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## Brief Literature Review

There exists a large body of work on ram air heat exchanger design for liquid-cooled aircraft engines, much of which dates to the World War II era. Miley (1986) has given an excellent survey of this work, as well as detailing the main concerns in achieving an efficient installation. Meredith (1935), Harris and Recant (1938), Rauscher and Phillips (1941), Beeton (1945), Katzoff (1945), Kuchemann and Weber (1946), Brodel (1950), and Ruden (1950) all have made contributions to the understanding of this problem. Recently, Lednicer and Gilcrist (1991) have used CFD methods to analyze the P-51 Mustang, and have predicted that the cooling installation for this airplane developed a slight net positive thrust from the radiator installation.

The recent work by personnel at AFSC has emphasized the use of CFD and simplified math models in the design of such integrated engine cooling radiator systems. The simplified model described in Langford, et al. (1993) uses one-dimensional gas dynamics relations in the diffuser and nozzle, coupled with the semi-empirical heat exchanger performance model developed in Kays and London (1950, 1984). A similar model has been used in the present work (Kessinger, 1996, and Chaillou, 1996). Computational fluid dynamics has been used by Drela (1996) in the actual detailed design of the aerodynamic contours of the wing and diffuser-radiator-nozzle geometry for the Theseus engine cooling radiator installation. This design effort made use of the MSES low Reynolds number airfoil CFD code (Drela, 1990).

## Apparatus

All experiments have been conducted in the WVU closed-loop low-speed wind tunnel, which has a 6:1 contraction area ratio nozzle, and which is fitted with one turbulence reduction screen in the plenum. Test section dimensions were 32" by 45" in cross section, by 42" long in the flow direction. The airfoil model was placed vertically in the test section, with a span of 32", in order to reduce blockage for a given scale ratio and model chord. Flow is generated via a 150 hp variable-speed DC motor, AC motor-generator set, and variable pitch drive propeller; maximum test section speed is approximately 200 mph.

The tunnel test section ceiling and floor were modified to allow installation of the model, via a turntable mechanism which permitted variable angle of attack. The tunnel test section side walls were modified to allow installation of a wake rake used to measure the wake velocity profiles, and static pressure taps were installed in an attempt to measure static pressures above and below the model to determine lift.

The two-dimensional, 30 percent scale model of the central portion of the Theseus UAV wing, including the radiator-cowl installation, was constructed by Craig Aviation of Washington, PA, using foam core and fiberglas-carbon fiber skin construction. The model chord was 21.26". The model size was selected based on the wind tunnel test section size, along with performance predictions from a mathematical model of the diffuser-radiator-nozzle which was developed by Kessinger (1996) and was adapted from a similar model given in Langford et al. (1993). Wing and cowl surfaces were hand-finished to fit through laser cut female templates. Typical accuracy of the finished model dimensions was estimated to be approximately $\pm 0.005$", except for modifications just upstream and downstream of the model radiator core, which had to be made to fit the radiator into the model. (The radiator core was approximately 0.25" too long in the flow direction.) The cowl was fabricated so that the cowl flap setting could be adjusted, to vary the nozzle exit-to-radiator area ratio. The wing and cowl surfaces were fitted with static pressure taps located at mid-span; 20 taps were installed on the airfoil upper surface, 18 on the airfoil lower surface, and 7 on the cowl. No pressure taps were installed on the cowl flap, due to its thinness. In addition, 5 total pressure probes were installed: 3 just upstream, and 2 just downstream of the radiator . A schematic of the model is shown in Fig. 1, which also shows the static pressure tap locations.

The liquid-to-air radiator core was fabricated by American Precision Industries, with an air side flow area which was 32" spanwise by 4" tall, by 1.25" in the flow direction. Fin thickness and air flow passage size were not properly scaled to 30% full size; this was due to manufacturing limitations. As a result some experimental results have been obtained for the model with a gauze installed across the face of the radiator to increase the air side pressure drop.

A wake rake was fabricated in-house for wake velocity surveys, which consisted of 28 2" long 1/16" diameter stainless steel tubes, spaced 1/8" apart. This wake rake was mounted into a 1/4" thick support block and a 1" diameter pole, which fitted to a 2-D traverse which allowed movement across the wake and along the model chord.