Revista DERROTERO, ISSN 2027-0658, Numero 7, Artículo # 4, p 51-67, Año 2013
Escuela Naval de Cadetes "Almirante Padilla", Cartagena (Colombia)

DETERMINATION OF THE BASE LINE FOR THE ANALYSIS OF SHIP "RADAR CROSS SECTION" (RCS) BY USING TECHNOLOGICAL SURVEILLANCE TOOLS

Vladimir Díaz' **Karen Domínguez"**
vdiaz@cotecmar.com kdominguez@cotecmar.com
Jymmy Saravid
jsaravia@cotecmar.com

Fecha de recepción: julio de 2013, Fecha de aceptación: septiembre de 2013

Abstract: This work presents the application of a technological surveillance process by using Goldfire and VantagePoint tools to determine the state-of-the-art of Radar Cross Section (RCS) within the framework of the research project "Exploration of Tools to predict Radar Cross Section (RCS) of Coastguard Patrol Boats". The exercise stems from understanding radar behavior and is supported on the technological surveillance process conducted with scientometric analysis; thereafter, it presents the analysis and listings of each of the results obtained, finally arriving at a conclusion that summarizes the state-of-theart and makes recommendations on how to guide the research project.

Keywords: Radar detection, Radar Cross Section, Software tools, Technological surveillance, Ships.

Resumen: Este trabajo presenta la aplicación de un proceso de vigilancia tecnológica mediante el uso de las herramientas Goldfire y VantagePoint para la determinación del estado del arte de la Sección Transversal de Radar (Radar Cross Section - RCS) en el marco del proyecto de investigación "Exploración de Herramientas para predecir la Sección Transversal de Radar (RCS)

'Researcher in the Direction of Research, Development, and Innovation (DIDESI), Science and Technology Corporation for the Development of Naval, Maritime and Riverine Industries - COTECMAR, Cartagena de Indias, Colombia.
ь Technological Transference Manager in DIDESI, Science and Technology Corporation for the Development of Naval, Maritime and Riverine Industries - COTECMAR, Cartagena de Indias, Colombia.
ellead of the Technological Division in DIDESI, Science and Technology Corporation for the Development of Naval, Maritime and Riverine Industries - COTECMAR, Cartagena de Indias, Colombia.

de Patrulleras de Costas". El ejercicio parte del entendimiento del comportamiento del radar y se apoya en el proceso de vigilancia tecnológica realizado con herramientas de análisis cienciométrico, posteriormente presenta el análisis y las relaciones de cada uno de los resultados obtenidos, llegando finalmente a una conclusión que resumen el estado del arte y da recomendaciones sobre la manera de orientar el proyecto de investigación. El resultado de este ejercicio permite obtener una comprensión completa sobre los conceptos, métodos de predicción, fabricantes, tipos de materiales usados, entre otros, identificando además los criterios incidentes en el manejo de la RCS de buques, así como las técnicas más frecuentes y usadas para reducción de la misma.

Palabras Clave: Detección Radar (Radar Detection), Sección Trasversal de Radar (Radar Cross Section), Herramientas Software (Software Tools), buques, absorbente, reducción.

1. INTRODUCTION

Technological management has been in charge since the 1990s of facilitating the execution of different processes that streamlines research, development, and innovation within any organization. One of the main processes implemented to recognize the environment, state of technologies, tendencies, players, among others, is technological surveillance, so that through it the necessary information can be obtained that permits organizations to make decisions focused on planning and guiding projects on research, development, and innovation.

This document discusses all the aspects directly influencing on the RCS variation, seeking the best way to reduce the radar signature of ships, exploring via search tools and technological surveillance, which permit effectively and efficiently developing the state-of-the-art of this theme. The result of this investigation provides support to the research project "Exploration of Tools to

Predict Radar Cross Section (RCS) of Coastal Patrol Vessel", which seeks to identify and reduce the RCS of Coastal Patrol Vessel, design carried out within Cotecmar (Science and Technology Corporation for the development of Naval, Maritime and Riverine Industries).

Also, to conducta complete study of this ship signature, Vantage Point and Goldfire tools were applied, through them permitting to screen the information obtained from literature searches in structured databases and navigation through a vast number of results to, thus, elaborate a subsequent analysis that clears the relationships and finds critical patterns that help to convert said information into knowledge.

1.1. TECHNOLOGICAL SURVEILLANCE TOOLS

Vantage Point

Tool to analyze scientific articles and patents from databases, which permit quickly and efficiently processing large volumes of information (Search Technology 2012).

Goldfire

Software for innovation and knowledge management, which uses the method of the Theory of Inventive Problem Solving (TIPS) and a powerful research technology to provide decisive support in the resolution of technical problems, with facilities for collaboration and interaction among professionals. This software integrates knowledge bases, both from the Organization as from a global databank (IHS 2012).

Additionally, war ships must be designed to fulfill missions in scenarios with high levels of threats and danger caused by infrared or radar guided missiles, mines activated by acoustic, magnetic, or electric signatures, or acoustic or pressure self-guided torpedoes . (Vilches y Sierra 1999).

Low detection is one of the main objectives of design and construction in war ships, which is possible to achieve by reducing the ship's magnetic, infrared, acoustic, visual, etc., radar signatures; thereby managing to diminish the probability of detection and classification by enemy sensors. Given the aforementioned, this investigation focused on obtaining knowledge regarding the decrease of a ship's main signature (RCS) to be detected by enemy radars.

1.2. Radar behavior

To understand and analyze RCS behavior on surface boats, initially radar behavior is studied through its mathematical equation, which discusses the range of detection and the transmission characteristics, reception, antennae, target, and environment. Mainly, this equation is used to determine the maximum range at which given radar can detect a target and can be useful to understand the factors affecting radar performance and detection.

Two types of radars exist, bi-static and mono-static, where their main difference lies on the use of an antenna for transmission and a different one for reception in the bi-static, while the mono-static radar uses the same antenna for transmission and reception. Equation (1) for the mono-static radar,

$$Pt = \frac{I't\,G^2\,aX^2}{(47)3R4} \quad (1)$$

Where PT is the power received by the radar in (Watts). Pt is the transmission power (Watts). Gis the gain of the transmission or reception antenna, a is the radar cross section (RCS) (m2); X is the wavelength of the radar's frequency of operation (m), and R between the radar range and the target (m).

The radar's maximum reach (Rmax) is the distance beyond which the target cannot be detected. It is produced when the signal received (Pr) is only equal to the minimum detectable signal (Smin). Substituting Pr = Smin in equation (1) and reorganizing terms, we obtain:

$$R_{max} = \left[\frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 S_{min}} \right]^{\frac{1}{4}} \quad (2)$$

This radar equation excludes several factors and generally predicts high values for the maximum range; however, it represents the relationship between the radar range and the target's RCS.

As shown by equation (2), RCS is a target feature, which disperses a certain amount of radar signal received. This amount of signal is represented in the echo magnitude of the signal received in the radar and can be defined as:

$$\sigma = \frac{Pr}{Ip / 4\pi} \quad (3)$$

Where Pr is the power reflected to the receptor by the solid angle unit and Ip is the incident power density.

1.3. Radar Cross Section RCS

It is noted that a target's RCS is the measurement of the power dispersed in a given direction when the target is illuminated by an incident wave. This incident wave is normalized to eliminate the range effect and, hence, obtain a value of RCS that is independent of the distance between the target and the illumination source (Garrido 2000).

2 DEVELOPMENT

To develop the state-of-the-art, we had specialized search and technological surveillance software, which permits finding and processing information.

2.1. Surveillance with Vantage Point

Guiding the search to obtain conclusions and identify what techniques would be most frequent to reduce the RCS on surface boats and military vehicles, we conducted — in the first instance — technological surveillance with the Vantage Point tool by employing the Engineering Village database, with which 464 results were found for the search: "Radar Cross Section Reduction".

2.1.1. *Years ofpublication*

Initially, we sought to determine the research and development evolution in this area, where Figure 1 shows the continuous growth and the amount of documents carried out during the last 10 years in the 32 countries publishing in said regard in the database analyzed.

2.1.2. *Countries ofpublication*

After analyzing what countries have the greatest transcendence in the development of RCS reduction techniques, which reveals that of 464 results, the United States and China have over 90 publications each, making them the main countries developing these techniques Q. It could be said that these two countries concentrated nearly 48% of the publications worldwide.

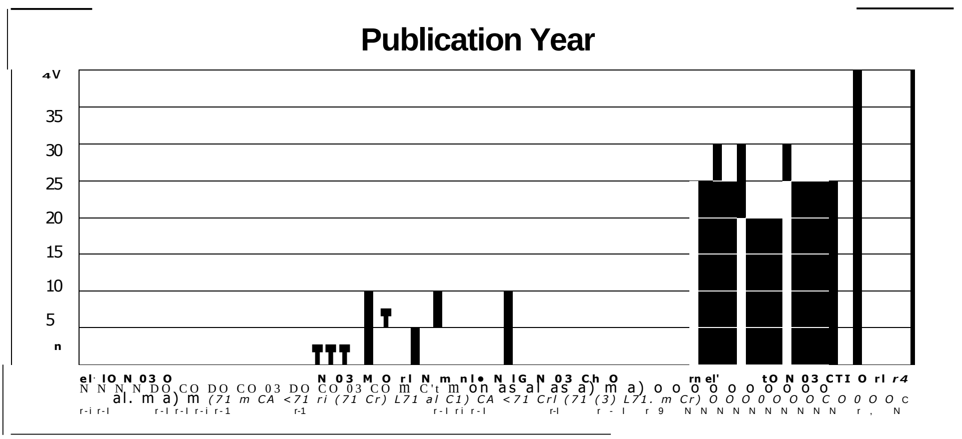

Figure 1: *Years of publications on Radar Cross Section Reduction (2012 in course)*

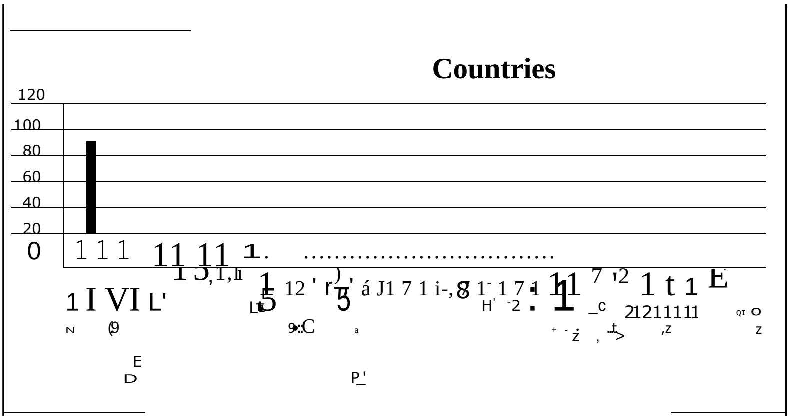

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Figure 2: *Number of publications per country*

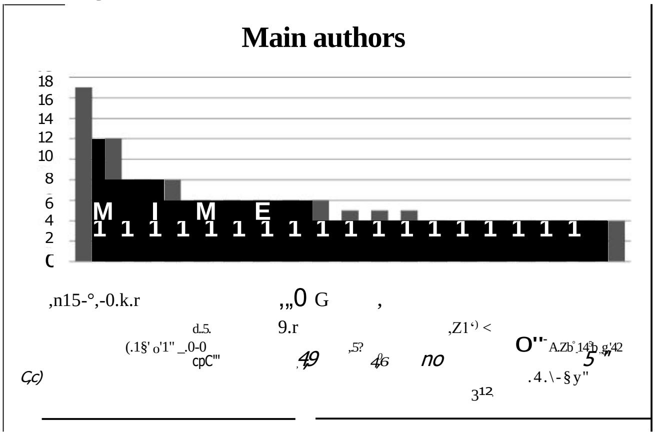

Figure 3: *Main authors in publications*

2.1.3. Main authors

The main producers of information regarding RCS are described in Figure 3, which shows the number of publications by each ofthese authors. Shu Xi Gong and Ying Liu stand out as the highest producers with 17 and 12 publications each, respectively.

2.1.4. Main institutions

The main institutions related to Radar Cross Section are described in Figure 4, where vine is the highest number of publications by the National Laboratory ofAntennas and Microwave Technology.

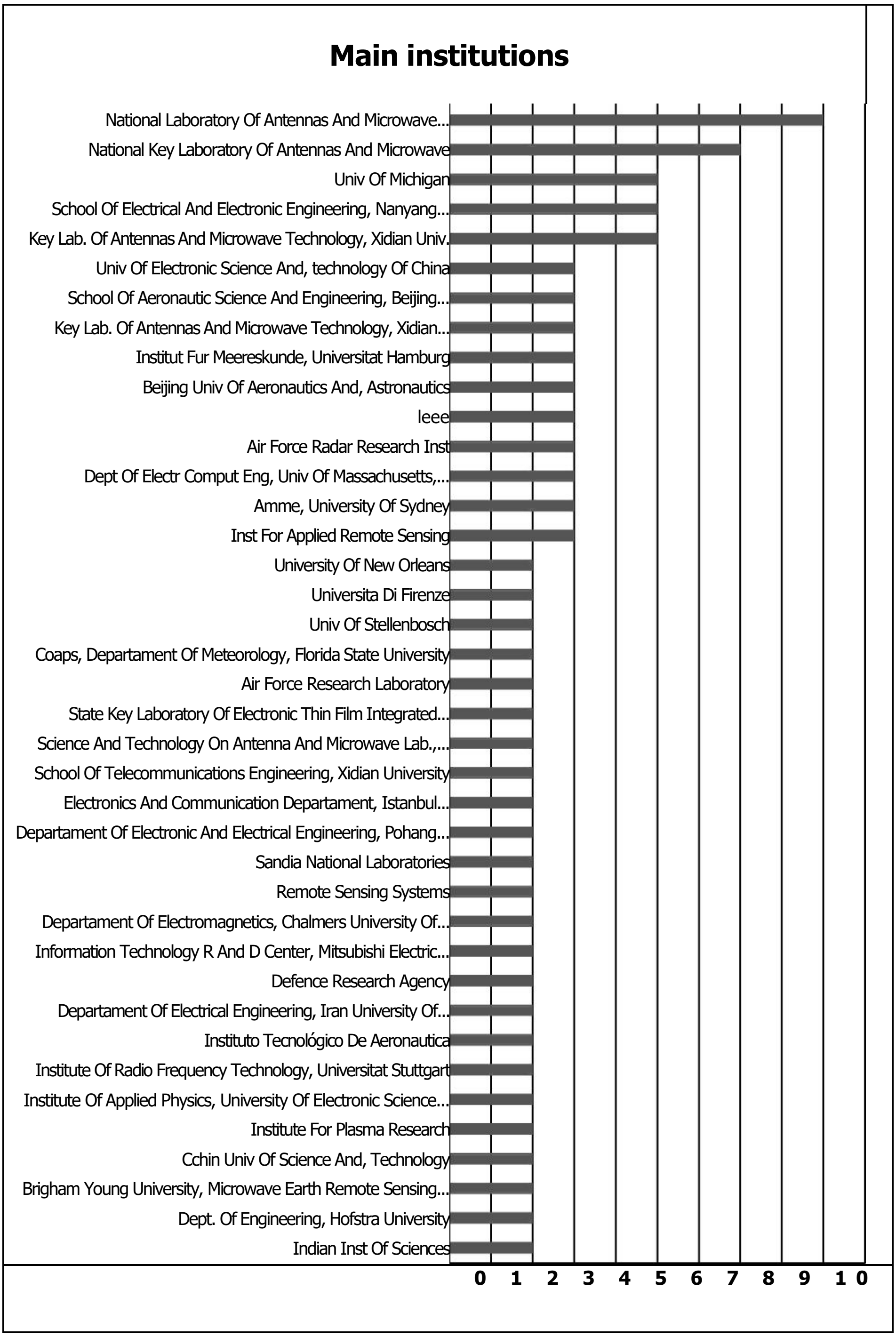

Figure 4: Main institutions related to RCS

2.1.5. Map of correlations

Figure 5 shows the correlations existing with the different reduction methods; dotted fines; like shaping management, use of Radar Absorbing Materials (RAMs), Paints, as well as their use within stealth technology.

The diagram gives us a first vision of the most frequent and most used techniques for RCS reduction. Use of RAMs and use of the shaping management technique are shown in relationship to the use of stealth technology.

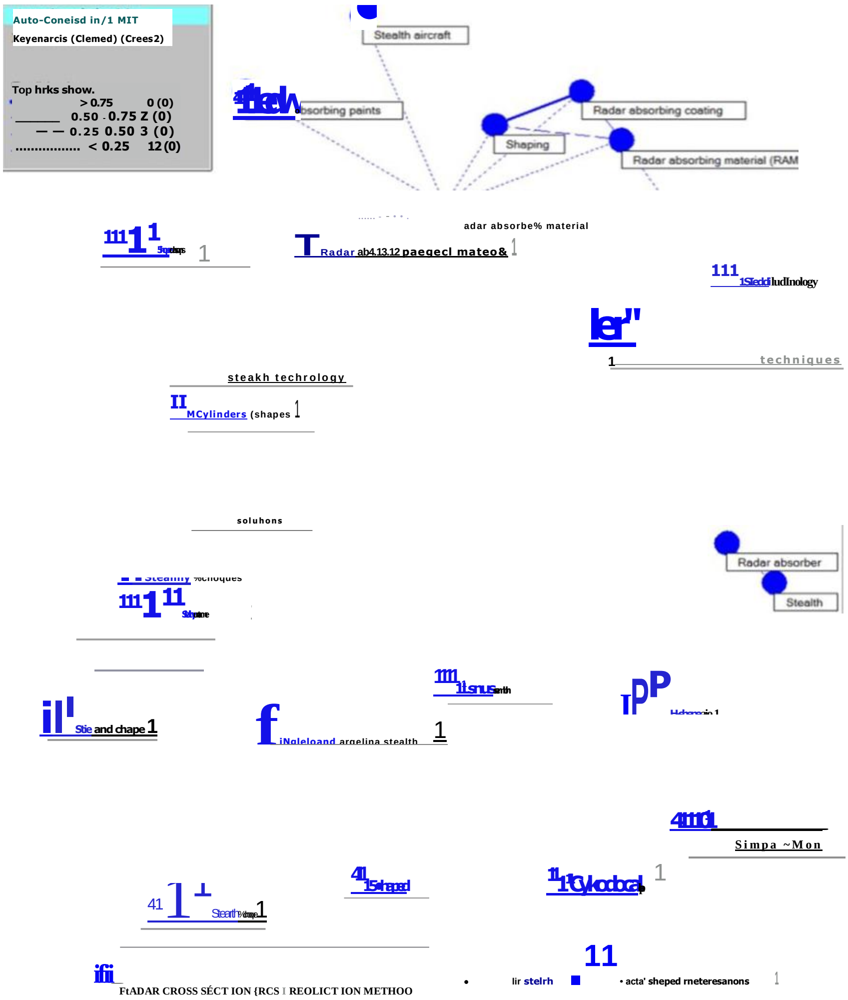

Figure 5: Map of correlations for Radar Cross Section

2.2. Technological surveillance with GoldFire

A more detailed search was conducted with the Goldfire tool, which is the software available to consult databases of international patents and scientific articles, making it innovation software that accelerates and simplifies research activities.

2.2.1. *Search parameters*

The following tables show the listing of inquiries made regarding the concept; also noted are the categories explored with their respective amount of results. The responses explored indicate the names of the most relevant articles that have been read during the inquiry, followed by the number of solutions explored and their information was considered valuable to be stored and subsequently visualized in a report.

Initially, the following terms are entered, yielding their respective results:

Table 1. Search results for radar cross section

Concept	Radar Cross Section
Inquiries	Radar Cross Section, what is radar cross section, radar cross section is
Categories Explored	what is radar cross section: Definitions (200) radar cross section: Detinitions (200), Companies (0)
Responses Explored	Radar Cross Section: radar Cross Section Measurement, radar cross section analysis, radar Cross Section Reduction, radar cross section is: reduction of clutter side, vertical incidente, in Table radar cross section: measure of strength of reflected radio frequency signal, parameter, and radar cross section calculation.
Solutions Stored	1
Open Documents	MiCTO1N ave energy scattered off building surfaces shows strong dependence on orientation of city blocks

Table 2. Results of the search for radar cross section material

Concept	radar cross section material
Inquiries	radar cross section material
Categories Explored	radar cross section material: More specific (5)
Responses Explored	radar cross section material: low radar cross section material, low radar cross-section material, radar cross-section reduction using radar absorbing material
Solutions Stored	2
Open documents	Foliage transmission measurements using a ground-based ultra vide band (300-1300 MHz) SAR system

Table 3. Results of the search for radar cross section ship

Concept	radar cross section reduction ship
Inquiries	radar cross section reduction ship, radar cross section ship
Categories Explored	radar cross section rcduction ship: Concepts (2)
Responses Explored	radar cross section reduction ship: "The Fast Ship Radar Cross-Section Reduction Using Shaping Technique", "Surface Effect Ship Radar Cross Section Reduction analysis"
Solutions Stored	2
Open documents	One Ocean initiatiN e and future generation vessels

The main solutions offered by the GoldFire tool are the "Elimination of radar detection range" (Richard Scherrer 1995), "One Ocean initiative and Future Generation Vessels (FGVs)"(Debziri 2005) , "Radar cross-section reduction using radar absorbing material" (Shen 1994), "The Fast Ship Radar Cross-Section Reduction Using Shaping Technique" (A. Mohammadian Dehziri June 2005), which generally describe the use, applications, methods, and techniques to reduce RCS in ships. The date of publication of these solutions shows the continuous development of this technology and application of techniques for RCS reduction in ships, which increases the importance and necessity to continue with the development of skills in COTECMAR to determine the radar signature of its current ship designs and in the new constructions made within the Corporation.

2.3. Listing of patents

The following shows the listing of patents at global level with respect the search topic:

Inquiry: radar cross section.

Table 4. *Listing of patents for radar cross section*

As signe(' ti):	Ntunb el of Patents	Tendency
Patents assigned to individual persons or to no Assignee	648	Activity on the rise between 1971 and 2012
Lockheed Martin Corp.	138	Activity on the rise between 1997 and 2012
Raytheon Co.	133	Activity on the rise between 1981 and 2012
Mitsubishi Electric Corp.	119	Activity on the rise between 1984 and 2012
The Boeing Co.	83	Activity on the rise between 1974 and 2012
The United States of America as represented by the Secretará of the Navy	79	Activity on the rise between 1976 and 2012
Hughes Aircraft Co.	75	Activity on the rise between 1988 and 2012
Northrop Grumman Corp.	59	Descending activity between 1995 and 2009
Automotive Technologies International, Inc.	53	Descending activity between 2005 and 2012
The United States of America as represented by the Secretary of the Air Force	42	Descending activity between 1977 and 2011
Hitachi, Ltd.	38	Activity on the rise between 1981 and 2009
BAE Systems ple,	35	Activity on the rise between 2002 and 2012
The United States of America as represented by the Secretary of the Army	29	Descending activity between 1976 and 2011
QinetiQ Ltd.	29	Activity on the rise between 2002 and 2011

Initially, a general search is conducted on patents on the issue of Radar Cross Section, observing that most of the patents are made by individual persons; results of studies in universities, followed by Lockheed Martin Corp. with 138 patents. The first appearance of the term Radar Cross Section as such is noted since 1971 in these results and, currently, important patents are still being registered in the management ofthis important radar signature.

Continuing with the search and lowering the level to something more specific, the following inquiry was made: radar cross section Ship.

Table 5 and Figure 6 show the listing of patents registered by two important institutions in the elaboration of systems for ships, Northrop Grumman Ship Systems and The United States ofAmerica as represented by the Secretary of the Navy and patents assigned to individual persons. These three stand out, with "Radar Cross Section in Ships" being the object of the search.

Table 5. Listing of patents for institutions

Assigned to:	Number of Patents
Northrop Grumman Ship Systems, INC.	5
The United States of America as represented by the Secretan: of the Navy	
Patents assigned to individual persons or to no Assignee	

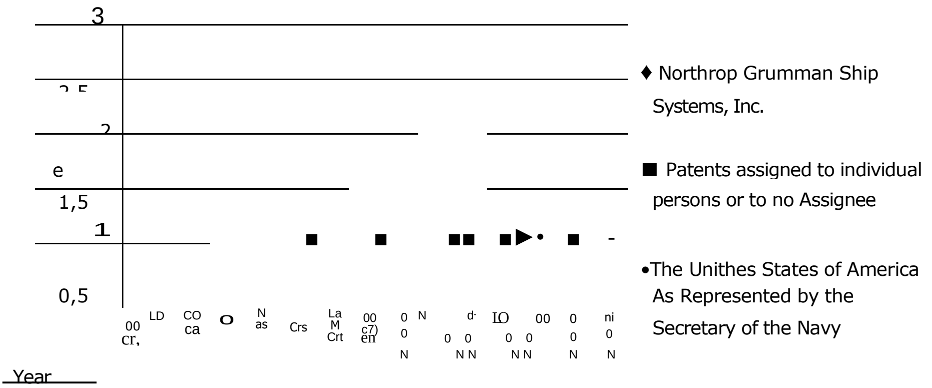

Figure 6: Diagram of Patents for** Ship **Radar Cross Section

Advancing exploration to more specific terms, the search is guided to Radar Cross Section Reduction, obtaining the following results:

Table 6: Listing of patents for radar cross section reduction

Assigned to:	Number of Patents	Tendency
Patents assigned to individual persons orto no Assignee	105	Activity on the rise between 1982 and 2012
BAE Systems plc	24	Descending activity between 2004 and 2012
Northrop Grumman Corp.	19	Activity on the sise between 1995 and 2008
Lockheed Martin Corp.	18	Activity on the rise between 1998 and 2010
Raytheon Co.	17	Activity on the rise between 1989 and 2012
The Boeing Co.	15	Descending activity between 1991 and 2011
Hughes Aircraft Co.	12	Activity on the rise between 1988 and 2005
The United States of America as represented by the Secretary of the Navy	12	Activity on the rise between 1979 and 2012
McDonnell Douglas Corp.	10	Activity on the rise between 1995 and 2004
The United States of America as represented by the Secretary of the Army	9	Descending activity between 1977 and 2007
Mitsubishi Electric Corp.	8	Activity on the rise between 1986 and 2001
The United States of America as represented by the Secretary of the Air Force	8	Activity constant entre 1978 and 2005
General Electric Co.	8	Descending activity between 1994 and 2010
YOKOHAMA RUBBER Company Ltd. : THE	7	Low activity
Goodrich Corp.	7	Descending activity between 2006 and 2010

As with the previous search, records by individual persons are still kept and BAE Systems appears as the first company that since 2004 has been developing activities for RCS decrease. It is worth highlighting that a search is made in which reduction techniques are excluded for ships, aircraft, land vehicles, buildings, among others.

Comparison is made of the activity of patent creation with the radar cross section reduction inquiry for the five most important entities (TABLE 7).

Table 7: Main listing of patents for radar cross section reduction

Assigned to:	Number of Patents
Patents assigned to individual persons or to no Assignee	105
BAE Systems plc	24
Northrop Grumman Corp.	19
Lockheed Martin Corp.	18
The Boeing Co.	15

It is highlighted that most of the production took place between 2003 and 2005, carried out by individuals and university institutions. A decrease in number of patents is shown in recent years, a product of the high design and construction of Stealth ships like the Visby corvette, Fremm frigate, class 45 Destroyer, as well as F17 aircraft and B2 Bomber, among others (Figure 7).

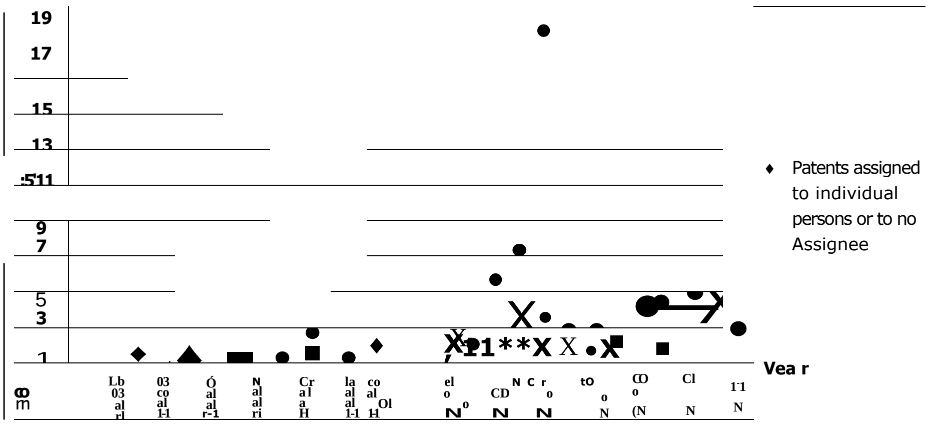

Figure 7: Diagram of main patents for RCS Reduction

3. CONCLUSIONS

It may be inferred that to reduce the RCS of platforms already constructed, RAMs are frequently used and to reduce the RCS in new platforms it is necessary to use shaping management technique combined with RAMs. The size of the platform apparently shows no relationship with the use of absorbent materials or with the Stealth technology; however, it must be tested if the size variation of a platform leads to a significant variation in the RCS.