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Infrared Signatures of Low-Flying Aircraft and Their Rear Fuselage Skin's Emissivity Optimization

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This paper analyzes the main contributors of infrared (IR) signature in a typical aircraft on a low-altitude mission. Various computational models are used to predict IR radiation from the aircraft. The bands within IR spectrum in which aircraft are susceptible to a typical IR-guided surface-to-air and air-to-air missile, for typical cases of tactical relevance, are identified. Lock-on range for aircraft against a typical missile is also computed. The feasibility of a low-altitude mission against a ground-based IR-guided threat is analyzed. The technique of emissivity optimization of aircraft rear fuselage skin, for reducing its infrared signature, is introduced and compared with other IR signature suppression techniques. The effectiveness of this technique in enlarging the safe flight envelope of aircraft, with respect to threat from heat-seeking missiles, for both surface-to-air and air-to-air missiles, is demonstrated. It is found that earthshine reflected off the aircraft surface plays a crucial role in the effectiveness of this technique against a surface-to-air missile (SAM) in 8–12 μm band.

Nomenclature

A = area, m^2
H = spectral irradiance, $\mu W/\mu m \cdot m^2$
h = aircraft altitude, km
I = spectral radiant intensity, $W/Sr \cdot \mu m \cdot m^2$
J = spectral radiance: comprising emission and earthshine, $W/Sr \cdot \mu m \cdot m^2$
L = length, m
M = Mach number
N = number of discretized elements
NEI = noise equivalent irradiance, W/m^2
R_{ma} = distance separating missile and aircraft, km
R_{LO} = aircraft lock-on range, km
T = temperature, K
ε = emissivity of rear fuselage skin
θ = angle of line of sight between SAM and aircraft, with ground (ref. Fig. 1), deg/rad
λ = wavelength of IR radiation, μm
ξ_{min} = minimum signal-to-noise ratio of IR detector required for lock-on
τ = transmissivity
ω = solid angle, Sr

Subscripts

atm = intervening atmosphere
bg = background
es = earthshine
fuse = rear fuselage skin
i = ith discretized element
pl = plume
λ = spectral quantity

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Introduction

ONE of the most important missions of a fighter aircraft in a tactical warfare is the surface target bombing, for destroying enemy's vital sites, which is essential for establishing air superiority. Radar was by far the most popular and widely used means of detecting an aircraft; hence, flying at low altitude helps an aircraft to evade detection by enemy radar, by camouflaging itself in the background clutter. Low-altitude missions (termed as terrain hugging) were popular with fighter aircraft, until the advent of infrared (IR) guided missiles. This is especially true after man portable air defense system (MANPADS) became popular, spearheaded by the shoulder-fired IR-guided surface-to-air missiles (SAM). Hence, low-altitude missions now pose a threat with respect to aircraft IR signature level. This investigation focuses on IR signature produced by a typical fighter aircraft on a low-altitude (bombing) mission and analyzes the feasibility of such a mission with respect to susceptibility against IR-guided threat.

The main sources of IR signature in an aircraft are airframe, tailpipe, plume, and rear fuselage.[1,2] The airframe, especially stagnation region of the aircraft nose and leading edges of wings, is aerodynamically heated at supersonic speeds. A typical low-altitude mission is carried out at a moderate subsonic flight velocity (thereby ensuring that the acoustic signature is at a relatively low level); hence, aerodynamic heating of airframe is insignificant. Because of high temperature and emissivity, engine tailpipe is the most prominent source of IR signature in a fighter aircraft from the rear aspect.[3] Further, the tailpipe emits IR radiation in the entire IR spectrum (and prominently in the midwave IR band). In this investigation, an aircraft on a nighttime bombing mission, entering the enemy territory is considered (in the ingress mode). Hence, the engine tailpipe is not visible to the enemy's IR-guided missile, and only the forward portion of the aircraft is visible.

The rear fuselage skin is heated by the low-bypass engine embedded within it. Emissivity of the rear fuselage skin is almost constant within the wavelength band of interest, that is, it emits like a gray body. The hot exhaust plume is also a source of IR radiation, is much longer than the aircraft, and is visible from wider view angles. Therefore, from the forward aspect of an aircraft, rear fuselage skin and exhaust plume are the prominent sources of IR signature, visible to the SAM's IR detector. Figure 1 shows the schematic of an aircraft entering into the enemy territory and approaching toward a SAM site.

The prime objectives of this investigation are 1) to analyze IR signature of a typical fighter aircraft on a low-altitude mission, as perceived by an IR-guided missile; 2) to identify IR bands in which IR emission is prominent, and to analyze aircraft susceptibility with respect to its IR signature level, in terms of R_{LO}; and

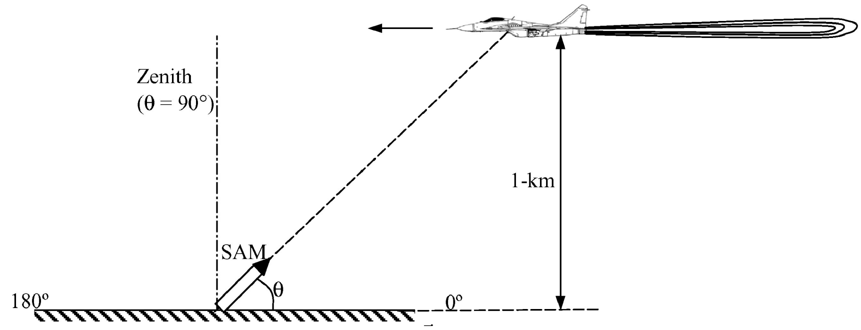

Fig. 1 Aircraft flying over a SAM site.

3) to introduce and assess the applicability of rear-fuselage-skin-emissivity-optimization technique, for reducing aircraft susceptibility to IR-guided threats.

Aircraft Infrared Signature Level Prediction Models

Aircraft IR signature prediction is an involved task, given the multitude of variables involved. Several models are developed, to predict IR radiation emitted by various sources in an aircraft.[4–7] Models used to predict IR signatures in this investigation are as follows.

Rear-Fuselage Skin-Temperature Prediction

Estimation of rear-fuselage skin temperature is required for computing its IR radiance. The model developed by Mahulikar et al.[8] is used here to compute heat transfer to the aircraft rear-fuselage skin, from the exhaust gases flowing in the jet pipe and the freestream flow. The jet pipe in military aircraft is long, and its large circumferential area is the main source of radial heat transfer to the rear fuselage skin. In this model, the engine layout commencing from the last-stage turbine exit plane onward and rearward until the nozzle-exit plane is analyzed. The rear-fuselage skin temperature is obtained from steady-state multimode thermal modeling of the engine-airframe layout, which comprises surface radiation interchange in conjunction with internal and external convection. The governing integrodifferential equations are numerically solved.

Because of the harsh operating conditions, most metallic surfaces develop an outer-oxide layer; hence, these surfaces are assumed as diffuse. The aerodynamic heating of rear-fuselage skin at high Mach numbers is also considered; however, at low altitudes and subsonic velocities, its effect is insignificant. The major constituents of exhaust gases passing through the jet pipe are Ar, CO, CO_2, H_2O (vap.), N_2, NO, NO_2, N_2O, O_2, SO_2, unburnt hydrocarbon, and soot.[9,10] The model in Mahulikar et al.[8] for hot air flow is upgraded for the present investigation by modeling the exhaust flow as this gaseous mixture of combustion products. Because the complete analysis is for the dry mode of the engine, the contributions of unburnt hydrocarbon and soot are negligible. Also, the variation of thermophysical properties of exhaust gases with temperature is considered using reported data and correlations.[11–15] The variation of jet pipe, radiation shield, and rear-fuselage skin temperature, along the jet-pipe length, are obtained for an aircraft cruising at an altitude of 1 km and Mach 0.6, and are in Fig. 2. The rear-fuselage skin temperature remains fairly constant along the length.

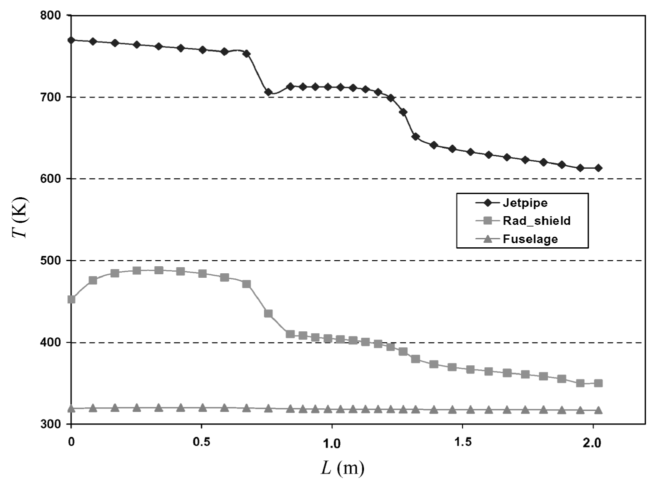

Fig. 2 Aircraft rear-fuselage axial temperature variation predicted by model.

Plume IR Radiation

The high-temperature exhaust plume is a mixture of several species in gaseous state (solid and liquid phases are negligible), which are produced from combustion of hydrocarbon fuels. Because temperature of the plume is less than 3000 K, gases with asymmetrical molecular structure in the plume, for example, H_2O, CO_2, and CO, are primarily responsible for IR emission. Other gaseous species, for example, O_2, N_2, Ar, etc., also present in the plume, are radiatively inert up to much higher temperatures and do not emit significant IR radiation, even in the afterburning mode.[16] The plume emits radiation only in the IR range of the electromagnetic spectrum. The number, width, and emissive powers of these emitting bands depend on the composition of gases, pressure, temperature, and thickness of gaseous volume. Band emissions exhibited by gases have a higher order of dependency on temperature, as compared to black/gray-body emission. Unlike tailpipe or rear-fuselage skin, the emissivity of gaseous mixture changes sharply with λ, because radiation is emitted by a gas at discrete frequencies, which is a characteristic of the vibrational mode.

The aircraft exhaust plume structure depends on several factors, for example, shape and size of the nozzle, pressure, temperature, and species concentration at the nozzle exit, and the freestream conditions. A methodology is presented by Mahulikar et al.[17] for determining spectral IR-radiation intensity of exhaust plume, from axisymmetric circular nozzle exit. The computed spectral IR-radiation intensity emitted by the plume, for a clear cloudless sky in tropical conditions, is in Fig. 3. The selective emission of IR radiation by the exhaust plume, that is, the sharp variation of spectral intensity with λ, is shown in the figure (by solid line). The plume emits IR radiation prominently in the 2.5–3.5 μm, 4–8 μm, and 13–17 μm bands. The plume emits maximum IR radiation at around 4.3 μm because of emission by the wings of CO_2 emission band. The attenuation of plume IR radiation by the intervening atmosphere is more than that of the rear-fuselage skin IR radiation, because the gases responsible for plume IR radiation [H_2O (vap.), CO_2, CO] are also present in the atmosphere. Only IR radiation emitted by the broadened wings of these emitting plume gases reach the SAM's IR detector. Superimposing atmospheric transmissivity (shown by dotted line in Fig. 3) on plume IR-radiance, it is seen that only a

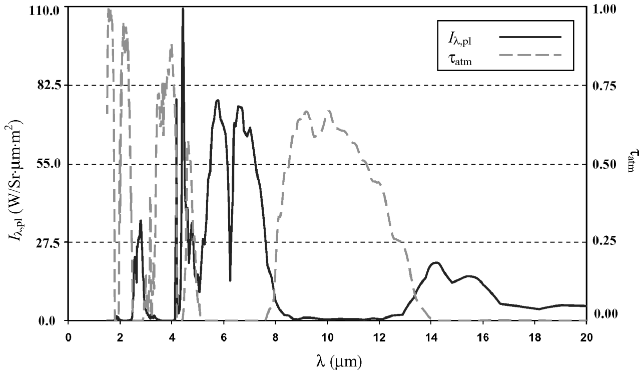

Fig. 3 Plume spectral radiant intensity and atmospheric transmissivity ($\theta = 60$ deg).

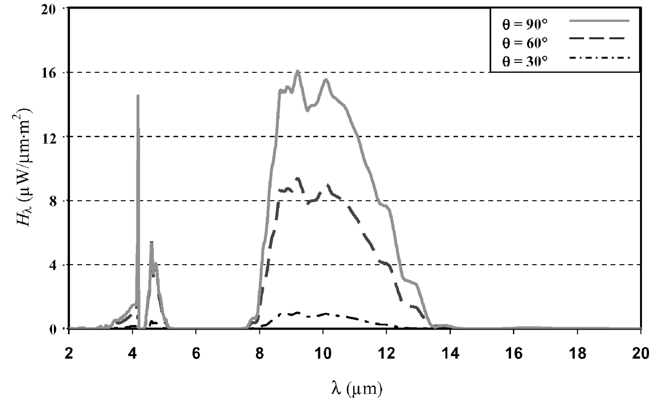

Fig. 4 Spectral variation of aircraft irradiance on missile's IR seeker (tropical condition).

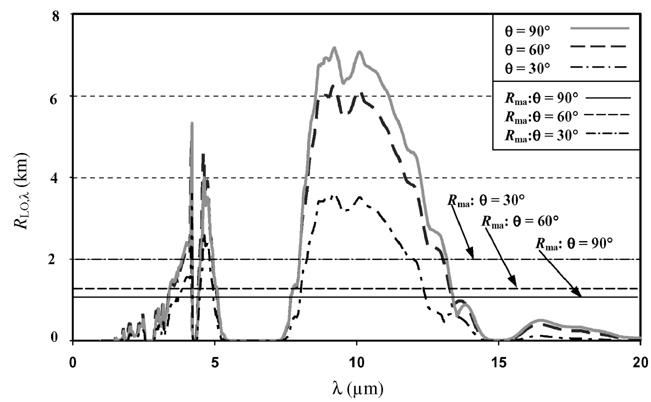

Fig. 5 Spectral variation of aircraft lock-on range (tropical condition).

small part of IR radiation emitted by the plume is within the atmospheric transmissivity bands. Thus, the net plume IR irradiance on SAM's IR detector is less, relative to IR irradiance from rear fuselage skin.

Earthshine Modelling

Earthshine is radiance from the Earth's surface, in turn reflected from the aircraft surface in the direction of the IR detector. It consists of emission from the ground and reflection of solar radiation. In this investigation, the aircraft is considered to be flying on a nighttime mission; consequently, the solar reflection from Earth (albedo) is absent. The emission from Earth is a function of many parameters, for example, vegetation, temperature, humidity, type of soil, type of rock, etc.[18] Most surfaces characterizing Earth are predominantly diffuse, and behave as gray bodies with high emissivity. Earthshine is especially dominant in the 8–14 μm band and is governed by the ground temperature. Salisbury and Aria summarized the spectral reflectance of a wide range of materials on ground, for the atmospheric windows: 8–14 μm (Ref. 19) and 3–5 μm (Ref. 20) bands. Most agricultural plants have an emissivity close to 0.95, and soil surface acts more as diffuse radiator with an emissivity close to 0.93 (Ref. 21).

Because missile and aircraft are surrounded by atmosphere, the atmospheric infrared characteristics play an important role in assessment of aircraft IR signature as perceived by the missile's IR-detection system and hence, aircraft susceptibility. The IR characteristics of atmosphere also depend on various parameters.[3]

Aircraft Lock-on Range

The prime sources of IR radiation in an aircraft in the ingress mode are rear-fuselage skin and exhaust plume. Figure 4 gives the variation of IR-radiation incident on missile's IR detector with λ, from typical fighter aircraft's rear-fuselage skin and exhaust plume, for different aspects from the horizon. The irradiance on the missile's IR detector after modulation (for eliminating background radiation) is calculated as[22]

$$H_\lambda = \sum_{i=1}^{N_{\mathrm{pl}}} [I_{i,\mathrm{pl},\lambda} - I_{\mathrm{bg,pl},\lambda} \cdot (1 - \tau_{\mathrm{pl},\lambda})] \cdot \tau_{\mathrm{atm},\lambda} \cdot \omega_{i,\mathrm{pl},\lambda} + \sum_{i=1}^{N_{\mathrm{fuse}}} (J_{i,\mathrm{fuse},\lambda} - I_{\mathrm{bg,fuse},\lambda}) \cdot \tau_{\mathrm{atm},\lambda} \cdot \omega_{i,\mathrm{fuse},\lambda}$$

where

$$J_{i,\mathrm{fuse},\lambda} = I_{i,\mathrm{fuse},\lambda} + (1 - \varepsilon_{i,\mathrm{fuse}}) \cdot I_{\mathrm{es},\lambda}$$

The lock-on range is then calculated as

$$R_{\mathrm{LO},\lambda} = \sqrt{\tau_{\mathrm{atm},\lambda} \cdot \left\{ \sum_{i=1}^{N_{\mathrm{pl}}} [I_{i,\mathrm{pl},\lambda} - I_{\mathrm{bg,pl},\lambda} \cdot (1 - \tau_{\mathrm{pl},\lambda})] \cdot A_{i,\mathrm{pl}} + \sum_{i=1}^{N_{\mathrm{fuse}}} (J_{i,\mathrm{fuse},\lambda} - I_{\mathrm{bg,fuse},\lambda}) \cdot A_{i,\mathrm{fuse}} \right\} \bigg/ (NEI \cdot \xi_{\min})}$$

The $R_{\mathrm{LO},\lambda}$ is a function of aircraft parameters ($I_{i,\mathrm{pl},\lambda}$, $I_{i,\mathrm{fuse},\lambda}$, $A_{i,\mathrm{pl}}$, $A_{i,\mathrm{fuse}}$), missile IR-seeker parameters (NEI, $\xi_{\min}$), atmospheric IR characteristics ($\tau_{\mathrm{atm},\lambda}$, $I_{\mathrm{bg,pl},\lambda}$, $I_{\mathrm{bg,fuse},\lambda}$), and the earthshine ($I_{\mathrm{es},\lambda}$). The tailpipe IR radiation is not considered, as it is not seen by the missile.

Aircraft irradiance on the missile and sensitivity of the missile's IR-detection system determine the condition for aircraft lock-on. Generally, IR-detection system of a missile has good responsivity in a narrow band of IR spectrum (which can vary from a fraction of a micron to a few microns); hence, the missile's capability to detect an aircraft is restricted to that band only. The spectral irradiance on the missile's IR detector is averaged over the wavelength band of operation for obtaining R_{LO}; hence, R_{LO} is less than $R_{\mathrm{LO},\lambda}$ (lock-on range at a particular λ, considering that IR detector has flat responsivity). Nevertheless, $R_{\mathrm{LO},\lambda}$ is a useful quantity for depicting the behavior of aircraft lock-on range with λ for investigating the wavelength bands in which aircraft IR signature is prominent. Therefore, $R_{\mathrm{LO},\lambda}$ and H_λ are used to analyze aircraft IR signatures, and R_{LO} and H are used for analyzing aircraft susceptibility in a given wavelength band of interest (1.9–2.5 μm, 3–5 μm, 8–14 μm).

For a typical missile, the spectral variation of lock-on range caused by emission from aircraft rear-fuselage skin and plume is in Fig. 5. The results are obtained for tropical conditions and for different elevation angles from the horizon. It is seen from Fig. 5 that $R_{\mathrm{LO},\lambda}$ exceeds the distance separating missile and aircraft ($R_{\mathrm{ma}} = 1$ km for $\theta = 90$ deg, $R_{\mathrm{ma}} = 1.2$ km for $\theta = 60$ deg, $R_{\mathrm{ma}} = 2$ km for $\theta = 30$ deg) in the wavelength bands of 4–5 μm and 8–13 μm; hence, the missile can lock-on to the aircraft. Also, from Figs. 4 and 5, it is seen that IR-signature level in 8–12 μm band is more prominent as compared to 3–5 μm band. It is also observed that the rear-fuselage skin exhibits some IR-signature level in 16–19 μm band. The IR signature in this band is a characteristic feature of an aircraft on a low-altitude mission; this band is also observed for an air-to-air-missile (AAM) lock-on case (discussed later). For medium- and high-altitude missions, IR signature in 16–19 μm band is generally absent.[3] However, the magnitude of signal in this band is insignificant. Further, IR detectors operating in this wavelength band are infeasible for missile applications. Hence, the 16–19 μm band is not considered for aircraft IR signature studies. The plume IR radiation is prominent only in the narrow bands of 4.15–4.20 and 4.45–4.80 μm.

Emissivity Optimization of Rear-Fuselage Skin

Aircraft IR-signature management is a multifaceted problem, and no single technique/method can be employed to reduce the entire aircraft IR-signature level under all flight conditions and across all wavelength bands of significance. Consequently, stealth aircraft concurrently employ several techniques for reducing their IR-signature level.[1,2] Most known techniques for reducing IR signatures are associated with performance penalties, for example, additional weight, increased aerodynamic drag, higher engine backpressure, reduced engine stability, larger radar cross section, etc. As an illustration, the slit-type nozzle exit is known to increase engine backpressure considerably, and to also reduce engine stability in terms of surge and stall. The centerbody tailpipe used on helicopter engine exhaust increases the weight and engine backpressure,[23] which is also the case with Black Hole Ocarina.[24]

The rear-fuselage skin contributes substantially to the overall aircraft IR signature level (refer to Figs. 4 and 5). Hence, reducing rear-fuselage IR emission can reduce aircraft susceptibility to IR-guided missiles, especially from the aircraft frontal aspect (which is of tactical importance). One feasible technique for reducing IR signature level from a metallic surface (which behaves as a gray body) is emissivity reduction/optimization. The emitted IR radiation is a function of rear-fuselage skin temperature and emissivity. Thus, by altering these two parameters, IR radiation emitted by aircraft can be varied. Emissivity is the surface property of a material and can be changed to a certain extent by surface treatment (both physical and chemical) or by painting/coating the rear-fuselage skin. The basic advantage of emissivity reduction/optimization technique is the negligible performance penalties incurred. The thickness of these coatings and paints is insignificant; consequently, additional weight is also insignificant. The other important advantage of this technique is that it can be applied to existing aircraft, with minimal modifications. The applicability of this technique to rear-fuselage skin IR-signature level reduction is now explored for two cases: against a SAM and against an AAM.

Aircraft Susceptibility Against SAM

Rear-fuselage skin IR radiance comprises thermal emission and the reflected earthshine. The models described in earlier sections are used for computing aircraft IR irradiance on the missile's IR detector. The variations in rear-fuselage skin spectral IR irradiance on missile's IR seeker H_λ and lock-on range $R_{\mathrm{LO},\lambda}$, with its emissivity, are in Figs. 6 and 7, respectively. The H_λ decreases with decreasing rear-fuselage skin emissivity; consequently, $R_{\mathrm{LO},\lambda}$ also decreases. When the rear-fuselage skin emissivity is made zero, IR emission from the rear-fuselage skin is absent; but its surface behaves as a perfect reflector, reflecting the entire earthshine incident on its surface. Because, spectral IR irradiance on the missile's IR detector from aircraft rear-fuselage skin is significant (above the considered threshold value of 0.25 μW/m^2), aircraft is susceptible to IR-guided missiles. Thus, aircraft on a low-altitude mission are susceptible to IR-guided missiles, even if the thermal emission from the rear-fuselage skin is absent. Hence, there exists a minimum R_{LO}

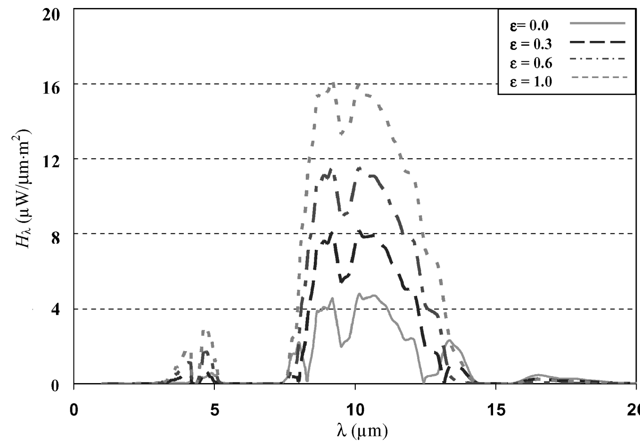

Fig. 6 Variation of rear-fuselage skin spectral irradiance on missile's IR detector with its emissivity (tropical condition).

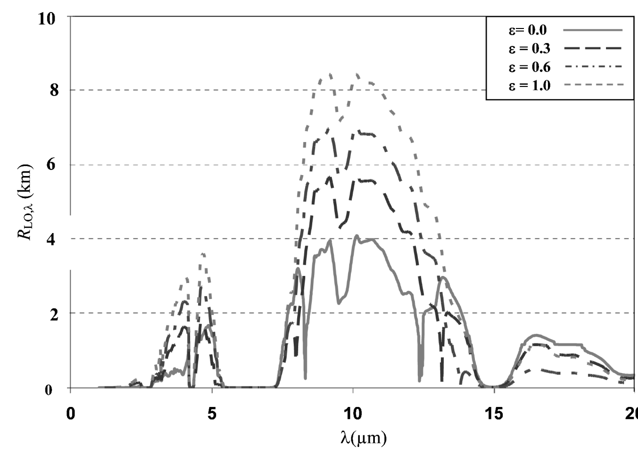

Fig. 7 Variation of rear-fuselage skin spectral lock-on range with its emissivity, against SAM (tropical condition).

dictated by the reflection of earthshine from the rear-fuselage skin lower surface (when thermal emission from rear fuselage skin is absent). The rear-fuselage skin temperature increases insignificantly with decrease in its emissivity, as a result of reduction in its radiative cooling.

For lock-on by SAM, IR signature of aircraft is most for the case when aircraft's line of path and SAM are in the same vertical plane. The variation of R_{LO} in the two atmospheric windows (3–5 and 8–12 μm bands), when the aircraft is overhead of the SAM, is in Fig. 8. The R_{LO} in 8–12 μm band increases with increase in skin emissivity, and the lowest value is when the rear-fuselage skin is a perfect reflector (minimum R_{LO} is dictated solely by reflected earthshine). As seen from Fig. 8, R_{LO} in the 3–5 μm band initially decreases with increase in emissivity, reaches a minimum, and then increases. Hence, there is a nonzero emissivity for which aircraft R_{LO} in the 3–5 μm band is minimum. At low emissivity, aircraft IR radiance is lower than the background radiance in the 3–5 μm band, and the resulting negative contrast is responsible for R_{LO}, illustrated in Fig. 8. Therefore, there is scope for optimizing surface emissivity to suit the mission requirements against an IR-guided threat. This technique of emissivity reduction/optimization is effective especially in reducing aircraft susceptibility in the forward aspect (as in the present investigation) and in the nonafterburning mode.

The earthshine plays a vital role in dictating R_{LO} for the 8–12 μm band, but is insignificant for 3–5 μm band. The variation of average contrast between aircraft IR radiance and the background IR radiance in 3–5 and 8–12 μm bands with surface emissivity,

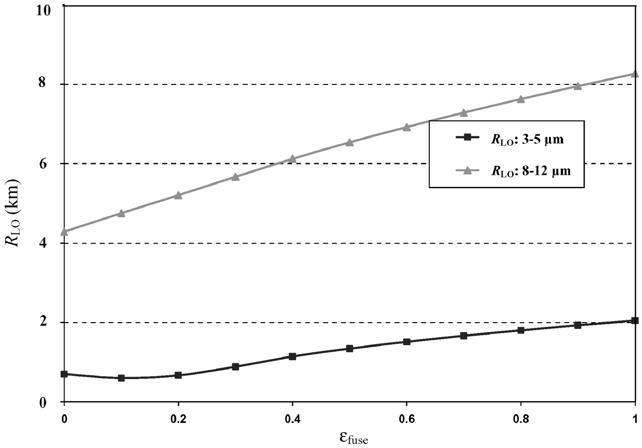

Fig. 8 Variation of peak aircraft lock-on range in atmospheric windows with rear-fuselage skin emissivity.

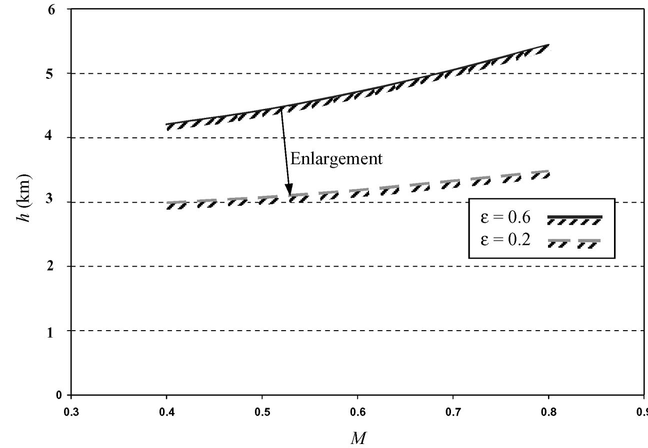

Fig. 11 Enlargement of safe flight envelope in 8–12 μm band by emissivity reduction.

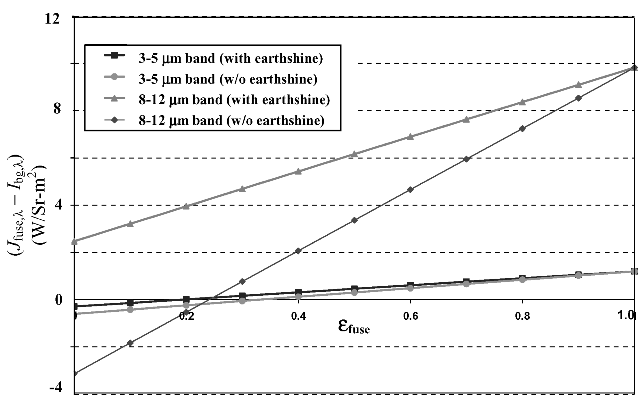

Fig. 9 Effect of earthshine on IR-radiant contrast in the two atmospheric windows.

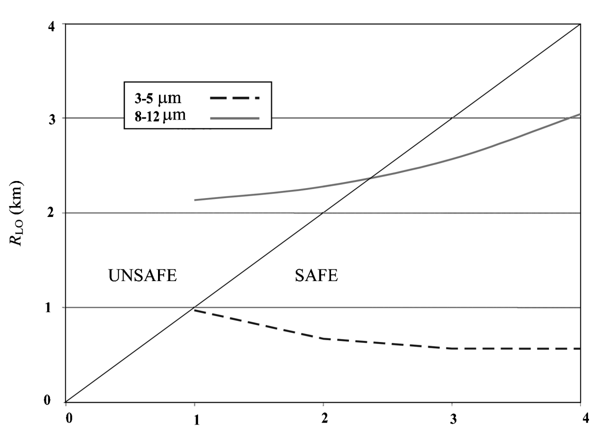

Fig. 10 Variation of R_{LO} caused by earthshine only in atmospheric windows.

for the two cases, with and without earthshine, is in Fig. 9. It is confirmed that the effect of earthshine is insignificant in 3–5 μm band, but is significant in 8–12 μm band. Also, the effect of earthshine decreases with increase in the surface emissivity, because of a decrease in surface reflectivity. Figure 10 shows the variation of R_{LO} due to earthshine only with aircraft altitude, in 3–5 and 8–12 μm bands. For this case, the emissivity of the surface is considered zero, that is, the surface acts like a perfect reflector; hence, R_{LO} is determined only by the reflected earthshine. A 45-deg line divides the figure in two parts: safe and unsafe flying regimes. If R_{LO} exceeds the aircraft flying altitude, the point lies on the unsafe side and vice versa. Thus, an aircraft, even with zero surface emissivity, should fly above 2.5-km altitude to avoid lock-on by IR-guided SAM operating in the 8–12 μm band.

It is inferred from Figs. 6 and 7 that rear-fuselage skin emissivity optimization can effectively reduce R_{LO}. This enlarges aircraft flight envelope, in which aircraft can perform their mission successfully, with respect to threats posed by IR-guided SAMs. The enlargement of aircraft flight envelope by reducing rear-fuselage skin emissivity from 0.6 to 0.2 is illustrated in Fig. 11. Thus, rear-fuselage skin emissivity optimization is a viable technique for reducing aircraft visibility to IR-guided SAMs. However, its scope is limited in the 8–12 μm band, by the earthshine reflected off the rear-fuselage skin.

Aircraft Susceptibility Against Air-to-Air Missile (AAM)

The aircraft is also susceptible to IR-guided AAM launched from enemy aircraft. In the previous case (against a SAM), the lower portion of rear-fuselage skin is visible to SAM. In the case of an AAM, the side portion of the rear-fuselage skin is visible. The major differences that affect the IR-signature level as perceived by an AAM as compared to a SAM are as follows:

1) The atmospheric transmissivity is more as compared to SAM case, because atmospheric transmissivity increases with altitude.

2) The background radiation behaves like a blackbody at the ambient temperature.

3) The earthshine reflected by the rear fuselage skin in the direction of AAM is much less.

The variation of aircraft $R_{LO,\lambda}$ against an AAM, with rear-fuselage skin emissivity, is in Fig. 12. Unlike in Fig. 7, it is observed in Fig. 12 that $R_{LO,\lambda}$ does not monotonically increase with emissivity; $R_{LO,\lambda}$ initially decreases with increasing emissivity and then increases. This is because there is relatively much less earthshine reflected off the side portion of the rear-fuselage skin. Hence, for low values of rear-fuselage skin emissivity, IR emission from rear-fuselage skin is less as compared to that from the background. This negative contrast is also responsible for lock-on range, as shown in Fig. 12. Therefore, there exists an optimum emissivity at which IR emission from rear-fuselage skin is equivalent to IR emission from the background; consequently, the lock-on range is minimum. The variation of average H and average R_{LO} with rear-fuselage skin emissivity, for the two atmospheric windows, is in Fig. 13. It is seen that for a particular mission, there is a unique value of emissivity for which rear-fuselage skin IR emission is minimum in 3–5 and 8–12 μm bands. For the present case, it is seen from

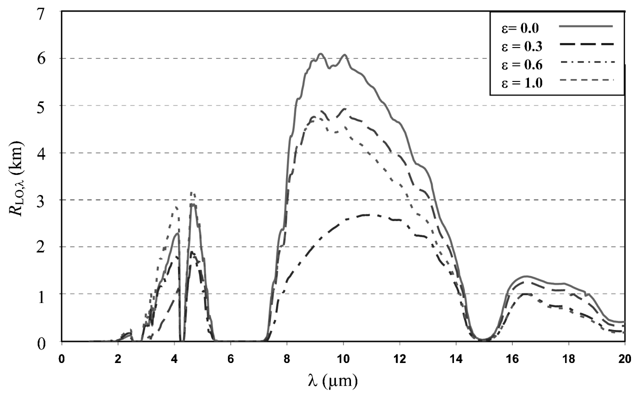

Fig. 12 Variation of aircraft spectral lock-on range with rear-fuselage skin emissivity, against AAM (tropical condition).

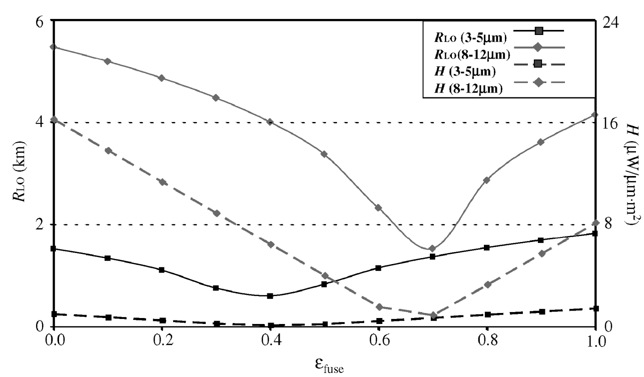

Fig. 13 Variation of average lock-on range and missile IR irradiance with rear-fuselage skin emissivity, against AAM (tropical condition).

Fig. 13 that for the 8–12 μm band, a rear-fuselage skin emissivity of 0.7 is optimum; whereas for 3–5 μm band, an emissivity of 0.4 is optimum. The variation of these optimum emissivity values with aircraft altitude is found to be negligible. Hence, these optimum values of rear-fuselage skin emissivity will suffice for the flight envelope pertinent to low-flying missions of tactical importance.

In summary, emissivity optimization technique is effective in reducing aircraft susceptibility against IR-guided missiles. Different sides of the rear-fuselage skin should have different emissivity, so that IR-signature level produced by aircraft in different directions is reduced.

Summary

1) Rear-fuselage skin is a significant source of infrared (IR) signature level from the forward aspect. Hence, optimizing rear-fuselage skin emissivity reduces the aircraft lock-on range, significantly.

2) In 3–5 μm band, rear-fuselage skin emissivity can be optimized to a nonzero value. In 8–12 μm band, rear-fuselage skin emissivity should be reduced to close to zero, for minimizing susceptibility against an IR-guided surface-to-air-missile (SAM).

3) Optimization of rear fuselage skin emissivity enlarges the safe flight envelope, against threat posed by IR-guided SAM/AAM.

4) Earthshine reflected by rear-fuselage skin is significant in dictating aircraft susceptibility to IR-guided SAMs in 8–12 μm band, but the role in 3–5 μm band is insignificant.

5) In case of an IR-guided air-to-air-missile (AAM), there is a nonzero value of rear-fuselage skin emissivity for which IR signature level from rear-fuselage skin is minimum.

6) The optimum value of rear-fuselage skin emissivity does not vary with altitude.

7) Different parts of rear-fuselage skin should have different emissivity, for minimizing its IR signature level against IR-guided SAM and AAM.

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