Aircraft Design: Present and Future

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This paper on the state of the art of airplane design is directed primarily to defining today's challenge to the aircraft designer. The project designer's tasks are design and synthesis, and these require the understanding and use of engineering data in distinctly different ways from the forms that normally are taught in schools or that result from analysis and research. Design requires the accomplishment of a competitive and optimum compromise among all the specialties and technologies, within the limits of the available time and money. The engineering department must also accomplish the research and analysis that provides, and advances, the state of the art in each of the functional specialty areas and see to it that the engineers and designers on all the projects are always up to date. The relationships between and the responsibilities of these functional organizations in accomplishing the successful systems engineering or design integration are discussed. Several areas in aircraft design are presented in which the engineer faces challenges, and it is suggested that design is a field, too often given too little attention by educational institutions and technical societies, that offers even greater personal satisfaction to the individual than achievements in research and analysis.

THIS paper on the state of the art of aircraft design in 1964 will be directed primarily to defining today's challenge to the aircraft designer. The aircraft designer is challenged to bring the best of modern technology and engineering management to a particular customer's needs and to thus produce an outstanding and competitive aircraft. This paper, which is directed toward a more thorough definition of this challenge, will not cover such subjects as the internal engineering department administrative and operating functions or the operational relationships between an engineering department and other departments of an aircraft manufacturing organization such as the manufacturing, finance, quality control, contract administration, and materiel departments. Tremendous improvements are being made in these very important relationships as well as in the design function that is the subject of this paper.

"Design" vs "Research" and "Analysis"

There is great debate in the engineering schools of this country concerning the practicality of teaching "design" as part of an engineering education. Many educators believe that a student should not be introduced to the problems of design until he has been thoroughly educated in all the matters of science that he might require to "analyze" some particular existing design. This author believes that design is an entirely separate subject from analysis and research and that design can and must be taught to engineers and potential engineers as early as possible, and certainly no later than their high school years.

What is meant by design as contrasted to analysis and research? Figure 1 is the common method for presenting the results of research on the strength of columns, in this case round 7075 aluminum tubes. Euler and numerous other scientists and engineers have developed theories and experimental data concerning the strength of columns. These theories and data are normally plotted in the form shown on Fig. 1. The strength of the column is measured by its load carrying ability per square inch of cross section area. This strength is plotted as a function of the column length divided by column radius of gyration L/ρ and as a function of the thickness-diameter ratio of the tubular column. This is the form in which column data are normally found in engineering textbooks. This is a very convenient form to use when one wishes to analyze the strength of some particular column which has already been defined as to its length, radius of gyration, thickness, and diameter. All of the characteristics of the column are given except its load carrying ability and one can enter the chart and move directly, without cut and try, to the strength of the column. It is straightforward to use this chart to analyze the strength of a previously defined column. This chart is thus particularly useful in defining the results of research and in making these research results available for use in the analysis of columns.

The column designer is faced with an entirely different problem. He starts out with the load that the column must carry and the length of the column. He wants to know what cross sections of the column would give him the desired strength. He is interested in the relative weight and other characteristics of different columns that would be satisfactory to meet the required strength. If one uses the chart of Fig. 1, such answers are difficult to obtain and there is no assurance that an optimum has been found. It is quite practical, however, to replot the data of Fig. 1 in the form shown on Fig. 2. Strength per unit area is plotted against strength divided by the square of the column length. The family of lines are for

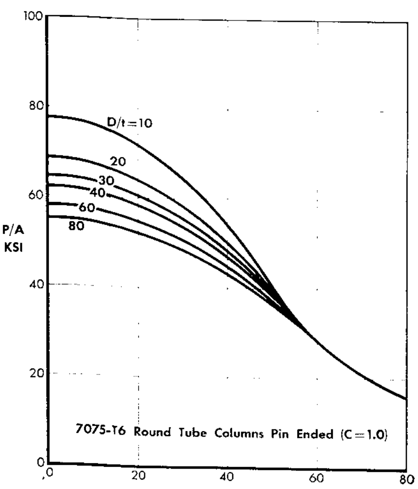

Fig. 1 Research and analysis method for the presentation of the strength of 7075-76 columns.

Presented as Preprint 64-533 at the 1st AIAA Annual Meeting, Washington, D. C., June 29–July 2, 1964; revision received May 24, 1965.

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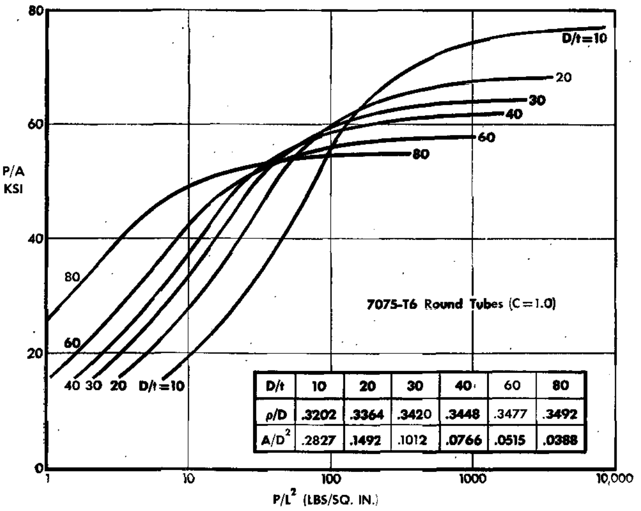

D/t	10	20	30	40	60	80
ρ/D	.3202	.3364	.3420	.3448	.3477	.3492
A/D²	.2827	.1492	.1012	.0766	.0515	.0388

Fig. 2 Design and synthesis method for the presentation of the strength of 7075-76 columns.

different thickness-diameter ratios. By the use of this chart, the designer can start with the required strength and length of the column and read immediately the load per unit area which a tubular column can carry as a function of thickness-to-diameter ratio. The cut-and-try process is almost entirely eliminated and, since the ordinate is a measure of the weight per unit of load, the data can be interpreted directly to find the lightest possible tube. Thus, the chart of Fig. 2 is particularly useful in synthesizing a design. It is a synthesis and design chart as contrasted to the analysis and research chart of Fig. 1. Synthesis or design is the art of choosing a design that, when analyzed, will be found to have both required and optimum characteristics. Design involves the use of engineering data plotted in entirely different forms from that normally found in analysis and research textbooks. Design or synthesis is an art that involves traveling through an engineering process in an entirely different direction from that involved in research and analysis. It is the art of traveling in this design direction that the author believes can and must be taught to all potential engineers at the earliest possible time in their lives. The thought habits involved in synthesis or design are entirely different from those involved in research and analysis. They are very stimulating to those who have been fortunate to experience them.

Synthesis

Figure 3 is one of many similar drawings that can be found in every aircraft drawing room in the world. Aircraft design is the art of pulling all the various specialties into a single design that is a compromise of all the specialties but with each optimized as much as possible yet still meeting the goal of a complete aircraft utilizing today's knowledge and within the available budget and schedule. This paper is directed toward the problems involved in reaching this central compromise. This action of moving toward a central optimum compromise decision is the fundamental process of aircraft design.

Engineering Matrix

Figure 4 is an attempt by the author to diagram some of the very complex relationships involved in a modern engineering department. In every engineering department there is a traditional debate over project orientation vs functional specialty orientation.

There are certain functions that must be accomplished to complete any particular design job. On Fig. 4 along the diagonal line from the upper left to the lower right labeled

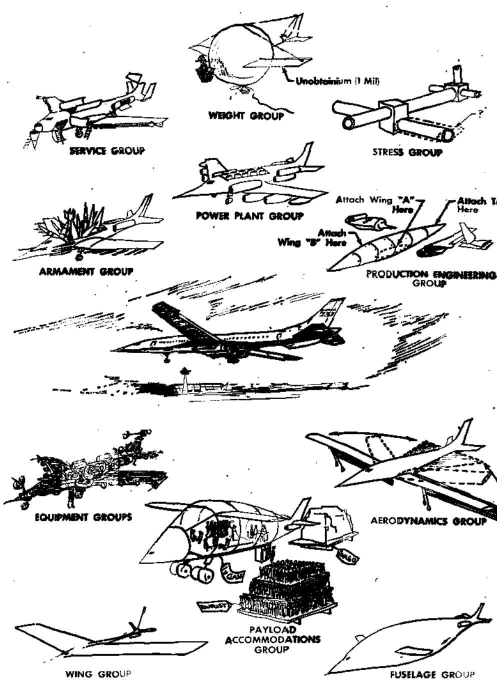

Fig. 3 Various special outlooks on design that are synthesized into a complete aircraft design.

"project A" some of these functions that must be accomplished in order to get the job done are listed. These are such functions as systems engineering, cost and schedule management, design and release of drawings and specifications for all parts of the aircraft, aerodynamic design, powerplant and aircraft performance, described here as flight technology, structural technology, electronics and physics, electromechanical component design, flight testing, laboratory testing, reliability assurance, maintainability assurance, as well as the numerous functions involved in housekeeping and management of a program.

Figure 4 is not an organization chart. It is not drawn with the intention of indicating that all of the functions along a project line would be accomplished within a project organization. This chart is an indication of the functions that must be accomplished in order to get the job done. Normally an engineering department will be carrying on more than one project, and a second project is indicated on Fig. 4 as "project *B*." Most of the same functions will be required for project *B*. Another function accomplished one way or another within every engineering department is that of preliminary design. It is required for the future growth of existing projects and for the planning of new projects. This is indicated on Fig. 4 by a third diagonal line labeled "preliminary design" and by the specialty labeled "new look" on each project. Not all of the functions of an engineering department project will be required to accomplish the preliminary design function. Here, again, Fig. 4 is not intended to represent an organization chart but rather is an indication of the functions that must be accomplished to get the job done. Another function usually accomplished within an engineering department is the conduct of research that brings the engineers up to the state of the art and also advances the state of the art. Research is not necessarily going on in all of the functional specialties shown in Fig. 4 but certainly is common in many of them as is indicated in this figure. These activities of multiple projects, preliminary design, and research are usually going on at all times within an engineering department. On occasion, an engineering department will engage in a major effort of proposing a new piece of business. These major efforts are usually on an ad hoc basis and are indicated on Fig. 4 along the line labeled "proposal team *C*."

An additional set of diagonal lines from the lower left to the upper right have been drawn on Fig. 4 through the functional specialties and are so labeled. Thus, it can be seen that, within an engineering department, there will normally be a number of projects, proposal teams, research, and preliminary design functions that require the accomplishment of similar functions. On Fig. 4 the size of the circles at the crossing points might represent the size of the activity at each point in the matrix. A successful engineering department is one that has faced the following two tasks: 1) organizing their functions on project lines so that each project is accomplished to perfection and 2) organizing so that the best that is known within each functional specialty is applied to each project on a timely and economical basis. It is required that all the different functions be coordinated along project lines and that many of the functions be coordinated across the projects on a functional basis. These projects must also be coordinated with the specialty research efforts. It can be seen that coordination along the project lines on Fig. 4 is on the basis of design, synthesis, and project. Coordination along the functional lines is on the basis of analysis, research, and function. These two basic directions of analysis vs synthesis, of project vs function, of research vs design are shown by the large arrows on Fig. 4. The big challenge of an aircraft design organization is to operate freely and competitively along both directions of the matrix of Fig. 4. Successful engineering organizations are characterized by clear-cut assignments of responsibility for both functions and projects with two lines of responsibility held equally accountable for proper performance at any point on the matrix.

The activities of the AIAA are divided between design, research, and analysis. Of the 34 technical committees under the Technical Activities Committee, 6 are directed toward the design of vehicles and engineering management, 1 is directed toward vehicle operation, and 27 are directed toward specialties. From the point of view of the aircraft or missile designer these 27 specialties are strictly research and analysis activities. Among the 27 research and specialty oriented committees are a number that direct their efforts to both research and the design of components such as aircraft engines, rockets, etc. The activities of many of these committees suggest that their predominant interest is in the research and analysis side of the specialty rather than in the design of components. The publications of the AIAA have shown a similar emphasis on research and analysis. The engineering educational institutions of the world direct most of their attention toward the research and the analysis function and ordinarily give little attention to developing design abilities in their students. The author recommends design and synthesis as a field offering even greater satisfactions to the individual than research and analysis.

Systems Engineering or Design Integration

The second item listed on Fig. 4 under each project is that of systems engineering. This title, systems engineering, is not well understood and is used by various people to describe a wide variety of different engineering activities. For the purpose of this paper, the author is using systems engineering to designate that engineering synthesis and design function that pulls the many functions, specialties, and technologies of the engineering arts and sciences together to define the over-all product and the technical procedures required to bring it into being. This function is seldom given organizational

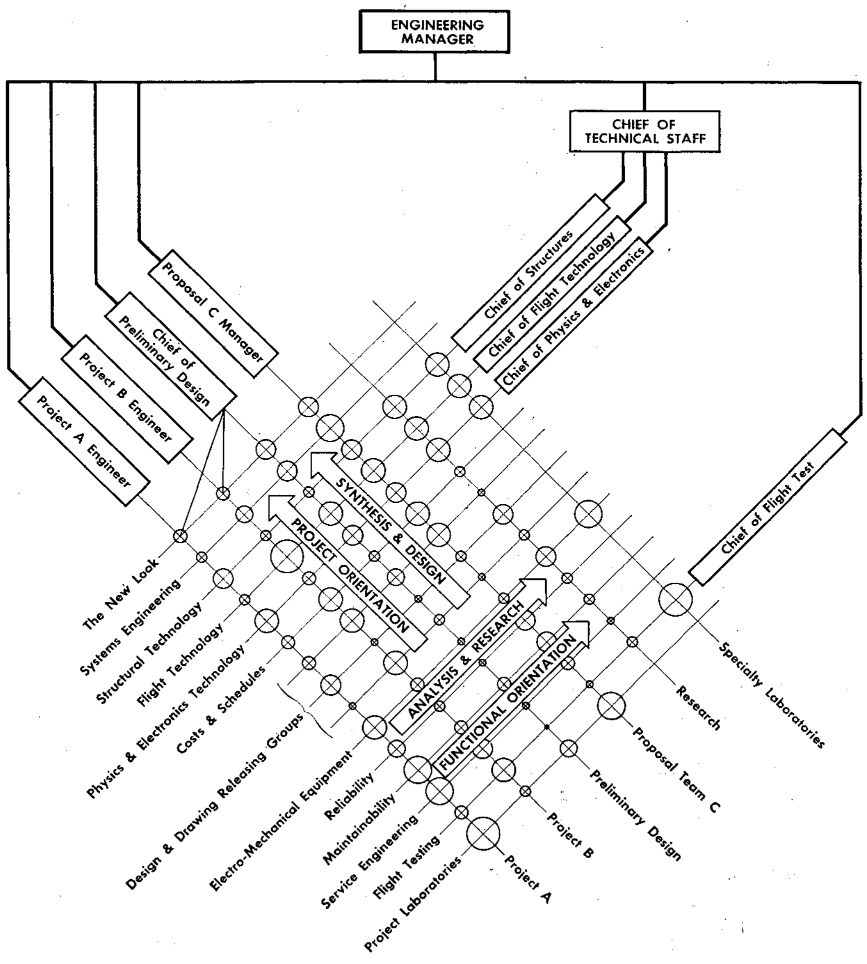

Fig. 4 Engineering matrix: some of the functions, projects, and relations found in the design operations of an engineering department.

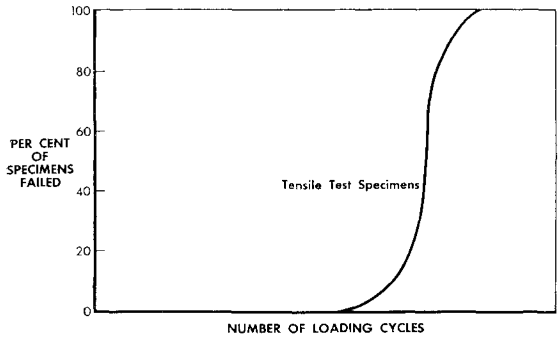

Fig. 5 Statistical fatigue characteristics of identical test specimens tested under identical conditions. (Many functions and organizational lines are omitted for simplicity.)

status on an engineering department organization chart. Ordinarily the function is accomplished by the principal design supervisors working together as a team. Several examples might help to clarify what the author means by system engineering.

As the first example, the next few paragraphs will describe the over-all problem the designer team faces in planning a structural design program that gives a safe, reliable, and maintainable structure. One of the major challenges to the aircraft designer in 1964 is to get a better understanding of, and design procedure to handle, the over-all problem of safety, reliability, and maintainability of aircraft structures. An increasing awareness of fatigue problems is going to require some reorientation of structural design procedures. A structural or materials research engineer sometimes plots the results of his research on fatigue in a manner such as shown on Fig. 5. This is a plot on a statistical basis of the test results of many identical tests of identical fatigue test specimens. All of the specimens are tested under identical loading conditions, and the data show the spread in the number of cycles at which they failed when tested under these identical conditions. A designer must acquire test data such as Fig. 5 for different loading conditions and for different materials and choose the materials and design of a structure that will give adequate service experience when flown under the service conditions of the customer. This is systems engineering and requires that the designers learn a great deal about the conditions under which the aircraft will be operated. The great nightmare of the structural designer, as well as the airplane operator, is the possibility that some major element of structure will fail due to fatigue without first giving inspectable warning of distress. Engineers like to talk about "Fail Safe" and use this concept to suggest that the structure will still be able to carry on with its normal load carrying functions for a reasonable period after a failure. Actually, Fail Safe has little or no meaning unless the operator can and does inspect the structure and learns of the initial failure. Thus, Fail Safe is intimately connected with inspection procedures. The design of the structure must be such that important failures are easily detected and become obvious to the relatively uninitiated. This is the only way to keep them from becoming major safety of flight items. Brittle fracture is a very unwelcome characteristic in such a structure, but many of the materials being used today exhibit brittle fracture. Brittle fracture starts in many materials with crack lengths that are so short as to be uninspectable. These cracks can be hidden under rivet heads, lap joints, etc. Operators seldom operate a single aircraft and the procedures used in fleet operation and maintenance have a major bearing on the safety, maintainability, and reliability record of the aircraft structures. If the aircraft operator has a practice of thoroughly inspecting, and on occasion tearing down, his high time aircraft, he will find many of the incipient failures as cracks before they have come to total failure.

The aircraft operator does not operate in accordance with the rules indicated on Fig. 5, but, rather, plays an entirely different game with himself. His game is to look for cracks and other indications of distress. He hopes that these inspections will advise him concerning when his first test specimen is approaching its failure point. Then he will either reduce the loads being applied to all of the specimens or will replace or strengthen the specimens as they approach a certain number of test cycles. His game is to prevent any of the specimens from failing and to learn from observing the specimens how to do this. Obviously, the objective is to do this under circumstances of minimum cost and maximum reliability. This must be done without disrupting operating schedules. Unscheduled maintenance must be avoided if at all possible. The aircraft operator's problem is better represented on Fig. 6 where the cost in dollars per flight hour of maintaining the structure is plotted against the total hours on the aircraft. The research engineer starts with the assumption that there is a close relationship between Figs. 5 and 6. One must ask whether the fleet maintenance cost and the reliability deteriorate suddenly with increasing life as would be inferred from Fig. 5, or whether the aircraft fleet operator finds a way to operate his fleet of aircraft such that fleet maintenance costs and reliability improve regardless of the life of the aircraft. Since the majority of materials used in aircraft construction have a fatigue life, as indicated on Fig. 5, it is obvious that some portions of the structure must be replaced or strengthened somewhere along in the life of the airplane if the aircraft life is to be extended indefinitely. The systems engineering design problem then is concerned with whether these particular fatigue and Fail Safe points in the structure can be determined without jeopardizing safety and reliability and whether the structure can be repaired and maintained at full strength without causing an increase in fleet maintenance cost as the age of the aircraft increases. The aircraft designer must synthesize an aircraft that can be inspected and maintained so as to give safety, reliability, and low maintenance cost regardless of the fact that he is working with materials whose characteristics are expressed on Fig. 5. The problem cannot be completely solved by designing for low loads since lightly loaded specimens also fail. A structure that cannot be inspected is certainly not very safe. Frequently such uninspectable structures cannot be repaired at a reasonable cost. Lengthy unscheduled inspections can do just as much damage to operating reliability as unscheduled maintenance and, thus, the aircraft designer must work the entire problem of designing a structure that can be inspected, that has adequate strength after cracking until it has shown inspectable distress, and that can be maintained at low cost to original design standards. The aircraft designer has the challenge of finding a way to assist the operator in defeating the fundamental characteristics of all materials. Accomplishing this goes way beyond the responsibilities of the structural designer, the structural analysis engineer, or the structural test engineer. The designer must be active in the operations and maintenance procedures of the operator. The task of planning and coordinating the design team so as to provide a Fail Safe, inspectable, maintainable, repairable structure is part of systems engineering. Systems engineering is the pulling together of many diverse functional specialties to come up with a suitable design.

As a second example, the competitive aspects of systems engineering will be described. Systems engineering is a major activity during the preliminary design and competition phases of new aircraft. During this phase of design, the designer is very attentive to the operator and finds such matters as schedule, cost performance, availability, reliability of components, and a host of other matters most important in his choice of the principal design features of an aircraft. After an aircraft has been placed on contract, the pressures requiring the accomplishment of systems engineering are much less direct. Sometimes they are so indirect that little systems engineering gets accomplished. The author believes that this is frequently the underlying reason for contract cancellations. When selling to commercial airlines, systems engineering is of utmost importance since the customer has an opportunity to gradually shift his business to your competitor if you are not doing a good systems engineering job for him. With a military customer, there is likely to be less warning of dissatisfaction on the part of the customer and, if the systems engineering job has not been accomplished diligently, a contract cancellation is likely and can come as a great shock to management. The author believes that those charged with systems engineering for a project can and should be expected to be diligent in keeping track of competitive systems and available design improvements as required to keep their product sufficiently attractive to the customer that the contract is not canceled.

A third example of systems engineering relates to make or buy decisions. Source selection matters are of utmost importance in good systems engineering. The aircraft designer is always faced with the question of whether he should use some product available from a component manufacturer or whether he should try to build a better one himself. There is a large gray area in which aircraft companies and component manufacturers overlap. This includes many mechanical items such as hydraulic and mechanical actuators and a substantial portion of the more routine types of electronics. A major challenge for the systems engineer is to choose an acceptable and quality source for his components whether it be in-house or from some particular manufacturer. Many an aircraft has become unsalable because it was not available with some preferred powerplant or some other preferred feature that the aircraft company could not offer because of inadequate attention to make or buy and source decisions in their systems engineering. The systems engineer must have great freedom to choose the optimum system without regard to who makes it if he is to come up with a fully competitive product. Frequently there are major conflicts of interest involved in this matter and aircraft design management must bend over backward to be sure that adequate attention and freedom is given in this matter. This is also systems engineering.

Structural Technology

Historically speaking, structural technology was the first specialty technology to be given separate organizational status in most aircraft companies. This organizational recognition of the importance of structural integrity usually takes the form of having an individual who is charged with responsibility for the structural integrity of the structures designed by all of the project organizations but who reports directly to company engineering management rather than through the project management. The structural technology or structural integrity organization covers such subjects as strength, the estimation of applied loads, the structural test, the flight test of the structure, and the vibration characteristics of the structure, including flutter and dynamic loads. The proper choice of materials is also a structural technology responsibility. Some of the principal technological subjects of interest in structural technology today lie in the following areas: 1) the application of modern metallurgy to the choice of materials; 2) a better understanding of fatigue; 3) the degradation of strength of structures with age and usage; 4) the difference between time limited parts and inspection limited parts; 5) crack growth, brittle fracture, and the design of Fail Safe structures; 6) the design of inspectable and repairable structures; and 7) the design of structures with high damping of all response modes.

Flight Technology

Flight technology includes the subjects of aerodynamics, powerplant performance, and the dynamic performance of an aircraft. Flight technology is usually of very great importance during the competitive phases of a product competition and also carries major responsibilities during the design and flight proving phases. Big things are happening in aerodynamics in 1964. Means for providing boundary-layer control to prevent separation are now available and are being recognized in design efforts. Laminar boundary-layer control is being used to achieve drag reduction. The current competition on supersonic transports is opening up new vistas in the lift and drag characteristics of large supersonic aircraft. Variable sweep wings and other forms of variable geometry are getting increased attention and are opening up new opportunities for better aircraft performance.

In the field of powerplant performance, increasing attention to high turbine inlet temperatures is opening up great opportunities in over-all aircraft design. Engines are now being optimized to provide good performance at a number of different design points. Specific fuel consumption and engine weight are coming down. The aircraft designer is learning to deflect the thrust of his main propulsion powerplant and to use special jet engines for lift purposes only. The noise produced by a powerplant is subject to much study and great improvements in engine noise are likely. The failure characteristics of modern turbine engines are so good that new standards for aircraft performance following engine failure are likely to evolve. The first evidence of this evolution will probably be seen in the provision of more redundancy on the engine in those engine parts that experience has shown can cause sudden failures. With redundancy applied to these common failure points, still higher aircraft standards of safety with simpler engine installations are likely.

The author includes many phases of dynamic aircraft performance in his definition of flight technology. The response of an airplane and its autopilot to rough air is an example. The flight technologist is providing increasingly better pilot handling characteristics by the application of artificial damping and by other modifications to the dynamic systems of the aircraft. The flight technologist takes responsibility for all of these and insures that an aircraft can be directed along desired flight paths whether chosen by the pilot or by an automatic navigation or landing system. This includes the dynamic characteristics of all of the servos involved in the flight control loop. The flight technologist takes responsibility for proper consideration of the man as a part of the feedback loop and also of man as one of the servo systems controlling an aircraft. Great improvements in the dynamic performance of aircraft are immediately available.

Physics and Electronics Technology

The fields of physics and modern electronics technology are developing very rapidly. The managers of physics and electronics technology have the responsibility to bring to each new project a proper understanding and use of all of the developments in their field and to be sure these are integrated into the over-all system. Tremendous developments are

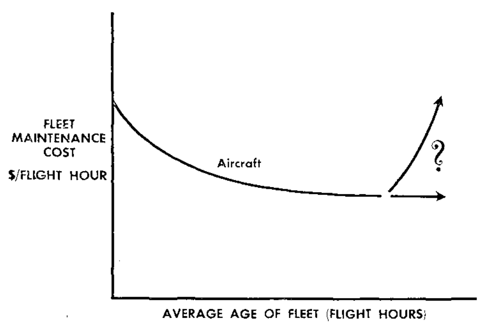

Fig. 6 Fleet maintenance costs as a function of the average age of aircraft in the fleet.

going forward in this area at this time. The development of adaptive circuitry will provide for immensely improved performance of many electronic systems and, in addition, will provide for greatly improved reliability. One of the adaptations that adaptive circuitry can provide is for self-healing of failures and improved reliability from redundancy. Major improvements in Fail Safe and reliability characteristics of electronic equipment can be expected in the next generation of aircraft. Developments in pattern recognition, in microelectronics, in servos, in navigation systems, in sensors of all types, including lasers, radars, low light level television, optical systems, and cameras, offer many opportunities for improved aircraft performance. There will be reliable blind landing systems. Devices will see clear air turbulence ahead of us.

Electromechanical Equipment

Electromechanical equipment continues to be one of the most important elements of an aircraft design. The reliability, maintainability, and functional capability of modern electromechanical systems are better than those of the past. However, opportunity exists for an order-of-magnitude improvement.

Very special efforts applied to several recent missile systems have demonstrated at least two orders-of-magnitude improvement in the reliability of electromechanical systems. The aircraft designer has the challenge before him to accomplish an equivalent improvement in the electromechanical systems of his aircraft. To accomplish this, he must go back to fundamentals and establish entirely new standards for such things as wiring, electrical connector plugs, hydraulic system connectors, the number of such connections in the systems, access and other features to provide proper maintainability and inspectability, and the development of special ground checkout equipment. He must formalize his analyses and tests so as to insure that failures caused by wear, friction, lack of lubrication, brinelling, gear loads, etc., all get the attention that is required to have components where failure is not expected. All too often the failures we experience in our electromechanical equipment are just exactly what we would expect and, in fact, what we have already encountered in our laboratories. The next generation of aircraft will be designed with greatly improved standards for these components. The aircraft designer will look inside the black boxes and satisfy himself concerning the probable success of the hidden design features, whether he makes the item himself or buys it from others. The aircraft designer will be increasingly less prone to explain the first of a series of identical failures as an "isolated incident." If the aircraft designer could find a way to treat every isolated incident as the first failure of an epidemic, he could provide tremendous improvements in the reliability of his electromechanical systems. This will require new standards for feedback of difficulty information from service, laboratory, and flight test.

Designing Groups

Time and space do not permit describing either the functions or the opportunities for future growth in all of the various groups shown on Fig. 4. Each group and its function are as important to the whole as any other group. This paper is directed to the integration of all of these functions and specialties. Forecasts within each specialty or engineering function cannot be made in this paper.

Systems Engineering

Aircraft design is the synthesis of technologies into an aircraft that, when analyzed and tested, can be shown to have the required characteristics and that is optimum in terms of availability, cost performance, and competitive features. On Fig. 4 the author has shown systems engineering as being a separate function. Systems engineering is the action of planning and integrating the whole aircraft. The systems engineering described here is a function to be accomplished by the organization as a whole. The author does not believe that very much organizational status can be given to the accomplishment of this function. The author believes that the various design and specialty groups are best prepared to know what can be done within their own specialty and that no central group separately organized can know as much about any one specialty as the specialist himself. The only way to bring the best that is known in each specialty to the systems engineering function is to have these specialists work together to accomplish the systems engineering function. They must also work within their own specialties to accomplish the tasks that they collectively have outlined for themselves during their collective systems engineering effort. Good systems engineering can be accomplished only by the collective efforts of the supervisors of the groups that will carry out the work. Whenever any significant portion of the specialty design decisions are directed from a central systems engineering group rather than by a concurrence of responsible supervisors, the author expects to find mediocre design, standards, performance, and morale.

This raises a question concerning the status of groups such as the structural technology group and the working relations of the man charged with structural integrity responsibility in the engineering department. A parallel exists within other specialties such as flight testing, flight technology, cost, schedules, etc. The author believes that a cross-checking, double-responsibility system is the only practical scheme to accomplish the objectives of a modern engineering department. The functional specialist chiefs must take responsibility that adequate standards for performance in their specialty have been established in each project. They must take responsibility that people are assigned to each project as required to meet technical standards, schedules, costs, etc. They must hire and train people, and bring them to bear on the particular projects. They must also provide technical supervision within their specialty to be sure that standards are being met. These specialty groups must not be considered consultative or advisory. They should be the groups that do the work and the only groups that do the work. The doing groups must have a dual reporting responsibility, i.e., to the project engineer for the project and to the technical specialty chief for the technical specialty. Any time the emphasis shifts too far one way or the other, an inadequate product can be expected. An adequate balance between these two lines of reporting is an indication of a modern and successful engineering department.

Modern aircraft design is so complicated that one or more full-time individuals will be required in systems engineering to record design integration decisions and to plan for integration meetings among all of the specialty supervisors. The challenge of this central systems engineering group is to be sure that all of the various functions are being pulled together but not to make decisions. This central group must be sure that all of the features of a new design are being analyzed to stated standards. They must be sure that the design objectives, contract requirements, technical standards, design decisions, testing decisions, schedules, and assignment of design responsibilities are clearly stated and understood by all. They must be sure that procedures are being used that result in a favorable design. They must insure that the necessary development testing has been planned and is under way. They must be sure that all of the deficiencies discovered during the tests are receiving corrective action. They must insure that the testing procedures are adequate to be sure that unsuspected deficiencies have a chance to show up, be recognized, and corrected. This includes the problems of maintenance and reliability found after the aircraft is in the hands of the customer. The permanent systems engineering group must be a coordination group and not an active design group.

Modern Design

Modern design is a synthesis process. It is not analysis or research. Synthesis is the process of designing an aircraft that 1) when analyzed and tested meets stated requirements, and 2) is the optimum aircraft that does meet these requirements. Synthesis integrates the interfaces between the various specialities. It is like the shear structure between the fibers of wood. The strength lies in the fibers but the fibers have no strength without the shear structure. Synthesis is the leadership by the top specialists that accomplishes an overlapping and interweaving of their specialties to provide an optimum design. Analysis can only tell you whether the design meets required standards. Analysis cannot tell you that the design is optimum and it cannot provide the design in the first place. Good design requires adequate provision for future growth, and the designer must be held responsible for coming up with a product that has adequate growth potential. A successful design team must be aware of alternate ways of accomplishing the intended function of their product and must be flexible and prepared to reorient their design or their objectives as necessary. They must not depend upon the customer to tell them when they have failed. Modern design involves designing to accomplish good cost performance. Program evaluation review technique (PERT), PERT cost, and similar procedures are a part of good aircraft design. The designer must take full responsibility for establishing competitive costs and schedules for the design and for meeting his schedule and cost goals. Design is the establishment of proper goals and the pulling of a whole project together to accomplish these goals. Modern design 1) is technically excellent, 2) is integrated, 3) provides for design growth, 4) reorients limited programs, and 5) provides good cost and schedule management.

Subsystems

The modern aircraft designer undertakes to discharge major responsibilities in the field of aircraft subsystems. The aircraft designer's performance is judged by the total performance of the product which he puts together. The name of the individual who designed a particular part, or the corporation for which he works, or the nature of the contractual relationship by which the work is committed and paid for make no difference to the customer. In subsystem matters, aircraft design is a management activity and the aircraft designer must find ways to manage successfully the design, integration, costs, performance, and delivery schedules of all of the parts that go into making the complete aircraft, regardless of the form of the contracting that brings these activities about. In many cases a designer's success is measured in terms of his ability to get some other government supplier with whom he has no contractual relationship to produce a product that, when used on the aircraft, turns in a superior performance. Alibis are not worth very much in explaining away aircraft design failures. Regardless of the nature of the contract, the aircraft designer must take responsibility for subsystem 1) integration, 2) performance, 3) reliability, 4) maintainability, 5) costs, 6) schedules, and 7) testing. In summary, the author suggests that the keynote for aircraft design in 1964 is systems engineering of the whole product.