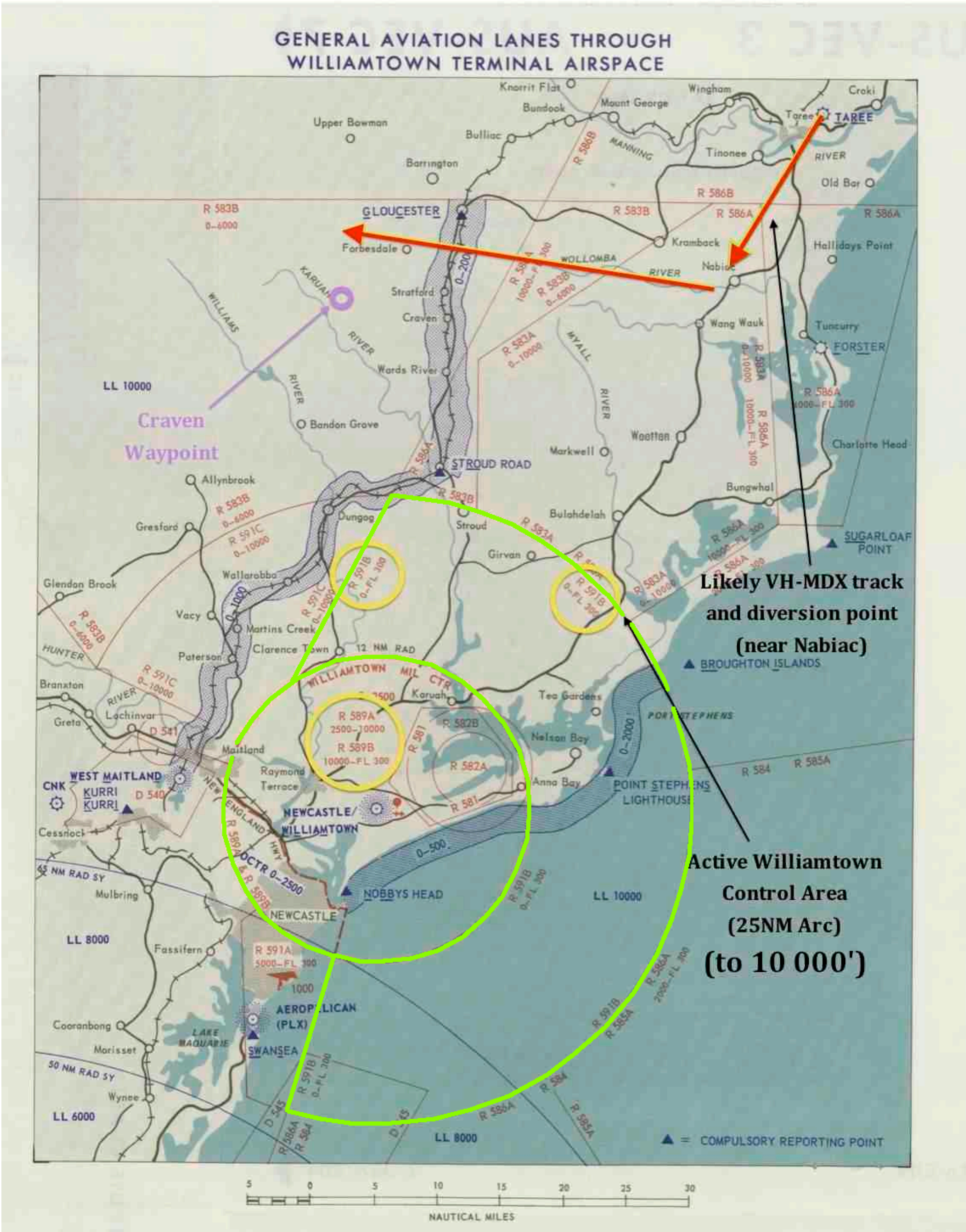


Figure 1: Williamtown airspace and surrounds 1980. Restricted Areas are marked with lime lines. The Restricted Area details are marked with yellow circles. Both active Restricted Areas were in force to 10000'. The red arrows depict the approximate flight path up to a possible turn point. Craven waypoint is marked in purple. (Base chart: AUS VEC-3, Australian Government (Department of Transport) 1980, additions: Glenn Strkalj 2014).

3. Radar

3.1.Overview

RAAF Williamtown had two air surveillance radars installed during 1981. One was an Air Defence surveillance and control radar and the other was an ATC surveillance radar[4][5]. There were other smaller radar units utilised for precision approach onto Williamtown's runways however these were not *surveillance* radars[4][5] thus are not relevant.

3.2.Air Defence radar

An Air Defence radar was located at the north-west section of the airfield. This radar did *not* support ATC operations. According to the Williamtown ATCO on duty during the night of the VH-MDX accident, the Air Defence radar was *not* operating[4]. Accordingly, this radar is not relevant to the VH-MDX accident.

3.3.ATC radar

RAAF Williamtown ATC utilised the *SURAD* (Surveillance Radar) radar at the time of the VH-MDX accident. SURAD featured both *Primary* Surveillance Radar (PSR) (big 'dish' antenna) and a *Secondary* Surveillance Radar (SSR) with the antenna of the latter 'piggybacked' on top of and mounted co-axially to the PSR antenna. SURAD was 1960's technology. PSR and SSR systems will be discussed later. All the following sections will *solely* discuss the Williamtown SURAD ATC radar is it was the only relevant radar at Williamtown.

Figure 2: SURAD radar head. The main antenna or 'dish' services the PSR system and atop this is the SSR antenna. PSR is passive, relying on radio wave reflections from a target. SSR is active in that ground interrogator and aircraft transponder 'talk' to each other. The two systems, PSR and SSR are *isolated* systems other than sharing the same display screens (PPI's). The radar head would be mounted at the top of a steel tower to increase line of sight thus increasing range unlike this museum piece mounted on the ground. (Photo: Fighter World Aviation Museum 2014).

3.4.SURAD head location

The SURAD radar head was located across from the Williamtown Air Traffic Control (ATC) Control Tower, on the southern side of the airfield in very close vicinity to the location of the current Australian Defence Air Traffic System (ADATS) radar head[2][4].

The author has confirmed the SURAD radar head position through a 1987 aerial photo of RAAF Williamtown that displays a shadow of a radar head that is clearly SURAD in shape (unique and distinctive base at top of the tower)[35]. Dispositions of various items of interest at RAAF Williamtown are shown below in figure 3.

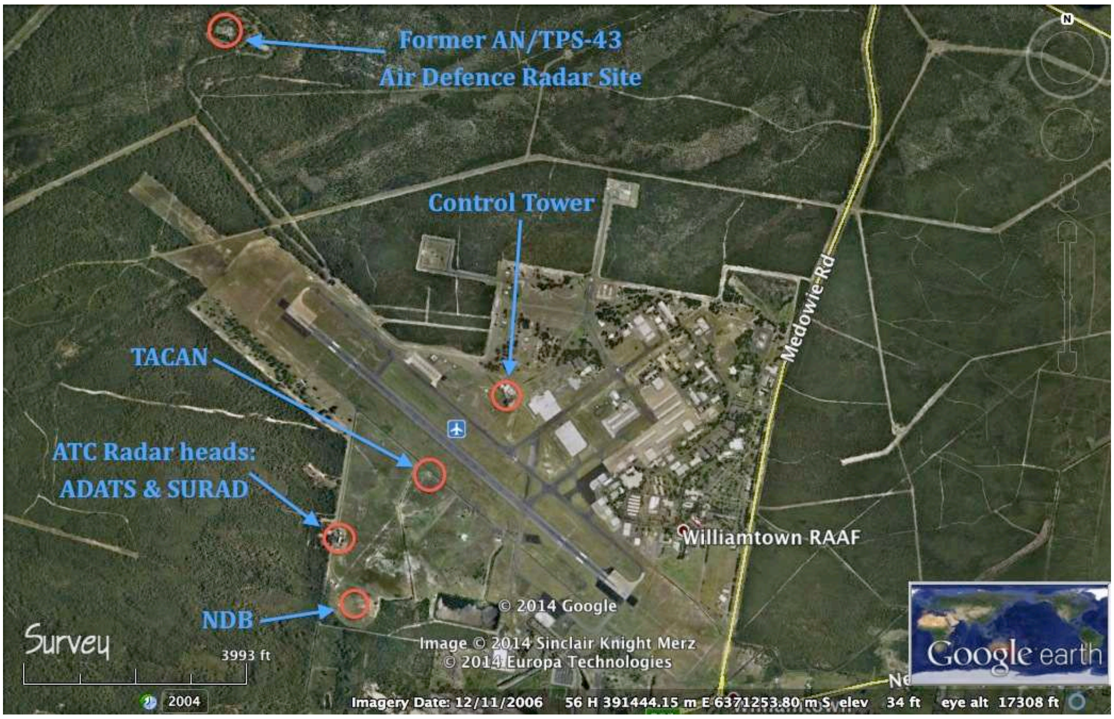


Figure 3: Williamtown air traffic, navigation, and radar equipment locations 1981. Equipment locations are valid for 1981 as depicted. (Image: Europa Technologies 2014, Google Earth 2014, Sinclair, Knight, Merz, 2014).

Of note is that ADATS, the replacement for SURAD, was installed post 1999[34]. The Air Defence radar was at the position marked in figure 3 in 1981. There was no other known permanent surveillance type radar on the base[4]. Accordingly, there can be no confusion with other radar heads in aerial photos.

The SURAD head was mounted on a concrete pad still shown on Google Earth[10] approximately 70m south of the ADTAS head at a position of (WGS84):

-32.800362°, 151.827794°
32°48'1.30"S, 151°49'40.06"E
56H 3 90248.29, 63 70236.35.

Figure 4: 1987 aerial photo of Williamtown SURAD. When comparing this photo with the SURAD photo in figure 2 the distinctive and unique shape of the head base is immediately obvious. The position of the radar head in this photo also matches the general position reported by ATCO's. SURAD was replaced by ADATS sometime from 1999 (Image: NSW Department of Land and Property Information 1987-2014).

Figure 5: SURAD head position 2014. The SURAD head was mounted on the concrete pad approximately 70m to the south of the current ADATS head (Image: Europa Technologies 2014, Google Earth 2014, Sinclair, Knight, Merz, 2014).

3.5. Magnetic variation

3.5.1. Chart derived

Based on interpolation of the c.1981 En-Route Chart from the BASI VH-MDX archives, and a Visual En-Route Chart (VEC) dated 5 August 1982, the approximate magnetic variation for Williamtown to True North is 12.2º East.

3.5.2. Australia Geomagnetic Reference Field derived

Research of the likely magnetic deviation values present in geographical areas of interest for the VH-MDX accident during 1981 was carried out by Glenn Horrocks[9].

This research was based on extrapolation of the Australia Geomagnetic Reference Field (AGRF)[9]. The following value of magnetic variation to *Grid North* in WGS84 datum charts for 1981 was found[9]:

- Williamtown SURAD: 11.430º East

Additionally from the same source the following values of magnetic variation to *True North* for 1981was found:

- Williamtown SURAD: 12.066º East

3.5.3. Conclusion: Magnetic variation

The AGRF values are more likely to be representative of the magnetic variation during 1981 and are recommended for use in plotting and calculations.

3.6. Primary Surveillance Radar (PSR)

3.6.1. What is PSR?

Simply speaking, PSR involves transmitting a pulse of Radio Frequency (RF) energy that reflects off a target then travels back to the radar unit to be received. Bearing (azimuth) of the target is determined by the direction the antenna is pointing and range is calculated by considering the time the pulse takes to go 'out and back'. The antenna is calibrated to magnetic north.

Most PSR systems project an RF beam that is a:

- Very sharp (small angle, 1˚-2˚) focused beam in *azimuth*
- Very broad (large angle, 80˚) in *elevation*.

The beam is mechanically (sometimes electronically) rotated around the full 360˚ in azimuth to enable scanning of the surrounding airspace. One full 360˚ rotation is dubbed a 'sweep'. As the *elevation* beam is broad, a large sector of *altitude* is covered.

The beam is normally pulsed at a very fast rate allowing the same antenna ('dish') to be used to transmit then, when the transmitter turns off for a brief period, to listen for the radar echoes that bounce off a target (receive).

The PSR system knows the time when each pulse was transmitted and when the same pulse is received hence the time interval of 'out and back'.

As the speed of the RF energy equals the speed of light and does not change, a basic distance = speed x time calculation is performed by the PSR system to yield a distance equal to 'out and back': radar head to target and *back to radar head again*.

This distance is halved to give the distance from radar head to target. The bearing of the target is known as the antenna rotation is calibrated to magnetic north.

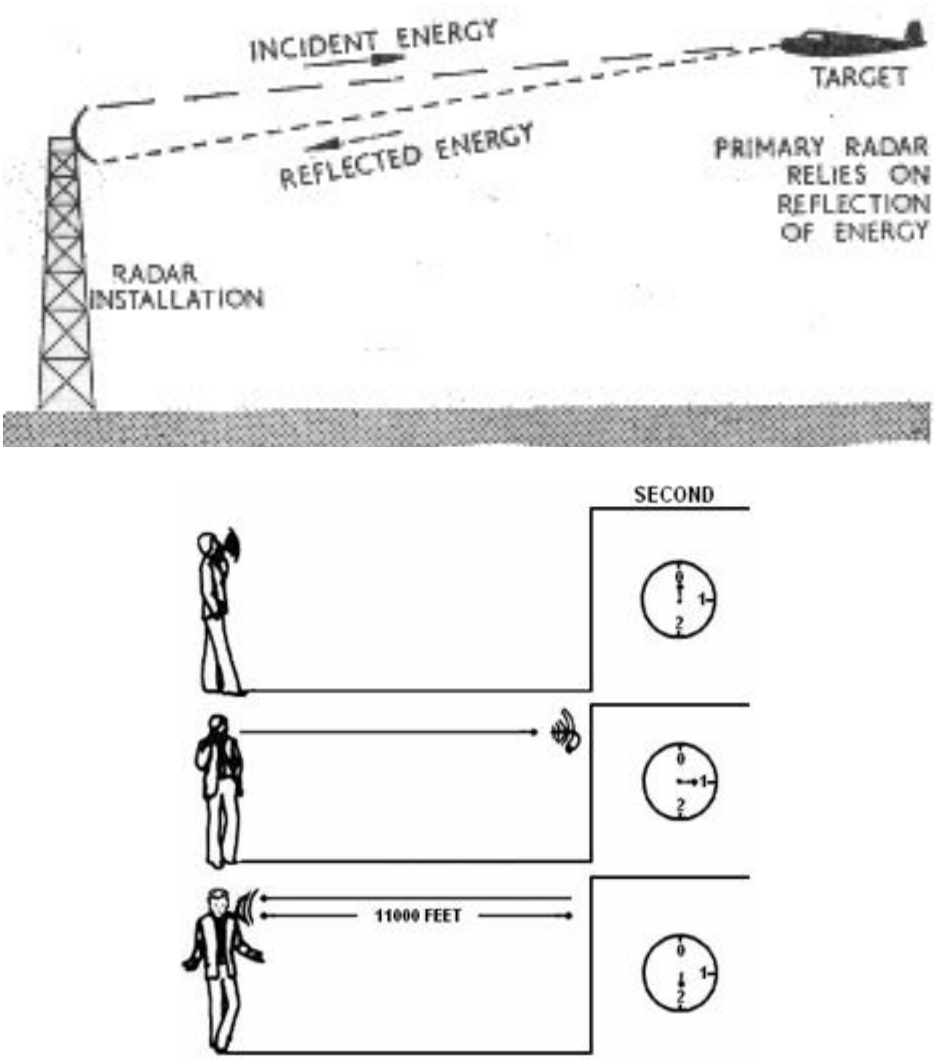


Figure 6: Primary radar concept. Primary radar may be likened to yelling a sound out then listening out for an echo and timing how long it takes for the echo to return (Images: Dick Barrett 2000-2002).

As the RF energy must travel out to the target and back to the radar head, (double the range from radar to target), rather *high* power outputs are required of the PSR transmitter to ensure a signal can be received over intended range.

In fact the received signal strength of PSR reduces dramatically with *range* as a result of the signal having to travel both out and back: $(1/R^4)$[29].

PSR relies heavily on aircraft shape, aspect, size and construction materials to yield a return. PSR returns were displayed on a radar display as arcs in azimuth ('slashes'), the size of which was dependent on factors such as:

- Aircraft *size/ shape/ materials* (effectively Radar Cross Section (RCS)),
- *Range* of the aircraft from the radar head and;
- Target *aspect*: the angular track of the aircraft relative to the radar beam.

The larger the RCS the larger the *PSR* return in azimuth. As a *general* rule (notwithstanding tangential fade and blind speed), a target tracking roughly tangentially to the radar beam would present a larger RCS than a target tracking straight to the beam, radially.

Accordingly, an aircraft on a close to tangential track to the radar beam would *normally* present a larger PSR return in azimuth than if it were tracking head on into the beam.

PSR or SSR returns are commonly dubbed 'paints'. Examples of PSR paints are given below in figure 7.

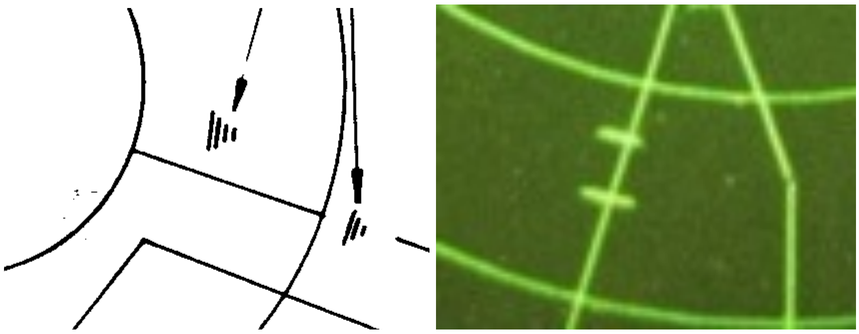


Figure 7: PSR paint 'slashes'. PSR paints on the SURAD PPI were displayed as 'raw' returns shaped as arcs known as 'slashes' as a result of their look. The picture at left shows two aircraft returns marked with arrows whilst the photo at right shows two aircraft along an air-route. PSR returns could easily blend into weather or terrain clutter becoming very hard to discern. Without superimposed *regular* shaped SSR symbols, identification of each PSR return becomes challenging relying heavily on pilot reported position (Image at left: Australian Government (Royal Australian Air Force) 1988, Photo at right: H. Howard c.1983).

SURAD PSR was a simple pulse out, hit target, reflected pulse back system[3]. The PSR was a dual frequency (channel A and B) transceiver selectable to operate either of the single channels or both[3].

PSR transmissions were in the Ultra High Frequency (UHF)[22] IEEE L-Band (1.3GHz)[11]. SURAD was installed at RAAF Williamtown around 1975[5]. Radar returns were displayed on a simple Plan Position Indicator (PPI)[3][4][5][11].

3.6.2. Sweep speed

The Williamtown SURAD was operated as a Terminal Approach Radar (TAR) that was used for decreased separation standards between aircraft (3NM vs. the normal 5NM) required for *terminal* operations (close to the airfield) within about 30NM of the radar head[2][3][4].

Accordingly, a 360° sweep of the antenna in azimuth took 4 seconds[2][3][4] and rotated at 15 Revolutions Per Minute (RPM)[2][3][4][11].

3.6.3. Examples of SURAD PSR paint sizes

An example was given of a 747 in a close to beam/ tangential track to the radar head as painting a 4NM-5NM azimuth paint on the PPI[3]. It was also stated that a pointy nose Mirage fighter or small Cessna 172 travelling radially straight towards the radar would generate a very small paint[3].

The same controller indicated a 1NM-2NM azimuth blip size was appropriate for a light aircraft with A and B transmitter channels on without Circular Polarization filtering (discussed later) selected[3].

3.6.4. Cessna 210 aspect vs. paint

A number of ATCO's also stated that although the RCS of a Cessna 210 would most probably be less head-on as opposed to in the beam considering the aircraft's *fuselage* and *wings alone*, the addition of a spinning propeller would make up for the reduced contribution of *structural* RCS head-on with the propeller presenting a giant radar reflector equivalent to the area of the circle it transcribes[3][4]. Indeed several ATCO's indicated that light aircraft paints did not significantly change with aspect[3][4][5].

The conclusion from this is that a C-210 would be expected to have similar azimuth returns in terms of arc length on the PPI no matter if in the beam or head on to the PSR[3][4]. Consequently, PSR arc size if noted during the VH-MDX accident is unlikely to reveal approximate aircraft track direction.

3.6.5. PSR errors

The SURAD PSR was subject to a number of errors that may have lead to anomalous paints and these are briefly described below[2].

Anomalous Propagation - Usually occurred on clear fine, settled days when the radar waves were refracted off the atmospheric layers causing the radar to see beyond the geometric horizon[2]. The dual beam system generally overcame this problem[2].

Angels - Unwanted radar returns which the MTI system displayed as moving targets[2]. The major cause of angels was unknown but was overcome by dual beam[2].

Lobing - Every radar has additional side lobe beams originating at the antenna and radiating to either side of the main beam[2]. Lobes are also generated by interaction between ground reflected and antenna beams. Lobes are capable of detecting aircraft & producing false images at the correct range, but wrong bearing[2].

Scintillation - Appeared as rapid displacement of the paint due to modification of radar signal as the target aspect changed[2]. Overcome with dual beam[2].

Terrain Shadow – A result of terrain reflecting radar energy. Can usually been seen as a large blob on the screen[2]. Overcome by using Moving Target Indicator (MTI) filtering[2].

Weather - Radar displays a large blob as radar pulses were reflected off raindrops[2]. This was overcome by using Circular Polarization (CP) filtering[2].

3.6.6. SURAD PSR filtering

3.6.6.1. Overview

To remove stationary objects such as terrain or weather from *PSR radar returns*, SURAD employed filters such as Moving Target Indicator (MTI), Fast Time Constant (FTC) and Circular Polarization (CP).

These generally degraded *PSR* performance in that valid targets could be suppressed and effective range limited. Such filters were generally only selectable by technicians and not the ATCO's[3].

3.6.6.2. Moving Target Indicator (MTI)

MTI involved suppressing targets with zero or little (near zero) *radial* velocity. This was achieved through phase comparison of emitted and reflected signals[11]. A range could be set *inside* which MTI was actively filtering and beyond which MTI did not filter[3][4].

SURAD *normally* transmitted on two different frequencies (Channel A and Channel B) simultaneously which assisted in preventing the MTI from filtering valid targets[3][11]. This was due to the differing properties of the two diverse frequencies (two different blind speeds)[3][11].

MTI was usually set to eliminate known objects or terrain. MTI did *not* filter out SSR returns of any speed as suggested in *Operation Wittenoom VH-MDX Research* (2013)[32]; only *PSR* returns that met the criteria were filtered out[3][5].

MTI has been confirmed as being active *inside* 44NM range of the Williamtown radar head during the VH-MDX accident (i.e. MTI was filtering returns from 0NM-44NM)[4].

SURAD MTI also reportedly 'washed out' light aircraft returns within the MTI boundary making PSR returns of such aircraft harder to discern despite being clear of the permanent clutter area[6].

3.6.6.3. Circular Polarization (CP)

CP was used for rain shower suppression and relied on spherical shaped raindrops reflecting CP radar energy in the opposite phase to the original radar transmission[3]. The radar can subsequently reject these opposite sense returns thus suppressing PPI display of rain showers[3].

Aircraft are generally not spherical shaped so stand out more with CP selected (in theory). Despite this, switching CP on does attenuate valid aircraft returns to some degree potentially 'washing-out' PSR returns as MTI did.

3.6.6.4. Fast Time Constant (FTC)

FTC minimizes displayed returns from rain by filtering *long duration* returns; i.e. those returns that persist in *range* are assumed by this method to be rain as rain showers occupy a much larger distance in range than an aircraft[3].

Aircraft have a return that rises and falls rapidly with time due to their small comparative size to a volume of rain. FTC is a differentiator that considers *rate* of change of a radar return which can then be used to discriminate rain related returns and aircraft returns.

3.6.6.5. PSR filtering relevance

Given the Williamtown ATCO easily identified VH-MDX amongst the Barrington Tops clutter by SSR returns[4] (SSR is explained in the next section) and, that it would be very unlikely the pilot of VH-MDX turned his transponder off or suffered a technical failure, SURAD filtering is *not* overly relevant *at this stage*.

MTI was confirmed to be set at 44NM during the VH-MDX accident[4], which is evidenced by the ATCO stating the terrain returns from the Barrington Tops were visible on the PPI set to 48NM maximum range. The mountain ranges associated with the Barrington Tops commence approximately 30NM north-west of Williamtown and extend beyond 50NM[10].

Of relevance is that PSR returns would be very difficult to detect *outside* 44NM in the terrain clutter. But, as long as VH-MDX was squawking an SSR code and within radar line of sight, it is assumed that the aircraft could have been seen on the PPI with a synthetic SSR symbol.

Target paint history (persistence) would have been 'washed out' by the terrain clutter beyond 44NM where VH-MDX would have likely have remained but, as will be seen would not have persisted for the likely time frame between terrain impact and the next conscious ATCO observation of the PPI in any case.

3.7. Secondary Surveillance Radar (SSR)/ ATC Transponder (ATCRBS)

3.7.1. What is SSR/ ATC (ATCRBS) transponder?

SSR does *not* rely on *reflections* of radio energy off an aircraft. Rather, the ground station 'talks' to a piece of equipment on the aircraft called an ATC transponder.

SSR systems allow easier identification and tracking of aircraft compared to PSR as a paint in the form of a synthetic symbol is presented on the radar display. The whole system encompassing both ground and airborne equipment is known as the ATC Radar Beacon System (ATCRBS).

The ground based SSR interrogator (radar) sends a *directional* RF interrogation pulse in *azimuth* on *1030MHz* from the rotating SSR antenna.

An aircraft ATC transponder in view of the directional beam receives this interrogation and replies omni-directionally on *1090MHz* 3us after reception of the ground station pulse with a coded transmission yielding a variety of data. These frequencies lie in the UHF band[22].

Aircraft without transponders fitted or with the transponder selected off or not functioning correctly will not be 'seen' by the ground based SSR.

It can be seen the ATCRBS is totally reliant on the aircraft having a functioning and operating transponder.

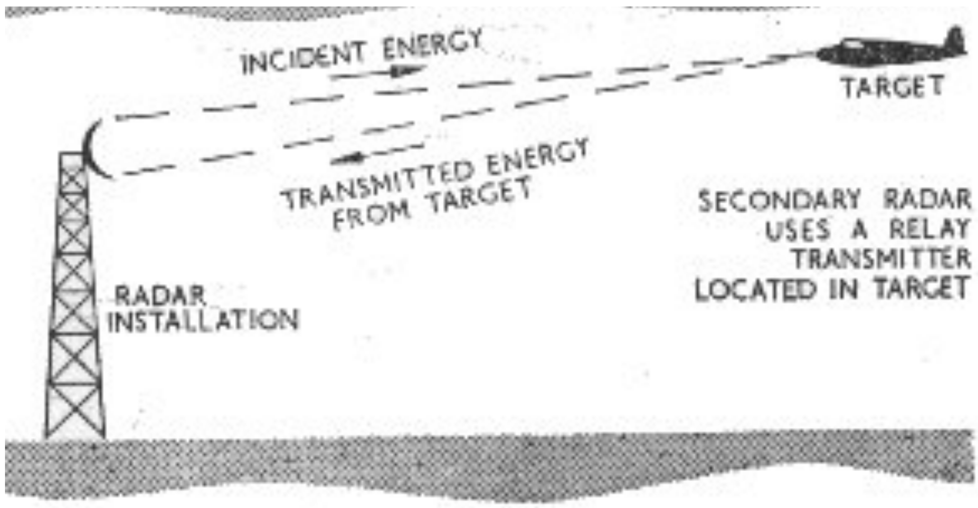


Figure 8: Secondary radar concept. Secondary radar relies on a 'conversation' between ground based and airborne equipment rather than reflections as primary radar does. This results in reliable, easily visible, clutter-free paints on the display (Images: Dick Barrett 2000-2002).

SSR antennas are normally piggybacked on PSR antennas to share the same drive mechanism. The interrogation pulse is transmitted broadly in *elevation* as per PSR to ensure good coverage in altitude.

Azimuth is yielded by the known angular position of the ground radar antenna whilst range is obviously determined from timing of the reply. The term 'squawk' is used to request a pilot to transmit a certain code e.g.: 'MDX squawk code xxx' with the pilot replying: 'MDX squawking code xxxx'.

The horizontal beam width of the SSR interrogator is a little wider (2°-3°) than PSR horizontal beams (1°-1.5°) as more interrogations of the aircraft (4-8) are required in a beam-width to yield reliable processing and display[29]. This does not suggest SSR systems have any less azimuth accuracy than PSR: indeed several SURAD ATCO's have stated that they do not recall the SSR and PSR paints ever misaligned away from each other[3][4][5].

3.7.2. ATCRBS benefits

As ATCRBS involves a communications exchange between ground SSR and aircraft transponder rather than detecting simple radio frequency *reflections*, ATCRBS[23]:

- Does not detect weather (no weather clutter)
- Does not detect terrain (no terrain clutter)
- Offers simple and fast *identification* of aircraft through assignment of discreet codes
- Displays synthetic, clearly discernable symbols on radar displays
- Requires significantly less radiating power than PSR as there is a transmitter at 'both ends' ($1/R^2$ vs. $1/R^4$ for PSR)[29]
- Allows simple receiver construction (high sensitivity not required)
- Offers encoded altitude readouts of suitably equipped aircraft
- Long range aircraft detection does *not* rely on aircraft shape, size, construction and aspect[29]
- High probability of detection (>95%) if in line of sight[29]
- Decreased chance of displaying false targets[29]
- Emergency codes can be transmitted alerting ATCO's of a problem[8].

3.7.3. ATCRBS paints

SSR symbols are normally displayed over the target's PSR paint (if available). The SURAD SSR system was reported by a former technician with extensive experience on the radar as being highly reliable from a maintenance point of view[12]. Examples of SURAD SSR paints are shown below in figure 9.

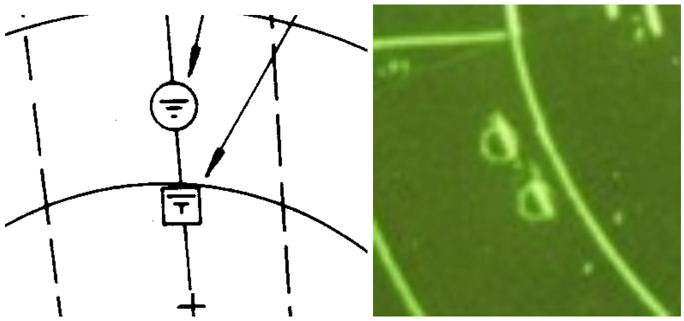


Figure 9: SSR Mode A symbols. Actual SURAD PPI photo at right. In the examples given PSR paints are bracketed by synthetic SSR symbols. The left image shows a circle for one aircraft and a square for the other and in the photo at right two circles. The synthetic shapes being of regular form can be discerned more readily if the aircraft is in terrain or weather clutter than PSR 'slashes' which would blend in (Image at left: Australian Government (Royal Australian Air Force) 1988, Photo at right: H. Howard c.1983).

3.7.4. Multiple ground station interrogations

It was stated in *Operation Wittenoom VH-MDX Research* (2013)[32] that: *'…only one radar (Sydney OR Williamtown) could see the SSR 'squawk' at any time, not both.'*

In the context of the document, this statement suggested only one SSR ground station could interrogate an airborne transponder across a period of time and further implied that a mode A code change was required to allow the 'other' ground stations to interrogate the airborne transponder.

This was <u>not</u> the case as multiple SSR ground stations could have successfully interrogated a single transponder across a short period of time and displayed the return[3]. Also, multiple aircraft could have squawked the same mode A code with all these aircraft being visible to the SSR ground station(s) in view. This is what the ATCRBS was designed to achieve.

The only real limitation was if multiple SSR ground stations interrogated a single transponder at the <u>same</u> <u>instant</u> but this occurs very rarely and valid returns are achieved shortly after the ground stations interrogate at differing times again.

3.7.5. Coded information

3.7.5.1. Mode A

A specific four-digit code known as Mode A or Mode 3/A could be dialed in by the pilot on the transponder. This code would be sent in the reply transmission back to the SSR ground station that could then be displayed on the ATCO's PPI with a synthetically generated symbol. The ground station could be pre-programmed to display a certain symbol type for a particular received code.

Mode A can allow identification of an aircraft through allocation of a *specific* code (e.g. 3726) or identification of an aircraft conducting certain operations through allocation of a *generic* code (e.g. Instrument Flight Rules aircraft squawking code 2000).

Today, most ATC surveillance radars are able to generate a tag indicating the code next to the applicable radar return for any mode A code possible; i.e. an ATCO can know the *exact* code of any aircraft returning SSR information to the radar simply by observing the tag next to the return.

The SURAD however, was only able to simultaneously allocate *four symbols* to *specifically defined* non-emergency mode A codes at a single time[4][5]. These symbols would then represent the *preset* codes.

There was no display of the numeric value of the codes as is possible these days thus the ATCO had no *other* way of determining what the mode A code of each aircraft displayed was[3][5].

The allocation of symbols were preloaded into the SSR equipment with thumbwheel switches[3][5]. All other SSR mode A codes other than the four preselected would appear with a common symbol, reportedly an inverted 'Y' at the Williamtown SURAD[5].

Once SURAD SSR received a mode A code from an aircraft transponder, either the pre-allocated or common symbol (inverted 'Y') for that code would appear on the PPI and would represent the aircraft's position as long as the aircraft transponder was 'squawking' and in line-of sight of the SURAD.

3.7.5.2. Mode C

Mode C involves providing the aircraft transponder with coded barometric altitude information (of the current aircraft altitude) that the transponder then transmits as a coded altitude message to SURAD. The altitude of the aircraft could then be presented to the radar operator.

Such altitude information from the aircraft is referenced to the 1013hPa datum and is not adjustable. Some ground radar stations can compensate for the actual Mean Sea Level (MSL) pressure (QNH) to yield an *altitude* rather than a *Flight Level* (referenced to 1013hPa).

SURAD could only interrogate a *single* aircraft transponder for mode C information at a time[34].

It was suggested likely by a SURAD ATCO that only the *approach* control station PPI had a track ball with which the ATCO would hover over the SSR identified aircraft in question to read off mode C encoded altitude information (provided the aircraft enabled the 'Alt' function on the transponder)[2].

A very experienced SURAD user at Williamtown asserted there was *no* mode C interrogation ability at the *tower* PPI[5]. Accordingly, it can be reasonably concluded that there was no mode C encoded altitude information available to the Williamtown ATCO in the control tower during the MDX accident.

Additionally, mode C was not indicated as available on VH-MDX's flight plan suggesting no mode C capability of the aircraft transponder[7].

3.7.5.3. Special Position Identification (SPI)

Special Position Identification (SPI) was a function directed by ATC and selected by the pilot pressing the momentary 'ident' switch after which the aircraft transponder would transmit the SPI code during each interrogation[23] for approximately 15 to 30 seconds[23].

The SPI code would be displayed by SURAD as a *triangle* over the PSR paint and mode A symbol if either were apparent[3][4][8].

Figure 10 shows a selection of SSR symbols including SPI triangle and PSR returns on a zoom of a notional PPI.

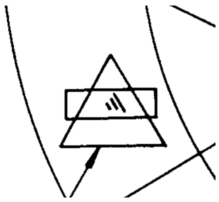


Figure 10: SSR SPI triangle symbol. When a pilot presses the 'ident' button on the aircraft's transponder, a sizeable triangle symbol appeared superimposed over the SSR mode A symbol and PSR returns (if any) for 15-30 seconds. In this picture there are PSR return 'slashes' bracketed with a mode A oblong symbol and SPI triangle. The attention getting effect of the SPI triangle can readily be seen and provides positive identification to the ATCO (Image: Australian Government (Royal Australian Air Force) 1988).

SPI enabled *positive identification* of an aircraft as theoretically the aircraft requested to 'squawk ident' would be the only aircraft transmitting SPI in the area of interest.

3.7.6. SURAD SSR symbols

3.7.6.1. Symbol size

In order to gain an understanding of how SSR symbols affected the accuracy of operator bearing readings, the question arises of the size and shapes of the SSR symbols that were presented on the SURAD PPI.

SURAD SSR symbol sizes on the PPI were actually variable in *size* set by the technicians[3].

So, dependent on what was set by the technicians, a grossly over-sized SSR symbol could be displayed or perhaps a much smaller and appropriate symbol may be displayed. There appeared to be no standard size.

3.7.6.2. Allocation of symbols

Only *four* SSR non-emergency, mode A codes were able to have *separate* symbols *allocated* and displayed at one time[3][5].

All other mode A codes (except the three emergency codes) would present as a common symbol: an inverted 'Y'[33].

It was stated the four available symbols for preselect were a diamond, square, oblong and bow tie[3], whilst a circle allocated to a common civil aircraft SSR code was also suggested[5].

The photo on the next page (figure 11) of Darwin SURAD SSR preset panels shows a square, oblong, diamond and circle alongside code preselect switches.

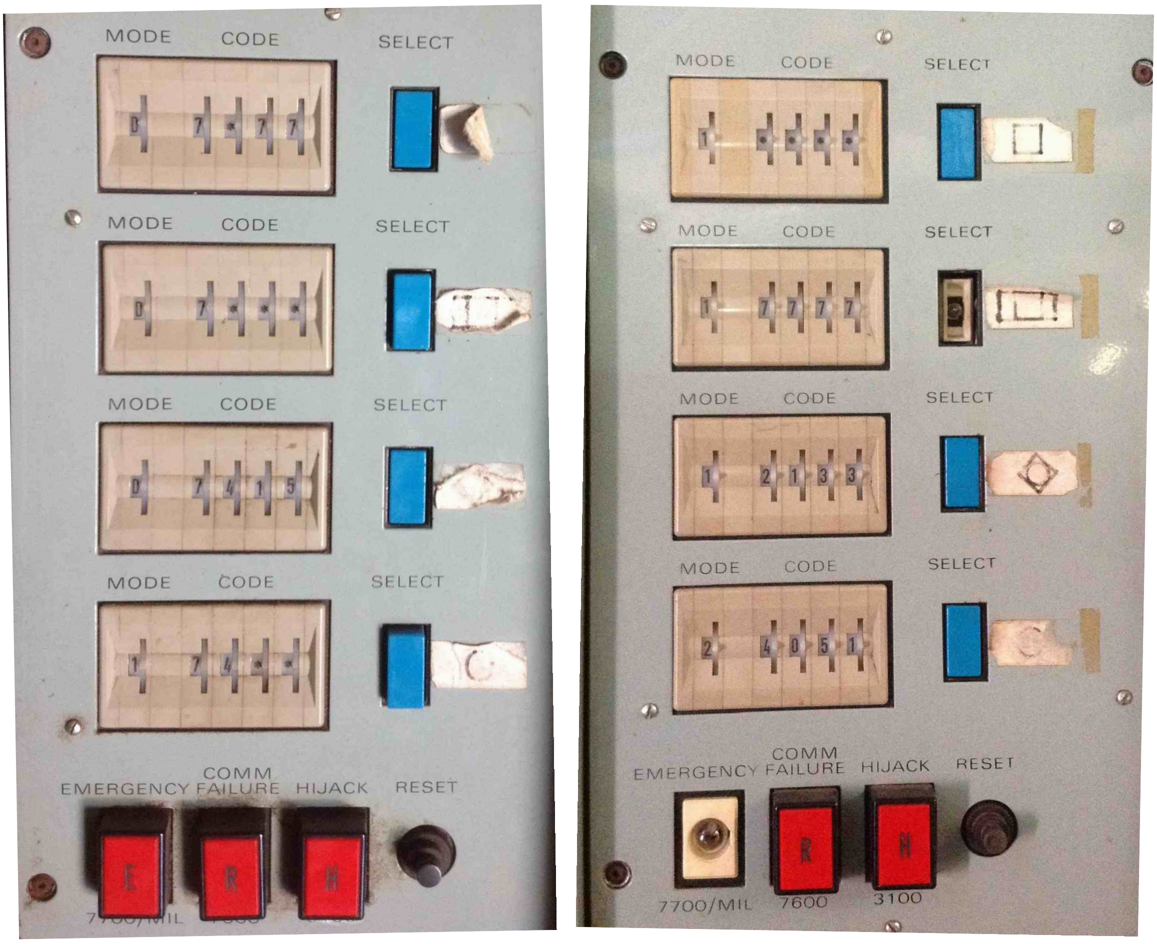


Figure 11: SSR Symbol presets: Approach PPI. Left photo Approach PPI, right, maintenance PPI. The 4 pre-settable SSR symbols could be set by these dial switches at the Approach PPI. It is believed these switches were *not* available on the tower PPI. The right photo shows the symbols allocated to each preselected code (square, oblong, diamond, circle). Emergency SSR codes are indicated with the three red lights at the bottom and were presented on the display with an 'R', 'E' or 'H' (Photo: Glenn Strkalj, 2014, access to SURAD PPI courtesy of The Australian Aviation Heritage Centre).

These four symbols were each preset to represent a mode A SSR code each preselected by the ATCO or technician[3][5]. On the *Approach PPI* (left photo figure 11) the ATCO could select the symbol allocation via rotatable dials positioned next to the relevant symbol[3] whilst a similar setup was located on the maintenance PPI (right photo figure 11).

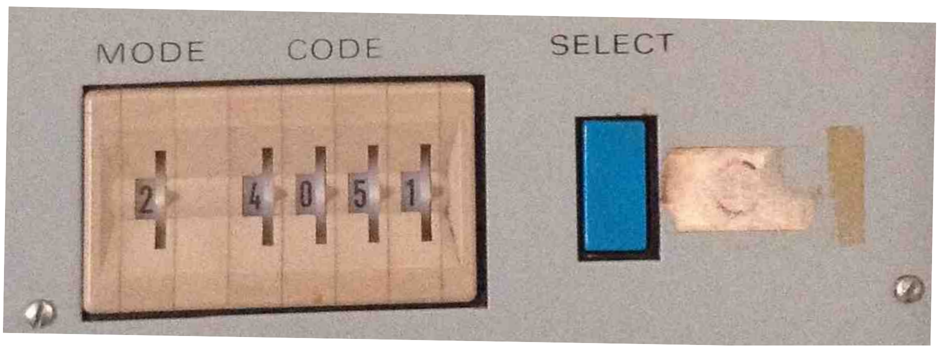


Figure 12: SSR symbol preset. Displayed SSR symbols could be allocated to a specific ATCRBS mode code as preset by the thumbwheel switches shown. In this case aircraft squawking mode 2 code 4051 would be displayed by a circle (as drawn on the sticker to right) on the PPI when the 'Select' button was pushed to on. Note: mode A is also known as mode '3A' so, would be represented as mode '3' using the thumbwheel switches (Photo: Glenn Strkalj 2014, access to SURAD PPI courtesy of The Australian Aviation Heritage Centre).

An individual code could be selected by the rotary thumbwheel switches that would then allocate the symbol marked adjacent to the switch to that particular code.

Alternatively, just the first digit could be selected and the remaining three digits could be selected to '*' (i.e.: 3***). This would allocate the symbol marked adjacent to the switches to every code that started with '3'; e.g.: 3000, 3277, 3600, 3123 etc.

An example of this is in figure 11, left photo, second rotary switch down from the top. A code of '7***' is selected and if one ignores the 'Mode' selector and assumes mode '3' was set, an oblong would be displayed for any non-emergency mode A code received with '7' as a first digit.

The *Control Tower* PPI had no SSR preselect switches installed and was a slave of the approach PPI. This meant the tower PPI displayed SSR symbols as allocated by the *approach* PPI switches[33].

An SPI triangle symbol as described in section 3.7.5.3 was also available to indicate an aircraft squawking ident. *Emergency* mode A codes were represented by a letter over the PSR paint: R (radio fail), E (emergency), H (Hijack)[5]. Figure 13 gives examples of SSR symbols over PSR returns including discreet mode A symbols and emergency letters.

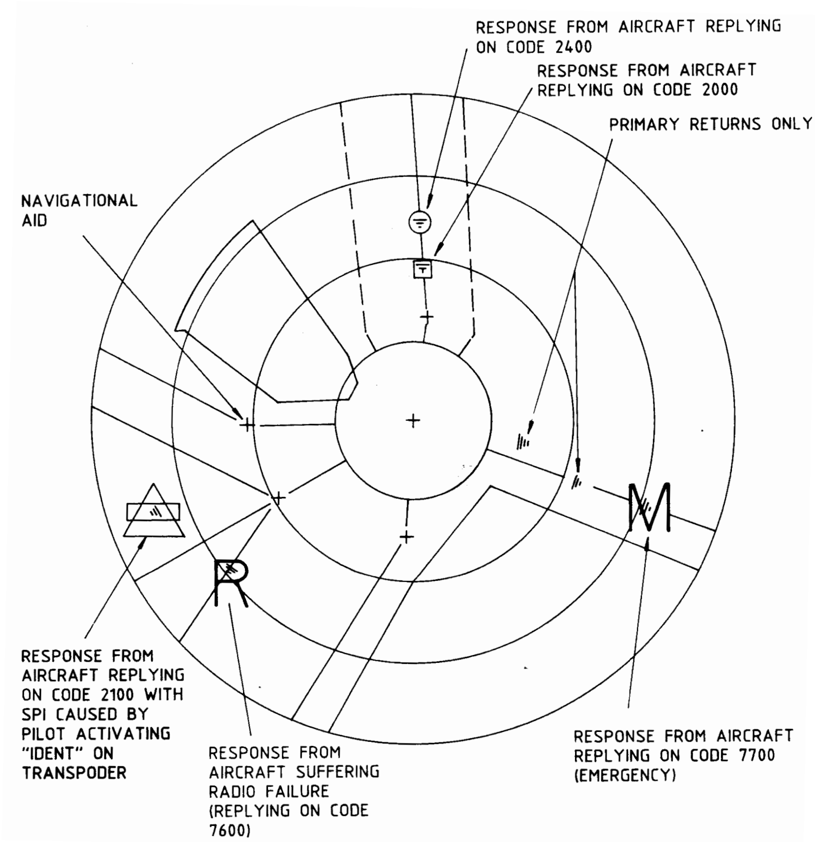


Figure 13: SSR and PSR returns. Note the SPI (ident) *triangle* over the top of an *oblong* that represents a mode A code of 2100 in this case and the PSR paint beneath. The 'identifying' effect of the SPI triangle over a PSR paint or SSR mode A symbol can be seen. SPI signals are transmitted for approximately 15-18 seconds following the push of the ident switch by the pilot. Note that SSR symbols can be allocated to different codes than displayed above (Image: Australian Government (Royal Australian Air Force) 1988).

3.7.7. ATCRBS errors

The following are some errors of the ATCRBS system that may lead to incorrectly displayed information[3].

Garbling - Occurs when two replies enter the radar system close enough in time for their pulses to interleave or overlap. Usually occurs when two aircraft are within +/- ½° of each other and <2NM in range. Resolved by getting one aircraft to squawk 'standby'.

Reflections - large surface areas close to the radar head reflects a true return in a spurious direction (multi-path propagation). The reflection tends to appear at a slightly greater range than a true return[3][8]. The reflection has an identical SSR characteristic as a true plot but no associated primary return. Elevating interrogator antennas to minimise projection of excessive power towards the ground assists in minimising multi-path propagation[29].

Fruiting/Lobing - Transponder simultaneously activated by more than one interrogator (e.g. Sydney and Williamtown radars). This is removed with coincidence circuits in the SSR unit.

3.8. Displays (Plan Position Indicator-PPI)

3.8.1. Overview

The radar track information was displayed on monochrome Cathode Ray Tube (CRT) screens, similar to an old green or amber only colored screen for a computer[3][5][11].

Such a screen in ground based radar use depicting *azimuth* and *range* in a map like 'plan view' fashion with basic map or range ring features is dubbed a Plan Position Indicator (PPI)[3].

3.8.2. Number of PPI's

A SURAD set up was reported as generally having a minimum of *four* PPI's[12]:

- An amber PPI in the radar head used for diagnostics purposes mounted on a wheels than could be wheeled around within cable length restrictions
- An exact, identical amber PPI as above located in the tower or Approach Center also used for diagnostic purposes and not used by ATCO's
- A larger (than the diagnostic scopes) green raster PPI in the control tower
- A green raster PPI in the Approach Center, larger than the control tower PPI[12].

The disposition and number of PPI's in the Williamtown ATC setup of 1981 is important to know in order to consider or eliminate who may have observed radar paints of VH-MDX.

Figure 14 on the next page presents a maintenance PPI and an approach room PPI.

Figure 14: SURAD Maintenance PPI (left) and Approach PPI (right). (Photo: Glenn Strkalj 2014, access to SURAD PPI courtesy of The Australian Aviation Heritage Centre).

There were *at least* two *ATCO usable* PPI's in the Williamtown ATC buildings; one was a display for the approach controller located in the approach center building (which was a stand alone building detached from the control tower) and another was located in the control tower for the tower controllers[3][4][5][12]. The approach PPI was larger than the tower PPI[3][4][5].

Figure 15: **RAAF Williamtown *Approach* room SURAD PPI.** North is at the top of the PPI. The compass rose on the circumference displays bearing in 10˚ increments with 5˚ markings in between. 10NM spaced rings are displayed to determine target range whilst airspace boundary markings and reporting points (small triangles) are also displayed. PSR returns show as arcs on the PPI with a good example of aircraft being at approximately 25NM west where three PSR returns are apparent. To the north-west from around 43NM are the permanent echo terrain returns of the Barrington Tops and the effects of MTI filtering can readily be seen with suppression of terrain occurring sharply from about 43NM and less. At approximately 32NM to the west-south-west are two PSR returns from aircraft that are also returning an SSR code as indicated by the symbols (circles) superimposed over the top. It can be seen from these two aircraft how SSR symbols overlay the PSR return. (Photo: H. Howard c.1983).

3.8.3. Range markings and origin point

On the tower and approach screens, tracks and airspace boundaries were illuminated to facilitate situational awareness for the controller.

Range rings were *selectable* between 5NM and 10NM intervals to allow assessment of target range from the radar head[5].

The center of the PPI is by default centered to the radar head position[2][3][4][5] but, there was a capability to offset the PPI origin[3][5][6] away from the radar head location. This will be discussed later.

Maximum range of the PPI (distance at the outer edge) was reported as selectable by Williamtown SURAD ATCO's between 12NM[5], 24NM[5], 48NM and 96NM[2][4][5]. This is shown in a photo of an approach PPI workstation in figure 16.

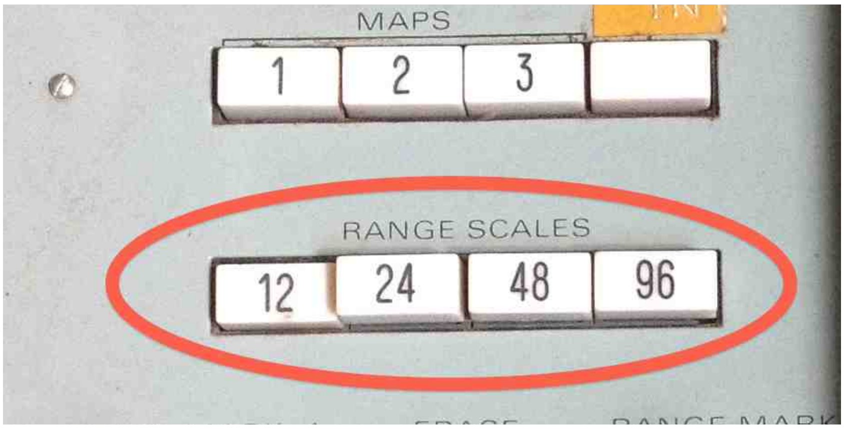


Figure 16: Maximum PPI range selection buttons. Range selector buttons shown were located on a SURAD *approach* console. Changing range resulted in long time periods of display blanking (Photo: Glenn Strkalj 2014, access to SURAD PPI courtesy of The Australian Aviation Heritage Centre).

Switching between these maximum ranges was reported as making the PPI go blank for 5-10 seconds thus, maximum range was switched only when absolutely necessary[4].

3.8.4. Bearings

A compass rose was situated on the outside of the screen to allow controllers to determine target bearing by either 'eyeballing' or placing a pen or other straight edge from the center of the screen through the centroid of the paint and then reading off the bearing on the compass rose[3][[4][5].

The compass rose on the *approach* PPI was marked with 10° markings annotated with the actual bearing and 5° intermediate markings in between[3][4][5].

It is believed that the tower PPI was marked similarly[3][5]. Bearings were referenced to *magnetic* north[3][4][5].

Bearings were also found by using the 'north sweep line', a single line oriented north on the PPI that would illuminate with every sweep then persist[3].

ATCO's could pick the east, south and west quadrants then break these quadrants down visually to assess the target's bearing[3]. This line also assured the operator the radar was still functioning[3].

One ATCO commented: '*When it comes to picking headings for vectors, instead of trying to pluck a heading, it is far easier to ask the pilot his present heading.*'[3]

3.8.5. Offset function

The center point or origin of the PPI could be moved to a different location by the ATCO[3][5][6] to facilitate controlling in instances such as:

- Where the radar head was located at a distance from the base[3][6]
- To maintain reasonable return sizes with 48NM scale at a distance beyond 48NM (as 96NM scale resulted in very small radar paints)[5]
- To monitor particular sectors more efficiently.

Offsetting the origin resulted in disqualifying bearings taken *from* the PPI *origin* through the target to the bearing rose thus, making bearing read offs a little trickier[3][5].

An example of such remote radar head mounting was at RAAF Pearce where the radar head was located some 5NM to the west of the base[3]. A former ATCO who served at RAAF Pearce talks of how he regularly used the offset function to move the PPI center over the TACAN as aircraft reported in reference to this navaid[6].

A button between the two offset controls reset the PPI origin back to the radar head[5]. Figure 17 highlights the offset controls and reset button.

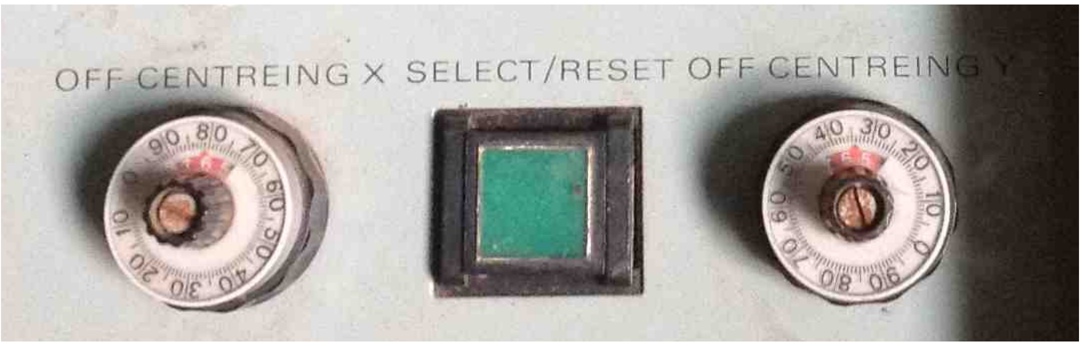


Figure 17: PPI offset controls. The displayed area on the PPI could be offset away from the radar head at origin position. Two controls were available to move the PPI origin position in both the X and Y-axis. The offset was then activated or cancelled by pressing the 'Select/Reset' button. (Photo: Glenn Strkalj 2014, access to SURAD PPI courtesy of The Australian Aviation Heritage Centre).

The Williamtown ATCO reports that offset was *not* used on the night of the VH-MDX accident thus, all bearings and distances were referenced to the radar head location[4].

3.8.6. Control tower PPI

A photo of the Williamtown control tower workstation is presented in figure 18 on the next page. The Williamtown control tower main work area (benches, displays seats etc.) faced south towards the runway[4].

The tower PPI was oriented north 'up' relative to the ATCO and this accordingly resulted in the north side of the PPI facing towards south (180° out)[4]. The Williamtown ATCO on duty during the VH-MDX accident indicated this was of no concern in regards to achieving correct situational awareness of radar targets[4].

Tower duties involved much moving around to visually check traffic and to access the various co-ordination communication lines, phones, printer and strips that were dispersed around the tower[4][5].

For these reasons, checking the tower PPI for information was a *conscious* effort[4]. Despite this, it can be seen how errors could easily be made particularly under high workload such as walking over and having a 'quick glance' at a paint position.

To block out sun glare, a cylinder about 30 cm high surrounded the tower PPI[4][5] and was reportedly only removable by technicians [4]. The Williamtown ATCO on duty during MDX's disappearance believed this screen was still attached but was not a factor, nor did he believe the smaller size of the tower PPI relative to the approach PPI, was detrimental in determining VH-MDX's position accurately[4].

Figure 18: Williamtown control tower c.1970's. The SURAD Tower PPI is apparent albeit not the information displayed. It was reported that the angle of the PPI and low layout in the console resulted in poor ergonomics[5]. Specifically, head movements between looking outside, strips and the PPI was unnatural[5]. As the tower was situated south, sun glare from a rising or setting sun would restrict readability of radar returns on the PPI[5]. Accordingly, a metal shroud was incorporated to reduce glare on the PPI[4][5]. Note the locations of communication equipment and flight strips away from the PPI. The ATCO during the night of the accident would likely have operated between the two green arrows, the distance being estimated at around two meters[5]. The main procedural area was between the second ATCO from the foreground to the position of the far arrow[5] (Photo: H. Howard c.1970's).

There was no ability to receive encoded altitude information (mode C SSR) from an aircraft transponder with the *tower* PPI[5]. The compass rose around the tower PPI was reported as being made of clear plastic and located around the edge of the PPI laying *flat* on the screen thus, negating parallax read off error[5].

10˚ magnetic bearing values with marks were displayed and it is likely intermediate 5˚ bearing marks without values were also displayed on the rose[5].

It was suggested by one ATCO[4] that the compass rose was *unlikely to be*, and by another ATCO, *definitely not,* backlit[5] to facilitate reading of bearings. Ambient light from the tower or light reflections from the PPI itself were required to read the compass rose bearings[5]. Accordingly, the compass rose was as reported by one ATCO 'not easy to read' at night[5].

Low ambient light conditions were generally set at night during arrivals and departures to facilitate visual sighting of aircraft and during these times the lack of such lighting would hamper compass rose reading according to one ATCO[5].

Figure 19: SURAD Tower PPI controls. Left photo is a zoom of the Williamtown Tower PPI control panel, the right photo a SURAD *approach* PPI control panel from Darwin SURAD. Both appear similar so, the Darwin SURAD panel can be used as a reference to determine controls (Left photo: H. Howard c.1983; Right photo: Glenn Strkalj 2014, access to SURAD PPI courtesy of The Australian Aviation Heritage Centre).

3.8.7. Read-off tolerances

In order to achieve an *accurate* bearing, it was important to determine the centroid of the radar return displayed so that the ATCO could take a bearing through it. This was regardless if using a primary or secondary return.

Section 3.8.4 described two methods of bearing read-off. A pen or other straight edge could be used to 'rule-off' a bearing through the centroid of the radar paint to the compass rose.

Another method was to use the 'north sweep' line illuminated during every sweep to break the display *visually* into smaller and smaller sectors: e.g. 90˚, then thirds to 30˚ segments followed by further visual dissection to thirds again (10˚ increments)[3]. A reasonable bearing could then be eyeballed of a target[3].

An ex user of SURAD stated 5˚ bearing accuracy could readily be achieved by a quick measure with 2˚-3˚ the norm and a reading accuracy down to 1˚ possible with a good operator taking an exacting method with the larger *approach* PPI[3]. A quick visual assessment of bearing could yield up to +/-10˚ of tolerance[3].

Another ATCO who utilised SURAD at Williamtown stated 5˚ was the 'normal' expected tolerance in read-off [2]. Bearing accuracy achievable with the tower PPI was suggested as 2˚-3˚ when assessing with care[5] and 2˚[4] when being particularly prudent. Range read-off tolerance was suggested by two ATCO's as +/-1NM[3][4].

3.8.8. PPI manning

During the night of the VH-MDX accident, the only ATCO present in Williamtown ATC was the *tower* ATCO[4]. A technician was also 'present' on call to the ATCO but may or may not have been in the ATC complex at the time of the accident[4].

It was stated by ATCO's[3][4] that the ATCO on duty could always contact the duty technician(s) and direct them to observe a PPI and listen to radios however, the ATCO on duty during the VH-MDX accident states no such direction was required or given[4].

Consequently, it is reasonably probable that only the tower ATCO observed the PPI during the VH-MDX accident although strictly speaking, *one cannot rule out the technician observing a PPI during the accident*.

3.9.Persistence

3.9.1. Definition

During each radar sweep, paints would be brightened if they were still reflecting PSR energy or responding to an SSR interrogation. As the sweep continued away, the return intensity would gradually fade to be reenergized by the next passing sweep; provided the paint was still reflecting energy or responding to a secondary interrogation.

This gradual fade of a non-responding paint is dubbed *persistence*.

3.9.2. Differing sources

The input to the PPI screen that 'directed' the sweep to brighten a paint was sourced separately from both the *PSR* detection and also the *secondary* radar response.

So, one could have a continually bright secondary symbol displayed on the PPI as a result of continued transponder interrogations but, at the same time, a fading *PSR* blip as a result of being beyond PSR range for instance.

The *individual* display *returns* were dependent on the *individual radar sources*.

3.9.3. Number of sweeps expected to fade

Should both primary and secondary returns from the aircraft cease, the fade rate of the returns (*persistence*) was dependent on factors such as age, condition and quality of the fluorescent coating on the PPI[3][4].

It was stated by one RAAF ATCO using SURAD at Pearce and East Sale[3] that such targets would normally vanish after 1-2 sweeps of the radar in azimuth but generally not beyond 2-3 sweeps.

A Williamtown ATCO suggested *around* 3 sweeps dependent on return strength[2]. The Williamtown ATCO on duty during the VH-MDX accident stated a maximum 4-5 sweeps before fade[4] and this was also suggested by another former Williamtown ATCO[5].

A characteristic of PPI's was a relatively short persistence time compared to a scan-converter type display as Sydney used[39]. This is apparent in the suggestions that SURAD ATCO's have given regarding persistence times.

3.9.4. Expected time of fade (persistence)

Considering a 4 second radar sweep and various reported maximum target persistence sweeps, the following times of maximum persistence are found:

Maximum sweeps before fade	Paint fade time (seconds)
1	4
2	8
3	12
4	16
5	20

Figure 20: PPI target fade times. Fade times were very much dependent on individual PPI condition but would have been within a certain fixed range. Reported fade times from a variety of different SURAD PPI's and ATCO's indicate reasonable consistency in fade times and also that fade times were measured in seconds not minutes.

From this it can be seen that target paint persistence on the SURAD PPI was typically between 4 - 20 seconds.

3.9.5. Effect of terrain or weather clutter

Dense clutter from weather or terrain can *pragmatically* reduce persistence times of returns after an aircraft ceases responding to interrogations.

This occurs by the green weather clutter 'washing out' the contrast between fading aircraft paints also coloured green[4][6]. Without weather clutter the screen background is normally black which provides a good contrast ability to green aircraft paints[4][6].

3.9.6. Determining track of an aircraft

The persistence characteristic can be used to determine an aircraft's track by observing the fading returns compared to the current return. An approximate bearing can be 'ruled off' along the fading returns or turns may be observed.

The Williamtown ATCO reported in the case of VH-MDX, that there were no history trails as VH-MDX returns were located in the Barrington Tops terrain clutter which 'washed out' contrast of the VH-MDX returns (green on green background rather than green on black background)[4].

Despite this, the ATCO did get the impression that VH-MDX was tracking easterly but was not completely sure what gave this impression. Section 4.4.9 will discuss this further.

3.10. ATC recording ability

3.10.1. Radar tracks

A former SURAD technician[12] and two former ATCO's[4][5] that operated SURAD have stated there was *no* radar track *recording* capability with SURAD.

One ATCO[4] advised that a still camera was sometimes available nearby to capture snapshots of the PPI. The ATCO on duty during the VH-MDX accident stated he did not have a camera[4].

3.10.2. Communications

Communications at Williamtown ATC was recorded through the use of magnetic reel tapes[3]. Recordings from Williamtown are evidenced in the ASIB (Air Safety Investigation Branch) communication transcripts as it appears *specific* events in the Williamtown ATC arena are recorded (aircraft landing etc.)[7].

Despite this, the latter may have been recorded via the Williamtown intercom to Sydney. It cannot be confirmed if the Williamtown tapes were used in ASIB transcripts.

3.11. Radar coverage in elevation

3.11.1. Background

There have been comments made by VH-MDX researchers of how preset upwards radar antenna tilt in elevation would cause radar blind spots below such an elevation tilt value. e.g., many radars have an upwards antenna tilt of 2°-3° so, conclusions were made that below this elevation angle, there would be no radar coverage.

In particular, Nolan in *Operation Wittenoom VH-MDX Research* (2013)[32] makes a suggestion that there was no radar coverage below 1° elevation at the Williamtown SURAD radar. This is *not* correct and the aim of this section is to offer theoretical reasons and provide pragmatic examples to support this assertion.

3.11.2. PSR Elevation coverage

3.11.2.1. PSR high-angle coverage

The SURAD PSR antenna reflector was deformed upwards at the lower edge to ensure PSR energy was transmitted and received in an area well above horizontal in the order of 80° to the horizontal[11][12].

This was to ensure there was radar coverage over the airfield for overflying traffic[11][12]. A cone of no PSR coverage was still apparent within about 10° of vertical[12].

Accordingly, it can be seen that SURAD's PSR reflector was not a *pure* parabola as one may assume in fact one radar technician has stated it was a 'modified cosecant squared' shape[11][12] that is a typical shape of air surveillance PSR antennas.

Medium level coverage from about 6000' to 20000' was stated as being '*pretty good*'[5].

3.11.2.2. PSR low-angle coverage: in practice

The modifications described in the previous paragraph did not appear to effect low-level PSR coverage within the *terminal* area as was evidence by a former RAAF Pearce ATCO using SURAD.

This ATCO stated that low-level aircraft at 200'-500' Above Ground Level (AGL) transiting the coast could easily be observed on the Pearce SURAD which was mounted on a slightly elevated terrain position looking over underlying flat areas of terrain at some 10 nautical miles away[3].

A radio technician that worked extensively on SURAD stated cars approximately 5.5NM away from the SURAD at RAAF Laverton could be picked up on PSR although, it was reported that the elevation of this SURAD set up was *lower* than the standard SURAD antenna height at the remainder of the facilities around the country[12].

Williamtown coastal light aircraft traffic at 500'AGL were generally visible on PSR and SSR from Nobby Head to Broughton Island and if the aircraft were squawking a transponder code, SURAD would *definitely* display these aircraft throughout the transit[5]. Radar head distances to Nobby's Head, abeam Williamtown and Broughton Islands is 7NM, 3NM, 27NM respectively[10].

A highly experienced Williamtown SURAD ATCO states that *primary* and *secondary* radar coverage of *low-level* aircraft in the light aircraft corridor from West Maitland to Dungog to Stroud Road to Gloucester was 'somewhat intermittent' but that low-level (approximately 500' AGL) traffic in this corridor would be seen[5].

Distances from the SURAD head to these respective locations in sequence is approximately 15NM, 24NM, 27NM, 48NM[10]. This ATCO also adds that primary aircraft returns at 500AGL within the permanent, unsuppressed terrain clutter of the Barrington/Gloucester Tops range were heavily drowned out by this clutter[5].

3.11.2.3. PSR low-angle coverage: design

The radiation pattern *vertically* has been described as: '*The overall radiation pattern looked a bit like a table tennis bat with no handle and part of one side cut off*'[11][12].

This shows that the *vertical* PSR beam covered an angle from the horizontal or possibly slightly below, to approximately 80° up from the horizontal.

As stated previously, the SURAD primary reflector was a modified cosecant squared shape. The radiation pattern in elevation of a *pure* cosecant squared reflector is shown in figure 21. As can be seen, coverage is apparent down to the horizontal.

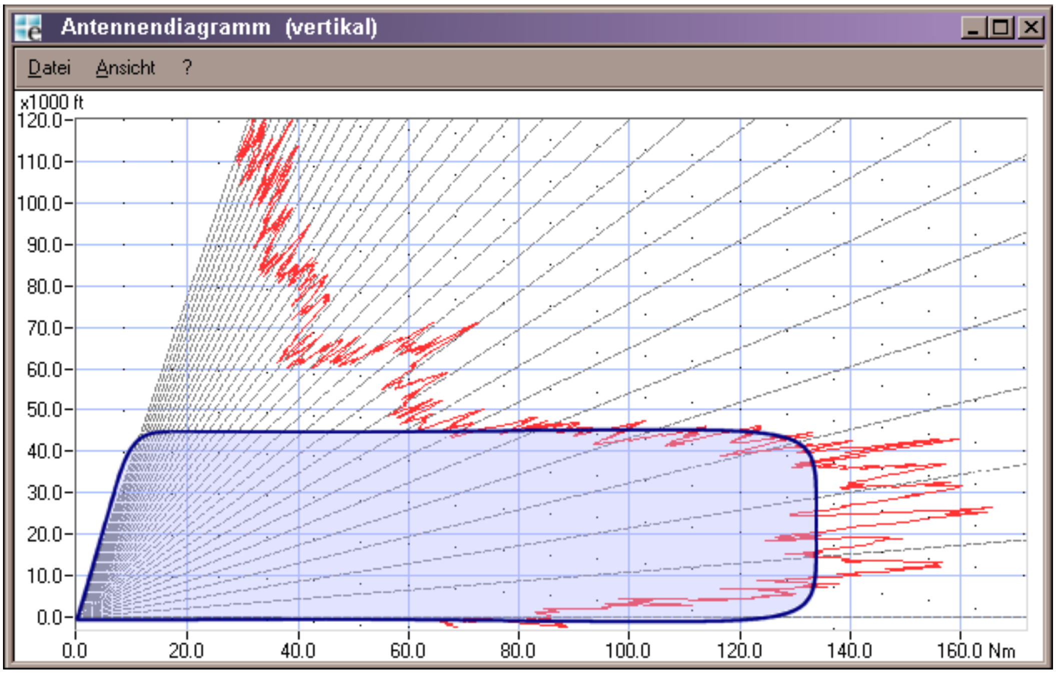


Figure 21: Theoretical vertical cosecant squared radiation pattern (blue) vs. actual pattern (red) (The Ohio State University 2014). SURAD featured a *modified* cosecant squared reflector so the graph above is only *coarsely* representative of the SURAD vertical beam. Note the actual coverage at low level (red). Terrain and obstacle masking then can be seen to be the major impeder to low-level radar coverage rather than the vertical beam pattern itself. The crux of this matter is that there is every reason SURAD had good low-level coverage from the PSR system thus, it is incorrect to assume some sort of blind sector below mechanical and electrical tilt angles as has been suggested in one VH-MDX research paper[32].

The PSR beam at the *feed horn* (and not the output beam) was reported as being set up to achieve a beam *center* of 3° above horizontal[12]. This was the standard set up with all SURAD units around Australia[12].

The feed horn faced the reflector and SURAD's large reflector ('dish') would then modify the vertical beam propagation from a simple 3° elevation projection to a broad elevation vertical PSR beam.

It must be highlighted here that this does not mean that the SURAD's *vertical* PSR beam center once reflected (output beam) was necessarily at 3° above the horizon: remember, the 'output' vertical PSR beam was of a broad elevation angle from horizontal (and probably slightly below) to approximately 80º up elevation.

Considering the examples given of practical *low-level* PSR coverage, and the theoretical vertical propagation properties of SURAD's beam as described, there is sufficient evidence to suggest that PSR coverage confidently existed in proximity to the horizontal at *close* range and, quite possibly at *longer* ranges given the radiating pattern. This was subject of course to terrain and obstacle masking.

There is no evidence at this stage to suggest an elevated angle *PSR* output beam from the radar head caused a significant blind area beneath. Thus, terrain and obstacle blanking is considered the main factor in low-level PSR coverage: not antenna tilt.

Elevation beam angle is required to be *broad* in order to cover as much vertical angle as possible. *Horizontal* beam angle however, is required to be *narrow* to achieve precise azimuth discrimination. SURAD had a 1.2 degree *horizontal* PSR beam width at the half power (3dB) points[11][12].

An important point from this section is that simple analysis of radar coverage using the PSR antenna tilt 'elevation angle' to the horizontal to determine a blind area will not yield a realistic analysis of propagation.

The aim of such mechanical or electrical tilt is to bias the power distribution of the emission. Such tilting would affect propagation to some extent in that power is minimised at lower elevation angles thus, range would be sacrificed at low angles.

But, there is normally no 'blind angle' as a result of antenna tilting in this manner and application. The findings of section 3.11.2.2 pragmatically demonstrate that PSR coverage of Williamtown SURAD existed at very low elevation angles.

3.11.3. SSR elevation coverage

SSR elevation coverage has been reported as similar to the *primary* system; from horizontal to approximately 80° up.

For civilian SSR systems, ICAO specifies that *adequate power* should be transmitted between 0.5° and 40° from the horizontal and that antenna height and tilt should be used to minimise *power* radiated towards the surface[29].

This does not imply a radar blind spot below 0.5° or above 40° elevation is required but rather that adequate power must be projected into this angle range.

A graph depicting the elevation plane radiation characteristics of an SSR 'hog trough' type antenna c.1975 is shown on the following page in figure 22[30]. The hog trough antenna is representative of many SSR installations c.1980's.

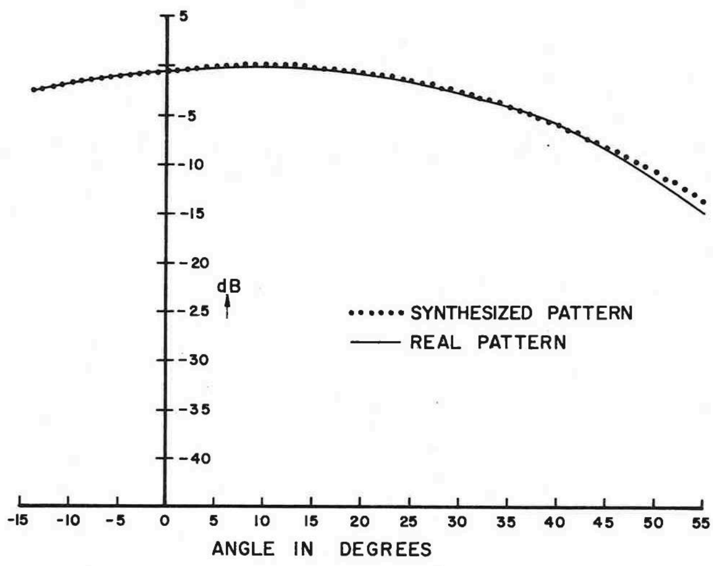


FIG. 11: Normalized free space elevation plane pattern of the existing "hog-trough" antenna.

Figure 22: Hog Trough SSR antenna elevation radiation characteristics. Immediately obvious is that significant power is still radiated down to 10° below the horizontal. Even with electronic and/or mechanical tilt of a few degrees up applied to the antenna, it can be seen coverage exists down to the horizontal and below. (Graph: Zatkalik.J, Sengupta. D.L, Tai. C, 1975).

It can be seen that:

- Maximum signal strength is radiated around +10° to +15° in elevation
- Signal is radiated with minimal loss (compared to +10°) to at least -10° in elevation

Other types of SSR antennae of the time were also shown to radiate below 0° elevation with many losing only small values of gain by the 0° elevation point[30].

It is obvious that electrically or mechanically tilting the antenna by a few degrees up will not cause a significant blind spot in elevation coverage down to at least 0° elevation but can be seen to simply bias the distribution of radiated power.

SURAD was likely certified and used in the civilian world under a different name so it is probable these civilian standards apply to SURAD. Radiating *large* amounts of power towards the surface increases the chances of false target display whilst also wasting power that could be projected at the elevation angles that cover most traffic (thus sacrificing range)[29].

So, it can be seen that detection down to 0.5° elevation from the horizontal was *required* or *highly likely* and, that detection down to 0° elevation or even below is *highly likely* notwithstanding terrain.

As stated previously in section 3.11.2.2 SSR paints were very reliable for low-level (500'AGL) traffic along the Williamtown coastal route out to *at least* 27NM up the coast[5].

In general, SSR returns from 500'AGL traffic in the Gloucester area that is approximately 400'-500' Above Mean Sea Level (AMSL) and 48NM from Williamtown[10], appeared *intermittent* and were close to 'below coverage'[5].

Low-level traffic at around 500’ AGL to the north-west were generally seen as *intermittent* PSR and SSR returns as a result of *terrain masking* and were never good with communications being the same[5].

Medium level coverage from 6000’-20000’ was described as *very good* within 48NM[5].

As described in section 3.11.2.2 secondary radar coverage of *low-level* aircraft in the light aircraft corridor from West Maitland to Dungog to Stroud Road to Gloucester was ‘*somewhat intermittent*’ but would occasionally see low-level (approximately 500’ AGL) traffic in this corridor[5].

Distances from the SURAD head to these respective locations in sequence is approximately 15NM, 24NM, 27NM, 48NM[10].

3.11.4. Conclusions: Radar coverage in elevation

PSR and SSR antenna elevation tilting is a method of minimising power radiated at very low angles to decrease the occurrence of spurious returns.

In the vast majority of air surveillance applications, it can be seen that radar blind angles would not be defined purely by such tilt.

Although intermittent at times, it can be seen that low-level SSR coverage at 500’AGL roughly equaling 900’- 1000’ AMSL[10] in many of the examples given near Williamtown, was possible out to at least 48NM from Williamtown subject to terrain masking.

Considering:

- VH-MDX was between approximately 8500’ and 5000’ AMSL in the final 15 minutes of flight[7],
- VH-MDX was close to 45NM from Williamtown at 0936:00UTC and given the reported final Sydney Radar position[16][17] or ASIB final Williamtown radar position[7] and likely to stay inside 48NM of Williamtown until impact with terrain,
- Based on the previous point, VH-MDX likely impacted terrain in the Barrington Ranges which themselves are approximately between 1500’ to just over 5000’ AMSL in elevation,
- There is no reason to believe that VH-MDX would have the transponder fail or be switched off until impact with terrain
- Air surveillance radar propagation is effectively line-of-sight[37]:

It can be reasonably concluded that regardless of antenna mechanical and electronic vertical tilt, if VH-MDX was within *line of sight* of the Williamtown SURAD SSR and PSR antennas, SSR and PSR returns would be displayed on the PPI.

Accordingly, simple line of sight analysis considering earth curvature, terrain and obstacles may be useful in determining or ruling out possible VH-MDX positions whilst use of propagation software accounting for other propagation effects such as diffraction would be advantageous in resolving borderline line of sight cases.

3.12. Antenna height

SURAD antennae were mounted on top of a steel tower to maximise range[11]. The PSR feed horn of SURAD was estimated at around 30m above ground level with the SSR antenna being estimated at a *further* 2m above the PSR feed horn[12]. Figure 23 shows a picture of the SURAD radar head installation.

Figure 23: SURAD radar head. The PSR feed horn was estimated at being 30 meters above ground level whilst the SSR antenna was estimated at being 2 meters above the PSR feed horn. Such information is important in radio propagation studies (Photo: Australian Government (Department of Defence) c.1980).

3.13. Relevant specifications: SURAD

The specifications on the next page in figure 24 have been selected as relevant for tasks such as simple propagation analysis. Some specifications listed have been derived from the experiences of personnel who used SURAD.

Accordingly, specifications may change with time as more people are contacted or appropriate references are located.

Item	Value
PSR radar emission band	UHF[22] L-Band (IEEE) 1.3GHz[11]
PSR horizontal Beam width	1.2° at half power points (3dB) [11][12]
PSR vertical beam elevation	Approx 0° - 80°[11][12]
SSR interrogation frequency	UHF[22] Band: 1030MHz
SSR reply frequency	UHF[22] Band: 1090MHz
PSR feed horn height	Estimated at 30m[12]
SSR antenna height	Estimated at 32m (PSR horn +2m)[12]
SSR horizontal beam width	2°-3° at 3dB (half power) points (estimated)
SSR vertical beam elevation	0°-80° (estimated based on ICAO requirements)[29]
SSR output power (estimated-based on civil SSR standards/predicted power)	300W-1500W
SSR receiver sensitivity	Better than or equal to -85dBm (based on ICAO standards)[29]
Target paint persistence (reported)	1-5 sweeps (4 – 20 seconds) [2][3][4][5]
Maximum number non-emergency SSR symbols available for allocation to specific codes	4[3][5]

Figure 24: SURAD specifications. Only limited information has been found regarding the SURAD system. Many specifications have been estimated by those who have used or maintained the system. Regardless, it is viewed unlikely that any differences will have a significant effect on analysis.

3.14. Findings: Radar

- SURAD radar head was located approximately 70m south of the current ADATS radar head at RAAF Williamtown
- The Air Defence Radar is not related to ATC functions and it's position should not be used as a reference for ATC radar bearings and distances
- The center of the PPI (origin) despite having an ability to be offset was stated to be centered on the physical position of the radar head during the VH-MDX accident
- SURAD sweep speed is 360º in 4 seconds
- Only the Tower PPI was manned during the accident to VH-MDX
- There were no VH-MDX radar tracks recorded by video or photography by Williamtown ATC
- Up to +/-10˚ bearing tolerance is possible with *quick* visual assessments
- Using the *tower* PPI, +/-5˚ bearing read off tolerance could be expected as 'normal' with +/-2˚-3˚ easily achievable when assessing with care
- MTI filtering does <u>not</u> filter SSR returns/symbols
- A primary return of a light single would likely be an arc of around 3-4NM
- Persistence of fading targets is around 1-5 sweeps equating to 4 – 20 seconds
- It is likely SURAD primary and secondary radar could provide good coverage at the 0˚ vertical angle and possibly below, at short ranges (10NM) and is likely to have provided good coverage, terrain line of site permitting, at the 5000' level and above at distances around 48NM given radiating patterns and ATCO reports.
- Aspect of a Cessna 210 with respect to radar does <u>not</u> change PSR paint size significantly
- SURAD PSR feed horn height of 30m and SSR antenna height of 32m.

4. Williamtown ATC RADAR track/fix information

Section 4 will overview RAAF Williamtown's contribution to positional information of VH-MDX.

4.1.BASI VH-MDX Accident investigation folio

4.1.1. ASIB communications transcripts

ASIB communication transcripts reveal *possible* Williamtown ATC VH-MDX radar fix information, *partially or well defined* from the following times[7]:

- 0934:00 UTC: '*…I've got no squawk but I've got a primary paint about 45 miles'*
- 0936:00 UTC: '*Yes I have got* a *squawk* '*about 45 miles just in the Barrington Tops just about 320 WLM 45*', '…he's *squawking ident now*'
- 0936:30 UTC: '*Yeah. I have got a 3000 squawk squawking ident now*'
- 0938:30 UTC: '*330* ______'
- 0939:00 UTC: '*To track him towards mine- about 150 would be good*'
- 0941:10 UTC: when questioned by another aircraft if Williamtown was still 'painting' VH-MDX on the radar Williamtown replies: '*Not anymore*'
- 0941:20 UTC: When queried by Sydney Sector 1 if Williamtown still has VH-MDX identified on Williamtown radar, the Williamtown ATCO goes through a process stating ' *I've lost his squawk he's primary paint in the Barrington Tops and the MTI our MTI's not cutting it out*' when pushed by Sector 1 *'…you've got him or not?*' WLM relies '*No I can't see him*'.

4.1.2. ASIB/RCC final radar position

There are at least three references to a 'final position' around the 0940UTC time in the BASI VH-MDX Accident Investigation archives and based on labeling these appear to have been derived by *Williamtown* radar[7]:

- A Minute from a DoT member stating: '*Last observed position by Radar*' '*LAT 320445S LONG 151 2855E*' '*UPPER WILLIAMS RIVER VALLEY*.'
  (S32°04'45", E151°28'55")
- A topographical map with a cross depicting a position and note: '*Williamtown radar returns disappeared at this position at 1940 EST*' and on the next page a free had written position: '*32° 04' 45" S 151° 28' 55" E*'. This position correlates approximately to the cross on the topographic map.
  (S32°04'45", E151°28'55")
- Hand written note on the back of the file cover: '*LAST POSITION 32° 04' 55" 151° 28' 55"* corrected from 32° <u>44</u>' 55'. **(S32°04'55", E151°28'55")**

Two of the three positions are the same whilst the third is very close by differing in latitude by seconds. Accordingly, it is assumed at this stage these three positions are the one and the same position with a map reading tolerance or typo resulting in the difference of the third position.

Considering this and, the reference to Williamtown radar, it is *assumed* these positions *all* refer to a single Williamtown radar position.

Given the era, position S32˚04'45", E151˚28'55" could possibly be based on a WGS72 datum if derived from an aeronautical chart or an AGD66 datum if derived from other topographical maps. If WGS72 based, the position is effectively equal to that of a current WGS84 datum position of same lat/long.

<u>If AGD66 based, this position converts to WGS84: S32°04'39.3", E151°28'59.0".</u> The chart appears to be a 1:250 000 non-aviation topographical map so it is likely AGD66 was the applicable datum.

Other than the references to '*Williamtown radar returns disappeared at this position at 1940 EST*'[7] and '*Last observed position by Radar*'[7] there are no explanatory notes or expansion as to how the positions were derived (e.g. no bearing/range information of the observed radar position).

If this position was determined by the information that the Williamtown ATCO gave then, given a basic PPI with no marked waypoints in the vicinity of this position, a *bearing/ range definition of this position must have been given*. No such bearing/range definition has been found so far.

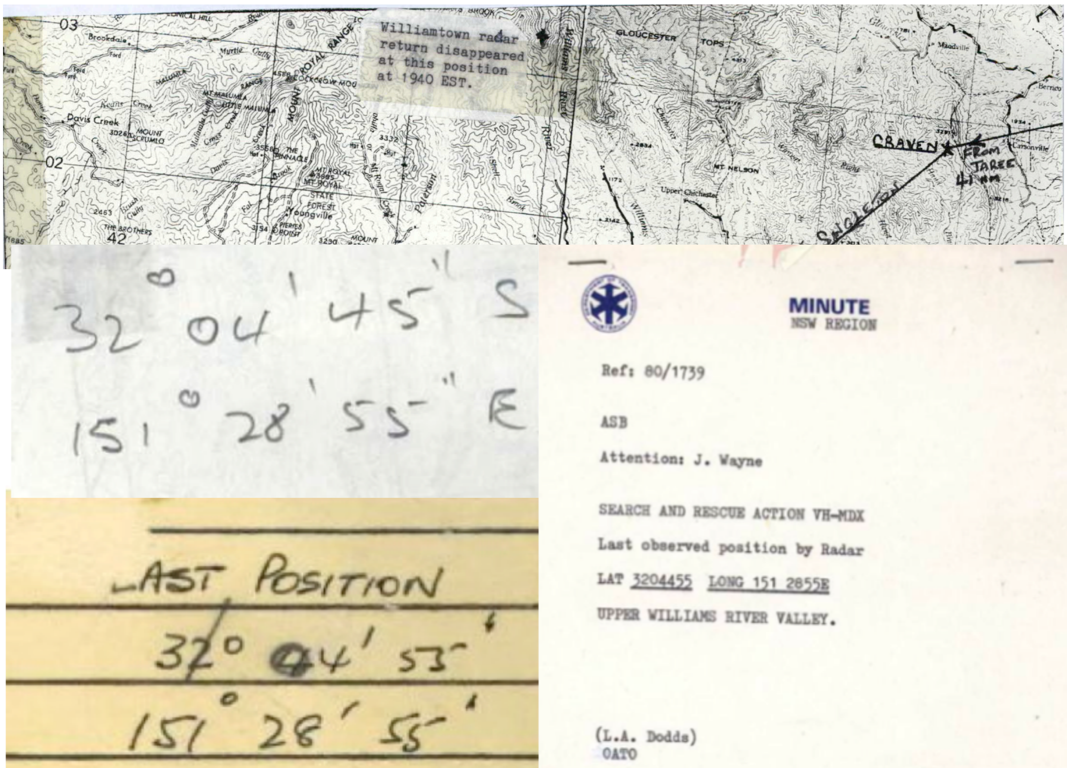


Figure 25: ASIB final Williamtown radar position references. The middle left lat/long was located on the flip side of the map displayed at top. Bottom left was located on the back of the folio cover. The minute displays the position given from RCC to the undersigned. The origins of these positions in terms of radar derived base data are unknown (Images Australian Government (Air Safety Investigation Branch/ Bureau of Air Safety Investigation) c.1981).

The Williamtown ATCO states with certainty that he did not contribute to this position directly nor did he view the returns of VH-MDX fading[4].

Additionally, observing SSR paint *fade* through persistence was stated as almost impossible in the terrain clutter where VH-MDX would have been at the ASIB/RCC final radar fix[4].

Plotting the AGD66 ASIB/RCC position corrected to WGS84 on Google Earth and adjusting for Williamtown 1981 magnetic variation gives a bearing of 325.9˚M and range of 46.7NM.

The Air Safety Investigation Report Released by the Department of Transport on 1st September 1981 indicates specifically that *Williamtown* radar lost contact with VH-MDX at 1939:30EST (0939:30UTC) as shown below in figure 26:

> reported his altitude as 7500 feet, one minute later in an increasingly agitated voice 6500 feet, then - at 1939½ EST. - 5000 feet. At that time, the radar return disappeared from the screen at Williamtown.

Figure 26: Air Safety Investigation Report 1st September 1981 Excerpt. A suggestion is made that VH-MDX was observed to have faded from radar at 0939:30UTC. The Williamtown ATCO only recalls observing VH-MDX at the 320˚M/45NM fix that occurred around 0936:00UTC. (Australian Government (Air Safety Investigation Branch) 1981).

Interestingly, the following section will describe how later in 1983 it is insinuated that the 320˚M/45NM position at 0936:00UTC was the final *Williamtown* radar fix rather than the ASIB/RCC Upper Williams Valley fix.

Additionally, the *final* radar fix overall at 0939UTC was not referenced to a *specific* radar head unlike in the 1981 report to Williamtown.

4.2. 'Final radar observed position' at 0936:00UTC

Handwritten notes on a map written by a BASI Inspector, is included in the BASI archives titled '*Possible Flight Path*'. This appears to have been drafted during March 1983 being about a year and a half following the accident. This is displayed in figure 27 on the next page.

0936UTC is referred to as the '*last observed position'* in the 'Summary' section and a '*Last Pos*' is given as: *32˚ 08'S, 151˚ 23'E*. This position is further expanded on in the sketched flight path as '*Last Radar (Williamtown) Pos'* marked with a cross and labeled '*0936*'.

As the chart is a World Aeronautical Chart (WAC), the lat/long specified is assumed (but not confirmed) to use a WGS72 datum. Accordingly, the position will be treated as a one with a WGS84 datum (same lat/long with either datum).

This position is located approximately 1.5NM west of the 320˚M/45NM position that will be defined in section 4.4.3.

The position described in this section obviously relates to the 320˚M/45NM radar fix from Williamtown given the close proximity between both positions and specified timing.

No other fully defined (bearing and range) fix was recorded as being obtained by the Williamtown ATCO.

Other than *possibly* observing VH-MDX near the 330 bearing, then the 320˚M/45NM position is the first and final *fully defined* Williamtown radar position. This is supported by the Williamtown ATCO[4].

The change of conclusions in 1983 is probably the result of allowing the dust to settle allowing time to overview all information and data to conclude the 320˚M/45NM position indeed was the final radar fix achieved from Williamtown TAR however, this cannot be confirmed.

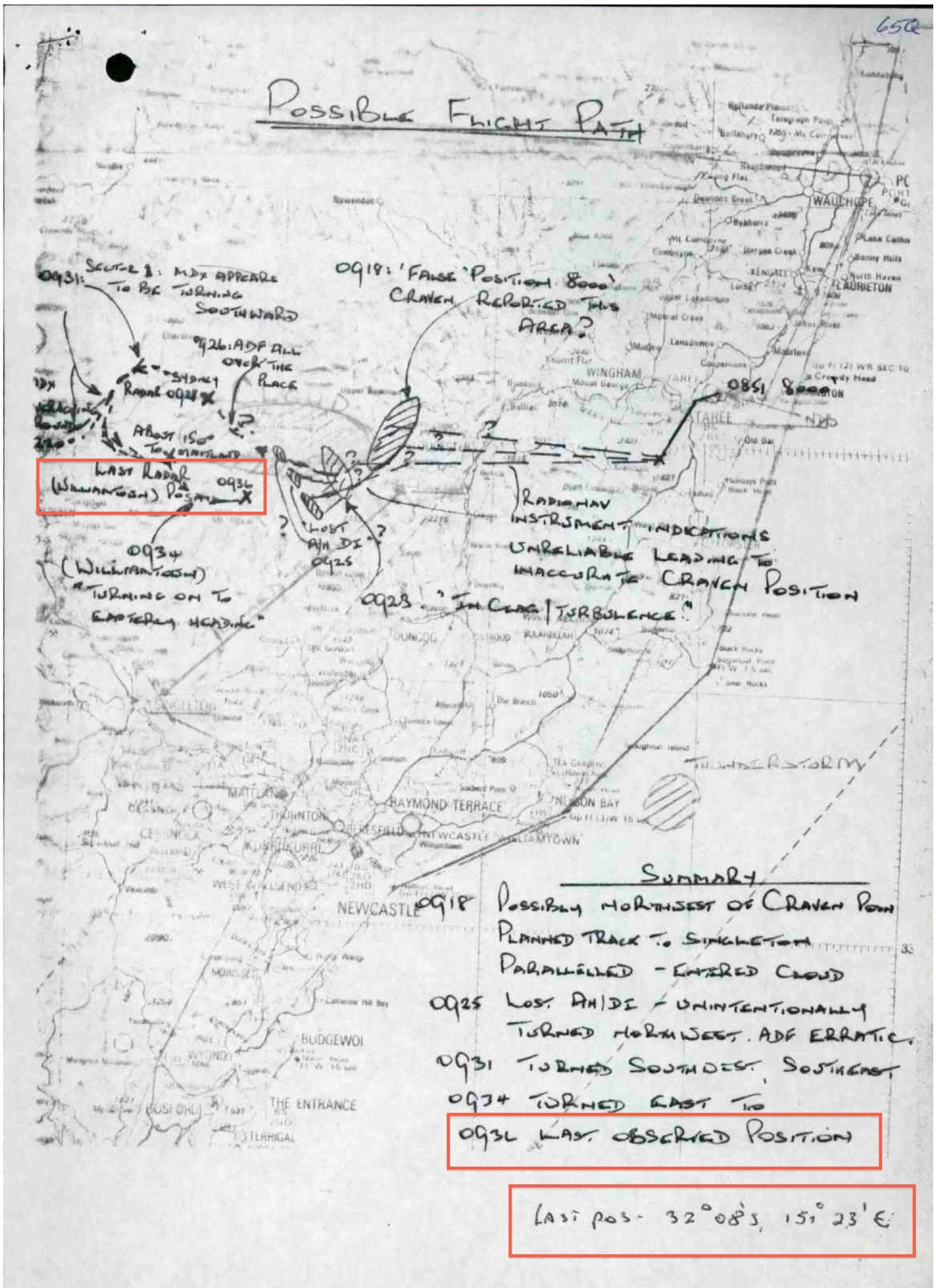


Figure 27: 0936UTC Williamtown fix being referred to as final position c.March 1983. Given the time frame after the accident, it was suggested that the 320˚M/45NM was eventually confirmed to be the final if not only radar position obtained by Williamtown radar (Image Australian Government (Bureau of Air Safety Investigation) c.1983, highlights: Glenn Strkalj 2014).

In addition, effectively the same position (E151˚ 25' vs. E151˚ 23' on the sketch) was declared as the '*most probable search position*' early in the search for VH-MDX to guide rescue resources on the day following the accident[7][40].

An extract of the most probable search positon is displayed in figure 28.

MOST PROBABLE SEARCH POSITION IS 6NM RADIUS AROUND POSITION 3208S 15125E WHICH WILL BE SEARCHED THOROUGHLY DEPENDENT UPON WEATHER.

Figure 28: Situation Report 2, Most probable search position. This message was released on the night after the VH-MDX accident (10 August 1981) (Image: Australian Government (Transport Australia 1981).

This appears to be the result of *assuming* radar *fade* was observed by Williamtown at this positon as figure 29 shows.

THE WM RADAR PLOT WAS LOST AT APPROX 320WM45 @0940. BASED ON RADAR INFORMATION, PRIMARY SEARCH AREA WILL BE CENTRED ON PX 32°08'S 151°25'E RADIUS 6NM

Figure 29: Williamtown radar fade at 320°M/45NM assumption. (Image: Australian Government (Department of Transport) 1981).

It is clear from ATCO interviews that no fade *at all* was observed by the Williamtown ATCO.

It must be clarified that during a distress SAR phase much communications are being carried out, information is flowing consistentely and normal ATS operations still are required to be attended to.

There is a significnat workload for all staff involved and simple miss-information or interpretation can easily result leading to incorrect conclusions.

If one considers all the aircraft operating normally that still need to be attended to whilst dealing with an aircraft subject to a distress SAR phase and the associated challenges then, one can begin to understand the situation at hand.

4.3. Sydney final radar position

The final position of VH-MDX observed by Sydney ATC radar was *deposed* months after the accident as approximately 5NM west to north-west of the Craven waypoint with no time given[16][17]. This is approximately 9-10NM[10] to the east of the 'ASIB/RCC' position described in section 4.1.2.

Communications transcripts also reveal Sydney ATC stating *'you got a present heading, we've lost him-to track towards yours'* just after 0939:00UTC. As the RSR had a 12 second sweep speed coupled with the need to have not observed radar returns for at least one sweep, VH-MDX may have fallen beneath Sydney ATC radar coverage just *before* this time.

Accounting for two sweeps without returns is realistic with this yielding a likely earliest radar fade time of 24 seconds prior to 0939UTC or approximately 0938:30UTC. Despite this, a 'pop up' paint could have occurred *after* initial fade invalidating a fade time of 0939:00UTC.

The latter is *not* considered probable given the significant downward rate of descent of VH-MDX in the final few minutes.

Figure 30: Sydney ATC final radar position. Position '2' was reported as the final radar position observed by one Sydney ATCO. It was deposed the position was approximately 5NM west of Craven waypoint/intersection. Of note is that the depicted straight track between both fixes was not possible given VH-MDX's track south then south-east to the 320˚M/45NM fix (tip of blue arrow). The following has been approximated by the author:

- 320˚M radial from Williamtown marked in green
- 330˚M radial from Williamtown marked red
- 320˚M/45NM position marked at the tip of the blue arrow
- 110NM arc from Sydney marked in purple

(Base image: Australian Government (Department of Transport) 1981, additions: Glenn Strkalj 2014).

The *Accident Investigation Summary Report* of 28th September 1983 suggests loss of radar contact at 0939UTC although not specifically stating which radar VH-MDX was observed fading from. This differs to what was shown in section 4.1.2/ figure 26 where in the 1981 Accident Investigation Summary Report *Williamtown* was *specifically* stated as being the radar VH-MDX faded from.

This is shown below in figures 31 and 32. Given the findings of Williamtown ATCO interviews that will be presented in the next section, it is highly probable that the 0939UTC radar fade time refers to fade from *Sydney* ATC radar rather than Williamtown radar.

reported his altitude as 7500 feet, one minute later in an increasingly agitated voice 6500 feet, then - at 1939½ EST. - 5000 feet. At that time, the radar return disappeared from the screen at Williamtown.

Figure 31: Air Safety Investigation Report 1st September 1981 Excerpt. A suggestion is made that VH-MDX was observed to have faded *specifically* from *Williamtown* radar at 0939:30UTC. The Williamtown ATCO only recalls observing VH-MDX at the 320˚M/45NM fix which occurred around 0936:00UTC and confidently states radar fade was *not* observed (Australian Government (Air Safety Investigation Branch) 1981).

that the aircraft was descending rapidly. The last recorded transmission from the aircraft was at 1939 hours, when the pilot advised the aircraft was at five thousand feet. Radar contact with the aircraft was also lost at this time.

Figure 32: Aircraft Accident Investigation Summary Report 28th September 1983 excerpt. Unlike the 1st September 1981 report, no reference to a specific radar is made in this report regarding the loss of radar contact at 0939UTC. Despite this, communications transcripts reveal radar fade from *Sydney* ATC radar at around 0939:00UTC thus aligning with the above statement (Image: Australian Government (Bureau of Air Safety) 1983).

Additionally, the statement in figure 33 clearly suggests Sydney radar fade at 0939:00UTC a approximately 330˚M/45NM Williamtown. This supports the argument of a 0939UTC radar fade at Sydney.

SYDNEY RADAR PLOT WAS LOST @ APPROX @ APPROX 330 NM 45 @ 0939

Figure 33: Sydney radar fade. Reported fade of VH-MDX on Sydney radar in Sydney ATS notes is likely to be more acceptable than the suggestion of Williamtown radar fade. This is because Williamtown reports would have been subject to interpretation errors between organisations (Image: Australian Government (Department of Transport) 1981).

Additionally, the *deposed* Sydney final radar position was found to be possibly displaced from the *actual* fade position[19]. From this finding, it was concluded that although the deposed final radar position may not be *precisely* the position of radar fade, the deposed position still offers a solid suggestion of final VH-MDX track[19].

All information must be treated with suspicion but, considering the information in this section it can reasonably be concluded that VH-MDX faded from Sydney radar at 0939:00UTC.

<u>Plotting the deposed Sydney final radar position on Google Earth and adjusting for Williamtown 1981 magnetic variation gives a bearing of 337˚M and range of 42.2NM for ‘5NM west of Craven’ and 340˚M/44.9NM for ‘5NM north-west of Craven’.</u>

Considering read-off deviations of up to +/-10˚ were possible when using the Sydney Northern Mosaic Bright display program[19], it can be seen that the bearing suggested in figure 33 *broadly* aligns with that found in the previous paragraph.

Also concluded, is that it was likely VH-MDX faded from Sydney radar near the 330˚M(+/-5˚)/45NM position from Williamtown and further west of the deposed final position.

4.4. Williamtown Air Traffic Control Officer (ATCO) interviews

4.4.1. Procedures in force

On the night of the VH-MDX accident, RAAF Williamtown ATC had *procedural* control in force[4]. As a consequence of this there was <u>no requirement</u> to have radar operating[4] and only a single ATCO was required[5].

Regardless, the ATCO on duty asked the technician to switch the radar on as the ATCO believed in using all available aids to assist and simplify work processes[4].

It is the author's opinion that this was a prudent and professional approach and the author would have done the same. This is similar to pilots using Instrument Landing System (ILS) approach guidance when conducting a visual approach.

4.4.2. Two radar 'fixes'

Detailed interviews with the RAAF Williamtown ATCO on duty during the VH-MDX accident reveal that the ATCO only *consciously* remembers looking at the PPI *twice* for VH-MDX during the accident period[4]. One must remember that over thirty years have passed since the accident.

The first time was obtaining the 320°M/45NM radar fix with SSR mode A code 3000 symbol, and SSR ident triangle aligned on top of each other at around 0936:00UTC[4].

The second time the ATCO consciously looked at the PPI was from 0941:10UTC and there were *no* detectable PSR or SSR returns in the Barrington Tops terrain clutter or surrounding areas[4].

The SSR returns for the 0936:00UTC fix were *completely* contained in the Barrington/Gloucester Tops permanent clutter[4]. When checking for VH-MDX returns from 0941:10UTC there were no SSR returns in the Barrington/Gloucester Tops permanent clutter nor in a *wide area* outside and surrounding the permanent clutter[4].

A *thorough* check was performed of the permanent echoes of the Barrington Tops area and also of the surrounding areas[4].

4.4.3. 320°M/45NM radar position

The Williamtown ATCO confirms that he identified VH-MDX with:[4]

- SSR mode A 3000 SSR symbol (likely to be a circle)
- ident (SPI) triangle;

Superimposed on each other with the centroid of the paints easily determined[4].

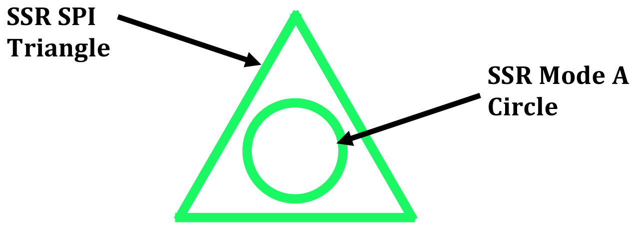


Figure 34: Observed VH-MDX returns at 320°M/45NM. The ATCO was not *completely* sure of the *type* of SSR mode A symbol that was displayed but was absolutely certain it was observed along with the SPI triangle. The ATCO believes the mode A symbol was a circle. The SPI triangle was observed as being unclipped by the outer edge of the PPI and not hanging over the 44NM MTI boundary (Image: Glenn Strkalj 2014).

The ATCO observed the *full*, *unclipped*, shape of the SPI triangle and mode A symbol, likely a circle, confirming the returns were *easily* and *definitely* inside the 48NM outer scale of the PPI rather than being right on the edge[4].

The SSR returns were *not* observed to 'bloom' (appear) in position nor were they observed to have transited from the outer edge of the PPI to the fix position[4]. What the ATCO recalls quite clearly is that he looked at the PPI and the SSR returns as described were apparent[4].

Consequently the ATCO suggests he must have been attending to procedural control tasks away from the PPI during some time period between 0934:00UTC (the initial check for VH-MDX) and 0936:00UTC when he observed the 320˚M/45NM fix[4].

This is deemed highly probable given the high procedural control workload at the time resulting in necessary movement away from the PPI to attend to strips, the printer, other screens and visually scanning for inbound traffic whilst handling the ATC communications 'party line' with multiple agencies on line.

To perform these tasks the ATCO approximates at *least one* full side step away from the PPI was required[4]. The ATCO stated there were many different agencies on the one party line and that there was no way of telling who was who unless verbal confirmation was used for each agency[4]. It was suggested up to around six agencies could be on the same line[4].

It was very roughly estimated that the returns of VH-MDX around 0936:00UTC were observed for two sweeps of the radar but in any case there was *no prolonged* period of observation of these returns[4].

Additional insight is given into this topic by a person who discussed the VH-MDX accident with the Williamtown ATCO at the Williamtown ATC facility within a few weeks of the accident. This person states the Williamtown ATCO suggested to him that he physically had to move across to the PPI and that the ATCO suggested a likely bearing of 324˚M[36].

It can be seen this backs the ATCO's own suggestion to the author of being away from the PPI conducting procedural duties then moving to a position to observe the PPI.

<u>It must be borne in mind that observation of the PPI was *secondary* to performing procedural duties and that a highly finessed radar position was neither required nor likely at the forefront of the ATCO's objectives.</u>

A rough bearing was all that was necessary to see where VH-MDX was and possibly later to provide more information to Sydney ATC. Determining the bearing of VH-MDX down to one degree was not required to support such actions.

4.4.4. Radar returns in clutter

VH-MDX radar returns were reported by the ATCO as being located in the *dense* sections of the permanent terrain clutter of the Barrington and Gloucester Tops and not hanging over and inside the MTI boundary[4].

This area of terrain clutter is displayed on the Williamtown PPI from 44NM outwards[4][5] and between approximately 310˚M to 330˚M thus, forming a gross error check of the reported position.

Terrain returns from the Barrington and Gloucester Tops were a permanent and prominent feature of the SURAD setup at Williamtown with no other *significant, widespread* terrain clutter being displayed on the PPI when set to 48NM range in the north-west sector[4][5].

Aircraft PSR returns were stated as 'impossible' to discern in the permanent terrain clutter of the Barrington and Gloucester Tops[4]. This is because both the aircraft PSR paints and terrain clutter are presented as 'slashes' tangential to the radar beam thus, coalescing into each other.

On the other hand, SSR symbols were described as relatively easy to detect in clutter if the ATCO was directed to look for such symbols in the clutter[4]. An example was given of SSR returns being easily discernible in the dense clutter generated by emissions from the Newcastle steelworks[4].

The Williamtown ATCO attributes this to the *transverse* nature of SSR symbols across the tangential primary returns[4]. As all known SURAD SSR symbols (square, oblong, diamond, circle, bow tie, inverted 'Y') had lines that would cut *across* the tangential PSR permanent terrain returns, it was highly likely that all symbols would be easily detectable. This was confirmed by the Williamtown ATCO[4].

4.4.5. Fix accuracy

The Williamtown ATCO, stated for the one and only fix he achieved for VH-MDX (320˚/45NM) a tolerance of 5˚ was *confidently* achieved but *probably* in the order of 2˚[4]. <   R   >

This good accuracy was attributed to the close position of VH-MDX (45NM) to the 48NM PPI outer edge[4]. VH-MDX's bearing was stated by the Williamtown ATCO as being confidently 'eyeballed' to the nearest bearing marker given that VH-MDX's radar returns were right next to the compass rose[4].

The ATCO stated[4] and, it can clearly be seen, that using a straight edge to determine bearing was not required.

The 320˚M/45NM position adjusted for magnetic variation for 1981 from section 3.5.2 is located at the following latitude/longitude when plotted on Google Earth (WGS84):

-32.135776°, 151.412712°

S32° 8'8.80", E151°24'45.76"

UTM: 56H 350285.12 6443411.07

4.4.6. '330____ 'call

The '330___' call at 0938:30UTC made over the internal ATC communications line is depicted in the Williamtown column of the ASIB communications transcripts[7]. This suggests the Williamtown ATCO made this call [7].

When questioned of this call, the Williamtown ATCO cannot remember making this call or consciously observing the PPI for the bearing but states if he did make the call, he would have observed the PPI to determine such a bearing[4].

4.4.7. 150˚ Heading for Williamtown

Regarding the 150˚ heading advice the Williamtown ATCO gave to Sydney ATS in order to track VH-MDX to Williamtown at 0939UTC, the Williamtown ATCO states he does not specifically remember making this call.

The ATCO does state that if he did make the call that it could have been a 'pluck' to roughly get VH-MDX tracking in the right direction and that he would have observed the PPI to gain the required information[4].

The Williamtown ATCO advises he was very busy conducting *procedural* control of other aircraft and managing co-ordination between ATC agencies and without any specific formal urgency language regarding VH-MDX, VH-MDX was not the *immediate* priority[4]. When queried if the heading would be adjusted for wind the ATCO stated that it would not have been[4].

A heading pluck is a very normal method of getting an aircraft tracking in a certain direction which is then followed up by more refined headings.

4.4.8. < Removed >

4.4.9. Easterly track

The ATCO 'feels' that VH-MDX was tracking in a generally easterly direction and made a statement to Police to this effect[4]. It was clarified by the ATCO that this was just an *impression* and that this 'feel' was not based on return persistence or multiple viewing of the PPI as[4]:

- Terrain clutter obscured the paint persistence of the one and only fix he made
- The ATCO did not look at the PPI long enough to gain a trend in direction
- The ATCO made only one full position fix.

The 'feel' of an easterly direction was indicated by the ATCO to quite possibly be a result of the power of suggestion from Sydney ATC communications passing on observed radar tracks in the south-easterly direction and comments such as '*...heading right towards you now*' and '*He's just turned onto an easterly heading…*'[4].

Alternatively, observation of VH-MDX near the 330˚M bearing from Williamtown may have confirmed in the ATCO's mind that VH-MDX was tracking east.

4.5.NSW Police statement

A statement to police by the Williamtown ATCO on duty during the VH-MDX accident describes how VH-MDX was initially observed at 320°M from Williamtown at 48NM[26]. The ATCO has since clarified that this distance was in error and in fact was 45NM[4].

Additionally the ATCO states within the statement that: '*I got the impression that the aircraft (VH-MDX) was travelling in a westerly to easterly direction'*[26]. It was described in the previous section that an easterly track was indeed just an impression that was not necessarily based on radar observed trends.

NSW Police arrived out of the blue at the ATCO's residence months after the accident (November) to obtain the statement[4].

The interview was brief and as a result of no notice, the ATCO was not particularly prepared for the interview and statement[4]. Accordingly, it can be understood why the statement has some differences to ASIB communications transcripts and later interviews.

4.6.Findings: Williamtown ATC radar track/fix information

- Communications transcripts suggest positions by Williamtown radar at 320˚M/45NM around 0936:00UTC and 330˚M around 0938:30UTC.
- Williamtown ATCO interviews suggest only one complete radar position fix by Williamtown radar at 320˚M/45NM
- VH-MDX was identified by the Williamtown ATCO by SSR ident triangle and SSR mode A 3000 symbol both coincident
- The Williamtown ATCO is confident of the accuracy of the VH-MDX fix he took at 0936:00UTC given the proximity of the aircraft to the compass rose and the conscious process taken
- A person who discussed the accident with the Williamtown ATCO within weeks of the accident states that a bearing of 324˚M was suggested by the ATCO
- A Sydney ATCO deposes that the final observed position of VH-MDX by Sydney radar is approximately 5NM west to north –west of Craven waypoint. No time is given.
- In a 1st September 1981 report, ASIB suggest that VH-MDX was observed as fading from *Williamtown* radar at 0939:30UTC. This does not align with communication transcripts or Williamtown ATCO interviews.
- A map position c. September 1981, a minute from the Searchmaster to an ASIB inspector with coordinates and, the same co-ordinates handwritten in several locations suggest the final position by Williamtown radar at 0940UTC being in the Upper Williams River area. This position is not supported by the Williamtown ATCO or communications transcripts. It is also some 10NM west of the reported final Sydney observed radar position.
- In a 28th September 1983 report, BASI suggest that VH-MDX was observed as fading from an *unspecified* radar at 0939:30UTC
- Communications transcripts suggest VH-MDX faded from *Sydney* ATC radars by around 0939:00UTC
- Sydney ATS were advised that *Sydney* radar fade occurred at approximately 330˚M from Williamtown at 0939:00UTC

- Sydney ATS were advised that *Williamtown* lost radar contact with VH-MDX at approximately 320˚M/45NM at 0940UTC
- A BASI Minute of c.March 1983 suggests that the 320˚M/45NM fix by Williamtown radar at 0936:00UTC was the final observed position of VH-MDX by *Williamtown* radar
- It appears the 320˚M/45 position at 0936:00UTC was the only radar position of VH-MDX obtained by Williamtown radar and it was not a fade position.

5. Analysis of radar positions

5.1. Analysis of the 320˚M/45NM Williamtown radar position

5.1.1. Range

Range rings were illuminated bright green on the PPI and were hard to miss. They were selectable between 5NM and 10NM spacing[5] and this is an opportunity for error. It was stated the range rings were set to 10NM during the VH-MDX accident[4].

MTI filtering was set to 44NM[4] giving terrain returns *beyond* this range in the Barrington Tops area regardless of range ring setting. Terrain returns were acknowledged as existing during the VH-MDX accident by ATCO interview[4] and communication transcripts[7].

Accordingly, the limit of Barrington Tops terrain clutter returns generated a 44NM range reference making the range assessment easier to achieve correctly.

During the Williamtown radar fix at 0936:00UTC, the ATCO refers to the VH-MDX returns being '*just in the Barrington Tops*'. A range of 45NM for VH-MDX returns would be just outside the 44NM thus being 'just inside the Barrington Tops' as defined by the Williamtown radar display setup.

Additionally, a gross error check referencing VH-MDX returns to terrain clutter as depicted in Annex A, showed that the SSR return symbols were:

- Whole and unclipped and,
- Did not touch the PPI outer edge thus, VH-MDX was not at 48NM and likely not more than 47NM (to ensure no touching)
- *Not* hanging over the 44NM MTI boundary thus, VH-MDX would have had to have been at 45NM or greater

Annex A contains the gross error check process offered to the ATCO by the author. The ATCO selected 'Return A' to represent the observed *range* of VH-MDX returns. This return was located half way between the 44NM MTI boundary and the 48NM PPI outer edge: i.e. at 46NM.

Consequently, VH-MDX at 0936:00UTC is viewed as being:

- *Definitely* between 44NM and 48NM
- *Highly likely* to be between 45NM and 47NM
- *Likely* at 46NM

It can be seen 45NM is highly likely to be *representative* of the actual range of VH-MDX returns at 0936UTC within +2NM/-0NM. Additionally, it appears VH-MDX was quite possibly closer to 46NM.

5.1.2. Bearing

Sydney ATC passed a radar position reference to the Williamtown ATCO generally aligned with the Williamtown radar fix some one and a half minutes prior. (i.e. Sydney observed VH-MDX close to 320˚M/45NM from Williamtown on Sydney ATC radar and Williamtown ATC observed VH-MDX at 320˚M/45NM from Williamtown on Williamtown radar not too long after: two different radar units with similar positions at a similar time).

The 320˚M/45NM position is rather 'neat' in that it is a 10˚ increment but this is justified within +4˚/-2˚ for the reasons stated in section 4.4.3. Human factors aspects that must be considered include:

- The Williamtown ATCO was rather busy with primary duties
- Sydney passed the position of VH-MDX to Williamtown as 320˚M/45NM just after 0934:00 UTC (updated shortly after to 46NM)[7]
- Around one and one half minutes passed before the Williamtown ATCO obtained the 320˚M/45NM radar fix following the 46NM advice[7]
- Sydney was waiting for the fix (pressure on the Williamtown ATCO)
- The tower PPI required ambient light to display the compass rose
- The PPI was likely observed in a hurry as procedural tasks were paramount and the procedural area of the tower workstation was displaced away from the PPI
- The PPI could have been observed from some distance away
- There was no real need for an accurate position fix.

Taking into account the above, the ATCO could have been pre-disposed to *verbalizing* a 320˚M bearing regardless of VH-MDX's position.

As shown previously, the ATCO obtained a 320˚M bearing by simple and accurate reference to the compass rose as VH-MDX returns were very close to the rose. The ATCO is *very confident* of a read off tolerance of +/-2˚ on 320˚M.

Alternatively, the ATCO was suggested as stating to a person within weeks of the accident that a bearing closer to 324˚M was more likely for this position [36]. Given the close time frame to the accident and confidence and clarity of the report, it is viewed probable that VH-MDX was around the 324˚M bearing at 0936:00UTC.

Annex A contains results from a gross error check of the 320˚M/45NM fix by reference of VH-MDX radar returns to *terrain clutter*. These coarsely suggest that VH-MDX returns were in the middle of the Barrington/Gloucester Tops terrain clutter in azimuth.

Such terrain clutter can be seen from the SUARD PPI photo below as being approximately between 310˚M and 330˚M. Thus, it can be seen that 320˚M would be approximately in the center of the terrain clutter but 5˚ either way is also easily possible.

Accordingly, a bearing close to 320˚M is likely to be a *reasonable* representation of the actual bearing of VH-MDX returns at 0936:00UTC. +4˚/-2˚ is also accepted as the tolerance for the fix when considering the information presented in this section.

5.1.3. Sydney ATS interpretation

Uncertainty regarding the details of the 320˚M/45NM Williamtown radar fix was apparent at Sydney ATS.

This is understandable and expected because during the initial days following the accident communications transcripts were not likely to be available whilst audio recordings were not likely to have been overviewed with prudence and the benefit of time.

Sydney Sector 8 was a portion of airspace including the RAAF Richmond Control Zone (CTR) and associated Richmond Restricted areas. The airspace was administered by the RAAF.

The Sector 8 workstation was located in the Sydney AACC and included an offset Bright display using Sydney radar to cover the Richmond area. Sector 8 was manned by RAAF ATCO's rather than civilian Department of Transport ATCO's.

One day after the accident on the 10th August at around 1747 local time, Sydney Sector 8 advised that Williamtown first identified VH-MDX on radar at 0934UTC and that last radar contact was at 0937UTC at the 320˚M/45NM position[40].

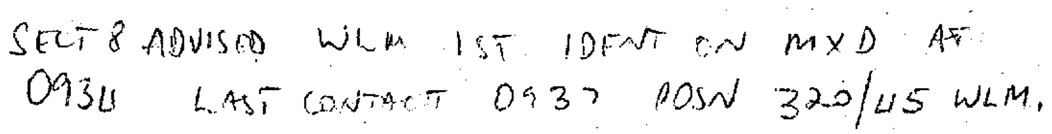

SECT 8 ADVISED WLM 1ST IDENT ON MXD AT
0934 LAST CONTACT 0937 POSN 320/45 WLM.

Figure 35: Sydney (RAAF) Sector 8 advice of Williamtown radar positions. (Image: Australian Government (Department of Transport) 1981).

Sydney Sector 1 began passing on the 320˚M/45NM position to Williamtown at around 0934UTC and the Williamtown ATCO was transcribed as achieving the 320˚M/45NM fix at around 0936:00UTC[7].

Interviews in 2014 have determined that the Williamtown ATCO did not recall making further radar observations of VH-MDX as revealed in section 4.4.

From this, it can be seen the times specified by Sector 8 are coarse in nature although bracketing the 0936:00UTC Williamtown fix time.

Later on the night of 10th August 1981, it was accepted that VH-MDX was lost on the Williamtown radar at *approximately* 320˚M/45NM at 0940UTC as figure 29 showed[40]. As section 4.2 described, this information was used as the center point for the primary search area.

Section 4.1.1 showed that the first indication of there being no VH-MDX paints on the Williamtown PPI was at 0941:10UTC. Consequently, a 0940UTC 'lost' time does not particularly align with communications transcripts or information from ATCO interviews.

Section 4.1.2 discussed a location annotated as '*Williamtown radar returns disappeared at this position at 1940 EST*'. It can now be seen that this position used the 0940UTC (1940EST) time proliferated during the second day after the accident. It will be shown in section 5.2.3 how a time of 0940UTC may have been arrived to.

The confusion with the Williamtown 320˚M/45NM radar position is readily apparent. Decisions were made and appeared to have possibly stuck during the search operation.

Section 4.2 showed that with the benefit of hindsight 0936:00UTC was concluded as the time of the 320˚M/45NM Williamtown radar position and communications transcripts agree with this.

Accordingly, the communications transcript time of 0936:00UTC is accepted as the most accurate and precise time the Williamtown 320˚M/45 radar position was made.

5.1.4. 320˚M/45NM fix in 1981 search area development

Initially on the 10th August 1981, the primary search area was based on a 6NM radius from a center point of S32° 08', E151° 25' based on '*radar information*'[40]. This position when plotted is effectively at a location 320˚M/45NM from Williamtown.

On the 11th of August 1981 RAAF Williamtown was consulted regarding radar and audio recording information[40]. On the same day the search area was amended to a center point of S32° 05' 30", E151° 26' 20" with 15NM radius applied[40]. The center location was '*based on last radar positions*'[40]. Plotting these co-ordinates yields a position of 323˚M/46.8NM from Williamtown.

It is can be seen that refinement of radar position was likely through debrief or the like and a position was concluded. This position (323˚M/46.8NM) is rather close to 324˚M/46NM.

The latter position was determined from information obtained from a person discussing the fix with the Williamtown ATCO not long after the accident combined with ATCO interviews.

Accordingly, the second search area center location more supports a 324°/46NM VH-MDX position at 0936:00UTC than a pure 320˚M/45NM position.

5.1.5. ASIB/RCC final radar position

The ASIB/RCC final radar position described in section 4.1.2 also broadly aligns with the positions discussed in the previous section. The ASIB/RCC final position was found to be 325.9°/46.7NM, which is within degrees of 323°/324°.

Accordingly, the ASIB/RCC final radar position may be the 0936:00UTC position as determined through the vectoring of aircraft to the fix position on the PPI or debriefing of the Williamtown ATCO.

Indeed there were clear intentions to vector aircraft to such positions[40] and one Department of Transport Officer recalls this task being performed[14].

5.1.6. Cluster of positions

Plotting the various positions described in the previous sub-sections reveals two closely associated (in radar terms) cluster of positions as presented in figure 36.

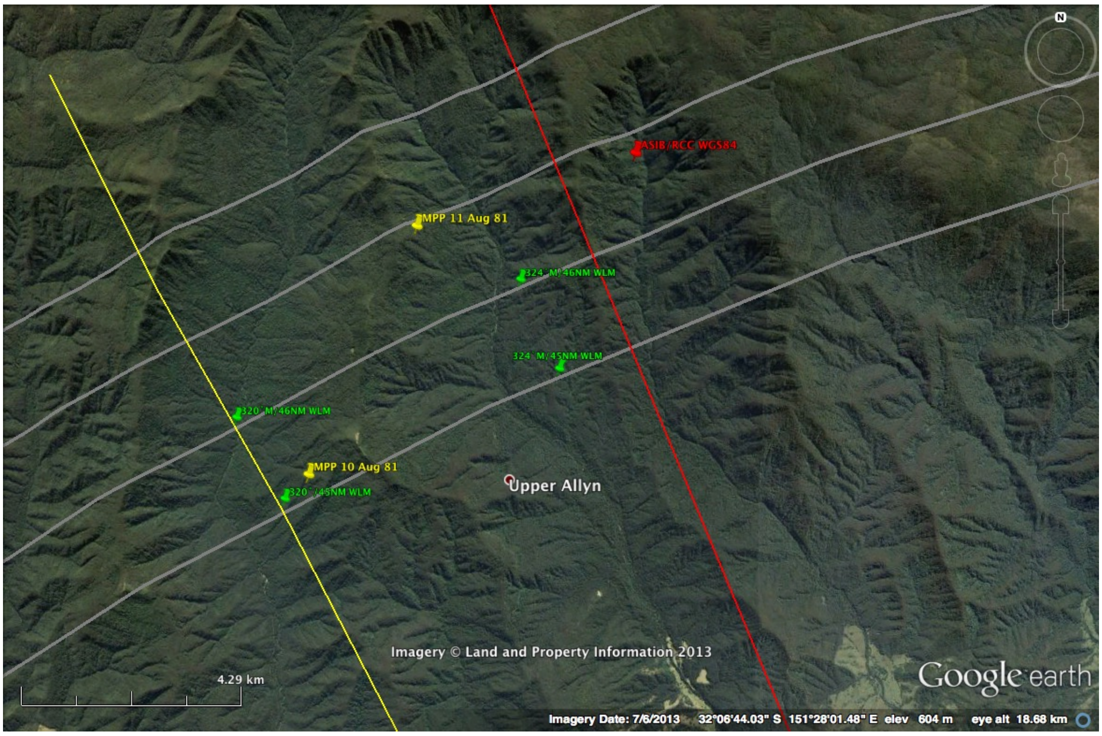


Figure 36: Most Probable Areas 10 and 11th August 1981. Yellow line is the 320˚M WLM, red line the 325˚M WLM. Grey lines are arcs from WLM TAR between 45NM-48NM. The MPP of 10 Aug 81 is clearly defining the pure 320˚M/45NM position. The 11 Aug 81 MPP lies very close to the 324˚M/46NM position that is viewed as a likely position of VH-MDX at 0936:00UTC. The ASIB/RCC position, viewed likely to be a refined 0936:00UTC Williamtown position, is also close by (Image: Google Earth 2015, Land and Property Information 2013).

Immediately obvious is the association of the 10th August 1981 primary search area center point to the 320˚M/45NM position. It is thought that this center point position was determined from the *initial* information flow concluding a pure 320˚M/45NM *fade* position on Williamtown radar.

It is likely that the 0936:00UTC position was discussed further between Senior Air Traffic Control Officers (SATCO's) and the ATCO on duty during the VH-MDX accident, probably with physical reference to the PPI resulting in a more finessed position.

This would have yielded the amended center point for the search area of the 11th August 1981 and would have been passed to Sydney during follow up discussions that were transcribed as having occurred on the 11th August 1981 between Sydney and Williamtown[42].

The 11th August 1981 search area center point can be seen in figure 36 to be associated with the 324˚ likely bearing as suggested and the 46NM likely range found thorough ATCO interviews. Additionally, this position is also close to the ASIB/RCC last radar position that will be shown in later sections to likely be a refined 0936:00UTC position.

The position of the plots in figure 36 coupled with the known sequence of information flow, suggest a 0936:00UTC position of VH-MDX around 323˚M-326˚M and between 45NM and 47NM from Williamtown.

5.1.7. VH-MDX change of squawk code

A request to change VH-MDX's mode A SSR code from 4000 to 3000 and to squawk SPI ident was given around 0935:41UTC[7]. This action was perceived necessary to interrogate VH-MDX on the Williamtown radar as VH-MDX was not visible on the PPI between 0934:00UTC and 0936:00UTC.

Section 3.7.4 identified that all SSR ground stations in view of an aircraft transponder could successfully interrogate and display positional information on their respective displays. Also identified in the same section was that the SSR ground stations could interrogate all SSR codes available and would display any positional information from any received code.

Accordingly, a change in mode A code was *not* required as either the Sydney or Williamtown radars could interrogate and display *all* SSR codes possible and could do so *almost* simultaneously.

As shown in section 3.7.6.2, *particular* display symbols could be allocated to *particular* SSR codes ('dialed up') on the Williamtown PPI through thumbwheel switches but, of importance is that all received SSR codes could be displayed by a synthetic symbol regardless of these thumbwheel settings[21].

Non 'dialed up' codes were represented by a symbol allocated to all *non-preselected* codes most likely being an inverted 'Y' this possibly being the same symbol allocation as Sydney ATC radar[19].

SPI ident from VH-MDX on the other hand was essential for the Williamtown ATCO to positively identify VH-MDX.

As described in the previous paragraphs, VH-MDX was squawking a mode A code and will be shown in later sections to have been within line of sight of the Williamtown SSR ground station out to at least 48NM. Accordingly, there was no reason VH-MDX would not be displayed *unless VH-MDX was not within 48NM of Williamtown*.

A refinement of position is given by Sydney Sector 1 at 0934:30UTC to assist Williamtown in locating the paints on his display[7]. This is in the form of a distance amendment of 46NM however, VH-MDX paints were still not detected by Williamtown[1].

It was suggested by ATCO's experienced with the Sydney Bright display that 2NM read-off resolution could be achieved when referencing the returns from fixed references such as waypoints and the like within 10NM of the return[19]. No such references existed in the vicinity of this particular position.

Furthermore, as the position had to be defined in reference to Williamtown, a simple reference to the closest waypoint was not applicable.

There were no range rings from Williamtown in the vicinity of the position so, the Sector 1 ATCO had to extrapolate. It can be seen that errors in range are almost assured.

It was also shown that range deviations of around 5NM all-round were applicable to paints that could *not* be referenced to map features within 10NM and this is viewed applicable to the 320˚M/45NM position[19].

From this it is clearly seen that although VH-MDX was stated to be at 46NM from Williamtown by Sydney radar, the aircraft could in fact have been as far as 51NM away. Considering:

- The Williamtown radar could *detect* and *display* <u>all</u> mode A codes possible
- The Williamtown ATCO describes to the author a high level of detail in searching for radar returns amongst and away from the Barrington Tops PE's
- That the primary paint referred to at 45NM was unlikely to be VH-MDX as the ATCO was referring to the PE's whilst an SSR symbol would have been associated with it and visually detectable if an aircraft
- VH-MDX was squawking a mode A code at the time[7]
- Propagation analysis suggests VH-MDX was within line of sight of Williamtown ATC radar during the times in question out to 50NM along the 320˚M bearing to altitudes well below 7000'
- The outer limits of the Plan Position Indicator (PPI) (radar scope) was set to 48NM during the accident
- A read-off tolerance of around 5NM was applicable for the Sydney observed position at this time;

<u>It is concluded as likely that VH-MDX was outside of 48NM from Williamtown just after 0934:00UTC and possibly up to 0935:00UTC although it cannot be confirmed when the ATCO ceased observing the PPI.</u>

Of note is although the Williamtown PPI could be set to a 96NM maximum range, changing maximum range would result in the PPI going blank for a significant time that is obviously an undesirable state when experiencing high workloads.

5.1.8. Conclusions: 320˚M/45NM Williamtown radar position

It can be seen with little doubt that the 320˚M/45NM Williamtown radar fix was actually VH-MDX and the position of VH-MDX at 0936:00UTC given:

- The rough position Sydney Sector 1 gave (320˚M/46NM) approximately 1.5 minutes prior *coarsely* aligned with the observed position (320˚M/45NM)[7] (two separate radars with similar position at *similar* time)
- The observation of a mode A 3000 SSR symbol[4]
- The observation of an SPI ident triangle symbol[4]
- Communications transcript time is considered accurate
- Confirmation that the SSR returns were approximately in the middle of the Barrington/Gloucester Tops permanent echoes in range and azimuth (gross error check that *coarsely* confirms 320˚M +4˚/- 2˚ and 45NM-47NM range)
- Interaction between Williamtown ATC and Sydney ATS alludes to a 0936:00UTC position of 323˚M/45NM.

The last two points quashes to a large extent the possibility of pre-disposition of the Williamtown ATCO to have simply read back '320/45' (regardless of actual VH-MDX position).

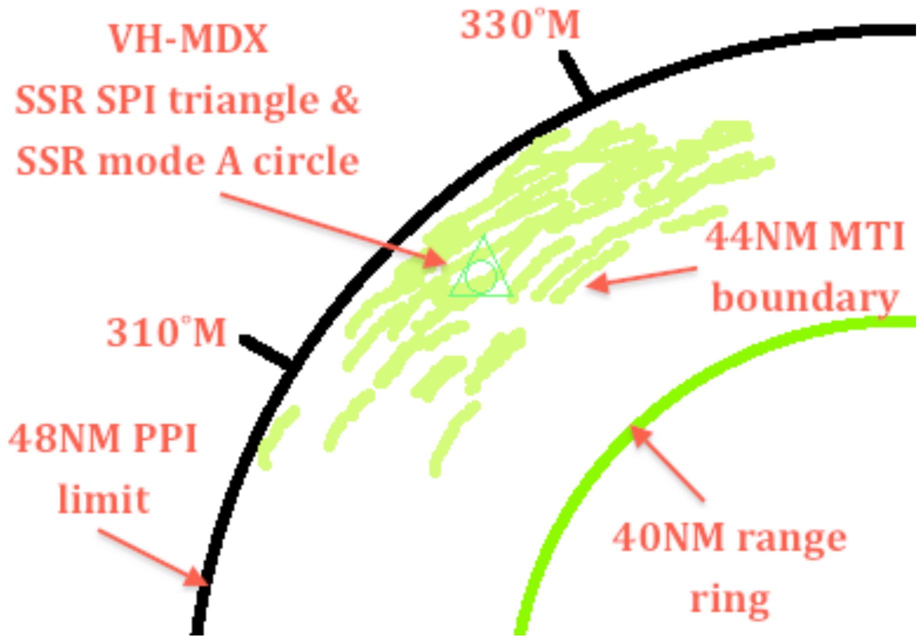


Figure 37: Reported position of the 320˚M/45NM Williamtown fix. SSR returns are purposely dulled down in the picture to show the effect of terrain clutter on the ability to discern returns. Regardless, the Williamtown ATCO did state that the SPI triangle and mode A squawk (circle) were 'clearly visible' despite the clutter (Image: Glenn Strkalj 2014).

<u>The 320˚M/45NM position is considered representative of VH-MDX's position at 0936:00UTC within +4˚/-2˚ and +2NM/-0NM although it is viewed more likely that VH-MDX was closer to 323˚-326˚ and between 46NM and 47NM at 0936:00UTC.</u>

5.2.Analysis of the 330___ Call

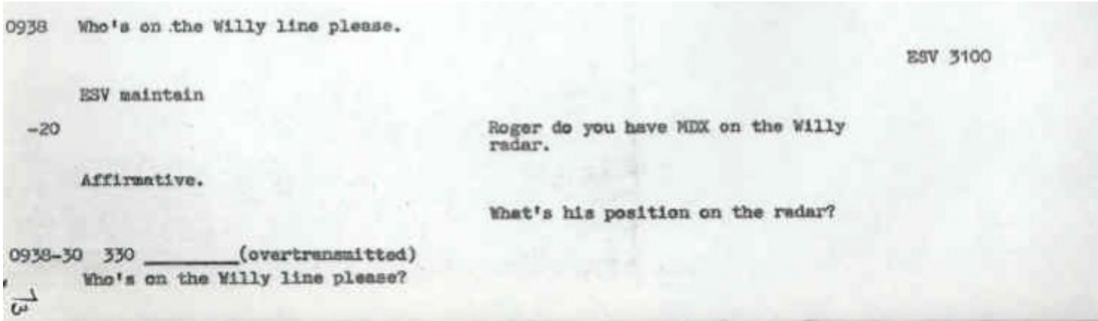
5.2.1. Overview

As shown in section 4.4.6, the Williamtown ATCO cannot remember making the '*330___*' call at 0938:30 UTC. The last portion of the call, likely to have been range was over-stepped by another party. So far, no audio recordings are available of this particular communication exchange to attempt verification of voices.

What is interesting is that the ASIB reportedly did not interview the Williamtown ATCO[4] so, the chances of determining the range of the fix or simply verifying that the call was made is viewed as minimal.

About 20 seconds prior to this call, the Williamtown ATCO advises Sydney ATC that VH-ESV was 7NM north of Williamtown. The Williamtown ATCO although not specifically recalling in 2014 as having done so, suggests that this position would have been determined by procedural dead reckoning possibly backed by radar[4].

VH-ESV would have tracked approximately along the 340˚M bearing from Williamtown, positioning himself on the south side of the runway complex for a left base for runway 30.



Time	Williamtown	Sydney	Aircraft
0938	Who's on the Willy line please.		
			ESV 3100
	ESV maintain		
-20		Roger do you have MDX on the Willy radar.	
	Affirmative.		
		What's his position on the radar?	
0938-30	330 ________(overtransmitted)		
	Who's on the Willy line please?		

Figure 38: 330 Call ASIB Transcript. The columns from left to right depict the transmitting agency and are Williamtown, Sydney and 'aircraft' respectively. What must be remembered is that the transcripts reflect what ASIB *interpreted* the recordings as. Because Williamtown ATC audio recordings around this time frame have not been located, it has been impossible to verify what was actually said and by who (Image: Australian Government (Bureau of Air Safety) 1981).

5.2.2. Under pressure

The Williamtown ATCO was alone in the Williamtown ATC complex conducting *procedural* separation duties with a number of transiting and landing aircraft[4]. Consequently, the ATCO had a continual workload[4] and was under some amount of pressure.

Communications transcripts show there were many parties on the internal ATS communications line around this time with confusion amongst parties obvious.

Just prior to the 330 call, the Williamtown ATCO was talking to VH-ESV and appeared to be interrupted by Sydney ATC[7]. This possibly terminated his transmission to VH-ESV early as evidenced by 'ESV maintain' (incomplete) at 0938:10 UTC.

It would be expected today that 'maintain 3100' would be the call in this instance although communication standards were different in 1981.

From this, it can be seen how the Williamtown ATCO may have been under pressure to deliver 'a fix' to Sydney resulting in a 'pluck' bearing based on the mental picture the ATCO had rather than observing the PPI.

Alternatively, the ATCO may have observed the PPI, assessed the position and transmitted the information without remembering having done so. The transmission may have been an automatic process for the ATCO without even realising he had replied.

5.2.3. Williamtown media release

Comments from a RAAF Williamtown spokesperson within days of the accident suggest Williamtown had VH-MDX on radar about one minute before the aircraft vanished as shown in figure 39.

Considering the last received *radio call* from VH-MDX was around 0939:30UTC, one minute prior is 0938:30UTC: the time of the 330˚M call.

On the other hand, accepting ‘vanished’ as the time that VH-MDX was noticed not to be on the Williamtown PPI, which was 0941:10UTC then, taking a minute from this equals 0940:10UTC.

What was observed at this time if anything at all is not known.

It can be seen how this time (0940:10UTC) may have been incorrectly used for the ASIB/RCC final Williamtown radar position at 1940EST (0940UTC). This position is described in sections 4.1.2 and 6.

Considering communications transcripts and ATCO interviews, it appears more likely that the one minute before was referenced from the final received call from VH-MDX thus, relating to the 330˚M bearing call.

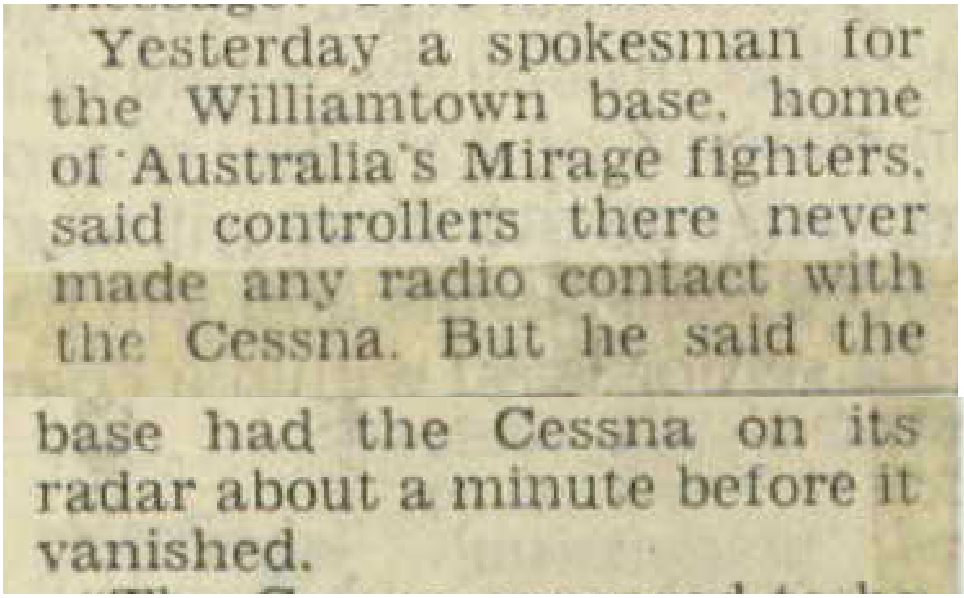

Yesterday a spokesman for the Williamtown base, home of Australia's Mirage fighters, said controllers there never made any radio contact with the Cessna. But he said the base had the Cessna on its radar about a minute before it vanished.

Figure 39: RAAF Williamtown possibly suggesting the 330˚ bearing was observed at Williamtown radar. As the last received radio call from VH-MDX was around 0939:30UTC, one minute prior is 0938:30UTC: the time of the 330˚M call. Alternatively, the one minute before was probably applied to the first instance the Williamtown ATCO noticed no VH-MDX paints. This could then be the origin of the reference to Williamtown radar returns disappearing at 1940EST (Image: The Weekend Australian, 15th-16th August 1981).

5.2.4. Sydney ATC call?

There were multiple agencies on the ATS internal communications line[4][7] and Sydney ATC could have made the call in order to pass a bearing of VH-MDX from Williamtown as observed on the *Sydney ATC* radar to:

- Update the Williamtown ATCO
- Update FIS-5 or;
- To record the final position on Sydney radar after noticing paint fade.

Indeed the position of 330__ may have been intended to be passed between Sydney ATS members for the purposes of an update. e.g. Sector 1 ATCO to SOC or to FIS-5. Communication transcripts imply that the Sydney Sector 1 ATCO reports radar fade of VH-MDX at 0939:00UTC when the Sector 1 ATCO states *‘…we’ve lost him…’*.

Given the relatively slow update rate of the Sydney and Round Mountain RSR's it is probable that detection of radar fade would have taken at least one sweep if not more. One sweep of the RSR is 12 seconds. This leads to an actual fade time *from* around 0938:30UTC (the time of the 330___ call) to 0939:00UTC.

If the 330 call was based on Sydney ATC radar information then given the situation, workload, type of radar (RSR) and display, bearing tolerances would likely be broad. +/-10° was suggested by one Sydney ATCO[19] when determining bearings on the Northern Mosaic display program used during the accident.

Despite this, Sydney passed a bearing of 320°M to Williamtown that ultimately resulted in the 320°M/45NM fix suggesting an reasonable bearing determination.

If it was Sydney who stated '330' then an angular difference would have been observed from VH-MDX's 320°M position thus eliminating the application of a +/-10° tolerance in this specific case.

Furthermore, an ex-Williamtown ATCO stated Sydney ATCO's were '*generally accurate*' with aircraft radar position handovers to Williamtown[5]. Accordingly, +/-5° would not be unreasonable in the circumstance.

Also supporting the suggestion of a 330°M bearing call made by Sydney Sector 1 is the acceptance by Sydney ATS on the day after the accident that VH-MDX faded from radar at approximately 330°M/45NM from Williamtown at 0939UTC. Figure 40 presents this information.

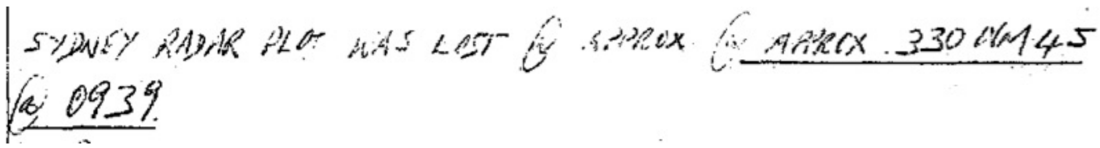

SYDNEY RADAR PLOT WAS LOST @ APPROX @ APPROX 330 NM45
@ 0939

Figure 40: Accepted Sydney radar fade position and time. (Image: Australian Government (Department of Transport) 1981).

This time generally aligns with transcripts and with radio propagation analysis compared with dead reckoning tracks, rates of descent and altitude calls[19]. The position of 330°M from Williamtown will be shown in section 5.2.6 to have been generally achievable within expected tolerance (+/-5°) and certainly within maximum tolerance (+/-10°).

The confusion around this time on the ATS internal communications intercom was described previously[41]. Considering the things said, it could easily be seen how a conversation between FIS-5 and Sector 1 was apparent at this time. Sector 1 may have been passing the 330°M bearing and later even, the 150°M heading advice.

5.2.5. Discussing another aircraft?

Given that the transponder of VH-MDX was not squawking ident by the time of the 330___ call and that other civilian aircraft were being managed by Williamtown ATC, there is a possibility that 330 may have referred to another aircraft.

Assuming the Williamtown PPI maximum range selection remained on 48NM throughout, this becomes the limit of consideration for other aircraft from a Williamtown perspective.

From communication transcripts[7], the only other aircraft to the north-west of Williamtown around 0938:00UTC was a Cessna-402 VH-ESV that was tracking Sandon East-Craven-Williamtown.

Section 5.2.1 identified VH-ESV was 7NM north of Williamtown about 20 seconds prior to the 330___ call. VH-ESV should have theoretically been tracking 163˚M (variation adjusted for 2014 plotting) to Williamtown (which is the 343˚M bearing from Williamtown) but was positioning for a left base[7] which, given the wind would have been runway 30.

To position for a left base onto runway 30 would require maneuvering through the 330˚M bearing from Williamtown. Also, Williamtown and Sydney were discussing VH-ESV at length approximately 30 seconds before the 330 call.

Additionally, the Automatic Direction Finders (ADF) of VH-ESV and VH-MDX were reported by the respective pilots as swinging around and being generally unstable. This was attributed to the thunderstorm offshore of Port Stephens by the pilot of VH-ESV[7]. Williamtown's primary Navaid to civilians was the NDB.

From this it can be seen that VH-ESV could have easily been tracking ten degrees off the required course thus, being on the 330˚M bearing instead of the 343˚M bearing from Williamtown some distance out.

As a result of these points, there is a possibility that the 330____ call was related to VH-ESV's position although the Williamtown ATCO strongly believes this did not occur[4]. Given VH-ESV was very close to Williamtown it is viewed as unlikely that the ATCO confused the two aircraft.

VH-AZC was being handed off to Sydney FIS-3 around the time of the 330 call with much discussion being had between Williamtown and FIS-3. VH-AZC was enroute to Aeropelican at the time.

Accordingly, VH-AZC was to the north-east of effectively all the relevant southerly Navaids to which it may have been referenced to. It can be seen that VH-AZC could not be referenced to relevant Navaids (Sydney, Mount McQuoid, West Maitland) at a position of 330˚M *from*.

Considering all this and the fact that the request for radar information of VH-MDX was *specific* and *acknowledged* by the Williamtown ATCO, it is viewed likely that if the Williamtown ATCO made the 330˚M call, he observed and reported on the position of VH-MDX as 330˚M.

5.2.6. Ability to reach 330˚M bearing

VH-MDX was identified by Williamtown radar at 0936:00UTC whilst the 330___ call was made at 0938:30UTC; an interval of two and one half minutes. This section will take a *simplistic* approach to determine if VH-MDX could have been close to or at the 330˚ bearing from Williamtown.

It is understood that VH-MDX may not have simply tracked in a *purely* straight line from the 320˚M/45NM fix to the relevant last positions however, a *simple* check of ability to achieve the 330˚M bearing is being performed, not a detailed analysis.

The following is assumed or used:

- A *straight* course flown by VH-MDX from the 320˚M/45NM fix
- Initial track at 320˚M/45NM position equaling course flown
- A tailwind of 40 knots based on the most likely wind of 225°T-270°T, 30-50 knots[38]
- Constant True Airspeeds (TAS) of 111 and 192KTAS representing the slowest expected Indicated Airspeed (IAS) (climb at 100KIAS) and fastest *possible* IAS (powered dive)
- 0936:00UTC VH-MDX positions of 318˚/45NM, 320˚M/45NM and 324˚M/46NM
- A track from the previous points to the Sydney final radar position
- Time interval of 2.5 minutes (time from 320˚M/45NM to 330˚ call).

Two *final* radar fixes are suggested in VH-MDX records. These fixes are separated by at least 10NM and so do not fall within expected radar tolerances.

Only the Sydney final radar position would involve *crossing* the *actual* 330˚M bearing from Williamtown and so will be the only final radar position considered.

If VH-MDX's final observed radar position was at the ASIB/RCC position, then VH-MDX would be within approximately 4˚ of the Williamtown 330˚M bearing line and thus would meet the definition of being on the 330˚M bearing line (within +/-5˚ as determined in section 5.2.4).

Results are depicted in figure 41. Distances of 6.3NM (slowest speed) and 9.7NM (fastest speed) result from the parameters specified.

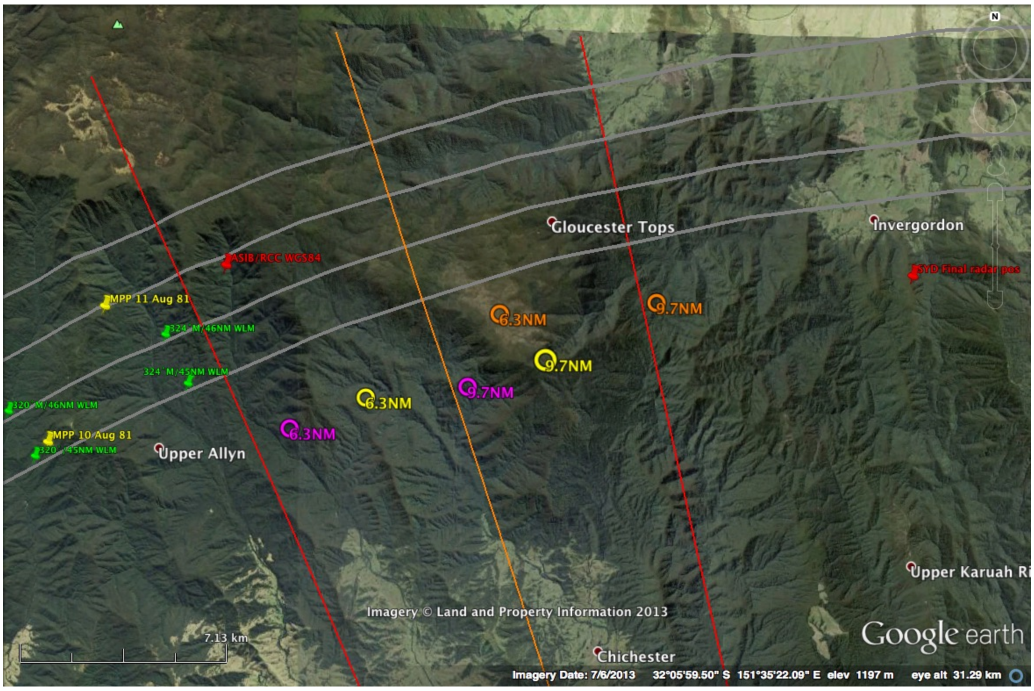


Figure 41: Ability to achieve 330˚M bearing Williamtown. Orange line is the 330˚ WLM. The two red lines represent the 325˚M and 335˚M WLM bearings. Purple circles are results from 318˚M/45NM, yellow circles results from 320˚M/45NM, orange circles results from 324˚M/45NM. Readily obvious is that 330˚M WLM +/-5˚ is easily achievable flying at airspeed of 100KIAS (representing a climb profile) beginning from either 318˚M/45NM, 320˚M/45NM or 324˚M/46NM. The fast speed case from 324˚M/45NM exceeds 335˚M but, not by much. If VH-MDX ended up at the ASIB/RCC final position then the aircraft would be within 4˚ of 330˚M WLM (Image: Google Earth 2015, Department of Land and Property Information 2013, Additions: Glenn Strkalj 2015).

5.2.7. Does 330˚M on radar represent 325˚M on the ground?
It is possible the ASIB/RCC final radar observed position that is approximately 325˚M-326˚M from Williamtown was actually a radar observation of VH-MDX on the 330˚M bearing as displayed on the PPI.

As will be discussed later in this paper, a Department of Transport aircraft was vectored around the Barrington Tops area within days following the accident for comparison of PPI and physical positions[14].

This combined with an apparent ASIB assumption at the time that 330˚M was the final position observed on Williamtown radar may have generated the ASIB/RCC final position by radar. This will be discussed in section 6.

Should it be the case that the radar was *displaying* approximately 4˚-5˚ away from *actual physical* magnetic bearing, then the 320˚M/45NM position would likely be displaced possibly by a similar amount.

This is considered *unlikely* given that ATCO's have described how aircraft were generally observed on radar probably within a few hundred meters of *well defined* reporting points and rarely miles out[4]. Equipment was strictly maintained to standards.

Any errors of this magnitude are likely to be the result of read-off errors. Accordingly, if 325˚M was the 330˚ call related fix, the difference would be attributed to operator read-off and rounding.

5.2.8. 150 Heading backs 330 position
When Sydney Sector 1 asked the Williamtown ATCO for a heading to track VH-MDX to Williamtown the response was 150˚(M). This call was given approximately 30 seconds following the 330˚M call.

Given that 150˚ is the reciprocal track of 330˚ and that there was only approximately 30 seconds between calls, notwithstanding human factors considerations there is some confidence in the validity of the 330˚M position.

It is also quite possible that the 150 call was based on a preconceived frame of mind based on either hearing or transmitting 330 previously then simply stating the reciprocal. But despite this, 150 does support the 330˚M position.

Indeed the Williamtown ATCO may not have made the 150 call and it is quite possible Sydney ATC made the call to pass on to FSC or the SOC.

5.2.9. Discussion: 330˚M call
Regarding the 330___ call, of importance is determining:

- Whether the bearing was a pluck or accurately determined by radar
- Which radar the bearing was determined from.

Given some 30 years since the accident, it is entirely possible the Williamtown ATCO determined this bearing with reasonably accurate reference to the PPI even though not remembering. The ATCO's workload was high during this period with many agencies on the internal 'party line' causing confusion amongst each other.

Considering that the Williamtown ATCO cannot remember making the 330 call but does suggest that if he did observation of the PPI would have been carried out[4], it is assumed at this stage that if the Williamtown ATCO did make the call the bearing would be accurate within +/-10˚ (quick visual assessment) as no further refining evidence is available.

Despite this, as the previous fix was on the 320˚M bearing, some angular change must have been observed to yield 330˚M. Accordingly, +/-5˚ would be an appropriate tolerance to apply.

The 330___ could also quite possibly have been derived from Sydney ATC radar instead and subsequently passed between Sydney ATS members on the party line. If derived from Sydney ATC radar, the accuracy of the 330 bearing is accepted to likely be within +/-5˚ given the accuracy of the 320˚M bearing passed to the Williamtown ATCO and the required change from the 320˚M bearing discussed but definitely within +/-10˚.

It was certainly concluded in the day after the accident by Sydney ATS that Sydney ATC observed radar fade of VH-MDX approximately on the 330˚M bearing and 45NM from Williamtown at 0939UTC[42].

VH-MDX could have reached the 330˚M +/-5˚ bearing from the 320˚M/45NM position at 100KIAS climb speed within the *timing* specified from communication transcripts and likely wind during the accident.

Additional to discussions in this section, the ASIB and/or RCC could have used the 330 call to determine the ASIB/RCC final radar position (326˚M radial Williamtown).

An approximate *range* at the 330˚M bearing could have been determined by ASIB and/or RCC based on VH-MDX's *apparent* and *approximate* tangential track from the 320˚/45NM position to 5NM west of Craven waypoint.

5.2.10. Conclusions: 330˚M call

What can be concluded as certain is that someone made the 330___ call and it has some meaning to VH-MDX. As a result, any flight path analysis should *consider* this bearing to some degree but with a cautious approach.

It is concluded that it is not a question of whether VH-MDX was at 330˚M +/-5˚ at around 0938:30UTC but rather, what radar the position was observed on thus, what tolerances are to be applied in flight path analysis.

5.3. Analysis of the 150˚ heading call

The 150˚ heading call was transcribed as being made by the Williamtown ATCO approximately 30 seconds following the 330___ call[7]. Section 4.4.7 reveals that the ATCO does not remember making the call and if he did this heading may have been a 'pluck' although based on some source of hard information (i.e. radar observation, current or previous)[4].

Given time proximity to the 330___ call and the fact that 150˚ is the reciprocal of 330˚, it may have indeed been a pluck but one based on a valid radar position (330˚M bearing line from Williamtown discussed in previous section) even if not the most current radar position.

Alternatively, Sydney Sector 1 may have given the heading to an agency such as FIS-5 to pass on to VH-MDX. Hard conclusions cannot be drawn.

5.4.No VH-MDX returns

As section 4.4.2 highlighted, the only other time the Williamtown ATCO *consciously* recalled looking at the PPI after the 0936:00UTC (320°/45NM) radar fix was when he observed no primary or secondary returns of VH-MDX[4].

Communication transcript extracts from section 4.1.1 reveals the Williamtown ATCO was consciously looking at the PPI at 0941:10 UTC when he advised another aircraft that his radar was not painting VH-MDX anymore and, at 0941:20 UTC when he systematically verbalised his thought process by[7]:

- Confirming no SSR returns
- Confirming no PSR paint
- Confirming that MTI filtering is *not* cutting out VH-MDX's PSR paint,

Thus, confirming VH-MDX was not displayed on his PPI[7].

Section 3.9.4 identified target paint persistence to be approximately 4-20 seconds. Subtracting these maximum persistence times from the times the ATCO observed no VH-MDX return yields *latest* target disappearance times of:

- 0940:50 UTC - 0941:06 UTC ('*not anymore*')
- 0941:00 UTC - 0941:16 UTC (systematic check for VH-MDX paints).

Just because VH-MDX disappeared from Williamtown radar approximately *no later* than these times does not suggest the aircraft crashed by these times; VH-MDX may have descended below the radar horizon or terrain clutter may have masked fading returns for a little extra time.

As stated, if VH-MDX was outside the MTI filter boundary at 44NM, fading returns would have been harder to discern earlier. Inside this boundary, the persistence would have revealed VH-MDX's position rather clearly if terrain impact or flight below the radar horizon occurred at around the times calculated above.

VH-MDX's last transmission was at 0939:26 UTC reporting 5000' altitude[7]. This last transmission time is between 1 minute 24 seconds to 1 minute 40 seconds before the *persistence* based *latest* lost radar contact times.

VH-MDX was shown to have an increasing rate of descent in the last two minutes of radio transmission with approximately 1700 feet per minute being evident in the last minute of recorded communications[7].

Accordingly, it would be difficult to assume that VH-MDX continued flying for too much longer given the flight path trend, terrain and perhaps controllability given the icing reported.

It was stated by a Department of Transport officer that the radar returns of VH-MDX on Sydney ATC radar were observed as to indicate the aircraft was slowing down[14]. This could be due to the aircraft slowing down IAS flown, turning into wind or departing controlled flight that would result in the slower ground speed.

Notwithstanding changing wind velocity with altitude, if VH-MDX was slowed down further in an attempt to increase climb performance or to simply prepare for the inevitable contact with terrain, given the significant ice accumulation reported it is likely rate of descent *increased further* as a result of stall, autorotation or spiral dive.

These two scenarios would be a strong possibility given the fact that:

- Maximum power was likely set (to climb), and;
- Ice accumulation could easily lead to asymmetric aerodynamic properties between wings;

Both of which contribute individually to a much-increased chance of wing drop at or approaching the stall. Accordingly, rates of descent well in excess of 2000 feet per minute would not be unexpected.

A spiral dive is equally likely given the pilot had no primary attitude or heading instrumentation with similar results.

Such a rate for one minute after the 5000' call would result in an altitude of 3000' AMSL that, in the general area of the final Sydney or ASIB/RCC radar fixes would likely result in terrain contact.

Terrain elevations of approximately 1500'AMSL to 3000'AMSL are in the area of the Sydney final radar position and when considering an-ever increasing rate of descent in the maneuvers described, terrain contact could occur faster than one minute following the last received radio call.

Adding one minute to 0939:26 UTC gives 0940:26 UTC which is 24 seconds before the earliest *persistence* based *latest* lost radar contact time. <u>Consequently, there is no benefit in considering fade times to allude to the final position of the aircraft.</u> It must be remembered that persistence would be artificially reduced if VH-MDX were located in the permanent terrain clutter as described in section 3.9.5.

6. Analysis of 'last observed position by radar' (ASIB/RCC final radar position)

6.1.Overview

This position was reported as originating from the RCC[14]. The Department of Transport Officer who's name appears on one of the position entries on a Minute was <u>not</u> involved whatsoever in defining the position[14].

So far, considering the evidence in section 4.1.1, it can be seen that the *communications transcripts* imply the Williamtown ATCO made the following fix related calls from 0936:00 UTC onwards[7]:

- 0936:00 UTC: 320°M/45NM
- 0938:30 UTC: 330_____
- 0939:00 UTC: 150° heading
- 0941:10 UTC: No VH-MDX radar paints
- 0941:20: Methodical check of no VH-MDX radar returns

On the other hand the Williamtown ATCO interviews from section 4.2 suggest the following fixes from 0936:00 UTC onwards[4]:

- 0936:00 UTC: 320˚M/45NM
- 0941:10 UTC: No VH-MDX radar paints
- 0941:20: Methodical check of no VH-MDX radar returns

So, according to communication transcripts, the final Williamtown radar position was a bearing 330˚M from Williamtown but from the ATCO's perspective it was the 'one and only' 320˚M/45NM from Williamtown.

Its was suggested in section 5.2.4 that the 330 call could possibly have been made by a Sydney ATC member referring to VH-MDX being radar observed by *Sydney* ATC. This suggestion was backed by:

- Communications transcripts implying radar contact was lost at 0939:00UTC (so radar fade between 0938:30UTC and 0939:00UTC)
- The 330 call being made just before loss of Sydney radar contact (final position observed, time to confirm and react at 0939:00UTC)
- Transcribed *Sydney* radar fade at approximately 330˚M/45NM Williamtown at 0939UTC
- Radio propagation analysis suggesting likely VH-MDX altitude at fade matches approximate fade position.

Any suggestion as to the origin of the 330˚M call can only ever be a considered a possibility and nothing firmer as original audio recordings of this time frame of the accident have not been located.

Section 4.1.2 identified the ASIB/RCC final radar position as being located at 325.9˚M/46.7NM from Williamtown. As can be seen, this position could represent either the 320˚/45NM 0936:00UTC fix or the 330˚M bearing.

6.2. ASIB assumptions

The ASIB communications transcripts reveal a point of interest regarding assumptions of the ASIB Inspectors. Figure 42 is an extract of the transcript of interest[7].

Listen in on the line
(around time 0938 comms FIS 5 ASST - Willie - ESV
FIS 5 asks Willie if MDX on Willie radar - affirmative
position on Willie radar 330, FIS or Sector asks Willie
to keep MDX on radar for tracking to Willie
MDX to land at Willie - 150°.)

Figure 42: ASIB excerpt from communications transcript. Although being a *transcript* of communications between ATS agencies and various aircraft, the statement above reflects the *conclusions* of ASIB Inspectors as to the 330___ call and 150 heading instruction as being from Williamtown. The background for making such a conclusion is not defensibly known (Australian Government (Air Safety Investigation Branch) 1981).

These comments were located in the communications transcripts obviously to 'clarify' what the Inspectors believed the communications implied. As is clearly evident, the '330___' call is taken as a *definite* position whilst the 150° heading (reciprocal of 330°) appears to be considered in the same vigor.

There is no reference to distance and as will be shown, it was not likely sourced from the Williamtown ATCO[4] nor was there radar track recording ability. Despite this, range may have been 'found' or derived from:

- The *raw* ATC communications recordings despite not being reflected in the communications transcripts
- Third hand talk within the RAAF ATCO community
- From an assumption of an easterly or tangential track to Williamtown and deriving a range from a 'cut' across the 330°M bearing.

The latter is a possibility given:

- Sydney ATC's final radar position well to the east of the 320°M/45NM fix[16][17]
- The Williamtown ATCO's statement to Police suggesting a likely westerly to easterly track[26]
- A Sydney ATCO suggesting a generally easterly final track[19]
- A transcribed last radar heading in an easterly direction[40].

But a strong option at this stage of research suggests a 330°M call of Sydney ATC origin as described in the previous section. This suggestion conflicts with the ASIB's conclusion discussed in this section.

6.3.Radar vectors of aircraft to final radar positions

As touched on in section 5.2.7, the Department of Transport reportedly flew a light aircraft possibly to what ASIB or the RCC determined to be the final radar fix from Williamtown as vectored through observation of the Williamtown PPI, within a few days of the accident[14].

It has been confirmed that the Department of Transport *planned* to use helicopters for the role[40] so, it is reasonably safe to assume that such flights were actually conducted.

The physical position of the aircraft was reportedly recorded[14]. This position could possibly be the ASIB/RCC final radar position particularly given that there is a cross on a map rather than a bearing/range from Williamtown. This alludes to an airborne position to map determination. This cannot be positively confirmed.

6.4.Aircraft over-flights

Additionally, civil aircraft during the night of the accident were radar vectored over last known positions of VH-MDX[15][42] for the purpose of searching. It was also stated that aircraft attempted to take fixes over radar based final known positions[15] and accordingly, the '*Last observed position by Radar*' may be based on such information.

At least three aircraft were diverted to overhead the Barrington Tops within 5-10 minutes of the final call from VH-MDX[7].

As it was night, aircraft with appropriate navigation systems could record the position. Indeed during the search operation in the days to come, there was at least one request for an Inertial Navigation System (INS) equipped aircraft to conduct a specific search of an area[40].

6.5.ATCO Discussions with RAAF pilot

Discussions regarding the possible areas VH-MDX may have impacted terrain around were had between the Williamtown ATCO on duty during the VH-MDX accident and a RAAF Iroquois Helicopter Pilot[4].

The pilot had plotted the position where he thought VH-MDX may have impacted terrain on a topographical map[4]. Whether this map is the one shown in figure 25 is unknown. The pilot died in an Iroquois crash during a test flight not long after the VH-MDX crash[4].

6.6.Same position as deposed Sydney ATC final radar position?

The Sydney ATC deposed final position of approximately 5NM west of Craven waypoint and the ASIB/RCC final observed position by radar were recommended in this paper to be treated as separate, distinct fixes for analysis unless further information and data could account for the approximate 10NM distance separating the two.

Some may argue the significant distance between the two positions could possibly be attributed to operator read-off and equipment alignment tolerances resulting in both positions referring to the same observation.

Assuming this, the ASIB/RCC position appears likely to be the refined version if one assumes these agencies reviewed the radar information critically.

The ASIB/RCC final observed radar position lies approximately on the 326˚M bearing from Williamtown: a difference of 11˚ (reference to Williamtown) to the final Sydney position.

It was described how +/-10˚ of bearing read-off error could be apparent when using the Northern Mosaic by a Sydney ATCO. Two Williamtown ATCO's also described how Sydney ATCO's gave rather accurate positions during hand-over of aircraft from Sydney ATC to Williamtown ATC.

Additionally as discussed in this paper, the handover from Sydney to Williamtown of VH-MDX at 0936:00UTC indicates a bearing determination within around 5˚. Sydney also reportedly observed radar fade at 'approximately' 330˚M/45NM from Williamtown indicating an ability to judge the 320˚ and 330˚ bearings.

It is therefore viewed possible but unlikely that the two positions discussed are one and the same.

6.6.1. A refined 320˚M/45NM (0936:00UTC) position

The ASIB/RCC position may actually be a composite (Sydney and Williamtown radars) or refined, 320˚M/45NM 0936:00UTC position if one ignores the stated time of the position (0940UTC). Indeed there was a reference by a NSW Police officer to having '*...taken a cross vector*' between Sydney and Williamtown radars in an effort to obtain a more accurate fix[31].

The exact mechanics of this statement is not expanded on however, one can clearly see if a comparison of the same radar position occurred between Sydney and Williamtown radars *there was only one common position*: the 320˚M/45NM position at 0936:00UTC.

From section 5.1.2, it was described how the 320˚M/45NM fix was more likely to have been 324˚M/46NM. The ASIB/RCC position is approximately 325.9˚M/46.7NM from Williamtown (+5.9˚) so, being rather close to 324˚M/46NM. Section 5.1.3 discussed how the ASIB/RCC position could be representative of the 0936:00UTC Williamtown fix.

It is readily apparent that this is such a relatively small angular difference (+1.9˚) and range difference (0.7NM). Considering this, the ASIB/RCC 'final' position could simply be the 320˚/45NM 0936:00UTC position mislabeled as 'final'.

Additionally, the Williamtown ATCO described VH-MDX's position at 0936:00UTC as being '*...just in the Barrington Tops*' and just after 0936:40UTC as: '*He's just over the top of the Barrington Tops*'[1]. These generalised descriptions broadly align with the geographical position of the ASIB/RCC 'final' radar position.

Overall, it can easily be argued although not with absolute certainty that the ASIB/RCC final radar position is indeed the 'final' position by Williamtown radar at 0936:00UTC rather than at 0940UTC but not a radar *fade* position.

This aligns with the BASI views of 1983 as described in section 4.2 suggesting the 320˚M/45NM position at 0936:00UTC was the 'final' Williamtown radar position.

6.7.Discussion

Of interest is that:

- The ASIB apparently did *not* formally interview the ATCO that was on duty during the VH-MDX accident[4][14]
- There was no recording capability of radar plots with SURAD[4][5][12]

As the Williamtown ATCO *confidently* states[4]:

- The only full position fix he obtained of VH-MDX was the 320˚M/45NM position and considering that;
- The ASIB 'Last observed position by Radar' (325.9˚M/46.7NM) is *approximately* 6˚ farther north and an extra 1.7NM away from the radar head in range compared to the 320˚M/45NM position[7] or;
- Approximately 2˚ farther north and an extra 0.7NM from the radar head compared to the 324˚M/46NM definition of the 0936:00UTC position;

One may conclude that the ASIB/RCC 'Last observed position by Radar':

- <u>Is</u> the 0936:00UTC Williamtown position when compared to the likely value of the fix being 324˚M/46NM (within +2˚ and 1NM)
- Is <u>not</u> the 0936:00UTC Williamtown position when compared to a pure 320˚M/45NM position (outside expected maximum errors being approximately +/- 5˚ and +/- 1NM and actual error being +6˚ and +1.7NM),
- Could possibly have been based on a composite of Sydney and Williamtown radar positions,

- Could have been determined by the '330' call with the azimuth position being within expected radar tolerances from the 330°M bearing from Williamtown,

The *only* sources possible for ASIB or the RCC to determine the Williamtown final radar fix *as observed by the ATCO* were:

- The ATCO on duty; who confidently asserts that he does *not* recall being interviewed by ASIB
- Raw communications recordings directly listened to by ASIB
- Communications transcripts/logs used by ASIB
- Duty technician who may have observed the final radar position, considered possible but unlikely by many ATCO's who were asked of this
- An ATCO/SATCO that had debriefed the ATCO on duty during the VH-MDX accident may have briefed ASIB
- The ATCO discussing the accident with another RAAF member who then had discussions with ASIB or RCC.

6.7.1. Conclusion: ASIB/RCC final radar position

The most reasonable explanation of the ASIB/RCC final radar position is that the position is actually the 0936:00UTC Williamtown fix finessed and/or conglomerated with the position observed on Sydney ATC radar at the same time.

This is not a hard conclusion and is simply the most reasonable conclusion made at this point of research.

6.8. Radar propagation analysis

6.8.1. Overview

Section 4.1.2 discussed how the ASIB/RCC final radar position although stated as having been determined by Williamtown TAR was unlikely to have been because the Williamtown ATCO did not observe VH-MDX radar fade.

A basic radar propagation check can be carried out regarding the likeness of Williamtown TAR and Sydney's Round Mountain remote RSR interrogating VH-MDX successfully at the ASIB/RCC position.

From this, the feasibility of the ASIB final radar position can be confirmed. The Round Mountain RSR was found to be the only Sydney ATC operated radar to be able to interrogate VH-MDX in the Barrington range area[19] thus will be the only Sydney operated radar considered for propagation analysis.

As discussed in section 3.11.4, line of sight analysis offers a simple and robust indication of radar coverage.

Radio Mobile propagation software will be used which considers a number of variables, Earth curvature and terrain effects[27]. As Radio Mobile is a tool for Amateur Radio operators[27], the precise radio frequencies of the radar equipment in interest is not able to be inputted.

The author strongly believes that selecting the closest Amateur frequency to the radar frequency in interest will provide a result that has negligible deviation.

Information on the Sydney ATC and Williamtown ATC radars is not completely accurate or available to such an extent that *precise* population of all variables in the Radio Mobile software is possible.

Despite this, there is sufficient information and data currently available in the author's opinion to achieve highly *accurate* and *defensible* results.

6.8.2. Variables

Radio Mobile requires various transmitter and receiver variables and these are discussed in Annex B. Should line of sight not be achieved, these variables can aid further propagation analysis beyond simple line of sight although line of sight in air surveillance radar is currently viewed as *essential* for aircraft detection.

The ASIB/RCC final radar position was indicated to occur around 0939-0940UTC, and VH-MDX called 5000' altitude at 0939:26UTC. The *lowest* line of sight altitude will be found and presented in results. This can then be used to assess the probability of the ASIB/RCC position being valid.

Only SSR propagation analysis will be carried out and the path analysed is ground radar to aircraft transponder. Specific values of the link analysis results have been omitted for simplicity and are only mentioned where absolutely required (when the link is marginal).

It would be expected that the aircraft transponder had a receiver sensitivity of between -69dBm to -77dBm and the SSR ground station downwards of -85dBm[28].

6.8.3. Williamtown TAR

The following figures depict the SSR propagation from RAAF Williamtown TAR to the ASIB/RCC final radar position by radar at different altitudes.

VH-MDX at 5000'AMSL

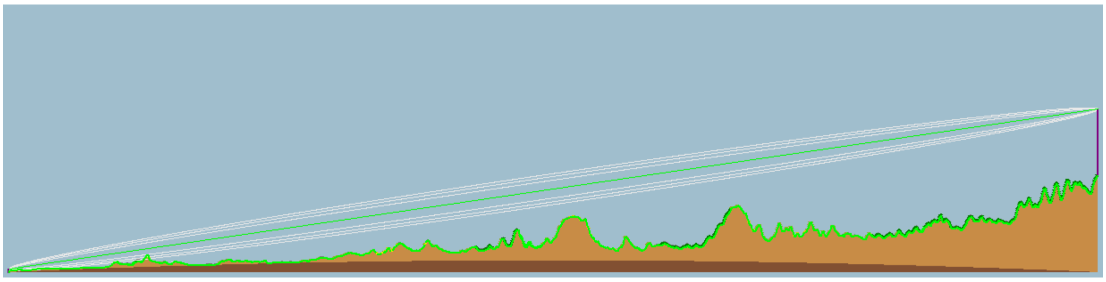


Figure 43: Williamtown TAR to ASIB/RCC final radar position prorogation at 5000'AMSL[27].

Immediately obvious is the line of sight achieved between Williamtown TAR and VH-MDX. From this alone one can be confident of SSR coverage.

VH-MDX at 4000' AMSL

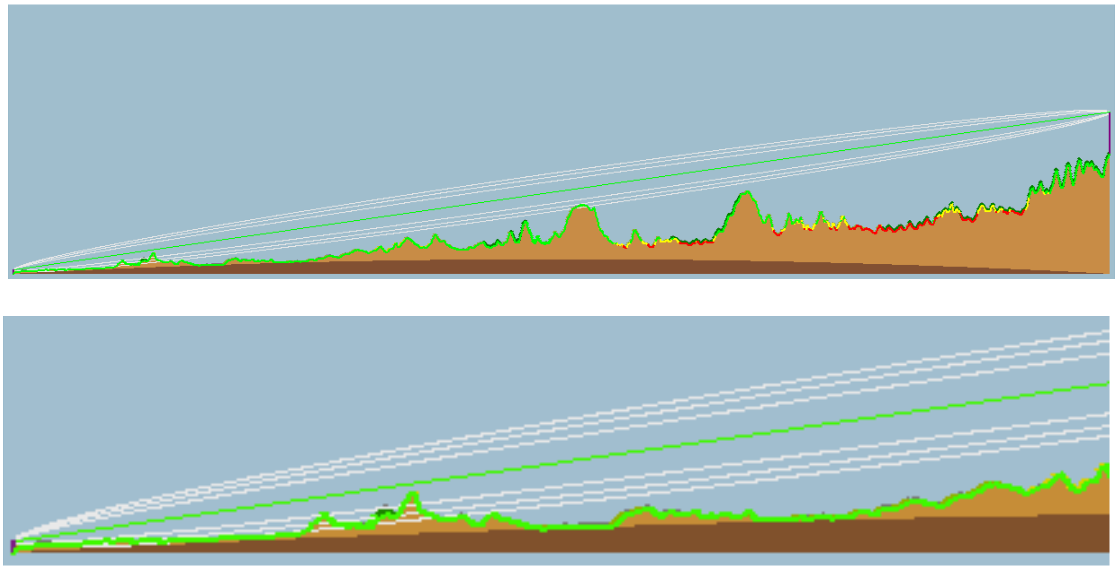


Figure 44: Williamtown TAR to ASIB/RCC final radar position prorogation at 4000'AMSL[27]. Bottom image zooms in on the most limiting terrain.

Line of sight is still indicated from Williamtown TAR to a VH-MDX altitude of 4000' AMSL The lower figure zooms in on the most restrictive terrain to line of sight propagation. Received signal was -77dBm, on limits but within the specification range for aircraft transponders.

VH-MDX at 3500' AMSL

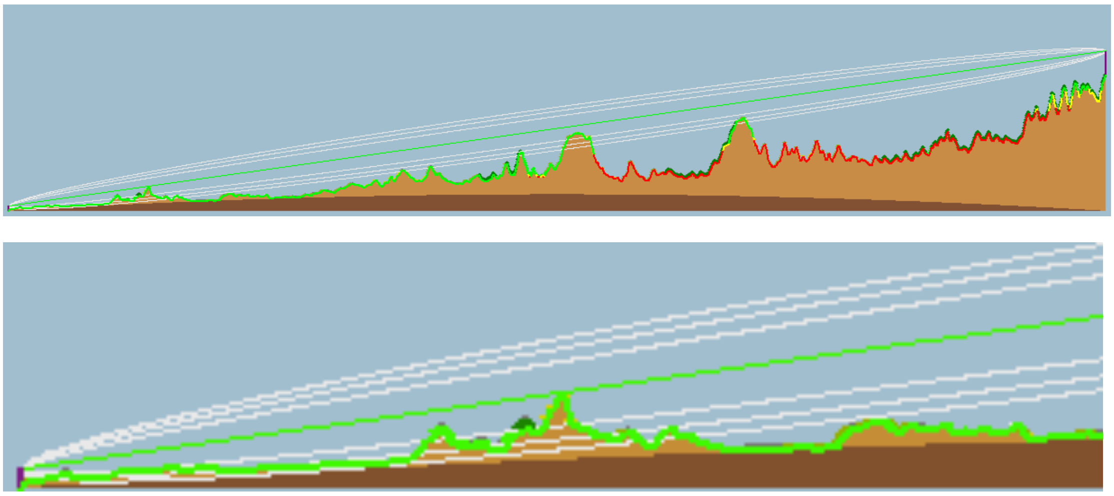


Figure 45: Williamtown TAR to ASIB/RCC final radar position prorogation at 3500'AMSL[27]. Bottom image zooms in on the most limiting terrain.

At a VH-MDX altitude of 3500'AMSL, line of sight is maintained but only just. As can be seen in the zoomed figure, the boresight path now is touching the most limiting terrain feature.

Regardless, a radio link is possible as diffraction effects of the radio energy would allow prorogation slightly beyond line of sight.

The Fresnel zones depicted by lines emanating from the green boresight line give an indication of non-line of sight propagation. Accordingly, despite possible vegetation on the most limiting terrain depicted and a received signal of -85dBm that is below transponder standards, SSR coverage was still possible, dependent on the *sensitivity* of both receivers amongst other variables.

At 4000'AMSL the received signal is at the -68dBm level which suggest an almost certain ability for Williamtown SURAD to interrogate VH-MDX at this altitude.

6.8.4. Sydney RSR

It has been shown that Sydney RSR could not contribute to VH-MDX positions below 10000'AMSL in the final 15 minutes of flight[19].

6.8.5. The Round Mountain RSR

The Round Mountain RSR was located just west of Point Lookout on the NSW north coast perched atop an almost 5200'AMSL high mountain. Similar tower heights to Sydney RSR are assumed.

In addition to the ASIB/RCC position being assessed, various points east and west of this position within 4NM were assessed for interrogation ability.

This was to yield insight into the radar ability leading into the ASIB/RCC final position. The results are only a snapshot and not completely conclusive.

Minimum interrogation heights of above approximately 7000'AMSL were found to the west and heights above approximately 6500' to the east.

<u>VH-MDX at 8200'AMSL</u>

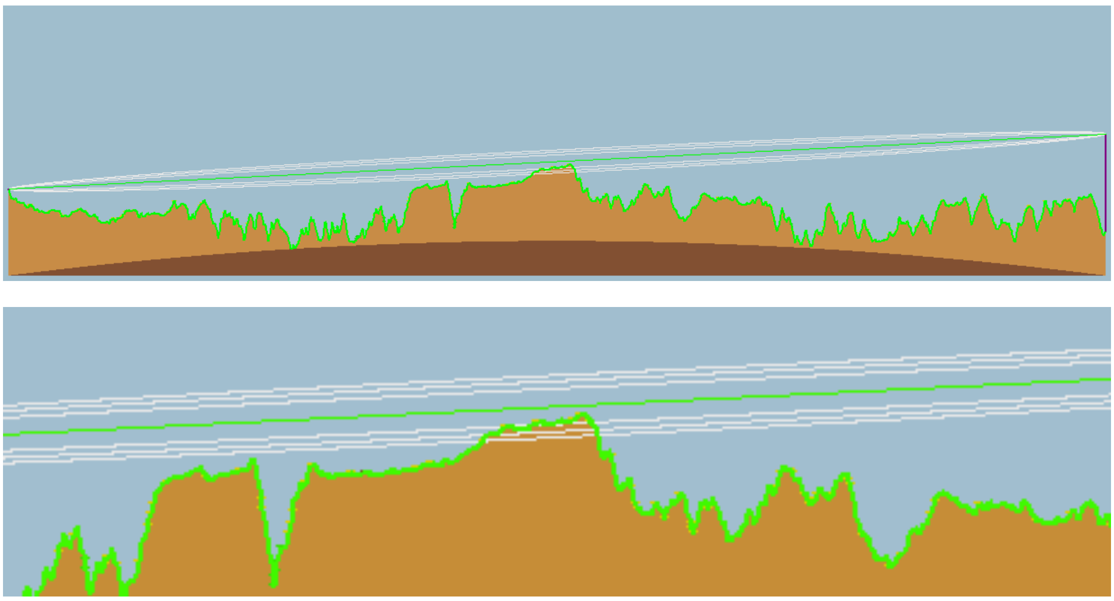


Figure 46: The Round Mountain RSR to ASIB/RCC final radar position prorogation at 8200'AMSL[27]. Bottom image zooms in on the most limiting terrain.

The lowest altitude that VH-MDX could have been interrogated above the ASIB/RCC final radar position as found through propagation analysis is 8200'AMSL. A received signal of -84.70dBm was found.

6.8.6. Discussion: radar propagation analysis

Regarding different ATC radars having the ability to detect VH-MDX above the ASIB/RCC final radar position:

- Williamtown TAR was *highly likely* able to detect VH-MDX down to 4000' AMSL aircraft altitude, possibly down to 3500'AMSL.
- Sydney RSR was *not* able to detect VH-MDX below 10000'AMSL in the Barrington ranges area thus, was definitely not a contributor to the position
- The Round Mountain RSR was able to detect VH-MDX from 8200'AMSL and above.

Additionally, The Round Mountain RSR was found able to interrogate VH-MDX not below approximately 7000'AMSL within 4NM west of the ASIB/RCC position and not below around 6500'AMSL to approximately 4NM east of the ASIB/RCC position. These were very coarse results to view trends approaching the fix.

The lowest altitudes found for line of sight all had received signals between approximately the -77dBm and -85dBm level suggesting that interrogation may cease a little above these altitudes.

As point to point propagation analysis was carried out, moving slightly either way of the ASIB/RCC position specified may yield different results.

Despite this, it is viewed highly unlikely that minimum altitudes found for interrogation would change much at all with small deviations either side of the ASIB/RCC final position. This view is based on over-viewing the obstructing intermediate terrain.

Considering these results and transcribed altitudes, it is *highly likely* the Williamtown TAR radar was the source of the ASIB/RCC final radar position if *radar fade* occurred at this position.

However, the Sydney ATC radar fade time was just before or at 0939:00UTC and the approximate altitude of VH-MDX at this time was shown to be around 6000'AMSL[19].

As Sydney ATC would have observed VH-MDX up until around this height, The Round Mountain RSR must have had interrogation capability of VH-MDX at around 6000'AMSL leading into the or at the ASIB/RCC final radar position.

4NM roughly accounts for 1 minute of flight time leading into the ASIB/RCC fix position which then relates to the likely Sydney fade time range of 0938:30UTC - 0939:00UTC. It was found there was generally no interrogation capability below 7000'AMSL within 4NM west and, below 6500'AMSL within 4NM east of the ASIB/RCC position.

Accordingly, VH-MDX approaching from the west and fading at the ASIB/RCC position is viewed as highly unlikely. VH-MDX approaching from the east and fading at the ASIB/RCC position is possible but right on the limits of Sydney fade time (0938:30UTC).

As VH-MDX was stated to be radar observed on an easterly track for the last few minutes[19] and, deposed to have faded further east than the ASIB/RCC position[17], a prolonged easterly tack leading into the ASIB/RCC position is considered unlikely.

Radio propagation analysis has shown that The Round Mountain was only capable of interrogating VH-MDX down to 8200'AMSL in the ASIB/RCC final radar position.

6.8.7. Conclusions: Radar propagation analysis

It was shown that Sydney ATC was unable to radar interrogate VH-MDX in the ASIB/RCC final radar position at around the time that Sydney ATC observed radar fade of VH-MDX.

Also shown was that with VH-MDX approaching from the west, the aircraft would have faded much earlier on Sydney ATC radar than expected. An approach from the east was not viewed as likely.

Accordingly based on radio propagation analysis combined with other evidence, despite Williamtown TAR having the ability to interrogate VH-MDX at altitudes below 5000'AMSL, it is viewed that that ASIB/RCC last radar position is unlikely to be a radar *fade* position.

6.9. Sydney ATC final radar position

A Sydney ATCO made a deposition[16] and completed a radar plot sheet[17] to describe VH-MDX's final radar position observed by Sydney ATC radars.

The Deposition describes the final radar position as being approximately 5NM *west* of the Craven waypoint[16] whilst the radar plot sheet shows the centroid of the final radar return positioned approximately 5NM *north-west*[17]. No time of fade was recorded in the deposition.

It was verified that a bearing and range description of the final position was *not* required given the radar return's close proximity to the Craven waypoint thus, making position reference simple and as accurate as could be expected[19]. The approximate area of interest with this position is in the vicinity of The Pimple/ Whispering Gully/ Gloucester River Camping Area[19].

It was also recorded that Sydney ATC lost radar contact with VH-MDX at approximately the 330˚M/45NM position from Williamtown at 0939UTC[40]. This position is to the west of the deposed Sydney final position. The ASIB/RCC position just falls into the ≈330˚M/45NM definition.

The final deposed Sydney ATC radar observed position is approximately 10NM east of the ASIB/RCC described position in section 4.1.2 [10]. As section 6.6 found, this is *not* considered within expected radar tolerances to reflect the same aircraft position.

The Williamtown ATCO's statement to Police[26] supports VH-MDX taking an easterly track from 320°M/45NM to the approximate 5NM west to north-west of Craven waypoint position. The 330˚M bearing call also supports VH-MDX tracking east towards the Sydney final radar position.

Radar propagation coupled with transcribed radar fade time and the likely altitude VH-MDX was at based on rates of descent from communications transcripts, suggest that VH-MDX would have been located generally to the east of the Upper Chichester River Valley[19] (Approximately).

The above finding suggests the ASIB/RCC position (being west of the Upper Chichester River Valley) is unlikely to be Sydney radar derived.

The previous section also found it unlikely that the ASIB/RCC position is a radar fade position derived from Sydney ATC radar.

6.10. Conclusions: ASIB/RCC final position by radar

The ASIB/RCC final observed position at WGS72/WGS84: S32°04'39.3", E151°28'59.0 by radar:

- Does *not* correlate with the *deposed* Sydney ATC final radar position
- Just fits the definition for the transcribed ≈330°M/45NM from Williamtown final Sydney observed final position
- Is derived from unknown primary data and is *not* defensible as a *final* radar position from this consideration
- Is defensible from a basic radar *propagation* point of view from Williamtown TAR
- Is not defensible when considering other factors tied in with propagation analysis
- Is defensible from a dead reckoning *time*/ *wind* point of view
- *Should* be considered as a 'final radar position' in flight path modeling, separate from the Sydney final radar position (i.e. conduct separate analysis with the separate radar positions) secondary to the Sydney final radar positions
- At this stage is viewed unlikely to be derived from Sydney ATC.

<u>The ASIB/RCC final radar position is currently not viewed as being a radar fade position from either Sydney or Williamtown ATC radars.</u>

7. Conclusion

Various aspects of:

- RAAF Williamtown ATC
- RAAF Williamtown SURAD TAR Radar
- Radar obtained information on VH-MDX;

Were covered in this paper and form a useful reference for current and future analysis of the VH-MDX accident.

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Annex A: Confirmation of 320˚M/45NM fix position relative to terrain clutter (Gross Error Check)

It is important to confirm the accuracy of the 320˚M/45NM fix as this fix will likely be the latest, most precise and defensible radar fix obtainable of VH-MDX.

Consequently, this fix will be heavily used in flight path modeling and statistical analysis. It can then be seen that confirming the accuracy of the 320˚M/45NM position and determining the tolerances to the lowest pragmatic levels is important.

The purpose of the following is to conduct a *gross error* check of the 320˚M/45NM fix and define tolerances based on reference of the VH-MDX radar returns to the *permanent terrain clutter* of the Barrington/Gloucester Tops rather than the compass rose.

Pictorial representations of VH-MDX returns as described by the Williamtown ATCO on duty during the VH-MDX accident were drafted in different positions in azimuth and range. The ATCO was then asked to consider:

- Firstly, pictures representing azimuth *only* then,
- Secondly, pictures representing range *only*.

The ATCO had to select one radar return of each that best represented what he remembered observing during the 320˚M/45NM fix.

The pictures only include the permanent echoes of the Barrington and Gloucester Tops Range and no bearings are shown. Permanent clutter depiction was based on photos of the Williamtown PPI and ATCO reports.

At either side of the mountain range (north and south of the clutter) was a sharp reduction in clutter to effectively zero and this was reported as being a permanent feature of the SUARD Williamtown radar display.

Additionally, the MTI boundary was set at 44NM thus, a sharp reduction to near zero terrain clutter was apparent *inside* approximately 44NM.

Azimuth Check

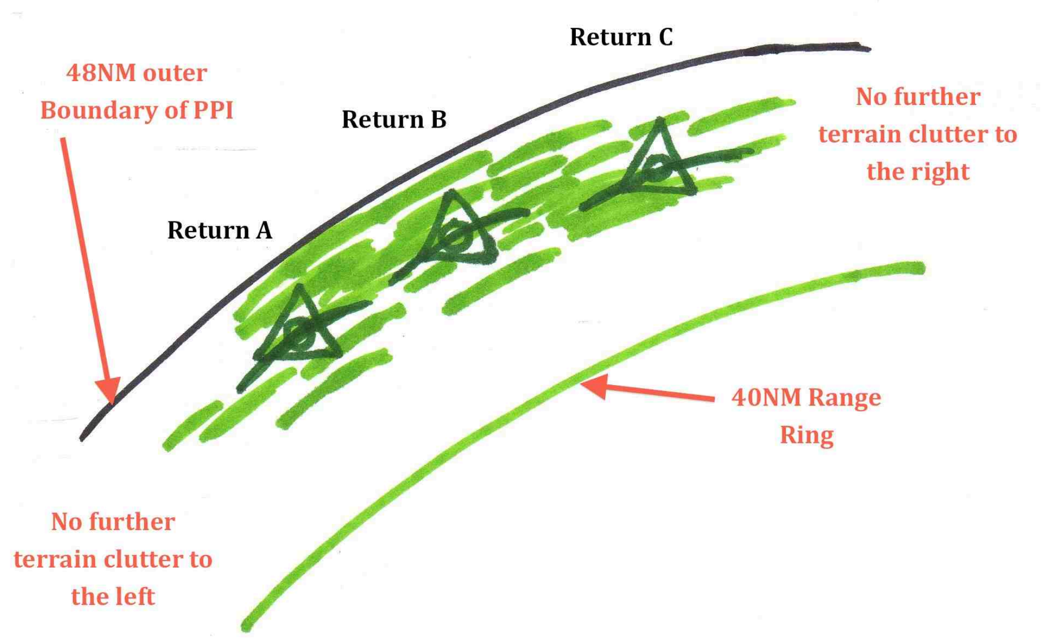

Figure 47: Multiple choices relating to *azimuth only* of the 320°M/45NM fix in relation to clutter. The Williamtown ATCO chose Return B and also stated that he was more concentrating on the bearing rose than relative position to clutter when considering azimuth alone (Images: Glenn Strkalj 2014).

'If I had to choose one it would be 'B'. I have never considered the ident of MDX relative to the PE's. I was focused on the bearing markers on the edge of the screen and the PE's assisted in giving me a more accurate range as I knew the MTI only went out to 44NM.'

Range Check

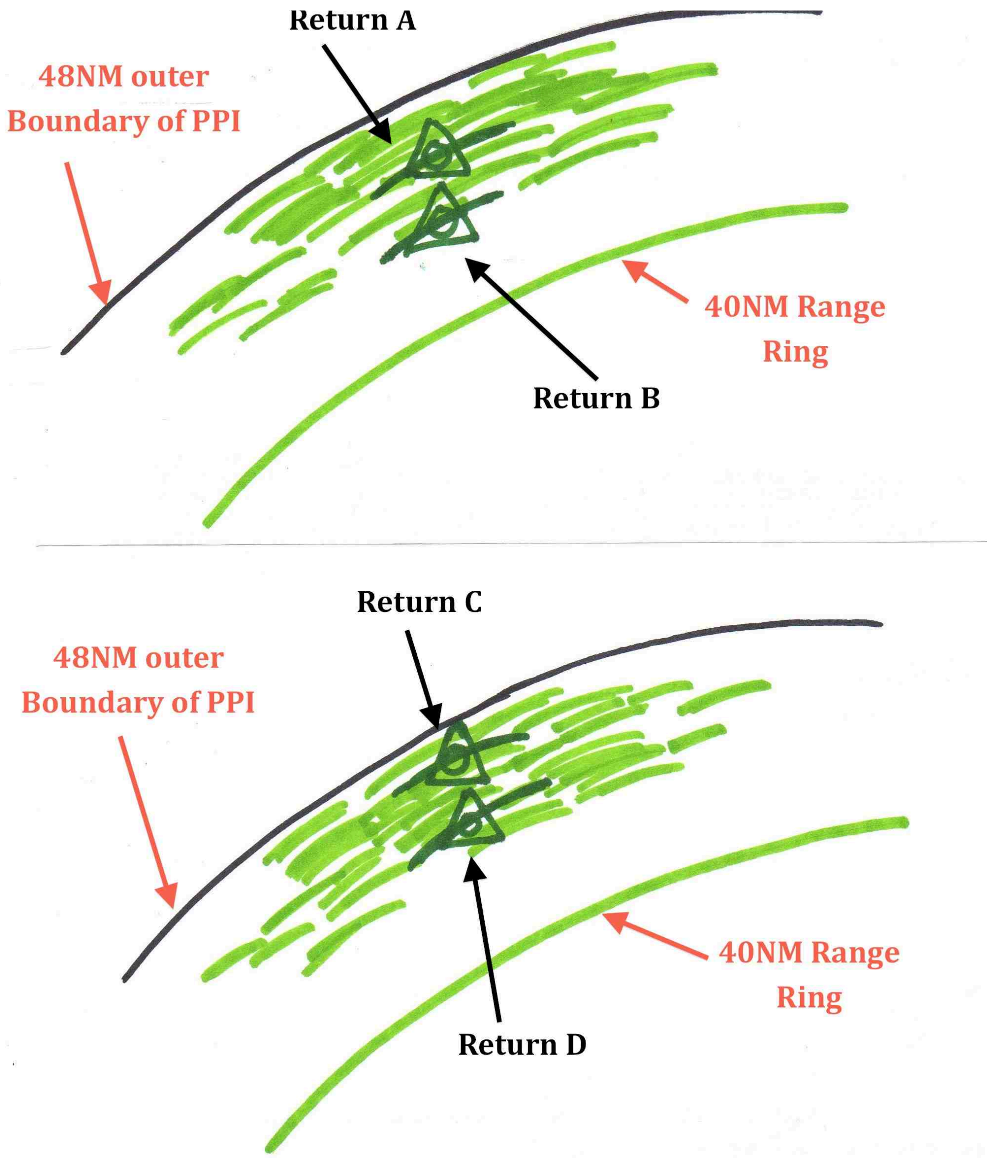

Figure 48: Multiple choices relating to *range only* of the 320˚M/45NM fix in relation to clutter. The Williamtown ATCO chose Return A (Images: Glenn Strkalj 2014).

'*I don't recall any of the ident squawk* <SPI triangle> *being outside of the PE's* <Permanent Echoes-Terrain Clutter> *and I did see all of the triangle. As a consequence, I would select 'A' from your options. The triangle was not cut off in range (outside 48nm) although it was clearly visible probably due to the transversal nature of the triangle sides compared to the returns from the PE's. Also the symbol (3000 squawk) was clearly visible in the centre of the triangle. My bearing and range measurement would have been taken from the centre of the 3000 symbol.*'

'*I recall seeing the triangle return but I would have been focused on the 3000 squawk to establish the range and bearing. (You will have to factor in a 33year old memory!) I am reasonably confident that none of the symbol (including the triangle) were cut off on the edge of the screen (outside 48nm) or the PE's (inside 44nm). The PSR return was impossible to see in the PE's. I feel there was a gap but I would not be confident in quantifying that.*'

Annex B: Radar Propagation Analysis Background

1. Overview

To conduct RF propagation analysis of ATCRBS or PSR systems, some basic transceiver parameters such as transmit power and receiver sensitivity are required.

It has been difficult to source and confirm various specifications required. An alternative method to provide assumed specifications to a high reliability is to overview applicable standards required of the systems.

2. ATCRBS

ATCRBS are designed to keep airborne equipment simple by placing the performance onus on the *ground* equipment where size and weight does not matter to the same degree.

Thus, *ground* SSR transmitters output more power and have more sensitive receivers than *airborne* transponders. The downlink (aircraft transponder to ground interrogator) is designed to be the more sensitive link (by 3dB-6dB) to ensure that if a transponder was interrogated, there is a good probability of receiving the reply[29].

2.1.1. Aircraft Equipment

Antenna wise, the aircraft transponder antenna is required to be *omni-directional* in azimuth to ensure best transponder coverage. Such an antenna results in gain values not more than approximately 2dBi.

The SURAD antenna on the other hand, has *directional* properties and accordingly would have a gain in the order of 20dBi. For propagation analysis, 20dBi will be used as the receiver antenna gain, 2dBi for the transmitter.

The applicable standard for *airborne* ATC transponder equipment[28] specifies for VH-MDX type transponders operating not above 15000':

- Nominal *line* loss of 3.0dB
- Receiver sensitivity of -69dBm to -77dBm, nominal -71dBm
- A 90% reliability of the link
- 18.5dBW to 27dBW (71W to 500W) (*peak* transmission power)
- A simple quarter wave antenna (0dBi <2dBi)

The peak output power of the ARC RT-359A transponder fitted to VH-MDX is 125W[24].

2.1.2. Ground Equipment

Not many specifications of the SURAD SSR have been confirmed thus far. Radar technician input has given a reasonable insight into specifications that can be used for propagation analysis with a good degree of confidence.

SURAD SSR transmit *power* and receiver *sensitivity* are two unverified specifications that are required for propagation analysis.

Regardless, applicable guidelines and specifications for civilian systems can be used to yield reliable information and data. Although used in a defence application, SURAD was likely a civilian used radar as well.

Additionally, SUARD had to integrate with civilian traffic and civilian ATS. Accordingly, it is deemed appropriate to assume SUARD met civilian specifications as a general rule.

To achieve a signal strength sufficient to trigger the transponder at minimum specified sensitivity (-69dBm) at the maximum SURAD range (96NM) a minimum power must be transmitted by SURAD. Guidance for Effective Radiated Power (ERP) transmitted for required range for civilian systems is given below.

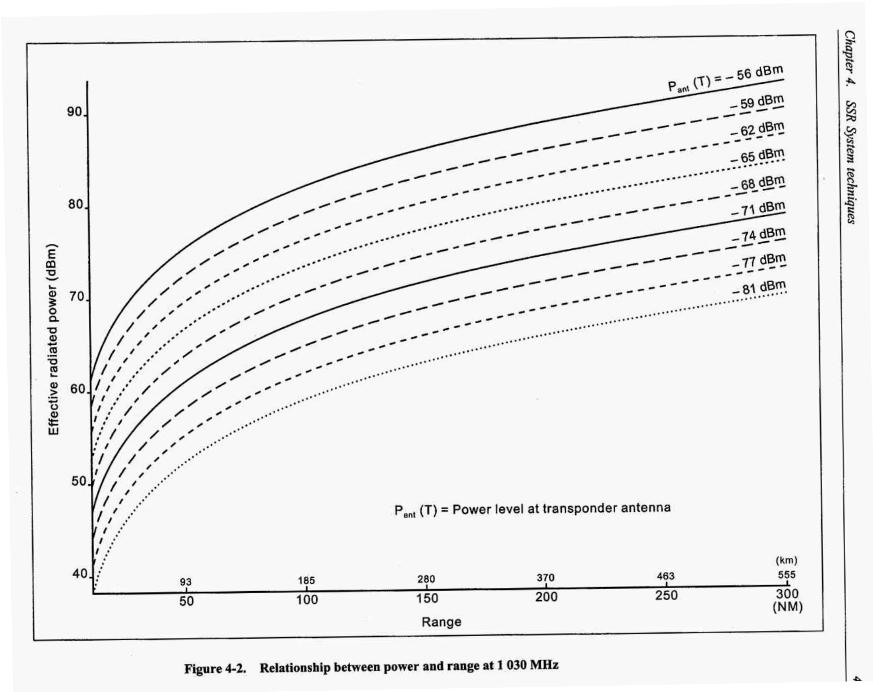

Figure 49: Effective transmitted power vs. received power at the *Transponder* and useable range[29]. The SURAD PPI could be selected to a maximum range of 96NM. Assuming this, and to be safe, assuming a maximum range of 150NM and a minimum received signal at that range of -69dBm to meet transponder minimum sensitivity requirements, it can be seen an effective radiated power of 73dBm is required from the SURAD SSR transmitter. This equates to just under 20kW (Graph: International Civil Aviation Organization 2004).

Assuming a maximum range of 150NM to provide a buffer from the 96NM displayed range, it can be seen an ERP of approximately 73dBm (20kW) was required to ensure a minimum received signal of -69dBm at 150NM.

ERP considers the ‘amplifying’ effects of the directional antenna that in many contemporary SSR units possess a gain of approximately 20dBi. Using this antenna gain value to adjust the ERP value of 20kW, SURAD could be expected to have a minimum transmitter output of approximately 325W.

SSR ground transmitters generally have power outputs of 0.5kW-1.5kW. It is therefore considered likely that a transmitter output of 500W would not be unrealistic and possibly conservative given the likely ability of SURAD SSR for further range.

Regarding SSR ground receiver sensitivity, a minimum tangential sensitivity of -85dBm is required for 200NM range[29].

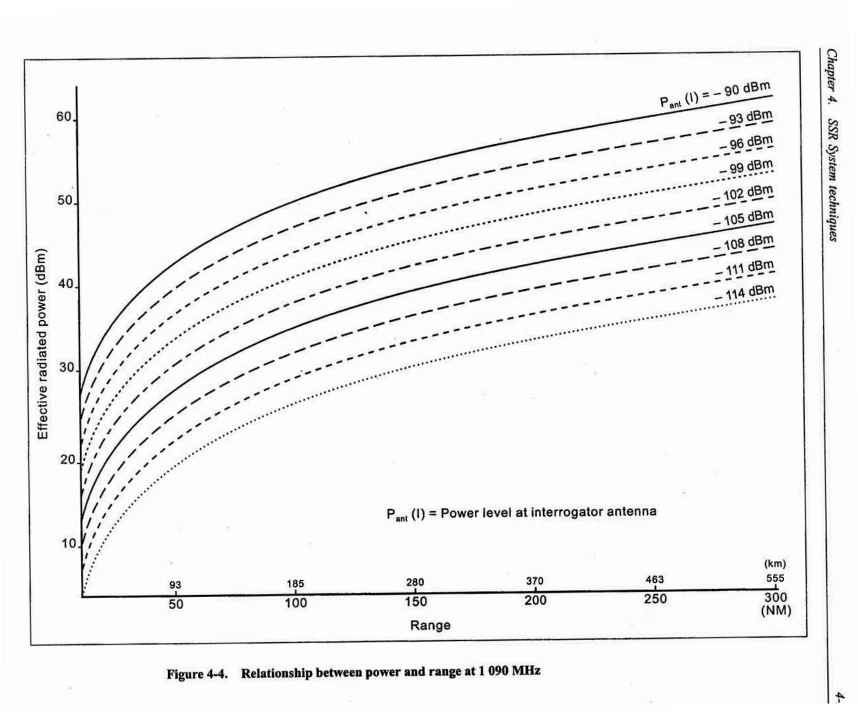

Figure 50: Effective transmitted power vs. received power at the *Ground Interrogator* and useable range[29] (Graph: International Civil Aviation Organization 2004).

2.1.3. Detection Accuracy

Typical standard deviations for SSR as of 2004 are 250m in range and 0.15° in azimuth[29].

ICAO has specified that radar north should be aligned to geographical north within 'about' ≈0.1° for *overlapping* radar coverage installations (multiple radar heads feeding a single display)[29].

PSR and SSR paints were observed to be co-incident for the vast majority of the time on the Williamtown SURAD and Sydney Bright display[19]. Additionally, PSR and SSR bearing and range accuracy values of more recent times are specified very close in value to each other.

Accordingly, it is viewed reasonable that PSR accuracy values can be used for SSR and vice versa to yield a reasonably accurate position assessment .

No accuracy values for the SURAD system have been located so far however, given the SURAD and the Thompson CSF system used by Sydney ATC were of a similar vintage, it is viewed as reasonable to use the Thompson CSF values.