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FINAL REPORT ON COLD STARTING OF RECIPROCATING AIRCRAFT ENGINES

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PREPARED BY

Committee S-4, Cold Starting Requirements

SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
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FINAL REPORT
ON
COLD STARTING OF RECIPROCATING AIRCRAFT ENGINES

INTRODUCTION

Conventional internal combustion aircraft engines require the same basic conditions for starting in cold weather as they do in warm weather. These are:

(1) The engine must be cranked at a reasonable speed.

(2) A combustible mixture must be delivered to the cylinders.

(3) An ignition spark must be supplied which is capable of igniting the charge at the proper time.

(4) The fits and clearances of mating parts in the engine must be such that normal functions occur at all temperatures.

(5) The engine must receive a usable lubricant.

(6) The engine must develop sufficient power to overcome its own friction and accelerate itself to the desired operating speed.

Of these basic conditions, supplying a combustible mixture to the cylinders during the cranking period, the acceleration period after initial firing, and the interim idling period prior to the carburetor or fuel metering device becoming active, present the most difficult problems.

The use of an ignition system "booster" has been found necessary to insure an adequate spark to ignite the charge in the cylinders under all conditions. Spark plug icing, resulting from unsucessful starting attempts, has been a major obstacle. By maintaining a steady and uniform supply of combustible mixture to the cylinders, resultant continuous firing prevents the formation of ice.

Oil dilution has been one of the most difficult problems because in practice it was not always possible to:

(1) Anticipate correctly the temperature at the time of the next starting of the engine.

(2) Obtain the desired amount of dilution, and

(3) Prevent occasional associated difficulties such as oil spewing during warm-up and poor control over the dilution of the oil in the main reservoir.

Proper engine cranking from the standpoint of available electrical energy does not present a serious problem because cranking batteries must be kept warm. Therefore, with the proper use of oil dilution the starting motors are able to turn the engines at adequate speeds.

Since successful starting requires that the engine be undamaged as a result of the starting sttempts, it is obvious that the fits and clearances of mating parts must be such that temperatures encountered under any conditions will not lead to internal failures. By the same token, oil dilution and special priming fuels must be carefully used so that scoring and scuffing do not result.

Allison Division, GMC, Pratt & Whitney Aircraft, Ranger Aircraft Engines, and Wright Aeronautical, conducted extensive laboratory cold weather tests on aircraft engines, Jack & Heintz and Electric Storage Battery conducted many investigations with electrical starting equipment, and the Standard Oil Development Company has spent considerable effort in the blending of high volatile priming fuels and the development of oils and greases for low temperature operation. These investigations have produced considerable data, the scope of which is too broad for this report. Reports of these investigations are listed in the addendum.

SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.

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FINAL REPORT
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OBJECT:

To devise, develop, and evaluate methods of cold weather starting of conventional internal combustion type aircraft engines.

CONCLUSIONS:

1. Conventional type aircraft engines can be started successfully in cold weather provided the necessary fuel, lubricant and equipment are used and the proper precautions are taken.

2. Of the several methods of starting engines in cold weather none have been developed to the point where the equipment used may be considered completely satisfactory.

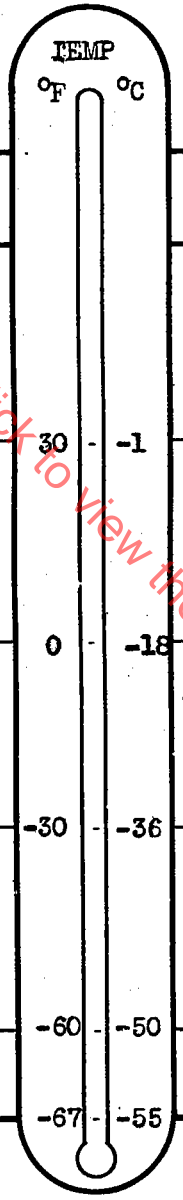
RECOMMENDATIONS:

Although other forms of aircraft propulsion engines are being developed which may gradually displace the conventional engine the development of cold weather starting equipment should continue in order that military aircraft using conventional engines will have a quick and positive method of starting under cold weather conditions.

STARTING OF AIRCRAFT ENGINES

WARM ENGINE METHOD

OIL DILUTION	PRIMING FUEL	BATTERY HEAT	PREHEAT TO ENGINE
No	Regular Fuel	No	No
No, if oil system is warm.	Regular Fuel	Preferable	Preferable
No, if oil system is warm.	Regular Fuel	Yes	Yes
No, if oil system is warm.	Regular Fuel	Yes	Yes
No, if oil system is warm.	Regular Fuel	Yes	Yes



COLD ENGINE METHOD

OIL DILUTION	PRIMING FUEL	BATTERY HEAT	PREHEAT TO ENGINE
No	Regular Fuel	No	No
10% of mixture by volume	Regular Fuel	Preferable	No
20% of mixture by volume	Special Fuel Preferred. Possible to use Regular Fuel.	Yes	No
30% of mixture by volume	Special Fuel	Yes	No
35% of Mixture by volume	Special Fuel	Yes	No

DISCUSSION:

Conventional internal combustion aircraft engines may be started under cold weather conditions by either of two basic methods. These two methods are known as the "Warm Engine Method" and the "Cold Engine Method". Figure 1 divides each method by temperature ranges and gives the salient features of each method and the temperature ranges covered. Northern "bush" operators for years have used the "Warm Engine Method" and due to their aircraft being small, single engined, and their operation being very linited in scope, this method has been satisfactory for their use.

Heating of any sort requires continuous maintenance of the heating unit and in operation in the still northern air the tell-tale plume of white vapor issuing from the stack can be seen for miles. Intermittent heating, or heating prior to starting, has been provided by means of small internal combustion engine driven heaters. These engines are required to operate on aircraft engine fuel (AN-F-28) which to date has contained considerable lead compounds. The products resulting from these compounds in the combustion process are deposited in the combustion chamber, on the valve mechanism and on other exposed surfaces, thereby seriously affecting the life of the engine and requiring frequent maintenance.

COLD WEATHER STARTING OF AIRCRAFT ENGINES

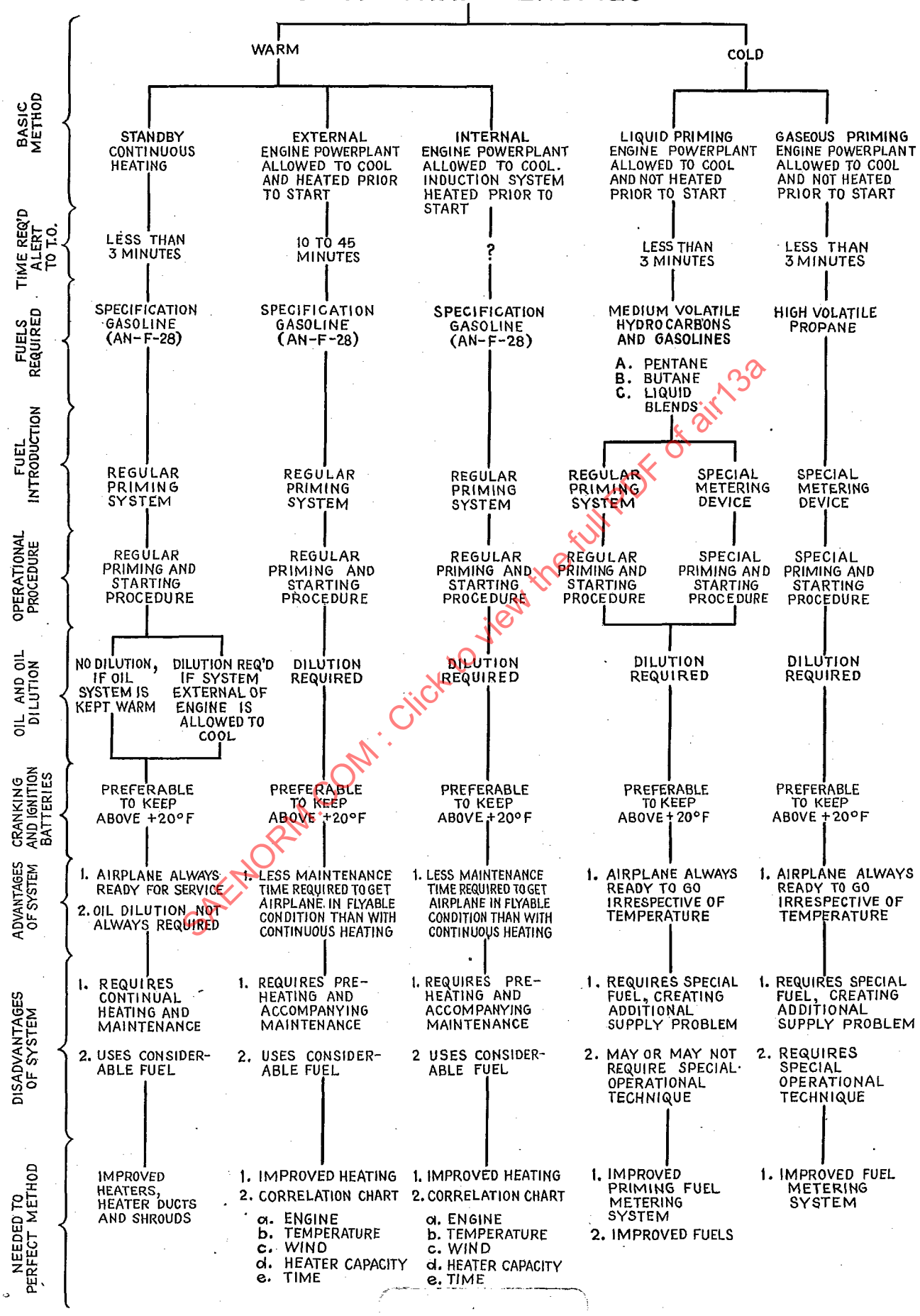


Figure 2 further breaks down figure 1 into three sub-divisions for the warm engine method and two sub-divisions for the cold engine method.

The three major sub-divisions of the warm engine method are:

a. Standby or continuous heating

b. External heating of the power plant with the heat being applied prior to starting.

c. Internal heating of the power plant with the heat being applied prior to starting.

The two major sub-divisions of the cold engine method are:

a. Priming the engine with liquid fuel.

b. Priming the engine with gaseous fuel.

The cold engine method of starting possesses a great advantage in that the engine may be started within three minutes from the sounding of the alert for military aircraft. This is of utmost importance in military theatres of operation because aircraft on the ground during an air raid are often lost.

To perfect the cold engine method of starting, the delivery of priming fuel to the engine requires a metering system both for liquid and gaseous fuels. This is essential because of the narrowing of the range of combustibility with decreasing temperatures. Many of the difficulties encountered with high volatile fuels are directly traceable to improper fuel-air ratio during the starting period.

The cold engine method of starting requires that oil dilution be used. This is a very controversial subject, and indications are that with the proper control of dilution many of these difficulties will disappear. Laboratory testing with oil dilution has frequently led to disastrous engine conditions; however, recent investigations reveal that this need not be so with proper control. Service operations reveal that oil dilution, when properly used, is not harmful.

ADDENDUM:

Shortly after the entrance of this country into World War II, it became evident that military operations would be conducted in cold weather areas and that the aircraft industry was not prepared to cope with the extreme conditions that might be encountered. This condition brought about the formation of the SAE Committee E-16, Cold Starting Requirements for Aircraft Engines. This committee undertook the following:

1. To determine the extent of possible conformance of existing aircraft engines to the paragraph on cold starting in the AN specifications for aircraft engines and to recommend modifications to either or both the specification and engines to achieve starting at the lowest possible temperature in the shortest possible time.

2. To act as a clearing house for the dissemination of cold weather information throughout the aircraft engine industry.

3. To act as a service and advisory group to the military services.

In performing the above many conferences were held and reports issued. A chronology of the committee's activity is revealed in figure 3.

Fig. 3

DATE	COMMITTEE MEMBERS	CONSULTANTS	SERVICE REPRESENTATIVES	COMMITTEE ACTION	INDUSTRY ACTION
July, 1942					Jack & Heintz supplied calibrated starters for tests conducted by Wright Aeronautical resulting in WAC 716, 859. Allison Div., GMC started tests resulting in report I4-2
Aug.20-21, 1942					ETC requested formation of this committee to study and make recommendations on the requirements of paragraph D-26, AN 9500B. SAE Engine Subdivision requested committee to study complete problems of cold starting of aircraft engines.
Aug.24,1942 Meeting Detroit, Michigan	C. R. Paton, Chmn. W. H. Sprenkle R. E. Johnson B. J. Ryder Max Epps	J. H. Little E. F. Webb		The committee discussed proposed revision to spec. AN 9500B, paragraph D-26.	
Sept.1942					Allison completed tests for report I4-2. Jack & Heintz supplied calibrated starters for tests conducted by Pratt & Whitney on R-1830 and R-2800 engines for report PWA 418. Allison started tests for report I4-2A. Wright Aeronautical Serial Report 716 on R-2600 engine to -20°F.

DATE	COMMITTEE MEMBERS	CONSULTANTS SERVICE REPRESENTATIVES	COMMITTEE ACTION	INDUSTRY ACTION
Sept.19, 1942 Meeting New York, New York	C. R. Paton, Chmn. W. H. Sprenkle M. Epps B. J. Ryder R. E. Johnson	J. A. Keeley H. C. Riggs G. A. Bleyle B. W. Geddes J. H. Little F. L. Miller Maj. Heenan	Committee agreed upon proposed rewording of paragraph D-26, Spec. AN 9500B. Report transmitted to ETC:	
Oct.8,1942				Standard Oil Development completed general study and laboratory data for report "Low Temperatures Performance of Fuels and Lubricants."
Oct.29,1942 Meeting Detroit, Michigan	C. R. Paton Chmn. W. H. Sprenkle R. E. Johnson M. Epps B. J. Ryder	B. W. Geddes L. L. Bettz R. N. DuBois Ed. Webb J. Little J. M. Hall J. A. Keeley G. A. Bleyle H. C. Riggs. Jud Buttner	Committee agreed to issue cold starting requirements report, and discussed type of report to be issued.	
Dec., 1942				Standard Oil Development completed development of information on fuels and lubricants for report "Cold Starting Requirements of Aircraft Engines."
Dec.15,1942 Meeting Detroit, Michigan	W. H. Sprenkle (Act. Chmn.) M. Epps R. E. Johnson C. R. Paton B. J. Ryder	H. J. Buttner B. W. Geddes H. C. Riggs	A draft of the Cold Starting Requirements report was prepared by the committee. This draft was approved by SAE Engine Subdivision & Aeronautics Division. As a restricted report it was forwarded to chief engineers of all aircraft, aircraft engine and propeller manufacturers and applicable accessory manufacturers. Copies also sent to Services.	

DATE	COMMITTEE MEMBERS	CONSULTANTS	SERVICE REPRESENTATIVES	COMMITTEE ACTION	INDUSTRY ACTION
Feb.10,1943					Pratt & Whitney completed tests for report PWA 418.
March,1943					Jack & Heintz supplied starters for tests with 17 and 34 ampere hour aircraft batteries, for J & H report S-40. Allison completed tests for report I4-2A.
Apr.10,1943 Meeting New York, New York	C. R. Paton, Chmn. R. E. Johnson W. H. Sprenkle M. Epps B. J. Ryder	C. E. Bachle G. A. Bleyle H. J. Buttner B. W. Geddes R. C. Keane H. C. Riggs C. Van Hartesveldt		Continued discussion of cold starting problems and starter report on "Effect of Oil Dilution."	
Apr.29,1943 Meeting Wright Field Dayton, Ohio	C. R. Paton, Chmn. R. E. Johnson M. Epps B. J. Ryder W. H. Sprenkle (M. Epps resigned Van Hartesveldt replaced him.)	G. Bleyle H. Buttner J. Heenan F. Dougherty R. N. DuBois B. W. Geddes K. C. Peggs J. M. Hall J. H. Little H. C. Riggs M. A. Trisler C. Van Hartesveldt	Col. Gaffney Capt. Luther Capt. Miller Lt. Col. McKinley Maj. Schneider Lt. Col. Stewart Maj. Wagner	General discussion of cold starting operation problems with the Service personnel.	

DATE	COMMITTEE MEMBERS	CONSULTANTS	SERVICE REPRESENTATIVES	COMMITTEE ACTION	INDUSTRY ACTION
May, 1943					Jack & Heintz supplied starters for test to determine the optimum engine cranking speed and the starter characteristics which would provide this RPM with longest cranking period from aircraft batteries, for Buaer report AEL-LR-421.
May 13, 1943 Meeting Indianapolis, Indiana	C. R. Paton, Chmn. B. J. Ryder C. Van Hartesveldt R. E. Johnson W. H. Sprenkle	J. Little G. A. Bleyle H. Buttner F. Dougherty B. W. Geddes J. Heenan E. A. Metz W. G. Ovens H. C. Riggs M. A. Trisler R. M. Williams		A tentative list of suggested operations to be conducted at Ladd Field for the comming winter was agreed upon. This list was presented to the Services at Ladd Field, May 14, 1943.	
May 14, 1943 Meeting Wright Field Dayton, Ohio	C. R. Paton, Chmn. B. J. Ryder C. Van Hartesveldt R. E. Johnson W. H. Sprenkle (Johnson resigns. Bleyle takes his place.)	J. Little G. A. Bleyle H. Buttner R. L. Davies F. A. Dietz F. Dougherty B. W. Geddes W. G. Ovens H. C. Riggs M. A. Trisler J. Heenan	Wm. Weitzen Lt. Collins Col. R. Keiller Maj. C. Lawson Capt. D. Rialson Lt. J. Rice Maj. J. Schneider Lt. H. Shute Maj. N. Thyson Lt. Col. Warburton Capt. W. Woodard Forest Vernon L. C. Smith Otto Spevacek N. Carpenter	General discussion of cold starting requirements with the Service representatives with the view of assisting in establishing program for cold weather testing.	
May 26, 1943					Standard Oil Development completed tests on alcohol-gasoline cold storage studies for report, "Use of Alcohol to Prevent Ice Formation in Gasoline at Low Temperatures."