COMPRESSOR RESEARCH AND BLADE MANUFACTURE

Speakers: Donald J. Todd
John F. Klapproth

Our modern aircraft gas-turbine engines devour 5 or more tons of air per minute. This air must becompressed to the operating pressure of the engine by some form of small, light weight compressor. The compression process must be efficient. The demand for higher and higher flight speed requires that even larger quantities of air be used. This must be accomplished with little or no increase in engine size. Minimum compressor weight and size are essential.

The NACA, together with other organizations, has been working on the compressor problem for some time. Many ideas have been explored and appreciable progress has been made in achieving larger air-flow handling capacities with smaller and lighter weight compressors. Considerable research remains to be done in this field and, in view of the international situation, it must be done as expeditiously as possible.

Let us consider briefly how advances in compressor design are made. First, theories are developed, based on the fundamental principles of fluid mechanics, to help describe the flow of air through the compressor. These theories lead to many new blade designs. The new blade

designs must then be checked and evaluated in experimental compressors. An example of the variety of complicated shapes that have been investigated is illustrated by this array of blades. The research engineer must know to the highest degree of accuracy howwell his theoretical blade shapes have been translated into their metal counterparts.

Many times, theoretical considerations of new ideas lead to blade shapes that are quite unconventional. This mixed-flow impeller, for example, was designed to overcome the disadvantage of the large diameter of the centrifugal compressors. Frequently ingenious machining techniques are required for accurately reproducing the desired rotor configuration.

Our research usually proceeds from point to point as theories or concepts were built up. For example, a supersonic compressor may yield pressure ratios of 6 or possibly even higher in a single stage. The attainment of this performance is largely dependent upon the efficiency of these stator blades. They must diffuse the high supersonic velocities leaving the rotor. Their performance is very sensitive to small changes in geometry of the flow passage or the shape of these blades.

In developing these stators, information obtained in one set of blades is usually applied in the design of successive blade rows. If it required months to fabricate each stator row, the ultimate development of this compressor would require years to complete.

Even after new compressor type has been developed to the point of being feasible for application in the engine, considerable work remains to be done. Information on the effect of systematic variations in the geometry of the compressor must be compiled. This information is required to enable the designer to apply the idea in his particular engine. For example, the transonic compressor when used as an inlet stage of a multistage compressor is capable of increasing the air flow capacity to 130 percent of its present day values, this may be accomplished without increasing the size of the engine. Before the transonic compressor can be used to improve the performance of our jet engines, investigations on a number of related blade shapes must be made.

In summary, I would like to emphasize that the realization of our compressor research aims and our turbine-cooling objectives which will be discussed later today depend to a large extent upon our blade fabrication cleverness. We must obtain a large number of different blade shapes, each of which may present a unique fabrication problem, in a short period of time, and at a reasonable cost. By the use of the latest machine tool techniques and by the application of calculating methods or electronic brains to duplicating equipment, the NACA has been able to continually improve its blade fabrication process.

Our next speaker will describe some of the methods and techniques presently being applied to the fabrication of experimental blades for our research work.

BLADE FABRICATION

Speakers: Bob W. Sheflin
Frank L. Cimperman

The previous speaker has shown why the research scientist needs a quick and accurate check on his compressor design theory. What I should like to do is to explain how experimental blades are produced. First, I would like to point out that I will not be discussing production methods, but rather tool room techniques. The reason for this is found in the quantity of blades ordinarily produced of any one type. Our usual blade order is for 6 to 100 blades and since we are serving a research organization, repeat orders are never received.

Now let us suppose that the design for a blade of this type is given to us, and it is requested that we produce 36 of them and install them in the rotor of a single-stage research compressor.

Now this blade is tapered both in thickness and in chord. The camber varies from root to tip. The blade is twisted and the angle of twist does not change uniformly from root to tip, and to further complicate the problem, the blade is so thin that cutting forces easily deflect it. In this case, dimensions for the shape of the airfoil are specified at five different stations. It is found that a

block of metal such as this is the smallest from which the blade and its base can be cut. Our problem then becomes one of how to remove all of this excess metal, controlling our cut so as to produce smooth contours blending into each of the specified sections, and remembering the 2/1000th of an inch tolerance, always cutting deep enough but never too deep.

May I point out that in developing processes to take care of this and other problems, we can place no limitations whatsoever on the ingenuity of the designer. We must also keep in mind that since we seldom produce more than 100 of any given type of blade, our tooling costs must be kept to a minimum. The diversified application of our product also complicates the problem. In this exhibit are represented blades used in wind-tunnel compressors, 72-inch research compressors, 14-inch research compressors, turbines for aerodynamic research, turbines for cooling research, and other types. Some of these blades have been made from aluminum, some from mild steel, some from heat-treated steel, and some from heat-resistant alloys.

Manufacturing processes represented include investment casting, sheet metal forming, die casting, and machining. This impeller was cut from a solid forged blank.

In the past few years, many blade-making processes have been developed and quite a few are in use at this laboratory. I would now like to show you a short movie

giving the high points of one of our processes by which blades of this general type are made.

This blade is for the rotor of a single-stage research compressor. It is tapered in thickness but not in chord, and is twisted non-uniformly from root to tip. It was specified by five radial stations, templates for which were laid out on this machine. Each point defining the airfoil shape is laid out as a cross on a brass plate. When completed the points are connected by a solid line and a second line 1 inch outside of the specified contour is scribed onto the template. The template is band-sawed to the outer line. It is perhaps apparent that all of the layout lines have been exaggerated for clarity in this film. When the band-sawing is completed, the contour is machine-filed to the center of the line. One of the reasons for the line 1 inch outside of the specified contour becomes apparent in the next scene.

The holes which determine stacking arrangements and twist fall outside the specified contour, but well within the outside contour. This template, and others are assembled as shown here, and plastered in several steps. This master, as we call it, is not tied together with plaster until the first coat, being applied here, has had time to set. A second coat ties the master together. A final finish coat is later applied and faired carefully with flexible splines to produce a finished master.

The airfoil section of the blade is cut directly from this master in the 4-inch airfoil machine. Here the master is being installed in this machine. The master at this point is six times size and has a 1-inch envelope all around. The follower wheel has a radius 1 inch smaller than six times the cutter radius. This size difference compensates for the 1-inch envelope on the master. The follower wheel and cutter are connected through a pantograph linkage of 6:1 ratio, and the stock, the end of which is painted orange in this case, is fed axially through these jaws at the same time the follower is fed axially along the master. Close tolerances are conveniently held with this machine because of the enlarged master, mechanical duplication and support of the stock very close to the cutter.

A series of short scenes are shown with the blade in various stages of completion, so that you may see the progress of the work in this machine. You will note that the blade stock rotates continuously while the cutter rocks back and forth as controlled by the master. When removed from the airfoil cutting machine, a base is generally machined on the blade. One of the simplest types, a bulb base, is being machined here in a vertical mill with a form cutter. You will note that the airfoil section of the blade has been cut down to a horizontal line. The rotor disk in which the blade is to be mounted is tapered. It is therefore necessary to contour the blade at this point as shown here. This root-fairing operation is done in a milling machine equipped

with a manually controlled duplicating attachment using as a master a blade which has been worked down by hand to fit the rotor. The root fairing operation is proceeding here.

The blade at this point is normally completed by abrasive belt polishing, filing, or a high-speed burring operation which is being performed here in a pantograph. The setup you see here utilizes a carbide burr running at grinding speeds on a special vibration-free spindle. The pantograph on which this operation is being performed represents a convenient means of conducting our experiments, but it will be replaced by an automatic machine in the near future, particularly since a special master is required for the pantograph. (Movie ends.)

The completed blades are mounted in the rotor and located in the proper axial position. The ends of the blades are turned down to the proper outside diameter, and the excess stock on the end of each blade base is turned off flush with the rotor.

You have just seen the major steps in one of our blade making processes. In the movie, the airfoil section of the blade was cut on this machine; a development of the NACA. At the other side of this exhibit is a much larger machine of this type. In addition to these machines, we also cut blades on Cincinnati hydrotels, duplicating planers, duplicator-equipped milling machines, and on this machine which I will tell you about later. The characteristics of each of these machines makes them especially well adapted to certain blade types.

I have talked thus far about machines and processes in use at this laboratory for some time. May I now show you some equipment which shows considerable promise for further reducing the labor involved in making a set of blades.

As previously mentioned, designing new compressor blades is a science and occasionally the research engineer will combine mathematics with layout techniques to get a new design. The result is a large-scale drawing of the new airfoil section which he wishes to use. Our old method of reproducing the blade required us to accurately measure the curvature of the airfoil section with reference to horizontal and vertical lines. The points were then replotted on a template as shown in the movie. In order to eliminate this tedious work, the NACA has developed a method by which a layout is originally made 20 times size on paper-backed aluminum foil (hold up sample). This large-scale template is mounted on this turn table and a small metal template is cut from a stock mounted on the turn table of this milling machine. An electro-mechanical duplicating system, consisting of this tracer, these gear boxes, and this electronic equipment, controls the motions of the milling machine to automatically cut the small template. The outline of the template cut here accurately represents one section of the new blade to be cut.

This is a sample of the kind of template cut on this machine (hold up sample). It is somewhat larger than the one being cut now. These templates are assembled on a shaft and this assembly (exhibit assembly) becomes the master pattern for the blade cutting machine which you see here.

This unusual machine was developed by the New England Special Machine Company. From these templates, it machines the complete airfoil part of the blade. It automatically fairs between the stations established by the templates and it cuts a twisted blade from an untwisted master. The method for accomplishing this is difficult to explain in detail, so let me just cover some of the principles of operation. As I have said, these templates form a master pattern. The space between the templates is spanned by a very thin metal strip, which is bent to the spanwise curvature of the blade by these light mechanical followers. The most important feature of this machine is an electronic duplicator, the tracer of which follows this metal spline without actually touching it. Therefore, the fairing between the templates cannot be affected by the follower. Let me demonstrate the sensitivity of this duplicator. With this piece of foil from a stick of chewing gum I will move the cutting head of the machine in and out. This is not a large motion, nor is it very fast, so I would like to place this paper cup on the carraige to help you observe the motion. If I were sufficiently steady, this piece of foil would never touch the tracer.

The machine introduces twist by simply changing the angle between the master and the blade during the cutting. Another interesting feature of this machine is its ability to follow a finished blade, duplicating it or producing a new blade with a different rate of twist. Completed blades are checked in the next machine. As a blade passes between these probes, suitable linkages within the machine cause these light beams to indicate the position of the probes. The lights will now be turned off and a blade will be put through the measuring process. Observe the lights on this scale, their motion is proportional to the displacement of the probes. The blade has now passed through the probes and a complete record of blade shape at one section has been produced. This is a sample of the chart produced. It is a 20-times size reproduction of the blade section measured. The horizontal and vertical coordinate lines are produced at the same time that the blade contour is drawn so that any paper shrinkage during developing does not affect its accuracy. The research engineer, after studying this sort of chart, is assured that his design has been accurately reproduced. At the same time that a visual indication of the blade shape is shown here, a photographic chart of blade shape is being produced within the machine, a sample of which I will show you in just a minute.

Although considerable progress has been made in reproducing the designer's idea in metal, the future looks bright for additional progress. In fact, the time may

come when large-scale layouts or large size models will not be required. Our goal is to take the mathematical description of the airfoil section to be investigated directly from computing machines. These data will be fed into an electronic bfain and the machine tool automatically guided through its required motion. The first and biggest step in this direction has already been successfully taken. The mathematicaly data describing the airfoil are set up on these dials. This information is automatically scanned by the methods commonly used in electronic computing equipment and the data are used to control the motions of the milling machine so that a template is automatically cut. Refinements are currently being made to this equipment; however, our work is far enough along for us to be confident that we will eventually be able to cut blades in metal directly from the mathematical data furnished by the designer.

These exhibits do not represent a complete process nor have they been developed to our complete satisfaction. They do, however, represent the kind of process advancement that will reduce our blade-making problem and greatly reduce the time between the design and its testing.

In order that you may spend about 5 minutes in a first-hand inspection of this shop and these exhibits, I will conclude this demonstration by starting the 14-inch airfoil machine, which is cutting an aluminum pattern for a large wind-tunnel blade.

Setup -- Blade Fabrication Demonstration

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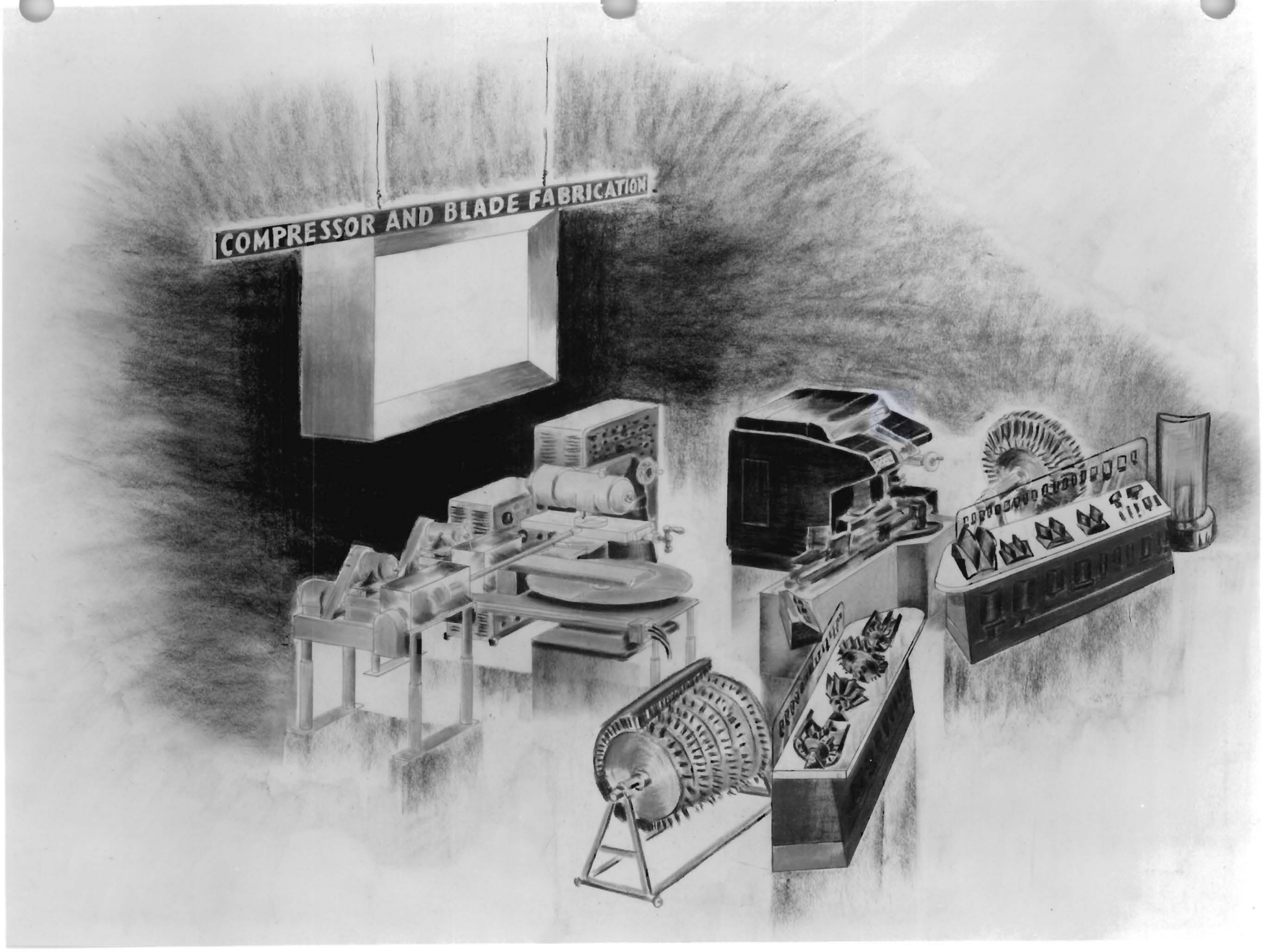

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