JETS and ROCKETS

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LONDON
CHAPMAN & HALL LTD
37 ESSEX STREET, W.C.2
1959

First published 1959

Catalogue No. 442/4

Printed in Great Britain by C. Tinling & Co., Ltd.,
Liverpool, London and Prescot.

FOREWORD

by PROFESSOR A. D. BAXTER
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FROM time to time friends and colleagues of mine have turned their talents to setting down in a permanent form for the benefit of others, something of the experience and knowledge they have gained in their work as scientists and engineers. Most of them have been fortunate in being associated with the interesting and exciting problems arising from new developments and techniques in aeronautics, and the present authors are no exceptions. I have had the pleasure of working with all of them on some of the subjects they discuss in the following pages and can vouch for their practical knowledge.

There can be no doubt that they were well qualified for the task they undertook, but as I look back over the post-war years and remember the rapid developments that have taken place in jet and rocket propulsion, I doubt if they realised its magnitude when first this book was conceived. Now however, they and the reader can see in these pages how vast is the subject and how far it has progressed. No doubt it will continue to progress, but the present is an appropriate time to take stock and this has been done in a way which should satisfy the needs of all for whom it is prepared.

A.D.B.

Edgware.

PREFACE

THERE is quite a long story attached to the publication of this book. As junior author and the villian of the piece, I am almost tempted to expand it at great length ; but I will forbear. I would have had to go back ten years ago to 1945, when Mr. Ronald Smelt—then at the Royal Aircraft Establishment, Farnborough—undertook the preparation of a new volume for " The Frontiers of Science " series, inaugurated by Pilot Press. Not long afterwards he gave up his position as Head of the Guided Weapons Department at Farnborough, and went West to the States.

In the meantime, our present publishers took over the publication of the book, and at some date I do not wish to remember, sent the galley proofs to me for correction. For reasons too embarrassing to recall, I never completed this task, and as time went on, the need of revision—in the light of the rapid post-war progress in aviation—became more and more apparent.

Happily, the situation was saved by the intervention of Mr. Allan Barker, then a colleague of mine at Cranfield in the Department of Propulsion, who undertook the task of bringing the text up-to-date. It says much, I think, for Mr. Barker's ability and the foresightedness displayed in Mr. Smelt's original text that outwardly the general form of the book remains unchanged ; and here, at last, it is. What credit the reader may find fit to bestow belongs to them, and to our publishers, whose faith and pertinacity will, we naturally hope, be amply rewarded.

In the preparation of a book of this kind, it is unavoidable that insufficient credit is given to the many experts who have contributed to the advancement of this field of research. To these workers, and in particular to the authors' many colleagues, we wish to express our indebtedness. The original typescript was carefully prepared by Mrs. J. Graves and Mrs. I. Aylesbury, and the later one by Mrs. P. Bedingfeld, to whom we still owe our grateful thanks.

Photographs and figures have been kindly supplied by the Institute of Mechanical Engineers, the proprietors of *Flight*, Armstrong Siddeley Motors Ltd., the Engine division of Bristol Aircraft Co. Ltd., D. Napier and Son Ltd., Rolls-Royce Ltd., A. V. Roe & Co. Ltd., and the Ministry of Supply. Figs. 1 and 2 have been reproduced by permission from *Jane's All the World's Aircraft.*

T. NONWEILER.

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CHAPTER I

INTRODUCTION

It is usual in a book of this type to devote the first chapter to a historical survey of the subject. The history of jet and rocket propulsion can indeed be presented as a particularly romantic story. There is a strong temptation to offer to the reader a picture of jet-propulsion activities through the ages, from the rocket developments of the early twentieth century, through the weird military application of earlier years, to the beginnings of the art in Hero's steam engine or the Chinese firecracker.

We have resisted this temptation, for two reasons. Firstly, the history of rockets and jets has already been surveyed in several very good books which are listed in the Bibliography at the end of this book. But a more important reason lies in the fact that every mechanical achievement in its initial stages has had to contend with the scorn of the man-in-the-street. The pioneers in jet and rocket propulsion seem to have suffered rather more than the average from these attentions, varying from mild amusement to active ridicule. There is a striking incongruity between the grandeur of the goal of these early workers—nothing less than the stars—and the silly misbehaviours of their little toy, the rocket motor. Such an incongruity is inevitably a spur to derision. We hope that by omitting a survey of the past, we shall avoid implanting in the mind of the reader any of this early attitude to the subject ; although by doing so, we are paying scant justice to the good work of many enthusiasts.

The fact is, of course, that the public attitude to rocket and jet propulsion has changed completely in the last few years. The man who has seen and read of jet-propelled aircraft breaking all existing speed records by a handsome margin, or had the more unpleasant experience of the arrival of a German V.2 projectile, views these events with rather mixed feelings, but ridicule plays very little part. The technical achievements of the last few years are very far removed from the experimental work of the earlier enthusiasts ; they have, in fact, earned the respect of scientists and engineers throughout the world.

There are many factors which have combined to produce this change of attitude towards the rocket and jet ; it will be sufficient here to mention only two of them. Firstly, the workers on high-speed power units have for several years aimed their developments at a much more restricted field than formerly. The old aim of the Interplanetary Societies of the world has become lost in the more immediate military necessities of producing aircraft or projectiles of the greatest possible speed. The most blatant example of this lowering of the ideals may be seen in the development of the

German V.2 missile, which was achieved by collecting together the brightest members of the German Interplanetary Society, under a General of the German Army, for this purpose.

A second important factor has been the steady increase in the top speed of the aeroplane. Practically every one of the high-speed power units discussed in these chapters was suggested many years ago. They all, however, rely upon achieving very high speeds of flight ; almost without exception, they were completely uneconomical at the speeds which could be attained when they were first conceived. The aircraft has at last reached speeds so high that their application becomes feasible. Indeed, at the highest aircraft speeds now attained, the turbo-jet unit is far more economical than any reciprocating-engine-propeller unit which could be conceived for the same speed. The rocket motor and the ram-jet are not yet economical means of flight, although they are possible ones ; they are awaiting further development in the aeroplane, towards the achievement of high supersonic flight speeds.

It is surprising that many of the earlier workers in the field of jet and rocket propulsion apparently did not realise that the success of their endeavours rested so largely upon aerodynamic developments towards high-speed flight. Indeed, the rocket enthusiasts of the past seem to have expended a large part of their energy on rocket-propelled cars and railway trucks, and even on rocket-propelled ice-skaters ! The pioneers of the turbo-jet engine appear to have been very much wiser in this respect ; they realised from the beginning that the turbo-jet unit was essentially an engine for very high speed aircraft. This may have been a consequence of the fact that the development was, throughout, in the hands of men with aeronautical training. For example, Whittle, the "father" of jet-propulsion in England, is an R.A.F. officer, and has a very comprehensive knowledge of the aerodynamic problems of high-speed flight. It is amusing to read, in the Journal of the Royal Aeronautical Society for February, 1938, an account of the discussion which followed a paper by Lock on the aerodynamic problems of high subsonic flight speeds. Many of the aerodynamic experts were frankly pessimistic over the possibility of achieving flight speeds much in excess of 500 m.p.h. Indeed, the only dissenter against this attitude was Whittle, then a comparatively unknown Flight-Lieutenant, who stated quite categorically that he did not believe the data upon which these predictions were being made, and that there must be something wrong with the wind-tunnels in which they were obtained. His remarks have proved subsequently to be quite correct !

The fact which we have stated in the last two paragraphs, that the development of the rocket and jet unit is closely inter-linked with the advance of high-speed aerodynamics, can almost be described as the theme of this book. In practically every chapter it has been necessary to draw on some aspect of high-speed aerodynamics ; not only when considering

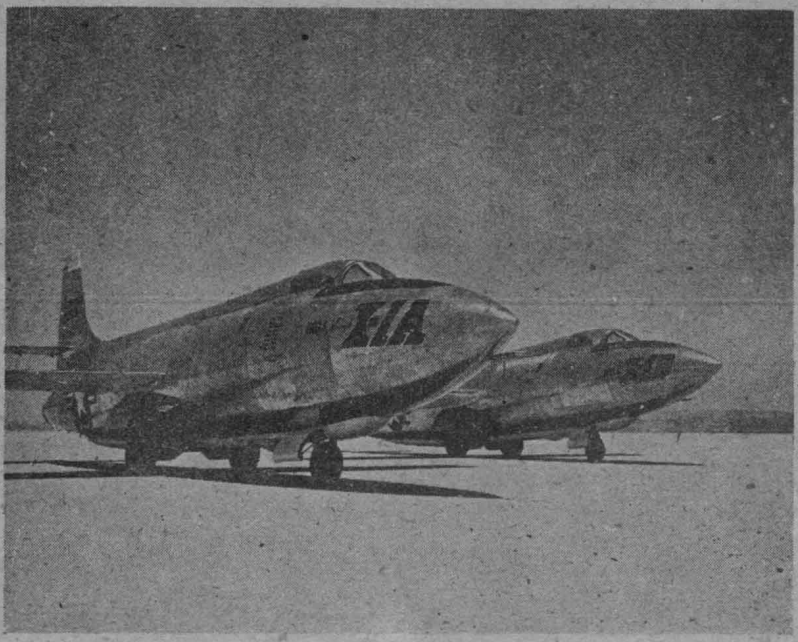

Fig. 1. Bell X-1A Rocket Propelled Aircraft.

Fig. 2. Leduc 0-21 Ramjet Propelled Aircraft.

(Figs. 1 and 2 are reproduced by courtesy from Jane's All the World's Aircraft.)

the applications of the rocket and jet unit, but even when discussing their internal processes. The reader can form a mental picture of three broad lines of research and development, towards the rocket motor, the aircraft gas turbine-jet engine, and the high-speed aeroplane. Up to 1938 these lines can be visualised as completely independent. In 1938 they converged, and they are now continuing side-by-side, closely linked.

The year of " convergence ", 1938, is notable for two important events. During that year rocket-propulsion with a liquid-fuel rocket was first accomplished in flight ; and, towards the end of the year, the first flight of a turbo-jet-propelled aircraft, the Heinkel 178, was achieved. Both developments occurred in Germany ; indeed, many of the advances in all three fields of jet-propulsion, rocket-propulsion, and high-speed flight seem to have been made in Germany at least a year before the corresponding British development.

The present state of development can be represented by the American rocket-propelled Bell X-1A (Fig. 1) which in 1954 set up a record by flying at over 1,600 m.p.h. to become the fastest piloted aircraft in the world ; by the French Leduc 0-21 (Fig. 2) which is the developed experimental model of the first piloted ramjet-propelled aircraft ; and, in this country, by the Fairey F.D.2 (Fig. 3) which was the first aircraft to raise the world absolute air speed record above 1,000 m.p.h. All three, like many other

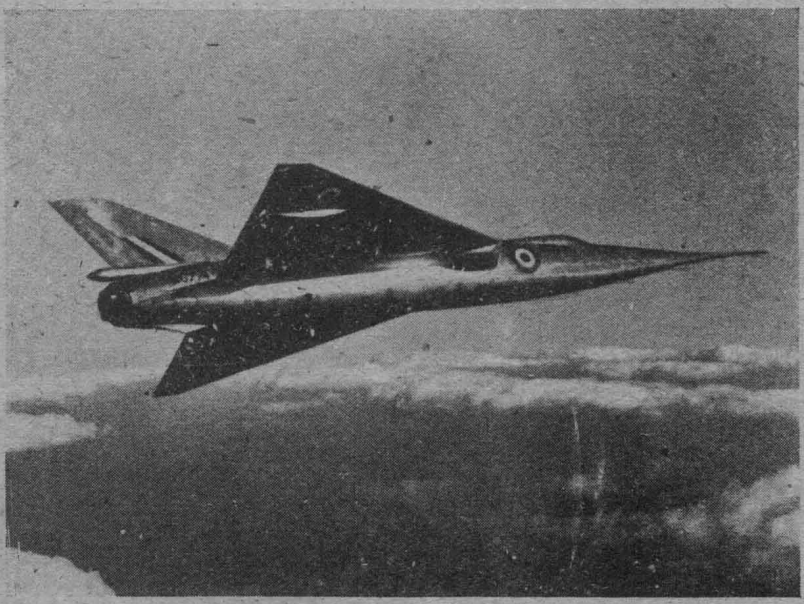

Fig. 3. Fairey F.D.2 Jet Propelled Aircraft.

jet and rocket aircraft, are affected, one way or another, by the problems of flight at speeds near to and above the speed of sound (762 m.p.h. at ground level, 660 m.p.h. at 36,000 ft. and above). Were it not for the increased resistance presented as this speed is approached, even greater progress would have been possible. This is a unique challenge, both to the engine designer to produce the greater thrusts that are required, and to the aeroplance designer to evolve means of reducing the air resistance near the speed of sound. This challenge has been accepted, and many of the facts presented in this book are coloured by the nature of the work thereby involved ; in the circumstances, this is inevitable.

CHAPTER II

MOMENTUM THEORY OF JET AND ROCKET PROPULSION

THE complete jet or rocket engine is a complex system abounding in aerodynamic and thermodynamic problems. Its operation can be understood, however, and many of its basic characteristics derived, without any reference to the internal processes, by a simple consideration of the momentum and energy of the jet. This " momentum " theory will be presented in the next few paragraphs, leaving the internal processes of the unit to be described in later chapters.

It is first necessary to define what we mean by a jet or rocket engine. This might be thought to be superfluous, at first sight, for everyone has a clear perception of a jet ; a high-velocity fluid stream issuing from a nozzle. A jet engine is presumably an apparatus which manufactures such a jet and uses it for propulsion. In fact, however, it is usual to make a clear distinction between the following two types of engine (see Fig. 4) :—

1. The rocket-propulsion unit, in which the propelling fluid is all carried on the aircraft or moving vehicle. This propelling fluid is usually produced by the combustion of a fuel, and in the rocket-propulsion unit not only the fuel, but also the oxidising agent, are carried. Usually fuel and oxidiser are carried separately, but occasionally a single propellent combining both fuel and oxygen is used to produce the propelling fluid.
2. The jet-propulsion unit, in which the fuel only is carried, and the oxygen necessary for combustion is drawn from the outside air. The aircraft employing jet-propulsion is necessarily rather more complicated than the rocket-propelled aircraft, as provision must be made for an air intake. Not all the oxygen drawn in is necessarily consumed ; usually only a fraction of the oxygen supply is needed. The rest, together with the much larger nitrogen quantity swallowed, is merely a diluent in the process : it has the important duty of keeping temperatures low throughout the jet-propulsion unit.

It is entertaining to observe, at this stage, that all aeroplanes are propelled by a jet. They obtain the force necessary to overcome air resistance and to increase speed, by throwing backward from the aircraft a jet of air. This jet usually conforms to the popular conception by being circular ; its difference, from the jet we usually visualise, is that it can have a diameter of the order of 10 feet and be produced by a whirling propeller. The aero-