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AN INTERLABORATORY COMPARISON BETWEEN THE RCS RANGES AT FOA DEFENCE RESEARCH ESTABLISHMENT AND SAAB DYNAMICS

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Abstract

An interlaboratory comparison is made between radar cross section (RCS) measurements at the test ranges at FOA Defence Research Establishment and SAAB Dynamics, Sweden. The comparison is made in order to increase the measurement and calibration quality at the ranges. An analysis of the deviations in the measured RCS data from the ranges provides a better understanding of the sources of errors. The RCS of two generic targets are measured at the X-band. The targets are simple airplane models, length and width are approximately 1.0 m, with no cavities. A brief comparison between some theoretical results and experimental RCS data are also presented.

Keywords: Interlaboratory Comparison, ISAR, Measurement Systems, RCS Measurements

1. Introduction

This interlaboratory comparison is made in order to increase the measurements and calibration quality of the static radar cross section measurement ranges at FOA Defence Research Establishment and SAAB Dynamics in Linköping, Sweden.

A comparison between radar cross section (RCS) data of well characterized targets, measured at different types of ranges, can provide information of how e.g. different background conditions and measurement methods are affecting the RCS. It may also provide a better understanding of the sources of errors. This comparison would help to find out:

- How to use different ranges and get similar results.
- Sources of deviation in results.

Four different ranges have been used for this purpose; two indoor ranges and two outdoor ranges. The measured targets, the ranges, and the measurement methods are described below along with the analysis methods that have been used.

2. Measurement Targets

In these comparative RCS studies, simplified and well defined targets have been used. "RAK" and "RUND" are two aircraft targets designed by FOA using only simple shapes, see Figure 1. The target "RAK" consists of a cone, a cylinder and rectangular slabs, which represent nose, body, and wings, respectively. "RUND" is a more aircraft looking model with simple smooth surfaces. "RAK" is approximately 0.9 m long and wide while "RUND" is around 0.8 m long and wide. The targets do not have any cavities.

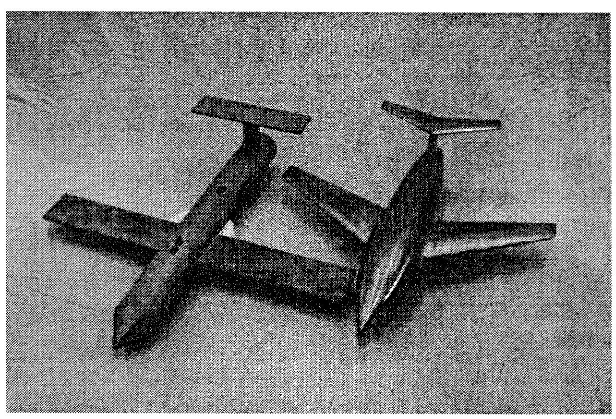

Figure 1. The targets "RAK" (left) and "RUND" (right) on which the RCS measurements have been performed.

The relatively simple shapes of "RAK" and "RUND" make comparisons between different experimental RCS measurements easier. The analysis of RCS measurements are not complicated by any multipath reflections from cavities from the models. The simple shapes of "RAK" and "RUND" also reduce the computational time significantly when the RCS of the models is calculated.

3. RCS Measurements

This interlaboratory comparison was made using the indoor and outdoor ranges at FOA and SAAB Dynamics. Not all measurement parameters could be the same at all four ranges since the design of the ranges are somewhat different. The parameters that were the same was the frequencies and the angles, azimuth and elevation. The elevation was set to correspond to the case when the wings and the body of the models are in the horizontal plane. The ranges are described below and the measurement parameters that were used at the different ranges are summarized in Table 1.

Range	FOA outdoor	FOA indoor	SAAB outdoor	SAAB indoor
Frequency (GHz)	7.5–12.5	6–16	8–12.3	2–12 6–16
Freq. step (MHz)	16	12.5 50	10.7	12.5
Azimuth (°)	0–360	-25–25 -10–190	0–380	0–380
Azimuth step (°)	0.022	0.25	0.072	0.25
Range (m)	100	25	102	10
Calibration object	Circular plate	Sphere	Corner reflector	Sphere
System	Pulsed	Pulsed	Pulsed	CW

Table 1. Summary of the parameters used at the different ranges.

3.1. FOA's Outdoor RCS Range

The FOA outdoor free space range is equipped and designed for coherent monostatic and bistatic RCS measurements [1] from 1–110 GHz. For this measurement the 100 m long monostatic range was used, see Figure 2. The target support consists of a turntable mounted on top of a column made of metal. This construction is about 5 m tall and is overall covered with radar absorbing material. The antennas are located about 5 m above the gravel ground. To reduce the unwanted target movements caused by the wind, the targets were tied to the pylon using several nylon wires. The turntable was rotated in a continuos mode during measurements where the frequency was stepped for every revolution.

Data over a full turn in azimuth (0°–360°) and 0° elevation angle were recorded in both horizontal (HH) and vertical (VV) polarization at 7.5–12.5 GHz. A circular plate with a diameter of 25 cm was used as calibration object.

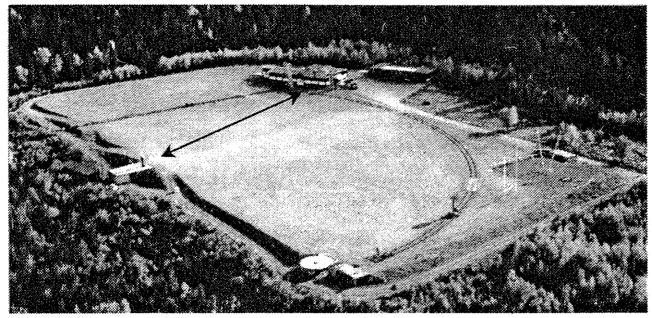

Figure 2. The FOA outdoor RCS ranges. The 100 m free space range is indicated by the black arrow.

3.2. FOA's Anechoic Chamber

The indoor measurement performed by FOA was made in an anechoic chamber. This chamber, 16 m wide, 33 m long and 12 m high, is internally covered with radar absorbing material. A schematic sideview of the experimental setup is shown in Figure 3.

The two antennas which were used (transmitter and receiver) are mounted in pair at one short side end of the chamber. The distance between these antennas is 0.54 m. The target support, located 25 m from the antennas, is a 3 m tall column made of styrofoam. The column is mounted on a turntable which can be rotated from 0° to 360 ° in azimuth and from -15° to 15° in elevation. However, the elevation angle was in this measurement set to be 0°. The target and the antennas are mounted approximately 5 m above the chamber floor. About 1.5 m in front of the target support, a radar absorbing wall is located to reduce the signal coming from the turntable. With this experimental setup the background scattering contribution is very low.

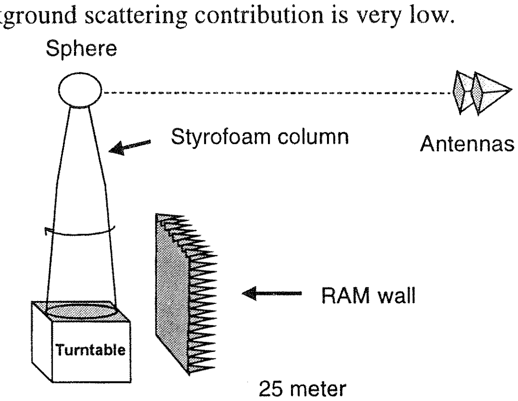

Figure 3. A schematic sideview of the indoor experimental setup belonging to FOA.

The measurement was performed at the frequency range 6–16 GHz and in the angular range -25°–190°. Both HH- and VV-polarization data were taken. Two spheres with radius 0.1524 m and 0.2540 m were used as reference objects.

3.3. SAAB's Outdoor RCS Range

SAAB's outdoor RCS range, located close to Linköping airport, is designed for full scale measurements of aircraft. The distance between the turntable center and the aperture of the measurement antennas is 101.8 m. The ground-bounce is utilized during RCS measurements, therefore the area between the measurement antennas and the turntable have been paved with a 15 m wide asphalt strip. The turntable is 8 m in diameter and takes loads up to 30 000 kg.

The radar measurement equipment is installed in a 40' mobile sea container. The container have been modified to be useable as a control room for the radar hardware, data acquisition, and offline analysis. The frequency range of the system is 2-18 GHz.

For the RCS measurements of "RAK" and "RUND" at SAAB's outdoor range, a styrofoam column approximately 2.20 m tall was used, see Figure 4. It was tied to the ground using several thin nylon wires (ϕ=0.50 mm). RCS data over more than a full turn in azimuth (0°-380°) at 0° elevation angle were recorded in both horizontal (HH) and vertical (VV) polarization at 8–12.3 GHz. A quarter circle corner reflector with a side of 385 mm was used as calibration object.

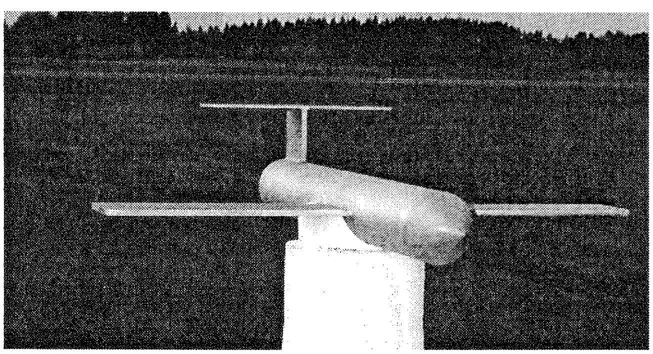

Figure 4. RCS measurements of "RAK" at SAAB's outdoor RCS range.

3.4. SAAB's Anechoic Chamber

The SAAB anechoic chamber designed by Emerson & Cuming for antenna and RCS measurements was also used for RCS measurements of "RAK" and "RUND", see Figure 5. The size of the anechoic chamber is approximately 8 m x 12 m x 4 m. The distance between the antennas and the target, mounted on the metal pylon is, 8.0 m. The frequency range is 2-18 GHz.

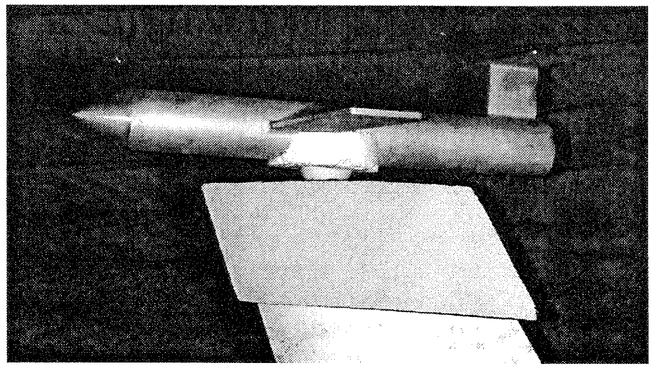

Figure 5. RCS measurements of "RAK" on a pylon in SAAB's anechoic chamber.

RCS data over more than a full turn in azimuth (0°–380°) at 0° elevation were recorded in both horizontal (HH) and vertical (VV) polarization at 2–12 and 6–16 GHz. Spheres (ϕ=203 mm and 365 mm) were used as calibration objects.

4. RCS Analysis

All RCS data, presented in this paper, are for simplicity raw data. SAAB do not make any further processing of the data beside the calibration. Raw data from SAAB are thus calibrated data. FOA, on the other hand, make a coherent background subtraction on all the calibrated data. This is done both for data measured at one frequency and for data to be used in inverse synthetic aperture radar imaging. Thus, raw data from FOA are both calibrated and background subtracted. No detailed error analysis have so far been made.

The inverse synthetic aperture radar (ISAR) imaging technique is used as a tool to visualize which parts of a target that gives large contributions to the total RCS. It is also an efficient way of localizing background sources.

5. Results

The target "RUND" has a relatively low radar cross section at several aspect angles, e.g. the front. It is difficult to estimate the RCS if the background RCS is of the same magnitude as the RCS of the target and no coherent background subtraction have been made. Calibrated "RUND" radar cross section data measured at 10 GHz, horizontal polarization, can be seen in Figure 6 and 7. The ordinate in each diagram shows the measured radar cross

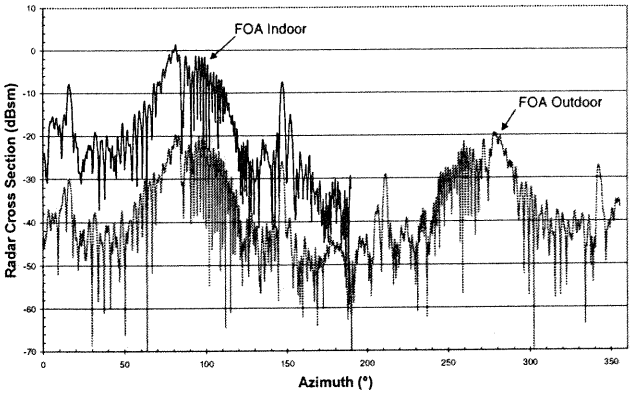

Figure 6. FOA measurements of the target "RUND". The outdoor data is shifted down by 20 dB for clarity.

Azimuth (°)	RCS Indoor FOA (dBsm)	RCS Outdoor FOA (dBsm)	RCS Indoor SAAB (dBsm)	RCS Outdoor SAAB (dBsm)
0	-25	-23	-19	-15
90	-3	-3	-1	-6
180	-31	-36	-33	-24

Table 2. The RCS values of "RUND" at different azimuth angles.

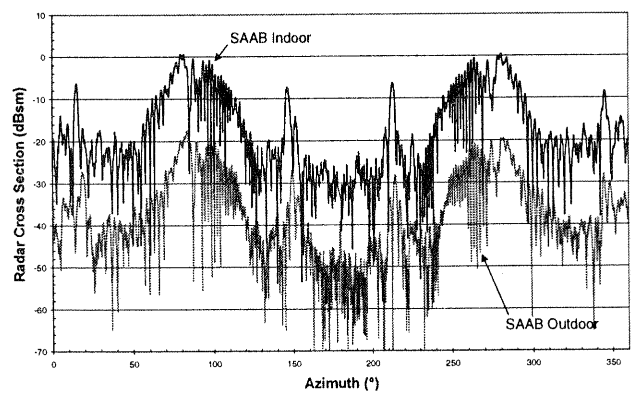

Figure 7. SAAB measurements of the target "RUND". The outdoor data is shifted down by 20 dB for clarity.

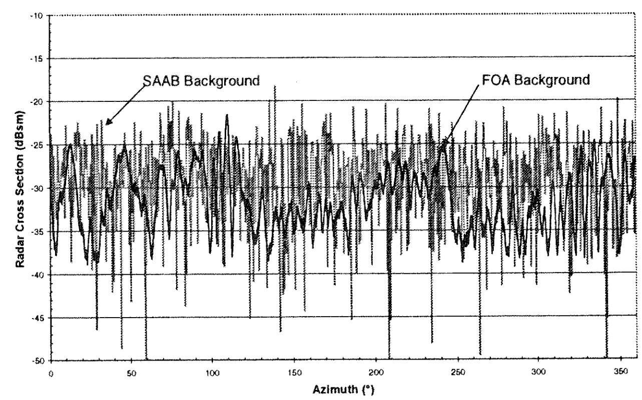

Figure 8. The outdoor backgrounds at SAAB and FOA measured at 10 GHz and HH-polarization.

section in dBsm. The RCS curves from the outdoor measurements have been shifted down by 20 dB for clarity. The abscissa shows the azimuth angle in degrees. The azimuth angle of 180° corresponds to the situation where the front part of "RUND" was facing the antennas. The twofold symmetry of "RUND" can clearly be seen in the curves. Note that the FOA indoor measurement is made for only a half revolution. The RCS values at 0°, 90°, and 180° are summarized in Table 2. The azimuth angles corresponds to back, broadside, and front respectively.

The general feature for the comparison is that the SAAB RCS data are larger than the FOA data at these angles. The differences are greater where the target has its lower RCS values. The greatest difference is found between the outdoor data at 180°. At this angle the RCS value is about the same level as the background, see Figure 8. The figure shows the background levels, at frequency 10 GHz and HH polarization, at the outdoor ranges. The ordinate in the diagram shows the measured radar cross section in dBsm and the abscissa shows the azimuth angle in degrees. The SAAB background include the asphalt strip and the turntable. The FOA background include the metal column and its turntable. The background varies mainly between -40–-20 dBsm at SAAB and -38–-25 dBsm at FOA. The difference in RCS value of "RUND" is likely explained by the difference in RCS analysis. Raw data from SAAB are calibrated data. FOA, on the other hand, do a coherent background subtraction from all the calibrated data. A meaningful coherent background subtraction could be made if the background signal is stable. That means, the signal may vary with frequency and azimuth angle but it is not allowed to vary with time. This condition is normally fulfilled in anechoic chambers. However, the asphalt strip at the SAAB outdoor range is surrounded by grass and the grass moves in even a small wind. It is thus hard to get a signal constant in time.

Even with a background subtraction, the background can still contribute to the total RCS of the target. Figure 9 and 10 shows two ISAR images made in the frequency range 8–12.2 GHz, angular span 24°, and polarization HH from measurements of "RAK". The front part of the target is facing the antennas and the target is seen from above in the images. The ordinate in the figures shows the down-range and the abscissa shows the cross-range. An overlay of the target is added in the images. This is done in order to show what parts of the target that contribute to the total RCS. The ISAR images in Figure 9 and 10 are made of calibrated data measured at the FOA and SAAB outdoor ranges, respectively. The FOA data have been coherently background subtracted.

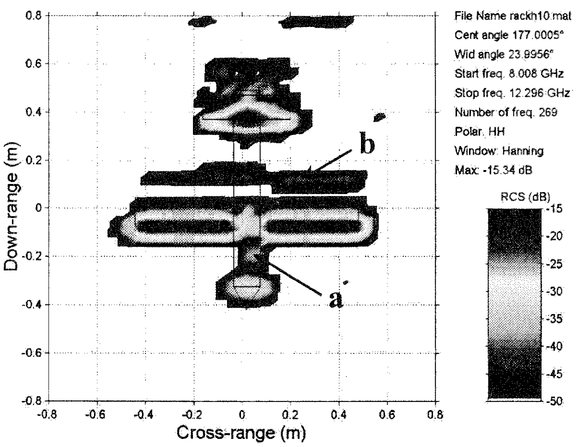

Figure 9. ISAR image of the target "RAK" made at the FOA outdoor range.

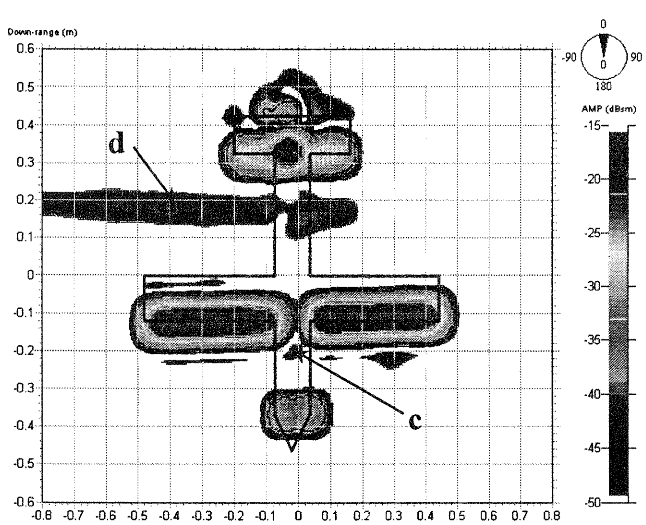

Figure 10. ISAR image of the target "RAK" made at the SAAB outdoor range.

It is not always an easy task to characterize and identify the background sources using ISAR images. The background contributions in the figures, indicated by the arrows a and c, could be explained in several ways. Firstly, parts of the background are hidden by the target. These parts could therefor be enhanced by the coherent background subtraction. This could explain why the contribution a in Figure 9 is quite large despite the background subtraction that have been made. Note that there is a similar contribution in Figure 10, indicated by c. Secondly, bounces between the front parts of the target and the pylon might have occurred. Thirdly, it could also be a contribution from the edge of the target support. The contributions can not be separated in depth from such ISAR images shown in the figures. It would take an image in three dimensions to do that. The background contributions, indicated by the arrows b and d in the figures, could be cross polarization effects and background effects, respectively

The results from these measurements have also been compared to calculations made at both "RAK" and "RUND" by FOA. These calculations are based on physical optics in combination with geometrical optics, which incorporates multiple scattering. The targets in these calculations have been modeled by triangular plane facets. Figure 11 shows a comparison between the radar cross section from a calculation and the FOA indoor measurement of "RUND" at 10 GHz HH-polarization. The ordinate in the diagram shows the measured radar cross section in dBsm and the abscissa shows the azimuth angle in degrees.

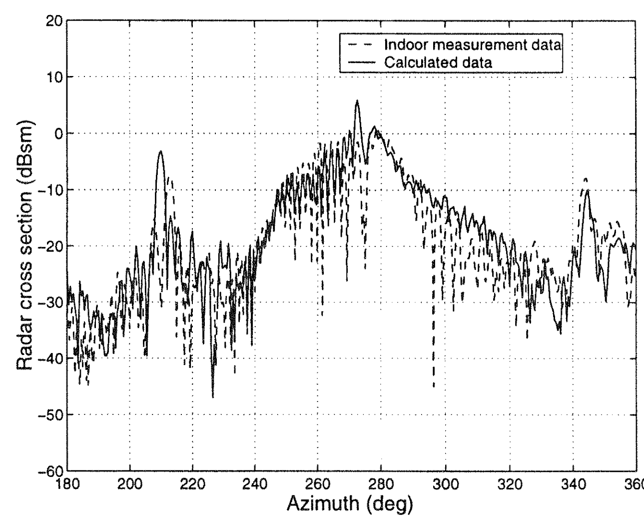

Figure 11. Comparison between calculated and measured RCS data at 10 GHz and HH-polarization of the target "RUND".

Since there are no error limits included in the experimental results, one should be careful to draw qualitatively conclusion from such comparison. Furthermore, one should also be aware of the fact that physical optics is an approximate method which do not include, e.g. edge diffraction scattering, and creeping waves. However, it is encouraging to see the relatively good shape agreement between the calculated and the measured RCS.

6. Summary and Conclusion

The RCS for two simple aircraft targets has been measured at four different test ranges, two outdoor and two indoor, which belongs to FOA and SAAB Dynamics. The angular range covered was -25°–190° for the FOA indoor measurements and 0°–360° for the other measurements. All measurements has data in the overlapping frequency interval 8.0 GHz to 12.3 GHz. Each measurement has used different reference objects for calibration of data. The data from SAAB are not background subtracted in contrast to FOA data. A comparison between the measured data and data from a calculation has been made.

It was found that ISAR techniques is useful to localize target support and background features which contribute to the total RCS. The use of more similar parameters at the different RCS ranges such as bandwidth and number of frequencies would have simplified the comparison of the ISAR images.

The use of coherent background subtraction of all RCS data would have simplified the comparison at discrete frequencies. "RAK" and "RUND" are good, but demanding, test targets for RCS measurements. Their RCS are, in some aspect angles such as the front, of the same order of magnitude as the background level of the outdoor ranges. The background levels, at the different RCS ranges, and the use of coherent background subtraction makes restrictions on which targets we can perform good RCS measurements and analysis.

Our received experiences from this interlaboratory comparison will be a good starting point for detailed error analysis.

References

[1] Roland Erickson, Olof Lundén, "A Bistatic RCS Measurement Facility With Imaging Capability", Proc. AMTA, pp. 14-5–14-9, Columbus, Ohio, Oct. 1992.