

Constructing a 3D model of a complex object from 2D images, for the purpose of estimating its Radar Cross Section (RCS)

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Abstract

Evading the enemy radars plays a crucial role in today's warfare. All weapon systems are designed with the aim of minimising their radar signature or Radar Cross Section (RCS). It would also be desirable to know the RCS of any potential target. However, RCS values are not publicly available. This paper examines the concept of estimating the RCS of a complex object, such as an aircraft, on the basis of available photos and videos. Initially, a basic 3D model is created, which is further refined, taking into account details shown in photos, with the help of CAD software. Consequently, a computational approach, based on Physical Optics, is employed to calculate the RCS of the final 3D model. The proposed method is applied to the F-16 and F-35 jet fighters, as well as the DF-15 ballistic missile, yielding plausible results.

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1 Introduction

The RCS is a measure of a target's ability to reflect radar signals back to the emitting radar. RCS reduction is the cornerstone in the design of any military aircraft, ship or ground vehicle, since lower RCS values mean shorter detection distances [1].

Looking at this issue from a different perspective, a reliable estimate of the RCS of the means expected to be employed by a potential aggressor would allow for the optimal allocation of the early-warning and tracking radar systems of the defender. Therefore, it would be highly desirable to obtain predictions of RCS values of all relevant assets. However, real RCS values are kept well hidden by the respective manufacturers and primary users, who may release only vague innuendos, e.g., RCS “equivalent to a metal golf ball” or “about that of a metal marble”, possibly exaggerating the low observable capabilities of their products. A comprehensive list of known RCS estimations for various targets can be found in [2].

In this context, a complete procedure is proposed, aiming at the RCS estimation of a potential target using only open-source information, such as 2D images and drawings, as well as some basic knowledge concerning its design and the materials used. The proposed procedure extends the idea of constructing a model and employing the physical optics approach for computing the target cross section, presented in [3], and consists of the following steps:

- Preprocessing of high definition 2D images (or still images from videos) of the object under test, by converting them to drawings, using image

processing software, such as GIMP. Ideally, these images should cover the front, side and plan view of the object, allowing for third angle orthographic projection. If this is not the case, a rough blueprint could be used as the starting point.

- Estimation of the overall dimensions of the object, either using open source information, or in comparison with nearby objects of known dimensions (e.g., from a photo at an air-show).
- Construction of a properly scaled 3D model, based upon the above-mentioned drawings and dimensions, in the AUTODESK 3ds Max environment.
- Refining the 3D model with AUTODESK AutoCAD, trying to eliminate any obvious differences with respect to the available images.
- Running a series of simulations with the help of the POFACETS program, a code utilizing the Physical Optics approximation technique for the RCS calculation, implemented in MATLAB [4][5]. POFACETS provides relatively accurate results for most “large” models, at least in the high frequency domain (optical region). These simulation runs may take into account various possible set-ups, frequency bands and materials of the surfaces of the object.

The proposed procedure has been applied to a number of aircraft types and missiles. In this paper, it will be applied to the F-16 and the F-35 by Lockheed Martin, and to the chinese ballistic missile DF-15. The provided results are quite plausible, compared to the existing vague estimations of the real RCS values. Preliminary results of the proposed approach have been presented at [6].

2 Constructing a 3D Model from 2D Images

It is rather impossible to find accurate blueprints of a modern aircraft, missile or any other weapon system, since they are classified. In order to create a 3d model, it is necessary to obtain high-quality drawings and pictures to use as reference. If a weapon system is mature enough, it is probable that several high resolution pictures, specifications and even relatively reliable blueprints or drawings are available. Concerning new weapon systems, available photos or drawings may have been altered, in some way. A small change in the diameter or the fins of a missile in the published specifications or a slightly processed aircraft photo are some examples, which may result to significant changes on the estimated RCS.

The first step is the selection and processing of available high resolution photos or still images from videos (by capturing screenshots), providing front, side and plan view, if possible. With the help of photo processing software, such as the open-source GIMP2, the selected photos can be transformed to drawings, using *desaturation* and *edge detection*. The idea is to create a basic 3d model, which will be consequently refined with the help of appropriate CAD software, trying to match details depicted in available photos and videos.

Three different methods will be employed for the 3D model creation:

1. For the F-16 model, the design will start from scratch, in the AUTODESK 3ds Max environment, which is used for 3D modelling, animation, and rendering.
2. For the F-35, an existing 3D model is selected and then edited with the help of the 3ds Max software.
3. In the DF-15 missile case, a new model will be created with the help of the well known design and modelling software CATIA v5, by Dassault Systèmes.

The three models will be exported in STL format (STereoLithography) and then imported to the POFACETS program, in order to calculate their RCS.

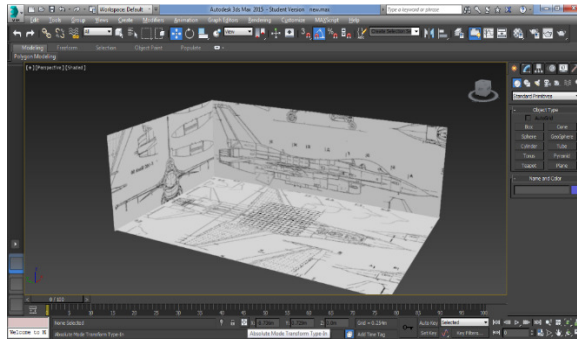


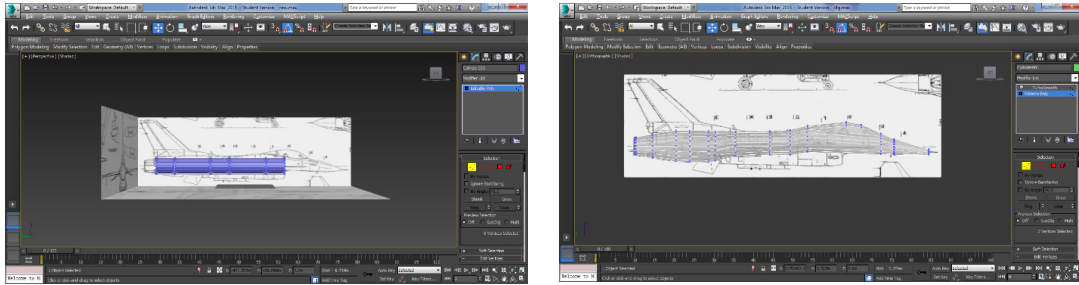
Figure 1: The F-16 blueprints setup

2.1 F-16 Modelling

The F-16 was initially designed as a lightweight day fighter and has evolved to a very capable multi-role combat aircraft. More than 4500 airplanes have been built, making it one of the most successful jet fighters, ever. The frontal aspect RCS value of an F-16 C (i.e., not of the early versions, such as the F-16A), without external loads (weapons, pods or tanks), in the X-Band (8 to 12 GHz), is estimated at 1.2 m^2 [2].

Since the F-16 is a mature aircraft type, one can easily find specifications, photos and even quite accurate drawings. Therefore, blueprints available from the internet will be used as a reference to create a 3d model of the aircraft. These prints are simple sketches of the aircraft, without referring to its dimensions. However, compared to properly edited 2D images of the aircraft, they prove to be good enough to be used as a starting point. Apart from the blueprints, the 3D model will be compared to numerous photos, taken from various angles.

In the 3ds MAX software, it is possible to use simple geometrical forms (*geometries*), like cylinders and cubes, to create a more complicated design. Any simple *geometry* can be an *editable poly*, consisting of vertices, edges and polygons. By extruding and moving the elements, more complicated geometries can be defined.



Figures 2,3: Adjusting the editable poly representing the fuselage, according to the blueprints data.

For the purpose of creating an F-16 model, a cylinder is designed in left view representing the fuselage. Then, the geometry is converted into an editable poly. After editing the vertices, the fuselage can be modelled. The next step is the modelling of the canopy. The polygons in the front part of the fuselage, which can be edited to model the canopy, are extruded and then edited by moving vertices to represent the shape of the canopy. The canopy is not projected accurately in the blueprints, so the use of reference photos is necessary. Regarding the engine nozzle, the edge on the end of the fuselage is moved and then scaled. For the radar nose cone, a sphere is created, scaled and deleted in half. Then, it is further edited, to approach the desired shape.

The main part of the model is now ready. It will be used as a base, to design and attach the remaining parts. The model should be more or less symmetrical, therefore the command *symmetry* will be applied. In this way, the model is mirrored. Changes in one side will automatically be applied to the other side, as

well. As the model is projected in front view, the deletion of half the model is necessary. Then, by applying the *symmetry* command, the model is mirrored. Also, the *turbosmooth* command is very useful, as the flat areas are smoothed and the design of curves is more accurate.

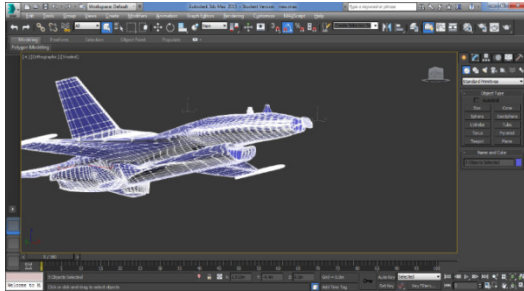


Figure 4: F-16 model
with radar modelled.

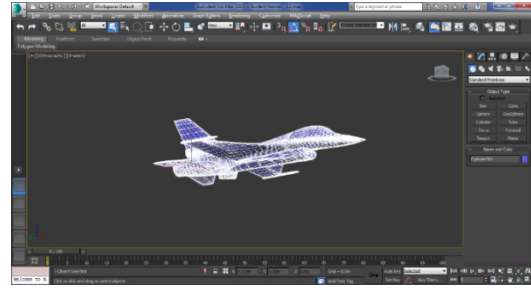


Figure 5: F-16 model
with radar nose cone modelled.

The wings can be modelled by extruding the polygons in the side of the fuselage where the wing root is located. Then by scaling along the z axis the polygons that model the wingtip, the wing will be modelled as the scaling affects all the connected polygons. The stabilators will be modelled separately by applying the same process. External armament, pods or fuel tanks can be also modelled separately, and then can be attached to the main model, if necessary.

2.2 F-35 Modelling

The F-35 is a 5th generation, multirole jet fighter, with low observable characteristics, designed and built by Lockheed Martin. It is expected to replace a number of legacy fighters in the US and will be exported to several countries. At the present time, the F-35 is in initial production and at the final stages of testing.

For the F-35, a relatively consistent model was found in the POFACTS library files. This model was further edited by comparing it to available photos and videos. Several minor corrections had to be made and a number of polygons have been optimized. Parts with curves had to be modelled with more polygons to achieve higher fidelity to the original. Two models were created, one with and one without the nose cone (which in fact is transparent, from the RCS point of view).



Figure 6: F-35 HD photo.

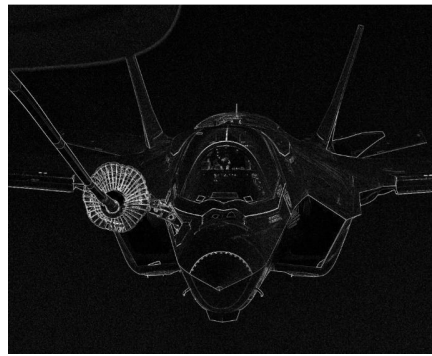


Figure 7: F-35 edited photo used as reference.



Figure 8: F-35 screenshot from video.



Figure 9: F-35 original and modified models.

2.3 Modelling of the Dong-Feng 15 (DF-15) Missile

The DF-15 is a short-range ballistic missile developed in China, in three variants (-A, -B, -C). Creating a 3D model of a simple missile in CATIA v5 is a fast and accurate process. If the details are known, the modelling could be completed in a few minutes. The photo, which will be used as reference, is inserted in CATIA v5 in *Sketch Tracer mode*, having selected the *front view*. The image may not be placed in the center of the axis system. The user can move the axis system before accepting the inserted image. The axis system should be placed in such a way that the z axis divides the missile in two equal parts. Then, a new part is inserted. In *sketch mode* the outline of the missile must be drawn. *Profile* and *spline* are in most cases enough to complete the half outline. The next step is the *shaft command*. In the *workshop mode*, the outline is selected. By applying *shaft* and selecting the z axis as reference, the outline is rotated 360° and a solid missile is created. Finally, the model is properly scaled, according to available info on the dimensions of the missile.

The fins should also be modelled. In a new sketch, the outline of a fin is created using the same process. Then, the *pad command* is applied and the outline is extruded creating a solid fin. Three other fins must be created symmetrically, by using the circular pattern and placing each fin at 90° from the previous one, while selecting the fuselage axis as reference.

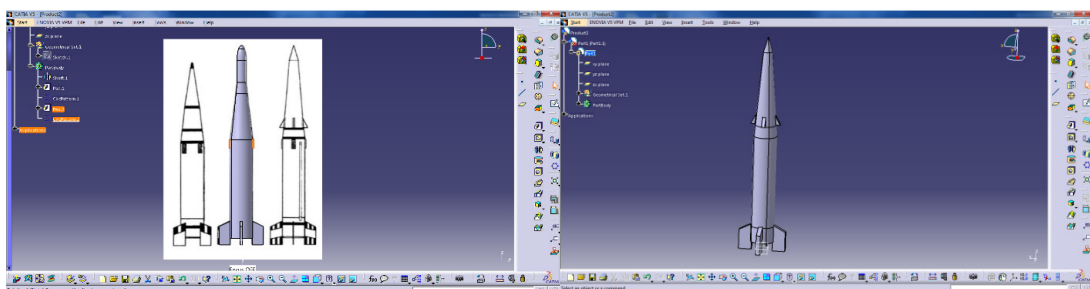


Figure 10: DF-15 models in CATIA

Figure 11: DF-15 -C 3D model
in CATIA.

3 Radar Cross Section (RCS) Computation

The POFACETS code, which was used to calculate the target RCS with the help of the Physical Optics method, is running in the MATLAB environment. It can import .stl files and convert them to .m files, to be processed by MATLAB. The imported 3D models are considered to be *Perfect Electric Conductors*.

3.1 F-16 Model RCS Simulation Results

The RCS of the F-16 model was computed for a carrier frequency of 10 GHz, emulating a typical aircraft fire control radar. The RCS pattern shown in Fig. 12 corresponds to the front aspect view of the fighter from the same level ($\theta=90^\circ$ and φ ranging from -45° to $+45^\circ$, at a step of $0,2^\circ$). The mean RCS is $-2,88$ dBsm ($0,52$ m²). This is a little less, but not so far, from the reported value of $1,2$ m² [2].

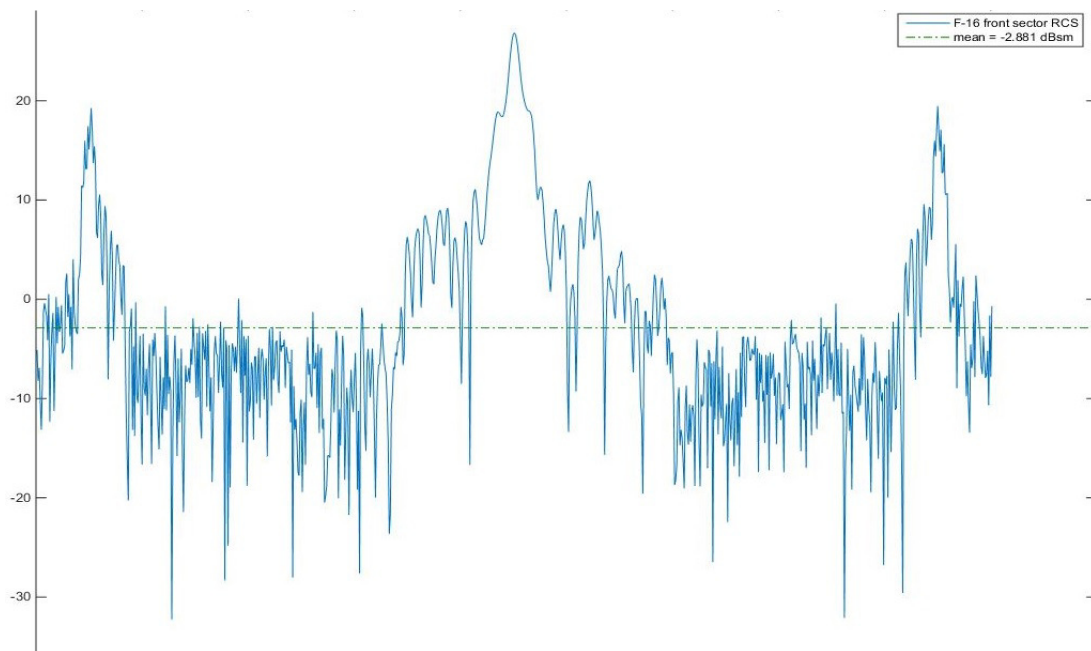


Figure 12: RCS diagram for the F-16 model, front sector ($\pm 45^\circ$ from head-on), at the same level.

3.2 F-35 Model RCS Simulation Results

The elaborated F-35 model presented in the previous section was imported to the POFACETS algorithm and was employed for a series of simulation runs. The computed RCS does not take into account the possible coating with a *radar-absorbent material* (RAM), which decreases the RCS by distributed loading [7]. The F-35 features advanced RAM (fiber mat), which is more durable and requires less maintenance, with respect to older stealth aircraft [2]. Therefore, the real RCS values are expected to be lower than the ones shown in the results. It should be noted that such coatings are frequency selective, i.e., they are more efficient at specific frequency bands, for example the X-band. At lower frequency bands, RAM coatings are less effective. To take into account RAM, a rudimentary approach would be to subtract 10 dB from the values calculated by the POFACETS algorithm.

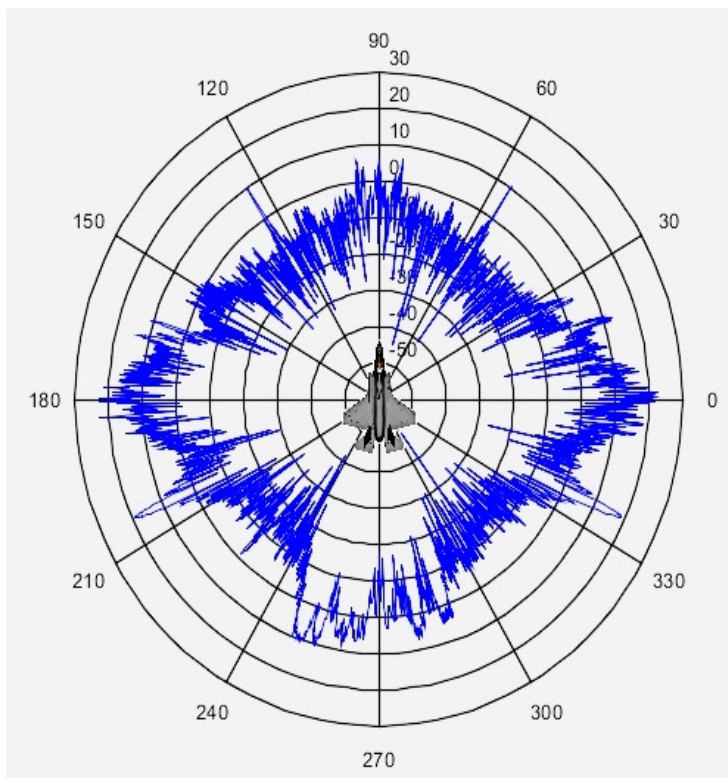


Figure 13: RCS polar diagram for the F-35 model, seen from 10° below, at a carrier frequency of 10 GHz. The mean RCS for the front sector (from -45° to $+45^\circ$), averaged from -15° to $+15^\circ$ in elevation, is approximately -11 dBsm. This value does not take into account the use of Radar Absorbent Materials (RAM), which further reduce the RCS.

At first, the RCS was computed, looking at the target from below (10° depression angle), at 10 GHz (X-Band). The results are shown in Figure 13. The RCS appears to be relatively small in a wide sector in the front, while it attains high values at the sides (as expected, due to the wings) and also (unexpectedly) in the aft sector.

Then, the mean RCS was calculated for various frequency bands, for the front and aft sector (-45° to $+45^\circ$ off each axis), averaged from -15° to $+15^\circ$ in elevation. The results are shown in Figure 14. It is confirmed that the RCS is not so low in lower frequency bands. Considering that RAM is less efficient at lower frequencies, it turns out that VHF or UHF radars seem to be a promising counter-stealth approach.

The mean RCS for the front sector (from -45° to $+45^\circ$), averaged from -15° to $+15^\circ$ in elevation, is approximately -11 dBsm. Taking into account the use of RAM, the RCS would be further reduced to the class of -20 dBsm, which corresponds to 0.01 m². This result is a little higher but close to RCS values appearing in various sources, which estimate the front sector RCS of the F-35 from 0.0015 to 0.005 m² [2].

3.3 Dong-Feng 15 (DF-15) Model RCS Simulation Results

The simulation runs were performed on the DF-15 -C model. The results at 10 GHz (X-Band) yield an average head-on RCS at the class of -17 dBsm. Subtracting 10 dB, as a rough compensation for the use of RAM, the RCS becomes -27 dBsm (0.002 m²). At 150 MHz, the average head-on RCS reaches -13 dBsm (0.05 m²). In the VHF-Band, RAM is quite ineffective, without any considerable RCS reduction.

The RCS of the DF-15 missile is reported to be 0.002 m² in the X-Band and 0.6 m² in the VHF-Band [8]. In the X-Band, the above mentioned result coincides with the reported RCS. In the VHF-Band, the computed RCS is higher than the

one at 10 GHz, but the difference is not as dramatic as implied in [8]. However, it should be noted that the POFACETS algorithm is expected to yield more accurate results at the higher frequency range, closer to the optical domain.

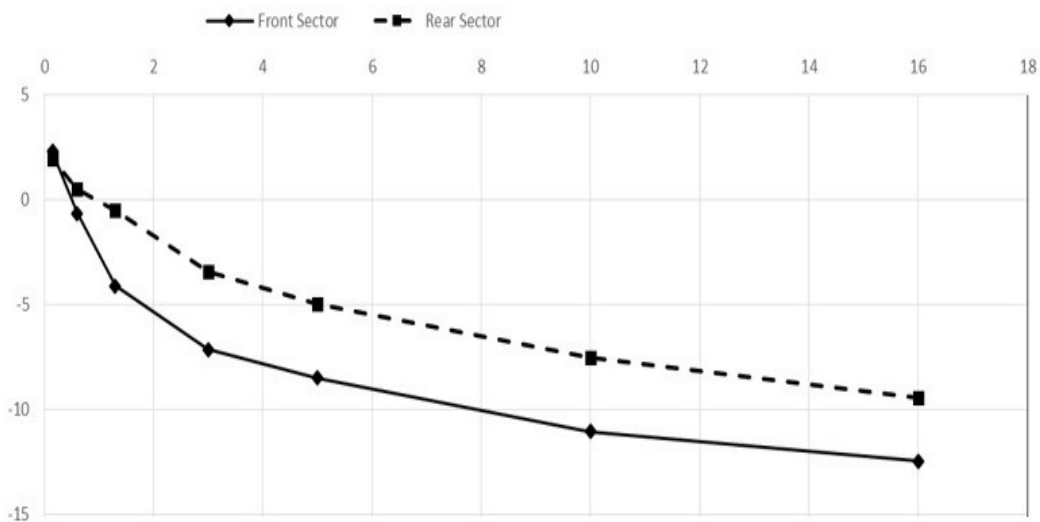


Figure 14: The mean RCS for the front and the aft sector of the F-35 (from -45° to $+45^\circ$) vs frequency, averaged from -15° to $+15^\circ$ in elevation. It is clear that RCS is getting higher at lower frequency bands.

4 Conclusion

In order to estimate the Radar Cross Section (RCS) of a potential target, a 3D model is created and further elaborated, with the help of appropriate software, in an attempt to minimize any obvious difference with respect to available images. The refined 3D model is imported to the POFACETS code, running in the MATLAB environment, which is a computational approach to the issue of RCS calculation, based on the Physical Optics principle. The proposed approach has been tested on the F-16 and F-35 jets, as well as on the DF-15 -C missile, with encouraging results.

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