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Modeling the impact of surface emissivity on the military utility of attack aircraft

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ABSTRACT

An analysis scheme and a mission system model were applied to the evaluation of the military utility of efforts to reduce infrared signature in the conceptual design of survivable aircraft. The purpose is twofold: Firstly, to contribute to the development of a methodological framework for assessing the military utility of spectral design, and secondly to assess the threat from advances in LWIR sensors and their use in surface-to-air-missile systems. The modeling was specifically applied to the problem of linking the emissivity of aircraft coatings to mission accomplishment. The overall results indicate that the analysis scheme and mission system model applied are feasible for assessing the military utility of spectral design and for supporting decision-making in the concept phase. The analysis of different strike options suggests that LWIR sensors will enhance the military utility of low emissive paint, at least for missions executed in clear weather conditions. Furthermore, results corroborate and further clarify the importance of including earthshine when modeling.

1. Introduction

It is well known that any combat aircraft is a complex compromise of attributes, and that features introduced to enhance one of them risk having penalties for others. Design is always a trade-off between offensive capability, survivability and availability [1]. Recently it was suggested [2] that effective solutions to these kinds of problems, while acknowledging that a technical system is but one of the components of a capability (e.g. [3,4]), benefit from formulating the problem to maximize the military utility of the technical system in focus. The military utility [2] of a technical system is a compound measure of: the military effectiveness in a specified context, the assessed technical systems' suitability to the military capability system, and affordability to the military actor operating it. It is anticipated that the concept will support holistic decision-making, but is in need of a framework for performing assessments.

In this study survivability engineering is of particular interest. Its aim is to decrease an aircraft's susceptibility and vulnerability to man-made threats, while having minimum impact on other attributes [1]. Considerable sums of money are spent on low observability technology in contemporary combat aircraft development programs, like the F/A 35, in order to reduce signature and hence susceptibility. Here the signature of a combat aircraft is any characteristic that makes it detectable with a sensor. A reduced signature leads to shorter detection range from an adversary's weapon systems, and consequently shorter response times, giving increased survivability and freedom of action. Due to developments in bi-static and passive radar, and the fact that low-frequency radar systems are becoming operational [5–7], investments in stealth radar are being questioned. In addition, the cost and size of infrared (IR) sensors have decreased, while their performance has increased, and current developments point towards higher spatial and spectral resolution [8].

Research has shown that, for the front sector of an approaching aircraft, emission from aerodynamic heating and reflected earthshine are the dominant IR sources [9,10]. Since the intensity peaks of both sources are in the long wavelength IR (LWIR) atmospheric transmission window (8–14 μm), LWIR imaging sensors are of particular interest. Early versions of LWIR sensors are already operational [11]. This calls for further analysis of the implications for the duel between attacking aircraft and defending surface-to-air missile systems (SAMs); what can be done to increase aircraft survivability? Since emissivity is the most important surface property affecting the magnitude of IR radiation [12], it is important, from a signature adaption perspective, to study whether an optimum can be found.

In a first paper from this study [13] a model and method for quantitatively assessing signature reduction efforts on aerial plat-

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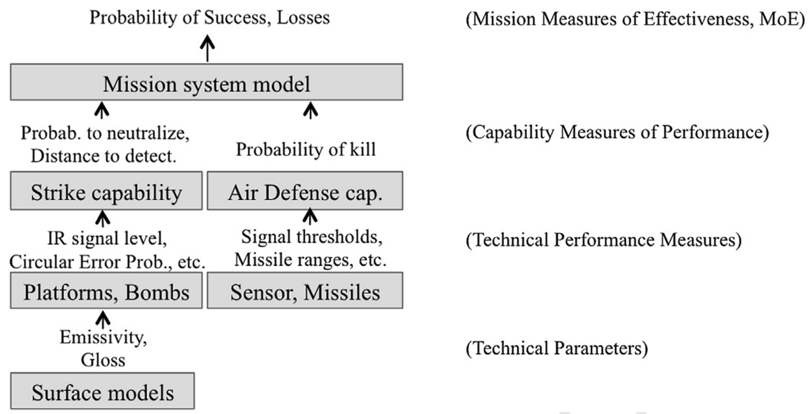

Fig. 1. An illustration of the models necessary at each system level to support analysis, and the variables of interest needed to link them.

forms were developed. It was shown that the LWIR sensors integrated with SAMs are indeed an increasing threat to aircraft and that efforts to reduce signature in radar and LWIR need to be balanced. The aim of this paper is to use a tailored version of the same model for assessing the military utility of features to reduce LWIR signature in more detail. The focus is on efforts to adapt surface emissivity. The purpose is twofold: Firstly, to continue contributing to the establishment of a methodological framework for assessing military utility, and secondly, to contribute to the survivability of combat aircraft.

In the first section the methodological approach using modeling is outlined. The starting point is survivability and the concept of military utility. Then the mission system level model and its technical sub-models are described, followed by analysis and discussion of the results. Finally, conclusions are drawn and presented.

2. The methodological approach

2.1. The military utility concept

The interdependent nature of the attributes of combat aircraft calls for a system approach to design. Researchers in the field of combat aircraft survivability have shown that trade-off studies on the effectiveness of aircraft design should be at the mission system level or higher, to avoid the risk of sub-optimization [1,14]. This approach is compatible with the concept of Military Utility mentioned previously. It is defined [2] as having three dimensions:

- The Military Effectiveness dimension is a measure of the overall ability to accomplish a mission when the Element of Interest (EoI) is used by representative personnel in the environment planned or expected for operational employment of the military force.
- The Military Suitability dimension is the degree to which an EoI can be satisfactorily taken into military use in a specified context, taking into consideration interaction with other elements of the capability system.
- The Affordability dimension is a measure of compliance with the maximum resources a military actor has allocated to the EoI in a timeframe defined by the context.

A military capability is hence viewed as a system composed of various interacting elements, such as doctrine, organization, training, personnel, materiel, facilities, leadership and interoperability, as in NATO publications. In this paper a combat aircraft is the element of interest in a potential military capability for air to surface operations. The bottom line is that a component, in this case a combat aircraft, only has military utility if it is seen as a contributory element in a capability system [4,2].

In the first paper from this study [13] an analysis scheme and a model, adopting the view on capabilities described, were developed for assessing the military utility of a low observable aircraft in attack missions. The model allows for low observable properties to be obtained through varying different parameters, tactical or technical, and observing responses in mission outcomes. The first phase of the study concerned the balancing of efforts to reduce radar and LWIR signature. In this paper the spectral design activity deciding the LWIR signature is of particular interest. Spectral design is here understood as the engineering activity to vary surface structure and materials to obtain the desired spectral properties [15]. Hence, the methodological approach is to analyze a tailored version of the mission system model developed earlier, but to focus on responses from varying the surface emissivity.

2.2. Modeling the military effectiveness dimension, including a surface

There are rapid developments in materials for spectral design coatings and it seems safe to assume that there will be suitable paints available for surface coatings once the preferred IR emissive properties are known [16,15]. This simplifies the exploratory part of the study since it will not be necessary to model the military suitability or the affordability dimensions of the military utility concept in detail. It can be assumed that exchanging the quality of paint will not require changes in maintenance concepts, maintenance facilities, training facilities etc., which is why the military suitability dimension will not be directly affected. Furthermore, for our purposes, the increased life cycle cost for more advanced paint is presumably negligible and will not affect affordability for the aircraft operator. Consequently, any differences between different aircraft concepts in terms of their military suitability or affordability will only be identified as a direct result of potential differences in their military effectiveness. Thus, the problem is reduced to modeling the military effectiveness dimension in sufficient detail; i.e. a more survivable aircraft will, for example, allow doctrinal development, or reductions in the life cycle cost for the aircraft system as a whole.

In order to be able to analyze the military effectiveness of spectral design at mission level, a functional system model has to link surface models to mission measures of effectiveness, MoEs. See Fig. 1.

In the system model developed, see [13] for details, it is sufficient to gauge military effectiveness through probability of success and own losses at the mission system level. At the capability system level the model requires assembly of strike packages and selection of a mission profile. Correspondingly, on the defending side, SAM systems, surveillance and firing doctrines have to be chosen in order to define the air defense capability. The capability measures of performance defined link the capability models to the

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