MALTON AVRO CANADA ONTARIO

GAS TURBINE DIVISION

PROVIDING
a
POWER PLANT
for the
AVRO SUPERSONIC AIRFRAME

PRIVATE

MARCH 10, 1954

UNCLASSIFIED

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FOREWORD

A broad understanding of the nature and behavior of designing, developing and producing a jet aircraft engine is essential to a clear understanding of the details involved. It has been demonstrated in the past that the best possible manner of assimilating an understanding of a complicated and obscure arrangement of facts is by the use of a simile and in this particular case it is highly desirable to approach the task of understanding the details involved in the process under consideration by the use of a simile. While a number of similes do exist which can serve very well to clarify some separate point in the discussion there is only one that adequately demonstrates the whole process.

This simile is the generation, education and life of a human being.

While the process of bringing a jet aircraft engine into existence is, in many respects, a more painful one than bringing a human being into existence, since both of the parties involved are subject to birth pains that do not begin at the time of birth only, but begin at the very start of the process, it is still a striking parallel if the creative design engineering organization is considered as the father and the experimental shop as the mother.

In both cases the result is that an intricate entity is brought into being which must be "brought up" and educated to perform a useful function during its lifetime.

The next phase is the education of each of these entities. In the case of one it is a matter of developing both the mental and emotional characteristics that will prepare the individual to fill a useful place in the social world. In the other case, it is a matter of developing the mechanical and aerodynamic characteristics to enable the engine to fill a useful role in the aviation world.

The schools and universities perform this function in the case of the individual, while the developing and testing organizations perform this function in the case of the engine. The parents, in both cases continue to perform a very useful and indispensable part during this period.

After a long process of this development, both entities are subjected to an examination which establishes whether or not they have reached the stage that they can begin the performance of the task at which this development was aimed. The individual passes an examination and gets a degree. The engine passes a qualification test, and, in effect, gets a degree by the customer signing a contract clearing it for production and flight.

Both of these examinations are evidence of the fact that each one of these entities is ready to begin the task for which it was being prepared over a long period of time.

One major consideration that must be kept clearly in mind is the point at which this degree is obtained must be correctly timed if both the individual and the engine are to be successful. There is a very definite "deadline" between success and failure in both cases. If an individual gets a degree too late to use it in life, or if an engine is developed to qualification test standard after it has become obsolete, both have crossed this "deadline". With the individual this may mean complete failure, with the engine there is no doubt it is complete failure.

Both from this point on must develop or be developed much further before they reach peak efficiency. The one goes through this in learning how to fill a position, while the other one goes through it while being produced and providing the power to fly aircraft.

Adopting an individual and licensing an engine complete this simile. If an individual is adopted early in his life, then the adoptees and the educational institutions have the job on their hands of developing him to a point where he can satisfactorily discharge his purpose in life. If an engine is licensed early in life, then the licensee and the test facilities have the same task. The difference between adopting and licensing compared with doing the complete job is that the entity has been brought into existence only. The work from this point on does not change.

While advice may be given by the creators of the entities, they cannot successfully participate in the "bringing up" process. This must be left in the hands of the adoptees and licensees. Two sets of parents, no matter how close or how far apart they may be, cannot successfully develop one child because their methods of doing it and their ideas on how it should be done are greatly different. Clashes in this respect between them would be inevitable and the results on the child catastrophic. This applies no less to licensing an engine.

If this process is started after the point at which the degree has been obtained, then both the adoptee and the licensee have to accept what has been done with perhaps minor changes only to suit the entity to the changed environments. The point at which basic changes can be made has passed.

If this simile is kept in mind in reviewing this study, it will be much easier to grasp the significance of the things that have been said and to understand the nature of the complicated activities that must be carried out in designing, developing and producing jet engines.

S.H. Deeks
March 15, 1954
Revised: March 31, 1954

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PROVIDING A POWER PLANT FOR THE SUPERSONIC AIRFRAME BEING DESIGNED AND DEVELOPED BY A. V. ROE (CANADA) LIMITED

INTRODUCTION

The consideration before us deals with the most advantageous means by which power plants can be provided when they are required for the supersonic airframe being designed and developed for the R.C.A.F. by A.V. Roe (Canada) Limited. Can this be done by obtaining a license to manufacture an engine designed and developed in some other country, by an arrangement in which A.V. Roe would develop some other company's design, or by A.V. Roe designing and developing an engine of their own? This is the question that must be answered.

A detailed analysis of the factors involved and a thorough examination of each of the courses of action that can be taken will have to be made to determine which one of them is best.

This analysis and examination is carried out in this memorandum in three major parts. These are:

Part 1: The evolution of the design and development of a jet engine.

Part 2: The effect on elapsed time of carrying out the different arrangements which must be considered.

Part 3: The effect on economics of carrying out the different arrangements which must be considered.

The following are comments in summary form related to these three parts:

PART 1

A decision regarding the course of action which should be followed to accomplish our purpose within the time limits established by the airframe deliveries most satisfactorily, most economically, and most advantageously from all points of view can only be made intelligently by understanding what is involved in the evolution of the design and development of a jet engine with respect to the following:

(a) The design period.
(b) The development period.
(c) The elapsed time requirement for a jet engine design and development.

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(d) The pattern of the evolution of a jet engine design and development.
(e) The economics of a jet engine design and development.
(f) The nature of producing an engine under license.

Each of these points is considered separately under Part 1 of this memorandum.

PART 2

Once having reached an understanding of the factors covered by Part 1, consideration must then be given to the effect of carrying out the various means of providing engines suitable for this airframe application to determine which course of action will meet the airframe delivery requirements and at the same time do this in the most economical, reliable and advantageous manner possible.

There are only five different approaches possible in the consideration of this problem. These are:

(a) License an engine after it has been developed to the point where it is suitable for licensing.
(b) Design and develop an engine of another company's design in parallel with the originator of the design.
(c) Design and develop an engine in parallel with another company with their technical assistance.
(d) Procure the engine from some other company in its finished state.
(e) Design and develop an engine in Canada.

Each of these approaches is examined in some detail in Part 2 of this memorandum.

PART 3

The economics of carrying out the various arrangements that can be considered while they are not vital are important and should influence our course of action, if, all other things being at least equal, there is an economic advantage involved. Time, of course, is the essence of this whole matter and must take precedence over economy. The economics of each arrangement is considered in detail in Part 3 of this memorandum.

We believe that the evidence contained herein conclusively demonstrates that:

1. It is completely impractical to attempt to have two companies collaborate in the design and development of an engine regardless of the type of arrangement that is made. Nothing can be gained, but much can be lost by involving two companies in one design, regardless of the point at which an association might be initiated during the design and development periods.

   The reasons for this are:

   (a) Contributions to the design and development of an engine must be made "on the spot". Two companies cannot participate in a design and be at different locations, regardless of how close or how far apart they may be.

   (b) Communication systems are inadequate to substitute for the transmission of information and knowledge by discussion.

   (c) Even if these difficulties were overcome, two companies could not successfully participate in one design without reconciling their design standards and manufacturing techniques. No two companies design, develop and manufacture engines in the same manner and a design, to be successfull in a given company, must reflect that company's standards and methods.

   (d) It would cost much more than designing and developing an engine of our own.

   (e) It would take longer and the result would be having airframes ready to fly with no engines available initially.

2. It is completely impractical to license an engine under a conventional licensing arrangement and hope to deliver engines to the airframe when they are required because such an arrangement would result in:

   (a) A delay of from one to two years compared with A.V. Roe's engine program before the engine is suitable for licensing and a further delay of from one to two years before production deliveries start. This would be from three to four years late for the airframe requirements because our own program is a very "tight" one.

2. (b) The engineering team now working at Malton would have to be disbanded and organized on a smaller basis when some design was ready for licensing, which would possibly be about 1959-60. It would be a difficult task indeed to build up an organization in Canada again to carry out the work required to introduce a design into production and a jet engine production facility cannot operate and produce engines unless it is supported by a fully qualified engineering organization.

(c) The cost of paying the license fees, re-establishing an engineering organization, arranging for release to production and communication expense would be very large. While it is not possible to state definitely what these costs would be, some indication can be obtained from reviewing licensing arrangements of the past.

3. The only possible means of providing production engines on time for this airframe and produce them in Canada is to proceed post-haste with our own design and development program.

PART 1

THE EVOLUTION OF THE DESIGN AND DEVELOPMENT OF A JET ENGINE

This part of the memorandum examines in some detail the evolution of the design and development of a jet engine under the headings referred to in the introduction. These are:

(a) The Design Period

(b) The Development Period

(c) The elapsed time requirement for a jet engine design and development.

(d) The pattern of the evolution of a jet engine design and development.

(e) The economics of a jet engine design and development.

(f) The nature of producing an engine under license.

THE DESIGN PERIOD

During the period of original design there are three major considerations necessary to understanding the nature and purpose of the work involved. These are:

1. The types of organizational units.

2. The objectives these units are attempting to accomplish.

3. The nature of the effort these units must engage in to accomplish their objectives.

1. The types of organizational units involved are as follows:

   (a) Aerodynamic Design
   (b) Technical Administration
   (c) Mechanical Design
   (d) Stress Engineering
   (e) Drafting
   (f) Producibility Engineering
   (g) Experimental Tool Design
   (h) Experimental Machine Shop
   (i) Experimental Procurement
   (j) Development Engineering
   (k) Aerodynamic and Thermodynamic Laboratories
   (l) Mechanical Laboratories
   (m) Test Engineering
   (n) Mock-up Shops
   (o) Production Tooling
   (p) Production Machine Shop
   (q) Production Procurement

   Figures 1 and 2 demonstrate both the type of work required by each of these organizational units as well as where it starts in the programme. Each of these units have specific tasks they must accomplish during the design period to ensure an efficient operation during the development and production phases of the programme.

   The important fact to note about these activities is that they go on in parallel during the greater part of the design period as is demonstrated in figure 2 and that they are interrelated as is demonstrated in figure 1.

2. The objectives these units are attempting to accomplish during this period are as follows:

   (a) Design an engine that will:

      (1) Meet the design specification.

2. (a) (Cont'd)

(2) Be producible on experimental shop machine tools.

(3) Be economically producible on production shop machine tools.

(4) Be producible from materials that are available now or will be available when production starts.

(b) Make preparations for providing the development organization with engines as follows:

(1) Make changes in experimental shop tooling.

(2) Procure materials for building experimental engines.

(3) Procure or manufacture experimental parts for first batch (about three) development engines.

(4) Build first experimental engine.

(c) Make preparations to satisfy contractual requirements as follows:

(1) Prepare preliminary model specification

(2) Prepare mock-up of engine.

(3) Ensure installation suitability of engine.

(d) Make preparations for testing engines and components as follows:

(1) Prepare test beds for engines.

(2) Modify component testing apparatus for testing parts.

(3) Build test specimens of components.

(e) Make preparation for production of engine as follows:

(1) Review production tooling.

(2) Commence to develop sources of production material in conjunction with experimental procurement.

3. The nature of the effort these units must engage in to accomplish their objectives:

There are two major considerations necessary to understanding the activities during this period and their effect on the remainder of the programme . These are:

(a) The reasons for the various activities.
(b) The nature of the process of an engine design activity.

(a) The reasons for the various activities

Briefly the reasons for the activities during this period are to:

(1) Provide an ongine with which the development engineers can begin the testing program. .

(2) Prepare for the development program that must begin as soon as the engine is available.

(3) Commence preparation for the production program.

The important consideration under this item is that all of these activities must occur during the design period or a serious delay will occur in the development period which will reflect itself all the way down the line to a delay in production deliveries.

The design and preparation of test facilities and apparatus is just as important as the design of the engine. Lack of proper facilities at the correct time can have just as serious effect on delaying the program as lack of some vital part of the engine.

A. V. Lovesay O.B.E., B.Se., FR.Ae.S. in his lecture before the Royal Aeronautical Society, London, said: "The design of the testing program for an engine and its components is no less important than the design of the engine itself, and time devoted to careful thought in this direction is well repaid. The design of special equipment or instrumentation should run in parallel with the main design so that when the engine or component is built special test apparatus is available for the first run."

(b) The nature of the process of an engine design activity

In some respects at least, designing and building the first

3. (b) (Cont'd)

engine is not greatly different from designing and constructing a building. The architect must prepare plans and then in conjunction with all kinds of building skills, convert those plans into a physical structure. Collaboration is essential and each different skill has to contribute his part at the right time and in agreement with the others, or the results are anything but satisfactory. The major differences in building a jet engine are that this collaboration must begin at the stage of preparing the plans and when the engine is built the work has just started, not finished.

The principal consideration is that the organizational units involved must work very closely together during this period. As in constructing a building, everyone must be on the location to make their contribution, and their contribution must be made in the correct sequence. The reason for this is that a contribution cannot be made by any one of them singly. It must be made in conjunction with and with the concurrence of one, or more of the other units. Independent decisions are normally impossible.

It is not a matter of completing one part such as in a machine shop operation and forwarding it to stores. It is a matter of progressing the whole design at the same rate. Each part is designed in parallel since a change in one can effect one or more of the others or a change of material in one part can drastically effect the whole design.

Numerous changes are made during this process. The evolution of the design of one part can have as many as twenty sketches before the design is final and in the more complicated parts the number is much higher than this. An example of the type of work that is done can be observed by referring to figure number 14. This shows the evolution of the design of a turbine blade. By multiplying the number of sketches per part by the number of parts in an engine, some understanding of the magnitude of the task can be reached. Literally thousands of sketches must be prepared. All of these sketches have to be discussed among and must be co-ordinated by the organizational units involved before the design can be finalized.

THE DEVELOPMENT PERIOD

This period begins as soon as a development engine is available and has as its major goal the development of the engine to a standard dictated by the contractual specification. It reaches this goal when it passes its qualification test. Subsequent development has as its objective improvements in this standard with respect to performance, mechanical reliability, production facility and service improvements. Consideration of this period is reviewed under the same headings as the "Design Period".

1. The same organizational units that were outlined in the "Design Period" carry on during this period with their objectives somewhat altered. As soon as the engine runs most of the engineering organization performs a service function to the development engineers in their efforts to develop a satisfactory product.

2. The objectives during this period are:

   (a) Develop the engine mechanically and aerodynamically by ground running until it is suitable for flight in a flying test bed.

   (b) Flight test the engine in a flying test bed to establish that the aerodynamics are satisfactory at altitude and ensure that it is suitable to install in an airframe as a prime mover.

   (c) Carry out both flight testing and ground running to prove the engine is satisfactory for use in service in the Air Force and that it will comply with production requirements.

   (d) Pass on official qualification test that certifies the engine has reached the requirements of (c) above.

   (e) Commence producing and assembly of parts.

3. The nature of the work involved in this process is also evolutionary because many of the parts as represented by the first paper design are not suitable for release to production. They must go through a long proving process first and be changed a number of times before they can be released. Those that are suitable must also go through the same tests as those that are not because at this stage it is not known whether or not they are suitable.

The essential difference between changes in the design that are

3. (Cont'd)

made in the development period compared with those made in the design period is that the engine now demonstrates what is unsatisfactory and providing the test engineers can correctly interpret what the engine is attempting to tell them the amount of assumption is much less than that required during the original design. The original design must, of necessity, be based on calculations and assumptions.

This proving process during this period requires that about eight thousand engine running hours on the ground be run as well as about one or preferably two thousand flying hours. Many tests on components must also be carried out on both aerodynamic and mechanical test rigs separate from engine running. This latter type of test is used where the trouble is local and of mechanical origin. The rigs which are used are constructed in such a manner that they similate the engine conditions. Running is carried out without the expense and sometimes the time penalty of engine running.

This whole process is one of "trial and error" and the development engineers must try out many different schemes to solve a problem. In some cases a number of these schemes are tried before the design is changed, so that the number of trials is a multiple of the number of changes made.

Experience has proven that a part goes through an average of four changes during this period and these involve an average of ten drawing changes each. An engine has as many as three thousand to four thousand parts and consequently there are thousands of drawing changes made during this process.

Figure 3 shows in chart form the various relationships of the organizational units during this period.

Figure 15 shows an historical record of changes required to solve a representative problem.

The changes, resulting from development experience made in the design standard as originally laid down must go through the same process as the original paper design. Everything that was said about the original paper design applies during this period as well. The organizational units must make a common effort in parallel to make these changes satisfactory.

In briefer terms, the whole process involves the manufacture of

3. (Cont'd)

parts and building them into engines, or test rigs and running the engine or rigs until faults and weaknesses are found and then going through this cycle over and over until the development engineers are satisfied that the part is suitable for inclusion in the qualification test engine and release to production. The changes resulting from these activities are made progressively in the drawings, parts lists and specifications so that these are satisfactory for release to production as soon as the engine has demonstrated its suitability for production and service.

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THE ELAPSED TIME REQUIREMENT FOR A JET ENGINE DEVELOPMENT

The period of elapsed time required for the design and development of a new aircraft engine is well established, and supported, not only by the ten to twelve years experience the world has had in the jet engine field, but also the broader experience in the piston engine field.

The total elapsed time required for the design and development of a jet engine from the time the creative designers and engineers start making calculations, sketches and drawings, until the engine has passed its qualification test at its rated performance, is normally five years, and the period of time from passing the qualification test until deliveries to the airframe for which the engine is intended is from one to two years, or a total of from six to seven years from the commencement of design until the first production delivery.

Figure number 6, together with the relative comments shows the history of some of the major jet engine developments of the world, and demonstrates this to be factual.

Since changes in human activity involving intellect, education and technology, all of which are essential to this type of endeavour are progressive, and not instantaneous, it is certain that we can expect history to repeat itself with some improvement in elapsed time in the next cycle of jet engine design and development which is the one under consideration. The principal factor contributing to the shortening of the elapsed time is the progress that has been made in the technology, art and science related to this field of endeavour. Part of the gain in this respect is offset by the increased complexity of the engine and therefore the gain in elapsed time is less than would be expected.

History has demonstrated conclusively that any company in the world today would still require from four to five years to create and develop a completely new design of a jet engine to qualification test standard and from one to two years from passing qualification test to prove it in production and to deliver the first production engine.

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THE PATTERN OF EVOLUTION OF A JET ENGINE DEVELOPMENT

Within the total period of seven years a pattern is followed in the design, development and production proving of a jet engine. The following periods of elapsed time between each stage of design, development and production have been established as normal:

Beginning of the design to first experimental engine delivery	15 months
First engine run to first flight	23 months
First flight to qualification test	22 months
TOTAL	60 months
First production engine delivery	12 months
Proving in production	12 months
	84 months

Confirmation of these periods can be obtained by reference to figures numbered 7 to 10 and their relative comments.

THE ECONOMICS OF A JET ENGINE DEVELOPMENT

The process of designing and developing a jet engine up to qualification test standard, as has been demonstrated covers a period of from four to five years, and follows a definite pattern. Closely related to this is the fact that the cost of designing and developing a jet engine also follows a pattern and is confined within a total limit.

These two factors are closely integrated and any change in the one effects the other. Lack of funds in the correct amount at the right time can lengthen the elapsed time considerably and consequently increase the costs. Failure for other than economic reasons to stay within the four to five year period can also increase the cost considerably.

Consideration of these facts is arranged under two major headings. These are:

1. The total cost of designing and developing an engine to qualification test standard.

2. The relationship of costs to the different types of effort required or the economic pattern of designing and developing a jet engine to qualification test standard.

1. The total cost of designing and developing an engine to qualification test standard

The following costs which are related to three of the major axial flow engines in production today, which are also reflected in figure number 11, demonstrate that from $30,000,000 to $40,000,000 are required to design and develop an engine to qualification test standard.

(a) $22,000,000
(b) $45,000,000
(c) $32,000,000

Within this total amount, a definite pattern of expenditure is followed, and each type of expenditure represents the different types of effort which are required on different phases of the programme.

In addition to history substantiating the total costs, a detailed analysis under present day conditions of the manpower and material requirements for designing and developing a jet engine to qualification

1. (Cont'd)

test standard has been made which also demonstrates that these total costs will fall within the $30,000,000 to $40,000,000 range. Figure number 12 shows these costs in graph form.

2. <u>The relationship of costs to the different phases of a design and development programme</u>

The following table of expenditure indicates the cost of the various phases of the programme required to design and develop a jet engine to qualification test standard:

Aerodynamic Design	$ 445,000
Mechanical Design	2,009,000
Building Experimental Engines	18,479,000
Testing	6,713,000
Development	1,453,000
Material Costs	10,621,000
	$ 39,720,000

Figure 12 indicates the cumulative effect of these costs over the four to five year period of design and development.

THE NATURE OF PRODUCING AN ENGINE UNDER LICENSE

A licensing arrangement can only be made successfully when there is something satisfactory to license, that is, a product that has not only been designed and developed, but one that has also proven its produceability. When this has been done, the licensee can undertake to produce the engine as issued to them at this stage, or in other words, to make a copy of it with freedom only to make changes that will not effect the design standard as represented by the licensor's drawings, parts lists and specifications.

It is on this basis that most, if not all, successful licensing arrangements have been conducted. This is evident by an examination of the licensing arrangements of the past. (See Fig. 13-2)

Air Commodore Banks, in his speech at the Eighth Annual Flight Propulsion Meeting I.A.S. Cleveland entitled "The Birth of an Engine", said "When considering a licensed engine, it is important not to make any changes from the original purely to facilitate production. In fact, a licensed engine should be a "chinese copy" of the original with regard to both materials and manufacture.

"An engine that has just passed the type or model test, is still in the early development stage and, therefore, more vulnerable to engineering and material changes".

When a licensing arrangement is considered it can only be considered, from a practical point of view at least, to take effect when the licensor has a proven finished product to license. The licensor does not have a proven finished product in the jet engine industry until it has passed the production phase when numerous changes are being made. These are required as a result of the fact that when the engine is first being produced it is "still in the early development stage". This proving period is from one to two years after the qualification test has been run.

The licensee does not have a clear release of the licensed design until this stage is passed and then he must still take additional time to complete his production arrangements and then produce and start to deliver engines. This is another period of from one to two years.

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PART 2

THE EFFECTS OF CARRYING OUT DIFFERENT ARRANGEMENTS TO PROVIDE AN ENGINE FOR THE AIRFRAME UNDER CONSIDERATION

This part of this memorandum examines in some detail the five considerations referred to in the introduction regarding the different approaches that can be considered for providing an engine for the airframe under review. These are:

(a) License an engine after it has been developed to the point where it is suitable for licensing.

(b) Design and develop an engine of another company's design in parallel with the originator of the design.

(c) Design and develop an engine in parallel with another company with their technical assistance.

(d) Procure the engine from some other company in its finished state.

(e) Design and develop an engine in Canada.

LICENSE AN ENGINE AFTER IT HAS BEEN DEVELOPED TO THE POINT WHERE IT IS SUITABLE FOR LICENSING

If a licensing arrangement is considered, it must be on the only reasonable basis of carrying out a licensing arrangement, and that is to license an engine that has proven itself in production. Our course of action to provide an engine by this means is either one or the other of the following:

(a) Find a satisfactory engine which is proven in production and then license it immediately.

(b) Failing this, wait until a satisfactory engine has progressed to the point where it is suitable for licensing.

We can dispose of choice (a) immediately, because it is known that no engine is in production at the present time that is suitable for the production installation requirements of the airframe under consideration.

This leaves us with choice (b) only, and at this point we must examine whether or not this can be accomplished and still meet the date on which engines are required.

Figure No. 5 indicates the elapsed time required to carry out an engine design and development and to release this design and place it in quantity production. It is necessary for us to establish at what point in this cycle the licensor can release the design to the licensee and comply with a conventional licensing arrangement.

Reference is again made to Air Commodore Banks' statement that "An engine that has just passed the Type or Model Test is still in the early development stage and therefore more vulnerable to engineering and material changes".

It is only at the point where most of these changes have been made, that the licensee can satisfactorily produce the design, which would be from six to seven years after the licensor began the design. Added to this period is the time required by the licensee to get the engine in production and deliver engines. This would be an additional period of from one to two years. The total elapsed time, therefore, for a licensed engine to reach production deliveries in the licensee's plant from the beginning of the design by the licensor is from seven to eight years.

The target date for the pilot batch of production aircraft is 1958. In order to meet this date, we will have to begin to deliver engines no later than the fall of 1958.

Starting from this date and going backward, we would have to find an engine that had:

(a) Commenced its design in the fall of 1950
(b) First engine run about the fall of 1951.
(c) Qualification test to be passed early in 1955.
(d) Proven for production and ready for licensing early in 1957.

There is no engine, to our knowledge, suitable for this application that is in such a state of development. The engines which might be considered suitable are at least two years behind this schedule.

Since it is obvious that a licensing arrangement conducted on the conventional basis of licensing the engine after it has been proven in production is unsatisfactory from a time point of view, the question naturally arises, "What can be done, if anything, to eliminate or shorten this time discrepancy?" The only thing that possibly can be considered is to bring the licensee into the design before the engine is developed to qualification test standard, and proven itself in production. If such a course of action were considered, and it was agreeable to all the parties involved, then the consideration is "What type of arrangement should be carried out, and at what point should the licensee be introduced to the design?"

These alternatives are considered under headings (2) and (3) referred to in the introduction.

DESIGN AND DEVELOP AN ENGINE OF ANOTHER COMPANY'S DESIGN IN PARALLEL WITH THE ORIGINATOR OF THE DESIGN

No such arrangement, to our knowledge, has ever been undertaken, but for the purpose of exploring every possible angle, we should at least examine the conditions in which such an arrangement would be involved.

The question that must first be answered is "At what point should the licensee commence picking up the design?"

We have already considered in some detail the various phases of activity in the design and development of an engine to qualification test standard and it is only up to this point that the possibility of such an arrangement needs to be considered, since any arrangement after this point would obviously be a conventional licensing arrangement, which has already been discussed.

This narrows our considerations down to the following phases in the pattern of design and development:

1. Beginning of the design to the first engine run.
2. First engine run to Flight Substantiation Test.
3. Flight Substantiation test to Qualification test.

Each of these periods are considered separately hereunder.

1. Beginning of the Design to the First Engine Run

If it were considered advisable to introduce the licensee to the design during this period there are two factors which must be thoroughly examined before a decision is made. These are:

(a) What part can the licensee effectively take to accomplish our objectives.
(b) What is the effect of the nature of the activities on the part played by the licensee.

What part can the licensee effectively take to accomplish our objectives:

There is no means of having the licensee involved in the design during this period except by actual participation in the original design because there is nothing else with which he can become involved.

1. Beginning of the Design to the First Engine Run (Cont'd)

What is the effect of the nature of the activities on the part played by the licensee:

An examination of the nature of the work that is carried on during this period is essential to determine whether or not the licensee could participate in the design.

The objectives of the activities during this period are covered in Part 1 of this memorandum. A review of these objectives, together with Figure 1, 2 and 14, will demonstrate the impractibility of two companies at different locations participating in the same design.

As indicated in Part 1 under the "Design Period", the means of accomplishing these objectives is not an activity where one person performs an operation and passes it on to the next one, somewhat after the manner of parts flowing through a machine shop. It is a co-ordinated effort of several different types of organizational units operating in parallel.

Because it is a process which goes through an evolution to which different types of contributions are made by different types of organizational units, the participants must be sitting side by side to make the contribution.

This is further complicated by the fact that no two engineering organizations evolve the design of an engine in the same way or with exactly the same results.

2. First Run to Flight Substantiation Test
Flight Substantiation Test to Qualification Test

These two periods need consideration in parallel since they are subject to the same conditions as defined under the Development Process in Part 1, the difference being one of degree only.

Since the licensee is attempting to duplicate the development he must be advised of every change the licensor makes and reflect that change in his development program.

Reference is here made to the Development Period and the charts shown in Figures 2, 4 and 15, which demonstrate the activity involved during this period.

2. First Run to Flight Substantiation Test
Flight Substantiation Test to Qualification Test (Cont'd)

Attention is especially directed to the number of changes that have to be made to the engine design during this period, which can result in thousands of drawing changes and each of these changes have to be communicated to the licensee.

The communication system required to accomplish this obviously would have to be a tremendous one, but the point that must be stressed here is that no communication system can substitute for the "across the table" exchange of information and the co-ordinated contributions that have to be made to successfully design and develop an engine.

It must be remembered here that the licensee must not only be advised of the change, but he must understand the reason for it and what it is intended to accomplish. Even if this difficult problem were overcome, in order to duplicate the development, the results obtained from tests and the conclusions reached as a result of analysing tests would have to be the same. This would be a humanly impossible task. Results on engines produced from the same drawings are not the same and consideration of getting the same results on different engines in different companies in different countries where thinking and methods differ would be completely unrealistic.

It is possible to give consideration to resolving difference and deciding on a common result, but here again this is not realistic because of the rapidity with which changes are made. A part on which differences are being resolved would be going through additional changes in parallel with resolving differences and nothing but confusion and frustration could result from such action. If this were not done, then each company would be designing and developing different engines, which would be a violation of the terms of this arrangement and would make it null and void.

Once having embarked on such a program, we must not lose sight of the fact that we have committed ourselves to the co-ordination required as a result of introducing changes in the design that will originate in production after qualification test has been passed. Here again, we can be involved in a tremendous number of changes, all of which would be subject to the same difficulties outlined above for changes up to qualification test.

2. First Run to Flight Substantiation Test
Flight Substantiation Test to Qualification Test (Cont'd)

Our conclusions are that this course of action is completely impractical, both from an economic and elapsed time point of view. It would cost twice as much at least to take an indeterminate longer period of time and the results would obviously be unsatisfactory.

DESIGN AND DEVELOP AN ENGINE IN PARALLEL WITH ANOTHER COMPANY FROM THEIR DESIGN AND WITH THEIR TECHNICAL ASSISTANCE

If such a course of action as this were considered, it must be considered in the light of the stage of development that has been reached by prospective engines that would be suitable for this application, together with the advantages and disadvantages that would result when compared with the program of the distinctly Canadian designed and developed engine which is being carried on as a private venture by A.V. Roe.

A licensing arrangement made at this time, of any engine design suitable for this application, would provide the licensee with a paper engine only. It could not be more than this since more than this does not exist.

The engine being carried as a private venture by A.V. Roe has reached the point of a paper engine, and therefore, our consideration is confined to examining the merits of A.V. Roe Canada picking up a paper design of some other company, if such merits exist, and dropping their own engine.

These merits can only exist in one of the following factors:

1. Economic advantage.
2. Shortening of time period required to deliver engines.
3. Reliability of the design.

These factors are considered separately hereunder.

1. Economic Advantage

The question of economics has been treated separately and reference here is made to Part 3, which demonstrates that there would be no economic advantage but that it would cost considerably more as a result of licensing or technical assistance and communication costs.

There would be no advantage in this respect.

PART 3

FIGURE INDEX

2. Elapsed Time

While it is not possible to determine the delay that would result, it is obvious that a considerable delay would be inevitable. This is due to the following facts.

(a) Negotiations would have to be completed and arrangements made for information to be communicated to us.
(b) Our engineers would have to become familiar with a new engine design and commence to alter it to suit our manufacturing techniques and material supply.
(c) The morale of engineering staff would take a very severe drop and the enthusiasm and impetus that has been generated in our staff for our own engine could not possibly be duplicated.

No advantage could possibly result as far as improvement in elapsed time is concerned. On the contrary, a very serious delay would result and since the program for provision of an engine for this application is already an extremely difficult one to meet, it would be inevitable that we would fail to meet the production dates for the production airframes under such an arrangement.

3. Reliability of the Design

The consideration under this heading of necessity involves a comparison of the capabilities of the aircraft engine companies who are designing engines suitable for this application.

Since we are examining the implications of licensing an engine at the paper stage only, the question of mechanical reliability is a somewhat irrelative consideration, since regardless of whether we develop our own paper engine or develop a licensed paper engine, the mechanical reliability of the engine is dependent on A.V. Roe.

Consideration is confined to the aerodynamic reliability of the design. History will bear evidence to the fact that the Engineering Department of A.V. Roe Canada possesses the ability to produce aerodynamic designs which are second to none anywhere.

This is not an unsupported general statement. Evidence of its authenticity can be observed from facts about aerodynamic engine designs from several of the world's best aircraft engine firms in Figure No. 16.

3. Reliability of the Design (Cont'd)

Our conclusions under this consideration are that there is nothing to gain and much to lose by licensing someone else's paper engine. It would cost more, take longer and there is no guarantee that the reliability of another company's aerodynamic design would be greater than our own. On the contrary, there is evidence to indicate that it might not be as good.

PROCURE THE ENGINE FROM SOME OTHER COMPANY IN ITS FINISHED STATE

While it is conceded that such action as this could be taken with reasonable assurance that an engine would be made available when required, there are three major factors which require serious consideration before such action was initiated.

These are:

1. The effect on Canada's industrial life.
2. The effect on the jet aircraft engine industry in Canada.
3. The dependence on another company in another country to provide engines to us during armed conflict.

1. The Effect on Canada's Industrial Life

The consideration of this factor involves both the economic and industrial life of Canada. It is impossible in a few short lines to demonstrate the tremendous effect of an aircraft engine industry on the technological advances, the manufacturing techniques, the new types of machine tools, the development of new materials, the technical educational programs and other aspects of industrial activity in a country, but it must be remembered that the aircraft engine industry is the prime pioneer of progress in these things. Any country that wishes to establish and maintain itself in the vanguard of the nations leading the world to a mature and well developed economic and industrial life cannot do so without the pioneering resulting from such an industry. It was the aircraft industry that gave America much of its manufacturing potential today--that gave the world such materials as magnesium, nickel and aluminum that created new arts and sciences whose application is almost universal in their relationship to manufacturing industries other than the aircraft industry.

Second rate nations must remain second rate nations without an aircraft industry. It is impossible for a country without an aircraft industry to keep pace with other countries who do have aircraft industries.

2. The Effect on the Jet Aircraft Engine Industry in Canada

Obviously the jet engine industry as established with great foresight on the part of the Canadian Government and which has now developed from adolescence into prime manhood over the years since 1946 would be completely redundant. The engineering talent would be scattered to the four winds, mostly outside Canada, where they would seek work congenial to their qualifications and interests.

The manufacturing facilities established at great cost would be diverted to some use less relative to industrial growth and national safety.

3. <u>The Dependence on Another Company in Another Country to Provide Engines to us During Armed Conflict</u>

This is the most serious of any of the disadvantages of following this course of action. If the technical and production facilities in a country on which we were dependent for engines for our aircraft were destroyed, our airframes would be valueless.

Even if the country were not destroyed, the best that we could hope for under conditions of armed conflict would be secondary consideration. Any country in such circumstances would be preoccupied with its own safety. Our requirements would likely receive first consideration only to the extent that they contributed to the other country's safety. Beyond this, our requirements would be secondary.

We feel very strongly that we should be self-sufficient as far as it is possible for us to be.

From all these points of view, the advantages are all in our favour if we decide to design, develop and produco our own engine, rather than procure one from another country.

DESIGN AND DEVELOP AN ENGINE IN CANADA

The conclusions developed from all other alternatives for supply of an engine for this airframe demonstrate that, when time and economy influence the consideration, the only way to produce an engine in Canada in time to fly the aircraft and at reasonable cost is to proceed post-haste with A.V. Roe's own design and development program.

This conclusion is based on the following facts:

1. A.V. Roe has an engine design at almost as advanced a stage as any other engine suitable for this application and they are proceeding with the program of design and development of this engine with dispatch.

2. The program laid down for this engine as shown in Figure 17, which, while it is better than has been done in the past, is not unrealistic. This program will provide production engines on time.

3. A.V. Roe have demonstrated their ability to design and develop jet engines within the same period of elapsed time, within the amount of expenditure of money and with equal reliability in both aerodynamic and mechanical design when compared with any engine design and manufacturing company in the world.

4. Success and security generates complacency and consequently impetus and the "will to win" suffer when such a condition exists. When a condition exists whose final result is one of "life or death", impetus and the "will to win" receive a stimulus that cannot be provided any other way. This type of condition exists when we are at war.

   The A.V. Roe engineering team find themselves in a somewhat similar situation. They realize that only by meeting the engine requirements for this application with respect to performance, economy and elapsed time, can they survive. The impetus and will to win generated by this condition cannot possibly be duplicated anywhere in the world today because there is no other organization that depends for its existence on this one program.

   This ensures that the Canadian Government will get more for each dollar invested in A.V. Roe than they can possibly get elsewhere.

PART 3

THE EFFECT ON ECONOMICS OF CARRYING OUT THE DIFFERENT ARRANGEMENTS DISCUSSED IN PART 2

This part of the memorandum deals with the economics of the various arrangements under consideration using the same headings as the discussion in Part 2. These are:

(a) License an engine after it has been developed to the point where it is suitable for licensing.

(b) Design and develop an engine of another company's design in parallel with the originator of the design.

(c) Design and develop an engine in parallel with another company with their technical assistance.

(d) Procure the engine from some other company in its finished state.

(e) Design and develop an engine in Canada.

LICENSING AN ENGINE AFTER IT HAS BEEN DEVELOPED TO THE POINT WHERE IT IS SUITABLE FOR LICENSING

Of necessity, remarks regarding economics under this heading must be general. It is not possible to know what the economic arrangements would be, but history can provide some indication of what might be expected as far as license fees are concerned. Reference is here made to Figure number 13 which indicates that the license fees alone could equal a very large portion of the cost of designing and developing an engine of our own. As a matter of fact Robert Schlaiffer says licensing a foreign engine would be no cheaper than designing and developing an engine of our own.

In addition to the original license fee, there would be costs in connection with:

1. Production royalties

2. Communication which would be very extensive. Literally thousands of explanations would have to be made by the original designers in getting the design into production.

3. Familiarizing an Engineering staff with the licensed design.

4. Establishing a new engineering team when the licensed design is ready. The existing team would be disbanded since there would be a period of from three to four years in which there would be nothing for them to do.

5. Altering the licensor's drawings so that our production personnel could interpret the drawings or alternatively training the production staff to interpret the drawings in accordance with the licensor's design and drafting standards.

6. Developing sources of supply for materials which would not be used in a Canadian design.

7. Changing our tools and manufacturing techniques to suit the licensed design. These changes would be those that would be in addition to what would be required by a Canadian design.

Some indication of the cost of placing a licensed design in production can be obtained by reference to the Pratt & Whitney license arrangement with Rolls Royce on the Nene and Tay engines. Each of these engines absorbed over 1,000,000 manhours in changing the drawings and getting the design into production. In terms of today's costs per manhour in labour, material and overhead, this would amount to many millions of dollars. Our problem would in some respects be more complicated than this license arrangement since Pratt & Whitney had an engineering organization waiting and both ready and willing to tackle the problem. At the time a licensed design would be ready for us to tackle, we would have to build such an organization.

DESIGN AND DEVELOP AN ENGINE OF ANOTHER COMPANY'S DESIGN IN PARALLEL WITH THE ORIGINATOR OF THE DESIGN

The assumption in the beginning of this argument, is that some company, suitably qualified would be agreeable to a course of action that would commit them to permitting another company to have free access to all the information during the evolution of their design and development of an engine that would enable A. V. Roe Canada to duplicate the effort in their own plant. It is advisable to point out that they would not likely agree to such action.

The point at which this arrangement begins is irrelative insofar as costs are concerned, since both companies would be developing similar engines in parallel, and the cost in both companies would not be less than if they were each independently developing their own design. They would actually be more costly, since additional effort would be required in both cases in connection with carrying out the technical assistance programme and very extensive communication costs would also be incurred.

The savings initially would be the cost of the aerodynamic design activity for the first twelve months in the company receiving the technical assistance. This would amount to approximately $100,000. This would be a very small contribution towards the cost of liaison and technical assistance.

THE EFFECT ON THESE COSTS OF CARRYING OUT A TECHNICAL ASSISTANCE PROGRAM

In consideration of the effect of eliminating certain parts of a program of engine design and development, we can, by identifying this part with the type of effort involved, together with the relative cost of the effort determine the changes in total cost of the program.

If a decision were made to start on a program of collaboration with some other company in the design and development of an engine, the first logical starting point would be when the contributing company had something on which collaboration could begin.

The first point would be at the paper engine stage, which would be about one year after the design started. The effect on the economics of such an endeavour can be observed from reference to Figure 12. We would not be required to spend a part of the $445,000 for the aerodynamic design. As indicated previously this would amount to approximately $100,000. This part would be the cost of this effort for the first twelve months only, since aerodynamic design work would have to carry on subsequent to this in parallel with the mechanical design.

Starting at this point, we would have to begin with the aerodynamic design provided to us and carry out all the remaining types of effort in the same manner as we would for our own design, except we would have additional costs to pay to the contributing company for their technical assistance, plus cost of communication.

Regardless of the point, between the commencement of the design and the qualification test, at which a technical assistance arrangement was placed into effect, the economic results would be the same. The reason for this is that regardless of the point at which collaboration began, the only reasonable approach is for both companies to develop separate engines in parallel and consequently we would save only the part of the aerodynamic design costs referred to above in the licensee's plant. At this point, we must not overlook the fact that the Canadian effort for producing an aerodynamic design at the point it could be licensed has already been expended, and looking at the whole problem from the point of view of the expenditure of effort nothing would be saved but a considerable loss would be sustained because of the additional effort required to become familiar with and prepare for the production of a different design than our own.

The advantage of beginning the collaboration later would be that the contributing company would be in a better position to provide technical assistance and the aerodynamic design would be developed further. The disadvantage is, that we would still have to go through the normal cycle of design and development, no matter when we started, and the later we started, the later we would have production engines.

FIGURE INDEX

PROCURE AN ENGINE FROM SOME OTHER COMPANY IN ITS FINISHED STATE

The question of economic advantage cannot be considered under this item because it is not known how the design and development costs would be applied to production, nor is it known whether the engine would be produced for more than this application.

It can be safely said that design and development costs would not be greatly different from these costs on our design and development and that if the engine were exclusively designed, developed and produced for this application, there would be no economic advantage.

DESIGN AND DEVELOP AN ENGINE IN CANADA

There is no means by which an engine can be designed and developed more economically than by designing and developing our own engine. This cost will be between $30,000,000 and $40,000,000, but can be considered an investment rather than an expense in view of the great contribution to the industrial and economic growth it makes to this country. It is not only an investment in national growth, but what is, in some respects more important, an investment in national safety. By no other means can we be self sufficient in the contribution this industry makes to national safety.

CONCLUSIONS

The conclusions reached from the considerations of this study are that:

1. We cannot undertake to develop another company's design without:

   (a) Delaying the production programme of an engine for the airframe.

   (b) Spending more money than if we designed and developed our own engine.

2. We cannot undertake a licensing arrangement without delaying the production of engines for the airframe by from two to three years.

3. We cannot buy a production engine without serious repercussions on our economic and industrial growth and national safety.

4. We can only fulfill the time schedule and not only maintain, but improve on our economic and industrial growth as well as save on both effort and money by designing, developing and manufacturing our own engine in Canada.

5. Nothing can be gained by waiting for some other engine design to prove itself more satisfactory than our own, since there is no means by which another engine can be produced in Canada in time for the production airframes. Much good can result from the Canadian Government providing its support of this Company's effort since they alone have the power to remove some of the obstacles that are presently causing some concern to those responsible for this project.

INDEX TO FIGURES

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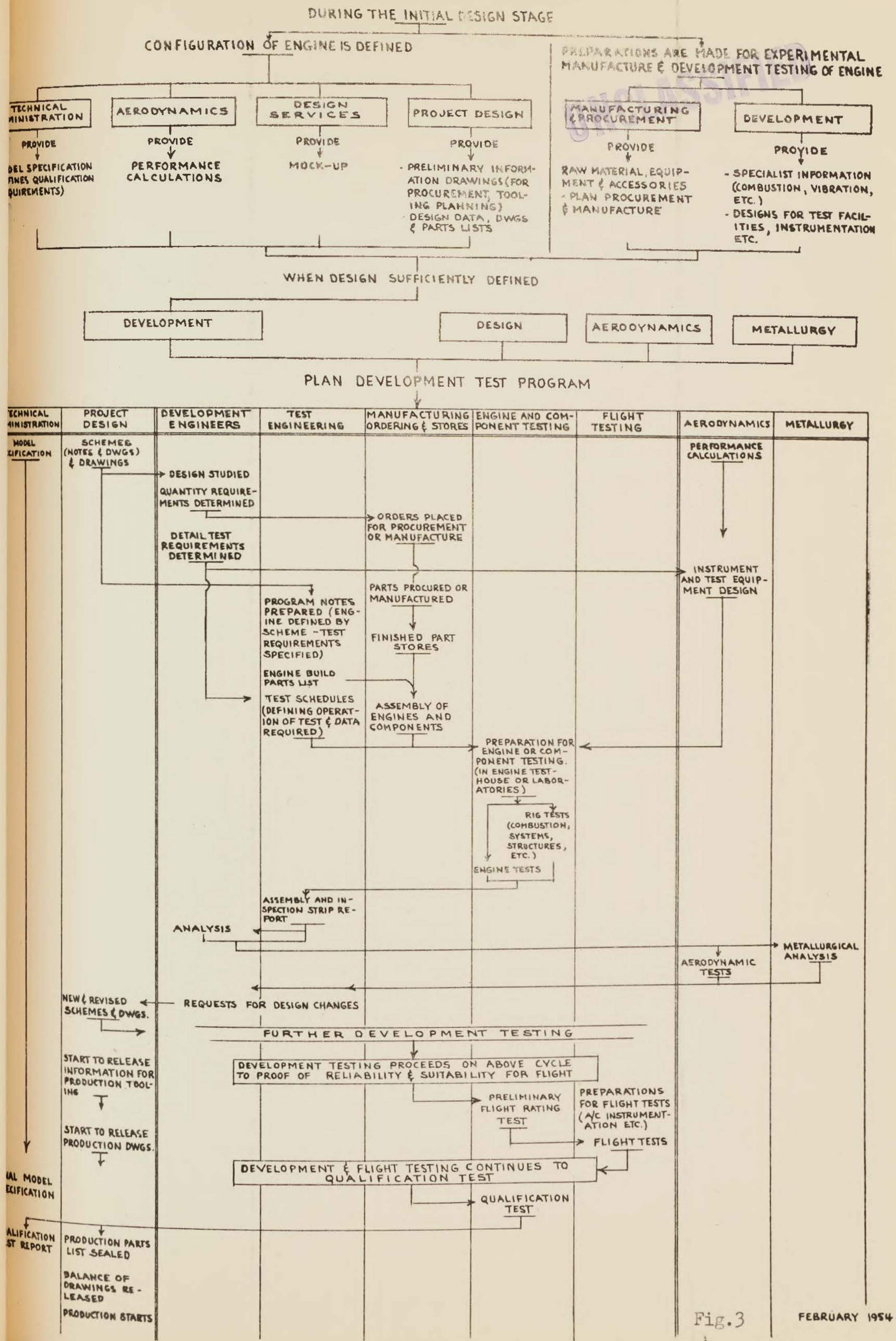

Fig.3

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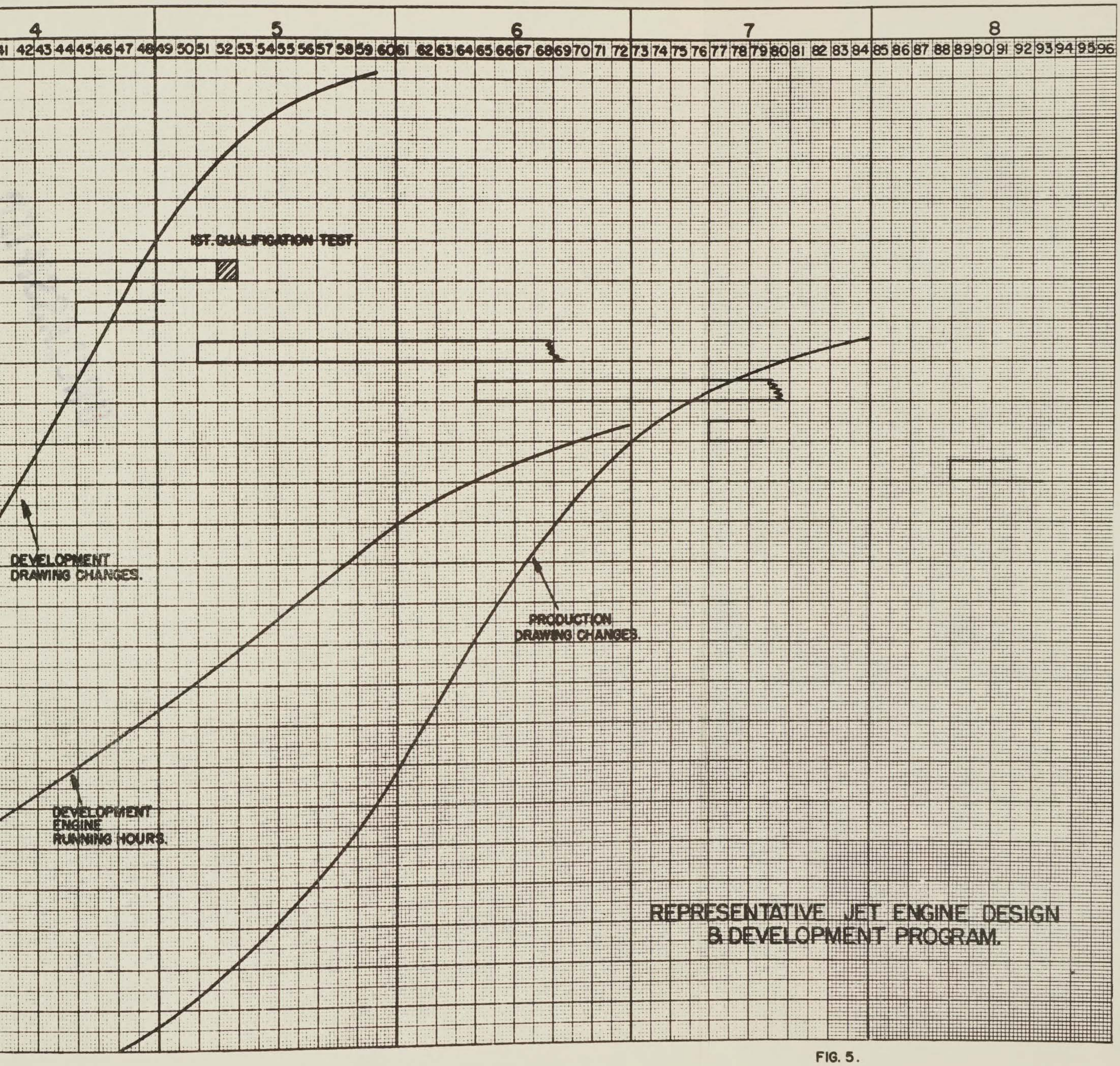

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41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96
1ST. QUALIFICATION TEST.
DEVELOPMENT DRAWING CHANGES.
PRODUCTION DRAWING CHANGES.
DEVELOPMENT ENGINE RUNNING HOURS.
REPRESENTATIVE JET ENGINE DESIGN & DEVELOPMENT PROGRAM.

FIG. 5.

UNCLASSIFIED

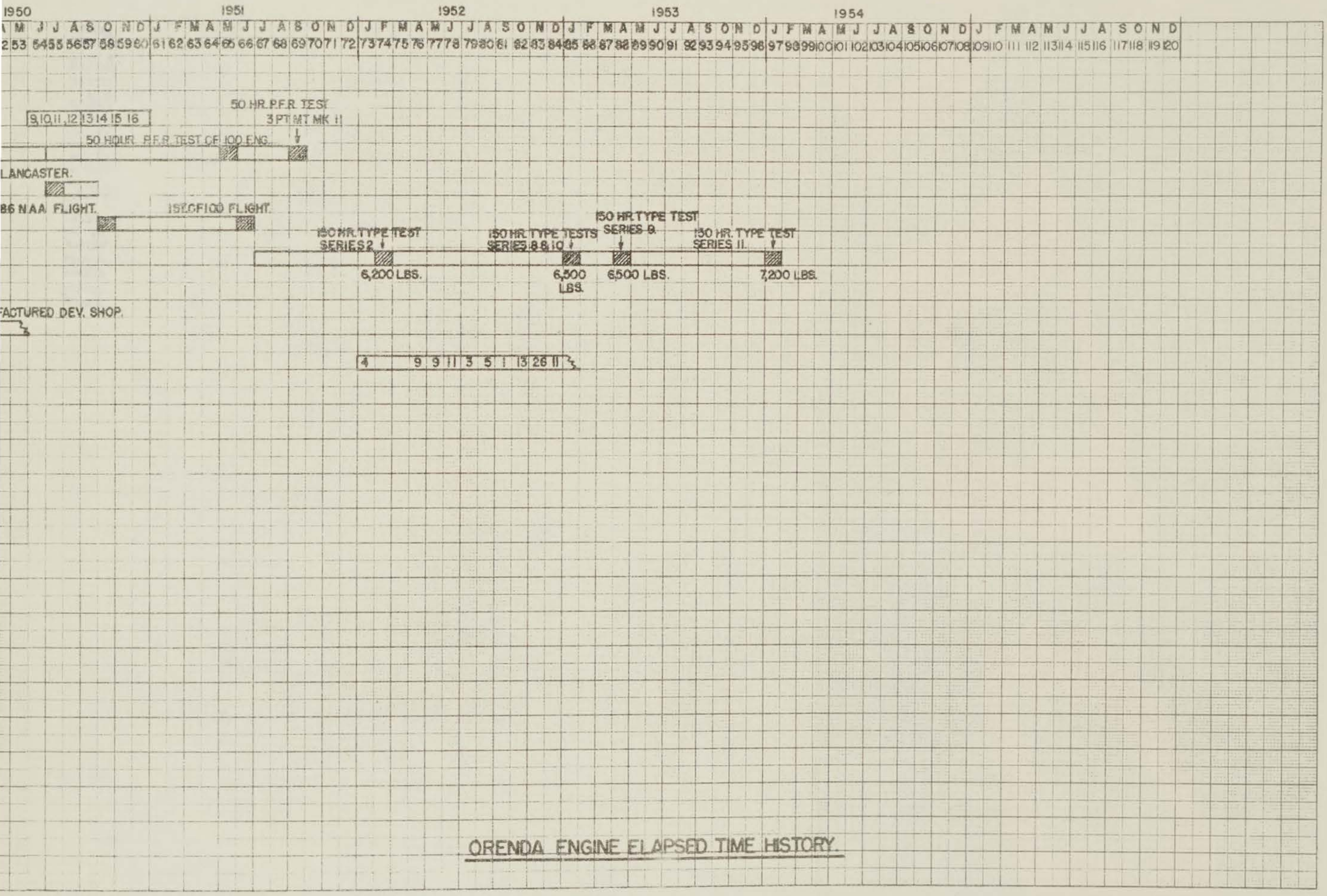
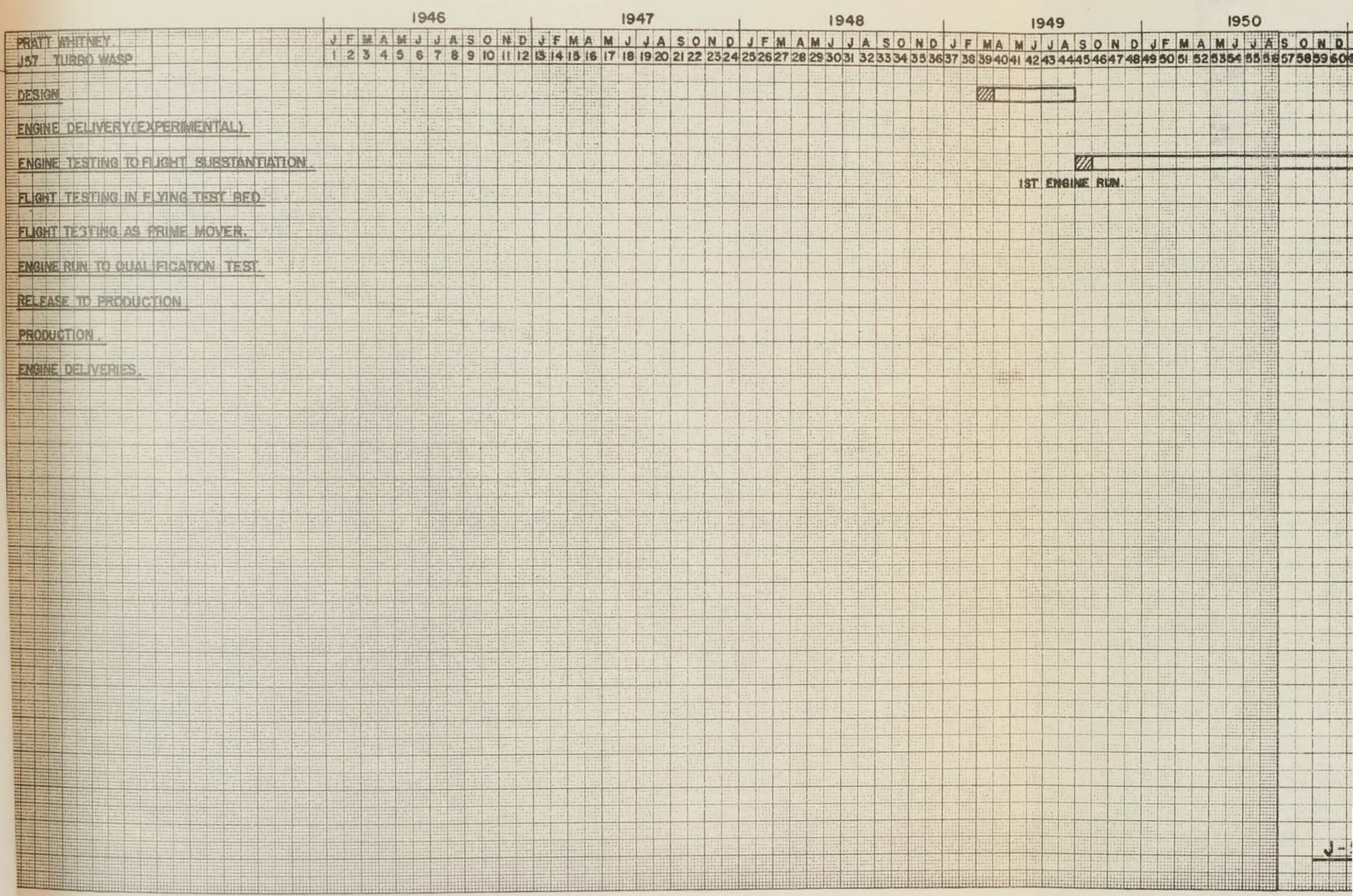


FIG. 6-2.


PRATT WHITNEY.
J57 TURBO WASP
1946
1947
1948
1949
1950
DESIGN.
ENGINE DELIVERY(EXPERIMENTAL)
ENGINE TESTING TO FLIGHT SUBSTANTIATION.
FLIGHT TESTING IN FLYING TEST BED
FLIGHT TESTING AS PRIME MOVER.
ENGINE RUN TO QUALIFICATION TEST.
RELEASE TO PRODUCTION
PRODUCTION.
ENGINE DELIVERIES.
1ST ENGINE RUN.

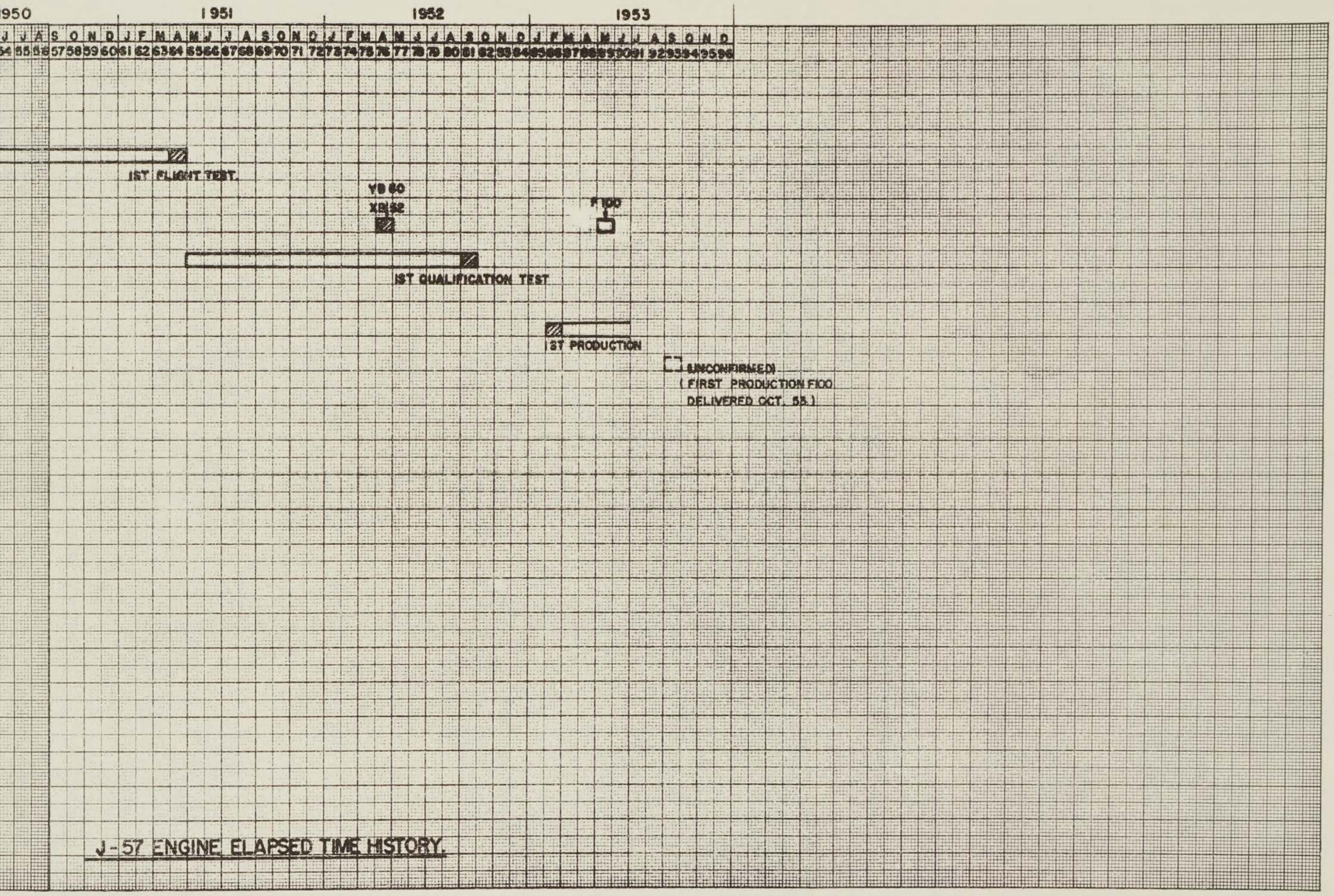

1950
1951
1952
1953
IST FLIGHT TEST.
YB 60
XB 52
F100
IST QUALIFICATION TEST
IST PRODUCTION
(UNCONFIRMED)
(FIRST PRODUCTION F100
DELIVERED OCT. 53.)
J-57 ENGINE ELAPSED TIME HISTORY.

FIG. 6-3.

REMARKS ON FIGURE NO. 7

This chart demonstrates that from 12 to 15 months are required from the beginning of the design of a jet engine until the first engine runs.

In instances where a longer or shorter period has been taken there are very logical reasons explaining the discrepancy. The following comments explain the greatest differences on the engines shown on the chart.

Orenda

The long design period on this engine is accounted for by reason of the fact that Canada was establishing an industry in this field as well as building up an engineering staff during this design period. It is interesting to note that during the remaining phases of development the elapsed times on the Orenda compare favourably with others.

Avon

The discrepancy here is not great and is attributed to the fact that Rolls Royce had difficulty with their compressor which undoubtedly caused delay in getting the engine running. This difficulty was not disposed of until an arrangement was made with M.O.S. to use Armstrong Siddeley Motors to help them with the problem.

UNCLASSIFIED

Sapphire

This discrepancy is accounted for by the fact that this engine was designed originally by Metropolitan Vickers and was transferred to Armstrong Siddeley Motors who redesigned it for production.

Metro Vick took 23 months on the design and A.S.M. took 10 months to redesign it. If the design had been done completely by A.S.M. it is safe to say that the elapsed time for this phase would have been somewhere between 10 and 23 months and would likely have compared favourably with the average elapsed time for other designs.

J-57 Turbo Wasp

The short design period on this engine was due to the tremendous post war effort Pratt & Whitney put in the project after their war contracts for the piston engines were cancelled. It was a life and death struggle for them to remain leaders in the aircraft engine industry and they had a large engineering organization, almost unlimited funds and a tremendous manufacturing and testing facility at their disposal.

J-57 Turbo Wasp (Cont'd)

A considerable amount of work was carried out, prior to the commencement of drawings, on rig tests and trials on an original jet engine design which must have made some contribution to this design.

UNCLASSIFIED

Phoebus

This engine is a pure jet version of the Theseus which was a low priority task. Bristols had sufficient orders for other types of engines on their books and therefore did not press their jet engine work very hard.

Theseus

This was a low priority job at Bristols.

Centrifugal Engines

The design period on these engines was generally shorter than for axials and turboprops because they were much less complex to design.

REMARKS ON FIGURE NUMBER 8

This chart demonstrates that from 16 to 27 months are required to develop an axial flow engine from the first run until it is suitable for flight in a flying test bed.

It also demonstrates that turbo props fall within this period also. The two turbo props which are shown as taking much longer were ready for flight long before they flew. The period of time from when the engines were ready to fly until they were installed was unusually long. This was possibly due to the fact that the aircraft were not available when the engines were ready.

A shorter period is required for the centrifugal engines because they are much less complex and are easier to clear for flight.

REMARKS ON FIGURE NUMBER 9

Information is not so plentiful on the last phase of the development of jet engines, but what is shown does demonstrate that it takes from 18 to 22 months to develop a jet engine to qualification test standard after its first flight.

One of the factors that is missing from this chart that is essential to make a proper assessment of the elapsed time required, is the number of engine running hours on each of the engines. Reference is here made to the development period discussion in Part 1 of this memorandum in which it was pointed out that it takes from 8000 to 10,000 engine running hours before an engine can be considered to be developed to a sufficiently mature state to release to production.

It is possible to pass a qualification test without having run this number of hours, but this is an unwise course to follow since the weaknesses and limitations that should have been discovered during this running will be postponed until the engines are in production and service, with much more drastic results.

If the maturity of an engine is measured in terms of engine running hours, then the elapsed time for this phase will be about 22 months. This is demonstrated on the engines for which information is available. The four axial engines were run the following number of hours to the points shown on the chart:

Orenda	9,000
Avon	7,000 (1)
Sapphire	7,000 (1)
J57 Turbowasp	14,200

(1) Partially estimated

ELAPSED TIME FROM QUALIFICATION TEST TO PRODUCTION DELIVERY

The elapsed time between qualification test and the first production delivery is controlled by the point at which production are authorized to commence producing. A delicate balance has to be struck between bringing production into the program before the qualification test has been run and involving them in the changes through which the design goes in the development period and providing engines when they are required.

If a company is willing to subject its production facility to the confusion that arises by starting too early some time can be saved in the delivery of the first production engine, but the effect on proving the engine in production to make it suitable for licensing is not changed. The fact still remains that regardless of when production starts, it is still in an early development stage when it has passed its qualification test and still must go through the same proving process before it can be licensed.

From the economics point of view it is an unwise course to follow to start production earlier than the qualification test point. It is undoubtedly more economical and infinitely easier to introduce a change in the design before parts are in production and service since no consideration has to be given to changes in production tooling, interrupting the production line and sometimes production testing, scrapping of parts and material and retrofits in service which can involve modifications in the field as well as at overhaul. The objective should be to make a super-effort to find a cure to all the problems possible before the engine is released to production.

Reference to the attached chart indicates that when an engine is started in production at the time of, or after the qualification test has been passed it takes about one year before the first engine is ready for delivery. Where production starts before the qualification test, engines are ready for delivery sooner than this. The difference between these two approaches is in the one case engines are delivered sooner but both production and service are subjected to the cost and difficulty of introducing additional changes while on the other hand engines are not delivered as soon but production and service are both spared the cost and difficulty of introducing many changes.

Regardless of the delivery date of engines, it is important to remember that the design still must go through the same development and-production process before it is proven sufficiently for licensing. The production portion of this process takes from one to two years after the qualification test has been passed.

The one possible means of providing engines earlier for the airframe and at the same time avoiding the cost and confusion of introducing a design too early into production is to use a Pilot Production Shop.

By this means it is possible to introduce Production people to the design at some reasonable point between the flight substantiation test and the qualification test without involving a large cumbersome organization which must be fed with a large volume of parts to utilize its capacity economically and efficiently.

The use of a Pilot Production Shop has all the advantages of introducing Production as early as possible to the design, but none of the disadvantages of the cost of operating and the efficient uses of a large organization. When it is necessary to make a change in parts that have been released to production through a Production Pilot Shop disrupting a planned and ordered flow of work is avoided, and changes do not effect the large quantities of production tooling as well as large quantities of production parts that are either in stores or in process. Better arrangements with vendors are also possible.

The employees responsible for the Pilot Production Shop can later direct the production activities.

Since under this arrangement changes in the design, as a result of development experience and changes in the design to facilitate production are being made in parallel, some saving in elapsed time from the qualification test point until the first production engine is delivered can be made, and consequently an engine being designed, developed and produced in this manner can be ready for licensing sooner. A good example of this type of operation was Pratt & Whitney's J57 Turbo Wasp and the licensing arrangement that was made with Ford less than a year after the qualification test was passed.

The one major disadvantage in this type of an operation is the fact that there is a considerable additional load placed on the design office to make changes in designs that are coming from two separate sources during the development period. If the design office can accommodate these changes, and are so organized that they can satisfactorily co-ordinate changes that are made for development purposes with those that are made to facilitate production, then both time and money can be saved.

Obviously the design office would have to be staffed to a greater extent for this kind of an operation than for one in which production does not begin until the qualification test has been passed.

UNCLASSIFIED

If it is absolutely essential, and it usually is in the jet aircraft engine business to have engines earlier than they could be obtained by commencing production at the qualification test point, then having a Pilot Production Shop is the best possible manner in which to accomplish this and is the most economical on both money and elapsed time.

Fig. 13-1

COSTS OF LICENSING ARRANGEMENTS

Part of the cost of licensing arrangements, other than the cost of introducing another company's design into production, can be observed from the following facts:

1. The Ministry of Supply and the British House of Commons on December 15, 1952, stated that some 12½ million dollars had been received on the Sapphire and Tay licenses.

2. Senate Appropriation Sub-Committee in the United States about July, 1953, stated that the Wright Aeronautical Corporation were paying Armstrong Siddeley Motors $499,800 for rights to build the Sapphire and on engines produced at Buick Armstrong Siddeley Motors will receive $62.50 per engine.

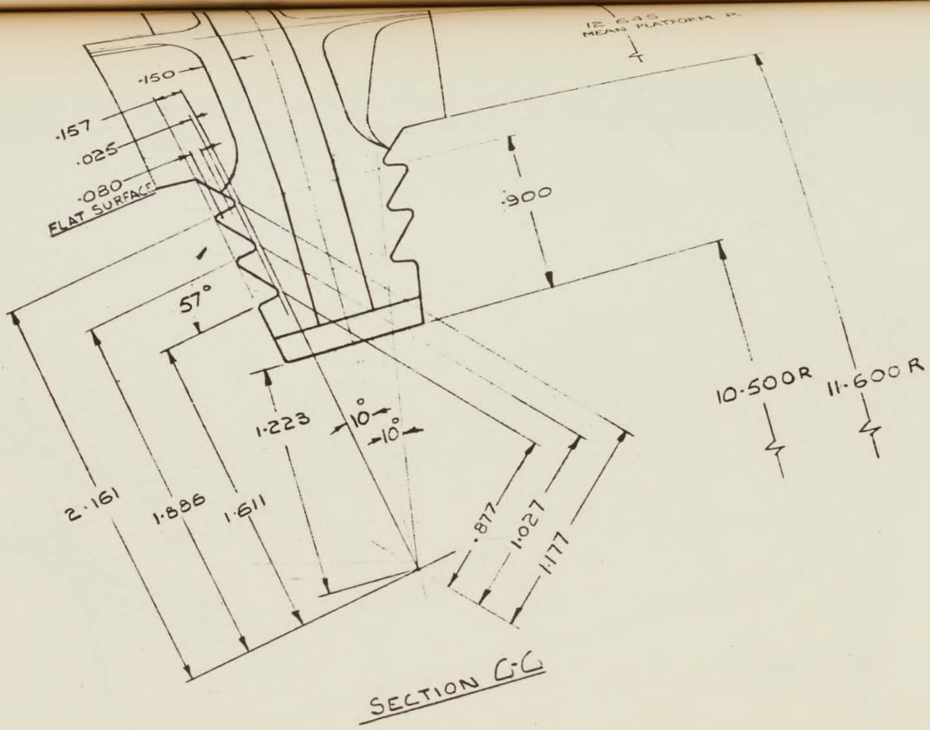
   Whether the amount paid by the U.S.A.F. is in addition to the above, has not been indicated, but it was stated in the same article that the U.S.A.F. had paid Armstrong Siddeley Motors 12.3 million dollars for the Sapphire.

3. It is reported that the Olympus license originally cost Curtiss-Wright $3,000,000.

4. It is reported that the U.S. Government paid the British Government $4,000,000 for all Whittle patents. Originally this amount was $10,000,000, but was changed to $4,000,000 later.

5. It has been reported that the contract between Armstrong Siddeley Motors and Curtiss-Wright on the Sapphire was to net Armstrong Siddeley Motors $35,000,000 for a fixed number of engines.

In considering a licensing arrangement from an economic point of view, it must be remembered that over and above the initial license fee and royalties that have to be paid there is a tremendous cost related to getting a licensed design into production. Some indication of the magnitude of these costs can be observed from a statement made by Pratt & Whitney to the effect that on each of the Nene and Tay licensed engines there was 1,000,000 manhours spent in addition to other costs in connection with materials, tools etc.



CLEARANCE BETWEEN BLADE
PLATFORMS TO BE ·010 MIN

FIG. 14-11 SECTION B.

TURBINE ROTOR BLADE
41 BLADES PER DISC

PRIVATE

Fig. 14-11
Section B.

15
16
17

FIG. 14-11. SECTION C.

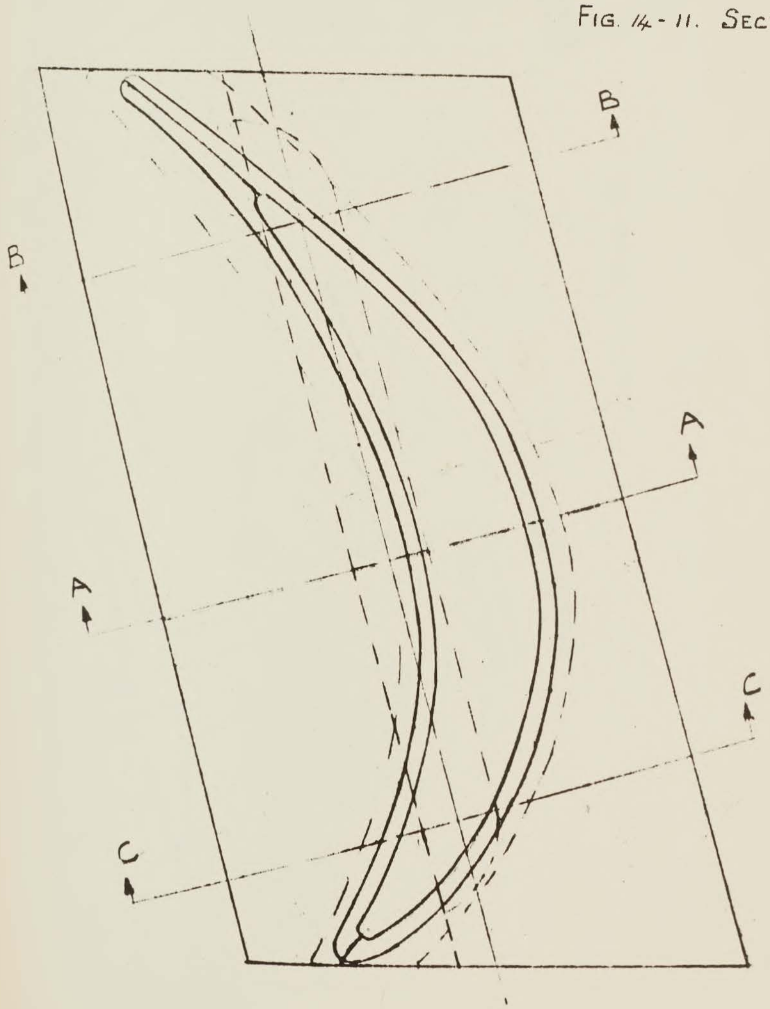


Fig. 14-11
Section C.

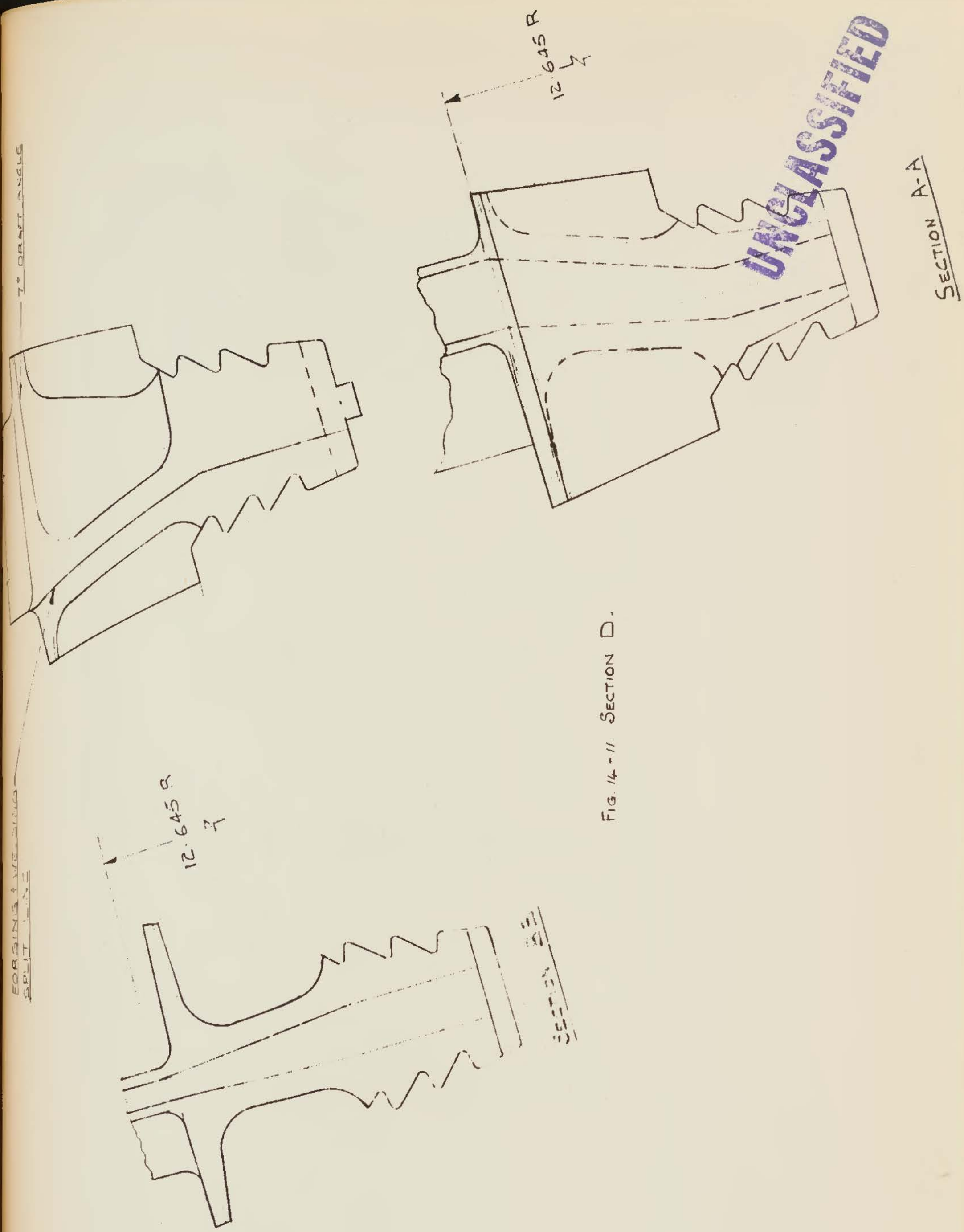


Fig. 14-11
Section D.

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16
17

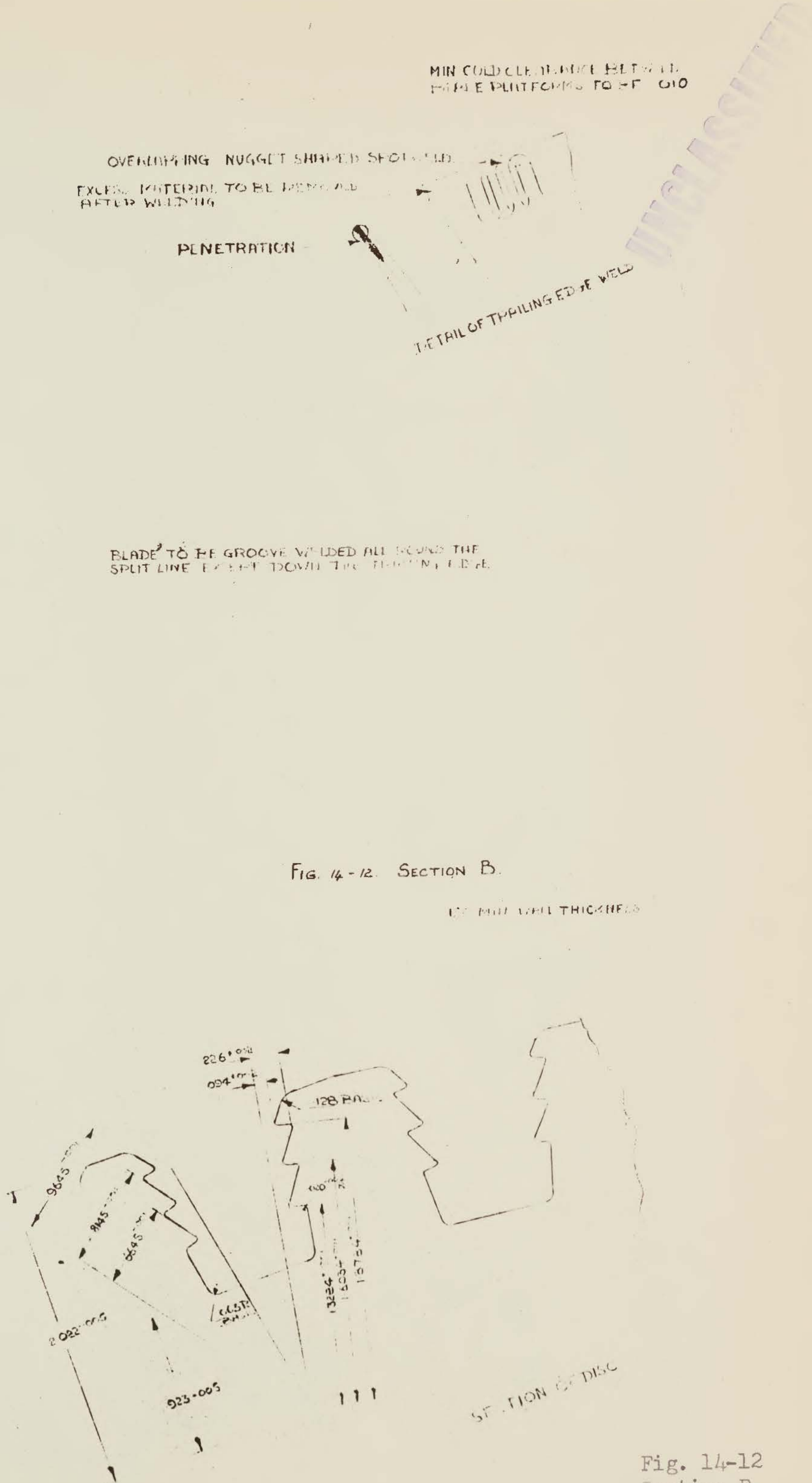


Fig. 14-12
Section B.

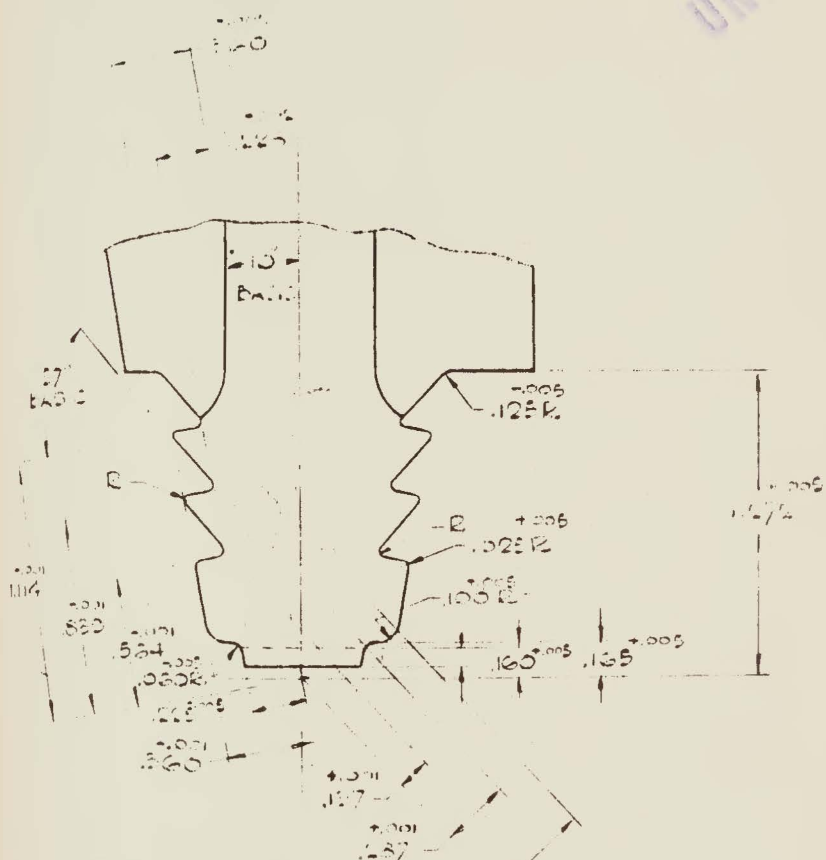


FIG. 14-13. SECTION B.

TURBINE BLADE ROOT

PART NO. 50121 & 50122

THE FINISHED RADIUS MUST BE WITHIN THE HIGH & LOW LIMIT FIGURES PRODUCED BY THE ABOVE DIMENSIONS.

Fig. 14-13
Section B.

15
16
17

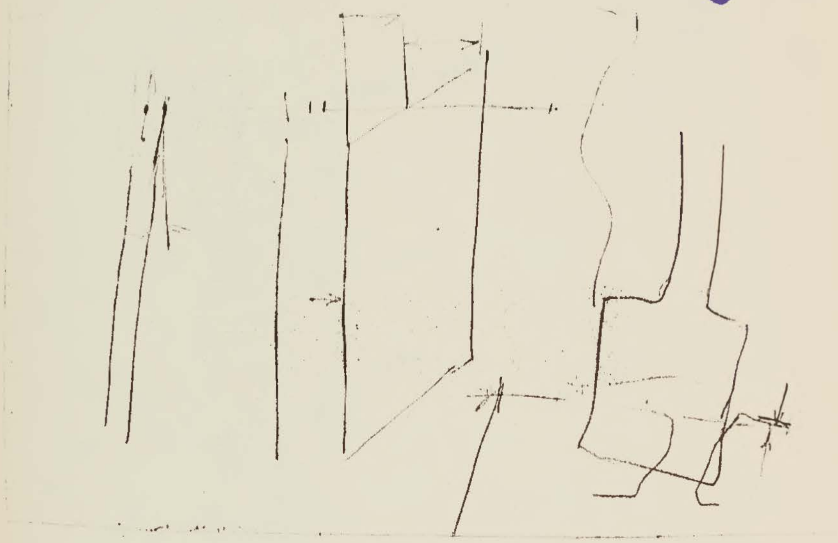


FIG. 14-18. SECTION B.

Fig. 14-18
Section B.

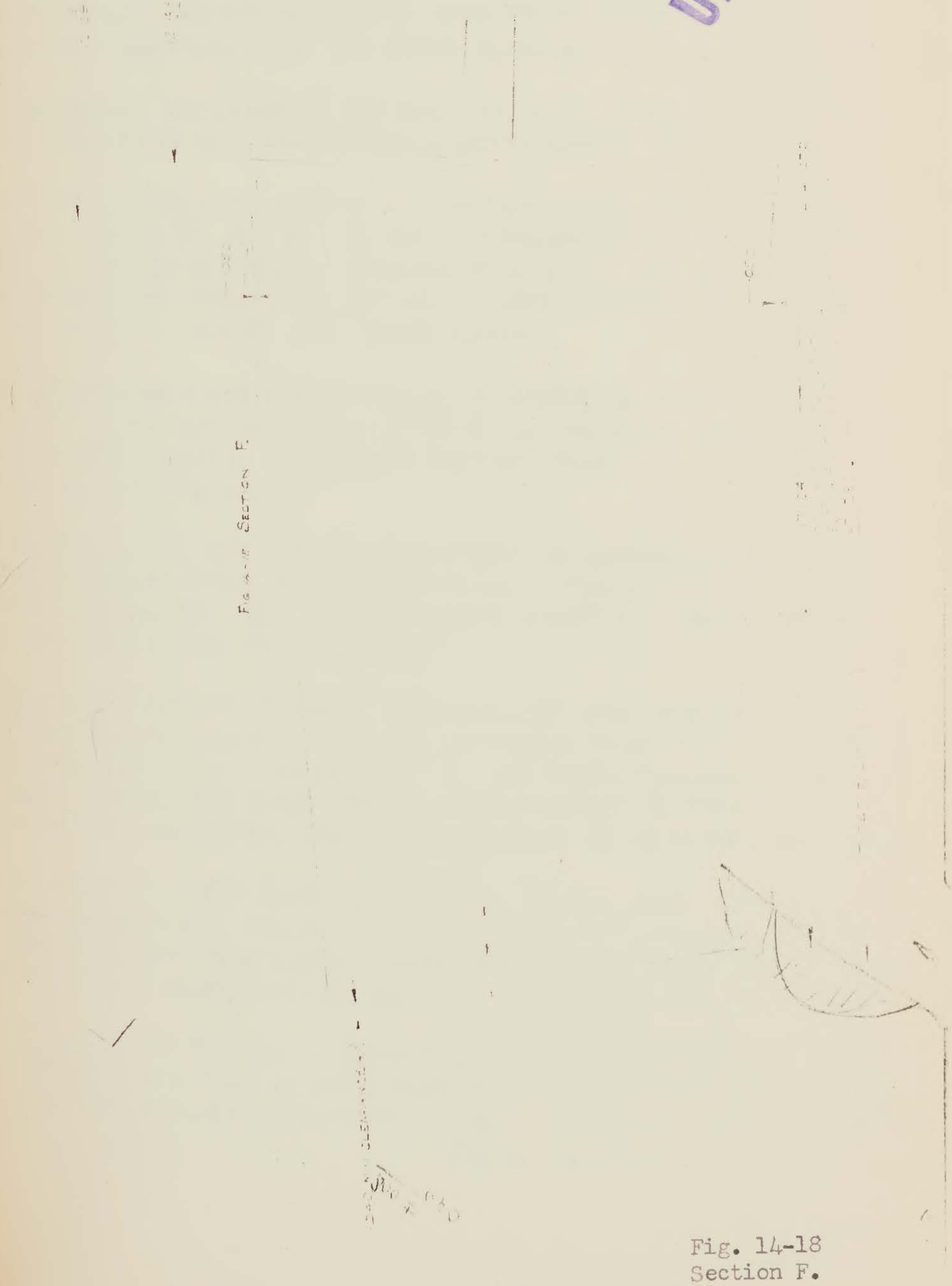


Fig. 14-18
Section F.

UNCLASSIFIED

UNLESS OTHERWISE SPECIFIED
TOLERANCE ON THREE PLACE DECIMAL DIMENSIONS IS
TOLERANCE ON ANGLES IS
FINISH ON MACHINED SURFACES IS 32 RMS MICRO-INCHES
MACHINE ALL OVER.
FORGING STOCK TO BE PROVEN SOUND BY ULTRASONIC TEST.
FINISHED PART TO BE SUBJECTED TO FLUORESCENT PENETRANT INSPECTION TO AMS. 2646.

1. ALL AEROFOIL SECTIONS TO LIE WITHIN THE TOLERANCE BAND CREATED BY THE HIGH & LOW LIMIT PROFILE.

2. WITH THE BLADE LOCATED BY INTERSECTING PLANES PASSING THRU E & F & AT TANGENTIAL POINTS G & H A THEORETICAL STACKING LINE IS J & D THE STACKING POINTS OF ALL AEROFOIL SECTIONS TO BE WITHIN ·010 OF THIS LINE.

3. THE STACKING LINE AS DEFINED IN NOTE 2 MAY BE INCLINED ·020 AT SECTION MM IN PLANE OF SECTION RR WHEN CHECKED FROM THE MEAN ℄ OF ITS ROOT

4. THE TWIST ANGLE OF THE SECTION IS CONSIDERED TO ROTATE ABOUT THE THEORETICAL STACKING LINE AS DEFINED IN NOTE 2. THE TWIST ANGLE TOLERANCE FOR ALL SECTIONS IS ± 0° 30'

5. DISPLACEMENT OR TWIST ERROR OF THE AEROFOIL SECTION THAT TAKES PLACE WITHIN THE TOLERANCE BAND AS DEFINED IN NOTE 1 IS PERMISSABLE & IS ADDITIONAL TO THE DISPLACEMENT & TWIST TOLERANCE AS SPECIFIED IN NOTES 3 & 4 RESPECTIVELY

6. FROM STATION Z-A TO STATION Z-E THE TOTAL TAPER BETWEEN PLANE N AND THE TRAILING EDGE AS DEFINED BY THE LOW LIMIT PROFILE MAY DECREASE WITHIN THE TOLERANCE BAND BY ·007 AT PLANE N

7. THE TAPER BETWEEN STATION Z-A & STATION Z-E AS DEFINED BY THE LOW LIMIT PROFILES MAY DECREASE WITHIN THE TOLERANCE BAND BY ·005 AT STATION Z-A

FIG 14-19 SECTION A.

Fig. 14-19
Section A.

UNCLASSIFIED

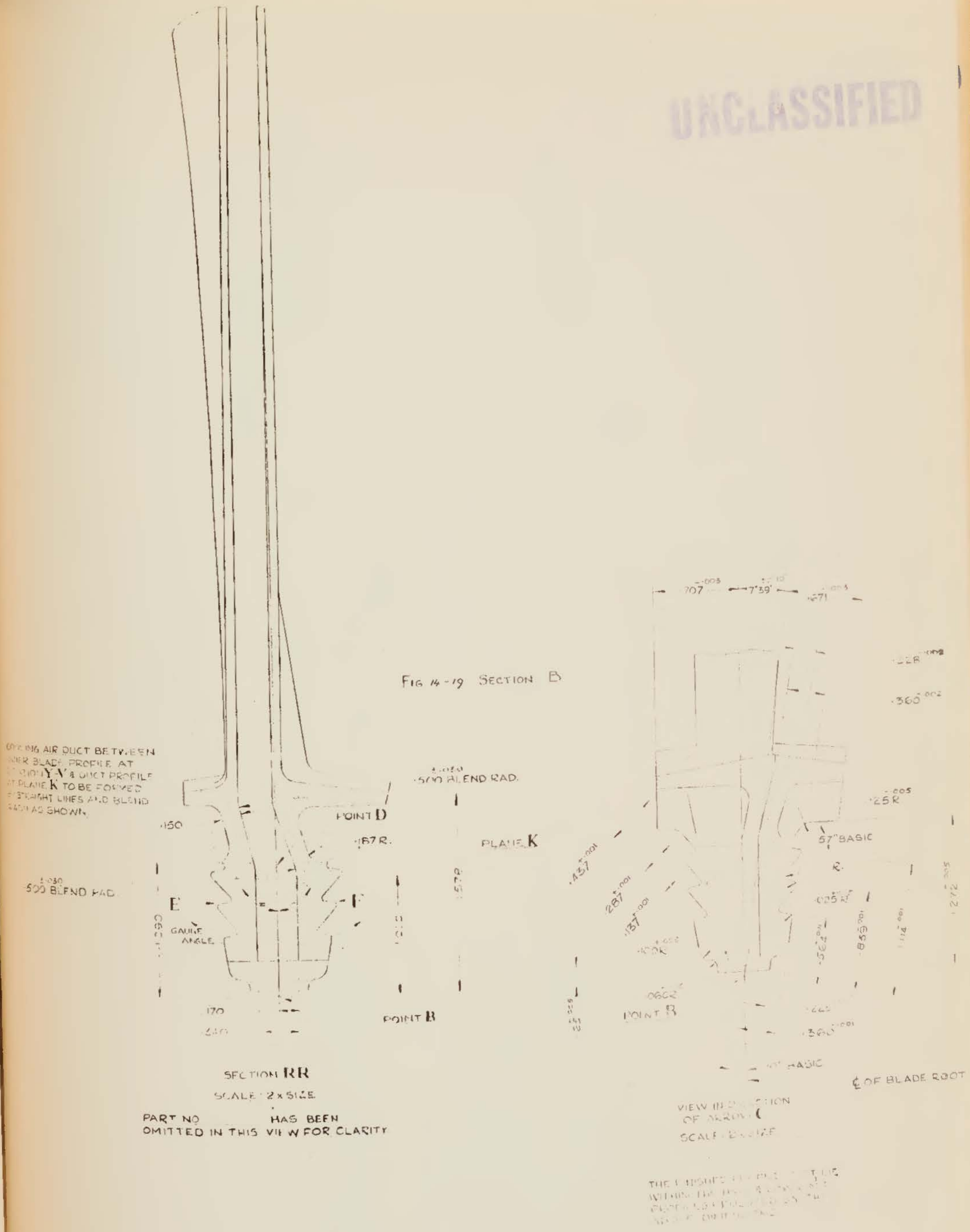


Fig. 14-19
Section B.

EXAMPLE OF THE EVOLUTION OF A PART IN DEVELOPMENT

The figures numbered 15-1 and 15-2 demonstrate the nature of the activity that is required to develop a part from its original form until it is proven in production. Figure 15-1 demonstrates the number of trials that have to occur and the interrelationships of these trials. Many of them fall by the wayside and never do reach the production stage and many of them become production changes.

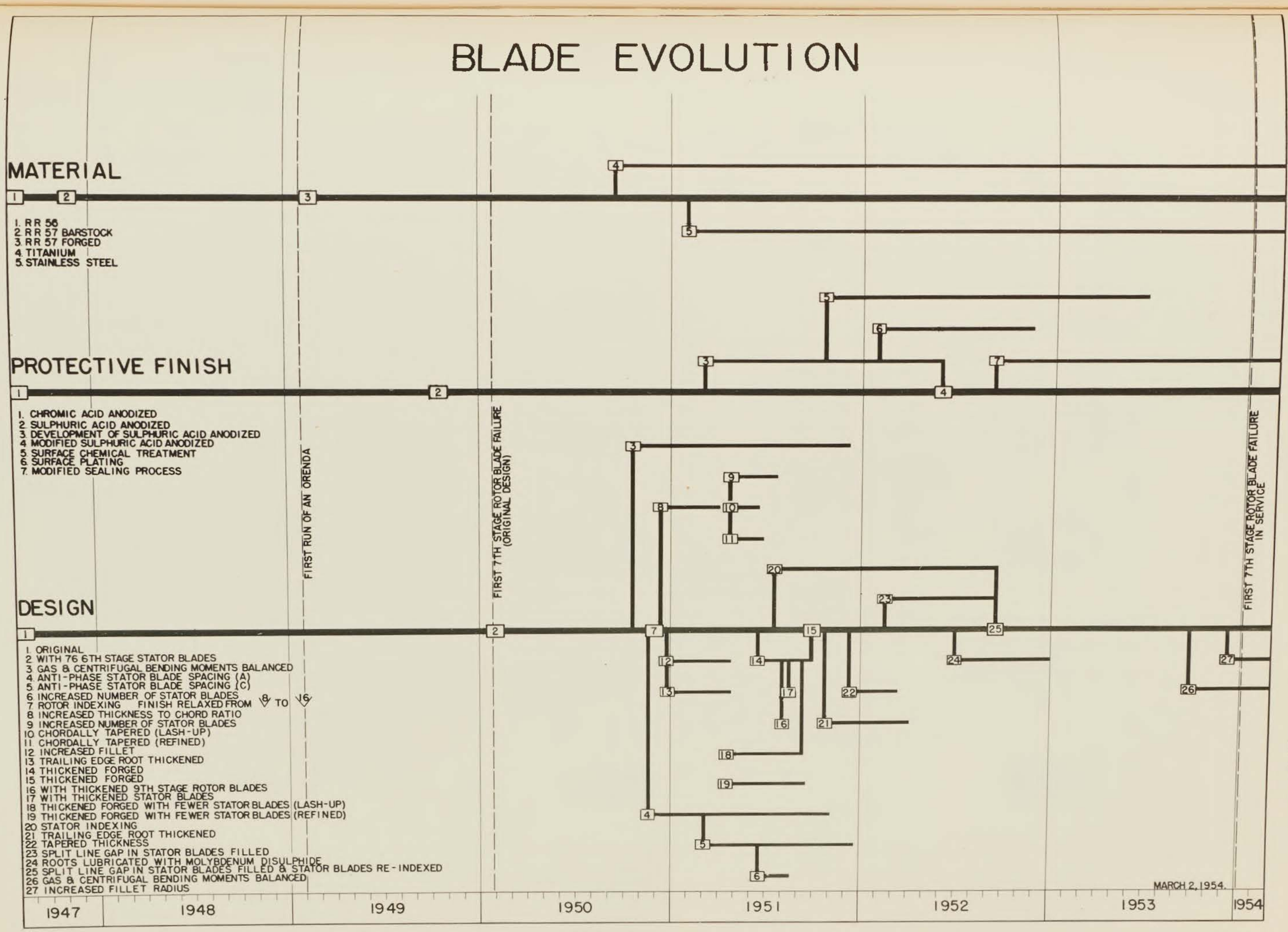
Figure 15-2 gives some indication of the physical nature of these changes. Changes in this type of part fall into three major categories. These are:

1. Material
2. Protective Finish
3. Design

There is also an interrelationship among these major groupings as well as a relationship among the changes themselves. That is a material change can effect the design or a design change can effect the material or a change in the form of the blade can effect both the design and the material as well as other related parts.

16

17



BLADE EVOLUTION
MATERIAL
1. RR 56
2. RR 57 BARSTOCK
3. RR 57 FORGED
4. TITANIUM
5. STAINLESS STEEL
PROTECTIVE FINISH
1. CHROMIC ACID ANODIZED
2. SULPHURIC ACID ANODIZED
3. DEVELOPMENT OF SULPHURIC ACID ANODIZED
4. MODIFIED SULPHURIC ACID ANODIZED
5. SURFACE CHEMICAL TREATMENT
6. SURFACE PLATING
7. MODIFIED SEALING PROCESS
FIRST RUN OF AN ORENDA
FIRST 7TH STAGE ROTOR BLADE FAILURE (ORIGINAL DESIGN)
FIRST 7TH STAGE ROTOR BLADE FAILURE IN SERVICE
DESIGN
1. ORIGINAL
2. WITH 76 6TH STAGE STATOR BLADES
3. GAS & CENTRIFUGAL BENDING MOMENTS BALANCED
4. ANTI-PHASE STATOR BLADE SPACING (A)
5. ANTI-PHASE STATOR BLADE SPACING (C)
6. INCREASED NUMBER OF STATOR BLADES
7. ROTOR INDEXING FINISH RELAXED FROM 8 TO 16
8. INCREASED THICKNESS TO CHORD RATIO
9. INCREASED NUMBER OF STATOR BLADES
10. CHORDALLY TAPERED (LASH-UP)
11. CHORDALLY TAPERED (REFINED)
12. INCREASED FILLET
13. TRAILING EDGE ROOT THICKENED
14. THICKENED FORGED
15. THICKENED FORGED
16. WITH THICKENED 9TH STAGE ROTOR BLADES
17. WITH THICKENED STATOR BLADES
18. THICKENED FORGED WITH FEWER STATOR BLADES (LASH-UP)
19. THICKENED FORGED WITH FEWER STATOR BLADES (REFINED)
20. STATOR INDEXING
21. TRAILING EDGE ROOT THICKENED
22. TAPERED THICKNESS
23. SPLIT LINE GAP IN STATOR BLADES FILLED
24. ROOTS LUBRICATED WITH MOLYBDENUM DISULPHIDE
25. SPLIT LINE GAP IN STATOR BLADES FILLED & STATOR BLADES RE-INDEXED
26. GAS & CENTRIFUGAL BENDING MOMENTS BALANCED
27. INCREASED FILLET RADIUS
MARCH 2, 1954.
1947
1948
1949
1950
1951
1952
1953
1954

Fig. 15-1

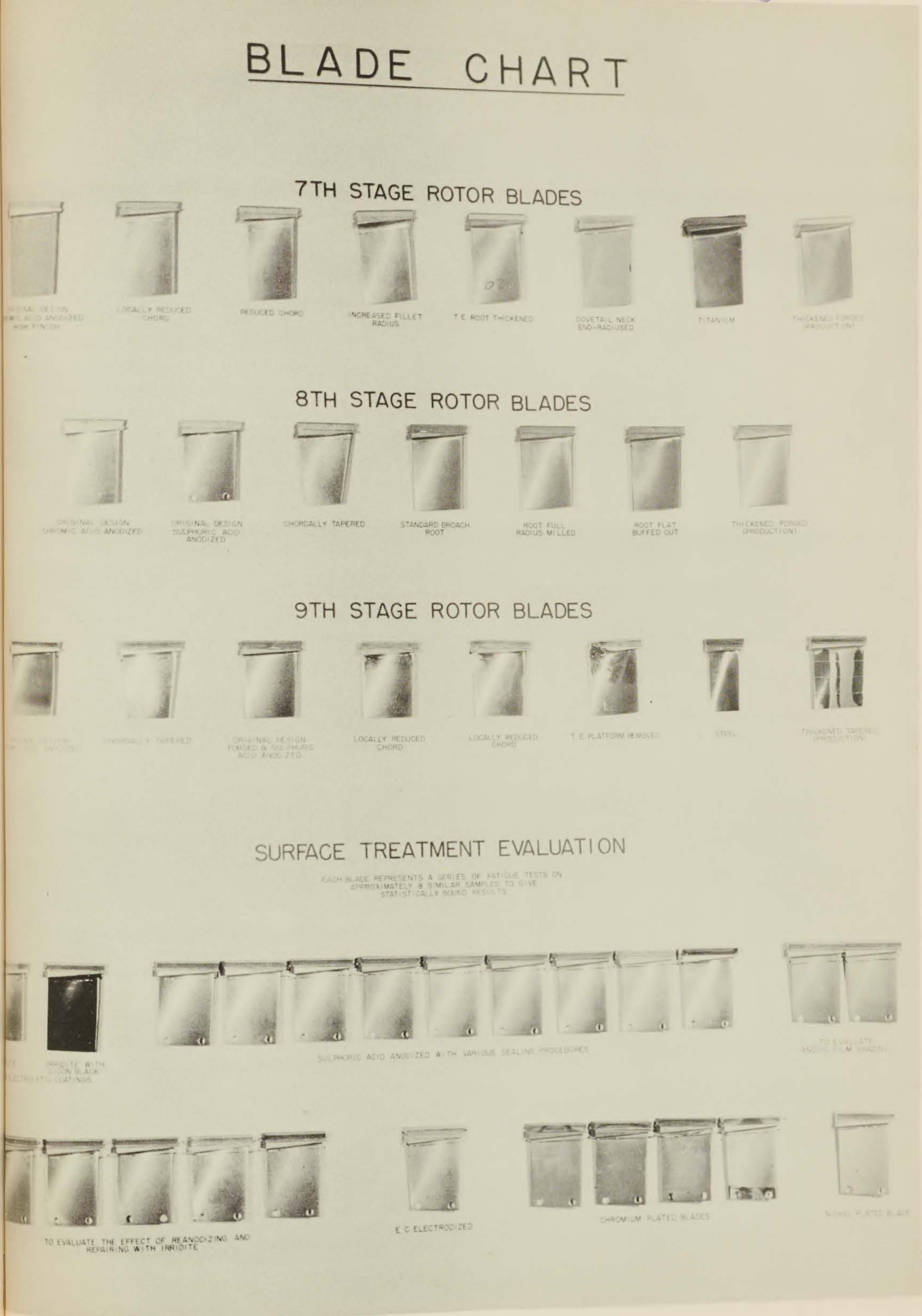

BLADE CHART
7TH STAGE ROTOR BLADES
LOCALLY REDUCED CHORD
REDUCED CHORD
INCREASED FILLET RADIUS
T.E. ROOT THICKENED
DOVETAIL NECK END-RADIUSED
TITANIUM
8TH STAGE ROTOR BLADES
ORIGINAL DESIGN CHROMIC ACID ANODIZED
ORIGINAL DESIGN SULPHURIC ACID ANODIZED
CHORDALLY TAPERED
STANDARD BROACH ROOT
ROOT FULL RADIUS MILLED
ROOT FLAT BUFFED OUT
THICKENED FORGED (PRODUCTION)
9TH STAGE ROTOR BLADES
ORIGINAL DESIGN FORGED & SULPHURIC ACID ANODIZED
LOCALLY REDUCED CHORD
LOCALLY REDUCED CHORD
T.E. PLATFORM REMOVED
STEEL
SURFACE TREATMENT EVALUATION
EACH BLADE REPRESENTS A SERIES OF FATIGUE TESTS ON APPROXIMATELY 8 SIMILAR SAMPLES TO GIVE STATISTICALLY SOUND RESULTS
IRRIDITE WITH SIOON BLACK
SULPHURIC ACID ANODIZED WITH VARIOUS SEALING PROCEDURES
TO EVALUATE THE EFFECT OF REANODIZING AND REPAIRING WITH IRRIDITE
E.C. ELECTRODIZED
CHROMIUM PLATED BLADES

Fig.15-2

16

17

Fig. 16

UNCLASSIFIED

FACTS ABOUT AERODYNAMIC DESIGNS

A. V. Roe Canada Limited

Chinook

The Chinook engine, in its first run, met its design pressure ratio, mass flow and efficiency.

Orenda

The Orenda engine went into production and service with the original aerodynamic design with no changes from the design as it was prepared originally on the drawing board. This was the Series 2 engine.

This engine also met its design pressure ratio, mass flow and efficiency on its first run.

The only fault that could be found with it was that the acceleration times were a little long, and these were cured on the Orenda 8 by redesign of the first two stages of the compressor.

This aerodynamic design has been developed in the Series 11 with an increase in mass flow of 10% over the original design, and better surge characteristics than in the Series 8.

CT.103 Test Compressor

This test compressor met its design pressure ratio, its mass flow requirement, and efficiency rating on the first run, and has since been increased by 5% mass flow as a result of minor changes.

The only fault with this aerodynamic design was that it exhibited a surge line kink, but we are more than confident that on the next build or two, this will be cured.

Rolls Royce Limited

Avon

The original compressor design was so poor that a considerable period of the initial engine development work had to be done with the first four stages of the compressor removed. During this period, the engine ran at a rating of about 3500 lbs.

No neat aerodynamic cure was ever found for this compressor deficiency, and even the RA.7 production engine is equipped with

Avon (Cont'd)

a clumsy and complicated mechanical system of variable inlet guide vane and blow-off valves in order to meet acceleration requirements.

Later versions of the Avon do not have the same compressor as that originally designed by Rolls Royce. The compressor on these later versions is the Sapphire compressor, which was provided to them by arrangement with the Ministry of Supply in which there was some "horse-trading" with Armstrong Siddeley Motors in connection with flutter problems. Rolls Royce agreed to trade their "know how" on curing these flutter problems, for the privilege of using the Sapphire compressor.

This compressor was originally designed by Metro-Vick.

The Mamba

This engine was designed for a pressure ratio of 5:1, and on first testing gave a pressure ratio of only $3\frac{1}{2}$:1.

The Python

Power Jets had to sort out the turbine troubles on this engine for Armstrong Siddeley Motors.

Bristol Aircraft

Theseus

The original aerodynamic design of this engine was 20% wrong on the turbine throat areas in the early stages of development.

Westinghouse

24-C Engine

This engine had a design pressure ratio of 4.7 to 1 and on the first test gave only 3.7 to 1.

Violent surging at 10,000 to 10,600 rpm. was experienced. The design rpm, was 12,000.