

Role of Radar Cross Section facilities, in a Radar and Electronic Warfare Defence Research and Evaluation capability.

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Abstract:

This paper demonstrates the role of Radar Cross Section (RCS) facilities, consisting of modelling and simulation (M&S), Hardware in the Loop- (HWIL) and field Test and Evaluation (T&E) environments, in a Radar and Electronic Warfare (EW) Defence Research and Evaluation capability. The link between the development and utilisation of radar and EW facilities and the scientific process is illustrated by examples.

The paper follows the following structure:

1. The role of a Defence Evaluation and Research Institute (DERI) is described
2. Discussion of the wide scope of Radar & EW capabilities required by this role
3. Designing the structure of the Radar & EW capability
4. Examples of RCS facilities utilised in such a capability
5. Lessons learned from utilising these facilities to fulfil the DERI role

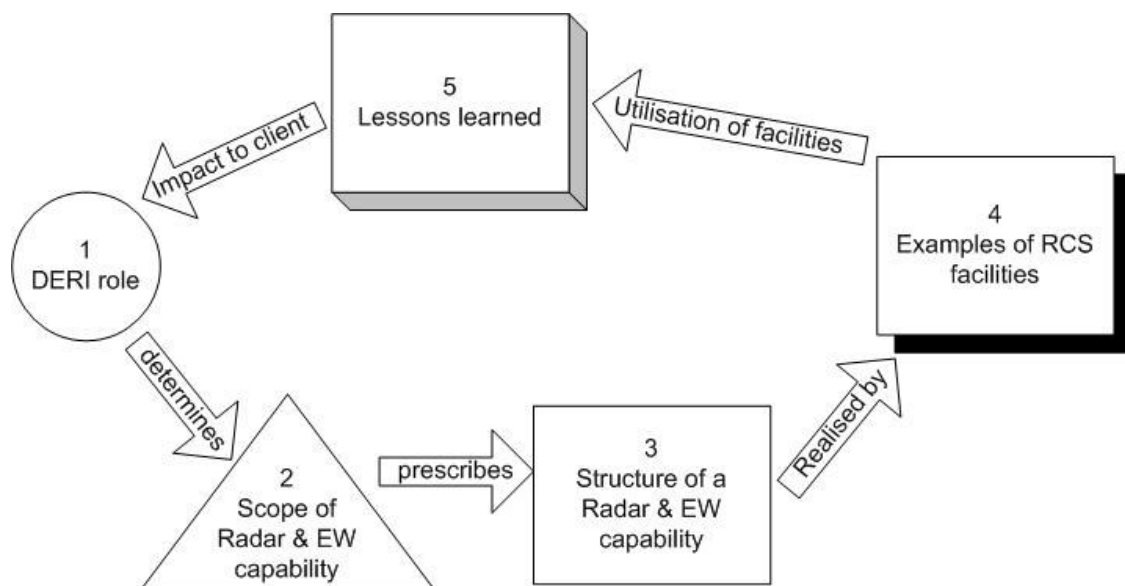
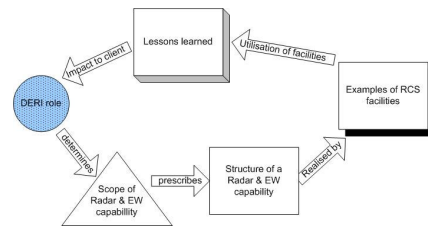


Figure 1 Layout of the paper

1. What is a DERI capability?

The application of RCS facilities must be seen in the context of the organisation which uses such a facility and in relation to the functions and the roles of such an organisation. In this case, the type of organisation is a “Defence Evaluation and Research Institute”. The definition of such an organisation, including its roles and functions are briefly explored in this section.



1.1 Definition of a DERI

The term Defence Evaluation and Research (DER) generally refers to “*the whole field of Science and Engineering in which Technology is generated and applied through the performance of Research and/or Development, Test and/or Evaluation, or Operational Research in Defence applications*”. [1]

In the DERI choice of name South Africa is following the example of similar international organizations, for example: [1]

1. Australia: DSTO (Defence Science and Technology Organization).
2. Canada: Defence R&D Canada
3. Sweden: FOI.
4. India: Defence Research and Development Organization (DRDO)

1.2 Role of a DERI

In general, the following roles were found to be common in DERI-like organizations worldwide [1]:

1. Provide scientific and technological (S&T) support to the Department of Defence (DoD) to enable them to be knowledgeable buyers of equipment (on acquisition projects).
2. Provide S&T support to the DoD (specifically the Defence Force) to enable them to be knowledgeable users of equipment (operational test and evaluation, training, force preparation, intelligence gathering and interpretation and operations).
3. Ensure continued effectiveness of military systems while minimizing the cost of ownership by performing the DER part of pre-planned maintenance, logistic support, and modifications to improve reliability.
4. Maintain the winning edge through the performance of some of the DER part of the development of equipment with unique capabilities or, when conditions or doctrines change or equipment becomes obsolete, by supporting the continued product improvements and/or upgrades.
5. Provide equipment to satisfy unique requirements in cases where the Defence Industry cannot do so.
6. Provide strategic independence in some niche areas by enabling independent indigenous military product development, manufacturing and commissioning,

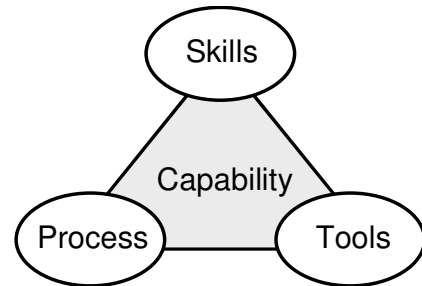
thereby reducing supply vulnerability and improving the probability that special, differentiating features that may ensure a winning edge in battle, remain secret.

If these are the roles of a DERI, then what are the capabilities which are required by such an organisation to enable it to perform these roles efficiently through activities such as research, development, test and evaluation?

1.3 Definition of a capability

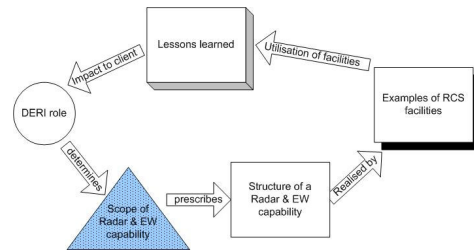
A capability is commonly defined as an integrated combination of three components [2]:

1. **Skills:** (people and the knowledge that they have) form the basic building blocks of a capability. For example, a software development capability requires skills in programming, software testing, project management, etc.
2. **Process:** (routines, procedures, structures, responsibilities, accountabilities, etc.) enable the collaboration between individuals. For example, a software development capability uses a software development process to produce software. Capability maturity is often measured in terms of the consistency and predictability of its underlying processes.
3. **Tools:** (models, computer programs, laboratory equipment, prototypes, fieldable concept demonstrators, etc.) allow humans to interface more effectively with their environment and enable them to capture and manipulate knowledge. For example, a software development capability uses computers, programming languages and compilers.



2. The wide scope of capabilities required by a DERI

Each DERI organisation is unique and has unique capability requirements due to its history, legacy systems, unique roles and local industry structure. This paper does therefore not describe specific capabilities required by any Radar & EW DERI, but rather demonstrates the scope of capabilities required and then introduces tools for designing such a capability.



As can be seen from the role description, the scope of client requirements is widely varied. The scientist needs to support the soldier (and DoD) by understanding his operational environment and requirements and how technology impacts on this. Typical Scientific, Engineering and/or Technology (SET) questions are divided into three categories:

Mess	A complex issue which is not well formulated or defined; “wicked problem”
Problem	Well formulated/defined issue, but with no single, clear-cut solution (various solutions depending on...)
Puzzle	Well defined problem with a specific solution which can be worked out

Note that the number of possible solutions to the questions increased from the bottom to the top. Figure 2 combines the wide scope of questions with the solution space and relates this to the system hierarchy.

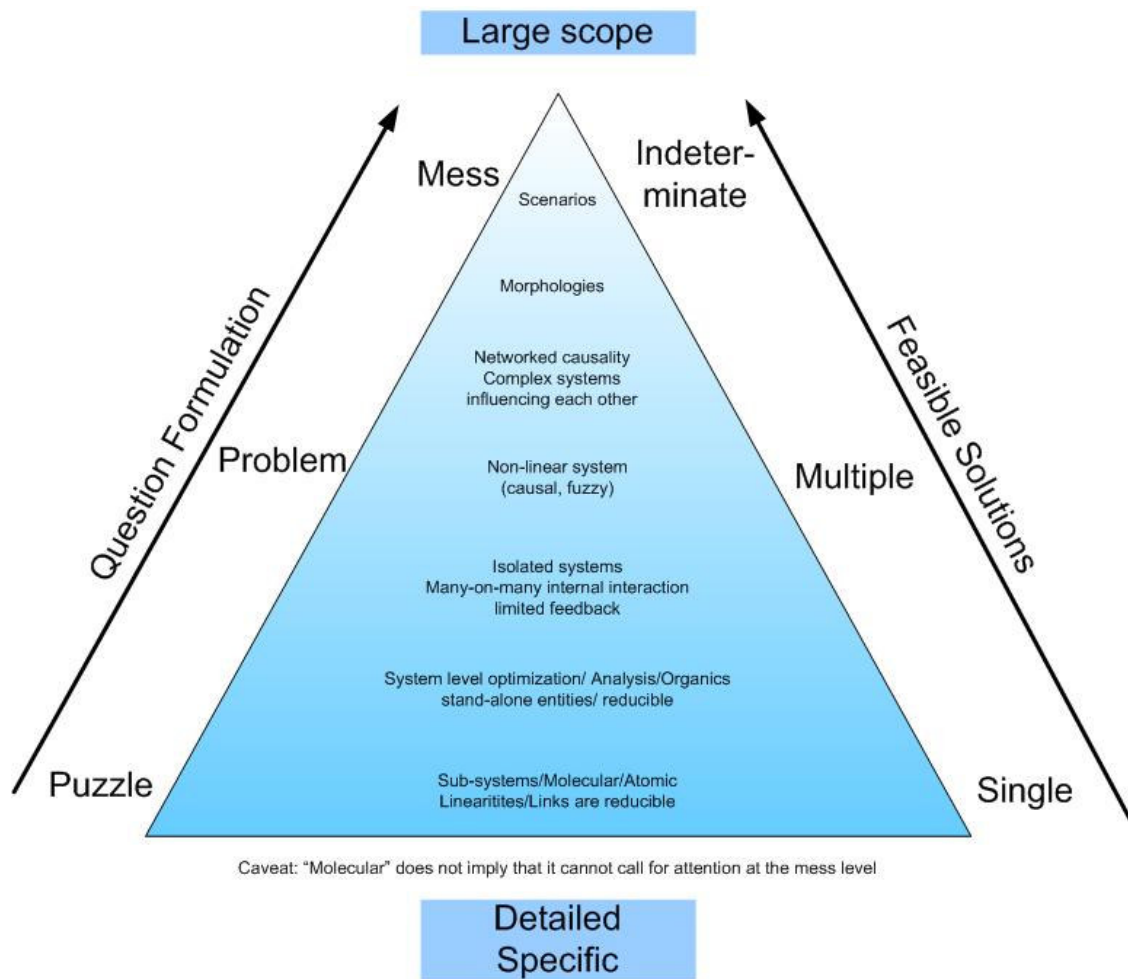


Figure 2 Relationship between question formulation, solution space and system hierarchy

The figure illustrates the relationship between the levels of aggregation of the system under investigation (middle of pyramid), the type or scope of question (left of pyramid) that needs investigation, and the possible solution space (right of pyramid).

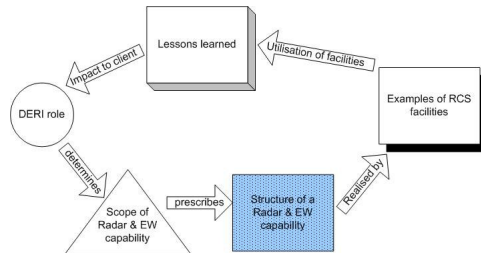
- The levels of aggregation can be compared to system hierarchies, starting at the bottom with detailed or specific models of sub-systems and components, increasing in complexity to systems and many-on-many interactions, to fuzzy scenarios.
- The type or scope of questions also change from the bottom (Puzzles) where questions pertain to the investigation of a single piece of the puzzle, to problems where interactions of systems are investigated, to what is referred to as a mess where structure and interactions are unclear.
- The solution space increases from singular quantifiable answers at the bottom, through multiple solutions, to an indeterminate number of possible solutions at the top.

Typical questions at sub-system level might be the effect of an Electronic Counter Measure (ECM) technique on a specific part of the Radar signal processor, e.g. Constant False Alarm Rate detection (CFAR). Complex system questions might be the composition of an air defence system and morphological analysis can assist in the design of a capability.

This section demonstrates that a DERI capability requires a wide range of capabilities, given the wide scope of problems it needs to solve and that it is important to use the right tools at the right level. For example, it would be inappropriate to use the tools and methods used to optimise or define a sub-system, to address a messy problem, where the structure and interactions are unclear.

3. Designing the structure of the required capability

In the previous section it was shown how wide the scope of possible problems is that face a DERI organisation. This section introduces a tool which can be used to design a versatile capability which can address such a wide scope of problems. An example is also given of such a capability design.



Morphological Analysis (MA) is a generalised method for structuring and analyzing complex problem fields [3]. In the MA analysis, the variables which define the complex problem are listed in columns. The parameters or states of each variable are then described in more detail forming the rows of every variable (see Figure 3). A work session with experts is then facilitated to yield all the interdependencies between the parameters. Once all interdependencies have been established, the MA can be compiled. The completed MA then serves as a tool which can be used as a communication tool and as an inference tool to make decisions about the original complex problem.

MA can be a very useful tool to design something as complex as a DERI capability, as illustrated in the following example.

3.1 Example of a DERI capability design using MA

Figure 3 shows a compiled version of a DERI capability design MA. The columns represent some of the main considerations in the design of a DERI capability. It also shows some of the capabilities required (e.g. the facilities column) and some of the roles (e.g. DERI activities), as discussed in previous sections of this paper.

Figure 3 also shows some of the interdependencies between these design parameters by means of the colour scheme. The DERI activity (column 4) of “Field Test and Evaluation” was selected (highlighted block). The subsequent elements impacted by field T&E evaluation are highlighted in a darker shading. For example, in the client system lifecycle field, the following states are impacted:

- Acceptance testing
- Operation
- Optimisation
- Training

The implications of this specific MA selection are that *field test and evaluation are required in the client system lifecycle stages of acceptance testing, operation, optimisation and training.*

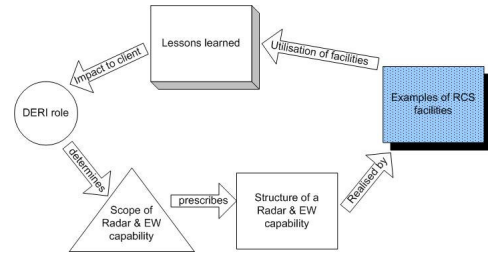
In a similar way, different elements of the matrix can be selected and the MA reveals implications in the other dimensions. This allows the operator of the MA to get familiar with the implications of various actions pertaining to such a complex problem (e.g. what are the facilities required to perform certain DERI roles)

Facilities	System hierarchy	Fidelity	Deri activities	Client system lifecycle	Client technology
Enigma 3	Campaign	Field trials	Decision support (acquisition)	Needs identification	Radar (sensor)
Digital receiver	Mission / many on many	HML in the lab	Doctrine development	Option trade-off	ECM
Fynmeet	System / engagement	Software simulation (signal level)	Lab Test and evaluation	Acquisition	ECCM
EW Range	Sub-system / component	Software simulation (parameter level)	Field Test and evaluation	Doctrine development	ELINT
GRS 1		Software simulation (behavioural)	Operational (decision) support	Acceptance testing	Air defence
GRS 2			Training	Operation	Platform protection
GREES			Sensors + RFEW Research	Optimisation	Force protection
SEWES			Technology demonstrator development	Training	Surveillance & reconnaissance
GBADS			Strategic decision support (capability planning)	Dispose	Command & Control
SIZA					Comms
Enigma lite					Capability management
Matlab signal analysis					

Figure 3 Example of MA for required Field T&E facilities

4. RCS capabilities for a DERI

The previous sections of this paper have described the generic role, scope and structure of a DERI capability. This section of the paper focuses on one specific element of a Radar/EW capability, namely the RCS capability.



4.1 Why is RCS so important?

The effectiveness of Sensors and Electronic Warfare (EW) systems is central to mission success and survivability under battle conditions. A platform's radar echo will influence the sensor's detection- and burn-through range, as well as required jammer power. The relationships in Table 1 can easily be deduced from the radar equation [4].

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Table 1 Relationship between radar or jamming parameters and RCS (σ)

Radar or jamming parameter	Proportional to
Detection Range	$\sigma^{1/4}$
Burn-through Range	$\sigma^{1/2}$
Required Jammer Power	σ

Parameter Reduction

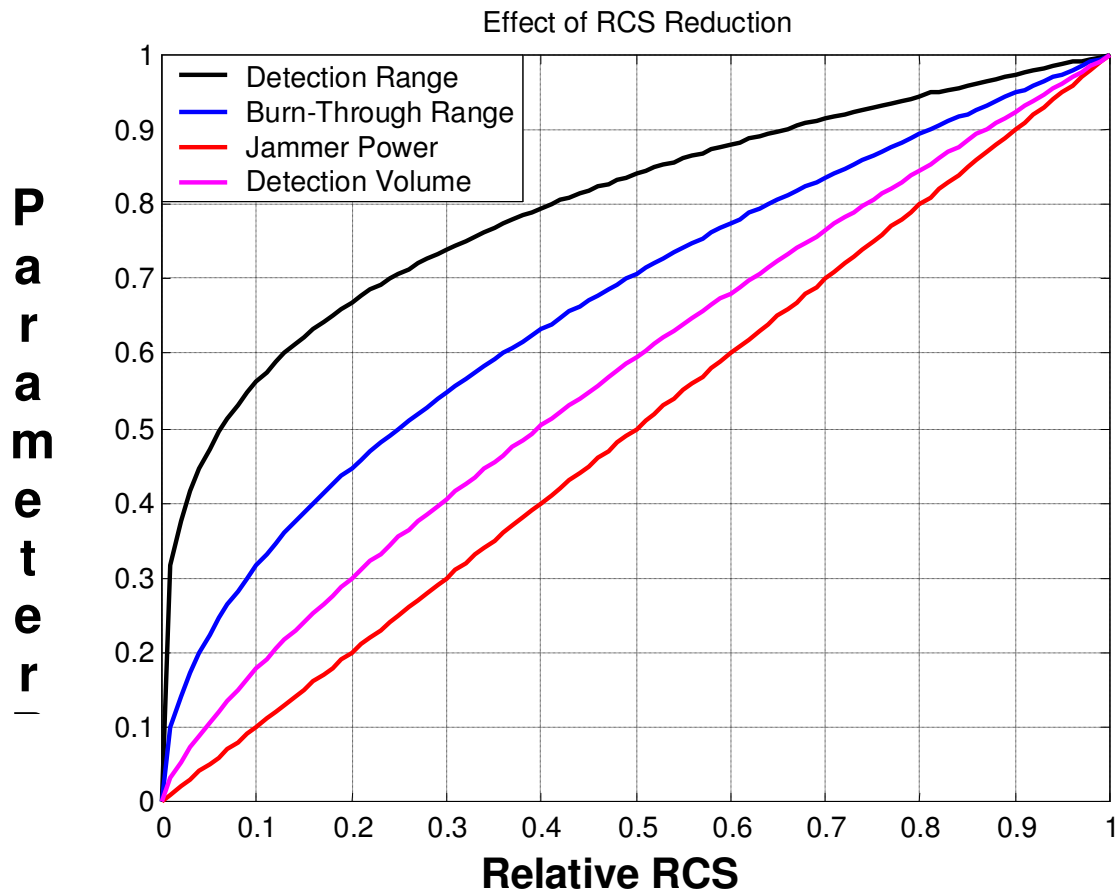


Figure 4 Influence of RCS on sensor and ECM effectiveness

Figure 4 shows that improved RCS management can result in a shorter detection range, shorter burn-through range and reduces required jamming power. These advantages result in delaying detection, identification and target acquisition while increasing first strike capability and survivability.

4.2 Examples of RCS facilities

As illustrated in Section 2, the DERI role requires capabilities that must address a large scope of questions. Figure 5 shows the scope of questions that needs to be addressed by a DERI and that requires an RCS capability. Tools and RCS facilities are shown on the right and address questions at an increasing hierarchical system level from the bottom to the top.

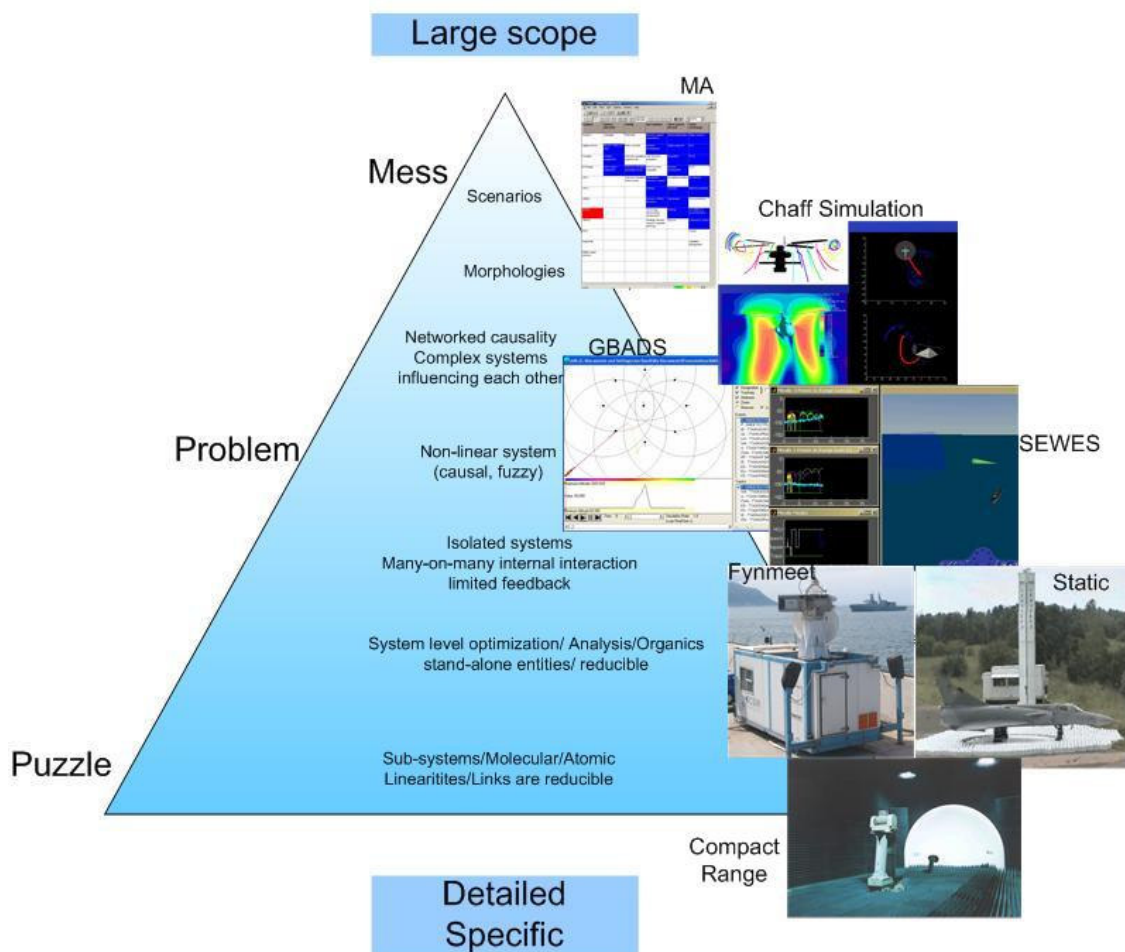


Figure 5 Examples of tools in RCS capability

At the bottom, a compact range is shown that enables component measurement, followed by dynamic (Fynmeet) and static (STATIC) RCS measurement facilities used for system evaluation. Many-on-many system interactions can be evaluated using SEWES (Sensors and EW Environment Simulation), where J/S and doctrine (aspect angle presented to the threat) is especially important. This is followed by non-linear system design and evaluation, such as the composition and operation of weapon- and Command and Control elements of a Ground Based Air Defence System (GBADS). Questions like the placement of chaff dispensers on helicopters, involve complex systems influencing each other, e.g. the airflow influences the distribution of the chaff particles that will determine the RCS of the chaff cloud. Again scenarios and Morphological Analysis (MA) can be used to assist in the structural design of a peace keeping force.

RCS measurements are a key input to all the examples shown above, by serving as a mechanism for verification and validation of theoretical models. Methods of measurement (or data generation) include:

4.2.1 RCS Software Prediction Models

Software prediction models of the platform or EW technique (Chaff) include:

- Method of Moments (MoM)
- Physical Optics (PO)
- Geometrical Theory of Diffraction (GTD) & Derivatives
 - Uniform Theory of Diffraction (UTD)
 - Physical Theory of Diffraction (PTD)
- Geometrical Optics (GO)
- Finite Element Analysis (FEM)
- Hybrid Techniques

4.2.2 Static Measurements

- Measurement of models or small targets using a compact range or anechoic chamber
- Measurement of the actual platform (target on a positioner)
 - Near field
 - Far field

4.2.3 Dynamic Measurements

Dynamic RCS measurements are recorded while the platform is in its operational scenario and is similar to how operational radars will measure the platform. ECM can also be measured at the same time.



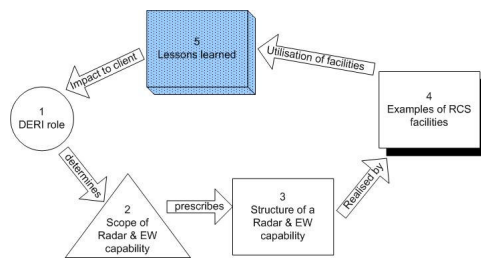
Figure 6 Fynmeet dynamic RCS Measurement facility

5. Lessons learned during utilisation

5.1 RCS Modelling

RCS modelling plays a valuable role in the total RCS capability for the following reasons:

- It is difficult to measure the platform at all aspect angles, e.g. the top aspect angles are difficult to measure using a ground based system
- The availability of the platform can be limited, e.g. a threat platform or during the platform design stages
- Statistically significant datasets must be gathered, which can be time-consuming and difficult using real measurements.
- Trade-off studies (e.g. the placement of chaff dispensers) usually require the evaluation of many different configurations (e.g. multiple installations). Issues like flight clearance and the number of flight trials required for such an experiment makes this prohibitively expensive to implement in the field



Usually, a combination of modelling techniques is required, depending on the method that is used (e.g. exact or approximate method) as well as the object that is modelled (e.g. chaff or platform). The following paragraphs illustrate some of the lessons learnt in modelling RCS.

5.1.1 Exact methods

Exact methods can be useful for modelling small and simple objects. However, at radar frequencies of interest, a typical fighter would be approximately a thousand wavelengths long. Since the platform is modelled with small elements ($\leq$ a fifth of the wavelength) a large platform would require a very large number of fundamental modelling elements. For exact methods this would result in large matrices [6]. Approximations during digitization and matrix solving cause instabilities and singularities which makes it impossible to solve and therefore approximate methods are used to model large/complex objects.

5.1.2 Approximate methods

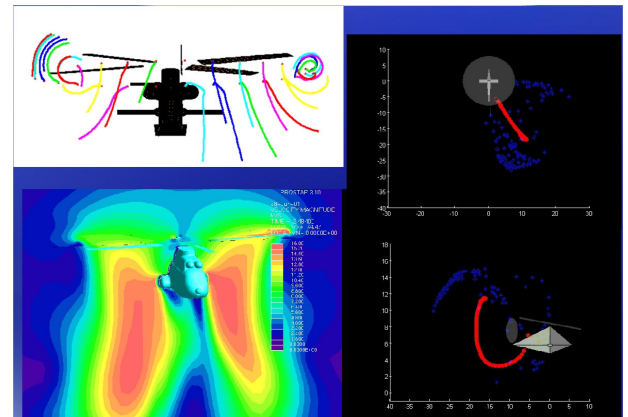
Approximate methods model the platform, by approximating it with a number of scattering surfaces. Typically triangular surfaces are combined to model the object. The contribution of all the surfaces is then integrated to estimate the RCS. Physical Optics (PO) can be used to model fighter aircraft and helicopters. The disadvantage of the approximate techniques is that small platform features and cavities can not be modelled.

5.1.3 Chaff modelling

Chaff particles are small with regard to wavelength, typically half a wavelength per element, therefore exact methods (MoM) are used to model the elements. However, there would be millions of particles in a typical chaff cloud, resulting in computationally impractical calculations.

The following approximations can be applied:

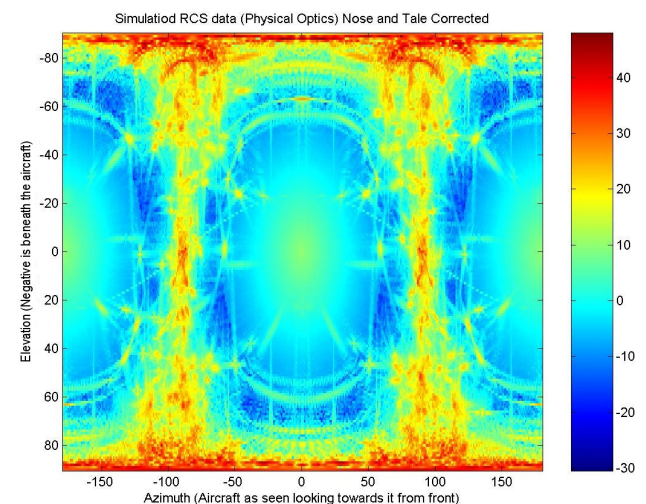
- Reduction of the amount of particles by modelling portions of the cloud and scaling the results to the total cloud.
- Reducing the number of particle interactions, e.g. assume that particles more than 2 wavelengths apart do not interact electromagnetically.



Other approximations, e.g. all particles are orientated horizontally, are not always applicable. The orientation of particles is not static during chaff deployment, e.g. the orientation of chaff deployed close to a helicopter, will be influenced by the airflow around the helicopter. This effect is accentuated close to the ground. Modelling of the temporal aerodynamics of the scenario plays a crucial role in the credibility of the results. The close integration and cooperation of the aeronautics and electronics programmes in Defencetek was crucial during the trade off studies for the placement of chaff dispensers.

5.1.4 Fighter aircraft modelling

The RCS of a fighter aircraft was modelled using Physical Optics. The results obtained in the forward and backward directions were dramatically different from measured data. This can be attributed to the fact that PO does not model multiple scattering paths, such as engine inlets and exhausts. This problem was solved using specific mode matching methods, e.g. modelling the inlet as a multimode waveguide instead of a PO surface.



5.1.5 Verification and validation of models

The modelling methods are complex and based on assumptions. Therefore verification and validation of the results at certain platform aspect angles of interest should be performed. Static and dynamic facilities are used for these measurements. Subsequently the models can be refined and increased in fidelity and credibility.

5.2 Static RCS Measurements

The near field static RCS measurement facility, called STATIC (shown in Figure 7), was custom developed for the unique South African requirement. STATIC is a fixed Radar RCS measurement facility that utilizes Inverse Synthetic Aperture Radar (ISAR) processing to determine the relative contribution of reflecting elements to the total RCS of an aircraft or land vehicle.



Figure 7 STATIC Near field RCS measurement facility

STATIC was developed to address the following requirements:

- High resolution measurements that can identify individual contributors are required for RCS management
- To determine the affect of new stores or weapons that will be integrated into existing platforms
- Support development programs of new equipment, e.g. scale models and mock-ups can be measured during system design
- Support systems acquisition during acceptance testing and verification of RCS specifications
- Operational support by measuring system performance during the complete operational time, e.g. deterioration of absorbing material
- Scientific method requires repeatable measurements that are difficult to accomplish using expensive flight trials.

5.2.1 Considerations

Cost effectiveness was an important consideration during the development of the STATIC RCS measurement facility. The angle coverage and frequency range measured by the system are especially big cost contributors and lead to the choice of a near field facility.

Engineering challenges include environmental effects such as scattering, reflections and multi-path. Multi-path can be reduced by utilising radar absorbing material between the

antenna and illuminated object. Absorber underneath the target eliminates multiple reflections between the target and ground. Range gating is used to reduce the effect of environmental scattering and reflections.

For RCS management it is important to determine the contribution of individual scatterers. This was accomplished by implementing ISAR imaging. The ISAR images are translated to the far field using back projection.

Calibration of an ISAR imaging RCS measurement facility is complex and were implemented by calibrating the complete path, i.e. RF transmit, -receive, ISAR imaging and back projection.

5.3 Dynamic RCS Measurement

It is a fundamentally important consideration in the development of any wideband dynamic Radar Cross Section measurement facility that the measurements will be translatable into Jamming to Signal (J/S) ratios for a specific operational radar (own or threat radar). Without this capability the measurements are only of academic value and cannot be utilised for the evaluation of the effectiveness of an operational aircraft's electronic self-protection systems. The J/S for a specific operational radar is obviously strongly influenced by factors such as effective radiated power and processing gain. However, specific design implementations such as range resolution (and range gate sizes) and tracking filter design (most radar tend to track on the centroid of the target return) also has significant influence on the J/S that will be experienced by a specific operational radar. This implies that a dynamic RCS measurement facility must be designed to be sufficiently programmable (e.g. in range gate sizes) in order to ensure accurate translation into J/S for a wide range of operational radar.



Figure 8 Fynmeet dynamic RCS measurement facility

5.3.1 Considerations

The following issues deserve careful consideration:

- The pencil beam required for RCS measurement is not suitable for target acquisition
- The wide band antenna required by RCS measurement, makes integrated monopulse tracking impractical

- Platform attitude information needs to be recorded on a synchronised time base. Internal systems are preferable since it does not influence the recorded RCS.
- Careful positioning of the facility reduces clutter and multi-path
- Cost and time limitations make dynamic RCS measurements of aircraft for total coverage (azimuth and elevation) prohibitive. Dynamic measurements and RCS models are therefore complimentary.

5.3.1.1 Calibration

Internal calibration functionality is very useful but needs to be supplemented by calibration against a simple target with a known RCS. Utilising a sphere with a known RCS that is suspended below a helicopter has proven to be a good calibration method. Practical considerations in the design of such a sphere, e.g. getting it flight cleared for a target helicopter's cargo sling deserves thorough consideration.

5.3.1.2 Chaff measurements

Chaff effectiveness evaluation was efficiently achieved utilising the facility's multiple programmable range gates that can simultaneously be positioned to measure the RCS of the launch platform and the "blooming" chaff. The next figure shows measurements made of the RCS of a fighter aircraft dispensing chaff. The measurements were made by utilising 10 adjacent measurement gates which are 15m in length.

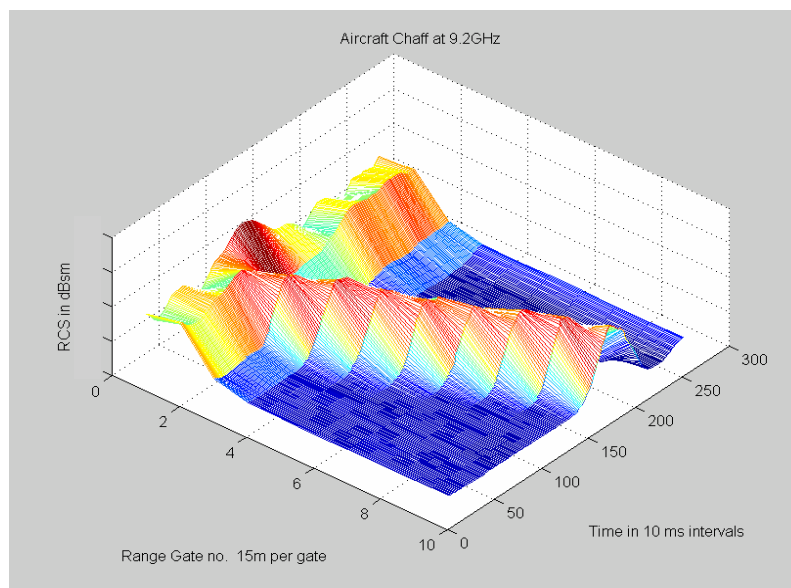


Figure 9 RCS of fighter aircraft and chaff

Repeatable measurements require consistency with regards to:

- Integrated weapon systems (missiles or pods)
- Position of radar antenna(s)
- Emissions from target platform, e.g. from fire control radar
- Other emissions from the environment
- Environmental effects, e.g. multipath, clutter and ducting

5.3.1.3 Expanding the facility's utilisation

A wideband dynamic RCS measurement facility is in terms of its cost a significant element of a developing country's total Radar and EW defence research and evaluation infra-structure. Novel design of such a facility can expand its application to support several other needs in addition to that of dynamic RCS measurements:

Operational test and evaluation

A facility of this nature has the potential to be utilised for the verification of installed EW system performance in an open air range. By designing the facility to emulate a single or multiple radar threat emitters, the system can be utilised to trigger and record the operational ECM system's automatic response to a high priority threat radar wave form. The image below shows results of an evaluation of an EW system's performance that were performed in support of the South African Air Force. The data was recorded in an open air range and was aimed at evaluating the effectiveness of a range gate pull off technique.

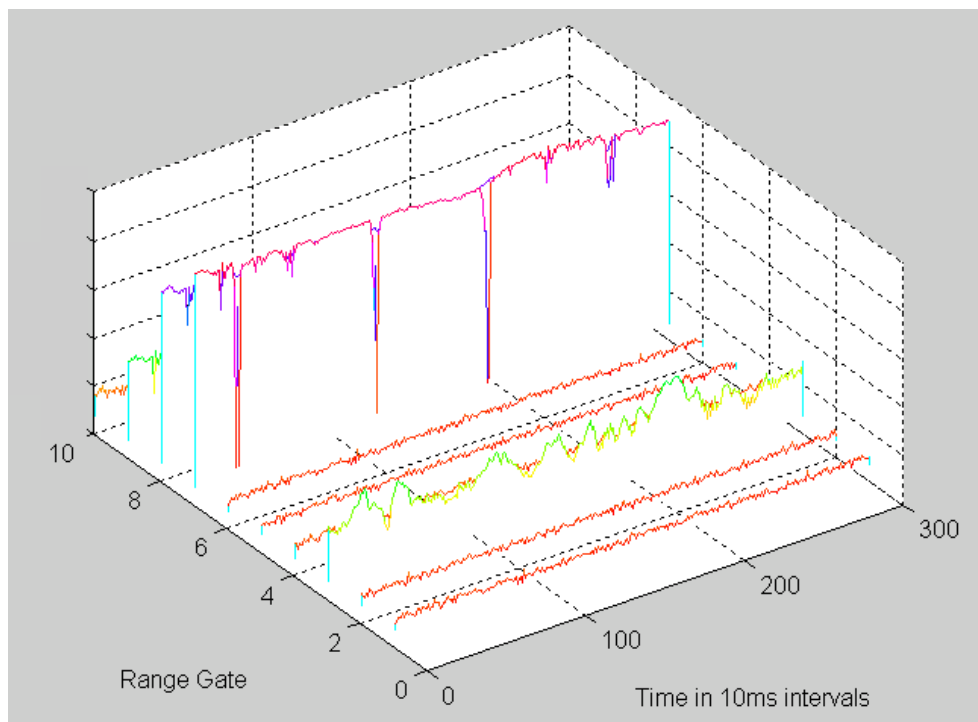


Figure 10 Evaluation of range-gate pull-off technique

Research

Defencetek utilised the Fynmeet facility as part of its research programmes in Non-Cooperative Target Recognition (NCTR) and advanced ECMs and ECCMs (Electronic Counter-Counter Measures). The next image shows a Doppler signature of a helicopter that was recorded as part of the NCTR research programme.

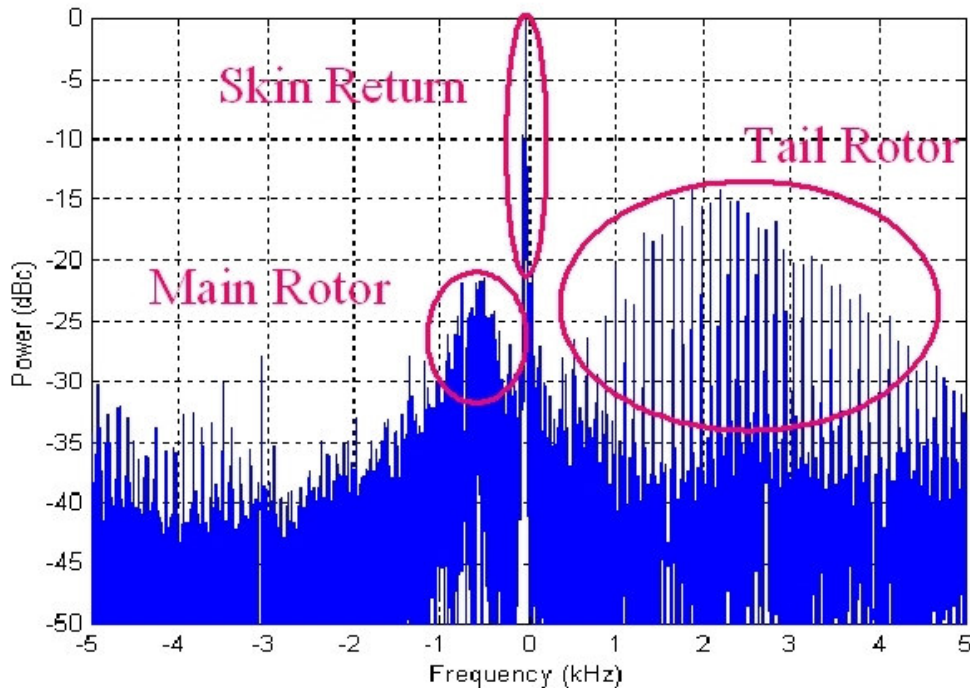


Figure 11 Doppler signature of helicopter

Training

EW is only a force multiplier once it forms an integral part of the doctrine and tactics of a defence force. A facility of this type is a very useful element of an EW range as it can emulate a high priority threat radar and record the electronic countermeasures and manoeuvres utilised by the trainee. The trainee develops insight into the complex interplay between the sensor and electronic self-protection systems in addition to whether or not a specific technique was successful.

6. Conclusion

The role of a DERI prescribes the required Radar and EW capability. A large scope of questions needs to be addressed with this capability. The structure of such a capability can be designed using morphological methods. Examples of facilities that fit such a structure was shown, as well as the lessons learned that delivered impact in the client domain.

7. References

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