Infrared Signature of Jet Nozzle in Off-design Operation of Combat Aircraft Engine

A Thesis

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Doctor of Philosophy

by

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Affectionately dedicated to my loving parents

and almighty

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Declaration by Research Scholar

I hereby declare that the entire work embodied in this thesis is the result of investigations carried out by me in the School of Engineering, Indian Institute of Technology Mandi, under the supervision of Prof S.P. Mahulikar and Dr. M. Talha. I also declare that this work has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.

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Declaration by Research Advisor

We hereby certify that the entire work in this thesis has been carried out by **Nidhi Baranwal,** under our supervision in the **School of Engineering,** Indian Institute of Technology Mandi, and that no part of it has been submitted elsewhere for any Degree or Diploma.

Signature:

Guide: **Prof. S.P. Mahulikar**

Date: 28.March'18

Signature:

Co-Guide: **Dr. M. Talha**

Date:

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Abstract

Air superiority is needed in modern warfare for dominance in air-battle but shoulder-fired MANPADS, IR-guided surface-to-air missiles, air-to-air missiles and other smart munitions are lethal threats to aircraft. The study of IR signature and lock-on range of an aircraft is of fundamental interest for determining its susceptibility to infrared (IR) guided threats. IR suppressors are used to minimize the IR-signature level below a threshold value and maintain engine performance, thereby preventing the aircraft from threats posed by the IR heat-seeking missiles. But the incorporation of an IR-suppressor is generally accompanied by a compromise in engine performance, which indirectly reduces the effectiveness of IR-signature suppression. Reduction in the exit area of a choked convergent nozzle below the design point value results in optical blockage of hot parts and therefore, solid angle subtended by the hot parts reduces. However, the effect of back-pressure penalty generated due to the choked nozzle exit area reduction is to increase the IR signature level from the rear aspect. This study discusses the effect of reducing the exit area of a choked convergent nozzle of a turbojet engine on its IR signature and lock-on range. This shows that the technique incorporated for reducing the IR radiance can adversely affect the IR signature level of an aircraft. Appropriate thrust in an aircraft in all stages of the flight, i.e., take-off, climb, cruise, descent and landing is achieved through variation in the nozzle exit area. The variations in the nozzle exit area result in either choking or unchoking of a just choked (i.e., nozzle pressure ratio is same as the critical nozzle pressure ratio) converging nozzle. Results for these two cases (choked and unchoked) are analyzed in terms of thrust, mass flow rate and specific fuel consumption using GasTurb software. When design point thrust (F_{dp}) is maintained, variation in the exit area of a just choked converging nozzle results in higher combustion temperature. Hence, IRSL due to temperature based emission increases from the rear aspect in both the cases (choked and unchoked). At constant F_{dp}, increase in combustion temperature is greater in choked case as compared to unchoked case. Hence, higher IRSL increase is observed in choked nozzle than unchoked nozzle from the boresight ($\phi = 0°$, from the rear side), for the same percentage change in nozzle exit area relative to the $A_{ne,dp}$ (just choked nozzle exit area). Incorporation of a variable area nozzle in the military aircraft engine has become common these days, as it provides wider airflow range through the engine than a fixed area nozzle. The fixed-area convergent nozzles are mainly preferred for low nozzle pressure ratios (generally less than or equal to two) and for engines without afterburner. This study also shows the effectiveness of a FAN over the VAN in a turbojet engine from IR signature perspective on ground running condition. The aircraft engine's IR signature level from the boresight (direct rear view of the engine) has been studied, for the fixed and variable area converging nozzle in the 1.9-2.9, 3-5 and 8-12 μm bands.

Aircraft cruising at flight Mach numbers greater than 1.5 generally incorporates a converging-diverging (C-D) nozzle, because C-D nozzle provides optimum performance. But the diverging part's inner surface of the C-D nozzle is visible for almost full range (0°-90°) of view angle from the rear side, which is not desirable for the low observable aircraft. Whereas, the engine with simple convergent nozzle needs to operate at higher combustion temperature to attain the same thrust as obtained using a C-D nozzle. The temperature of the tailpipe and the exhaust gases increases with the increase in combustion temperature, which increases the IR signature level of convergent nozzle from the rear side. For the same thrust level, the study is performed to compare the IR signature from the rear side of the engine (boresight, $\phi = 0°$) from a C-D nozzle with the choked convergent nozzle in all three important bands (1.9-2.9, 3-5 and 8-12 μm).

Keywords: IR signature, Choked nozzle, Engine design point, Lock-on range, Boresight

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