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THE RESEARCH AND DEVELOPMENT BOARD
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REPORT ON SURVEY

OF

NATIONAL RAMJET PROGRAM

Prepared by:

Panel on Propulsion and Fuels
Committee on Guided Missiles
Research and Development Board

A. G. [signature]
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Chairman

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Item 5 - Agenda 24th
GMC Meeting

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I. INTRODUCTION

The development of ramjet engines for operational use is based upon the development of reliable components and their integration into complete engines having the desired characteristics. The accomplishment of this objective requires the intensive development of components and thorough testing of the complete power plant under static and flight conditions. It is to be expected that different solutions of similar problems will exist for a few years and the best of the solutions can be resolved only after competitive approaches have been thoroughly tested. Optimism regarding the solutions of the different problems to be overcome must be regarded with a certain amount of skepticism until the solutions of the problems have been demonstrated under conditions simulating operational use.

In addition to research and development having for its objective the development of useable engines at the earliest possible date, it is important to realize that continuous effort should be devoted to improving the potentialities of the types now being developed and in addition exploration of the improvements to be expected by modification of existing designs should not be neglected.

This report presents the conclusions of the Panel on Propulsion and Fuels regarding ramjet engine development. The conclusions are based on the considerations presented above.

II. SUMMARY OF RAMJET ENGINE PROGRAM

Ramjet engine developments are being conducted by the following organizations and for the end objectives listed below.

Item	Contractor	Engine Diam	Design Mach No.	Operating Duration	Application
1.	Wright Aeronautical Corporation	43 in	2.85	30 Min	Navajo (MK 770)
2.	Wright Aeronautical Corporation	20	3.0	3 Min*	General Ramjet Development
3.	Applied Physics Lab.	28	2.4	2 Min	Talos
4.	United Aircraft Corp.	14	2.4	1 Min	Meteor
5.	Gen. Electric Co.	24	4.0	2 Min	Hermes B-1
6.	Fort Bliss	Split Wing	3.3	15 Min	Hermes II
7.	Marquardt Aircraft Co.	28	2.0	20 Min	Rigel
8.	Marquardt Aircraft Co.	20	3.0	3 Min*	Gen. Ramjet Dev.

* Operating duration limited by fuel capacity, but engine should be re-usable after recovery. Engine is to have a total operating life of several hours.

All of the items listed above with the exception of items 2 and 8 integrate into the Guided Missiles Program. The latter items are the only ones which may be regarded as being solely research engine developments from which technical information for the further development of ramjet engines may be forthcoming.

It is to be noted that the development of a 20 in. ramjet engine at the Continental Aircraft Corporation has been discontinued, and no further work is being conducted on an engine of the same scale at the Boeing Aircraft Corporation (GAPA missile engine).

III. GENERAL DISCUSSION

a. Wright Aeronautical Corporation, Marquardt Aircraft Company, Bumblebee (Applied Physics Lab/Johns Hopkins University)

To obtain a well rounded picture of the ramjet program it is convenient to consider the projects at Wright Aeronautical, Bumblebee and Marquardt, as an entirety, since these three projects constitute the most intensive portion of the overall ramjet program. All three organizations have qualified technical personnel and great familiarity with the ramjet engine problems. They represent as a whole parts of a thoroughly sound program which is essentially complementary. At this time any curtailment of the work being conducted by these contractors would seriously impair the overall program. The Bumblebee group accomplished the first supersonic ramjet flights; has emphasized broad basic studies pertinent to ramjets to a greater extent than either of the other two, and has accumulated an impressive background of experience and accomplishment in pioneering a new field. The Wright Aeronautical Corporation, on the other hand, appears to possess a greater ability to recognize and define the scope of activity required for developing specific engines in the development program. They indicated marked ability to analyze the problem of developing specific engines, to organize their personnel and facilities, and appear to attack the pertinent problems in an experienced manner and that would indicate the ability to supply developed useable engines in a minimum time. The Marquardt Aircraft Company, which has supplied most of the subsonic ramjets in this country, has demonstrated its ability to utilize available technical information and to construct operable ramjets with less expenditure of development effort. The technical studies made by the Marquardt Aircraft Corporation have not approached as broad a basis as those conducted by Bumblebee; nevertheless, Marquardt has built engines incorporating techniques being considered by Bumblebee, and has conducted original research in special fields such as boundary layer removal on diffusers.

The technical thinking of each of the aforementioned organizations is not foreign to the others and there is some familiarity with different concepts originated by each company; it was apparent to Panel IPF, however, that the exchange of information between the three organizations should be improved. There appears to be sufficient diversity in the methods each

organization employs in handling the various problems pertinent to the development of supersonic and subsonic diffusers, combusion chambers, flame stabilization, ignition, fuel injection systems, metering controls, etc. Judged from the overall ramjet program, however, the Panel MPF is of the opinion that the work being conducted by each of the above organizations is remarkably free from undesirable duplication in component development. In diffusers Wright Aeronautical has used a conservative approach utilizing established design for spike diffusers with compromises as indicated appropriate after extensive tests to provide stability and minimum external drag. Bumblebee is carrying on extensive development of a novel bleed diffuser which they expect will permit improved drag with streamlined convergent-divergent type of diffuser design. Their low Mach No. of 2.2 is less critical however in requiring high diffuser efficiency. Marquardt is using a spike type diffuser, and has partially tested a boundary layer removal arrangement that may contribute substantially to the problem.

In the case of combustion chamber development, very substantial contributions in rationalization of ramjet combustion phenomena have been made by Bumblebee. They have investigated center piloting, bleed diffusers and wide gutters for flame holders with reduction in width possible where the gutter is a spreader for the pilot. They also have developed a can type combustion chamber and some supporting theoretical rationalization. Marquardt has utilized the center pilot idea with his own conception of wide and narrow gutters, and obtained results in NACA tests that are the best reported in regard to an efficiency and range of F/A ratios under altitude conditions. Wright Aeronautical in its combusion chamber development follows the piloted theory but uses multiple pilots to insure coverage of a large chamber and surrounds the pilots with a variation of the can principle (so-called "cabbage cutter"). It also provides separate metering of the pilots to insure stroichiometric piloting regardless of metered flow to the main air stream. This not only gives more latitude in throttling but will permit reignition in case of a lean or rich blow out during a transient.

All three companies have different approaches to the solutions of their individual metering unit problems. The approaches are to some extent dictated by the particular fuel range requirements of their individual ramjet engine programs. Bumblebee is developing a rather simple system with a time response of approximately one second. The Panel MPF was not able to determine the engineering effort which has been devoted to that system; but there was the general impression that both Wright Aeronautical Corporation and the Marquardt Aircraft Corporation had conducted more intensive detailed engineering on the development of their particular systems. The fuel metering system being developed by the Wright Aeronautical Corporation is a pneumatic control type which in basic design incorporates the well tried features which have been utilized in many air-operated industrial controllers. It will provide maximum thrust during acceleration and has a 1/25 second response rate. Currently it is being proof-tested under the full range of temperature conditions to be encountered. The Marquardt system in general represents a mean between the two systems discussed above, but does include several novel features.

b. Meteor - United Aircraft Corporation (UAC)

On this project the fundamental research and background for the ramjet engine development is supplied by MIT and the ramjet engine is being developed by UAC. At the present time MIT is carrying out fundamental combustion studies in two general projects; one on flame stabilization, the other on vortex flow systems. The UAC engine differs from the engines discussed previously in the piloting system and method of fuel injection; furthermore while the other engines employ hydrocarbon fuels for piloting, this engine utilizes hydrogen and oxygen as pilot fuels. Present plans call for inner body piloting and initial tests have been conducted at Daingerfield with promising results. The oxygen-hydrogen piloting used to solve the high altitude ignition problem would be less attractive if the ultimate application required longer operating periods.

The most significant developments at UAC appear to be their multi-unit burner and the metering unit both of which are basically different from any other similar developments. The basic advantage of the metering unit is the reduction in number of parameters that must be sensed, and the elimination of the matching of metering units to predicted engine characteristics as is normally required. The system is to have the property of adjusting the fuel flow of the burner so that the engine can be operated at maximum thrust under all conditions.

The multi-unit burner system is in its early stages of development and is an effort to devise a means for scaling-up ramjet burners so as to reduce experimental work. The multi-unit burner program is not tied to any missile. The ultimate objectives of the project are still a long way from being accomplished, but the current work should be continued until more definite results for evaluation purposes have been obtained.

The UAC organization is well qualified technically and operates in an efficient engineering manner. They are making beneficial contributions to the ramjet engine development program and their component developments do not duplicate those being conducted by other organizations. It is the opinion of Panel MPF that closer coordination between the Bumblebee and Meteor ramjet developments would be beneficial to the entire ramjet program.

c. Ordnance Research and Development Division, Sub-office, Fort Bliss, Texas

The HERMES II program at Ft. Bliss, Texas is staffed by approximately 125 former German personnel (Technical), 30 officers and 400 enlisted men, 75-100 civil service personnel (mostly clerical & administrative) and 175 G. E. personnel (for procurement and shop functions). Of these, approximately one-third must be charged to housekeeping and other duties involved with a military post. Training aspects for Army personnel also are significant.

Expenditures of Research and Development funds have totaled $6.8 mil through FY 1950 at a rate of approximately $2 mil per year. Approximately 40% of the project funds are properly chargeable to ramjet work. Valuable

use of site, buildings, machinery and military personnel add to the project without drain of R&D funds.

The group has had important functions in transferring German experience with missiles to U. S. personnel, and in handling of V-2 firings at WSPG, apart from the HERMES II project.

The ramjet work in HERMES II is quite different from that of other projects, since it is the only two-dimensional, split-wing ramjet of the projects discussed in this report actively under development. It is designed for M-3.3 at altitude of 66,000 ft.

The good spirit of the group and able administration under the officer in charge were noteworthy. The technical competence and the ingenuity of the staff are apparent, especially in improvising static test facilities at low cost in dollars.

The present effectiveness of the HERMES II ramjet work is questioned, because of the use of CS_2 as fuel, which is easy to ignite but of poor specific impulse (but it is understood that transition to higher energy fuel is to be expedited.) Also the geographical and administration factors affecting procurement seem to impair effectiveness. It is anticipated that changes attending for move of the project to Huntsville, Alabama should increase effectiveness substantially.

The most significant feature of the HERMES II ducted-airfoil ramjet is the investigation of two-dimensional diffusers and combustors, which can be first tested in small sections and put together in multiple for airfoil and propulsive systems of low drag. One of the principle problems is to secure adequate combustion in the short length of chamber.

It is the opinion of Panel MPF that consideration should be given to the study of means for deriving greater benefit to the guided missiles program from the scientists in the Fort Bliss group.

Continuation of ramjet work by the Ft. Bliss group is recommended.

d. General Electric Company (HERMES B)

General Electric has in its ramjet program two vehicles: the HERMES B-1 as a test vehicle for M-4 data (5 units only without guidance, to be fired from V-2's); and the HERMES B-2 an eventual weapon on which only preliminary study has been made as yet.

HERMES B ramjet work has been in the region of M-4.0 because this appears to offer much less likelihood of interception in future years, and because the problems of high temperature materials and design for ramjets at M-4 require long term effort for solution. Whereas interception of subsonic missiles appears immediate or soon imminent, interception of low supersonic (M-1 to 2) vehicles likewise appears only moderately behind, and interception

of higher speed steady flight vehicles at M-2 to 3 is considerably more difficult but possible at least in principle, the operation of vehicles in the region of M-4 approaches the ultimate for requirement on structural materials and propulsive systems and hence little margin of speed possible for interception maneuvers. The General Electric Company, with extensive research in high temperature, metallurgy and combustion has qualified personnel to participate in the HERMES B ramjet work. As presently constituted the program includes firing of five propulsion test vehicles (HERMES B-1) for data only. The extent of General Electric efforts in the ramjet field to date have not been sufficient to permit an evaluation of that phase of their work comparable to that possible with other ramjet projects.

The technical competence of the personnel in charge of the project and the personnel available for engineering consultant work is unquestionably high, and methods of operations appear to be good, with complete consultation between the several parts of the General Electric Company on the powerplant phase of this project. The quantity of the work accomplished thus far is certainly good. There is no overlap with other projects, this being the only ramjet project designed for Mach number 4.

IV. GENERAL CONCLUSIONS

The Panel MPF concludes from their inspection and recent study of the ramjet engine programs that the overall program is well integrated, provides a balance in experience and operating methods, is sufficiently diversified technically, and does not include any undesirable duplication. Improvements, however, in the program should be effected by improving the exchange of information between the different development groups.

The Panel MPF studied the facilities available to the different development groups and is of the opinion that adequate facilities are available or authorized for the static testing of complete ramjet engines up to sizes equivalent to 20 to 28 in. diameter, but facilities for testing engines of 40 in. diameter and larger over the complete performance range are unavailable. From the propulsion standpoint, development of means for recovering engines after flight testing should be encouraged.

It is the opinion of Panel MPF that the desired exchange of information between different development groups is not accomplished by the present system of reporting. Discussions with the different groups indicated that small symposia of personnel actively engaged in this field would be of great benefit.

In the opinion of Panel MPF the individual programs complement each other and there are no serious gaps.

While several detailed problems remain to be solved, ramjet engine development has reached the stage where the potentialities for propelling vehicles in the Mach number range 2 to 3 have been clearly established.

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Ramjet availability is more dependent upon the expenditure of a large amount of development effort rather than upon any as yet undetermined characteristics inherent in ramjet operation.

The current level of expenditures for ramjet engines is satisfactory at this stage in its development. It is the opinion of Panel MPF that as ramjet engines become available for flight testing the current level of expenditures will be insufficient.

V. SPECIFIC RECOMMENDATIONS

1. The Panel on Propulsion and Fuels recommends that the $400,000 USAF FY 1950 research and development funds for the Marquardt ramjet engine development that was impounded by the Management Committee be released as recommended by the Committee on Guided Missiles in GM 36/83.

2. Serious consideration should be given to means for improving the exchange of information between the different development groups by informal symposia sponsored by the services under the auspices of NDB.

3. Substantially the current level of expenditures of each development group should be maintained through FY 1951.

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If you have any questions, contact me by phone at 703-696-2197 or by e-mail at storer.robert@whs.mil or robert.storer@whs.smil.mil.

Robert Storer

Enclosures:
1. DTIC request
3. Six documents

Robert Storer
Chief, Records and Declassification Division

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