FLIGHT TESTING

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INTRODUCTION

Until comparatively recently, flight testing was used only to insure the proper functioning of an aircraft and its component parts in flight and to give an approximate indication of the performance capabilities of the aircraft. Under the impetus of the war, flight testing techniques and methods of instrumentation and reduction of data have improved and progressed rapidly to the point where flight testing must now be considered at least a complement to wind tunnel testing in providing the Aeronautical Engineer with various data for use in the development of future aircraft. Actually, flight testing is unique in certain cases such as the determination of dynamic air and landing loads and their true effect on the aircraft structure. By no other method can the actual dynamic loads be properly applied and measured at the present time.

No attempt is made in this thesis to contribute any new work to the field of flight testing, because of the relative inexperience of the authors. The concerted efforts of many learned men have advanced the art to its present state and this paper does not presume to instruct these men in their own fields of endeavor. Rather, the purpose of this report is three-fold.

1. To present in convenient form what might be considered a basic manual on flight testing.

2. To stimulate the thinking of both the manufacturers and the using agencies along lines of standardization and possible simplification of certain basic flight test procedures.

3. To discuss any apparent trends in the development of the art of flight testing.

In attempting to write a basic manual on Flight Testing, the authors had originally intended to cover the Philosophy of Flight Testing, the Instrumentation of Flight Test Aircraft, and the Reduction of Data. However, Army Air Forces Technical Report No. 5069, by Mr. P. F. Bikle, entitled "Performance Flight Testing Methods in Use by the Flight Section, Wright Field", was published a few months after the preparation of this thesis had begun. Since that Technical Report deals principally with Reduction of Data, the authors decided to leave out this part. Therefore, this thesis is a collection and discussion of those ideas in connection with the Philosophy of Flight Testing and the Instrumentation of Flight Test Aircraft which appear to have been most successful in producing the greatest amount of reliable and useful engineering data per dollar invested in flight testing. In conjunction with AAFTR 5069, perhaps it will be of some value in those organizations where the constant need for training new flight test personnel is a major problem. The Aeronautics Departments in some colleges which are considering giving courses in Flight Test Engineering may find this thesis of interest.

Standardization of procedures in any complex and rapidly improving art such as flight testing is possible but naturally difficult. Any standardizing process would have to be well-considered, and special safeguards would have to be taken to insure that the field of flight testing was not deprived of the valuable benefits of individual initiative among the various aircraft companies. However, the advantages to be gained from standardization of certain basic phases of flight testing are so great as to make worth-while a complete and thorough investigation of this possibility. Direct comparison of the performance and flying qualities of various aircraft, without any question as to the reliability of any of the data or the methods by which they were obtained, and elimination of a great amount of the duplication of testing between the manufacturers and the services would be two immediate benefits derived from a standardization project. These benefits would naturally assume more value after the war when the sale of aircraft to commercial airlines becomes possible and when the funds available both to the industry and to the services for the development of aircraft may be expected to be somewhat restricted. Army Air Forces Technical Report No. 5069 is an excellent and important step in the direction of standardization. It is interesting to note that all of the flight test organizations visited by the authors were either planning to prepare or actually preparing a manual describing their own flight test methods.

Certain trends in the development of the art of flight testing have become apparent to the authors during the survey of various flight test organizations. The last part of this paper discusses those trends and attempts to point out their importance to the future progress of the aircraft industry.

The authors will be happy to discuss further, with anyone interested, the material presented and to be informed of any errors which may be found in this thesis. Where controversial questions are involved, especially in the part on Philosophy of Flight Testing, the views presented are those of the authors.

I. PHILOSOPHY OF FLIGHT TESTING

A. THE VARIOUS PHASES OF FLIGHT TESTING AND THEIR OBJECTIVES.

Flight testing can be divided into the following distinct phases:

1. Operational testing
2. Accelerated service testing
3. Tests to determine compliance with major specification requirements with regard to:
   a. Performance
   b. Flying qualities
   c. Power plant cooling and operation
   d. Operation of accessories
4. Research flight testing, i.e. flight testing as a design function

1. OPERATIONAL TESTING.

Operational testing generally consists of taxiing tests, simulated takeoffs, and then the first few flights of a new aircraft. Various components of the aircraft are operated for the first time during taxiing tests and simulated-takeoff runs in an attempt to determine whether or not there are any serious mechanical difficulties. When such items as power plant, propeller, hydraulic system, controls, brakes, etc. appear to be functioning satisfactorily, the initial flights are made. This phase of flight testing requires the utmost in diligence on the part of all personnel connected with the actual test flights. Careful procedures have to be planned and worked out in advance to insure that all of the components of the aircraft and all flight test equipment are properly operated by a relatively unfamiliar crew and that any unsatisfactory or dangerous condition which may develop during a flight will immediately be detected and brought to the attention of the pilot. The aircraft is given a thorough and rigid inspection on the ground after each flight to insure that everything is still in proper order. The objective of this phase of flight testing is to discover and correct those difficulties and faults in the design which, if they exist, will become readily apparent and will prevent the further safe operation of the aircraft.

2. <u>ACCELERATED SERVICE TESTING.</u>

Accelerated service testing begins as soon as it is evident that the continued safe operation of the aircraft is possible. A small number of the particular airplane type are flown practically continuously, undergoing rigid and complete periodic inspections. The inspections generally follow some predetermined plan, being more frequent and complete during the first few hours of flying time. This phase of the test program determines which of the various components of the aircraft would not stand up under repeated use and would require excessive maintenance or would have to be redesigned at some later date if the aircraft were immediately produced in quantity and put into service. It brings out the difference between a custom-built prototype, maintained by a staff of experts, and a production aircraft which has to be kept flying by personnel of somewhat lower caliber. Thus, insofar as the operator of the aircraft is concerned, accelerated service testing reduces maintenance costs and maintenance time, and cuts down the number of personnel and spare parts necessary to keep the aircraft in flying shape. Also, it helps the aircraft manufacturer avoid those costly production stoppages which will occur if serious service difficulties are encountered with a new aircraft after production has begun.

3. TESTS TO DETERMINE COMPLIANCE WITH MAJOR SPECIFICATION REQUIREMENTS.

a. PERFORMANCE - The third phase of flight testing determines the basic characteristics of the aircraft. Tests are run to establish such performance items as take-off distances, maximum rate of climb, speeds at various powers and altitudes, range, and landing distances. Often, some of these tests are repeated to determine the effects of different gross weights of the aircraft or of one or more inoperative engines. It is obvious that almost an infinite amount of flight testing would have to be done to determine specifically all of the performance data. To avoid such a time-consuming and costly procedure, only certain basic performance data are obtained from flight tests. These basic data are then interpreted properly to give the actual performance of the aircraft at any weight or altitude, under any conditions.

b. FLYING QUALITIES. - The flying qualities of an airplane indicate the relative ease and safety with which it can be flown. They also show whether or not the airplane is suitable for the mission for which it was designed. Such items as stability, maneuverability, and stall characteristics, for example, are considered part of the flying qualities of the aircraft. For long-range transport or bombardment aircraft satisfactory stability is of primary interest, whereas for a fighter type considerable flight test time has to be expended to show that its maneuverability characteristics make it satisfactory for combat use.

c. POWER PLANT COOLING AND OPERATION - The power plant manufacturer generally specifies maximum temperatures for safe, continuous operation of the engines. The cooling tests are made to show that these maximum safe temperatures are not exceeded under the most critical condition. For single-engined aircraft, the critical condition will generally occur with maximum continuous power at speed for best rate of climb. For a multi-engined airplane, the test will generally be conducted with one or more engines inoperative. Engine cooling during ground operation is frequently critical with some aircraft designs. In addition to the cooling tests, further tests are necessary to insure that the fuel, oil, and ignition systems will function satisfactorily at all altitudes and under all conditions.

d. OPERATION OF ACCESSORIES - The electrical and hydraulic systems, cabin heaters, deicers, radio equipment, and many other items are tested under various conditions in conjunction with the performance, flying qualitities, and engine cooling tests.

All of these phases of flight testing are carried out in some logical sequence, many of them simultaneously, and the results compared with various safety regulations and specification requirements.

It is obvious that, at any stage in this process, unsatisfactory operating characteristics or items which do not conform to specification requirements may be encountered. This will complicate matters, for the test program must then be changed and replanned to allow for the testing of modifications which will be made to correct the unsatisfactory items. Frequently, one of the modifications tested may be such as to affect the airspeed calibration of the test aircraft, making a recalibration necessary to insure the validity of data which will be taken during subsequent flight tests. If the unsatisfactory item be a major one, a good portion of the test program must often be repeated because of the interrelation of the various characteristics of the aircraft. For example, a major change in cowl design to improve engine cooling will probably necessitate the repetition of certain performance tests.

The actual sequence of tests will be different for each new prototype, depending mainly on the type of aircraft, the purpose for which it was designed, and on the previous experience of the particular aircraft company. In the case of a prototype designed during wartime to meet an urgent combat need, the operational and accelerated service test phases might be emphasized and expedited at the expense of tests to determine compliance with major specification requirements. The same might also be true in the case of a major modification of an existing, successful, military aircraft. Here the sequence of flight tests will be governed by the extent to which the modified aircraft departs from the existing, proven design. On the other hand, an experienced aircraft company, during normal times, would be most anxious to determine the performance characteristics of a new transport aircraft design. It would thus be able to determine probable operating costs and obtain a measure of the success of the new design before investing too heavily in the cost of additional flight tests. Here, also, some of the accelerated service testing might be combined with actual demonstration of the new transport to airlines. Any number of variations exist, but in the final analysis, the successful aircraft will have gone through the first three phases of flight testing outlined.

4. RESEARCH FLIGHT TESTING - FLIGHT TESTING AS A DESIGN FUNCTION.

It is often presumed that the flight testing of a new aircraft ends when the specification requirements have been checked, with the possible exception of further tests of various modifications or new type accessories. Such, however, is not the case. The flight testing of a new aircraft should never be considered finished until sufficient data have been gathered to enable the design engineer to check the validity and accuracy of all of the major assumptions made in designing the aircraft. The major assumptions will generally be those made in trying to force the new design to reach beyond the boundaries of present aeronautical progress. The engineer must know to what extent he was successful in his last design if he is to succeed in his next design. However, here the question of cost must be considered.

It will be noted that, up to this point, the cost question has not been discussed. The reason for this is obvious. The flight tests outlined thus far are actually part of the work of developing an aircraft and, as such, are paid for directly by the organization for which the aircraft is being developed. It is often argued that these flight tests are generally so pressing and involved as to preclude the gathering of additional data for research purposes. Thus, research flight testing is left to be done at a later data or, more often, left undone. There appears to be a certain amount of aversion to flight testing for research purposes when the aircraft manufacturer himself is paying the price. This aversion seems to be the consequence of a feeling that over-zealous flight test personnel often attempt to measure or determine by flight tests certain variables which are either inconsequential or of academic interest only. Of course, flight testing for research purposes must be undertaken, like research in any other industry, only when there appears to be an assurance that the potential gain will be worth the actual investment. However, the task of improving the modern aircraft can be compared with the solution of a riddle consisting of a maze of interrelated effects and compromises. The solution of this riddle will often require extensive instrumentation and carefully controlled flight tests to determine the small effects of several variables. By itself, any one of these variables may well appear to be unimportant, but when studied together small variables can often give important answers. However, there are many answers and many solutions to the riddle. Research flight testing must isolate the principal ones. That is, research flight testing must concern itself with those factors which are potentially most capable of increasing the economic value of the present aircraft as well as that of the next new design. The recent paper by J. B. Kendricks on "Aero-Economics" indicates an approach to the problem of aircraft development from the economic point of view. With this sort of an approach to the problem of research flight testing, there need not be any question as to economic justification. Then the entire flight research testing program can invariably be planned and executed at an earlier date and at a lower total cost than if only certain isolated phases of it are carried out at some later data, when it becomes imperative to answer the demand from design engineers for additional data which are needed in designing the next new prototype.

Research flight testing can be discussed from another point of view. It is economically sound to test a prototype airplane only if the probability of having a serious accident occur is below a certain maximum. Although it would be difficult to express this "accident probability" as a numerical relation, it obviously goes up as the number of new, experimental items and innovations in design on the prototype increases.

If a particular aircraft design is of a highly experimental and risky nature, the "probability of accident" can be reduced in two different ways. One way consists of transporting the aircraft to a large, suitably-flat and unobstructed area, such as a dry lake, and there gradually "feeling out" the airplane in extensive taxiing and "short-hop" tests. This method lowers the risk of accident somewhat, but it can become prohibitively expensive from the point of view of time consumed as well as actual cost.

Another way of reducing the "probability of accident" consists of testing various components of a new design on a piece-meal basis, by installing them on an older aircraft of proven design. This method becomes of great importance if it begins as soon as the work of designing the prototype is started. Research flight testing then becomes a design function, i.e., it becomes one of the tools which the design engineer can use to obtain solutions to current design problems.

Flight testing performs best as a design function when flight test personnel are used in an advisory capacity in connection with new projects. Frequently, their practical advice "builds into the new airplane" the lessons of a great amount of flying experience which are apt to be remote from the design engineer. Experimental design features and new type accessories are tested in flight as soon as they make their appearance on the design engineer's drafting board.

Flight testing as a design function greatly reduces the "probability of accident". It also cuts down the total amount of flight testing necessary after the prototype is ready and eliminates a lot of unsatisfactory items which "just get by" because it is too uneconomical to eliminate them later on, considering the time which would be required to do so. The B-17E airplane was an outstanding example of the use of flight testing as a design function. This airplane was ready for acceptance demonstrations one week -- 10 hours of flying time -- after completion of the prototype. In another notable case, the complete engine and cowl installation for the "Constellation" was flight tested on a twin-engine medium bomber.

5. SUMMARY OF OBJECTIVES.

Keeping in mind the various phases of flight testing which have been discussed, it is possible to summarize as follows the principal objectives of flight testing:

a. To determine and eliminate any undesirable characteristics which a prototype aircraft may have. (This must be done with maximum regard for the safety of the flight test aircraft and crew.)

b. To test a prototype exhaustively in as short a time as possible. so as to reduce to a minimum the amount of maintenance work necessary to keep the aircraft flying and the number of production stoppages due to the discovery of unsatisfactory items when the aircraft is put into regular use.

c. To gather (and present in some suitable form) all data which the services or a commercial operator will need to operate the aircraft safely and efficiently.

d. To provide the design engineer with sufficient flight research data to permit him to check the validity and accuracy of his solutions of important new problems encountered in the design of a prototype and, insofar as it is possible, to help him solve current problems which come up as the design of the next new prototype progresses.

Only when flight testing attempts to reach all of these objectives, does it become of maximum value to an aircraft company.

B. BASIC REQUISITES OF GOOD FLIGHT TESTING.

1. GENERAL.

Modern aeronautical science has progressed to the point where the successful aeronautical engineer must avail himself of every possible source of design information in attempting to develop a new, superior aircraft. These sources of information will generally include:

a. The latest research data available from wind tunnel tests, flight tests, and laboratory tests conducted by his particular company or by various research agencies.

b. Every latest refinement in methods of mathematical analysis.

c. His fund of practical knowledge based on past experience.

In using all of this design information, the engineer will invariably have to make many assumptions and extrapolations in order to apply it in some new way or in regimes not yet completely explored.

Further, the progress of aeronautics has made the modern aircraft so complex, that the aeronautical engineer is constantly faced with the necessity of making a series of compromises between various conflicting factors in attempting to satisfy all of the specification requirements. The relative importance of performance characteristics, safety requirements, serviceability, ease of production, and many other factors must repeatedly be weighed against each other as the design of an aircraft progresses. The prototype which is finally manufactured represents the design engineer's solution of the problem of applying basic information and making a series of compromises in an attempt to find the best answer to a set of inter-dependent requirements.

In general, before an aircraft company can realize a profit on its investment in the design and manufacture of a prototype, the company must be able to prove two things:

a. That the aircraft is safe to fly and possesses no serious undesirable characteristics.

b. That it can perform a certain task or mission more efficiently than any other aircraft, i.e., that it can meet or exceed specification requirements.

The future of the design, often even the future of the aircraft company itself, depends on the final answers which are obtained to these two questions. Flight testing is important because it answers these two questions. It is the critique which measures the success or failure of the company's attempt to develop an aircraft which will find a ready market. This unique responsibility of flight testing immediately attaches to this function certain basic requirements. It must be:

a. Carried out with maximum regard for the safety of flight test aircraft and flight test crews.

b. Reliable and accurate.

c. Executed as rapidly as possible.

d. As complete and exhaustive as possible, considering the time available and the cost factor.

e. Absolutely impartial in judging and passing upon the merits of various components and characteristics of the aircraft.

2. CARRIED OUT WITH MAXIMUM REGARD FOR SAFETY.

The disrupting effects of the loss of a flight test aircraft and crew hardly need be mentioned. The prototype aircraft invariably represents a considerable investment. It is a custom-built article, involving the high costs of extensive special machining, jigs and fixtures which may be used only a few times, and many expensive items such as engines, propellers, and various accessories. Flight test crews generally become of value to a company only after considerable time and money has been spent giving them additional training. In the case of engineering test pilots, it is often exceptionally difficult to find new personnel who are suitably qualified. Thus, the loss of a heavy financial investment, the job of finding and training replacements for important personnel, and the incalculable effects of the delay encountered before a second prototype is ready to fly -- any of these factors may well be the beginning of the end for an aircraft company. It is therefore axiomatic that nothing should ever be done in flight testing which will compromise safety considerations to even the smallest extent.

3. RELIABLE AND ACCURATE.

Unreliable or inaccurate flight test data, although they may be unwittingly used as helpful evidence in the sale of quantities of aircraft to a customer, can only lead to grief. Where the customer may be a commercial operator, the grief will express itself as a financial loss to the operator, with eventual discredit to the aircraft manufacturer. In the case of military aircraft, flight tests made by the services will invariably show up the questionable nature of the manufacturer's data. The ensuing negotiations can often cast a shadow on the reputation of an aircraft manufacturer for a long time.

4. EXECUTED RAPIDLY.

Such rapid strides are being made in the development of new aircraft that the obsolesence rate has been greatly increased. New discoveries and technical improvements constantly tend to decrease the useful, efficient span of life of modern aircraft. Considering the new design only from the time it has reached the prototype state, it is necessary that everything possible be done to increase the period of usefulness of that aircraft. This can be done by cutting down on the flight test time, i.e., by correcting any design faults which may be discovered, determining optimum operating characteristics of the aircraft, and making it available for service use in as short a time as possible.

5. COMPLETE.

In the final analysis, the reason for the "stationary assembly line", with all aircraft of a particular type grounded, can often be traced back to the flight test which was never made or is still being planned. There may, of course, be many very real reasons why the flight test was not made or was delayed. Further, it must be expected that abnormal use under wartime conditions will always continue to produce service difficulties or failures. However, it remains true that if the initial flight tests are as complete and exhaustive as possible, a great percentage of the production stoppages due to service difficulties can be eliminated. An additional investment in flight test instrumentation and even additional test flights in the first place will be less expensive than the same flight test later on, when service troubles make them necessary. Furthermore, dislocations in the production schedule are invariably very expensive.

6. IMPARTIAL.

The buyer of a new aircraft will generally demand that it meet all of his specifications. Flight testing must therefore be completely impartial in proving the reliability and determining the characteristics of all of the components of the aircraft. The high performance aircraft is not useful if a faulty fuel system prevents operation at high altitudes. Likewise, a low landing speed with flaps extended is not completely satisfactory if each extension of the flaps requires servicing of the flap actuating mechanism. Of course, the quality of the work done by the design engineer is the primary and major factor in determining how well the various components of the aircraft function. But flight testing must definitely prove that under all conditions of use the operation of all of the components of the aircraft satisfies the buyer's specifications.

C. ORGANIZATION OF FLIGHT TEST ACTIVITIES.

1. GENERAL CONSIDERATIONS.

The following two problems must be considered in a discussion of the organization of flight test activities:

a. Company policies governing flight test activities -- these policies determine the location of the flight test organization with respect to the subdivisions of the company as a whole and they outline the relationships which should exist between flight testing and these subdivisions; they also set forth the responsibilities and limits of authority of the flight test organization.

b. Policies within the flight test organization -- these policies outline the manner in which the flight test organization will operate to properly discharge all of its responsibilities.

The extent to which flight testing is successful and of value to the company depends mainly upon the wisdom with which these various policies are established.

There are probably no questions in connection with flight testing which would be discussed and even contested with more vigor than those concerning the proper organization of flight test activities. The reasons for this are readily apparent. Organizations are developed primarily with regard to peculiar conditions within a particular business. Actual applications of the fundamentals of good organization differ widely in two different companies, size in particular having a marked effect on the way in which an organization develops.

The growth of various aircraft companies, especially during the past five years, has not been a steady, predictable process. Some entire companies have doubled and tripled in size practically overnight. The production departments of certain concerns have grown tremendously with little change in the size or structure of the engineering departments whereas, in other cases, the engineering departments have grown in step with the general company expansion. It is a well-known fact that during times of abnormal and unusual expansion, especially in a comparatively new industry, there is frequently little experience upon which to base organizational decisions. The problem of personalities then takes on greater importance and becomes a governing factor in the resolution of organizational problems.

Further, certain unusual events in the history of a company often have a profound influence on the organizational development of the company. For example, the aircraft company which, during the pre-war period, may have suffered severe setbacks because of loss of prototype aircraft during flight tests is very apt to have a strong, well developed flight test organization today. On the other hand, a comparatively small company whose engineering department was successful in developing new military aircraft a few years ago -- designs so superior as to meet with immediate acceptance by the services -- might be expected to be well developed today from a production standpoint, but not necessarily insofar as flight testing is concerned. These two cases are extremes between which lie the actual courses followed by various aircraft companies in the historical development of their flight test departments. Of course, the factors which have been mentioned will influence not only the flight test function but often the entire organizational structure of the company. However, only their effects on the flight test organization are pertinent here.

Thus, since companies of various sizes are involved, with different personalities problems in each company and with different courses of historical development, it is natural that differences of opinion should exist as to the proper organization of the flight test function. However, it remains possible to discuss some of those policies and practices which appear to make a flight test organization of greatest value from the point of view of efficient and complete attainment of its objectives. A complete discussion of this subject would naturally be very lengthy and far beyond the scope of this work. Hence, only some of the more important questions are considered. In the actual application of these policies and practices there will be as many actual detailed solutions to the problem of organizing flight test activities as there are companies of different size, with different personalities problems, objectives, and financial problems.

2. COMPANY POLICIES GOVERNING FLIGHT TEST ACTIVITIES.

a. SHOULD FLIGHT TESTING BE A SUBDIVISION OF THE ENGINEERING DEPARTMENT OR SHOULD IT BE SET UP ON THE SAME ORGANIZATIONAL LEVEL AS THE ENGINEERING DEPARTMENT? - It is particularly difficult to discuss this question, since so many of the factors involved depend on peculiar conditions within each company. In one sense, flight testing is a mere continuation of, and oftime only a small part of, the work done by the engineering department. Yet, flight testing is a very important part of the development of an aircraft simply because it is the final part. It is a "catch-all", the company's last chance to discover and correct hidden inadequacies in design which may prove damaging to its reputation and future if the aircraft is put into service before they are eliminated. In this respect, the relations between flight testing and engineering may be compared to those existing between inspection and production. Flight testing constitutes a "final inspection" for each new work of the engineering department. There is no longer any question in aircraft companies that continued high quality of production requires an inspection department which is autonomous insofar as its relations with the production department are concerned. However, in the case of flight testing versus engineering, other factors tend to complicate the issue.

The axiom of "two heads are better than one" is readily applicable when advocating the use of an independent flight test organization, instead of one which is part of the engineering department, for making the final adjustments which insure that a new aircraft will be safe to fly and will meet all specification requirements. It will be admitted that a man, who is engrossed with the multiple details of a new design over a period of time, sometimes loses sight of the main objectives and frequently becomes prejudiced in regard to certain phases of the design. Such a man will find it very difficult to make the correct changes and proper compromises when flight testing reveals a flaw in one of his prejudices. This fact appears to be a major influence in favor of an independent flight test department, on a par with the engineering department, particularly in the case of the larger companies. Only an impartial judge, having none of the prejudices which often spring from previous connection with the detailed design of an aircraft, can be completely successful in evaluating the prototype and making those changes and compromises which will make it acceptable to the buyer.

But, flight testing is more than a final phase in the development of a new design or a measure of the success of the engineering department. The design of new aircraft or of modifications of existing aircraft very frequently depends on the availability of engineering data which can be obtained only from research flight testing. Often data which are obtained from wind tunnel tests or from mathematical analysis cannot be used with full confidence in the design of new aircraft without some preliminary correlation with research flight tests results. Furthermore, flight testing often produces new information which may alter the very basis of certain design practices. In the sense that it performs all of these functions, flight testing is then actually a phase of engineering. However, because of cost considerations, research flight testing, i.e., flight testing as a design function, has to be carried on together with and as a part of flight tests which are made to test and develop specific aircraft. Furthermore, the amount of research flight testing has to be carefully controlled and limited to items which are really necessary and important for, otherwise, expenditures for research flight testing can easily become unreasonable. It is true that the amount and nature of research flight testing can be controlled satisfactorily, if proper safeguards are taken, regardless of the position of the flight test organization. However, it is significant that the necessity for providing this control over research flight testing appears to have produced a trend in the direction of a stronger, more nearly autonomous flight test organization.

An arrangement involving an independent flight test organization is potentially very hazardous in that it greatly increases the possibilities of friction and can deprive the engineering department of the sense and satisfaction of doing a complete job. Special safeguards have to be taken to insure that the quality and quantity of work done by both departments are not diminished because of misunderstandings and lack of appreciation of each other's problems and responsibilities. If an independent flight test organization exists, the question of design changes when major difficulties are encountered in the tests of aircraft, the overall direction of the entire flight test program so that it is of maximum value to the company, the correlation of important wind tunnel test data and the checking of the results of theoretical analyses by means of flight tests, all of these questions should become agenda for a "flight testing department - engineering department committee". The committee work fosters a proper group spirit among members of the two departments, the spirit of helping each other for the good of the enterprise.

b. THE ORGANIZATIONAL CONNECTION BETWEEN FLIGHT TESTING AND AERODYNAMICS - Flight testing and aerodynamics are frequently associated with each other. However, this appears to be an outgrowth of historical development rather than of practical necessity. In its early stages, flight testing consisted of making a comparatively simple airplane safe to fly and then gathering some approximate performance data. Most of the work done required a good aerodynamics background, hence the reason for combining aerodynamics and flight test. But it appears that of all of the flight test work which has to be done on a modern airplane, perhaps less than 25% requires aerodynamic interpretation.

The combination of aerodynamics and flight testing may be advantageous in a small company where there is an insufficient amount of work to warrant the full-time employment of one good aerodynamicist on flight test work and another one on theoretical aerodynamics in connection with design work. However, as a company grows, the combination of flight testing and aerodynamics is apt to become somewhat risky, whether the combination be part of the engineering department or separated from it.

An aerodynamicist is not always critically observant of the performance of all of the components of an aircraft. He frequently concentrates on such items as drag and propeller efficiency and overlooks items such as the fuel system and the electrical system. His flight testing is apt to become academic in nature, with the inclusion of many test items which could not be considered "aero-economic".

Of course, these effects can be, and are, minimized by keeping the functions of flight testing and aerodynamics distinct from each other and, as the organization grows, by adding flight test personnel who are specialists in the analysis of the various components of an aircraft. However, in the case of larger companies where flight testing is not part of engineering, there does not appear to be any justification for making the engineering department dependent upon another department for theoretical aerodynamics work which is really part of the job of designing a new aircraft. The solution of this problem appears to lie in the provision of a sufficient number of qualified aerodynamicists in both the flight test and engineering departments, permitting each organization to perform the aerodynamics work which falls in its own sphere of influence. The work of the two groups should be coordinated and results compared frequently by a suitable committee. There would be no reason for competition between the two aerodynamics groups, and a regular interchange of aerodynamics personnel between the flight testing and engineering departments would probably be of considerable value in promoting coordinated effort and a spirit of cooperation.

c. RESPONSIBILITIES AND LIMITS OF AUTHORITY OF THE FLIGHT TEST ORGANIZATION.

1. General Discussion - One of the first rules which is apparently followed in organizing flight test activities is the lumping of responsibility for all of the various phases of flight testing in one organization. This is done regardless of the nature of the test item or the aircraft component with which it is concerned. Flight

testing becomes an organization of specialized skills for doing any flight test job safely, accurately and completely, rapidly, and at minimum cost.

In the past, specialized flight test projects have occasionally been put in the hands of various specialists who were not members of the flight test organization. For example, a stability and control engineer, regularly assigned to the engineering department, might be given the task of carrying out flight tests on a new-type flap, relying on the regular flight test organization only for assignment of pilots and some administrative assistance in "getting the test airplane into the air" and having the required test performed. The specialist with his special flight test problem becomes an intruder insofar as the regular routine of the flight test organization is concerned, especially if he is only one of a group of men with various assignments of a similar nature. Much sad experience has apparently caused the discontinuance of this practice. Primarily, disorganized flight testing becomes prohibitively expensive and complicated. One aircraft may be flown for many hours at great cost to find the answer to only one question, whereas with carefully integrated tests, the flights could have yielded the answers to many additional questions at much lower cost per answer. (The actual value of the answer obtained is often limited by virtue of the fact that it was impossible to obtain the same pilot to run the whole series of tests.) Thus, with disorganized flight testing, the amount of data obtained per hour of flying time decreases and the number of test aircraft necessary to do a certain amount of work increases. As the number of test aircraft increases, the problem of assigning and keeping track of priorities magnifies itself, and maintenance and installation work becomes confused and involved because of a multiplicity of orders and a greater number of aircraft.

Sometimes there is a belief that an important special task can be performed more rapidly by the assignment of a specialist outside of the flight test organization. This is very frequently not the case. Flight testing is a sufficiently specialized job in itself so that it cannot be "just picked up". The multiple details of preparing an aircraft for a flight test, details of test instrumentation without which the flight tests will seldom be of any appreciable value, can be handled most efficiently by an organization set-up to take care of them in a routine manner. The specialist has to find out about, perform, and worry about detailed matters which, ordinarily, would have been taken care of rapidly and automatically by the flight test organization. Furthermore, while he is doing these things, the theoretical or other work which he is best qualified to do and for which the company is paying him, is being neglected.

The case of accelerated service testing is a possible exception. By its nature, accelerated service testing is somewhat different from any other phase of flight testing. It does not require any special instrumentation and does not have to be performed under ideal weather conditions. Thus, it is frequently organized as a distinct and separate function. However, close liaison must be maintained between flight testing proper and accelerated service testing to insure that any basic difficulties encountered during accelerated service tests are promptly investigated and eliminated. A good example of the type of difficulty which is sometimes encountered is the case of a prototype aircraft which successfully passes all original flutter tests. Accelerated service tests begin and shortly thereafter flutter difficulties develop, due to an increased amount of play, caused by wear, in the control system. The flight test department must be made aware of such difficulties as soon as they occur and it must determine and flight test the proper corrective design changes as soon as possible.

Thus, with the possible exception pointed out in the preceding paragraph, effective flight testing must be completely organized. And this complete organization must attach to flight testing at least the following responsibilities:

a. The detailed planning of the entire flight test program, including the establishment of priorities for various tests.

b. The maintenance and instrumentation of test aircraft.

c. Execution of the actual test program.

d. Determining the changes necessary to remedy items which are found unsatisfactory during the course of flight tests.

2. Planning the Test Program and Establishment of Priorities for Various Tests - The complete utilization of every minute of expensive flying time requires that each test flight be carefully and completely planned. A single flight may cover a variety of items which

have to be tested at different altitudes and under different conditions. Careful planning will integrate these various test items so that all of the tests are made and the required data obtained in a minimum amount of flight time.

Furthermore, in the case of large aircraft to be tested at high altitudes, another factor must be considered. The testing of a large aircraft generally involves a considerable number of people. Considerable work has to be done by ground personnel to insure that the aircraft and the flight test equipment are functioning satisfactorily. The flight test crew, numbering often as many as ten people, has to spend some time reading oxygen equipment and undergoing denitrogenization. With all of this work to be done in preparation for a test flight, it is generally uneconomical to make flights of less than several hours' duration.

The planning of a flight test program requires the establishment of priorities for the order in which the work will be performed. This is especially true in time of war, when the volume of work to be done by a group of individuals generally multiplies considerably. Many factors have to be considered besides the overall importance of a particular project, when establishing priorities for different flight tests in a company. The relative importance of the project, the aircraft which will be available to perform the test, the amount of time necessary to make the required test installations in the aircraft, types of tests to be made and amount of flight time required, altitude at which the test must be conducted, and many other factors must be considered if an efficient, economical, and well-integrated test program is to be planned.

The entire process of setting priorities and planning tests can be handled properly only by someone who is intimately connected with all of the flight test projects and aware of all of the factors which must be considered. It is an easy matter for any one individual to find enough reasons why his particular project should be given first priority and therefore completed immediately, by itself, to the exclusion of all others. But such action rapidly makes flight testing prohibitively expensive from the point of view of the amount of equipment and number of personnel required to do a certain amount of work.

Experience appears to indicate that the entire flight test program in a particular aircraft company can be planned and carried out with maximum efficiency when the flight test organization is governed by only the most general type of priorities policy and allowed to use its own judgement in determining the order of various tests. The general priorities policy (usually set up by management) should specify, at most, the relative importance of only the major flight test projects.

3. The Maintenance and Instrumentation of Test Aircraft - Compared with airline flying or production flight testing, experimental flight testing is never routine, it always involves something different, something new. It requires a different type of mentality, a

different approach to the problem of a flying airplane. Good flight testing demands meticulous attention to details of aircraft maintenance and installation of flight test equipment. With this attention, flight testing is successful; without it, flight testing becomes just so much very expensive flying. For example, many days of preparation and many hours of flying can be made valueless by something as simple as a leak in the airspeed system. Again, a whole series of tests to determine aileron effectiveness may have to be repeated because of a minor change in configuration of the wing forward of the ailerons; something as minor as a muddy wing may have a marked and measurable effect. The proper control of these factors requires more "brains in the ranks" than is required for routine airline or production test flying maintenance work, i.e. it requires a higher level of intelligence among the men who maintain flight test aircraft and install and maintain flight test instrumentation and equipment. It is almost impossible to obtain and keep a high level of intelligence among these men if they are under the supervision of someone who is not connected with experimental flight testing, if they are frequently shifted around, and are not given the opportunity to get the continuous, specialized training and experience which they need to become proficient in doing work on flight test aircraft.

True, it is quite possible to simplify the maintenance of flight test, production, and company aircraft (used for personnel transports) and to show a definite saving in cost by combining all maintenance and service activities under one department. However, it is easier still to prove that the cost of one ruined test flight will often be greater than the total yearly expenditure for separate maintenance facilities for flight test aircraft would be. Furthermore, aside from measurable cost considerations, the delay involved in making a test flight over again to get urgently needed data may often prove damaging insofar as the production schedule is concerned.

4. Execution of the Flight Test Program - The flight test organization must be given the unqualified responsibility for carrying out the actual test flights in the manner deemed most suitable for producing the required results. Good flight testing involves careful technical preparations, painstaking attention to minor details, and well-controlled test flights which invariably have to be carried out under special weather conditions. In the case of one company which the authors considered to be well-organized, it was found that, over a period of three months, approximately 75 man hours of maintenance and instrumentation work and 27 man hours of engineering work were required per hour of flying time. These facts are often forgotten or overlooked in a spirit of eagerness to get the job done. This forgetfulness often leads to administrative controls or policies which are meant to "set the pace" for the flight test organization. The more common of these are: a tendence to judge the performance of the flight test organization on the basis of test hours flown, or even a requirement specifying the number of test hours to be flown in a certain period of time; and a tendency to require completion of

certain projects within a specified period of time, without a thorough consideration of the problems which may be encountered.

If they are not used with considerable knowledge and judgment, such administrative controls can only lead to grief in the long run. Flight test projects, like any other research projects, should be reviewed periodically and checked for satisfactory progress. However, an uninformed, arbitrary requirement that they be completed at a certain time can result in the expenditure of considerable effort to explain why the requirement cannot be met, or it can lead to futile attempts to perform satisfactory flight tests with inadequate instrumentation under questionable weather conditions. It can also lead to disaster. Safety demands that flight testing be carried out in a deliberate manner, by personnel who are not tired from overwork and are given time to scrupulously avoid taking unnecessary chances, even if aircraft have to be grounded for maintenance work and important tests delayed. A design draftsman who makes a mistake or overlooks something can make corrections several days later. However, mistakes or oversights in flight testing generally have frightfully final results.

To require an arbitrary amount of flying involves the risk of being caught with an aircraft needing maintenance work at a time when a combination of good weather and more adequate instrumentation would have made possible a test flight with satisfactory and complete results.

5. Determining Changes Necessary to Remedy Unsatisfactory Items Found During Flight Tests. - With the advent of the independent flight test organization, there has been some tendency to consider flight testing as a service function, authorized only to collect flight test data for various subdivisions of the engineering department. The responsibility for initiating tests and taking corrective measures when unsatisfactory items are encountered on an aircraft is assigned to the engineering department. Such an arrangement may be the only alternative if it is considered unwise or impossible to assign the required number of qualified flight test engineers to the flight test organization. However, it may become unsatisfactory for any of the following reasons:

a. The advantages of having "two brains" attack a common problem are immediately lost in such an arrangement. Flight testing should bring to the development of aircraft a strong, impartial desire to see the customer's specifications satisfied. It has been pointed out previously that it is generally more difficult for the engineering department to appraise its work critically and impartially, from the customer's point of view.

b. Unusual and costly delays are often encountered when flight testing performs merely as a service function. It is very difficult at times to adequately describe an unusual phenomenon which occurs in the air during a flight test. Considerable time may elapse before the required data are available in such form and in sufficient quantity so that the engineering department can understand completely just what is happening. Test flights then may have to be repeated to permit engineering department personnel to actually observe the difficulty as it occurs. The entire process is one which requires a great deal more time than it would require if proper decisions concerning corrective measures were made shortly after the flight during which the trouble is encountered.

e. Under such an arrangement, flight test personnel become uninformed, they do not always understand and appreciate what they are doing, and they lose their sense of doing a complete and constructive job. When the amount of flight testing increases, the engineering department may encounter a growing reluctance on the part of the flight test organization to perform important flight tests without extensive questioning and arguing about their necessity and importance.

All of these factors, if they were premitted to exist simultaneously, could so reduce the effectiveness of flight testing as to make it practically useless as a tool in the development of new aircraft. Thus the flight test organization should never be permitted to become solely a data collecting agency.

However, the flight test organization should not consider authority to make corrective design changes as a license to do as it sees fit, by itself, without any consideration of engineering or production problems. In such a case, flight testing becomes guilty of depriving the company of the benefits of having "more than one head" work on a common problem. When design difficulties are encountered, the important question is not "Who will decide what to do?", but rather, "What is the best way of eliminating the difficulty?" The final decision should naturally be made by the flight test organization because, in the final analysis, it is the responsibility of this organization to insure that the aircraft is what the customer wants. But the decision can be and should be based upon advice from engineering and production personnel which should be available to and taken advantage of by flight test personnel. "Flight testing, engineering, and production" committee action on more important design changes will go far to improve working relations between these departments. It will give the engineering department the satisfaction of doing a complete job, result in design changes which meet with ready acceptance by the production department, and still develop an aircraft which will be acceptable to the buyer.

d. PERSONNEL POLICIES. -

1. Health of Flight Test Personnel - Safety considerations demand that all of the members of a flight test crew perform their respective duties properly at all times. Assuming a knowledge of correct operating techniques, the performance of the flight test crew depends largely on their physical condition. This is especially true when a great deal of test flying is done at high altitudes.

The services of a flight surgeon versed in aviation medicine should be available at all times to flight test crews. A high-altitude chamber is indispensable if flight tests are going to be performed at high altitudes. The best in high-altitude flying suits, oxygen masks, and oxygen equipment should be provided. In general, any reasonable investment which the company can make to promote the physical well-being of flight test crews will be worthwhile. If proper preventative measures are taken, there should never be any occasion to terminate an important and expensive test flight because of physical incapacity of a crew member.

2. Engineering Test Pilots - Modern flight testing demands that the test pilot be primarily a good pilot, with a more-than-usual amount of ability to do precision flying. However, modern test flying also demands that he be an engineer, preferably an aeronautical engineer. The only acceptable substitute, in place of a formal engineering education, appears to be a considerable amount of test-flying experience, coupled with an open mind and a willingness to admit that good instrumentation is invariably more accurate than a "calibrated test pilot".

Whenever the rare combination of good pilot, good aeronautical engineer, and good executive can be found, it is common practice to choose such a man as the head of the flight test department. Otherwise, the engineering test pilots are made part of the flight test department, responsible to the director of that department whether or not he be a pilot. This arrangement appears to be very satisfactory from the standpoint of enabling test pilots and flight test engineers to work together closely as a team, with mutual respect for and appreciation of each other's abilities. It also eliminates a considerable amount of the friction which is bound to occur if management receives uncoordinated flight test reports from two different sources, from the test pilots and from the flight test organization.

3. Working Hours - Flight testing depends to a great extent on the availability of good flight test weather. The flight test organization which does little flying for a time because of bad weather may suddenly be called upon to spend whole days flying when the weather becomes suitable. It is generally advisable, because of health and safety considerations, to limit the maximum continuous working period of flight crew members and to require reporting to work later than usual the following morning when a test flight lasts late into the evening.

When flight testing is in progress, it is advisable to have maintenance crews at work early in the morning so that test aircraft may be given a pre-flight inspection and be made ready for use by the time the flight crews report for duty. Also, if flights are going to last late into the evening, it is well to have stenographic help available so that important flight test results can immediately be dictated and typed, in preliminary form, ready for distribution early the next morning.

In general, the entire matter of working hours for flight test personnel should be a flexible one, left up to the discretion of the director of the flight test department. A rigid working-hour schedule and efficient operation of the flight test organization are incompatible, especially if the working hours be set by company policy without due regard for the requirements of the flight test organization.

e. COST CONTROL - Cost control by means of a budget is one of the most effective tools available to management and needs little comment here. The cost system should provide for the collection of data on various expenditures for each flight test project. Data on expenditures-to-date should be available and consulted whenever flight test projects are being reviewed for progress.

f. ACCIDENT BOARD - An Accident Board can be organized in a very short time and will save a company much grief if it is ever needed. Specific instructions should be issued to the telephone switchboard operator, covering the manner in which all members of the Accident Board, or their alternates, should be contacted in an emergency. The Board should be ready to act at a moment's notice, having set procedures for the following: insuring that medical aid and fire equipment is dispatched to the proper location; conducting an investigation; guarding the damaged aircraft; handing out information to the press; and answering telephone calls. Generally, the Accident Board should function under the direction of a member of the Flight Test Department and should include an engineering test pilot, the project engineer, the flight surgeon, and representatives of manufacturing, public relations, plant protection, the legal staff, and the services.

3. <u>POLICIES WITHIN THE FLIGHT TEST ORGANIZATION.</u>

a. SAFETY OF FLIGHT TEST PERSONNEL AND EQUIPMENT - Flight testing is a science in which there is no substitute for experience. The judgment and decisions of an experienced man will invariably be tempered by the thoughts of many incidents which, with a little less luck, might well have been disastrous. One of the primary requisites for insuring safety in a flight test organization is an administrative policy which definitely places the responsibility for all important decisions in the hands of the experienced, key personnel. For example, the detailed plans for each test flight should be subject to rigid inspection and approval by the chief flight test engineer and by the chief engineering test pilot (or their first assistants), prior to each flight. This is especially important when new aircraft are being tested. Deviations from flight plans during the test flights should be allowed only in the case of minor items, except on those flights where one of the key men is acting either as engineering test pilot or flight test engineer.

The detailed installation drawings for flight test instrumentation should also be checked closely by experienced personnel, especially where the instrumentation involves the power plant controls or the primary flight control system. All such instrumentation should be designed so as to give the pilot all available control of the airplane, should he require it in an emergency. For example, in fuel consumption tests, it should be possible for the pilot to instantaneously switch on a by-pass for the engine fuel supply in the event of failure of the fuel-flow measuring system. Where tests are being conducted to check the structural integrity of certain portions of the aircraft, every effort should be made to provide the pilot with suitable warning devices so that he knows when near-critical loads are being encountered. It should be constantly remembered that the safety of the flight crew and test aircraft lies entirely in the pilot's hands during a test flight. His responsibility is a great one and every attempt should be made to assist him in discharging it properly. Lack of experience among engineers often results in a lack of appreciation of the pilot's task which should never be permitted to manifest itself in the form of experimental installations which hamper or limit the pilot in exercising complete control over the test aircraft.

A systematic training program for flight crews should be a permanent part of every flight test organization. The program should include flight training for pilots and co-pilots, under the direction of the chief engineering test pilot, and engineering training for all flight crew members, under the direction of the chief flight test engineer. In addition, every attempt should be made to give special engineering training to pilots who do not have a formal engineering education as part of their background. These training programs should be continuous, although they may be scheduled at irregular intervals to take advantage of slack periods when good flight test weather is not available. Nothing should be left to chance, no man should be permitted to perform a particular function during an actual test flight until he has previously demonstrated his ability to do it satisfactorily with complete safety to himself, to other members of the crew, and to the test aircraft. The training program should be as practical as possible. For example, a fuel flowmeter operator should be required to demonstrate his ability to perform satisfactorily while dressed in high altitude flying clothes, wearing his parachute and oxygen equipment. The principal objective of the training program should be to insure that all members of a flight crew are unquestionably qualified to perform safely and properly the duties which are assigned to them.

A rigid control over all work which is done on flight test aircraft is necessary. It should include maintenance work as well as installations of special equipment and instruments. This control should rest in one individual, generally the flight test engineer assigned to a particular aircraft. The method of control should be such that before a flight the test pilot can readily determine what work has been done on the aircraft since the last flight. The preflight inspection of the airplane should include a check of all special flight test equipment and instrumentation. (In addition to safety considerations, the importance of gathering as much useful and reliable data as possible on each flight makes the pre-flight checking of all flight test equipment absolutely necessary.) Before each flight, the pilot and flight test engineer should have definite evidence that the complete aircraft and all installations have been inspected and checked for satisfactory operation by qualified personnel.

Flight test personnel must always remember that flight testing is seldom routine. The design of each new aircraft consists of a series of compromises between weight and structural reliability, between simplicity and satisfactory operation under all apecified conditions. These compromises demand that the capabilities of an aircraft be determined gradually. They demand that no main component of a new design be tested under worst possible conditions without first being operated successfully under less-severe circumstances.

Finally, the unexpected must always be anticipated and provided for. Emergency procedures should be established and practiced at frequent intervals by all flight crew members. These emergency procedures should cover failure of oxygen supplyat high altitudes, first-aid treatment of personnel who become physically disabled during high altitude flights, and order and manner of bail-out. Common sense requires that as few key personnel of the flight test organization as possible should take part in the same test flight, especially during operational tests of a new prototype.

Considerable good judgement has to be used in establishing administrative policies and controls which will insure that safety requirements and safety considerations are never neglected in the execution of the flight test program. The fixed policies and controls must naturally get more inclusive and more demanding as they effect the activities of personnel with less experience. However, they must be limited only to items of importance and so used as to help the inexperienced man discharge all of his responsibilities more rapidly, in a systematic fashion. These policies and controls must be reviewed frequently and revised whenever necessary so as to encourage rather than limit the use of initiative on the part of the young engineer who is governed by them and who, most frequently, will be the first to detect their inadequacies and limitations. However, the strict adherence to established policies must be demanded for, without it, the less-experienced personnel will be making decisions which may easily lead to loss of valuable personnel and equipment. A spirit of teamwork must prevail and each member of the flight test organization must know his own limitations and accept administrative policies as the best insurance of safety, rather than regard them as necessary evils.

b. THE ENGINEERING TEST PILOT - The engineering test pilot generally brings with him a vast fund of practical knowledge and experience which can be of immense value to the flight test organization. Primarily, of course, the pilot possesses a high degree of skill in the precision flying of various types of aircraft. However, some companies have often hired test pilots whose flying technique needed additional development and improvement when those pilots possessed other qualifications which made them of still greater value to the organization. This has been especially true when the pilots in question have had a formal engineering education.

The good pilot-engineer is a rare individual. Every attempt should be made to insure that both his flying and engineering abilities are fully utilized. Frequently, he will be found most valuable as a test pilot of single-seater aircraft where he can also perform as a qualified engineering observer. He is particularly valuable when, because of lack of instrumentation, only qualitative tests are being made to determine the flying qualities of an aircraft. A test pilot-engineer will save the company much time and money by being able to speak the aerodynamicist's language in describing deficiencies in the control system and suggesting methods of eliminating the difficulties.

On the ground, he should be allowed to play a part in the approval of detailed flight test plans and installation drawings of flight test equipment and instrumentation, especially where the engine controls or the primary flight control system is concerned. His judgment and advice will often help the flight test organization avoid many expensive hours of grief in the air during flight tests.

Test pilots who are not engineers will frequently be found qualified to perform some ground function in connection with the administration of the experimental flight operations office. It is important that all of the abilities of test pilots be fully utilized, not only to keep them busy while not flying, but to insure that they acquire a genuine interest in and become thoroughly acquainted with the many engineering and practical problems which have to be constantly solved to make flight testing of value. Only when the pilots work very closely with these problems will their fund of practical knowledge and experience play a part in and be of value in the daily activities of the flight test organization. Of course, whenever a pilot is assigned responsibilities of a continuous nature, it is important that measures be taken to prevent his work from becoming a bottleneck when he is called upon to do a lot of flying. Since test flying is not always very regular insofar as the individual pilot is concerned, this problem has frequently limited pilots to non-flying assignments of an advisory nature only.

A common problem in flight test organizations is the one of dividing responsibility between the test pilot and flight test engineer so as to insure a maximum amount of cooperation and a minimum amount of friction. The ideal solution to this problem is found when a sufficient number of pilot-engineers are available for assignment to the various test aircraft, with the flight test engineers as their assistants. The pilot then becomes responsible for all of the details of planning and carrying out tests assigned to his aircraft. Unfortunately, a sufficient number of pilot-engineers can rarely be found. It appears to be common practice in such cases to make the flight test engineer responsible for the detailed planning and preparation of aircraft for the tests assigned. During an actual test flight, the test pilot is responsible for all decisions on matters of safety, but he is required to follow the instructions of the flight test engineer insofar as the details of conducting the test are concerned. Such an arrangement is frequently unavoidable, but it is an unhappy one, at best, and sometimes leads to friction over a period of time, until both pilot ant engineer learn to appreciate each others abilities and begin to realize their own limitations.

c. PLANNING AND CARRYING OUT THE FLIGHT TEST PROGRAM. - It would be an endless task to discuss the multiple problems which are generally encountered in planning a sound, sensible flight test program. In addition to the tests found necessary and planned by the flight test department, requests for various tests are received from many sources among which may be project engineers, the production department, and the aerodynamics or the wind tunnel subdivisions of the engineering department. All of these test requests or "test items" are assigned proper priorities, the major ones in accordance with prevailing company policies as to their relative importance. Such factors as instrumentation time and flight time are then considered and balanced against the priorities. The "test items" are assigned to various test aircraft in such a manner as to insure full utilization of each test aircraft, both on the ground and in the air, and yet minimize interferences between various test items which might seriously delay a high-priority test for one of lower priority.

The "flight test team" scheme appears to have been successfully applied by most flight test organizations for performing the detailed work of planning each test flight, preparing the particular aircraft for the tests, and actually carrying out the test flights. The "flight test team" generally consists of pilot, co-pilot, flight test engineer, instrumentation engineer and flight test observers. Qualified flight test engineers are occasionally given flight training and "checked out" as co-pilots on aircraft which have completed the operational phase of flight testing, thus permitting them to act as flight test engineer-co-pilot. (Instrumentation and installation mechanics and maintenance mechanics are sometimes considered part of the team when the test aircraft is a large one.) This "flight test team" is assigned one or more flight test aircraft and, insofar as possible, they are kept working together on the various flight tests performed on those aircraft. Either the pilot, if he be a qualified engineer, or the flight test engineer is made responsible for the activities of this group and all work on the test aircraft is performed through orders issued over his signature, subject to proper approval by higher authority if necessary. The "flight test team" has the principal advantage of bringing pilot and flight test engineer closer together and permitting each of them to apply his specialized ability towards the solution of the various problems which are encountered when test flights are being planned. It also reduces the amount of confusion which is sometimes created when maintenance personnel received uncoordinated orders for work to be performed on the same test airplane from pilots, flight test engineers, and instrumentation engineers.

One of the major factors which will greatly increase the cost of flight tests is the accuracy which is required. As instrumentation methods improve and develop, the same investment will naturally provide better, more accurate instrumentation. However, the greater the desired accuracy of results, generally the more flight time will be required to produce them. It is important that this problem be considered each time new tests are encountered and that it be approached with the "maximum permissible error" outlook rather than with the desire for "maximum possible accuracy." This approach will frequently give the desired results at much lower cost. But care must be exercised lest the approach be permitted to impair the accuracy of basic tests, such as power calibrations, where accuracy is essential.

All of the members of a flight test crew should be required to attend a pre-flight and post-flight conference in connection with each test flight. The pre-flight conference affords an opportunity to discuss the entire plan of test and insure that each crew member knows what will happen and what will be expected of him during each phase of the test flight. At the post-flight conference, the results of the test flight are discussed and each crew member is required to present his "squawk sheet", listing any items of equipment and instrumentation which did not operate during the flight. The flight test engineer is thus able to determine which test items may have to be repeated and how much maintenance work will be necessary on the airplane and test equipment before the next flight can be made. Strict discipline should be exercised in the matter of prompt attendance at these conferences. Nothing can be more demoralizing than to have the joint work of a group of men repeatedly held up by the tardiness of one individual.

d. REDUCTION OF FLIGHT TEST DATA AND DISSEMINATION OF RESULTS. -

Speed is the major consideration in reducing flight test data and disseminating flight test results, assuming that the reduction methods used are mathematically sound and sufficiently accurate. After the test flight is completed, nothing should be allowed to interfere with the job of making the results available in usable form as soon as possible. Many flight test organizations consider this problem when the instrumentation for a particular flight test is being planned. Every effort is made to make special flight test instruments direct-reading when they are calibrated. For example, a control surface position indicator should show directly the surface position in degrees, rather than an abstract number which then has to be converted to degrees by referring to an appropriate calibration curve.

This practice saves an enormous amount of time in data reduction and is very effective if it does not increase the time required for instrumentation to any great extent. Important instruments are often duplicated on the pilot's and flight test engineer's panel. It is thus possible to plot the results of certain phases of the tests being conducted while the test flight is still in progress. This permits immediate rechecks of data which appear to be inaccurate and makes the more important data immediately available for use when the aircraft lands. In particularly urgent cases, the data may be radioed down to a ground station before completion of the test flight.

A major portion of flight test data is, in most cases, recorded by automatic photo-observers. Every flight test organization should make provisions for rapid handling of the photo-observer film. Some companies provide for the complete finishing of this film within one hour after completion of flight tests. Data-recorders are then employed on an evening shift to read the film and plot all data so that it is available for flight test engineers early the following morning.

The results of flight tests should be promptly made available to all parties concerned. This is especially true when the particular test item is an attempt to correct service difficulties which have affected the production schedule. In general, a preliminary report, giving at least the raw flight test data, should be in the hands of the person requesting the test within twenty-four hours of the completion of a flight covering the test item. This prompt distribution of flight test results does two things:

1. It keeps everyone informed of the progress being made on particular tests.
2. Frequently, it results in the cancellation of part of a test when preliminary results either give a satisfactory answer or indicate immediately that the particular test item should not be tested further.

e. PROVISION OF ADEQUATE FLIGHT SCHEDULES AND RECORDS. - At least two different flight schedules should be provided. The first of these should list the entire flight test program, showing the priorities of the various test items, and the aircraft to which they have been assigned. It should also give an estimate of the probable completion date for the various test items and the causes for delays when they are encountered. Such a schedule is very valuable in providing management, the engineering department, the flight test department, and others with a graphic and complete picture of the entire flight test program. It makes the matter of priorities an open one and, in all fairness, gives management and other interested departments an opportunity to question priorities which are established.

The second flight schedule should be a schedule of actual flight operations for the period which it covers. The period may vary from one day in the case of a large flight test organization to several days in the case of a small organization where only a limited amount of flying is done. This second schedule, when properly distributed, will always save flight test personnel a considerable amount of time which would otherwise be spent giving flight plans verbally to those who request them. Typical examples of these two flight schedules are given in Sec. D , "Operating Procedures."

Adequate records of work and flight time performed under each test item should be carefully kept since they form the basis of cost control. Much time can often be saved in submitting cost estimates for flight test programs and the estimates themselves will be more accurate if carefully recorded data are available, covering work done on programs of a similar nature in the past. Cost data are also invaluable for balancing flight research costs against the potential profit or gain from the data which are being obtained.

f. THE FILING SYSTEM. - The story of lost or misplaced data is so common and well-known that perhaps even the wildest estimate of time and money lost because of it would probably be conservative. A rigid, consistent system of filing various data on flight tests which are in progress should be maintained. Data which are haphazardly filed or kept by several persons can seldom be quickly located when they are needed in conferences or in answering urgent telephone calls or correspondence. The filing system must obviously be simple and straightforward, for otherwise it will tax the valuable time of engineers who use the "data in process". A typical filing system for current flight test data is given in Sec. D.

A cross-indexed filing system should be kept of all reports covering work which has been done by the flight test organization. Problems occasionally repeat themselves and a past report which can be easily found for reference will often save much time, effort, and money. Some of the larger flight test organizations find it advisable and profitable to employ a full-time librarian to insure continual proper handling of the report filing system.

D. OPERATING PROCEDURES.

1. GENERAL.

The operating procedures for any particular flight test organization must be outlined specifically to fit that organization. Methods of operation will vary with the size and characteristics of the aircraft company and the flight test organization, and they will also vary with the types and sizes of airplanes to be tested. The basic principles underlying operating procedures were presented generally in preceding sections. This section discusses some of the practices which can be followed and standard forms which can be used in the application of basic principles to routine flight test activities.

Standard forms do three important things:

a. They outline a particular task completely so that the recipient may properly do everything required of him, according to established policies.

b. They permit the executives in an organization to forget about routine activities and concentrate their time and efforts on important current problems and problems which may arise in the future.

c. When properly filed, they form a complete historical record of the more important activities of an organization. Over a period of time, such a record can become invaluable as a guide in the establishment of new policies.

The success of an organization frequently depends on the extent to which executives can standardize routine activities, without burdening their personnel with an excessive amount of "paper work".

2. ORGANIZATION CHART FOR THE FLIGHT TEST DEPARTMENT.

For purposes of this discussion, a typical organization chart for a Flight Test Department is presented in Figure 1. The chart shown would be suitable for a large company. In the case of a smaller company, the same principles would apply but just a few individuals would be performing all of the functions listed.

The following important features of the organization chart should be noted:

a. The Flight Test Department reports directly to Management. The actual official to whom the Flight Test Department reports might be a "Vice-President in Charge of Research" in a large company, or the President in a small company. In both cases, however, the Flight Test Department would be independent of and on the same organizational level as the Engineering Department which designs the aircraft to be tested.

b. An "Engineering-Flight Test-Production" Committee is used to check on the importance of various flight research projects, to insure the correlation of important wind tunnel and theoretical data by means of flight tests, and to expedite any flight tests which might affect the production schedule.

c. The Flight Test Planning Engineers, in consultation with the Director of the Flight Test Department, plan the overall flight test program. They determine priorities for various tests, prepare flight schedules, and insure that equipment and personnel are utilized with maximum efficiency in carrying out the flight test program.

d. The Engineering Staff acts in an advisory capacity, assisting Flight Test Engineers in the solution of specialized problems in connection with power plants, propellers, hydraulic systems, and the like.

e. The Flight Test Teams plan each test flight, issue the orders to prepare the airplanes for each test flight, and then carry out the tests. Each team is composed of an Engineering Test Pilot, Flight Test Engineer, Co-pilot, Instrumentation Engineer, Data Analyst, and other necessary flight test crew members. Either the Engineering Test Pilot or the Flight Test Engineer is responsible for the actual activities of each team. The Chief Instrumentation Engineer and Chief Data Analyst exercise technical supervision over the work of the Instrumentation Engineers and Data Analysts assigned to the various Flight Test Teams.

f. The Director of the Flight Test Department exercises supervision, through the Chief of Maintenance and Installations, over all maintenance and installation work done on flight test aircraft and over the personnel (foremen, mechanics, etc.) who do the work.

The functions of all of the various units into which the Flight Test Department is divided and the duties of all key personnel should be closely defined so that there is no overlapping of responsibility. Figure 2 gives an example of the way in which the duties of the Flight Test Engineer might be defined.

3. PLANNING AND CARRYING OUT THE FLIGHT TEST PROGRAM.

This outline of operating procedures has been divided into the following four parts:

a. Initiation of the test and activities up to the time that the airplane is prepared for the test.

b. Carrying out the flight test program.

c. Typical safety precautions.

d. A filing system.

a. INITIATION OF THE TEST AND ACTIVITIES UP TO THE TIME THAT THE AIRPLANE IS PREPARED FOR THE TEST. - All of these activities and the manner in which they affect various individuals are pictured graphically in Figure 3, "Preparations for a Test Flight."

1. Request for Test. The request for test may originate in any one of the principal departments of the company and it is sent to the Director of Flight Test. However, before it is even transmitted, the request should be carefully evaluated for its necessity, its similarity to other tests, its singularity of purpose, and the possibility that the desired information might be more quickly and more accurately obtained from other sources. The request for test should state as completely and as concisely as possible the items to be investigated and the accuracy with which they are to be determined. Where exceptional accuracy is required, reasons for

the requirement should be given. The Director of Flight Test will examine the request and, if it appears logical, he will forward it to the Flight Test Planning Engineer together with any recommendations which he may have as to the action to be taken. A sample Flight Test Request is shown in Figure 4.

2. Flight Test Order. - The Planning Engineer then considers the nature of the test, the priority which it deserves, the airplane on which it can be performed, the possibility that it can be combined with other tests, and the amount of ground work and flying time which will be required to complete the test. The Budget Controller uses these data to estimate the cost of performing the test. If it appears that the cost will not be excessive, the Director of Flight Test will approve the test. The Planning Engineer will then assign the test to a particular Flight Test Team by issuing a Flight Test Order which authorizes the Team to perform the test. Figure 5 shows a typical simple Flight Test Order. On the basis of all of the Flight Test Orders issued, the Planning Engineer prepares an appropriate schedule of the Flight Test Program. The flight schedule is revised at frequent intervals and distributed to all concerned.

3. Configuration Sheet. - The Flight Test Engineer of that particular Flight Test Team then starts his work on the test. He first consults with the Instrumentation Engineer and Data Analyst of his team in determining the quantity and type of the instrumentation which will be required for the test. With these itemized data and a conception of the particular condition of the airplane which

is required for the test, he prepares a configuration sheet. On this sheet he lists the instrumentation and the alterations of the airplane which will be required for the test. This sheet is first coordinated within his own team and then with the Director of Flight Test. This form is primarily for file and record but it is also useful in helping Maintenance and Installations personnel plan their work and prepare a preliminary estimate of the time which will be required to prepare the aircraft for the test. An outline of a configuration sheet is given in Figure 6.

4. Test Conference - The Project Engineer then holds a conference with the Director of Flight Test, the Chief Engineering Test Pilot, the Flight Test Team, and the Requestor's Representative. At this conference the complete outline or program of this particular test is discussed. This outline will serve as a basis for performing the work required by the Flight Test Order, but it is subject to modification if the results of any of the individual test flights warrant a change. Specifically, the decisions reached in this conference are as follows:

a. The items which are to be measured on each flight. From a complete consideration of all of the items an estimate of the number of flights and the flying hours should be possible.

b. The instrumentation which will be required to secure the data.

c. An itemized list of the work necessary on the airplane and an estimate of the time that the airplane will have to be grounded to be prepared for the test.

d. A list of the persons who will form the crew for each flight. This list should also include persons from other departments who may have a valid reason for witnessing the tests.

e. A plan for the preparation of the report, i.e. whether a preliminary or a complete report is necessary, what persons outside of the flight test team will be needed to assist in the preparation of the report, etc.

If the frequency of conferences of this sort should warrant, it may be advisable to hold regular meetings at which test items may be discussed along with other topics. Some flight test organizations hold daily "morning conferences" which serve this purpose. The Planning Engineer attends these conferences and is thus able to keep the flight schedule accurate insofar as dates for the performance of the various test flights are concerned.

5. Service Orders. - The writing of Service Orders is the responsibility of the Flight Test Engineer. (Occasionally, service orders are written by the Instrumentation Engineer, but these must be coordinated by the Flight Test Engineer.) All service orders should be coordinated by the Director of Flight Test. A "check-off list" should be attached to the airplane as it enters the hangar and each service order is entered on this list and initialed by the Service Foreman as it is received. No change, whether it be alteration of the airplane or addition or removal of equipment should be made unless an appropriate written order is first coordinated by the Flight Test Engineer. The rigorous application of

this rule is vital to the successful execution of a flight test. The Flight Test Engineer must be in constant touch with the condition of his airplane. This is necessary not only for safety considerations but also for an accurate control of the airplane configuration and of the weight and balance.

If possible, the Service Orders should be issued in a group, before the airplane is sent to the service hangar, in order that the Service Foreman may schedule the work and complete it in the shortest possible time. Before the airplane leaves the service hangar, the Flight Test Engineer should inspect the airplane with the Service Foreman to see that the airplane has been weighed, properly ballasted, and that all of the work and only that work which has been entered and checked on the "check-off list" has been performed. This inspection should be performed in addition to the safety inspection which will normally be performed by the regular Inspection Department. The service orders and the "check-off list" should then be filed by the Flight Test Engineer. The Instrumentation Engineer should check the instrumentation to insure that it has been properly installed and calibrated.

b. CARRYING OUT THE FLIGHT TEST PROGRAM. - Figure 7 gives a graphic picture of activities from the time the airplane is ready for a test flight until the final report is written.

1. Test Flight Plan. - A typical Test Flight Plan is presented in Fig. 8. These are prepared by the Flight Test Engineer, for each flight. The Plans arrange the various tests in such order

as to take advantage of every minute of flying time. They must be sufficiently complete and clear to insure that all crew members will know when to operate the photo observers and other special instrumentation.

2. Pre-flight Inspection. - Service orders are issued to the Maintenance and Installations Unit and to the Inspection Department, showing the expected time of take-off, the names of the crew, and the purpose of the test. It is then the duty of those organizations, barring irregularities, to have the airplane ready for the flight. The pre-flight inspection is particularly important and should be performed with careful attention to details. To assist the crew chief and the Inspector in their jobs and to assure the Pilot and Flight Test Engineer that everything is in order, a special flight inspection sheet is prepared and must be signed as inspections are performed. The instrument mechanic also inspects, tests, and "checks off" the flight test instrumentation prior to flight, using an "Instrumentation Check-off List" which is prepared for him. The Flight Test Engineer also prepares data sheets for manual recording of important data. Since some time may elapse before automatic observer data is ready for use, manually recorded data will give an approximation of the more important results of the test flight and will expedite planning of subsequent flights. The data sheets should consist of a vellum original and a carbon copy of each sheet. The carbon copy serves as insurance against the loss of important data if the vellum should be destroyed.

3. Aircraft release. - The Engineering Test Pilot (or his co-pilot) is responsible for filling out the necessary forms to obtain aircraft clearance and for checking the weather. A sample form for aircraft release is shown in Fig. 9. Copies of this form are usually necessary for the Budget Controller, Flight Operations, Insurance, and Flight Test Files.

4. Pre-flight Conference. - A pre-flight conference for the flight crew is usually held one hour before take-off time. In this conference, the Test Flight Plan is discussed in detail, the duties of each crew member are enumerated, and the data sheets are distributed.

5. Test Flight. - The test flight is then performed. Each crew member keeps in constant communication with the Flight Test Engineer to receive instructions or to report any irregularities. Also, each crew member keeps an individual "squawk" sheet on which he notes any malfunctioning of equipment or instruments which he may notice. (For a more complete discussion of procedures for actually performing the test flight, the reader is referred to "Flight Test Organization, Procedures, and Crew Training" by A. C. Reed and W. F. Milliken.)

6. Post-Flight Conference. - After the flight is completed, a post-flight conference is held for the flight crew and any persons interested in the immediate results of the test. The test flight is discussed and irregularities are considered, giving the Flight Test Engineer an idea as to the success with which the various

phases of the test flight were carried out. Any malfunctioning of the instrumentation or the airplane is noted and entered on a composite "squawk" sheet which is given to the maintenance crew. The flight data sheets are coordinated and given to the Data Analyst.

7. Preliminary Report. - The Pilot and the Engineer usually dictate a Preliminary Report immediately after the post-flight conference. In a few cases this will be sufficient, and no other reports will be necessary. In a majority of cases, however, these Preliminary Reports will be used as references in the preparation of the Final Report.

8. Final Report. - When the Data Analyst has finished his work, he submits it to the Flight Test Engineer who uses it as a basis for writing the Flight Test Report. This report is coordinated properly and sent to the Requestor.

c. TYPICAL SAFETY PRECAUTIONS. - The careful consideration of and planning for every eventuality is of primary importance in the prevention of accidents. However, after this has been done, preventable accidents can still occur through oversight or neglect of some duty. A particularly effective method of controlling this last factor is the extensive use of "check-off" lists. Their use to insure complete pre-flight inspections of both the airplane and the flight test instrumentation has already been mentioned. The services find "check-off" lists very useful for reminding pilots of the proper procedures to be followed while flying particular airplanes.

Check-off lists are applicable to the duties of flight test engineers and other flight crew members, not only in the air but also on the ground. Since the preparations which are required for a high altitude flight are much more involved than those for an ordinary low-altitude test, the following examples of check-off lists given here are for high-altitude flights:

Figure 10 - Flight Engineer's Check-off List.

Figure 11 - Flight Crew Member's Pre-Flight Check List.

Figure 12 - Emergency Procedures.

All of these are taken directly from the paper on "Flight Test Organization, Procedures, and Crew Training" by A. C. Reed and W. F. Milliken.

d. FILING SYSTEM. - It is necessary that careful files be kept of the various orders, work sheets, correspondence, and other data pertinent to a flight test airplane when tests are in progress. The plan of having each Flight Test Engineer keep the files for his particular airplane or airplanes is one which seems to be very successful. It has also been found advisable to standardize the system of keeping these files. This is valuable in assisting anyone who is familiar with the system in using any of the files as reference.

The filing system which is presented here is only one of many, but is the one which appeared to be most satisfactory. This system consists of a series of eleven folders for every flight test airplane or major test item. Should a test item be too small to warrant an extensive file, it is kept in a single folder which is subdivided according to this system. The folders are used as follows:

Folder No. 1 - Daily Log

This folder contains a complete day-by-day log of flight time, purpose of flight, changes of the airplane weight and balance, and other pertinent notes. The carbon copy of each data sheet and one print of each automatic observer data sheet are also kept in this folder.

Folder No. 2 - Data Sheets

The original vellums of both the manual and the automatic observer data sheets are filed in this folder.

Folder No. 3 - Standard Forms

In this folder the various standard forms such as flight test orders, service orders, flight requests, etc. are filed.

Folder No. 4 - Correspondence

The correspondence concerning the test items is filed in this folder.

Folder No. 5 - Instruments and Calibrations

The serial numbers, purposes, and all calibrations for the instruments used to collect the data are filed in this folder.

Folder No. 6 - Calculations, Curves, and Results

All of the calculations, curves, results and the analysis of results are filed in this folder.

Folder No. 7 - Test Flight Plans

This folder should contain all of the test flight plans. it is convenient to file the plans for the completed tests on one side and those for the proposed tests on the other side of the folder.

Folder No. 8 - Weight and Balance

The original weight data and a complete tabulation of all of the equipment which was included in the original weighing together with the computations of weight and balance for each flight are filed in this folder.

Folder No. 9 - Configuration

This folder should contain information, such as photographs, sketches, etc., concerning the configurations of the airplane as tested.

Folder No. 10 - Miscellaneous

Any miscellaneous information or data which may be pertinent to the test, and which does not properly belong in any of the other folders, should be filed here.

Folder No. 11 - Final Report

All information that is to be used in the final report should eventually end up in this folder.

Some organizations prefer a decimal system which gives a more exact designation to the location of each bit of data. This system is more adaptable to variations in tests than the one presented, but the extensive division of the file is likely to lead to duplication of records, merely to keep each file complete, and the filing system is apt to consume too much of the engineer's time.

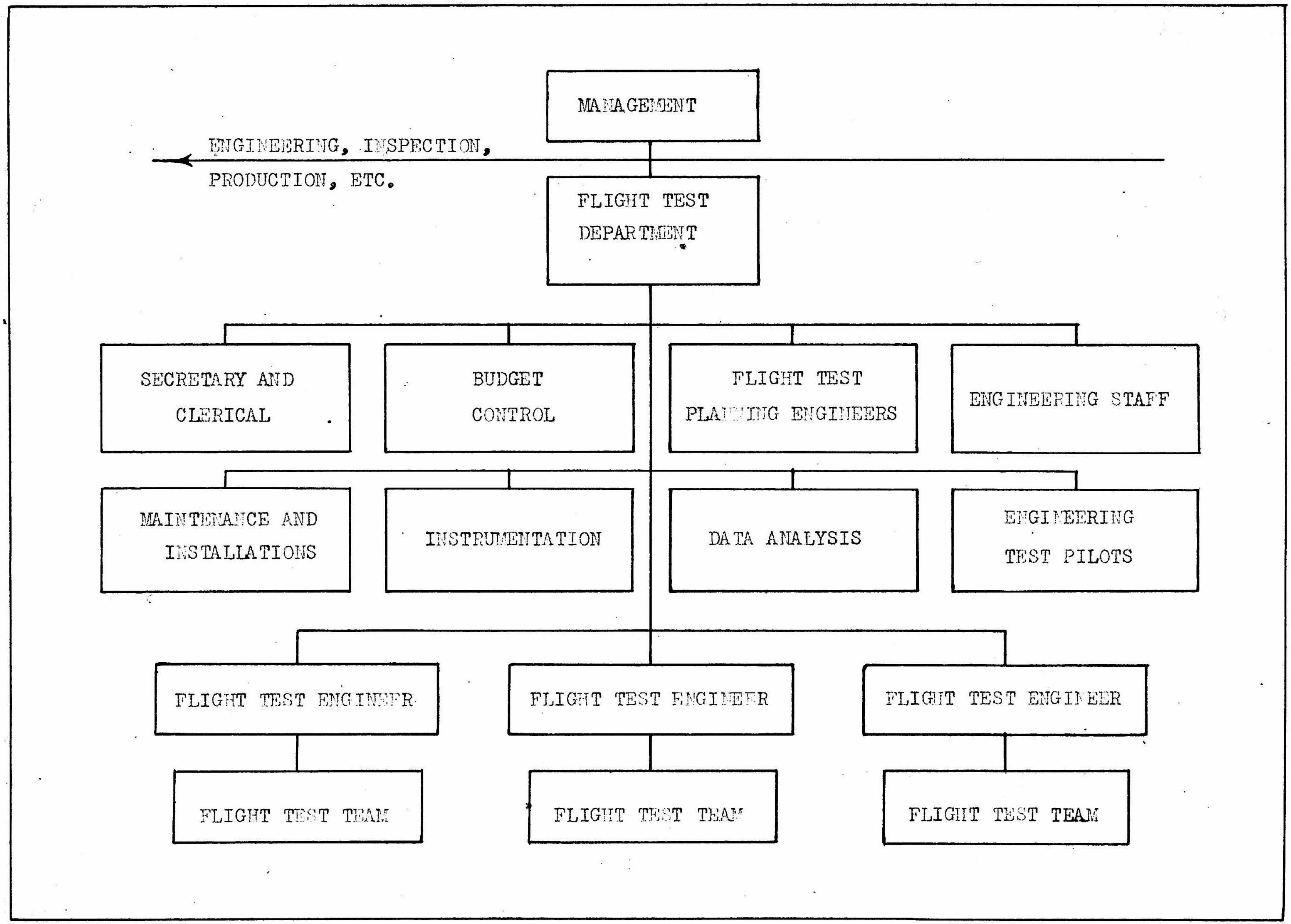
MANAGEMENT
ENGINEERING, INSPECTION, PRODUCTION, ETC.
FLIGHT TEST DEPARTMENT
SECRETARY AND CLERICAL
BUDGET CONTROL
FLIGHT TEST PLANNING ENGINEERS
ENGINEERING STAFF
MAINTENANCE AND INSTALLATIONS
INSTRUMENTATION
DATA ANALYSIS
ENGINEERING TEST PILOTS
FLIGHT TEST ENGINEER
FLIGHT TEST ENGINEER
FLIGHT TEST ENGINEER
FLIGHT TEST TEAM
FLIGHT TEST TEAM
FLIGHT TEST TEAM

Fig. 1

F L I G H T   T E S T   E N G I N E E R S

The Flight Test Engineer's duties and responsibilities shall be as follows:

1. To coordinate all flight test operations on a particular airplane. This function includes the preliminary planning and clarification of the test to satisfy a particular Flight Test Order which will normally require the close cooperation of the Flight Engineer, the Requestor's Representative, the Instrumentation Engineer, and the Data Analyst.

2. To prepare the final Plan of Test and schedule the Pre-flight Conference between the Flight Test Team, the Requestor's Representative, and the Chief Engineering Test Pilot.

3. To be responsible for the conduct of the flight test insofar as the particular investigations discussed in the Pre-flight Conference are concerned. It should be noted, however, that when any situation arises in which there is a question of the safety of the airplane or crew, the pilot has absolute authority to terminate the flight.

4. To issue all Service Orders necessary to prepare the airplane for the particular flight test.

5. To be responsible for the preparation of Plan of Test, Preliminary Report of the Test, and Final Report of Test.

6. To be responsible for maintaining a photographic record of all major test configurations on his airplane.

7. To be at all times completely familiar with functional aspects of his airplane which in any way affect flight testing.

8. To keep a Weekly Log of test work conducted on each test airplane. This Log should include reference Flight Test Orders, length of flight, and brief remarks on flight conditions, actually investigated, and any difficulties encountered.

* * *

He may allocate work to other flight engineers under his direction in order to fulfill the responsibilities listed above.

Fig. 2

KEY

I - Initiates

C - Coordinates

AC - Action

AP - Approval

FORM	ENGINEERING DEPARTMENT	PROJECT ENGINEER	OTHER DEPTS., COMMITTEES, ETC.	DIRECTOR OF FLIGHT TEST	PLANNING ENGINEER	BUDGET CONTROL	MAINTENANCE & INSTALLATIONS	FLIGHT TEST TEAM: FLIGHT TEST ENGINEER	FLIGHT TEST TEAM: ENGINEERING TEST PILOT	FLIGHT TEST TEAM: INSTRUMENTATION ENGINEER	FLIGHT TEST TEAM: DATA ANALYST
REQUEST FOR TEST	I	I	I	AP	AC						
FLIGHT TEST ORDER				AP	I	C		AC			
FLIGHT TEST PROGRAM	C	C	C	AP	I		C	C	C	C	C
CONFIGURATION SHEET				AP				I	C	C	C
SERVICE ORDERS				C			AC	I			

Fig. 3

FLIGHT TEST REQUEST   Submit in triplicate

This form to be used for all tests, only one test item to be requested on this sheet.

Model________ Flight Test________ Ground Test________ Date________

Test of:

Reason for Test:

Exact information required from test, state accuracy required:
(Use reverse side of sheet if necessary)

Parts and Special Equipment for Test may be obtained from:____________

Witnesses to be present:____________________________________

Date desired:__________ Requested by:__________ Approved by:__________

This information is to be filled in by Flight Test Department	Airplane No.________ will be available on________ for test. Test will be conducted: In conjunction with other tests___. Special flight___. Flight time estimate________ Probable completion date__________ Comments: Signed:____________________ Flight Test Planning Engineer Authorized by Director of Flt. Test:____________________

Estimated Cost________ By________ Date________

Time is to be charged to Charge No.__________
Time is to be charged to Schedule No.__________
Time is entered on Master Schedule by__________

Start Date______________ Finish Date__________ Hours Flown________

Fig. 4

FLIGHT TEST ORDER

To Be Performed on ____________ Airplane No. ______________

Test Item No. ________________ Priority __________________

Time Charge No. ____
(To be entered by Budget Control)

Discussion of Test:

____
Flight Test Planning Engineer

Fig. 5

CONFIGURATION SHEET

FLIGHT TEST ORDER ____________

Date ________________ Engineer ________________

Airplane Model ________ No. ________________

Purpose of Test ____

____

Flight No. or Nos. ____________

1. Special Conditions as follows:

2. Installations:

3. Instrumentation :

Approved ____________________

Fig. 6

KEY

I - Initiates

C - Coordinates

AC - Action

AP - Approval

FORM	FLIGHT TEST TEAM: FLIGHT TEST ENGINEER	FLIGHT TEST TEAM: ENGINEERING TEST PILOT	FLIGHT TEST TEAM: INSTRUMENTATION ENGINEER	FLIGHT TEST TEAM: DATA ANALYST	FLIGHT TEST TEAM: ADDITIONAL CREW MEMBERS	DIRECTOR OF FLIGHT TEST	FLIGHT OPERATIONS	AIRCRAFT INSPECTION	MAINTENANCE AND INSTALLATION CREW	TEST REQUESTOR
TEST FLIGHT PLAN	I -	-AP -	- C -	- C -	- C -	- AP	- -	- - -	- -	C
SERVICE ORDER FOR PREFLIGHT INSPECTION	I -	- -	- -	- -	- - -	- -	- -	AC		
FLIGHT CLEARANCE		I -	- -	- - -	- -	- -	AP			
PRELIMINARY REPORT	I -	- I -	- -	- -	- - -	AP	- -	- -	- - -	AC
"SQUAWK" SHEET	I -	- I -	- I -	- -	-I-	- -	- -	- - -	AC	
DATA SHEETS	I -	- -	- -	AC -	- I					
FINAL REPORT	I -	- C -	- - -	- - -	- - -	AP	- - -	- - -	- - -	AC

Fig. 7

TEST FLIGHT PLAN

AIRPLANE ________
DATE ________
TEST NO. ________
FLIGHT ________

PURPOSE

A. Elevator operation with no packing in boost valve (trim & friction) and direct cable system.
B. Tail cone flap loads with aft end sealed vs. Vi.
C. Water dump out of right hand chute.
D. Ventilation with new scoop.
E. Empennage de-icer direct inlet "q".
F. Aileron operation with direct cable system.
G. Right hand main landing gear check.
H. CO measurements at wing leading edge inboard of inboard engines.
I. Main brake system return pressure.

1-A. TAXI - take CO samples
B. TAKE-OFF 2600 rpm. 46" Hg. - Take CO samples
C. Climb to 10,000 feet at 2400 rpm. 40" Hg - 160 Vi - Take CO samples.

2-WATER DUMP OUT OF RIGHT HAND DUMP CHUTE IN CLIMB

a. Fly at 160 Vi
b. Have right hand side of ship in the sun
c. Open right hand dump chute and right hand water valve
d. Turn camera on (right hand)
e. Time water flow
f. Leave dump valve down for at least 5 minutes after dumping
g. Slow down to 120 mph and shut chute
h. Observe and note water from streamlined bump window
i. Pump water from lines back to tank No. 7

3-TAIL CONE FLAP LOADS
AUXILIARY VENTILATION
EMPENNAGE DE-ICER DUCT INLET "q"

a. Outflow valves open position (forward) - aux. vent exit open, scoop closed
b. Altitude 10,000 feet

A. 1800 rpm with power to give 160 Vi - cowl flaps open #2 and #3, pressure bulkhead sealed

a. Take CO samples.
b. Measure velocity distribution at duct outlet at 2, 5, 8, 11, 14, 17, 20 inches along outlet.
c. Measure velocity with the anemometer at stations 500, 600, 700, 800, and 900 inches, along the center of the ship approx. 4 feet above the floor level. Read for one minute at each station.
d. Observe tufts and note.
e. Read tail cone flap load.

Fig. 8

B. 1800 rpm with power to give 160, pressure bulkhead holes open

a. Repeat items (b) (c) and (d) of Part A.
b. Plug up duct outlet and note noise difference.

C. 1800 rpm at 140 BMEP, pressure bulkhead sealed.

a. Repeat items (a) (b) (c) (d) and (e) of Part A.

D. 1800 rpm at 140 BMEP, pressure bulkhead holes open.

a. Repeat items (b) (c) and (d) of Part A.
b. Plug up duct outlet and note noise difference

E. 2200 rpm at 140 BMEP, pressure bulkhead sealed.

a. Repeat items (a) (b) (c) (d) and (e) of Part A

4-ELEVATOR OPERATION

A. FRICTION

a. Fly at 1600 rpm, 140 Vi at 10,000'.
b. Trim airplane (note oscillations).
c. Move elevator tab slowly up at a steady rate of approx. 1/2°/sec. until elevator moves - note angle.
d. Same as "c" with down tab.

B. STABILITY

a. Fly at 2200 rpm, 140 BMEP, at 10,000'.
b. Trim airplane.
c. Pull up to 20% lower speed.
d. Push down to 20% higher speed.

C. FEEL CONTROLS AND NOTE RESULTS

5-AILERON OPERATION WITH DIRECT CABLE SYSTEM

A. Stability

a. Fly at 2200 rpm, 140 BMEP
b. Feel aileron control

6-GEAR CHECK

A. Lower the gear
B. If the right hand main gear doesn't lock at first, wait several minutes.

Fig. 8 (Contd)

Crew - stay at following stations except one test.

1. ________	Pilot	7. ________	Eng. A.O.
2. ________	Co-pilot	8. ________	Master A.O.
3. ________	Flight Test Engineer	9. ________	Over fire bottles
4. ________	Radio Operator	10. ________	Over fire bottles
5. ________	Flight Station	11. ________	At stress table
6. ________	At Flight Sta. Door	12. AAF Insp. - Seat halfway back in cabin - R. H. side	

Fig. 8 (Contd)

REQUEST FOR FLIGHT AND AIRCRAFT RELEASE

DATE ____________

AIRCRAFT MFG. SERIAL NO. ______ AIRCRAFT CUSTOMER OR LICENSE NO. ______

FLIGHT CLASSIFICATION ______ PURPOSE OF FLIGHT ____________

____

INTENDED DATE AND TIME OF FLIGHT ____________

TAKE OFF FROM ____________

LANDING AT ____________

INSTRUCTIONS:

PASSENGERS:

1. ____________ NAME ____________ IDENTIFICATION

2. ____________ NAME ____________ IDENTIFICATION

3. ____________ NAME ____________ IDENTIFICATION

CHECK FOR ALL FLIGHTS

______ CONTRACT FLIGHT ______ COMPANY PILOT ______ BEFORE FINAL ACCEPTANCE

______ NON-CONTRACT FLIGHT ______ CUSTOMER PILOT ______ AFTER FINAL ACCEPTANCE

ABOVE FLIGHT IS AUTHORIZED subject to provisions of FLIGHT CONTROL REGULATIONS

____
Work order charge number

CREDIT AND FINANCE DIVISION RELEASE
(FOR DELIVERY FLIGHTS OR DELIVERY)

By ____________

By ____________
Supplementary Signature when required

____
MANAGER

Fig. 9

FLIGHT ENGINEER'S CHECK-OFF LIST

AT OFFICE

1. Test schedule - make out.
2. Test plan - prepare.
3. Flight physical insurance and instruction of crew.
4. Tentative crew notification exclusive of Weights Dept. Rep.
5. Status of airplane. Note significant changes since previous flight.
6. Decision on time of flight from Chief Test Pilot.
7. Order lunches or milk if required. (Engineering Flight Clerk)
8. Final crew notification, including Weight Dept., Flight Data Analyst, Instrumentation Rep., Supt. Ground Operation, and Director F. & A.
9. Assemble personal and engineering equipment for flight.

AT HANGAR

10. Distribute flight plans to crew.
11. Put own equipment in plane.
    a. Pad of paper and 3 x 5 cards.
    b. Stop watch.
    c. Spare bailout bottle.
    d. Standby mask.
    e. Data board and sheets prepared.
    f. Graph paper.
    g. Calibration.
    h. Blank squawk sheet.
    i. Double headset.
    j. Pencils (2 or more).
    k. Helium-oxygen mixture.
    l. Medical set.
        (1) Hypodermic
        (2) Ammonia
        (3) Charcoal pills
        (4) Nasalator
12. Put pilot's equipment in plane.
13. Round up crew for pre-flight conference.
14. Ground Check-off Lists - Distribute and collect.
15. Distribute Flight Check-off Lists to new men.
16. Glucose capsules.
17. Check out flash lights if night.
18. Charcoal pills.
19. Announce standard time, coordinate watches.
20. Obtain weight sheet.
21. Instruct crew, put equipment in plane.
22. Call nurse (8155) when denitrogenation is begun.

IN AIRPLANE BEFORE FLIGHT

23. Set co-pilot's altimeter to standard and record P.A.
24. Record ground temperature.

Fig. 10

25. Standard time check if not done before - set cockpit clock and wind.
26. Check test equipment.

IN FLIGHT

27. Remind crew to get as many data as possible.
28. Keep crew informed.
29. Fuel readings - level.
30. Remind pilot to go through check-off list.
31. Fuel readings - radio to hangar just before landing.
32. Radio OAT to Weather Bureau.
33. Glucose capsules.

IN AIRPLANE, AFTER FLIGHT

34. Unfasten sliding windshield locks.
35. Turn off special autosyn, waste gate indicator, and generator switches.
36. Fill out "Form 1."
37. Collect squawks.

POST-FLIGHT DUTIES

38. Phone for nurse after denitrogenation flights, if one is not present.
39. Classify and deliver squawks to Instrumentation Clerk for typing before data sheets.
40. Round up crew for conference.
41. Collect final weight sheet and data sheet.
42. Check in flash lights if night.
43. Decision on next flight.
44. Phone Senior Flight Engineer.
45. Test schedule - make out.
46. Check in flight test equipment to locker.
47. Signature of pilot on squawks.
48. Dictate "Report of Test."
49. Check rough draft of test report.

Fig. 10 (Contd)

FLIGHT CREW MEMBER'S PRE-FLIGHT CHECK LIST

1. Physical Examination - regular semi-annual flight physical, including electrocardiograph within six months preceding flight.
2. Sleep - good night's sleep before flight.
3. Substitute in case of illness - make arrangements with flight engineer as far in advance as possible for substitute, if you have a cold or ear trouble or other illness.
4. Meal - if you have not eaten within the past three hours, eat a light lunch high in carbohydrate content, or at least a candy bar.
5. Emergency Alarm Bells - one bell, stand by; three bells, jump.
6. Emergency Exits - learn location and operation.
7. Oxygen Equipment and Supply.
    a. Oxygen pressure at 1200 psi or more.
    b. Mask sponge valve dry.
    c. Plug in bottom of re-breather bag.
    d. Re-breather bag for tears.
    e. Flometer for sticking, connections, etc.
    f. Rubber tubing for holes, connections, etc.
    g. Auxiliary oxygen outlet on regulator turned off.
    h. Adjust straps on regular and bailout masks.
    i. Check bailout bottle at 1800 psi or more.
8. Emergency - if a parachute jump is necessary, the order of exit will be ____________________
9. Designation of Emergency Exits to be Used for this Flight

    First Choice ____________ Alternate ____________

10. Parachute Equipment
    a. Parachute was last repacked ____________ 194__ (must be within 60 days.)
    b. Parachute pack cover flaps - see that flaps have not worked loose exposing silk canopy.
    c. Rip cord and pins - see that the rip cord is free and rip cord pins are engaged in their studs.
    d. Harness - adjust to fit snugly, seeing that no straps are twisted or crossed.
    e. Rip cord in place - see that rip cord ring is in its fabric pocket and clear of the horizontal chest strap.
    f. Protruding straps - see that shoulder and chest straps do not project in such a manner as to be easily caught on protuberances in the airplane.

____
Signature

Test No. ____________ Model ____________

Date ____________ Ser. No. ____________

Fig. 11

EMERGENCY PROCEDURES

I. PROCEDURE IN CASE OF EMERGENCY (MEMORIZE)

1. Stand By in Emergency. (1 bell on emergency alarm system)

   a. Safety belt - unfasten.
   b. Doors - open all doors inside airplane (unless doors in airplane are needed to isolate fire.)

2. Emergency Requiring a Jump.

   a. Oxygen - turn on emergency supply.
   b. Mask - remove.
   c. Mouthpiece - place emergency oxygen mouthpiece in mouth, pinch nose, and breathe through mouth.
   d. Goggles - place over eyes.
   e. Exits to be used for this flight:

      First choice ________ Alternate ________

   f. Jump after crew member ____________________
   g. Clear the airplane.
   h. Rip cord - delay pulling until certain of clearing airplane and/or until reaching a warmer altitude.
   i. Direction - try if possible to land facing the direction in which you are drifting.
   j. Leg straps - unfasten leg straps as water is approached, in case a water landing is evident. Cross the feet and keep the legs together to avoid straddling trees or fences.
   k. Tow ashore - if wind is light, and from sea to shore, hold to parachute to tow ashore.

Note: If no "standby" order is given before the command to jump, open all doors inside airplane before turning on emergency oxygen supply.

II. PROCEDURE FOR FAILURE OF YOUR OXYGEN SUPPLY (MEMORIZE)

1. Signal other crew member.
2. Oxygen valve - open slightly and tap it lightly.
3. Standby Mask - put on spare mask if regular supply cannot be fixed immediately. See that valve is on. Help will be given by other crew members.

Alternate: Transfer oxygen mask tube from regular supply to auxiliary outlet on standby supply.

4. Emergency Bailout Oxygen - if standby oxygen system is defective or in use, turn on emergency bailout oxygen, put mouthpiece in mouth, pinch nose, and breathe through mouth. Help will be given by other crew members.

Fig. 12

II. INSTRUMENTATION

It was pointed out in Part I that one of the requirements for the solution of the "riddle of the modern aircraft" is extensive instrumentation. The instrumentation of the flight test airplane is the basis upon which the qualitative analysis of any type of airplane is predicated. The very value of flight testing lies in the fact that all of the conditions, loads and forces which are to be studied are actually applied and not assumed. However, the value of this advantage is diminished greatly by a lack of the proper instrumentation with which to collect information necessary to evaluate the reaction of the airplane to the variables.

Flight test instrumentation has shown steady improvement both in quality and in scope in step with the progression of the aeronautical art. Standard instruments have been modified and improved to give the accuracy and reliability required of test equipment and new or particular instrumentation has been devised to measure other quantities as they are required.

A. PLANNING.

The first problem to confront the Instrumentation Engineer is that of planning. The amount of planning will vary from test to test, but the instrumentation should be planned as early as possible. In this manner any special problem can be foreseen and given due consideration without delaying the test. In the event of tests of a new prototype airplane, the instrumentation may well be planned even as the airplane is being designed and built. Special tubing, wiring, or other installations can then be "built into" the airplane. For other tests the planning may start when the work order reaches the Flight Test Team.

1. THE TYPE OF AIRPLANE

The airplane on which the tests are to be made will determine the available space for the instrumentation. If the airplane is a fighter type there will very probably be very little space and the number of instruments which may be carried on any one flight will be limited. The instrumentation will have to be flexible, capable of quick changes from one test to another. Most of the recording of data will have to be automatic because the pilot, busy performing a maneuver or holding stabilized conditions, will have little time in which to be recording data. For example, in a fighter it was found necessary to install the automatic observers on the gun mounts in the wings.

If, however, the airplane is a large bomber or transport, the problem is quite different. Plenty of space is usually a ailable and the instrumentation can be almost as extensive as desired. Fewer, less stringent restirctions are placed on space and weight in the larger airplanes, but as a general rule the tests are more complex and more instrumentation is usually required. Between these two extremes lie the tests of the intermediate sizes of aircraft which present a compromise between the requirements for instrumentation and the space limitation.

2. TYPE OF TEST

The limitations of space and weight are usually rather well defined and the factor which must be compromised is the amount of instrumentation. This is determined by the type of test. The engineer must determine from the work order and from the conferences as exactly as possible what data are to be measured and from his own experience and knowledge he must determine the best practical means for making the measurements.

One definite step in the simplification of this problem is the preparation of a list of the various standard or common tests showing the data which are usually required and the instruments necessary to obtain these data for each type of test. Any list of this sort must necessarily be subject to change with improvements whether in the method of testing or in the instrumentation. Also, a list of this sort for almost any company manufacturing airplanes for the army, the navy and commercial use becomes extensive if any attempt is made to cover all types of tests. At present, it is possible to list only those tests which are common to all three agencies and which have become routine with almost every flight test organization. However, such a list, which might properly be prepared by the Chief Instrumentation Engineer, would be of great assistance to the various engineers in planning their instrumentation. Carrying this idea farther, it would then be possible to prepare an installation manual for the use of the mechanics showing the method of installing and the precautions to be used in the installation of the various types of instrumentation. This would be possible, in any complete sense, only after a rather extensive program of standardization of the testing required to prove the airplanes.

3. QUALITY OF DATA.

It may seem to the reader, as a first impression, that a discussion of quality is unnecessary in any consideration of instrumentation for flight testing--the instrumentation should be "as accurate as possible". However, probably no other single factor can cause the instrumentation engineer so many "headaches" as an accuracy requirement of "as good as possible". Of course, care must be taken to avoid "throwing away accuracy", but requiring that control positions be measured to the nearest one-tenth of a degree, for example, unless it is really necessary can cause the instrumentation engineer many gray hairs which might well be avoided. This requirement is, of course, necessary in the case of the principal airplane controls but is usually not warranted for cowl flaps, and such auxiliary controls.

In order that reasonable accuracy may be maintained in the instruments used, it is necessary that they be calibrated at frequent intervals. The length of the interval between calibrations will vary for different instruments, but no instrument should be used while any doubt exists concerning its operation. The calibration of some of the instruments should be a routine function, performed in the instrument shop or the stockroom, while other instruments such as position indicators can only be properly calibrated after they are installed. The calibration should be checked, as far as is practical, before each flight.

The instruments themselves must be examined and considered with respect to their response to variables other than that which they must measure. The most important variables to which good instruments must be insensitive are:

a. Attitude and accelerations - cyclic acceleration loads up to -4g and +9g.

b. Vibrations - which may include both high frequency and large amplitude unless the instrument is carefully mounted.

c. Temperature - variation from 75°C to -65°C.

d. Pressure and density - corresponding to a pressure range of from 2 lbs. per sq. in. to 15 lbs. per sq. in.

e. Supply voltage (for electrical instruments) - variations of 15% of the normal voltage.

B. EQUIPMENT.

Although the selection of the particular means of obtaining the required data is strictly a part of instrumentation planning, it is such a major part of the function of the Instrumentation Engineer that it deserves special attention. Much of the engineer's time and thought is directed toward his equipment; the improvement of his present methods, and the continual search for better ones. It is intended in this section to discuss some of the methods and practices which are being used by instrumentation engineers as revealed to the authors during their survey.

The variety of the instruments and other equipment used in flight test instrumentation precludes any possibility of a complete discussion of all of them in any treatise such as this. Therefore, at the outset we must limit our discussion. The standard aircraft instruments such as airspeed indicators, altimeters, etc, although extensively used in flight testing, are rather universally understood both in their operation and installation and it is not feasible here to attempt to reproduce a discussion of these instruments as may be found in books on aircraft instruments. It is sufficient to say that the particular instruments must be selected for their sensitivity and reliability. A more complete discussion is attempted of those instruments which are, to a certain extent, peculiar to flight testing. Even here the discussions must be limited because thorough explanations of certain of the instruments would require special volumes for each.

1. STRAIN GAGES.

The application of strain gages to the field of flight testing is one of the recent developments of the science. At present, the number of possible uses to which these instruments may be put is increasing rapidly. Although the direct function of the strain gage is that of measuring deformations, indirectly they can be made to transform such items as control forces, accelerations, etc. into electrical quantities. The direct applications of the gages has been of great benefit to structural research both in flight and on the ground and their indirect use has a great influence on other aspects of flight testing. The primary value of the strain gage is its speed of response. This is particularly true of the wire-strip strain gage.

Basically, there are two types of strain gages, the wire-strip and the magnetic. Of course, strictly speaking there are numerous other types of strain gages, but these depend on mechanically moving systems for their indication. Thus the response of these gages is naturally slower and they have few applications to flight testing.

a. OPERATION

The magnetic gage depends for its operation on varying the permeability of a magnetic field. The field is created by a pair of electromagnetic coils placed so that their poles are in opposite directions. An armature of soft iron is placed across one end of the pair of coils with a given air gap between the armature and the poles. The points of attachment of the coils and of the armature to the structure to be studied are a given distance apart, usually one inch in the unstrained condition. Any variation in this distance, due to strain, changes the size of the air gap and thus changes the permeability and the flow of magnetic current between the coils.

The operation of the wire-strip strain gage depends on the change in resistance of a wire due to a change in its cross-sectional area. The actual physical appearance of these gages may vary considerably, but their principle of operation is the same. In general the gages are prepared by cementing a length of fine wire, usually about .001 inches in diameter, to a piece of thin paper with proper lead wires attached. In this way several gages, as nearly alike as possible, may be prepared in advance. When ready for use, the paper which supports the wire is cemented to the structure to be measured. Then any subsequent change in the length of the surface of the structure immediately under the gage results in a stretching or contraction in the wire and a consequent change in cross-section and in resistance.

The principal disadvantage of the wire-strip strain gage is the difficulty in calibration. Once the gage has been properly cemented to a member, it is practically impossible to remove it. Thus the only means of calibrating a gage of this sort is by calibrating one or more representative gage or gages and assuming that all others of the same type are identical. The magnetic gage eliminates this difficulty but has other disadvantages. Generally, the magnetic gage does not have a "straight line calibration curve", that is, a variation in length does not cause a proportionate change in current. No satisfactory means of attaching the magnetic gage has been found other than by means of bolts. This, of course, means drilling the structure, which is not usually permissible. Also, because of its greater mass, the magnetic gage is somewhat slower in response than the wire-strip strain gage. For these reasons, the wire-strip gage is used more generally in flight testing.

b. APPLICATIONS.

The actual applications of the strain gage to the field of flight testing are nearly as varied as the number of companies making use of them. There is much opportunity for the exercise of ingenuity both in the method of actually applying the gage itself to the quantities to be measured and in the method of operating the gage. It is intended here only to give an indication of a few representative applications and a general discussion of the principles of measuring the strain as indicated by the gages.

The most obvious use of strain gages is in the field of structural research. By the proper placing of the gages it is possible either to measure bending and eliminate any tension or compression effects in a member or to measure tension or compression and eliminate any effects of bending. It was originally considered necessary to use a dummy gage, which was cemented to an unstrained piece of metal similar to that under test, to eliminate temperature effects from the strain readings. Recently, however, the ingenious use of Poisson's ratio in the analysis of the strain data has permitted the application of all four gages to the strained member so that the sensitivity of the circuit is increased considerably and temperature effects are at the same time eliminated. Strain gages are also used in sets of three on a panel where neither the direction nor the magnitude of the strain are known so that both of these factors may be determined.

Structural investigations of this sort, aside from their research value are also very useful in structural integrity demonstrations or tests. In these tests it is usually intended that the full load factors shall be applied to the airplane in the final test. When the structure to be tested in this manner is vital, it is especially necessary that the full load conditions be approached gradually. If strain measurements of the principal members be made throughout the series of tests, the effects of the loads on the members can be determined and the final condition can be approached with more intelligence and greater confidence.

Another very important application of strain gages is in the measurement of control forces. By means of these gages it is possible to measure accurately and precisely the force which must be applied by the pilot to perform any maneuver. It is no longer necessary to use a pilot's opinion as a criterion for determining when controls are too stiff or too soft; the actual forces can be measured and evaluated.

One method for the measurement of control forces is the measurement of the strain of a member in a push-rod system or of a strain sample in a cable system. A more popular method is that of measuring the forces at the point of application. A special control wheel or stick is prepared with the strain gages on the spokes of the wheel or on the handle of the stick so that the elevator and the aileron forces are separately measured. Strain gages are also placed on the carrier for the rudder pedals to measure rudder forces. The latter method is especially popular because the special controls can be prepared and calibrated and then easily transferred among different airplanes of that type.

Strain gages have also been used as position indicators. To do this, the gages are placed on thin cantilever strips, fixed on one end and properly applied to the movable member on the other. The resultant strain of the cantilever strip in bending can then be calibrated in terms of position or motion. By the use of a cantilever beam in conjunction with the proper mass, strain readings may also be easily calibrated in terms of acceleration. The whole accelerometer unit is usually immersed in some non-conductive liquid for damping.

c. MEASUREMENT AND RECORDING.

Probably no aspect of the use of strain gages is so varying and is being so rapidly improved as the particulars of the circuits which are used to apply a voltage to the gages and to receive and interpret the signal from the gage in terms of strain. The gages are almost universally used in a bridge circuit, but other than this hardly any similarity exists between the various systems.

In the original method of using the wire-strip strain gage it was considered necessary to increase or decrease the resistance of one arm to equal that of the strained arm of the bridge so that no signal was returned. The change in resistance was then noted and evaulated in terms of strain. This system presented several problems. First, it was generally rather tedious to make this adjustment manually and very complicated to perform it automatically. Secondly, the connections to the strained arm had to be carefully made to avoid introducing a varying resistance into the line which would invalidate the strain readings. Thirdly, it was very difficult to make the measurements "direct reading". Readings taken in this manner were found to be capable of far more accuracy than other considerations would warrant.

As an improvement over this system it was found that the signal could be interpreted directly in terms of strain if the bridge were initially balanced. This method is essentially accurate within the limits of the allowable strain of most materials. It was also found possible as described previously to place all four arms of the bridge at the point of strain. This eliminated much of the care in making the connections to the gages; the lines could then be joined by cable connectors without fear of affecting the strain readings. It has also recently been found that by the proper selection of the resistance of the gages and the sensitivity of the indicating instruments, it is possible to apply sufficient voltage to the gages so that no amplification of the returning signal is necessary before it can be measured in terms of strain. These improvements have considerably simplified the strain measuring equipment.

In recording the strains from structural integrity tests or acceleration surveys it is almost imperative that the data be continuously recorded. The frequency of response of the recording elements must also be high because of the speed with which the strains may be applied and even reversed especially in the case of high speed dives, flutter, etc. These requirements practically specify oscillographic recording. The popular method of recording is by means of light beams reflected from galvanometers onto sensitized film or paper because of the high frequency response and the low inertia of this type of recording.

For recording strains from other phenomena such as control forces, position indications, etc. ordinary voltmeters either on the pilot's instrument panel and/or in the automatic observer is the commonly used. This is possible because these strains are usually present in a more or less stabilized condition and continuous recording is ordinarily not necessary.

d. STRAIN INDICATOR

A unique method of indicating strains has been developed which is worthy of special note. Although it is not an application of the strain gages as discussed in this section, the simplicity and usefulness of the idea make it very interesting. In this particular application it was not desired to measure the strains accurately; the only requirement was that the pilot be notified when a certain strain in compression was reached. It was found that a micro-switch would operate with a certain deflection of the button and that the variations in the deflection required did not exceed five thousandths of an inch. The micro-switch was, therefore, useful for the indication of strains if the gage length were large enough to make this error negligible. The switch was fastened solidly to the member at one spot and a rod of adjustable length bearing on the operating button of the switch was fastened to the member at another spot a few inches away. The length of the rod was then adjusted so that the required compression in the member between the two points of attachment would operate the switch. The switch, in turn, operated a trigger circuit which controlled a light in the cockpit. The circuit was such that the light would remain on until the circuit was reset by the pilot. An installation of the switch and the rod can be seen in Fig. 1.

2. THERMOCOUPLES

It is frequently necessary to measure temperatures during the progress of flight tests. The most convenient means of measuring these temperatures is by the use of thermocouples.

The operation of a thermocouple depends on the fact that if two wires of dissimilar metals be joined at one end to form a junction, an electromotive force which is a function of the temperature of the junction will be produced at the other ends of the wires. This electromotive force is extremely small, a few millivolts; therefore, the connections in the circuits and the measurement of the electromotive force must be carefully made to prevent errors. In the usual application of this principal, the voltage and thereby the temperature of the junction to be measured, the "hot junction", is compared with that of another junction which is at a known temperature. The temperature of the reference junction is usually obtained by immersing it in melting ice, thus it is called the "cold junction".

Different combinations of metals give different curves of voltage vs temperature. For most of the usual combinations used, the electromotive force in millivolts is directly proportional to the temperature of the hot junction if the temperature of the cold junction is held constant. Some of the metal combinations commonly used in thermocouples are; copper-constantan, iron-constantan, alumel-chromel, and platinum-rhodium. The selection of a proper metal to be used in a thermocouple depends primarily on requirements for:

(1) temperature range for which it is suitable

(2) a maximum of electromotive force

(3) a minimum thermocouple electrical resistance

(4) a smooth, straight calibration curve

(5) a high resistance of the metals to corrosion, oxidation, reduction and crystallization.

The iron-constantan thermocouple is the most commonly used because it satisfies most of the above requirements and in addition it is strong, readily welded, and does not conduct heat readily.

The electromotive force generated by the thermocouple is usually indicated by measuring the amount of resistance which is required to reduce it to a given standard value. This may be done manually by means of a good calibrated potentiometer or automatically by a Brown Recorder. The widespread use of the Brown Recorder in the field of flight testing necessitates at least a brief considera- tion of its features. The basic element of the Brown Recorder is the self-balancing potentiometer which automatically measures the thermocouple voltage and positions a marker so that the temperature is recorded on a chart. The instrument is capable of recording the temperature of 144 thermocouples in three minutes with an accuracy of ± 1/4% of full scale. The measuring circuit consists of twelve automatic switches, each controlling twelve thermocouple circuits. Many companies make extensive use of this instrument, but few have been able to make much improvement on its operation.

One type of thermocouple which has almost become standard is that used in measuring cylinder head temperatures. It consists of a thermocouple imbedded in a ring which fits under the spark plug. Another type, for measuring cylinder base temperatures, are usually installed by the engine manufacturers when the engine is built. Fig. 2 shows a third type of thermocouple which is an example of that which is widely used in certain installations such as fuel temperatures, oil temperatures, etc. Usually, in the measurement of the temperatures of gases such as the air in ducts, exhaust gases, etc. it is usually necessary to prevent radiation from affecting the temperature readings. This is especially true when the temperature of the duct is very different from that of the gas. To reduce the effect of such radiation a shielded thermocouple such as that shown in Fig. 3 is used.

The thermocouples which have been developed for the measurement of outside air temperatures deserve special attention. It is necessary that, for this purpose, special shields be designed to protect the thermocouple element from the cooling effect of the free air stream and from the heating effects of the direct sun's rays and the impact of air on the moving thermocouple. Several temperature "bulbs" or "probes" have been developed to perform this function. The most effective of these temperature probes has been the "Franz" type an example of which is shown in Fig. 4. This probe is designed to measure the adiabatic-compression temperature of an airstream. This information together with a knowledge of the static and total dynamic pressures of the air stream can be used to determine the temperature of the free air stream. Calculations based on the assumption that the air flow does not separate from the divergent walls of the orifice at the front have indicated that the effect of the finite velocity of air past the thermocouple is negligible. In fact, in actual tests on a modified probe of this type, it was found that 98 percent to 99 percent of full adiabatic expansion was obtained at sea level with only slightly less perfect expansion at higher altitudes.

3. PRESSURE MEASUREMENTS

The simplest method for measuring pressures, is of course a tube open to the air flow. This method is used in pressure "rakes" or "Christmas trees". These are special names given to arrangements of the pressure heads to measure certain patterns of pressures. The simple open tubes are practical for measuring dynamic plus static pressures when the speed of the airstream with relation to the tube is sufficiently great. If the dynamic pressure is not large enough to make this sort of head practical, another design must be employed. A sketch of the kiel type of pressure head which increases the velocity of the air at the entrance of the tube by means of a small venturi is shown in Fig. 5. This type of pressure head is usually used in ducts, air exits, etc. where the velocity of the air stream is comparatively low.

The most general application of pressure measurements on aircraft are those which operate the airspeed indicator. The standard pitot-static tube is widely used for this purpose. The total pressure as detected by the pitot tube is generally rather accurate; the greatest error resulting from the angle between the axis of the tube and the direction of the relative wind and this angle is usually rather small. The greatest error in the airspeed system is in the measurement of the static pressure because the pressure at the static holes around the outside of the tube is increased or decreased appreciably by even a small angularity of the tube. We shall here consider some alternate methods of detecting the static pressure.

a. One method of measuring the static pressure accurately is by the use of a "trailing bomb" which is essentially an alternate static source towed by the airplane at a distance great enough to insure its being outside the disturbances caused by the airplane. This method has been successfully used up to speeds of 250-300 M.P.H. Above these speeds the cable or tubing which supports the bomb and transmits the pressure begins to "whip" and becomes unmanageable. Wind socks at intervals along the cable may retard such motion somewhat.

b. Another static source is the "swiveling static" which has been used with some success if the installation is carefully planned. The swiveling head must be placed outside the airplane disturbances and if the data are to be very accurate, the head must be calibrated.

c. It has been found recently that a static orifice which is essentially a pattern of small holes properly placed in the side of the fuselage, provides a very effective source of static pressure which is practically free from error especially that due to speed. The operation of this "fuselage static orifice" is due to the presence of the boundary layer of still air immediately on the surface of the airplane. It has been demonstrated by flight tests that the position error of a properly designed fuselage static system is unaffected throughout the range of Mach numbers normally encountered.

The airspeed indicator is used to indicate the difference between the total or pitot pressure due to the airspeed and the static air pressure; however, in other installations, airspeed indicators are sometimes used to indicate various other pressure differences. More frequently, the total pressures or the differences between the total pressure and the static pressure for various test installations are indicated on manometers. Several of these manometers, for a series of pressures, may be arranged in a bank and photographed. Quite a variety of liquids have been and are used in the manometers, but many companies now use acetylene tetrabromide which has a specific gravity of approximately three (3). A liquid of this density permits the use of a size of manometer which, for the usual range of pressures, is a good compromise between accuracy of readings and limitations of the allowable size. In special conditions it is more advantageous to use pressure gages, of which there are many types on the market, rather than the manometers.

4. FUEL FLOW MEASUREMENTS

Generally, the standard fuel flow meters are not sufficiently accurate for use in flight testing. Most commercial flow indicators have been found useful when the totalizer is used to indicate the total amount of fuel used but the continuously indicating pointers do not accurately indicate the rate of fuel flow.

Some other means of measuring fuel flow is, therefore, necessary. Most companies make use of the "calibrated can" method of measuring fuel flow. There are many variations in the specific equipment used, but fundamentally the method consists of measuring the time necessary to consume a given amount of fuel. A known quantity of fuel is carried in a small tank and the time required for the fuel to pass two specific points in the tank is measured. The tank is "necked down" at these two points to facilitate the time measurements.

In the photograph, Fig. 6, is shown one of the more elaborate installations for the simultaneous or separate measurement of fuel flow to two different engines. In this illustration the containers are cylindrical and are made of transparent plastic with the level indicators inside the tank. The handles for filling the tanks and those for introducing the fuel from the tanks into the supply to the engines may be seen in the lower part of the picture.

A metallic float within the tank was used in one installation to vary a magnetic field and operate an electric circuit which automatically timed the fuel flow. However, this system has not yet been perfected and was used with only limited success. One of the pitfalls to be avoided in the operation of this equipment is that of sticking of the valves. This can be especially dangerous in the case of the valve which shuts off the flow of fuel from the regular tanks and draws the fuel supply for the engines from the measuring tank. In one instance such a sticking of this valve almost caused the crash of the test airplane.

5. ACCELEROMETERS.

The measurement of accelerations is one of the most important requirements of flight test instrumentation and also one of the most difficult to perform accurately. It appears that a good accelerometer has not yet been developed.

A good accelerometer must be essentially simple. Acceleration itself as a quantity is essentially simple and usually well isolated but it may vary widely in frequency and amplitude. For this reason the frequency response of the accelerometer must be wide, but the motion of the measuring system must also be carefully damped to give the proper readings and to avoid "over shooting".

The visual accelerometer is extensively used as a cockpit instrument, but it is hardly useable where accuracy is desired. The mounting of this instrument is very critical as vibrations may make the instrument ineffective especially with regard to the pointers which indicate maximum positive and maximum negative accelerations.

The V-G recorder, an acceleration instrument developed by the NACA, is frequently used to make acceleration measurements during test flights. The record of accelerations versus indicated airspeed is made on a small rectangle of smoked glass by a stylus. The stylus is moved vertically by accelerations and along a horizontal arc by a differential between the pitot and static pressures. The instrument is very simple, completely automatic and can be very accurate. It is calibrated by actually applying to it known accelerations, on a rotating table, and simultaneously applying pressure differentials corresponding to certain airspeeds. If the instrument is used within a reasonable time of its calibration, is properly installed, on a part of the primary structure, and is properly damped it can be very accurate in the measurements for which it is intended. However, the scope of these measurements is limited, principally by two factors. First of these factors is the absence of a time reference. Since airspeed is the other axis, the correlation of any particular acceleration with another function or occurrence except airspeed is very difficult. Secondly, the response to higher frequency accelerations is very erratic. The frequencies which are encountered even in landings are high enough to make the instrument "over shoot". In this connection, the question has also arisen as to the accuracy of the V-G recorder in sudden applications of acceleration, such as might conceivably develop in quick "pull-outs", sharp-edged gusts, etc. However, this instrument has been extensively used in structural integrity demonstrations, and in gust research and has well proven its merit for these applications.

Another type of accelerometer which is now being developed was discussed in connection with strain gages. This type shows much promise and it is possible that a completely satisfactory accelerometer may be developed along these lines.

6. ATTITUDE INSTRUMENTS.

It is necessary in many types of flight tests to know the attitude of the airplane in either pitch roll or yaw -- occasionally all three. The usual method of measuring the pitch, roll, and direction is by means of the standard gyro instruments.

The directional gyro or gyro-compass indicates the direction of the airplane with respect to the earth but not with respect to the relative wind as is usually required. One very popular method of measuring the latter is by means of a yaw-meter. A photograph of the vane of a yaw-meter is presented in Fig. 7. The movement of the vane moves the armature of a selsyn transmitter which operates an indicator in the airplane. It is necessary that the vane be so placed as to be unaffected by any disturbances which may be caused by the airplane. If required, this installation can also be made to indicate angles of attack.

A new "attitude indicator" is now undergoing test by one of the instrument companies. This indicator consists essentially of a gyroscopically controlled sphere which is free to rotate about any axis. The sphere is then calibrated to show the position of the airplane. The details of this instrument are not available as the instrument is still in the developmental stage.

7. TORQUEMETERS.

The development of the torquemeter has probably been the most beneficial advancement in performance flight testing in the past decade. It provides a method of measuring accurately the power being absorbed by the propeller which was previously estimated by a comparison of the manifold pressure and the engine RPM with the engine charts. This estimation based on the assumption that the engine was operating the same in the air as it had in ground tests was usually inaccurate.

The principal of operation of the torquemeter is that of measuring the reaction of the propeller torque on the reduction gearing in the engine. This reaction is converted into a pressure and transmitted to a gage. This gage may be located in the cockpit, engineer's station, or in a photo-recorder. However, in tests of multi-engine aircraft it is necessary to transmit this pressure through the wing to the fuselage. In high altitude testing especially, the low temperatures may cause the stationary oil in these lines to congeal giving false torque readings. The usual method of remedying this condition is to pump kerosene into the line until the oil is forced back into the engine compartment where it is heated. However, another solution to the problem is to use a short pressure line in the engine compartment, where the temperature is above freezing, to transmit the pressure to a selsyn transmitter which is located in the rear of the engine compartment; the electric signal is then transmitted to the selsyn indicator in the fuselage.

8. AUTOMATIC RECORDING.

Some difference of opinion exists concerning the relative merits of manually and automatically recorded data. The value of manually recorded data lies in its availability for immediate use. Most automatically recorded data require some sort of processing and transcription. However, the ease with which a greater amount of data may be recorded automatically, the reduction in flying time and the elimination of a certain amount of "personal error" far outweigh the advantages of manual recording. When data is recorded manually by either the pilot or the crew simultaneously with automatic recording, it should never be interpreted as more accurate than that which is recorded automatically. This, of course, assumes that the reliability of the instrumentation is the same at both stations.

There are many ways of automatically recording data, but essentially there are two methods in common use: chart recording and photographic recording. Chart recording is very useful where continuous records are required and is otherwise used occasionally in connection with selective recording. The Brown Temperature Recorder is a good example of selective or intermittent chart recording where the data are recorded on the chart as the various thermocouples are successively switched into the circuit. The primary value of chart recording is in its immediate availability for use; the true chart recordings require no processing. Examples of continuous chart recording as used in flight testing are the flight analyzer and the barograph. A recent advancement which has improved chart recording is the development of "teledeltos" paper on which the mark or trace is made by a high voltage arc from the pen or stylus to the foil backing of the paper itself. The use of the teledeltos paper has two advantages: pressure of the stylus on the paper is unnecessary, which reduces the friction in the indicating system and the operation of the recording system is improved rather than destroyed by altitude. The use of sensitized paper or film as a means of recording is sort of a hybrid between chart and photographic recording. This type of recording is used in many oscillographs and its application was discussed in connection with strain gages.

True photographic recording is the method most widely used in flight testing at present to record data automatically. In this method the instrument readings are photographed directly. The popularity of this system is primarily due to its flexibility and the ease with which standard aircraft instruments may be utilized.

a. CONSTRUCTION OF THE PHOTO-RECORDER.

The design of the particular photo-recorder must be made to suit the specific conditions; the type and number of the instruments to be photographed will of course, depend on the type of test. The physical characteristics of the photo-recorder will be determined by the location and the airplane in which it is to be installed. If the space and weight restrictions are liberal, size of the photo-recorder may be a minor problem. However, if these restrictions are considerable, such as is the case in a fighter airplane, the problem of the design of the photo-recorder is more complex. One common method of reducing the size is that of using a mirror to reflect the image of the instruments into the lens of the camera. This serves to increase the field of the camera without increasing the length of the recorder. Several pictures of photo-recorders are presented. The photograph, Fig. 8 shows a photo-recorder in which the mirror is inclined to the plane of the lens. This photograph is especially interesting because it shows an installation which was particularly difficult. Due to space limitations, it was necessary to mount the recorder on the gun mounts in the wing.

Figs. 9 and 10 show exterior and interior views of a photo-recorder which makes use of a mirror parallel to the plane of the camera lens. In Fig. 10 the curved instrument panel can be seen. This is an effort to reduce the parallax in the reading of the instruments along both edges and to improve the focus on these instruments.

The arrangement of the instruments on the instrument panel is another feature of the construction of the photo-recorder which should be given consideration. A convenient arrangement of the instruments in groups can greatly reduce the effort required to analyze the recorded data. Two photographs of instrument panels are presented to illustrate the grouping of the instruments. The white lines, in general show the groups of instruments. In the photograph, Fig. 11, the instruments in the upper left are oil and fuel flow and temperature instruments, below these are oil and fuel pressure instruments, the lower row are boost pressures, and to the right are miscellaneous flight and engine instruments. In Fig. 12, the instruments to the left of the white line are engine tachometers in the first row, manifold pressures in the second row and position indicators in the next two rows; the instruments on the bottom row are torque meters; and those to the right of the line are miscellaneous instruments.

b. LIGHTING.

The lighting of the instrument panel of the recorder is critical and must be arranged carefully. Reflections of the lighting of the instrument panel may easily ruin an otherwise good installation. One of the simplest means of lighting the panel is by overall lighting which is usually done by the use of fluorescent lights. However, this is also one of the easiest ways to introduce glare. Fig. 13 shows a mild case of glare trouble on four of the instruments. The photograph Fig. 14 shows an example of individual lighting for each instrument. Although very effective, this system is also more difficult to construct. This photograph and that in Fig. 15 also show the open type of construction. This open construction is much more convenient and may be used when light from other sources is not liable to affect either the glare or the exposure of the film. This type of photo-observer is very practical if it can be used; the instruments, lights, and other component parts are much more readily available for servicing than in the closed type of construction.

c. CAMERA.

The camera is a very important feature of the photo-observer. Some companies have been able to secure suitable standard electrically-driven motion picture cameras and adapt them for use in the recorders.

Two photographs of one of these cameras in different installations are presented in Figs. 16 and 17. The principal alteration is usually in the movement. It is necessary that the speed of the camera be controllable through a greater range than that usually available. The common speeds for the cameras in the photo-recorders range from one picture every thirty seconds to normal camera speed. Some cameras also need an increase in available film fottage. This factor will be determined by the nature of the airplane and the tests. The actual length of film required is largely a matter of judgement and should be estimated on the basis of the duration of a single flight and the number of tests normally conducted on a single flight. In this connection, it has been found advisable to run the photo-recorder at a slow speed continuously throughout the test flight allowing the operator to increase the camera speed when a test is being run. This policy will tend generally to improve the data by giving a continuous record of the functioning of the airplane before and after as well as during the test. An ordinary lens aperature is usually satisfactory because the intensity of the light and the type of film can be adjusted to suit the conditions. The focus may be critical if the space requirements are very stringent, but this is not usually the case.

d. <u>CONTROL AND CORRELATION.</u>

The controls for a photo-recorder will vary considerably with conditions. However, standard control boxes have been developed by some companies to fit their usual needs and if additional controls are necessary they are added separate from the control boxes. The photograph, Fig. 18, shows one such box for the control of one recorder. The controls shown on the box are self explanatory. In another organization where larger airplanes are usually tested and more than one recorder are usually installed, a multiple control box is required. Fig. 19 illustrates a multiple control box which also contains controls for a Brown potentiometer.

The correlation and identification of any single picture is a particularly important problem when more than one recorder is used. This was first attempted by the use of very accurate clocks, but even the best clocks did not perform this function satisfactorily especially when the flights were of long duration or if the pictures were taken in quick succession. To provide the necessary correlation between the different records the various photographs are usually numbered consecutively. This is accomplished by means of a counter which is advanced each time a picture is taken by any or all cameras. This number is also reproduced on the control box for the correlation of any notes which may be taken by the engineer or the pilot.

In connection with the controls of the photo-recorder, we might also consider briefly the more general aspect of the complete flight test engineer's station. This subject is of particularly importance in the large airplanes although it may be considered to a much less extent in the arrangement of the flight test controls and instrumentation for the pilot in a single-seat airplane. For purposes of this discussion, only the larger, multiplace airplanes will be considered. The primary consideration in the arrangement of the engineer's station is the convenient location of the controls, instruments and indicators. Two photographs are presented as examples of two very good installations. Fig. 20 is an engineer's station for the tests of a medium bomber where only one engineer is used. The strip across the upper right-hand corner is a writing table which folds down for the convenience of the engineer. The photograph, Fig. 20, illustrates an engineer's station in a larger airplane. Positions for two engineers were provided in the installation. A legend for the identification of the various components is provided.

e. PHOTOGRAPHING THE AIRPLANE.

In some tests it is impossible to secure sufficient information concerning the functioning of the airplane by conventional instrumentation. Occasionally, photographing various parts of the airplane is the solution to this problem. Cameras are mounted on the airplane and such items as wings, stabilizers, elevators, etc. are photographed in flight so that such phenomena as flutter or air flow (by tufts) can be studied. Fig. 22 illustrates one installation of a camera for the study of the empennage of an airplane. The camera is mounted inside the fuselage, out of the airstream and the empennage is photographed by means of a mirror.

f. RADIO TELEMETERING.

A recent line of improvement on the art of flight testing has been the transmission of test data to the ground by radio.

Three reasons can be assigned for the necessity for this type of equipment.

1. On flights of long duration it is convenient to have the data on the ground as soon as possible, especially on important tests, so that the data can be analyzed partially, at least, and the remainder of the test schedule be planned or considered with the least amount of delay.

2. On especially hazardous tests the loss of the airplane would not mean the complete loss of data which, because of the failure which caused the crash, might well be invaluable. With other means of recording, the loss of the test airplane, aside from the cost in time, personnel, and money, often means the loss of data which might show the reason for the crash and any other data which may have been collected on that flight.

3. The progress of the test may be charted and calculations made on the ground so that the pilot may be informed of the progress of the test. This might prevent accidents and should accelerate a test program because it would not then be necessary for the pilot to land to see how the test is going.

9. EQUIPMENT FOR TAKE-OFF AND LANDING TESTS.

One of the most frequent methods of measuring take-off and landing runs is by means of an adapted motion picture camera. The camera is adapted to photograph a stop-watch and the airplane simultaneously. In this method flags or markers are usually spaced along the runway to mark off units of distance. A variation of this particular method is the use of a recording theodolite. A theodolite which has been rigged with a means of recording its azimuth and deflection is used to follow the airplane. A combination of both of these methods and an improvement over both is the use of the photo-theodolite. A photograph of this instrument is presented in Fig. 23. It consists essentially of a camera which photographs the airplane at carefully controlled intervals. As each photograph is taken, a grid which is calibrated both in horizontal and vertical distance, is superimposed on the picture. The grid is actually stationary within the instrument and the photographs are taken through it.

In any of these measurements the location of the instrument with respect to the runway must be known and allowances must be made in the analysis of the data for the variation in distance from the camera to the airplane. For the Army the important requirements for take-off tests concern the distance to clear a 50-ft. obstacle while that for the Navy concerns the point at which the airplane leaves the ground. The distance to clear a 50-ft. obstacle is relatively easily measured by means of the camera, but it is somewhat more difficult to determine the actual point where the airplane leaves the ground. Therefore observers must be stationed along the runway to note and mark this point.

One method which has been used successfully on a large airplane to perform this function is that of using a small wheel, rolling on the ground to indicate the point at which the wheels leave the ground.

The large airplane happened to have dual main wheels and the small wheel was located between these. The cantilever beam which carried the wheel was hinged to move in the vertical plane. As the airplane left the ground the wheel dropped slightly breaking an electrical contact. This wheel was used further to drive a tachometer generator to indicate the ground speed and a revolutions counter which was calibrated in feet to measure the take-off run.

C. INSTALLATION AND MAINTENANCE

The instrumentation installation will be different for every type of instrument and must be given separate attention. This may be greatly simplified by the preparation of an installation manual as previously discussed. This is especially valuable in the training of new mechanics and even for the guidance of experienced men.

The installation of the instrumentation accessories can best be performed during the construction of the airplane. Such items as pressure lines, wiring, etc. can be easily placed in the airplane during its construction if the instrumentation has been planned far enough in advance. This will greatly simplify the instrumentation problem. The instrumentation should be checked before every flight; this is usually performed by the line crew in accordance with an instrumentation check-off list as discussed in Part I. Some companies require that the photo-recorder and any other recorders which may be installed, be operated during the ground run up. This length of film is then quickly developed and examined before the check-off list is "signed off".

If the data analysts find any data which is questionable, this fact should immediately be brought to the attention of the instrumentation engineer. The manually recorded data may also serve as a check on the operation of the instruments in the automatic observer. Each instrument which is not direct reading should be plainly marked and instruments which are inoperative should also be plainly marked, usually by a cross of white tape on the dial.

D. CONCLUSION.

In conclusion of this discussion it is obvious that the problems of the instrumentation engineer are many and varied. Besides a thorough knowledge of the instruments with which he works, he must also have comprehensive knowledge of the phenomena which he must measure. He must be familiar with the various technical subjects such as aerodynamics, mechanics, electronics, structural analysis, etc. and he must be able through personal experience to evaluate the various ideas and to select the most practical for his particular purposes. Many other personal attributes are required to make a good instrumentation engineer. Probably the most important among these is ingenuity. Many problems which may be confronted daily can be solved by the ingeneous application of elementary principles.

E. ILLUSTRATIONS.

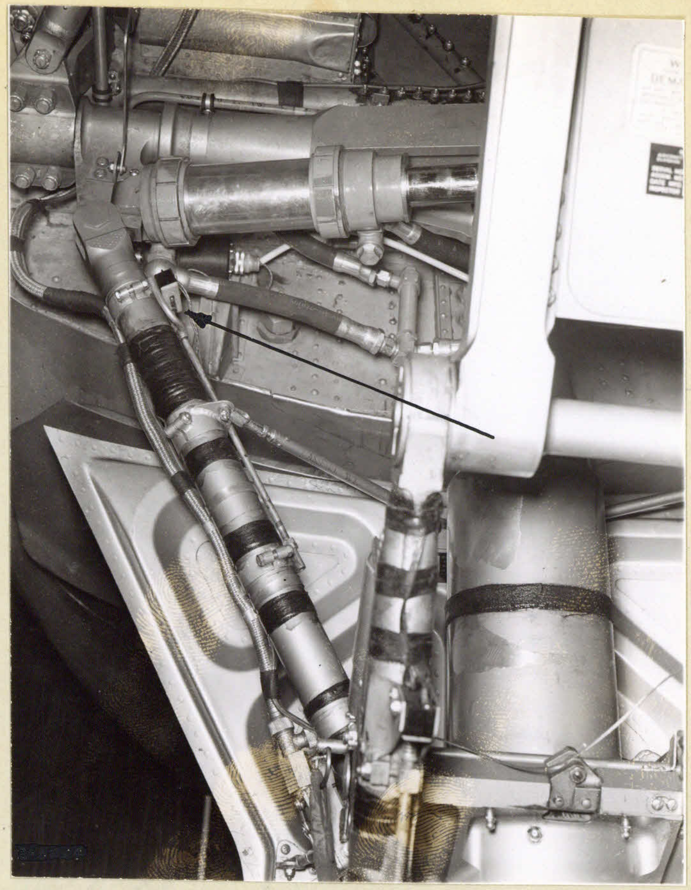

Fig. No. 1 Strain Indicator

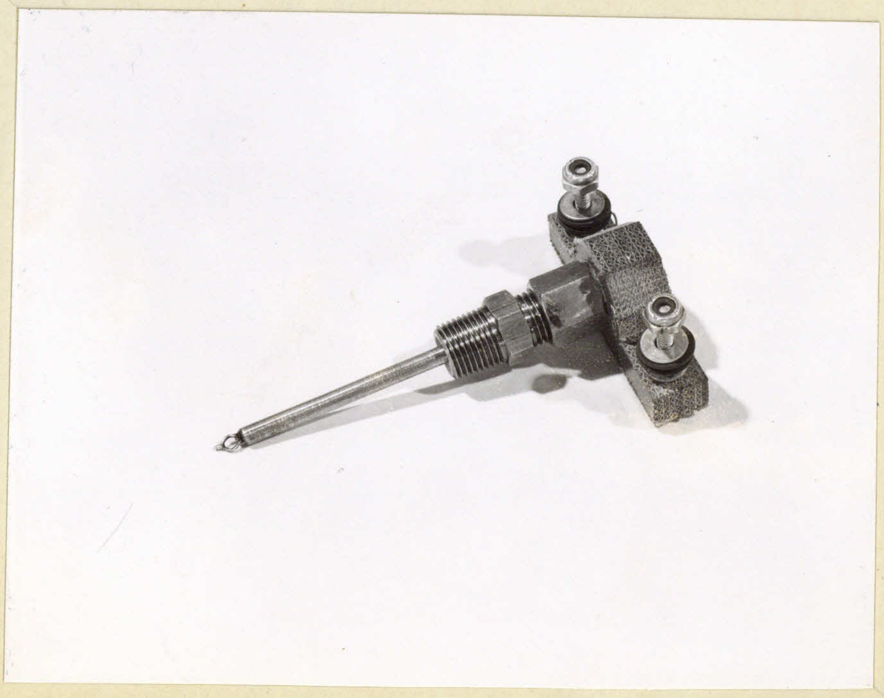

Fig. No. 2 Thermocouple

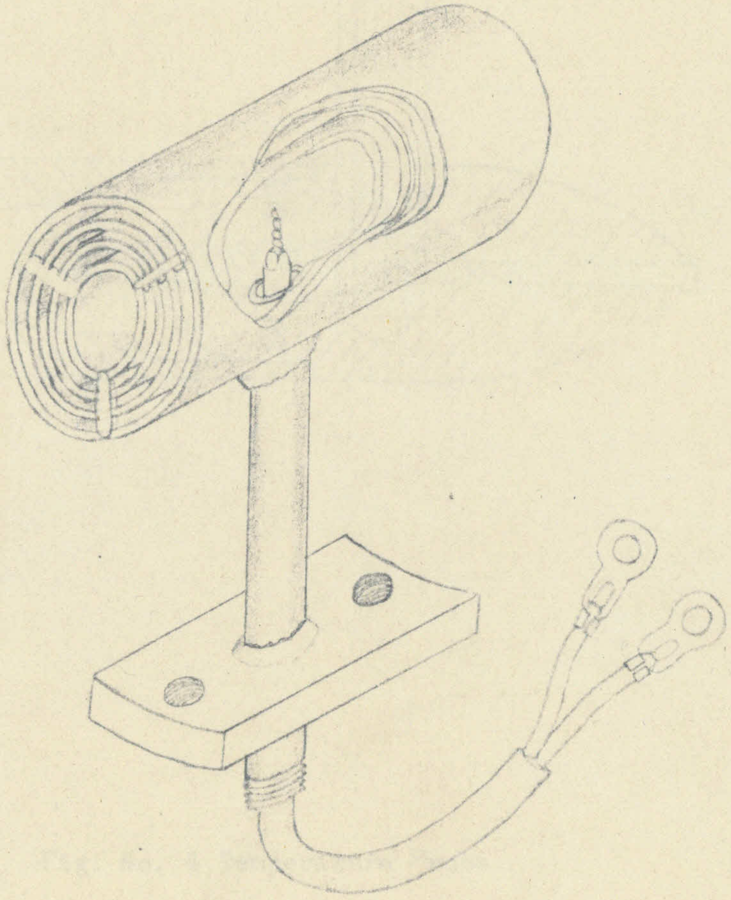

Fig. No. 3 Quadriple-shielded Thermocouple

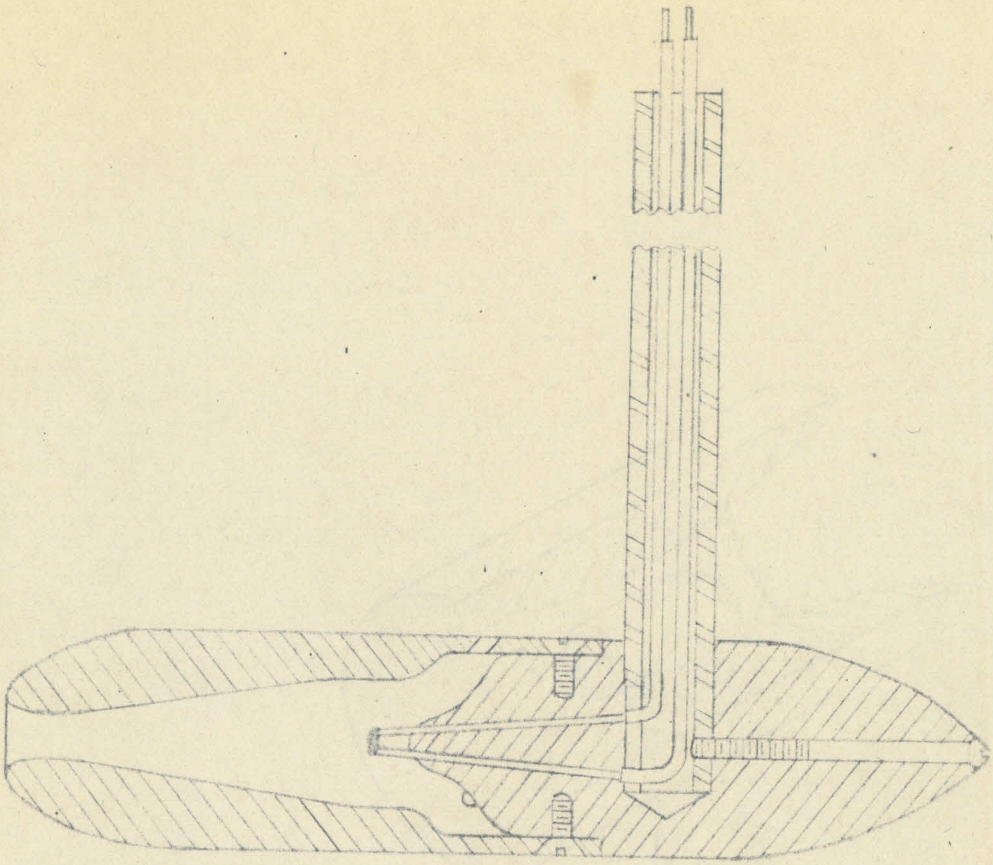

Fig. No. 4 Temperature Probe

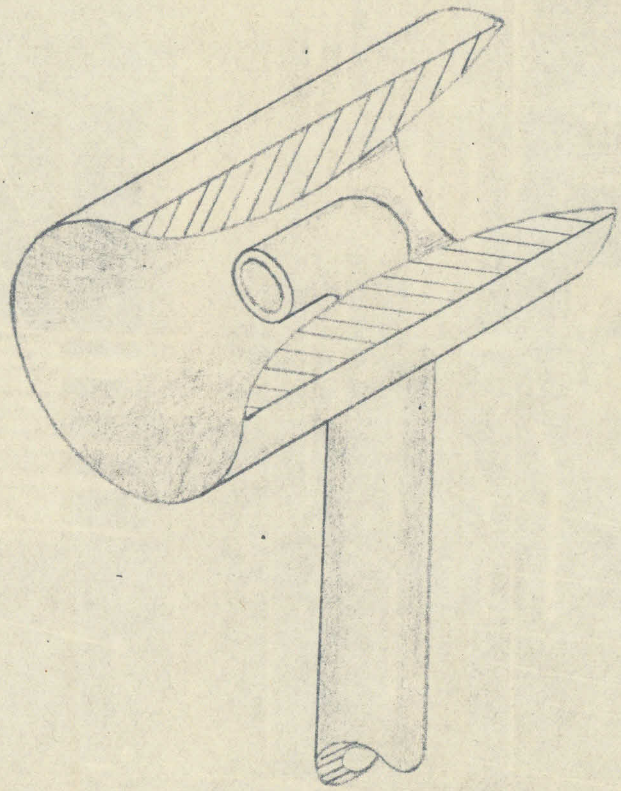

Fig. No. 5 Kiel Pressure Head

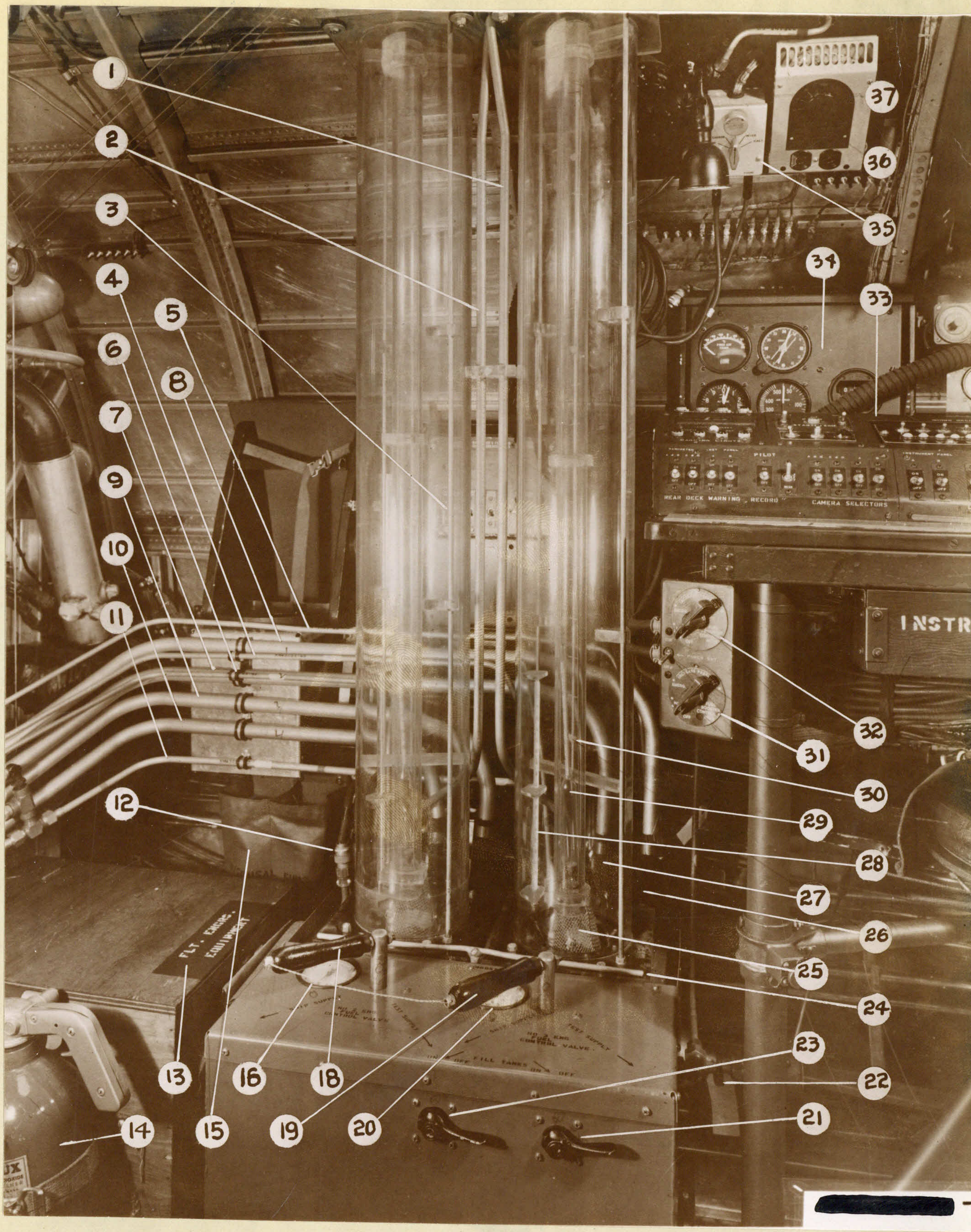

Fig. No. 6 Fuel Flow Meter

(A Complete Legend for the Numbers is not Available)

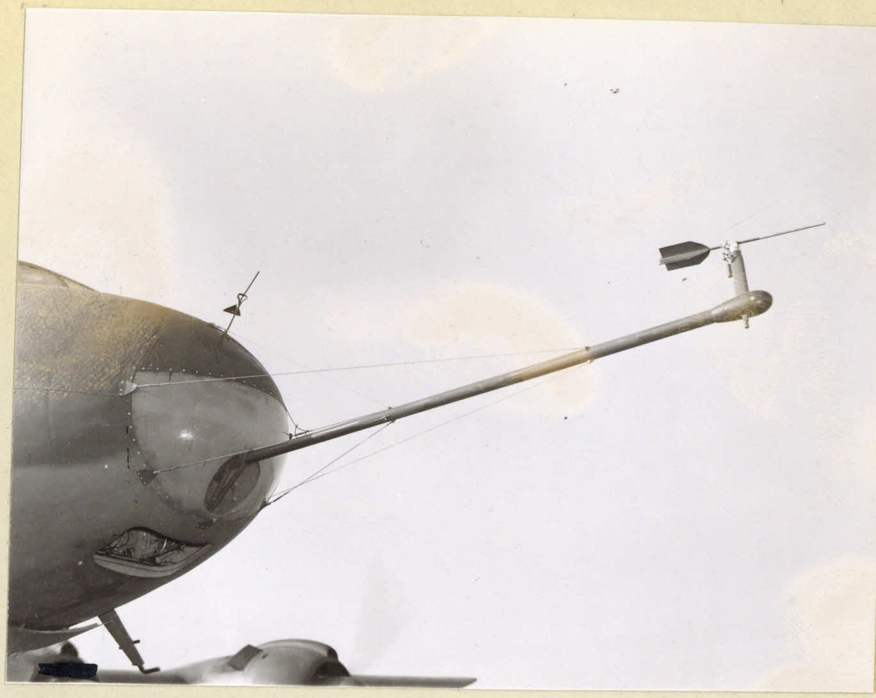

Fig. No. 7 Yaw Meter, vane

- Accuracy -
- Drawings -

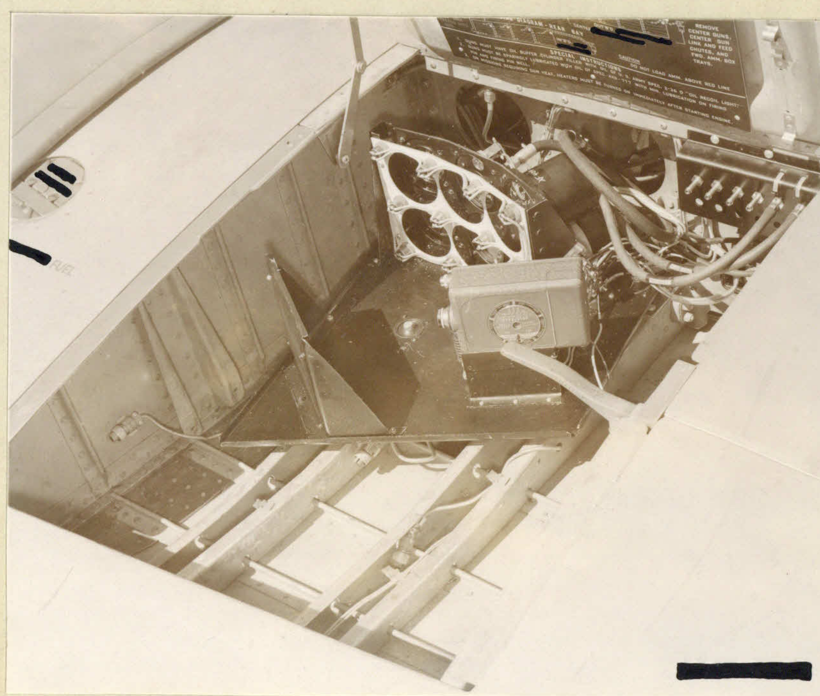

Fig. No. 8 Photo-recorder, Wing Installation

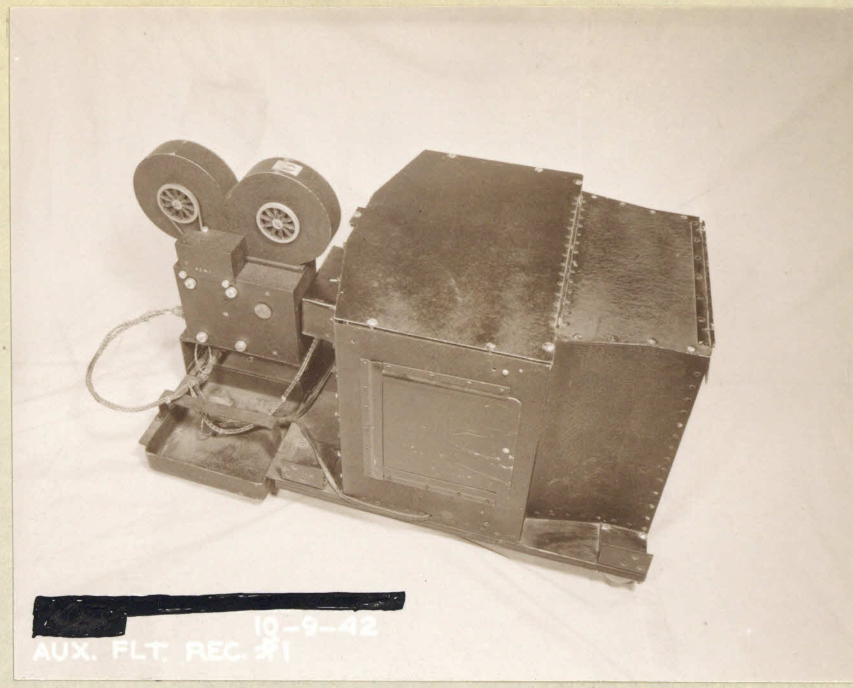

Fig. No. 9 Photo-recorder, exterior

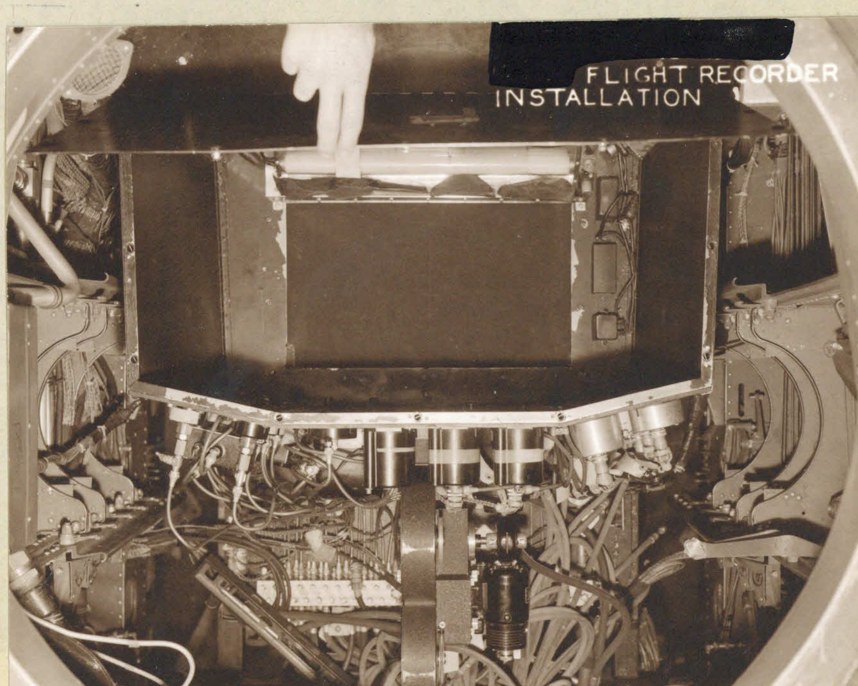

Fig. No. 10 Photo-recorder, interior

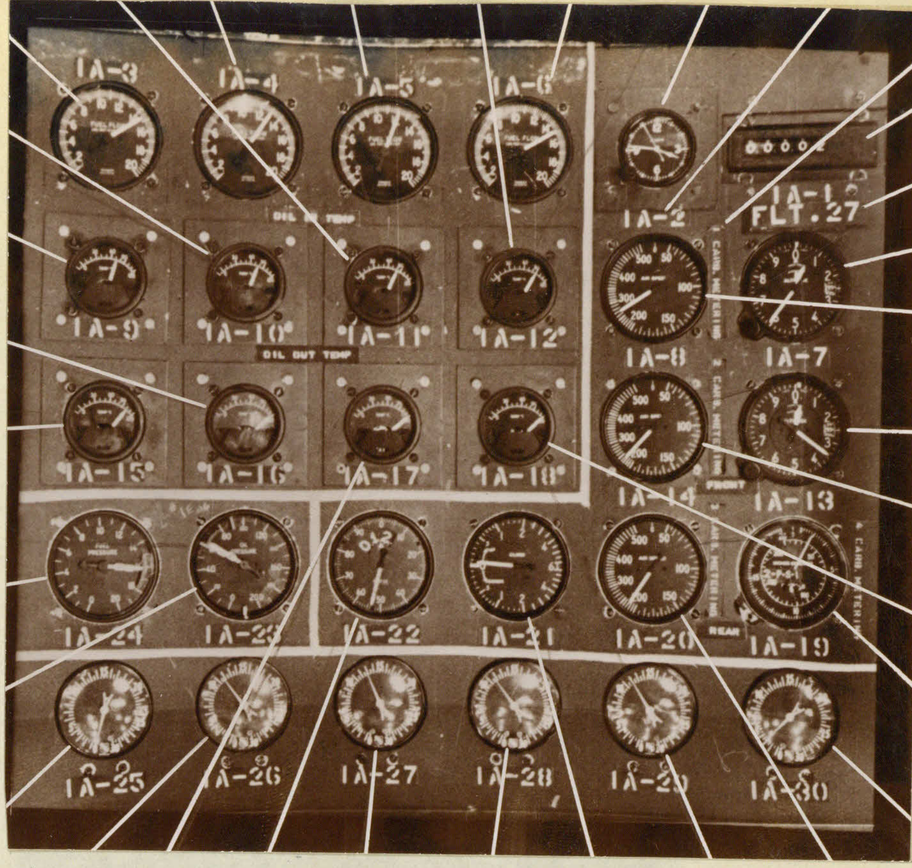

Fig. No. 11 Instrument Panel , No. 1

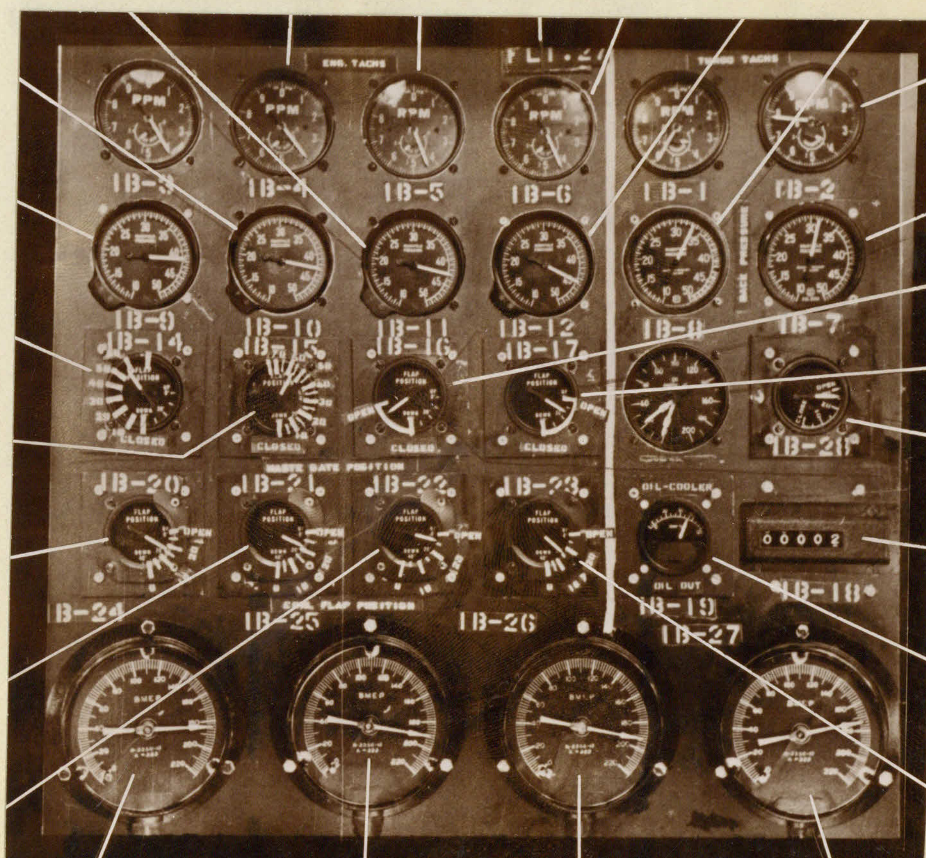

Fig. No. 12 Instrument Panel, No. 2

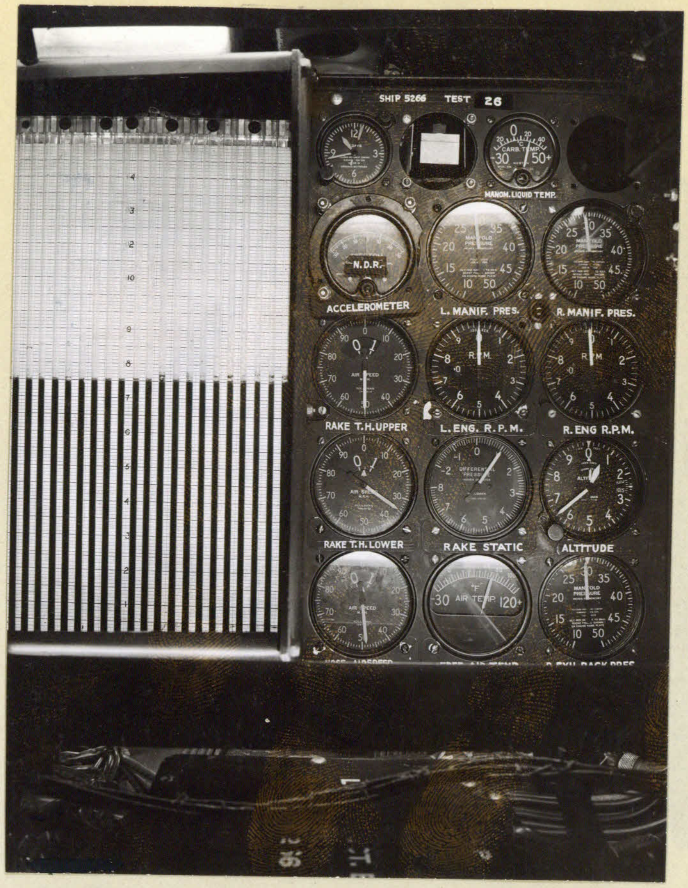

Fig. No. 13 Instrument Panel, No. 3

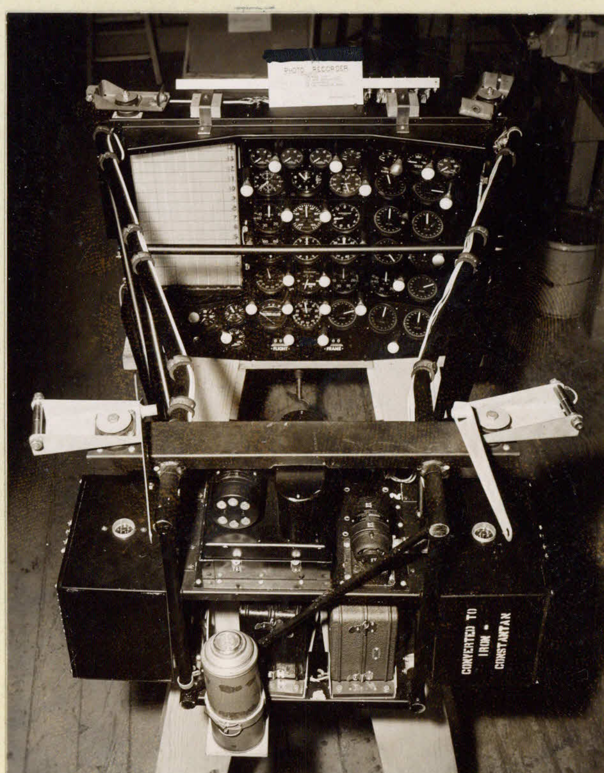

Fig. No. 14 Photo-recorder, Individual Lighting

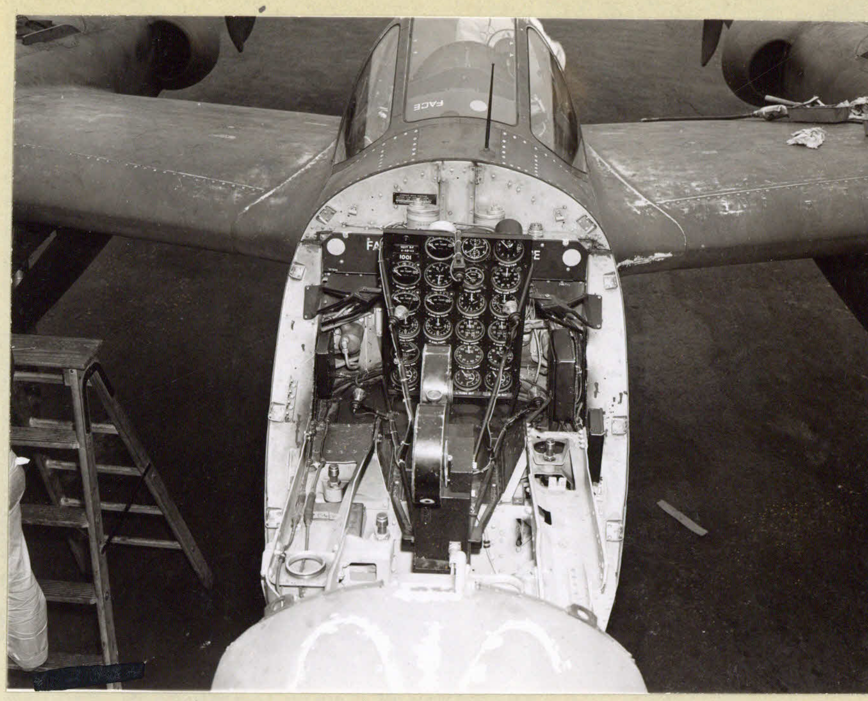

Fig. 15 Photo-recorder, Open Type

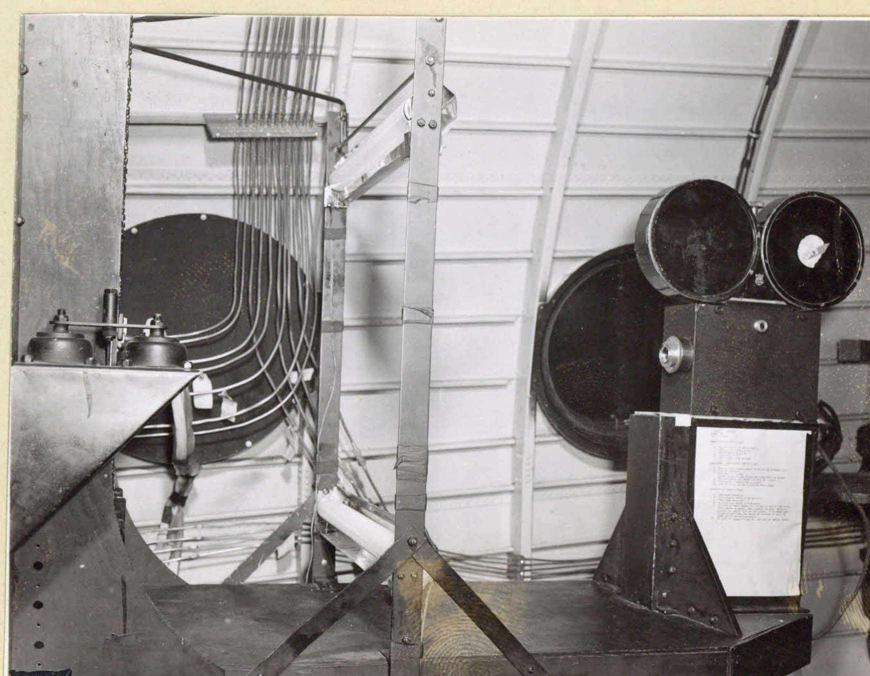

Fig. No. 16 Photo-recorder camera

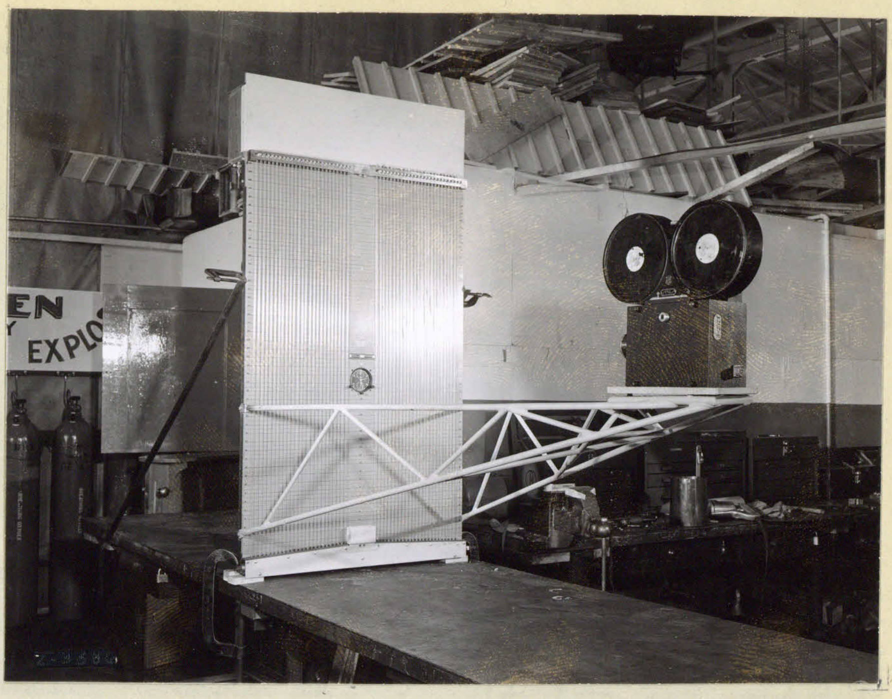

Fig. No. 17 Photo-recorder, Manometers

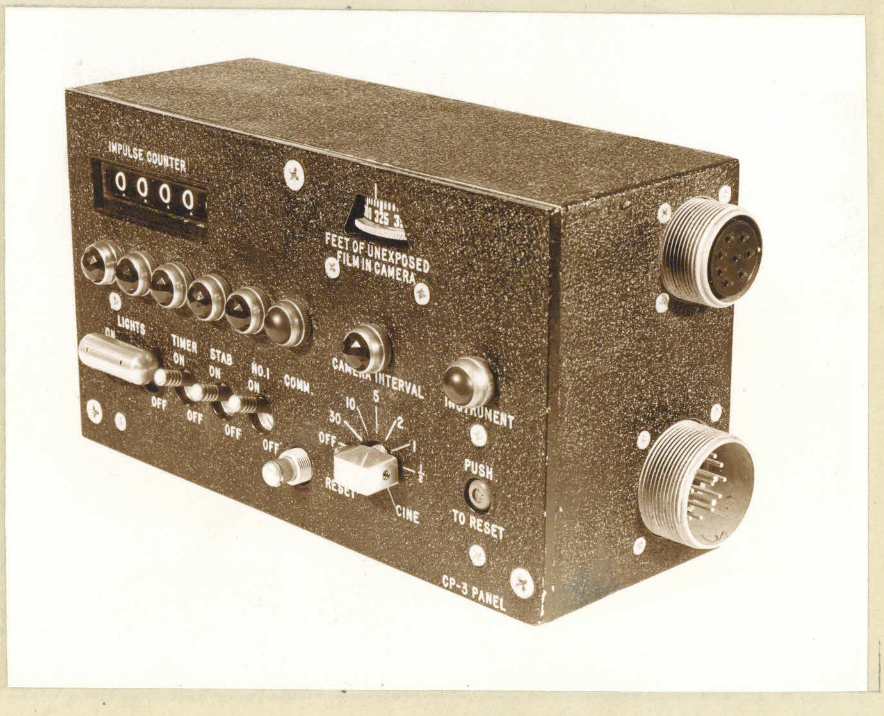

Fig. No. 18 Photo-recorder control box

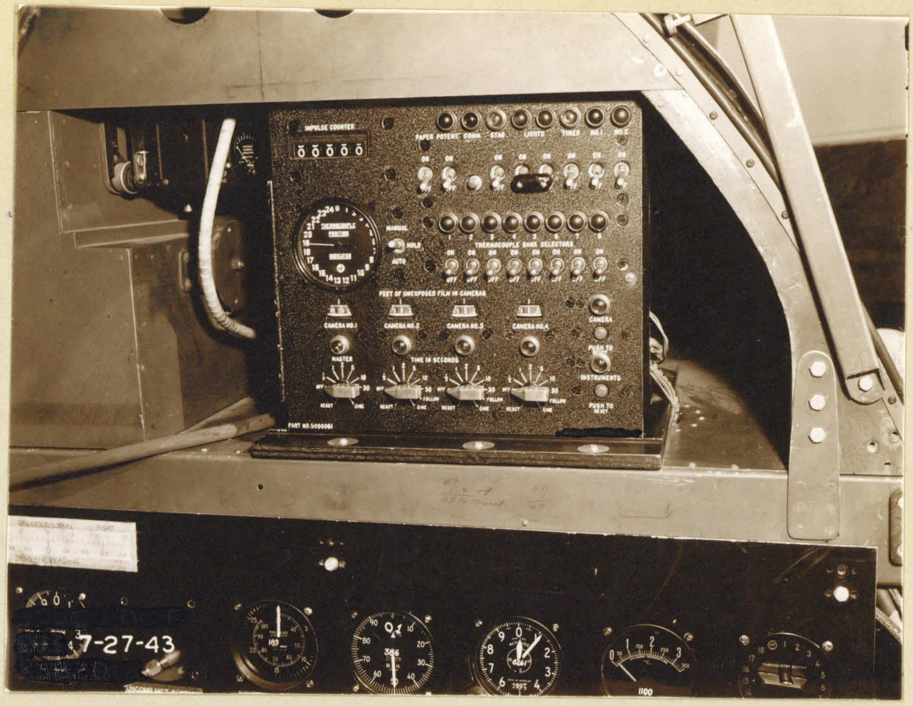

Fig. No. 19 Multiple Photo-recorder control box

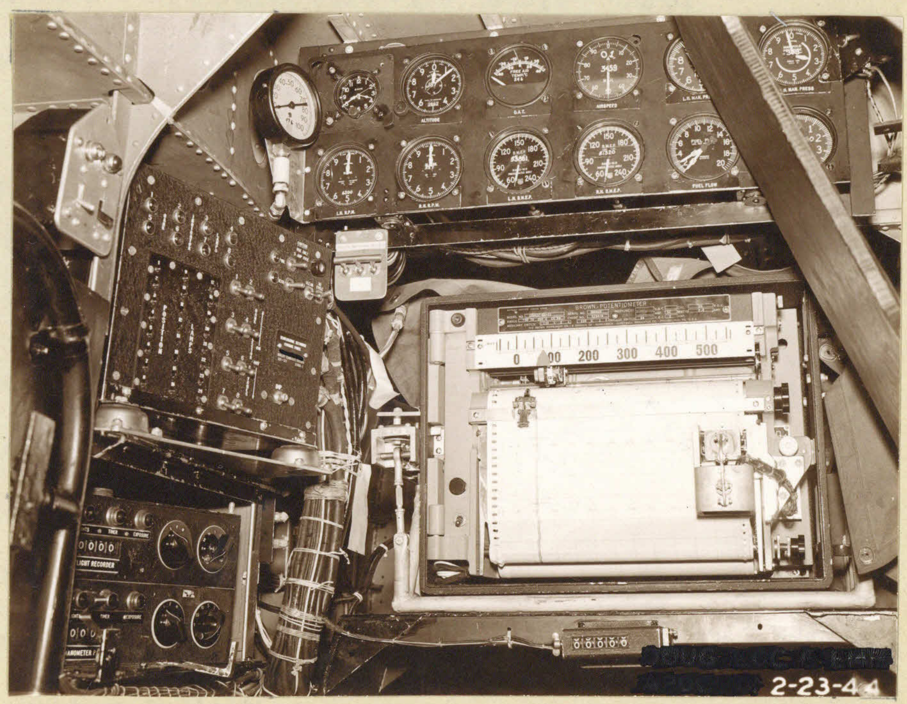

Fig. No. 20 Engineer's Station, single

LEGEND FOR PHOTOGRAPH

ENGINEER'S STATION, FIG. 21

1. Fuel Consumption Test Unit
2. Counter
3. Standard Navigator's Instruments
4. Instrumentation Engineer's Heated Suit Outlet
5. Instrumentation Power and Brown Rec. Power
6. Brown Recorder Control
7. Brown Recorder Voltage Control
8. Interphone "Mike" Location
9. Cambridge (N.A.C.A.) Fuel Analyser
10. Alumel/Cromel Pyrometer Potentiometer
11. Location for Fuel Consumption Unit Fire Bottle Control
12. Minneapolis-Honeywell Brown Temperature Recorder
13. Individual Engine Turbo Tachometer Indicators
14. Power Plant Engineer's Heated Suit Outlet
15. Individual Engine Back Pressure Indicators
16. Temperature Indicators -- Oil "out" of Engine
17. Engine "Nose" pressure Indicators
18. Landing Gear "Up" and "Down" Line Pressure Indicators
19. Oil Cooler Flap Position Indicators
20. Cowl Flap Position Indicators
21. Landing Gear and Cabin Alt. Warning Horn
22. Engine Oil Pressure Indicators
23. Manometer Board - Fuel Vent System - No. 1 Eng. Ind. Cyl. Back Pres.

24. Pilot's Instrument Panel

25. Pilot's and Co-pilot's Instrument and Control Panel.

26. Surface Control Position Indicators

27. Manometer Board and Photo Box Lighting Control

28. Camera (4) Selection and Control

29. "Recording Data" Control Switch to Pilot

30. Warning to Crew in Aft Cabin, "Pictures Being Taken"

31. Instrumentation Engineer's Table with Thermocouple Listing

32. Instrumentation Spare Parts Drawer.

33. Instrumentation Engineer's Station

34. Alumel/Cromel Thermocouple Control Switch

35. Individual Fuel Tank Booster Pump Pressure Indicator.

36. Iron/Constantan Thermocouple Control Switches, No. 2 Eng.

37. Iron/Constantan Pyrometer Potentiometer

38. Iron/Constantan Thermocouple Control Switch No. 1, 3 and 4 Eng's.

39. Main Entrance to Flight Deck

40. Turbosupercharger Waste Gate Position Indicators

41. Flight Test Engineer's (Power Plant Observer) Station

42. Aerodynamic Engineers Station

43. "Recording Data" Warning Light for Pilot

44. Power Setting Chart

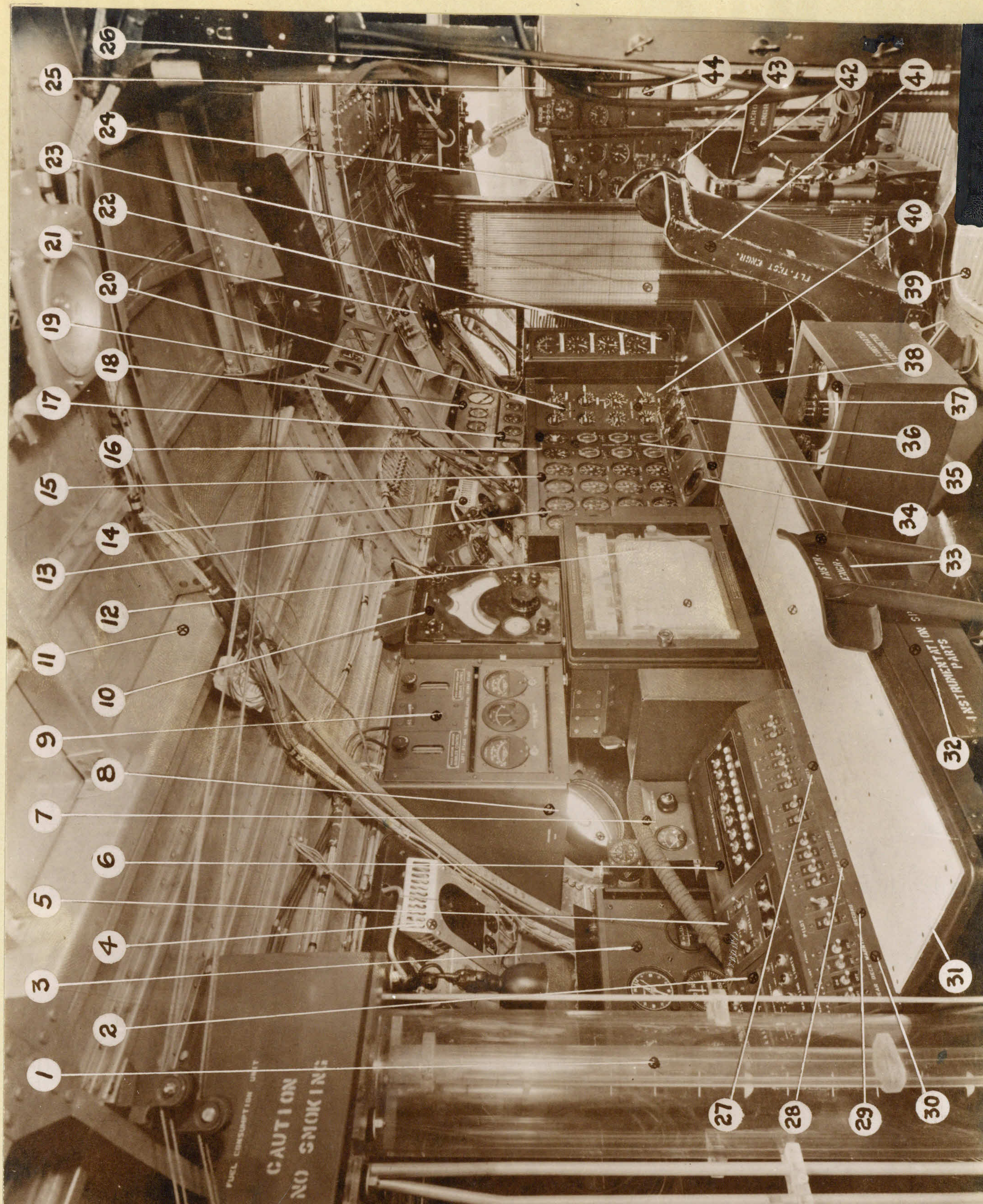

Fig. No. 21 Engineer's Station, dual

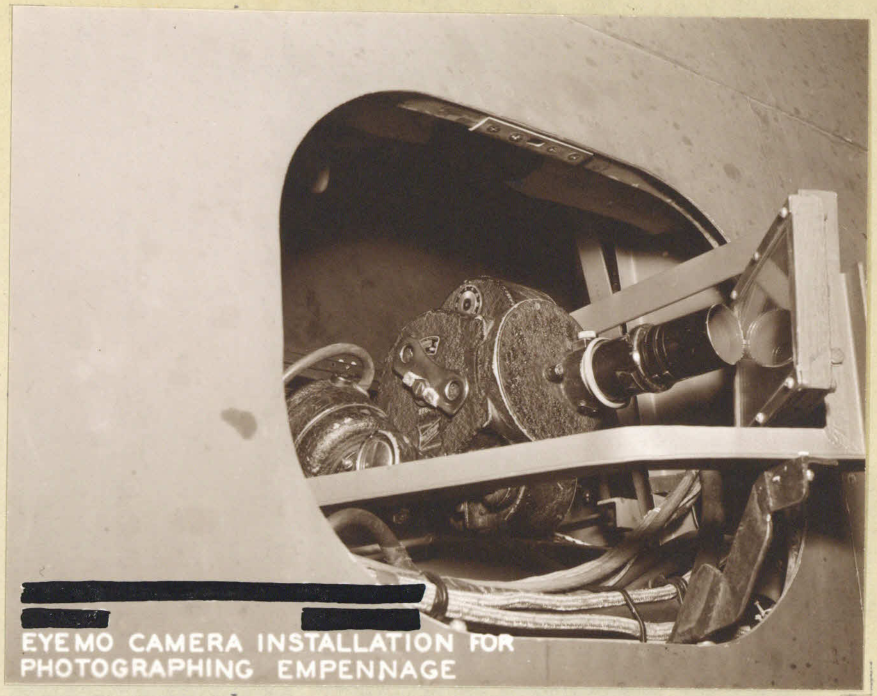

Fig. No. 22 Camera for Photographing Empennage

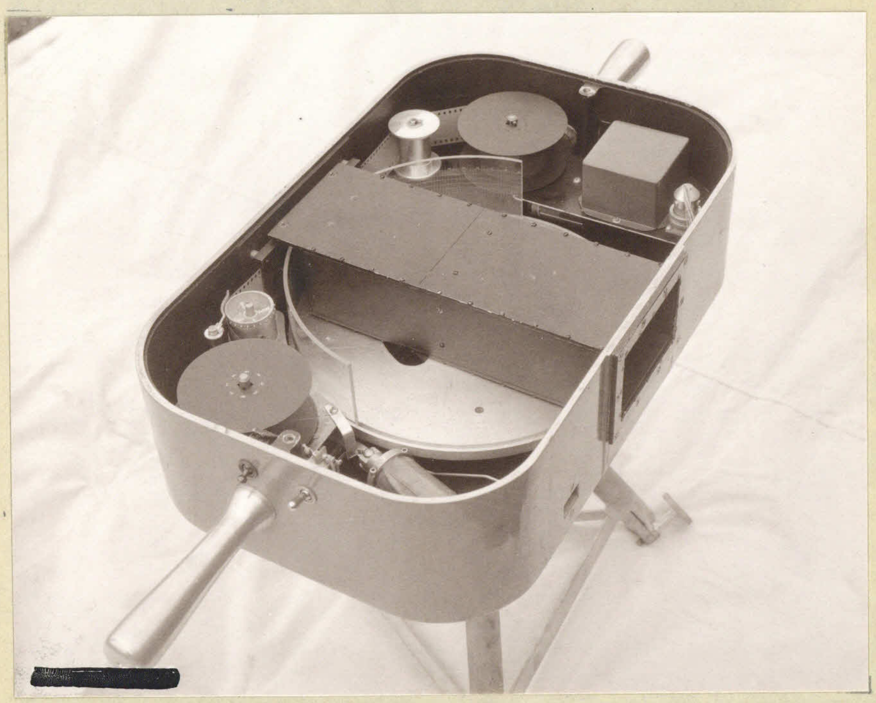

Fig. No. 23 Photo Theadolite

Although the control of the weight and balance of the test airplane is not strictly a part of the responsibility of the instrumentation engineer, it is still a major problem. One unusual method for controlling this factor and for shifting the balance in flight in a large airplane is by means of water in tanks as shown by the photographs below.

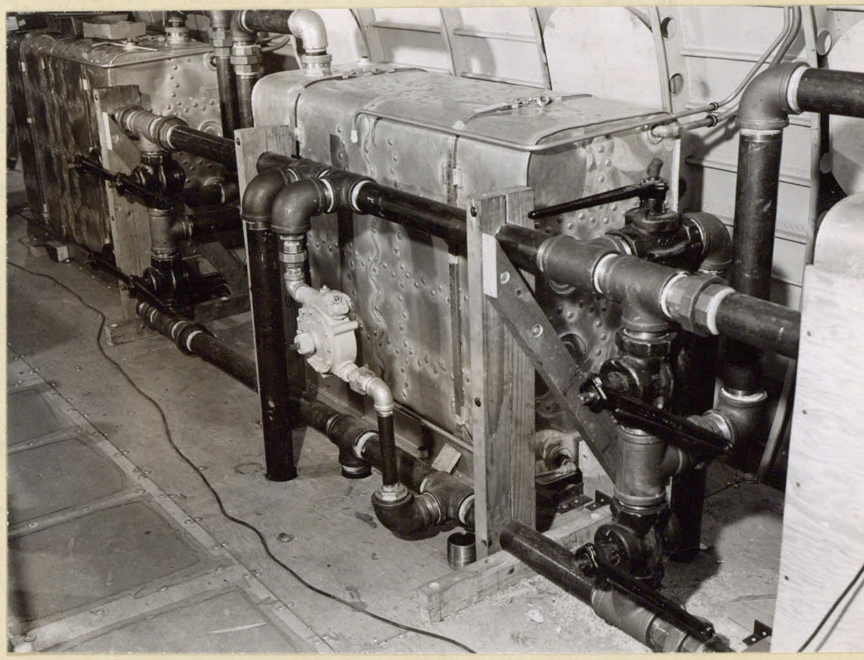

Fig. 24

Fig. 25

III. FUTURE TRENDS

A. GENERAL.

The development of the art of flight testing appears to be motivated by the following primary factors:

1. The importance of making flight testing more safe.
2. The design engineer's need for reliable, full-scale data on air loads and ground loads.
3. The necessity of reducing the time required and the amount of flight testing needed to approve an aircraft after the prototype is constructed.
4. Post-war financial considerations which will probably demand a considerable reduction in the cost of flight testing.

These factors are obviously interrelated insofar as their effects on the art of flight testing are concerned. However, their influence appears to be causing two significant and important trends.

B. THE DEVELOPMENT OF INSTRUMENTATION.

The instrumentation of flight test aircraft is rapidly becoming more complete and more comprehensive. Instrumentation is now available for warning the pilot when near-critical loads are being encountered in various structural components of an aircraft. Developments in the use and application of these and similar instruments will undoubtedly make possible reliable flight test checks of theoretical calculations of air and ground loads.

Some work is being done on the development of instruments which will indicate "reduced" data. For example, a torquemeter pressure guage and a tachometer might be combined into a single B.H.P. Indicator. Any trend in this direction will greatly reduce data reduction time and will be worth while if it does not complicate the instrumentation problem too much.

The development of radio telemetering and reliable radio control of the test airplane should be of great value in flight tests for structural integrity. Radio telemetering alone will probably be very useful in reducing the size of the crew required for flight tests and in making the data available on the ground while the test flight is still in progress.

Radical changes in the nature of aircraft will probably require different forms of instrumentation to evaluate new design features and to measure higher ranges of performance.

C. THE DESIGN FUNCTION OF FLIGHT TESTING.

Flight testing is rapidly becoming an important tool in the hands of the design engineer. Many new designs require very little flight testing because new features are installed on older aircraft and proven in the air before the prototype is completed. Design difficulties are thus eliminated while the prototype is under design and construction, rather than after it is completed.

BIBLIOGRAPHY

Some of the material which was used in the preparation of this thesis is contained in reports and papers which are classified, not because of the methods or data themselves, but because of the projects with which they were associated. For this reason the bibliography which is presented below is necessarily incomplete. Only that material which was used and which has actually been published is listed below.

The details of some of the reports examined represent much effort and research on the part of certain companies or individuals. The authors have been careful to present such material only in the form of ideas. This has been done wherever the techniques involved are peculiar to only one organization.

The authors feel that, in general, the various flight test organizations have contributed equally to the material presented herein and thus, the preparation and distribution of this thesis will not in any way compromise the competitive accomplishments of any organization or individual.

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