Review of Liquid-Cooled Aircraft Engine Installation Aerodynamics

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The aerodynamic behavior of liquid-cooled aircraft engine cooling installations is reviewed. Design considerations for inlets, diffusers, and exists are discussed. It is shown that the design of an efficient liquid-cooled installation is a techically sophisticated problem. This problem should not be underestimated in the development program of liquid-cooled aircraft engines. Questions are raised concerning the availability of suitable radiators for aircraft installations.

Introduction

TO many, liquid-cooled aircraft engines seem to have an aura, a fascination that has not been given to air-cooled engines. Some of this is certainly due to aesthetics. Liquid-cooled engines are synonymous with streamlining and aerodynamically clean profiles. The connection is readily made to the legendary Spitfire, Mustang, and Messerschmitt. The unappealing radial-air cooled engine does not enjoy this subjective attribute. Today's horizontally-opposed air-cooled engines fare no better. The mention of liquid-cooling immediately stimulates designers to visualizing low-drag shapes and improved performance, and stimulates marketing to thinking in terms of lightning-bolt and shark-mouth paint schemes. However, if more objective criteria are applied, the air-cooled engine compares more favorably with the liquid-cooled engine.

It is apparent from literature during the 1930s period that each had strong proponents and that it was relatively easy to start an argument over the relative merits of each. Most of the same technical points apply today. The author, though, will separate these points into propulsion concerns and aerodynamic design concerns. From the standpoint of propulsion, the liquid-cooled engine offers better fuel efficiency and longer engine life. Better control of cooling paths and subsequently of component cooling is realizable. On the other hand, the air-cooled engine offers system simplicity and is less vulnerable to system component failure. The weight of the cooling system is less. From the standpoint of external aerodynamic design, the liquid-cooled engine offers reduced frontal area and the potential for reduced drag, particularly compressibility drag. The internal combustion engine aircraft speed record was held by a liquid-cooled engine; however, it is now held by a radial air-cooled engine. Engine power must be factored into the comparison. Ground cooling is more of a problem for liquid-cooled engines. From the standpoint of internal aerodynamic design, the liquid-cooled engine has a definite advantage. Aerodynamically, each component of the system is in theory well behaved, i.e., no separated flows. The liquid-cooling system is more tractable to analytical aerodynamic modeling and design. The horizontally-opposed air-cooled engine configuration leads to large separated flows, because the relatively large internal volumes and ducting necessary to do otherwise are not practical. This is inherent in the geometry of the engine. The radial air-cooled engine configuration is aerodynamically much easier to deal with.

Liquid-cooled aircraft engines are presently available up to approximately 400 hp. There are developmental programs under way that could extend this range. In some cases, these are derivatives of automobile engines; in other cases, these are unique designs, such as the rotary type. The author's recent experience with one of these programs has brought forward an appreciation for the level of technology required to design an effective and efficient liquid-cooled installation. The technical problem of achieving the required cooling for minimum drag penalty should not be underestimated. It is the purpose of this paper to identify and discuss the various design problems of a liquid-cooled installation, indicating, where possible, what is known and what is unknown. Much of the information in this paper is taken from literature, particularly the works of Kuchemann and Weber.

Background

The first technical problem one encounters in aircraft liquid-cooling systems is the lack of current information. The state of the art is World War II, and this is where one must look for technical guidance. Immediately it is seen that there is very little available. The United States was far more successful in the development of air-cooled engines than liquid-cooled, and this is reflected in the literature. Success here is defined in terms of military requirements rather than civilian commercial requirements. The U.S. did produce liquid-cooled engine powered aircraft, but the engines were deficient in altitude performance in the European theater compared to their British and German counterparts.

Presently there are only three practical sources of information: the NASA Langley Research Center Technical Library, the Library of Congress, and the National Air and Space Museum. The key to building a data base in this area is to concentrate on foreign technology, principally German. What remains of the American developed technology is covered by the NACA indices. The few other documents that remain from industry and military programs can be found at the NASA library. The foreign programs of interest are the British and German efforts. Much of the British activity is inaccessible from the United States. While references to British documents are available at the NASA library, a large number of these still carry World War II classified status. Up to this point, there has been no reliable mechanism for determining which have been declassified by the British government; consequently, the WW II classified status is still in effect, and these documents are unavailable. There are two sources of German work, the National Technical Information Service (NTIS) and the ''Op-

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