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Beat the Heat: Diffusing Gas Turbine Jet Exhaust

Background:

In the modern battlefield, the most lethal weapon in aerial combat are guided missiles. In militaries around the world, heat seeking or infrared missiles are some of the deadliest and most cost effective weapons in their arsenal. Heat seeking weapons systems home in on the thermal energy of their target. During the Falklands Island conflict, heat seeking anti-aircraft missiles achieved a phenomenal 80% kill rate. Most of the heat generated by an aircraft results from the jet engine and to reduce this signature helps to defeat thermal tracking weapons

Purpose:

To determine how various nozzle designs for jet engines affect the exhaust's infrared signature. The traditional conic shaped nozzle with a circular outlet will be tested alongside a nozzle with a rectangular outlet. Both nozzle outlets will have the same area.

Hypothesis:

The rectangular nozzle will have a lower infrared signature due to the greater surface area offered its design combined with the theorized diffusion characteristics of the resulting exhaust stream.

Procedure:

Materials: (brief list)

- Air Research M10 turbocharger
- Various sizes of aclad exhaust tubing
- Leeson electric pump
- Ford V8 oil pump
- Propane
- Steel brake line
- _ inch sheet metal
- Laser temperature sensor

Procedure: (very brief outline)

- Design and construct single stage jet engine
- Design and construct rectangular and circular exhaust nozzle for engine with equal lengths and areas
- Start up jet engine
- Set fuel pressure to 15 psi and measure the temperature of exhaust stream at pre-determined points
- Repeat for other nozzle design

Results:

See Table 1

Observations:

Both nozzle designs had nearly identical temperature values immediately upon exiting the nozzle (round: 216 ^{o}C, rectangular: 212 ^{o}C). Therefore, the only factor affecting the cooling of the exhaust stream is the shape of the nozzle. At the center of the flow 6 inches downstream of the nozzle, the rectangular design's airflow was 38% cooler than that of the round nozzle. At 12 inches downstream, the temperature of the center of the air stream for the rectangular nozzle was 70% cooler than for the round nozzle.

Four inches above and below the center of the stream at the exit point, the rectangular nozzle's temperature was actually 16% higher than the circular nozzle. However, four inches above and below the stream at six inches *back* from the nozzle, the rectangular design is 4% cooler and 12 inches back the rectangular nozzle is 38% cooler than the circular design.

The physical end of the nozzle showed dramatic results in the two designs. The rectangular shape had a temperature registering off the scale for the measuring device, therefore in excess of 500 degrees Celsius after five minutes of running time. The temperature of the end of the round nozzle was only 357 degrees Celsius after the same duration.

After analyzing the results, the lower core temperatures of the rectangular nozzle can likely be explained by the greater surface area of the exhaust stream generated as a result of the rectangular shape. The initially higher temperatures noted 4 inches above and below the center of the stream at the nozzle for the rectangular design is likely attributed to the angular surfaces of the rectangular nozzle deflecting the gas stream at a more extreme angle. The result would be the routing of some of the intensely hot inner core flow outwards. This would account for the lower overall temperatures of the rectangular nozzle, suggesting a greater ability to diffuse gases and therefore to eliminate "hotspots."

Pressure directly affects temperature in a jet engine, the two variables moving together. The higher temperature of the metal at the terminus of the rectangular nozzle is likely the result of greater dynamic and therefore greater thermal energy transferred from the jet exhaust to the nozzle itself.

Conclusion:

In the controlled environment of the experiment, the rectangular nozzle had a lower gas stream heat signature than the circular design. The higher initial exhaust stream exit temperatures of the rectangular nozzle would not severely hamper its overall detectability, since on a full scale engine these hotspots would be relatively small compared to the resulting cooler exhaust. Also, in actual flight conditions, heat from the metal on the nozzle would be dissipated by the airflow over the plane. In conclusion, when a rectangular and a round nozzle have the same outlet area, the rectangular design will produce a lower heat signature.

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TABLE 1:

LOCATION	**CIRCULAR NOZZLE** Temperature ^{0}C	**RECTANGULAR NOZZLE** Temperature ^{0}C
Nozzle	>500	357
1 inch directly behind nozzle	216	212
1 inch back - 4 inches above	138	166
1 inch back - 4 inches below	135	157
6 inches directly behind nozzle	195	122
6 inches back - 4 inches above nozzle	131	135
6 inches back - 4 inches below nozzle	140	125
12 inches directly behind nozzle	185	57
12 inches back - 4 inches above nozzle	95	66
12 inches back - 4 inches below nozzle	89	68