The use of Scientific Infrared Cameras in Signature Measurement of Infrared Radiant Targets

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***Abstract* — The measurement of aircrafts and other radiant targets infrared signatures is a long-standing priority for the Brazilian Air Force Command. But, once the methods used to measure these signatures to this date show to be extremely costly, requiring a complex support infrastructure and making the measurements of a great number aircraft in a short period of time completely unviable, it is being proposed by the Electronic Warfare Laboratory (LAB-GE) of ITA a new method, based on the use of scientific infrared cameras. This paper describes the proposed methodology by presenting experimental results from a helicopter H-55 that prove the efficiency of this approach, allowing the analysis of its radiance during different operational maneuvers and on the ground. The results show a potential increase in combat and doctrine power to the BAF, allowing the creation of an IR signatures library and the development of tactics and techniques for attacks and air raids inside hostile territories.**

***Key-words* – Infrared Signature, Thermography, Electronic Warfare, Combat Doctrine.**

I. INTRODUCTION

The measurement of aircrafts and other radiant targets infrared signatures is a long-standing priority for the Brazilian Air Force Command. However, in view of the recent modernization of the fleet that took place after the 2000`s and concerning to the air power increase associated with this modernization, the creation of IR targets libraries took a strategic importance recently [1] [2].

Several works and studies were carried out on that goal by using different methods and tools for the acquisition of such data. One of the main drawbacks of the adopted methods is the necessity of using quite complex equipments, as spectroradiometers, requiring the employment of a specialist staff, big infrastructure and, consequently, presenting high costs [2] [4] [5].

Concerning to this scenario, it is being proposed by the Electronic Warfare Laboratory (LAB-GE) of ITA a new method for the measurement of such signatures, by using scientific infrared cameras. The use of this tool has proved to be of great simplicity and versatility, involving low operational costs and providing effective and comprehensive creation of infrared signatures libraries.

This paper describes the proposed methodology by presenting experimental results that prove the efficiency of this approach. Preliminary measurements of a helicopter H-55 signature demonstrate the feasibility of the method, allowing the analysis of its radiance during different operational maneuvers and on the ground, showing a high level of simplicity in the experimental arrangement and in the acquisition and analyzing data. Once validated, it will allow the creation, in a simple and inexpensive way, of infrared signatures libraries, with different aircrafts and targets, showing high strategic value.

The results presented hereafter show a potential increase in combat and doctrine power to the BAF, allowing the creation of an IR signatures library in a quick and efficient way, as well as the development and improvement of tactics and techniques for attacks and air raids inside hostile territories and evasive maneuvers against enemy attacks.

II. EXPECTED OPERATIONAL IMPACT AND THEORETICAL CONCEPTS

Currently, weapons using infrared guidance are a major threat to aircraft that fly in hostile territory [6]. Such devices have their operating principles based on the fact that any body above 0K emits radiation. This emitted radiation is higher as higher is the temperature of the body [3]. The target detection through the use of infrared radiation is very important in military environment, once it occurs in a passive way, regardless of day or night period. Infrared imaging equipments, which use this same principle, allow to "see in the dark," thus providing a huge advantage in tactical and operational theaters during military operations [3] [4] [7].

In addition, the knowledge and the domain of such radiation process, as well as the generating and transmission of infrared radiation, show to be of great importance for any Armed Force, particularly if it is used to the creation of infrared signatures libraries, since these libraries allow the development of various tactics and techniques of attack or escape, aiming the stealth in relation to the enemies weapons and sensors. Likewise, the estimation of the detectability of these sensors allows the mapping of safer routes for incursions into hostile territory with a major probability of success. The knowledge about foreign aircraft signatures also allows preparing a better positioning of the national air defenses. Finally, infrared signatures can also be applied in the design of sensors and specific weapons.

The range of the electromagnetic spectrum corresponding to the IR includes wavelengths between 0.75 and 1000 μm. This band can be further subdivided into four bands: near infrared (NIR - from 0.75 to 3 μm), mid infrared (MIR - 3 to 6 μm), far infrared (FIR – 6 to 15 μm) and extreme infrared (XIR – 15 to 1000 μm) [3].

The main law that models the emission of infrared radiation was formulated by Max Planck in 1900, and is commonly known as Planck's Law, Black Body Theory or Black Body Radiation Law. Equation (1) provides the spectral radiant emittance of a body, in W/m^2.µm, depending on the temperature at which the body is, and for each wavelength λ of the spectrum.

$$M_\lambda = \frac{c_1}{\lambda^5}\cdot\frac{1}{e^x - 1} \qquad (1)$$

In (1), $x = \frac{c_2}{\lambda T}$, radiation's first constant $c_1=3.741844*10^4$ [W.cm^{-2}.µm^{-1}], radiation's second constant $c_2=1.438769$ [cm.K], λ is the wavelength [µm] and T is the absolute temperature [K]. From (1), it can be seen that not only the radiant emittance but also the total emittance of a body depend on the temperature at which the body is, with a different value for each wavelength. In addition, for a specific temperature, a different emittance peak wavelength can be seen, what can also be described by the Wien's Displacement Law [3]. In Fig.1, it can be seen a graphical representation of these behaviors for different temperatures.

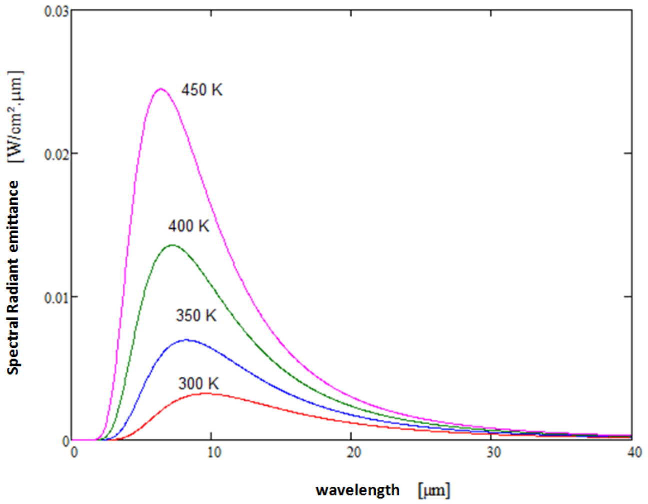

Fig.1 – Planck's Law curves for four different temperatures [4]

In order to obtain the radiance (L) from the radiant emittance (M) over a hemisphere, considering the source of emission as an isotropic radiator, M must be multiplied by the value of π [3] [8], being modeled by the following expression:

$$L = \pi.M \qquad (2)$$

In Fig.1, one can see that the total emittance (emittance considering the full spectrum) increases rapidly with the increasing temperature. This relationship is to the fourth power of temperature, being modeled by the Stefan-Boltzmann law [3]

$$M = \sigma.T^4 \qquad (3)$$

where σ is the Stefan-Boltzmann constant, with a value of $\sigma = 5.66961*10^{-8}$ [W.m^{-2}.K^{-4}].

Planck's Law, as it is shown in (1), applies to Blackbodies, which are perfect theoretical radiators, once they absorb all the incident radiation, without reflecting or transmitting it, and while being in thermal equilibrium. The concept of emissivity relates to the ratio between the emittance of a body when compared to the emittance of a black body, both at the same temperature [3] [8], being described as:

$$\varepsilon = \frac{M(\lambda,T)}{M_{BB}(\lambda,T)} \qquad (4)$$

where M(λ, T) is the emittance of the body at a given temperature, and M_{BB} is the emittance of a blackbody (obtained by Planck's Law) at the same temperature. Thus, the emissivity can be understood as a factor, that allows not only define gray bodies and selective radiators, but also derive the spectral and total emittance of these bodies .

The infrared radiation, once it does not correspond to the visible range, it cannot be detected by the human eyes. However, there are equipments, like the radiometers, that detect different bands of this kind of radiation, exhibiting the measurements as images. Such devices can be cameras or thermal imagers. These devices capture the incident radiation on each one of the pixels of their detectors, converting them into images, which have different shades (grey levels), or colors, in accordance with the level of incident radiation [7]. Brighter the pixel, more radiation is being focused on it [7].

Most infrared cameras, once they are focused on civil applications, display information relating only to the temperatures of the bodies. The calculation of this parameter is done through the use of specific algorithms, which take into account all the parameters of the previous presented laws, besides radiometric emissivity and temperature. Infrared Scientific Cameras, once they are developed for research and development, provide information not only concerning to the temperature of bodies, but also providing data on the total radiation received by each pixel [7].

Recently, LAB-GE has acquired a scientific infrared camera which, besides supplying infrared images, allows the user to analyze the images through specific software, obtaining data of the total amount of radiation received by the infrared sensor. Therefore, it was proposed and tested a new procedure, based on this new tool, for the measuring of infrared signatures of aircrafts.

III - EXPERIMENTAL SETUP AND RESULTS

In order to verify the feasibility of the method for IR signatures measurements, an experiment was conducted in DCTA, Sao Jose dos Campos, with the participation of the LAB-GE, Instituto de Pesquisas e Ensaios em Voo (IPEV) and members of FLIR Systems, Brazil. The experiment consisted in obtaining infrared images of an aircraft H-55 "Esquilo", using a scientific camera and performing a post-analysis of these images in specific software, obtaining radiometric data of the quantities emitted by the aircraft in different flight conditions and maneuvers.

The proposed experimental arrangement showed a greater simplicity and flexibility, besides lower cost, when compared to similar measurements using spectroradiometers [5,6]. It consists of a scientific infrared camera FLIR SC5000 supported on a tripod, an electrical source of energy to power on the camera and a notebook to verify the images and video recording. The camera placement allowed imaging the whole aircraft, which was maneuvering approximately 10 meters from the camera. The experimental arrangement did not require more than three people for their assembly. During the experiment, while one member of the team wielded the camera, moving it as necessary to obtain images of the aircraft, the other member used the computer to control the camera functions as well as recording the images and videos. The arrangement showed to be extremely simple and versatile and can be easily transported to any place, including embarked on an aircraft to measure “in flight IR”.

The FLIR SC5000 camera has an indium-antimonide (InSb) sensor, which is a quantum detector that operates in the spectral range from 2.5 to 5.1 micrometers. This detection range agrees with sensors often found in weapons used against air targets [1].

Initially they were taken images in four different positions of the landed aircraft, where 6 hours refers to an aspect angle of the backside of the aircraft, 9 hours refers to the left side, 12 hours refers to the front side and 3 hours refers to the right side of the aircraft. In all positions, the aircraft was landed and operated with the engine running at minimum power. All of those images were analyzed later in the laboratory through the ALTAIR software, from FLIR. The main factors influencing the detection of IR signatures (irradiance), such as air temperature, distance between target and sensor, humidity and emissivity of the target were selected and inputted to the camera software [4], once they influence the transmittance of the medium between the target and the detector. The input of these data was performed in order to allow the software to make the proper compensation, providing radiometric data relating only to the target, and disregarding reflections or atmospheric attenuation.

In ALTAIR software, the images were initially processed, and the areas of interest were delimitated. In this case, the area corresponded to the entire fuselage of the aircraft and the exhaust plume.

Analyzing Fig.2, it is possible to verify that the skis were not considered in the analysis, because the software allows only defining a polygonal area with 30 points at a maximum.

This restriction does not invalidate the analysis, once the skis have reduced emissions compared to the rest of the aircraft, what can be confirmed by its darker color in the image. In addition to the skis, the rotors of the aircraft were also disregarded, since these parts are in constant motion, preventing their selection. Likewise, these parts have a relatively small frontal area, not emitting a considered amount of radiation.

Fig.2 – Delimitation of areas of interest in the software ALTAIR (from the left to the right, it is possible to see the following aspect angles: 12 hours, 3 hours and 9 hours)

The next step was, by the using the Timing-Graph tool from the Software ALTAIR, to obtain the average emitted radiance in each one of the recording frames. Each one of these frames represents a temporal and sequential snapshot of the target. This tool allows obtaining the average radiance of all pixels included within the selected area. Figure 3 shows an example of one of these analyses, where the Timing-Graph tool from ALTAIR software was used to analyze the frontal image of the aircraft. In Fig.3 it can be seen that, as a matter of security, the vertical axis scale was omitted.

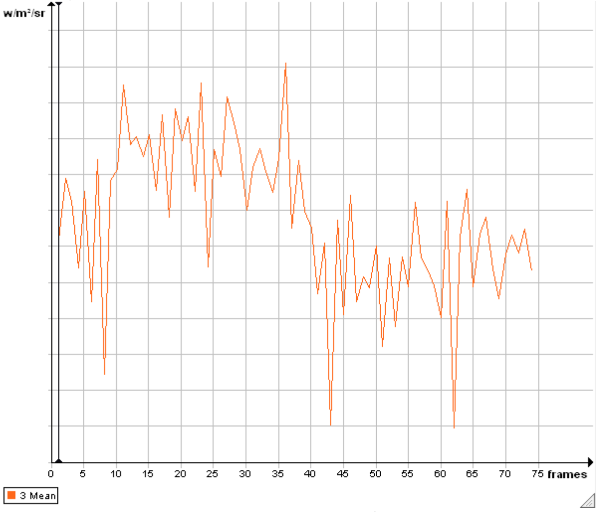

Fig. 3 – Mean Radiance Graph, according to frames to the selected area of interest (frontal view – aspect angle of 12 hours).

Based on Fig.3, it was calculated the average radiance, which, in this case, corresponds to 2.35 $W/m^2.sr$. The same procedure was performed for the other aspect angles of the aircraft, obtaining values of 2.81 $W/m^2.sr$, 12.372 $W/m^2.sr$ and 2.963 $W/m^2.sr$, to 3, 6 and 9 hours respectively.

Carrying out recordings positions with smaller angular intervals, it is possible to generate a diagram of infrared emission of the aircraft, that is, its IR signature.

In a second phase of the experiment, it was recorded the moving aircraft, while performing some kinds of maneuvers, in order to verify the feasibility of obtaining the flight signatures of the target and thus analyzing offensive and defensive maneuvers. It was kept the same experimental setup previously described, with the H-55 aircraft maintained at approximately 10 meters from the camera, making turns of 90 degrees in the hovering flight within the ground effect. In Fig.4 it can be seen some of the aspect angles of this measurement.

Fig.4 – H-55 during maneuvers in the hovering flight on ground effect during a turning from 6 to 3 hours aspect angle.

The images were analyzed in a laboratory using the ALTAIR software, using Timing-Graph tool. The graph obtained by the software can be seen in Fig.5.

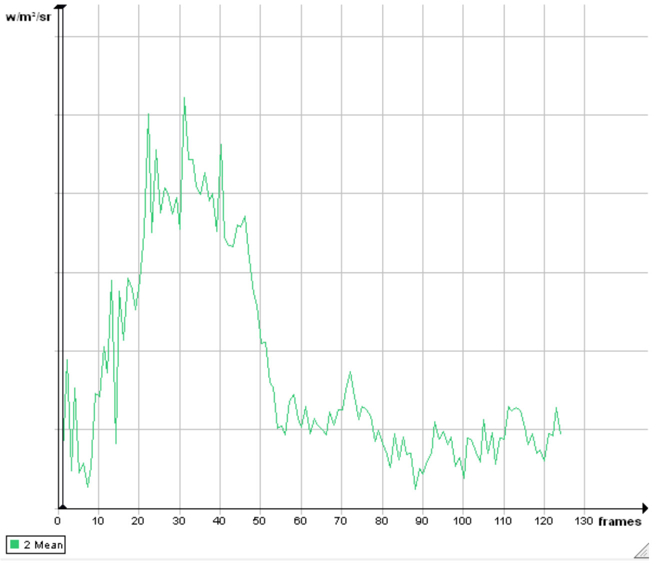

Fig.5 – Mean radiance captured for the turning of H-55 between 6 and 3 hours.

Analyzing Fig.5, it is possible to conclude that the sector of 6 hours of the aircraft is not the one that presents the higher IR emission. From the graph, the aspect angle at which is perceived a greater emission is when the aircraft is between the frames 20 and 40, corresponding to the aspect angle between 5 and 4 hours, once the helicopter applied a constant turning rate. This is due to the H-55 aircraft be a twin-engine helicopter, and thus showing its nozzles tilted slightly to the side. When the nozzle is positioned directly to the camera, it has a higher emission of radiation, representing the highest points on the graph.

This type of analysis can be performed frame by frame for a great variety of different maneuvers, showing a great value to the doctrinal development of tactics and techniques of attack or evasion, by all air squadrons. It can be assessed, for example, in which maneuver the aircraft is more or less exposed front to infrared sensors. The acquired data also allow the pilot to know what area of this aircraft emits higher radiation and thus is more susceptible to detection and attack of an enemy. Therefore, pilots may best plan a mission to foray into a hostile territory that is provided with infrared guided weapons, avoiding prolonged exposure.

In order to determine the detectability of an aircraft against an enemy sensor it is necessary to compare the data relating to its emitted radiation with the detection sensitivity of the enemy's sensor. Since the total radiation received by a sensor corresponds to the product of the radiance (L) emitted (by the target) by its exposed area and the solid angle occupied by the sensor [3], it is then necessary to know the exposed area of the aircraft and the exact distance to the sensor (which allows the calculation of the solid angle) [4]. Once knowing these data, one can estimate the detectability of the aircraft for an analyzed sensor. Knowing these estimations of detectability for the enemy sensors, one can then plan a foray into hostile territory to be safer, avoiding losses, and with a higher probability of success.

IV. CONCLUDING REMARKS

The development of infrared signatures libraries of aircraft and other radiating targets is a long-standing priority for the Brazilian Air Force Command [2] that has been gaining increasing relevance in recent times due to fleet modernization and expansion of air power that took place after the 2000's.

The methods developed and used to this date for signatures measuring show to be unviable for the measuring of a large fleet in a short period of time, due to their high costs and the need for complex infrastructure.

In order to make possible the creation of a signatures library, LAB-GE is developing a new technique for these kinds of measurements by the use of infrared cameras, which shows to be simple, versatile and cheaper than the previous ones. This paper described the necessary procedures to implement the method as well as some preliminary results.

By measuring an aircraft H-55 using a scientific thermal camera, preliminary results demonstrate the feasibility of the method, not only allowing the prediction of its infrared signature, but also the analysis of radiance during flight maneuvers. The results and potentialities presented here show a huge increase in combative and doctrinaire power to the BAF, allowing the creation of an IR signatures library in a quick and efficient way, as well as the development and improvement of tactics and techniques for attacks, air raids inside hostile territories and evasive maneuvers against enemy attacks. Future works lead to a comparison between the results achieved through the use of this method and the ones achieved by spectroradiometers, estimating the associated errors and improving the proposed method.

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