Production Engineering for the Civil Market

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THIS paper specifically refers to the civil market so that some of the problems of designing, producing and selling aeroplanes can be discussed in terms which are common to most competitive manufacturing enterprises. In addition, The de Havilland Aircraft company has always been interested in the civil side of aviation and has accumulated some experience in designing for, and selling to, civilian operators.

Perhaps the most salutary thing about engaging in the civil market is that the operators, just like the producers, must be commercially responsible, with clear commitments, and must stand or fall according to their achievements. In an industry which is young and in which technical development is rapid, design progress must be made quickly enough to meet competition but not so quickly as to pass outside the reach of the customer's pocket. Sustained commercial solvency is the criterion by which a company may be judged.

It has been said that the civil market involves a producer in excessive commercial risks. The element of risk cannot be denied. Confidence in the company's technical ability, estimation of price and market trends, effect of government policy and international situations—all these must be reduced to a calculated commercial risk. However, some of the risk is good since it does provide incentive. Without it there is less interest and less real progress.

Close Association: At this point the military side of aviation should be mentioned. While the civil and military are two different spheres, the technical problems of the two sides are quite closely associated. It is almost necessary for a concern which wishes to keep in the lead to concern itself with both sides. Apart from any technical considerations, and from the country's point of view, it would be a serious loss if an aircraft concern was not able to turn its facilities effectively to war machines in time of emergency.

One point of difference between the civil and military markets is that a military agency has some idea of the kind of aeroplane it is looking for and perhaps the quantities it requires, at least initially, whereas in the civil market the aircraft company must, on its own initiative, study the overall market situation and discuss requirements with many different operators, often in various countries. The company must then try to conceive an aeroplane which will penetrate this civil market as deeply as possible. The final decision to proceed with design and production rests solely with the company and the results of this decision are easily measured by standard business yardsticks, as the venture develops.

Where the potential market is made up of a large number of small operators, the company will probably have to make its own financial arrange-

A Plan for Airframe Production

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IN TODAY'S never ceasing search for higher productivity, the concerted efforts of the members of all groups engaged directly or indirectly in production are a prime requisite. To assume fully their share of this total effort, management must devise in advance the scheme of action for these groups. It is intended that the scope of this discussion be confined to a study of a pre-formulated method of getting the production job done.

After analyzing the subject, it seemed reasonable to present three basic aspects:

(1) The fundamental characteristics of such a plan.

(2) The data available that will influence the frame of reference or concept of the plan.

(3) The mechanics of assembly of the overall plan.

The first fundamental characteristic would seem to be that the plan be all inclusive. That is, it should place a time or quantitative value (or both) on each operation or element of production. It is suprising how often one finds Engineering working to a plan, Tooling working to a plan, Procurement working to a plan, and Manufacturing working to a plan, on a given project, each going in the same general direction but with no real co-ordination as to time or effort between the respective operations. There should be *one* plan that forms the central strand, around which all related operations are woven. It should:

(1) Set forth the objective,

(2) Specify how, when and by whom the plan is to be executed, and

ments. If a large operator is interested in the project it is likely that he will want to participate in the financing scheme in order to secure an option on the early production machines. This should in no way impede the work of the design organization in turning out a first-class aeroplane, although it rightly gives such a customer much freedom in planning many interior details and special equipment. It also commits the company to meet specific delivery dates and prices, and may call for guaranteed performance of the aeroplane.

Foresight Necessary: In all this, the company strives to judge the market for some years ahead because from the time of deciding to design an aircraft for a certain purpose to the time when it will be available for delivery in quantity, some years must inevitably pass. Remembering that aviation is young and rapidly developing, it is important to reduce this interval as much as possible. If a demand exists, the aim must be to fill it quickly before the market situation changes or before one's competitors try to fill it.

CREDIT IS DUE

. . . to the Society of Automotive Engineers, with whose kind permission these two articles are being reprinted in *Aircraft*. Both articles were originally presented as papers at the SAE International Production Meeting, held in Toronto's Royal York Hotel last October 29 and 30.

Before production deliveries of an aeroplane begin there are two easily recognized intervals:

(1) The period from initiation of design to the first flight of the prototype.

(2) The period from the first flight of the prototype to the beginning of production deliveries.

Each of these periods is generally anywhere from 1 to 4 years depending on the size and nature of the aeroplane. These time intervals are usually regarded as excessive! It is the main purpose of this paper to discuss the ways in which production engineering can help shorten these intervals and establish the manufacturing program at the earliest possible date.

If the production engineer could wait until all design details were stabilized, until all flight trials had been completed and Certificate of Airworthiness obtained, and until all drawings were issued on a production basis, his work would be greatly simplified. From a competitive point of view in aviation this would be an impossible situation because the time involved would be far too great. We must take it as axiomatic that time does not permit waiting for all these items to be completed before starting production. The trend is towards increased overlap between the prototype stage and production. Consequently the risks of modification are greatly increased. This overlap, which may not be common to other industries, introduces an interesting relationship between the design and production sides of the company.

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(3) Set up means of appraisal by management.

Difficult Objective: This is not easy to attain. The normal release of data throughout the successive steps in the production process does not lend itself to a smooth dovetailing of operations. For example, Engineering necessarily requires more time to design castings and forgings than simple sheet metal details, yet the procurement and factory people need these designs first because of their longer flow times. Tools that take longest to build generally take more design time and so are the last to be released to the shops. Special equipment for testing, because of its long procurement time, must be ordered before complete test procedures and specifications are available. Usually, because of the time element, initial lots of fabricated parts must be released for manufacture prior to completing assembly and installation planning. Customer programs are not always readily phased into the optimum manufacturing plans. However, in spite of these difficulties, to fail to set these problems out in their true perspective, one to the other, will surely lead to confusion and cost at a later date.

The second fundamental characteristic is this — the plan must evolve through several phases of development, each of which contributes to its detail and scope. In its simplest form, it sets forth the time element for the major processes of production, namely Engineering, Tooling and Manufacturing. In its broadest sense, as we shall see later, it embraces the detailed analysis of Men, Machines and Material. It may cover a span of only a few months, but more generally in this business it extends over a period of several years for any given program.

In each phase of devlopment, the plan must present a coherent picture. Major operations are not left unplanned nor is the plan allowed to shade off into vague generalities. When a specific answer is not known, the best possible assumption is made in the light of knowledge at the time.

In the early analysis of the plan, it is this second characteristic, evolution through stages, that makes it difficult to attain the all inclusive characteristic.

Flexibility a Must: The third fundamental characteristic is that the plan must be flexible. One of the predominant factors in aircraft production is the ever-changing nature of the industry. It has been jokingly said that in this business there is nothing constant but the change. The fact that today, after building substantial quantities of one particular model, we are still processing 750 changes per week, reminds one that there is a fair amount of truth in this statement.

There are many factors that force revision of an otherwise stable program. To name a few, there are:

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difficulty would be that between the north and the south stations, there would be thousands of square miles of territory not covered by radar. Thus, once a hostile aircraft had penetrated the northern screen, there would be no way of telling in what direction it was heading. The net result would be that the alarm would have to go to all potential targets, where the possibilities of an air raid would bring about a complete work stoppage, on a nation-wide basis.

Obviously, an enemy could make Canada's industry almost completely inactive, simply by sending aircraft through the northern screen at frequent intervals. These aircraft would not actually have to press home an attack, since in bringing work to a halt, their mission would have been accomplished. In this instance, a "spoof" raid would be as effective as a genuine attack.

The apparent answer would be to have radar stations completely blanketing all of Canada from north to south, and east to west. According to Mr. Claxton: "Rich as our countries are, the combined resources of Canada and the U.S. in men, materials, and money are not equal to undertake such an immense task even if it were possible."

Thus, the McGill fence has been developed. The indications are that it is some sort of an automatic electronic device which is capable of identifying aircraft, and by being located at strategic intervals, it will be able to track any aircraft. In this way, the defence system will know what targets to alert and when to alert them, instead of alerting all targets indiscriminately.

Collins in Canada

A Canadian subsidiary has been formed by Collins Radio Company of Cedar Rapids, Iowa. Known as Collins Radio Co. of Canada Limited, the new firm has offices at 74 Sparks Street, Ottawa. Headed by manager W. S. Kendall, Collins of Canada will initially provide a liaison service with the DDP, as well as promote the sale of Collins communication and navigation equipment in Canada.

AIRFRAME PRODUCTION

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(1) Design changes.
(2) Customer program changes.
(3) Sub-contract programs.
(4) Facility changes.
(5) New business.
(6) Supply problems.
(7) Errors in original estimates.

A well-designed plan must be able to absorb a due amount of alteration without requiring a complete revision. Several devices used to insure this flexibility are:

(1) A good system of change control.
(2) Well analyzed buffers in the non-concurrent manufacturing processes.
(3) Coded work days rather than calendar days.

These, plus a good share of ingenuity in periods of crisis, go a long way toward assuring sufficient adaptability in the plan.

Human Factor: The fourth characteristic is that the plan must be fostered under the most enlightened "work climate". At best the planning of aircraft production is a difficult process, calling for teamwork and co-operation of the highest order. Management today recognizes that such collective efficiency is not obtained without due regard for human relations.

Evolving as it does through several phases and through several operations, the plan is critically dependent upon communications — communications of a nature that permit the day-to-day relationship between supervisor and supervised to be on a genuine "two way" basis. The people concerned must hold the belief that they are directly and individually associated with an organization desiring labor management harmony, satisfied employees and the release of willing effort for the welfare of all concerned. Such conditions can exist only when the acts and expressions of management leave no doubt as to their sincere appreciation of the importance, dignity and uniqueness of the individual.

Having explored some of the characteristics of the plan, we can turn our attention to the second aspect — a review of the data available which will influence the frame of reference or concept of the plan.

Before the war, those who labored on the production plan occupied a hot spot indeed. At times it was pretty nearly an insoluble problem. The nature of the reduction in direct man-hours with increased quantities of production was not clearly understood. The relationship between the assimilation of working force and increased output was very much conjecture. The volume of production was not such that sufficiently large samples of data were available for statistical analysis.

Today we have available a wealth of information upon which to base decisions. While this data is significant, it is not so homogeneous as to be without limitations.

No Two Alike: Although there are certain restrictions implied, this lack of homogeneity in the data as it applies to even a single type of aircraft indicates one basic fact— no two aircraft programs are ever developed under identical circumstances. The factors influencing the variables involved do not maintain a constant balance of power one to the other but form an infinite number of patterns, as viewed by past performance.

This being the case, the important decisions with respect to any plan are made when we assume the frame of reference or concept of the situation. Further the history of prosperous companies demonstrates that the successful production-plan depends upon the degree of imagination and insight embodied in its beginning.

The first, and perhaps the most important set of data influencing the frame of reference deals with the nature of the reduction in direct man-hour costs with increasing quantities of production.

In 1936 Mr. T. P. Wright, writing in the "Journal of Aeronautical Sciences", made a basic contribution to the subject by identifying the rate of reduction in what is commonly known today as the learning curve. He set forth 80% learning as being applicable to the aircraft industry. It was not until about 1942 that the industry as a whole had come to accept this idea as sound.

We now have the learning curve record of wartime and subsequent experience for all types of aircraft, ranging from very heavy bombers to primary trainers. This industry experience shows there is enough difference in learning between aircraft types to be significant.

A Straight Line: It further shows that time reduction trends in unit man hour costs can generally be represented best by a straight line drawn on double logarithmic paper. The vertical axis, representing direct man hour per plane and the horizontal axis representing cumulative production. The mathematical implication of such a trend is that a constant per cent increase in the cumulative plane number is accompanied by a constant per cent increase in the unit hours. Thus T. P. Wright's 80% learning curve implies that the doubling of the cumulative plane number results in reducing the unit man hour expenditure to 80% so that if 10,000 direct man hours were expended on the 100th plane, cumulative plane number 200 would require 8,000 direct man hours. If, instead of a reduction from 10,000 to 8,000, the drop is from 10,000 to 7,500 man hours, the trend would describe a 75% curve.

It is often possible and desirable to analyze the aircraft by the types of labor comprising the total direct labor effort. Each type of direct labor has its own learning curve. These, when combined in the proper proportion, result in an overall learning curve for the aircraft.

Thus, presented with a variety of typical learning curves, the individual producer must make the decision as to which one will be used in estimating man hour requirements.

The second set of data influencing the frame of reference relates to the rate of production growth from initial delivery to peak rate.

Highly Accurate: For the detailed analysis of this problem we are indebted to Mr. P. J. Stanley of the College of Aeronautics, Cranfield. Mr. Stanley has exploited World War II experience in deriving his conclusions with respect to this problem. In his report number 30, published by the College of Aeronautics, he has made a detailed analysis of the wartime aircraft programs of Great Britain, the U.S., Germany, and Japan. In doing this he has demonstrated that the Logistics or Pearl-Reed curve fits the actual schedule acceleration data available to a high degree of accuracy and thus has concluded that statistics relating to the building up of output are of the same nature as those found in other types of build-up.

Using this basic assumption, Mr. Stanley has constructed a family of curves which illustrate a wide range of steepness and thus variation in the acceleration rate. These curves are identified by a "B" index of steepness. Once a particular curve has been selected from the family of curves, it is easy to develop a logical calculation of acceleration rate and a comparative analysis of the task set forth.

Mr. Stanley concludes that the evidence does not indicate any correlation between the per cent rate of built-up and the size of the production program or the size of the aircraft. Therefore it would appear that the skill and efficiency of the organization and the design of the aircraft are the determining factors. This being the case, the individual operator is again faced with a decision that contributes to the concept of the plan.

The third set of data influencing the frame of reference is that describing the production design, and tooling.

Degree of Adaption: Aside from certain technical developments that require radically new approaches from time to time, history in this instance indicates that the problem is not one of applying the new and different, but rather one of assessing to what degree present practices are to be employed.

Production rates of 15 to 20 aircraft per day call for a higher proportion of hard dies, the breaking down of operations into smaller segments, more positions in the sub-assembly and assembly lines, and possibly mobile jigs and moving production lines. Certain programs, primarily military, have as one of the stipulations that such thinking must be embodied in the designs for tools and production but that moderation must be practised in the actual production for peace time programs.

It is entirely possible for an exceptionally able production and tooling organization to go a long way toward setting up a 20 or 30 ship program on high volume methods without incurring costs in excess of those arising from a more conservative approach. Such an accomplishment would most certainly result in a distinct competitive advantage.

Thus the individual operator is faced with the paradoxical situation that says on one hand "do something new and bold and different in order to gain the potential advantage available", and says on the other hand, "use caution; historical data does not disclose any successful operation that varies to any considerable extent from custom".

However, this is a decision that must be made if we are to complete the frame of reference for the plan.

Miscellaneous: The fourth set of data contributing to the concept of the plan is comprised of the miscellaneous assortment of statistics used as parameters of magnitude and achievement. Such figures as: (1) the number of Engineering drawings, (2) the number of parts and assemblies, (3) the number of tools by type, (4) the number of tools per part number, (5) the percentage distribution of man hours by aircraft component, and (6) the amount of material per labor dollar, are typical of the statistics falling into this group.

As the pieces of the plan are gradually assembled into the whole, this kind of data is used as a check in order that we may develop a rational picture in all phases of the operation as measured by past performance. For example, if our plan is based on a release of 20,000 Engineering drawings, the other factors being equal, it is reasonable to plan for a related number of tool designs, shop orders, tools, etc.

Later in the development of the plan, but still early in the actual accomplishment of the over-all program, the same data is used as a barometer to indicate changes between actual and assumed conditions.

There are, no doubt, many more criteria that influence the decision-making necessary for the conception of a plan. However, the ones mentioned are representative of the others and, suffice to say, the problem is equally one of segregating applicable data from the total available, as it is one of developing new means of assessing optimum performance.

What Takes Place: Time does not permit a detailed analysis of the mechanics of assembly of the plan. However, it is desirable that we briefly study what happens during the major phases of development. For convenience, the evolution of the plan has been divided into three phases:

(1) Block considerations.

(2) Preliminary Detail considerations.

(3) Final Detail considerations.

In Phase I very little detail is actually known about the aircraft. The general character of the aircraft will be known—two-engine, four-engine, military, commercial, etc. In addition, the Engineering Department can generally supply an estimated weight and approximate dimensions.

With this somewhat sketchy information to go on three important fixes must be made:

(1) The date of first delivery.
(2) The peak production rate.
(3) The acceleration curve to peak production rate.

Since time is of the essence in most aircraft programs, a consideration of initial delivery dates usually boils down to visualizing as accurately as possible what must take place between an assumed contract date and the completion of the first aircraft. In general, Engineering, Planning, Tooling and Production operations are anticipated and a block of time is allocated for each sufficient to assure operations. The elapsed time allowed for these operations is a function of past performance modified to conform to the terms and conditions anticipated for the proposed program.

Production Rate: Having fixed on a delivery date, the next point to consider is the maximum production rate. It should be pointed out that the fixing of the maximum planned production rate establishes the magnitude of the manufacturing program. The number of men and machines, the production lot size, the rate of procurement, the floor space, and the nature of the tooling program are all tailored to accommodate this figure. There are no fixed rules for establishing the maximum rate. It is simply a figure agreed to by customer and manufacturer lying within the physical limitations of the plant.

With the initial delivery and maximum rate established, the remaining phase I consideration is the delivery acceleration curve. This is resolved as mentioned earlier by the application of Mr. Stanley's logistics curves.

Phase I development is now complete and we have as a result of our efforts an overall picture of the program from the start of the contract to peak production.

Phase II, Preliminary Detail considerations, is the phase in which we fill in the particulars of the plan. In the case of a representative aircraft the problem is one of integrating, on a given date and at a given rate, approximately 90 major assemblies, 3,000 purchased parts, 3,000 subassemblies, 18,000 detail fabricated parts, 30,000 tools and 15,000 pounds of raw material. It is the period in which the actual engineering data flows into the planning operations and through these into the shops.

At this point it becomes necessary to identify each tool, part, or assembly, with respect to its ultimate usage point on the aircraft. The basic requirement for this operation is the line position chart; on it are set forth the manufacturing breakdown of the aircraft, plus the number of work positions required to build the aircraft at the planned rate. As each part of the aircraft is released to the planning group, it is associated with a given component and work position on this chart. This identification also serves as a basis for segregating costs by aircraft component.

CHINOOK COMMANDER: Franz McTavish of Chinook Flying Service, Calgary, is shown with his company's new Aero Commander, which was the first sold in Canada by the Canadian distributor, The Babb Co. (Canada) Ltd. There are now three of this type with Canadian registration.

Requirement Dates: Having located the relative points of usage for all parts and tools, the next step is to establish requirement dates for these same items. To do this, a time cycle chart is constructed that sets forth the major assembly manufacturing flow times for the first and subsequent aircraft in the program.

Using these curves and standard lead times established for sub-assemblies, detail parts, raw material and purchased parts, the required completion dates for any part in any stage of production can be determined.

When the production orders begin to flow to the shops, it is essential that departmental man loads be developed as a guide for hiring. This is essentially a function of the man hours as determined by the learning curve, and the scheduled rate of production. These calculations, in conjunction with jig and fixture calculations, are also used to determine factory space requirements.

As processing is released, machine loads are confirmed and, where necessary, additional equipment is ordered or sub-contract programs are initiated.

In short, during phase II, all operations involving men, machines and material are set forth in detail with respect to the relative priority and quantitative requirements.

Inasmuch as phases I and II must be carried out in many instances without benefit of finalized planning, the primary operation in phase III, Final Detail considerations, is to screen the initial assumptions against the formalized planning as it develops.

Cutting & Stretching: The succeeding steps of cutting and stretching to fit are dictated by actual performance, change in objective, and inaccuracies in our estimates. In order to evaluate these factors a series of reports, charts and comparisons are prepared. These include records of hours expended against the budget; rate of tooling and processing release; rate of material procurement; records of scheduled plant rearrangement; and schedule status.

In addition, such operations as time and methods studies are introduced in order to accelerate the learning so necessary if labor costs are to stay in line with the assumed time reduction trends.

In the general nature of things, it is common to find actual performance deviating from planned performance. The reasons may be obvious or obscure and the amount of analysis will vary accordingly. In any case, efforts are directed toward keeping a thoroughly realistic, detailed and up-to-date plan of operation in the hands of supervision at all levels and in all departments.

In conclusion, the picture we have attempted to present of "A Plan for Airframe Production" has for its bold outline the factors of comprehensiveness, flexibility, evolution, and enlightened work climate. It has for background direct man hour reductions, acceleration curves, production design and tooling, and a variety of miscellaneous statistics used as parameters of achievement and magnitude. It is framed in Block considerations, Preliminary Detail considerations and Final Detail considerations, and is hung on the wall of every supervisor in every department involved in the program.

This then is the picture: the shadings and colorings are infinite as they are directly related to the decisions made by the individual operator.

CIVIL MARKET

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Up and At 'Em Boys: To begin with, the project must not be looked upon as "just another job" to be through. To achieve success all key personnel in the organization must have enthusiasm for their jobs coupled with an intense faith in the project at hand. This enthusiasm must be present to the greatest degree in the design team and the production team immediately associated with the project: for it is from these people that most of the original thought comes and the success of the entire project may well depend on their efforts and ability.

There should be no doubt about the importance of getting the prototype into the air as quickly as possible. Only when the prototype flies can the soundness of the design be assessed and any difficulties cleared up. It is usually at this stage that customers begin to press inquiries for delivery. The production engineers must therefore lend great assistance in speeding completion of the prototype.

In our experience, the real key to the smooth transition between design and production is the Experimental Department. The main function of this department is to produce prototype aircraft. It also deals with normal mock-ups, functional mock-ups, test pieces, structural tests and all special requirements and development work. This department should be as self-contained as possible, should be located close to the design department and be directly responsible to the Chief Engineer.

The Experimental Department is also responsible for prototype servicing and flying, the actual flying of course being in charge of the Chief Test Pilot and the flight programs under the control of the aerodynamics section of the engineering department.

Meeting Ground: The Experimental Department is a kind of common meeting ground for the design and production engineers. During the prototype stage we have found it profitable to station a group of production engineers right in the Experimental Shop in order to advise on all new details from a production angle. The following things can be done through this group:

(1) Suggestions can be made directly to designers before experimental drawings are prepared. These suggestions are made with a view to a certain method of manufacture making maximum use of existing production equipment. If the design demands the use of equipment not available in the plant, early consideration can be given to the locating of a competent sub-contractor or the possible purchase of the required equipment.

(2) The production group is able to draw up schedules of material, particularly castings, forgings, and extrusions, which have long delivery times thus giving the production department an early lead.

(3) The production team is able to guide the Experimental Shop as to the best way of making the prototype parts. In some cases freehand methods can be used. This applies particularly to machine shop items and simple sheet metal items where interchangeability can be achieved without tools or where it is not a factor.

More often some type of tooling is needed and it is here that very close liaison is called for between design, experiment and production. If there is time, the final production tool should be made but only where the designer feels that there is not too great risk of change. Sometimes the major portion of the production tool can be made, leaving certain sections "open" for future development as the design becomes stabilized. This latter procedure is often successful in the case of the larger assembly fixtures.

In the case of formed sheet metal parts it is best to produce drop hammer dies, stretch press dies, Hufford tools and rubber press tools right at the start. The prototype will benefit from all such parts being properly and smoothly formed, and of course the later production benefits because of the tool development which has taken place early in the project.

In other cases, temporary tools can be made, but here the production engineer can ensure that such tools are adequate for at least 5 or 10 sets of parts which can be used in the initial production. He can also watch the behavior of the temporary tools to get a practical idea of how the production tools can be better designed.

(4) The production engineer can observe the way in which various details assemble. Potential production difficulties can be discussed with designers and drawing changes put in train.

(5) The production engineer can arrange for some details to be fabricated in the production shops on a short batch basis. This relieves the load on the Experimental Shop and at the same time begins to make the production departments aware of and interested in the new project. Again this is most likely to happen on those parts requiring special equipment such as presses, hammers, furnaces and the like.

Modification Problem: In all this there is the ever present risk of modification. The amount of risk varies with every component and with every detail of each component. By means of smooth co-operation between design and production these risks can be reasonably well assessed so that production can be started earliest on minimum risk items. The successful completion of structural tests and functional mock-up tests are events of great importance to the production man. As each unit passes test the risk of modification on that unit drops considerably thus clearing

REAL COOL SUIT FOR BEBOP SET: Being produced by G.Q. Parachute Co., in England, this ventilated suit is said to be a must at high speeds in hot climates, even in a refrigerated cockpit. Worn over pressure suit, this unit distributes cool air to over 100 points of wearer's body.

many details for production.

Of course there is additional expense involved by the duplication of some tooling. This duplication is brought about largely by the need for temporary tooling, later duplicated by more robust and less skill-demanding production tools. To avoid duplication of large expensive assembly fixtures some success has been achieved by first making the large structural frameworks with a minimum of pick-up points. These are used by the Experimental Department in making the prototype and test components and possibly a few extra units for initial production. These basic fixtures are then turned over to the production department for the addition of the many pick-ups, locators, clamps, and labor-saving details required. The use of the fixtures by Experimental is of great assistance in enabling Production to establish the best assembly sequences and methods.

During the development flying of the prototype many detail changes are usually called for. The production engineers must keep in close touch with these on a day-to-day basis in order to introduce these changes into the production system as rapidly and smoothly as possible. It is not always feasible to wait for formal drawing changes since the time factor could be expensive in terms of work in process or material on order. The system must be flexible enough to enable fast action to be taken, later followed up by formal documentation.

The extreme volume of work to be accomplished between the first flight of the prototype and the beginning of production deliveries is one of the production engineer's major problems. The prototype is usually flown as a shell and the final fitting out and equipping of the machine is left until a later stage by the engineering department. Such items as seating, soundproofing, upholstering, heating, ventilating, lighting, radio and the like are in this category. Schemes for these must be worked out, material ordered, tools made, operations planned, and all details made in time for the first deliveries.

Problems at Hand: The following is a summary of the various problems which must be dealt with by the production engineers before a strong production line can be established:

(1) Design of jigs and fixtures.
(2) Manufacture of production tools.
(3) Settle the final production breakdown of the machine into components suitable to the plant equipment and tools.
(4) Develop producion methods and techniques.
(5) Make factory layouts and assembly line layouts.
(6) Write up, issue, and prove all process and operation sheets.
(7) Train the labor force in the use of the tools and processes.
(8) Handle all modifications.
(9) Design and produce special equipment for functioning tests on the line and at test flight.
(10) Determine the type and amount of work to be sub-contracted and assist sub-contractors in the initial phases of their work.
(11) Establish standard times for manufacture of all details and components.

Other Factors: While the above-mentioned things constitute the normal work of any production engineering department, it must be emphasized that the major portion of this work must be completed before the prototype trials are finished and before a Certificate of Airworthiness is obtained. In order to make this possible it is important to do several things:

(1) The Company management by weighing the financial risk against the potential profit must make its decision clear to all key people. The aims on timing and programming must be thoroughly understood and supported by all the people involved.

(2) The design department must not compromise its design merely to relieve the production department of the need for exercising skill and ingenuity in its execution. However, the engineering design department must give support to the production side in the matter of adequate drawings produced consistently to a system. This department must design for production from the outset even though this may mean slightly more man-hours in the drafting room and on the lofting tables.

(3) The production engineering group must organize itself so as to participate in the project from the earliest possible moment. Tool and methods specialists should be posted to the Experimental Shop. Production engineers should be appointed as contact men and advisors to the design staff. These men also serve to keep the production engineering group up to date on all phases of the work. Personal contact is to be encouraged on all sides.

(4) Regular meetings should be held with the following people: chief engineer, design project engineer, chief draftsman, production manager, production project engineer. These people can give regular attention to:

a. Current work, and work for the immediate future.
b. Basic schemes of design layout and breakdown for manufacture.
c. Points of trouble or controversy.
d. Drawing completion dates and estimated dates.
e. Adoption of new standards.
f. Discussion of new methods or materials.
g. Establish zones of minimum design risk for maximum production effort.

Men Wanted: In this matter of establishing production while the product is under development, the production engineering section has many difficult problems. The most difficult problem is that of obtaining men of adequate training and skill—men who can work smoothly among design, experimental and production departments: men who can discuss problems intelligently and make decisions promptly within their sphere of action. They must have enthusiasm and initiative and the ability to get their ideas across.

Probably the best training ground is within the company itself, but is is important to start with people who have a good background of training and experience. As the industry grows there becomes more need for a regular intake of technically trained men who are keenly interested in the production engineering side. It is easy to recognize the need for technical men on the design side. This paper attempts to show that there is just as great a need for technical men on the production side if this expensive gap between prototype and production is to be satisfactorily narrowed.