PROBLEMS IN AIRCRAFT PRODUCTION

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11 February 1953

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Mr. Edward H. Heinemann, Chief Engineer, El Segundo Division, Douglas Aircraft, has been interested in aircraft since he learned to fly in 1926 in a Curtis Jenny, and has been with Douglas since that date. He was transferred to the El Segundo plant of Douglas-Northrop when that Division started, and was appointed Chief Engineer in 1936. While at El Segundo he has supervised the design of such famous aircraft as the BT and famous SBD "Dauntless" dive bombers, the "Boston" and "Havoc" attack bombers for the French and British, the A-20 and A-26 "Invader" USAF attack bombers, the CG-7 and CG-8 Air Force gliders, and the TB2D "Devastator" Navy torpedo bomber. He has also been responsible for more modern service aircraft such as the AD "Skyraider," XA2D "Skyshark" turbo prop bomber, the fleet carrier A3D, the F3D "Skynight" Navy night fighter, and the F4D "Skyray" jet delta type interceptor. In 1952 he was awarded the Sylvanus Albert Reed trophy for his work with the high-speed "Skyrocket." This airplane has flown higher and faster than any other airplane in the world having reached 1,238 miles per hour at 79,494 feet. He is the author of many articles on aircraft design and is an advocate for the reduction of complexity in the aircraft industry.

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CAPTAIN HALE: Admiral Hague, gentlemen: Our speaker today, Mr. Edward Heinemann, Chief Engineer of the El Segundo Plant of the Douglas Aircraft Company, is a man who not only designs for speed, but who has designs on speed. For example, his very recreation consists of water skiing, skiing, ice skating, and speed boating, all sports which require a fineness of form and the ability to overcome drag to reach perfection.

His ability to understand the problems of form and drag won him national acclaim when he was awarded the Sylvanus Albert Reed trophy in 1952 for his outstanding accomplishment with the Skyrocket. This craft has flown faster and higher than any other airplane in the world, to 80,000 feet at a speed of 1,238 miles an hour, or 1,850 feet per second. Gentlemen, this is twice the speed of a 45 caliber bullet and about equal to that of a 75-mm cannon shell.

The El Segundo Division of Douglas Aircraft has produced many famous service aircraft--the Dauntless, Devastator, Invader, the Boston, and the AD and FD series of the present carrier fleet. Today Mr. Heinemann is famous in aircraft production circles for his stand on design for performance, for simplicity, and for producibility. Mr. Heinemann.

MR. HEINEMANN: Admiral Hague and gentlemen: It is indeed a pleasure to be with you today and I only hope that I will be able to tell you something about the problems encountered in current aircraft production that will be of interest to you.

Most of us remember quite well the many problems encountered during World War II that were so indelibly impressed upon us by the magnitude of that effort and the frantic way in which we had to find solutions for these problems. In the recent defense effort many of the same problems have reappeared, and in addition we are encountering many new problems since we are entering the second half of this century, the Jet Age.

In casting about for material, I found that there is relatively little information readily available on modern airplanes with respect to distribution of materials, use of machines, labor skills, and production time. In general, we still tend to think in terms of World War II and use factors of that time period. It has, therefore, occurred

to me that it might be well to present to you at this time a breakdown of a typical jet fighter so that you may be more familiar with the distribution of materials, manpower, production time, and so forth. First, however, it has appeared advisable to comment upon the various general problems by their common titles, or descriptive phrases. This I will do using those terms as subject headings.

As a beginning, let us talk about some of the problems that are currently the subject of so much discussion:

Long-Range Planning

Long-range planning, I am sure you will all agree, is one of the most common expressions, and one of the most difficult problems to do much about. Still it is perhaps the most fundamental and most important of our whole defense effort. It is especially difficult in the aircraft field inasmuch as manufacturing production times are so much greater in the aircraft industry than in most other fields of endeavor. For this reason, long-range planning, in my opinion, is of the utmost importance, for unless working space, manpower, materials, research facilities, and all the other functions that go to produce the finished article can be properly planned and integrated into an over-all program, the end result cannot be accomplished.

Since the time from bid invitations for a new model to actual combat involves from 5 to 10 years, it is especially important that all phases of research development and production be anticipated and planned as wisely as possible.

Working Space

In my opinion, next in the order of importance is the working facility. It was 27 years ago that I first started work in the aircraft industry. There has been no period during that entire time that I can remember where the plant or engineering department in which I worked had adequate facilities, especially adequate space. This is to be expected in a rapidly growing industry. Still, in retrospect, a great deal more could have been accomplished with more complete facilities, especially with more space.

I will be quick to admit that it would be very foolish to overcapitalize. There is always the danger of overexpansion and no one wants to be caught with white elephants in the way of plants or equipment in the event of procurement curtailment. Still, when professional engineers earning in the neighborhood of 5,000 to 8,000 dollars a year are given less than 50 square feet per man, with no reference tables and no air conditioning, they can't be expected to do their best. Compare this to the space occupied by a doctor, a lawyer, or any other professional man, or even a shoe clerk, any of which can be found to occupy 300 to 400 square feet per man.

Likewise, the manufacturing departments can't be expected to work at anywhere near peak efficiency when various airplanes are badly overlapping each other in the shop and workmen are constantly having to work around work stands, jigs, and equipment due to lack of the simple commodity of floor space.

While it is true that floor space now costs three to four times what it did during the thirties, and costs of 10 dollars per square foot are commonly quoted, especially for office buildings, I can still remember Bill Knudsen once said at the early part of the war that he didn't expect the entire facility investment to amount to more than 6 or 7 percent of the total manufacturing effort. As a check on this, the record of the El Segundo Division of Douglas has been reviewed and it is found that since Pearl Harbor the total facility investment has been only 5.2 percent of the cost of the total effort of that plant.

This is illustrated by chart 1, following page, which indicates that a 20 percent increase in facilities, for example, would make only a 1 percent increase in the total cost. This should certainly be a most important planning consideration.

Statistics are not available, but it is believed that this case is quite typical of the entire industry.

While we obviously should not overexpand or overcapitalize, neither should we provide inadequate facilities that will result in reduced efficiency. There was a time when loss of efficiency was expected to be made up by hiring more help. With our recent experiences in manpower shortages, especially in the technical fields, these inefficiencies will have a direct effect upon our production.

Material Lead Times

Material lead times, as during World War II, continue to be a major problem. After all, the effectiveness of a military operation is usually measured by its potency and availability or performance and production time. Thus, the problem of airplane deliveries is greatly influenced by material lead times.

Since lead times at present average a half year or longer, they usually account for a delay in delivery of that amount unless a large stock of materials can be kept on hand. This, obviously, is not possible with the availability of raw materials and processing time. Therefore, the designer is required to order materials before his design is complete and to fit the design to the materials ordered. Thus serious compromises are often made. Furthermore, the designer is always torn between trying to employ mass production methods, such as

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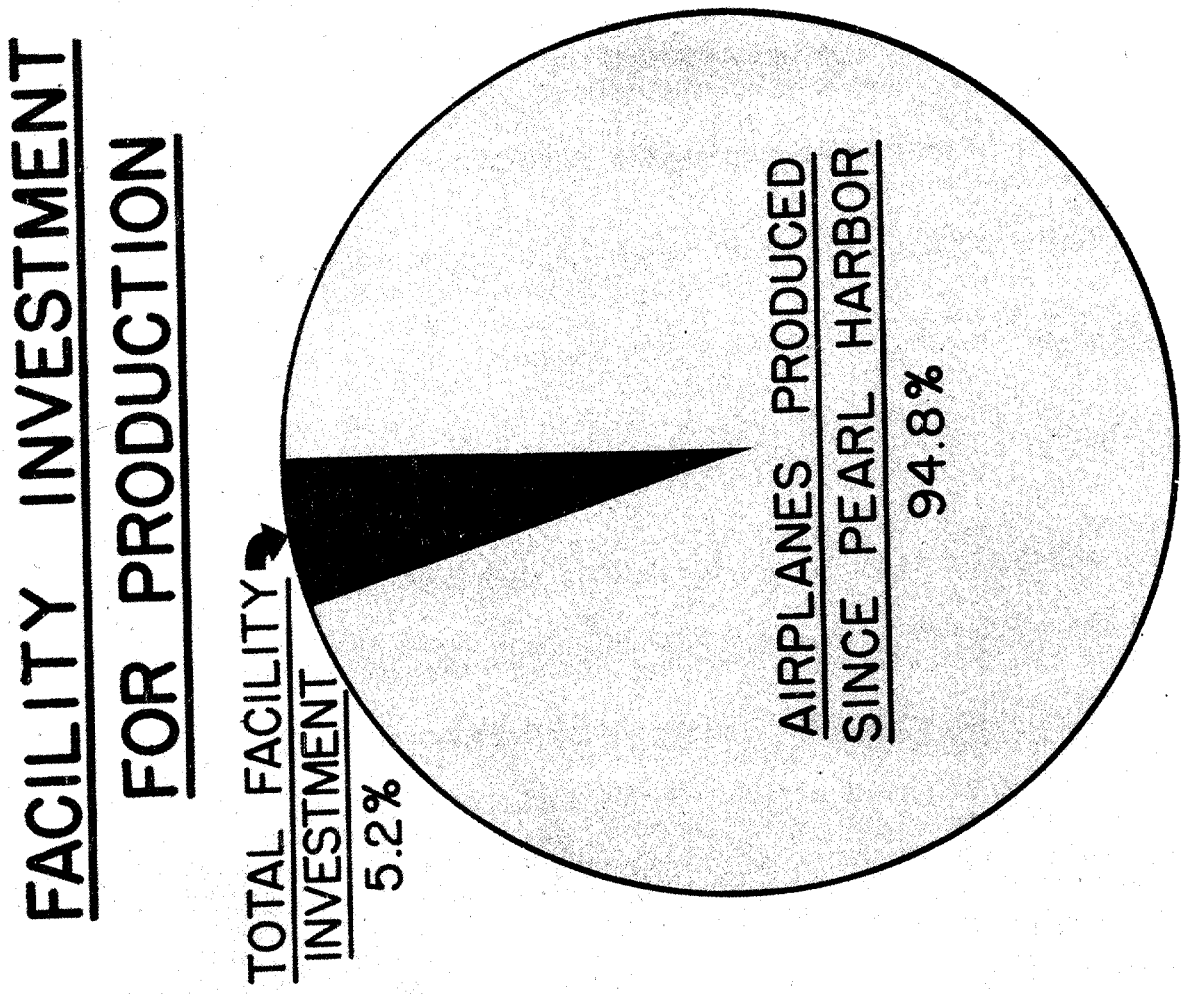

FACILITY INVESTMENT
FOR PRODUCTION
TOTAL FACILITY INVESTMENT
5.2%
AIRPLANES PRODUCED SINCE PEARL HARBOR
94.8%

the use of forgings and permanent mold parts--which result in the greatest production potential and lowest cost--and trying to use common materials, one example, such as sheet, that are readily available.

We have frequently been led astray by overdesigning for forgings where decisions were based upon relatively large production quantities, only to find that contract changes or cancellations have reduced the quantities to such an extent that the forgings were no longer economical.

There is a definite danger in becoming too extensively involved with mold or die type production methods which, during World War II as well as during the last few years, we have found to be very serious bottlenecks. Toward this end, great ingenuity to use sheet, plate, and extrusions appears to be very desirable.

Chart 2, following page, illustrates lead times on the most common material items.

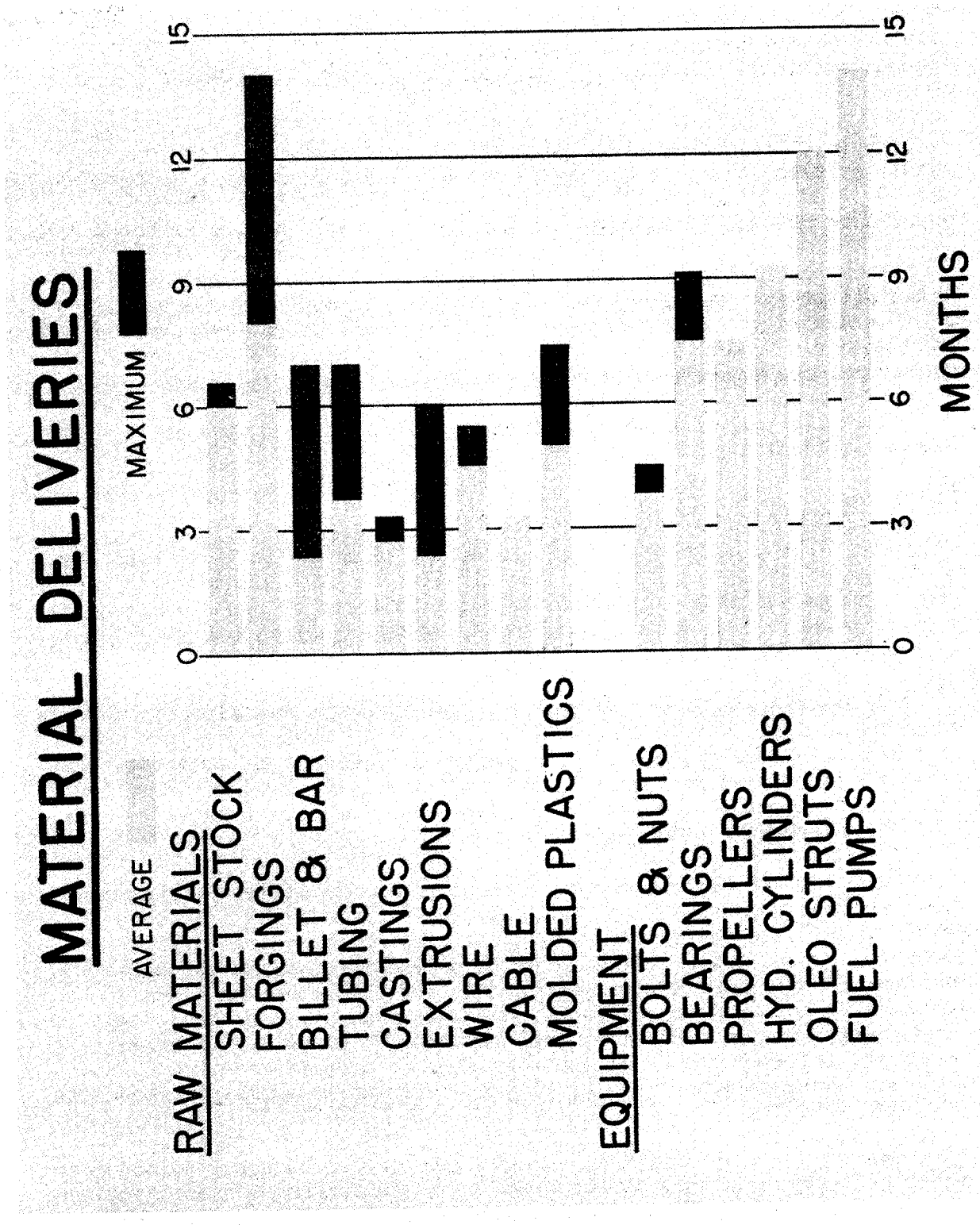
Proper use of Materials and Machines

We in this country are great faddists. Perhaps it is because our growth has been so rapid and in our lifetime we have witnessed so many new developments that we constantly think in terms of new developments. This is equally true with the engineer and the production man--in fact, everyone concerned with the business.

Whenever a new material or production method comes along it becomes tempting to rush into it in order to realize the advantages that appear on paper. In reality, the advantages are frequently not so great. The designer is, therefore, constantly torn between sticking to the tried and true on the one hand and being first with the latest so as to come out with a superior article.

There are times, of course, when new methods hit the jackpot and great strides are made. But, in general, it is believed advisable to guard against too rapid progress, especially in structural design, in order not to sacrifice integrity or to become involved in too many unknowns at one time. Frequently a construction method or a new device will appear sound on paper, but when such problems as fatigue life, intergranular corrosion, heat-treating problems due to size or shape, and many other not apparent similar problems are taken into account, the new method may actually be inferior to normal improvements of older methods.

One of the most outstanding recent trends has been the switch from sheet and extrusion type construction to large forgings, press forgings, and machined plate. If quantities were sufficiently large and the designs


MATERIAL DELIVERIES
AVERAGE
MAXIMUM
RAW MATERIALS
SHEET STOCK
FORGINGS
BILLET & BAR
TUBING
CASTINGS
EXTRUSIONS
WIRE
CABLE
MOLDED PLASTICS
EQUIPMENT
BOLTS & NUTS
BEARINGS
PROPELLERS
HYD. CYLINDERS
OLEO STRUTS
FUEL PUMPS
0
3
6
9
12
15
MONTHS

free from constant change, these new methods would no doubt reduce cost. But the quantities of aircraft now being procured leave our production in the custom-built category rather than in that of mass production. Thus, the high tooling costs for pressing out extremely large parts do not yet appear justified, although I will be quick to recommend that development along this line should continue.

Somewhere in between the older construction methods and the so-called optimum there are methods involving simple tools and simple materials that should be adequate for most construction of the immediate future. A few of these methods might be worth reviewing.

Chart 3, following page, is a typical example of a method used extensively at Douglas-El Segundo to make parts of readily available aluminum alloy plate with a minimum of tooling on a pneumatic high-speed router. This chart shows that the cost of the material and rough machining for parts constructed of five-eights plate by this method is equal to 5.22 dollars each in quantities of 600; whereas forgings would have cost 11.04 dollars each. The best feature of this plate construction is that should it become necessary to change the design by adding another lug, or to change the contour, the tooling could be changed in a matter of a few days; whereas to change the forging design might involve as much as nine months. This method is now used extensively for control arms, hinge brackets, and similar parts and has consequently released die sinking and forging time equivalent to hundreds of dies to parts where forging is an absolute necessity.

Another example, shown on chart 4, page 9, is a one-piece spar replacing a built-up spar. This particular example shows that the one-piece part weighed 48 pounds and cost 309 dollars; whereas the built- up part weighted 59 pounds and cost 426 dollars.

This lighter, cheaper method has been well proved and is now possible because of the increased billet size, capacity of extrusion and bar presses, and improved heat-treatment facilities. This method is still confined to small or medium size airplanes due to raw stock size limitations, but can be applied to the greatest quantity of airplanes being procured. Here again tooling is relatively simple and can be changed in a matter of days when necessary.

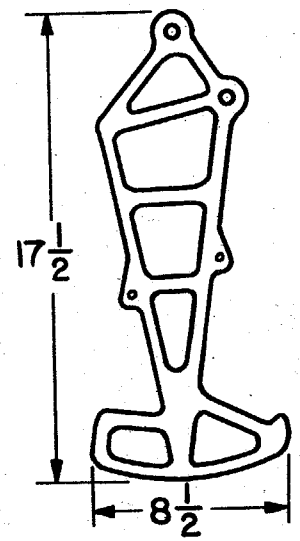
I was tempting to design this part as a press forging and the cost analysis was favorable; however, diesinking time and problems of incorporating changes resulted in a decision in favor of the milled design.

Subcontracting

Subcontracting continues to be a serious problem and a big headache. To the general public it would appear to have many advantages

PLATE STOCK VS FORGING

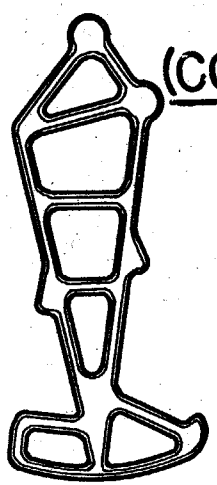
ALUMINUM ALLOY - 600 PARTS



(COST OF MATERIAL AND ROUGH MACHINING)

ROUTED FROM $\frac{5}{8}$ PLATE STOCK = \$5.22 EA.

VS



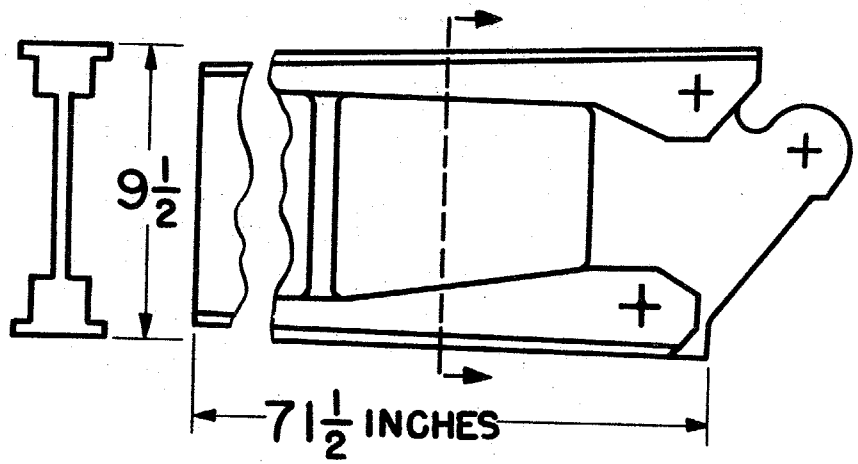
(COST OF FORGING BLANK, INCLUDING MATERIAL)

DIE FORGING = \$11.04 EA.

WEIGHT AND COST REDUCTION

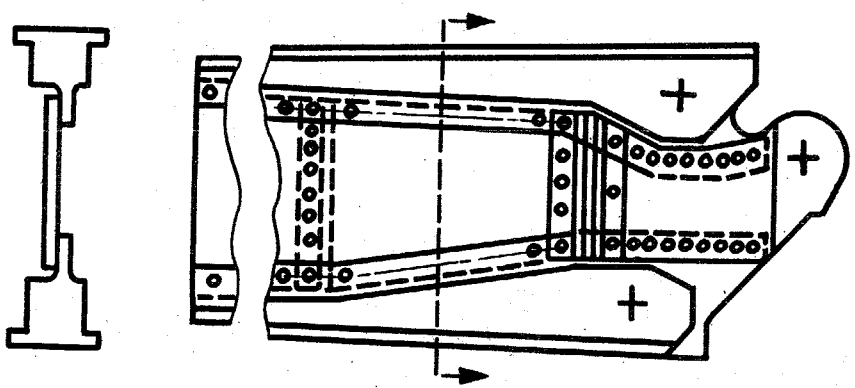
STRUCTURAL DESIGN DETAILS

ONE-PIECE SPAR



WEIGHT.....48.4 LBS.
COST.....$ 309.41
NUMBER PARTS.....1
MAT'L..... 75S EXTRUSION
(MACHINED ON SPAR CAP
MILL)

CONVENTIONAL SPAR



WEIGHT.....59.3 LBS.
COST.....$ 426.62
NUMBER PARTS.....18
PLUS.....17 BOLTS
PLUS....130 LOCKBOLTS
MAT'L.....(CAPS)-75S EXTR.

CHART 4

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in that it takes care of the little man who cannot get materials for civilian consumption and also decentralizes the labor market.

On the other hand, it works a great hardship upon the aircraft plant manager and his operations since it seriously dilutes his supervision, inspection, and engineering talent and confronts him with many new problems of trucking, shipping, rejection, reworks, supplying material, guaranteeing schedules, and so on.

Usually, also, it is found that only the most simple components can be subcontracted, as the more difficult and complex items must be kept close to the engineering design department that created them and that must nurse them through both their developmental and production stages. Here again, proper space in a prime contractor's plant would go far toward reducing the amount of subcontracting necessary and reduce the confusion that results therefrom.

At the present time the Douglas-El Segundo Division, which is probably a typical case, has approximately 40 percent of its work subcontracted. This is mostly in the form of sheet metal assemblies which, as will be shown later, are the most economical to construct and easiest to subcontract. It has also been necessary to subcontract tooling, primarily due to lack of space which prevented a build-up of tooling several years ago when it was indicated necessary.

The subcontracting of engineering has never been entered into by this plant inasmuch as the experience of other plants has indicated it to be very undesirable.

The Importance of Completely Integrated Plants

During the last war and even in recent years, much has been said about shadow factories, feeder plants, and other devices for decentralizing plants to take advantage of what might appear to be gains in labor markets, to reduce bombing vulnerability, and so forth. While at first consideration these plans appear to have merit, it is believed that experiences in this country, as well as abroad, have indicated that it is more important to have a close working relationship between engineering, tooling, and manufacturing departments, all within the geographical location of a plant.

The development of a new prototype and the meeting of new production schedules where we are constantly so far ahead of ourselves that we are frequently placing models into production before the research and development work is completed require heroics and a degree of homogeneity between various departments that is not possible with a decentralized arrangement. This has, I think, been demonstrated so many times during recent years that there should be no question regarding its validity.

Coordination between Agencies

Coordination of efforts between various government research and development agencies, equipment manufacturers, and the aircraft manufacturers continues to be a difficult problem. This is probably becoming worse inasmuch as airplanes are becoming larger and containing considerably more equipment.

The problem here is that in an effort to incorporate in each airplane design the latest equipment technologically possible, airplane specifications commonly contain many items of equipment not yet in existence. When the airplane specification is administered by one agency, the equipment is administered by another agency, and the equipment furthermore is developed by a manufacturer unfamiliar with aircraft characteristics, the end result is usually equipment too heavy, too complex, requiring too much maintenance, and in many cases seriously affecting the aerodynamic arrangement and performance of the airplane.

For example, in the past few years, at the El Segundo Division alone, there were four major radar installations made for various airplanes in accordance with equipment drawings supplied only to find upon receipt of the equipment that it would not fit. In several of these cases the external lines of the airplanes had to be changed with an adverse effect upon performance.

This resulted in throwing away tooling and a great deal of airplane engineering.

The aircraft manufacturer in these instances must bear his part of the responsibility. Still, in most cases, he does not even know when or where the equipment is being developed until it is too late to influence it materially.

There are too many cases where the development of bomb sights, gun sights, and stores of many descriptions have been administered by agencies or equipment manufacturers without coordination with the aircraft manufacturer. When this is done by individuals unfamiliar with the over-all aircraft problem and who fail to take advantage of the experience of the aircraft contractors, considerable time is lost and inferior articles result.

Perhaps the best solution for this problem would be to have the agencies procuring the equipment at least consult with the aircraft manufacturers or solicit the recommendations of the manufacturers before each new equipment design is frozen.

CFE vs. GFE

The foregoing coordination problem has resulted in much talk about switching from a GFE equipment system to a CFE system. This, of course, at first consideration sounds as though it might be a good solution. However, with such a system there would be a tendency toward a diverging considerably from standardization, and logistics would certainly suffer.

It is doubtful that switching completely to CFE instead of GFE would remedy the aircraft equipment problem. In many instances aircraft contractors have, due to their particular talents or abilities, done unusually good jobs in the development of equipment. Where such cases exist, it is believed they should be encouraged, but it is doubtful that a general change from the GFE system to the CFE system would be to the best interests of the Government.

Perhaps here again the best solution would be for aircraft contractors to be taken into the confidence of procurement and development agencies. Even further, aircraft contractors who show special interest in the development of equipment could be requested to submit proposals or design studies for equipment in order to influence equipment more favorably toward the end product, the complete fighting machine.

Many attempts to do this sort of thing have been made recently by so-called "system analyses." Unfortunately, most of these have been made by universities or agencies from a strictly academic point of view and in only a few cases have they been put into practice or has hardware been developed, so that there has in reality been little favorable influence by these studies.

Standardization

Standardization of equipment items in order to simplify logistics is certainly an extremely important part of the whole aircraft effort. Great strides have been made toward this end, but still there have been many cases where there has been too much standardization, with the result that the end product is affected adversely.

This is a difficult problem to administer, and great care must be taken to strike a proper balance between the objectives of the standardization agencies and the airplane designer. For example, on one recently designed airplane, a simplified part was submitted in place of a standard part, but was turned down because it was nonstandard. To use the standard part required making three special parts, resulting in the use of four parts; whereas the four would have been replaced by one simple nonstandard part. Although this is an extreme case, similar things do happen quite frequently.

Chart 5, following page, illustrates another example of problems encountered when following standard practices. This shows a typical AN standard tube fitting which, when used in small sizes, is reasonably satisfactory. However, when this tube fitting is used for two-inch or larger tubes, the design is no longer practicable. The standard part in the two-inch tube size weighs 1.66 pounds made in aluminum alloy and is unsuitable for high temperature engine air bleed systems. A simple new fitting designed to replace the old standard, weighs only .5 pound, or two-thirds less, has three parts instead of five, is made of stainless steel, and is good for high temperatures.

Chart 6, page 15, is another example which shows that an AN standard electrical plug and receptacle weighing .2 of a pound and containing 41 parts could be replaced by a new simplified design weighing only .018 pounds, or one-eleventh of the AN part weight, and has only 18 parts. It does the same job.

These are but a few typical examples of why we must be very careful and review our standards frequently to make certain that we are not overstandardizing and adversely affecting our end product. It is quite common to hear among aircraft designers the expression, when referring to a part, "It is no d--- good, but it is sure as h--- standard."

NIH

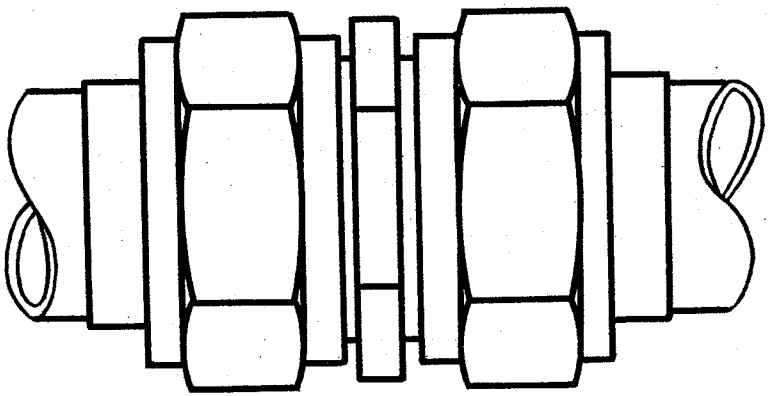
NIH, as you probably all know, is an expression that has become quite common during the last few years. I don't know where it started, but it is certainly used a lot. For those of you unfamiliar with the expression, it means "not invented here".

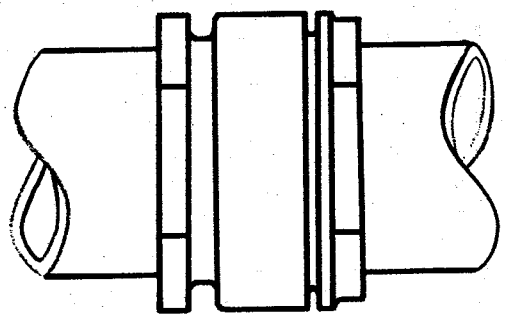
Now I know, as I refer to this expression, that it may sound to some of you like a case of sour grapes on my part and that I am being unduly critical. At the risk of that, I will undertake a brief discussion of the subject, for I think that where there is so much smoke there must be some fire.

This expression is most commonly applied in the discussion of equipment proposed by a manufacturer and refused by an agency because the agency has similar equipment under development.

This subject ties in rather closely with that of standardization and GFE mentioned previously, and it is a problem for which there is no easy solution. It is believed, however, that there are too many cases where equipment is developed under the shroud of security by a procurement agency and some manufacturing specialist only to find when it is given to the aircraft manufacturer that it is quite incompatible with airplane.

WEIGHT REDUCTION
HIGH PRESSURE COUPLING





"AN" DESIGN

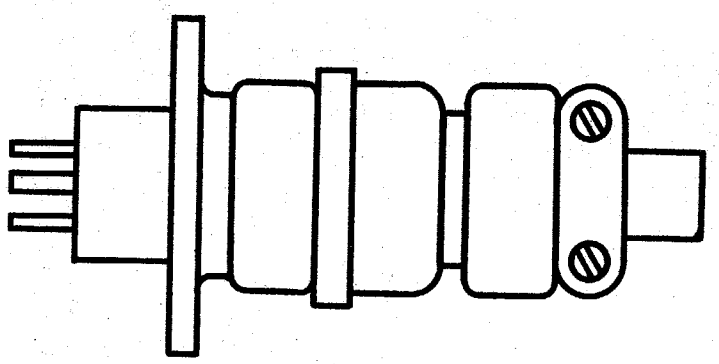
WEIGHT.....1.66 LBS.
NUMBER PARTS.....5
MATERIAL.....ALUMINUM
HIGH TEMPERATURE.....NO

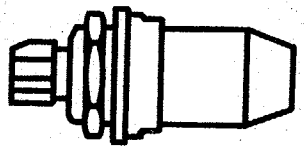
"NEW" DESIGN

WEIGHT.....0.50 LBS.
NUMBER PARTS.....3
MATERIAL.....STAIN. STEEL
HIGH TEMPERATURE.....YES

CHART 5

WEIGHT REDUCTION
ELECTRICAL PLUG & RECEPTACLE





"AN" DESIGN

WEIGHT.....0.20 LBS.

NUMBER PARTS.....41

CAPACITY....5 AMPS. OR LESS

"NEW" DESIGN

WEIGHT.....0.018 LBS.

NUMBER PARTS.....18

CAPACITY....5 AMPS. OR LESS

CHART 6

1387

It is this situation that forces the aircraft manufacturer to become supercritical and to start developing his own equipment, resulting in duplication and many hurt feelings.

The best solution to this problem, as with the GFE vs. CFE problem, would appear to be to have the agency responsible for the delivery of the complete airplane be responsible for the coordination of equipment items between development agencies and aircraft manufacturers at an early enough time to avoid the situations that now occur all too frequently.

Complexity

Complexity, during the past few years, has become one of the most commonly used and perhaps most important expressions in the aircraft business. Personally, I think it is the most important, since most any problem that is encountered would be minimized with simpler, or less complex, airplanes. Thus, this can be said to be the root of all our evil.

Some have tossed off this subject rather lightly, saying that increased performance and increased military requirements are bound to result in more complexity and we can't do anything about it. This I think is a grave error.

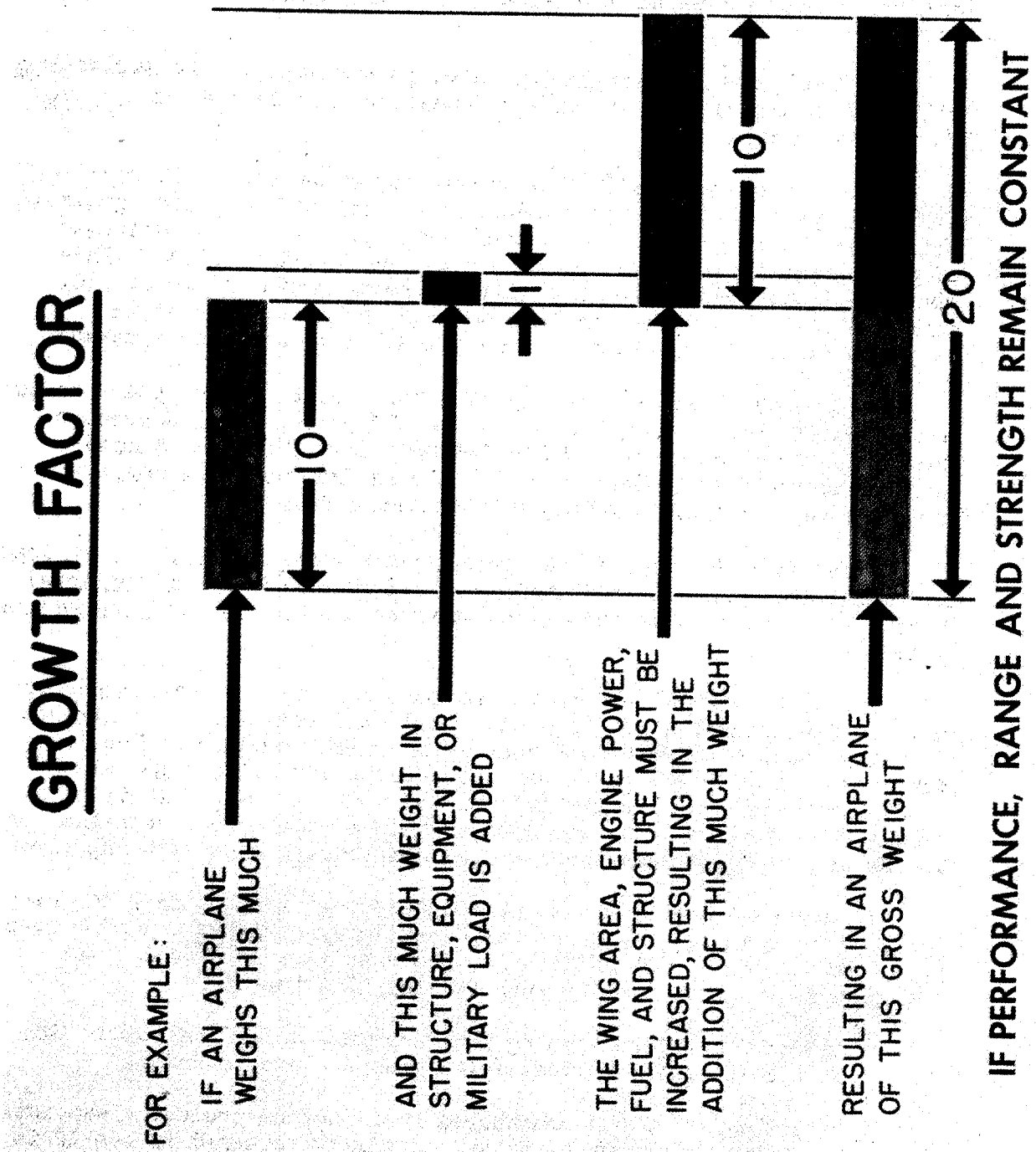
It is granted that, for improved gunnery and bombing and navigational accuracy, higher performance, and longer ranges, constant improvements and new requirements are necessary. Many of these requirements have justified a great deal of the present-day complexity but it is doubtful if the gains have been proportionate to the increase in complexity, cost, and time. In many cases, the added effect of requirements has had an adverse effect upon combat efficiency and safety.

There is a fundamental situation that we cannot alter and that has a very great bearing on this subject. This is what is commonly referred to as a "growth factor."

Chart 7, following page, is a simple explanation of the growth factor. This illustrates that if, on the average airplane, weight is added equivalent to one-tenth of the gross weight, it becomes necessary to increase wing area, power, fuel, and structure by 10 times that much, resulting in a gross weight twice as great as the original gross weight if the performance, range, and strength remain constant.

Now it is true that once an airplane is designed, the wing area, power plant, and so on, are not altered for each additional piece of equipment. But it is equally true that when invitations are sent out by the Government for bids to design new airplanes, that the size of those airplanes is directly dependent upon the useful load and equipment

CHART 7


GROWTH FACTOR
FOR EXAMPLE:
IF AN AIRPLANE WEIGHS THIS MUCH
10
AND THIS MUCH WEIGHT IN STRUCTURE, EQUIPMENT, OR MILITARY LOAD IS ADDED
1
THE WING AREA, ENGINE POWER, FUEL, AND STRUCTURE MUST BE INCREASED, RESULTING IN THE ADDITION OF THIS MUCH WEIGHT
10
RESULTING IN AN AIRPLANE OF THIS GROSS WEIGHT
20
IF PERFORMANCE, RANGE AND STRENGTH REMAIN CONSTANT

requirements and that for every unit of weight required by this equipment, the gross weight is increased by the growth factor. This factor, of course, varies between designs, but many recent jet airplane designs checked have shown 10 to be a reasonable and sound factor.

If this growth is not incorporated in the design, the performance will suffer, and we are--in effect--cheating the pilot by giving him an inferior weapon.

Consider the effect of this growth factor on cost. Chart 8, following page, illustrates another common expression--"cost growth." This term, "cost growth," is commonly used as the cost by which an airplane increases for each pound of equipment weight added. This shows that one pound of weight added, times a growth factor of 10, times 40 dollars a pound, amounts to a 400 dollars increase in airplane cost, if performance, range, and strength remain constant.

Forty dollars per pound is a value arrived at by our plant on an evolutionary basis during the last 10 or 15 years. A good check of this value can be found in the Finletter Report for 1948, "Survival in the Air Age," which showed that, on a national average basis, aircraft were actually costing a little more than that.

While statistics regarding present costs are not readily available, it is believed that the cost per pound based upon the total national aircraft effort must be at present somewhat greater than 50 dollars per pound.

The problem with respect to complexity is how it can be reduced without impairing the end product. This reduction of complexity has for many years been foremost among design requirements for Douglas airplanes. During the past year the efforts toward this end at El Segundo have been greatly intensified and as a result it is believed that much can yet be done to reduce complexity, decrease cost, and subsequently, increase quantities and shorten manufacturing times.

In a recent series of design studies, for example, this philosophy resulted in reducing the gross weight of an airplane from 30,000 pounds to a little over 14,000 pounds. At the same time in so doing the performance was increased by approximately 100 knots.

Time would not permit going into complete detail as to how this was accomplished, but I believe a few examples are in order.

First, the design was approached from the end product viewpoint. In other words, each requirement was carefully screened to see if it contributed to the ultimate military effectiveness of the airplane. If it did not, it was thrown out.

COST GROWTH

ONE POUND ADDED WEIGHT

X

10

GROWTH FACTOR

X

$40

COST PER POUND

= $400.00

TOTAL INCREASE IN AIRPLANE COST

IF PERFORMANCE, RANGE AND STRENGTH REMAIN CONSTANT

CHART 8

1391

All equipment was carefully arranged to result in the minimum wiring, piping, brackets, and so on. For example, chart 9, following page, shows that by mounting all communicating equipment in a common container, throwing away the old individual boxes, using a common power supply, and eliminating interconnecting wires between boxes, the weight of this equipment was reduced from 158 to 115 pounds.

The pilot's seat was completely redesigned over earlier models, as shown on chart 10, page 22, and the weight chargeable to the seat reduced from 78 to 28 pounds.

Extreme care was taken in the arrangement of the cockpit, and as a result it was possible to reduce the number of instruments and switches, making a smaller, more convenient cockpit that will result in greatly improved pilot efficiency and comfort.

As a result of these and other direct weight savings, the size of the airplane came out small enough so that wing folding could be dispensed with and power controls were considerably simplified, resulting in further indirect savings.

These are but a few examples of how weight, complexity, and cost can be reduced if they are given enough emphasis.

Performance

The success of an airplane is generally measured by its performance and performance is usually synonymous with the maximum velocity. Thus high speed becomes the yardstick by which the value of an airplane is measured and is one of the greatest design problems.

Chart 11, page 23, is a statistical record of airplane speed progress since the flight of the Wright Brothers in 1903. This shows that during the first half century of aviation speed has steadily risen to the present world speed record of 699 miles per hour, or an annual increase of 14 miles per hour.

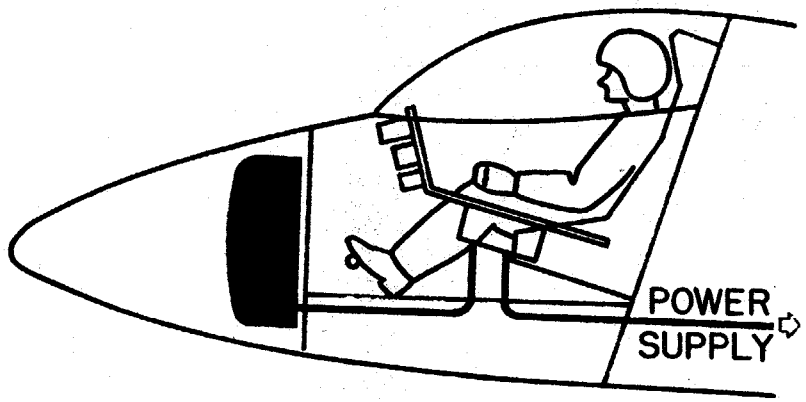
High speed up to 1,238 miles an hour have been reached, but only by special research airplanes carried to intermediate altitudes by large bombing planes.

For military airplanes, the rate of speed increase during recent years has been largely influenced by solving the aerodynamic drag, or drag-rise problem frequently referred to as the sonic barrier. The solution to this problem is now fairly well understood and supersonic speeds are possible, although adequate stability and control at supersonic

WEIGHT REDUCTION

COMMUNICATING EQUIPMENT

REPACKAGED

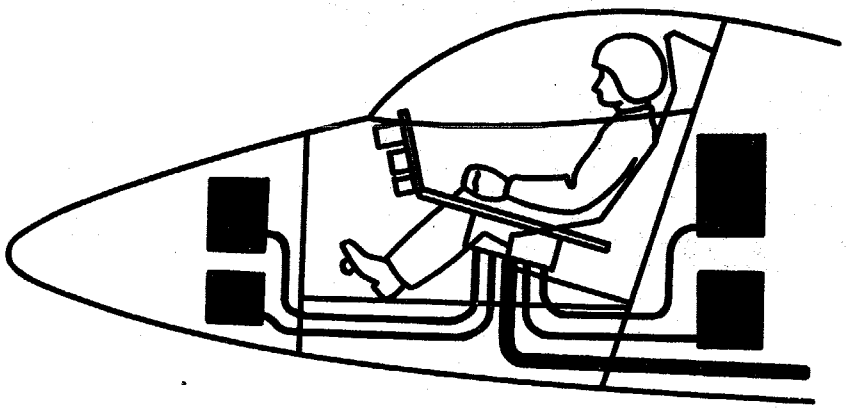


COMMUNICATIONS
NAVIGATION
I.F.F.
POWER SUPPLY
} ...105 LBS.

WIRE & BRACKETS.....10 LBS.

TOTAL....115 LBS.

"AN" SPECIFICATION



COMMUNICATIONS..... 75 LBS.

NAVIGATION.....6 LBS.

I.F.F.....40 LBS.

POWER SUPPLY.....12 LBS.

WIRE & BRACKETS.....25 LBS.

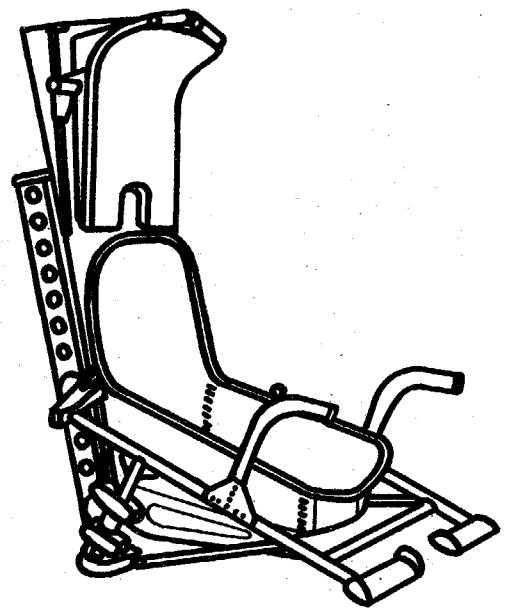
TOTAL.....158 LBS.

CHART 9

1393

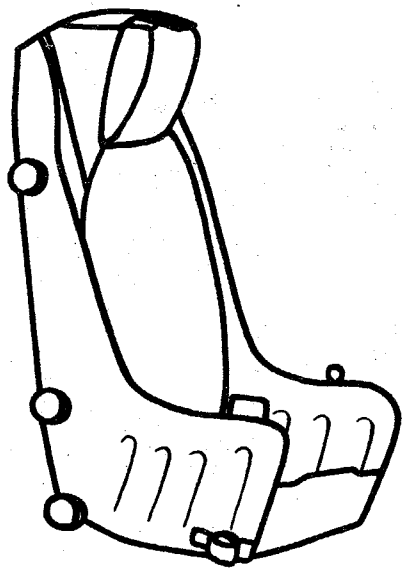
WEIGHT REDUCTION
EJECTION SEATS

OLD STANDARD



WEIGHT..... 78 LBS.
NUMBER OF PARTS.....138

NEW



WEIGHT..... 28 LBS.
NUMBER OF PARTS.....44

CHART 10

CHART 11

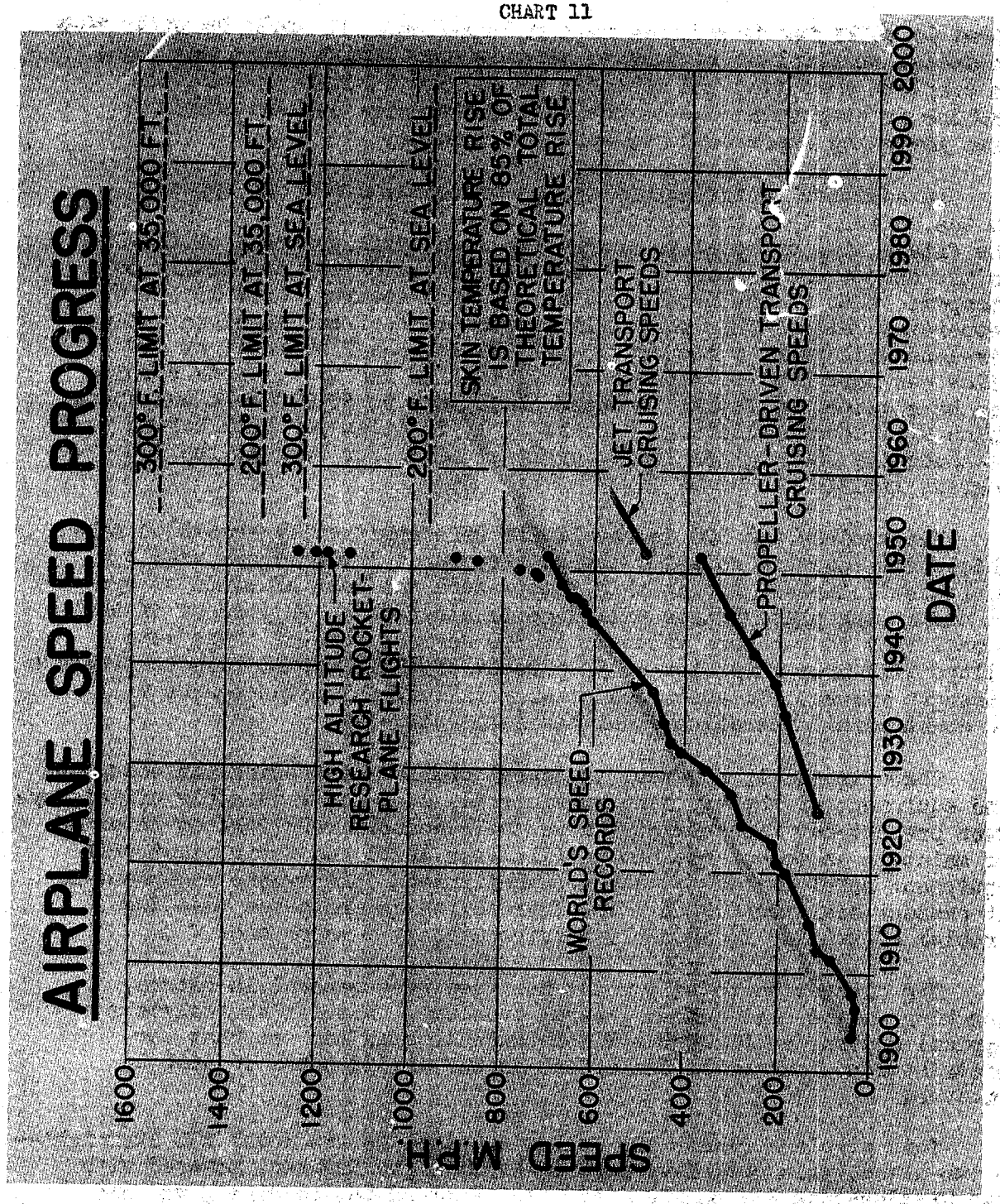


Figure 11.

speed is still far from being completely solved. It would be quite easy to design an airplane to operate at supersonic speeds only, but since an airplane must land and take off at the low subsonic speeds, the problem is compounded due to the wide differences between physical laws governing supersonic and subsonic speeds.

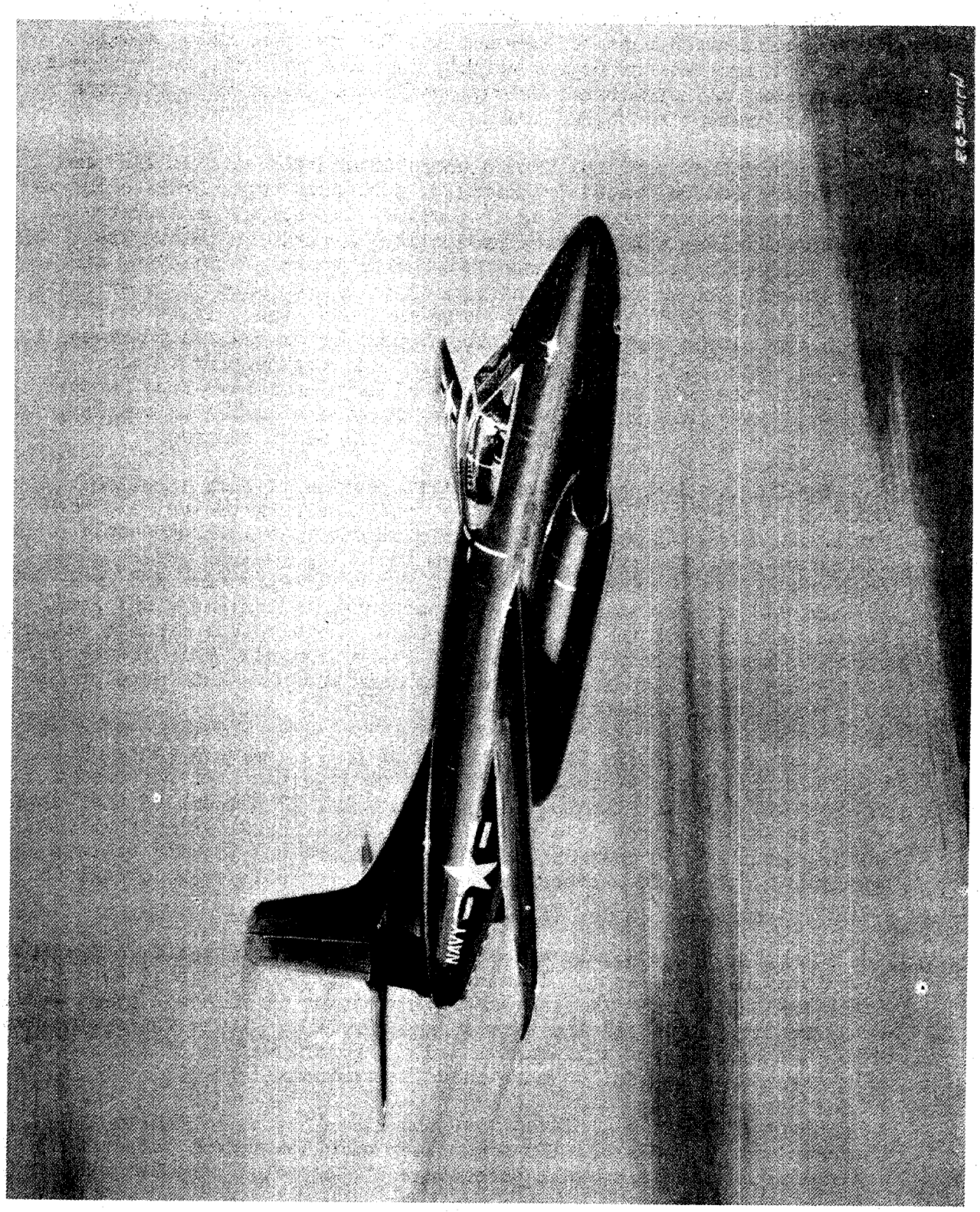
In addition to the normal design problems, a new one appears on the horizon that has already complicated airplane design and in the future will do so at an increasing rate until progress of flight in the atmosphere as we know it may be limited or may eventually be stopped. This is the problem of aerodynamic heating, or a diabatic temperature rise. This chart illustrates that at sea level an entire airplane will reach a temperature of 200 degrees Fahrenheit at 960 miles per hour and 300 degrees at 1,255 miles per hour. Some respite can be obtained by flying in upper atmosphere at 35,000 feet and above, which will permit attaining a speed of 1,318 miles per hour before reaching the 200 degrees limit, or 1,547 miles per hour at the 300 degrees limit.

Two hundred and 300 degree limits were arbitrarily chosen to make this point inasmuch as a 200 degree structural limit is now used by most manufacturers, for at this temperature the best aluminum alloys in use at the present time will drop in strength to 90 percent of their normal room temperature values. At 300 degrees some of these same alloys will drop to as low as 50 percent of their normal room temperature strength values. Titanium and other metallurgical advancements will no doubt permit operating at higher temperatures.

There is still, however, the great problem of keeping the occupants and equipment of the airplane sufficiently cool for reasonable efficiency. Even present-day fighters must have their cockpit refrigerated in order to maintain an acceptable human efficiency level and their electronic equipment refrigerated to keep it functioning. Electronic equipment is at present designed for only 165 degrees, which indicates that the problem of keeping it properly refrigerated is a major one.

The discussion to this point has been very general in nature, touching on the most common general problems. Now let us analyze a typical modern jet fighter a little more closely and see what the distribution of material and effort is and why it takes so long to produce.

This airplane (chart 12, following page) is the model F3D Skyknight--a two-place, twin jet, Navy carrier-based night fighter, powered with two Westinghouse J34 engines, carrying four 20-mm. machine guns, and equipped with Westinghouse AN/APQ-35 radar and fire control system with tail warning, and carrying 1,350 gallons of internal fuel.


NAVY

The airplane had an original design gross weight of 21,500 pounds, which was increased between the "X" and production models due to the increase in engine weight, increase in fuel, and increase in equipment and structural weights until the design takeoff gross weight at present is 26,826 pounds.

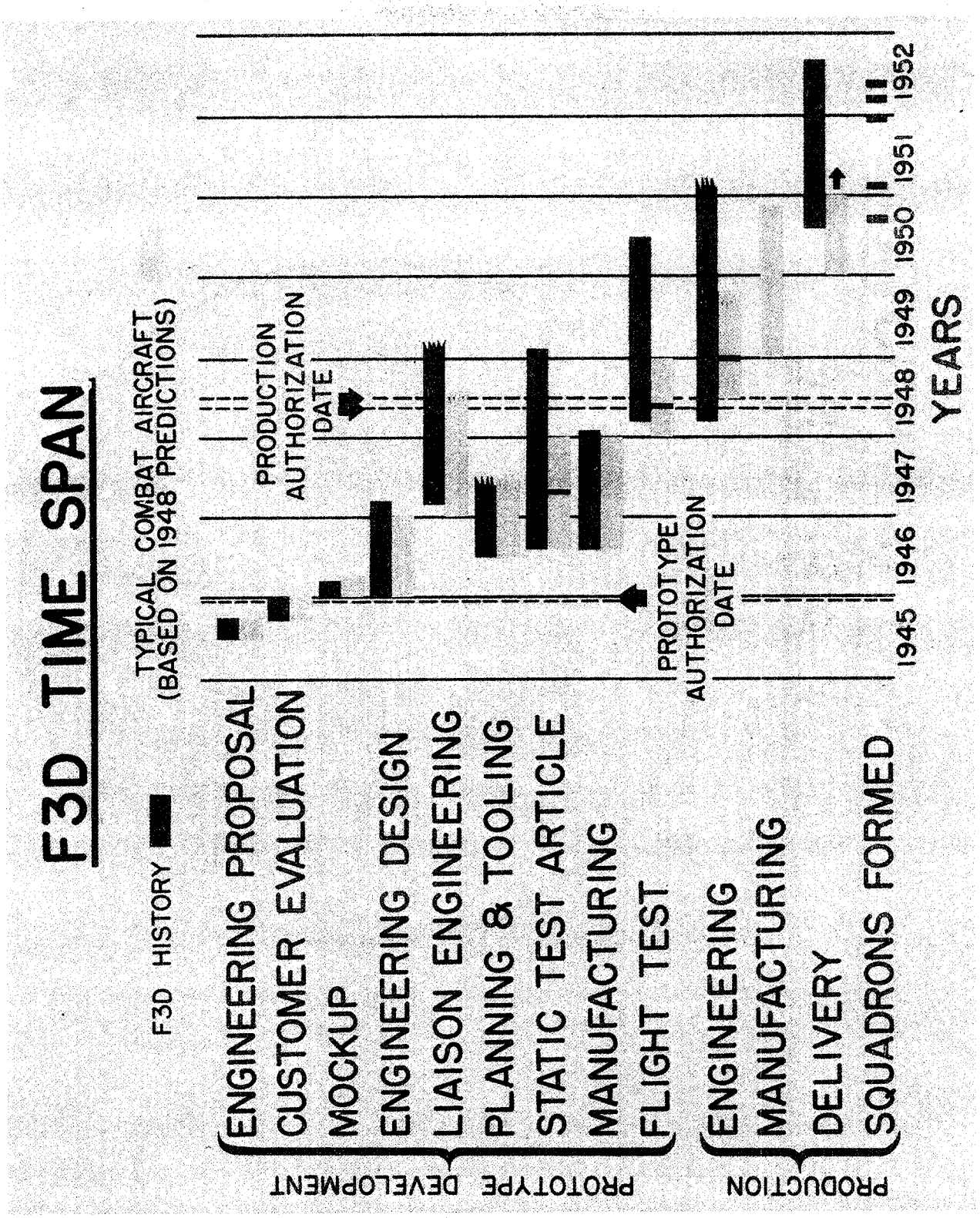
The airplane resulted from a competition held late in 1945 and its history can be traced by chart 13, following page. This chart is rather interesting inasmuch as it compares the actual performance of a recent airplane with average predictions we made in 1948. The light colored bars are what was predicted as "average" in 1948, and the black is the actual F3D history. This chart tells an interesting story inasmuch as it shows that it takes longer than six years for a relatively simple airplane to be developed, produced, and put into combat. Even so, it is necessary to release engineering before testing is complete and the experimental airplanes have been demonstrated. Likewise, most all other functions are forced to overlap, involving a considerable element of risk and added expense.

Now let us look at the weight distribution of this airplane. Chart 14, page 28, shows that of the total design gross weight, the equipment weighs 22 percent, the basic structure or airframe only 29 percent, and the propulsion system including fuel 49 percent. Inasmuch as, for a given performance, the basic structure and propulsion percentages are directly proportional to equipment and load, it can be seen that the size and weight of the airplane depends entirely upon the amount of equipment and load to be carried. This is why earlier in this discussion so much emphasis was placed on development of the lightest, simplest equipment.

Chart 15, page 29, is a breakdown of the airframe weight. This breakdown is rather typical and is not too important except that it illustrates that the landing gear accounts for 27 percent of the total airframe weight, which is a rather large factor considering that the landing gear is not used in combat or in flight and is only used on the ground. Thus it becomes very important to apply every effort to reduce landing gear weights.

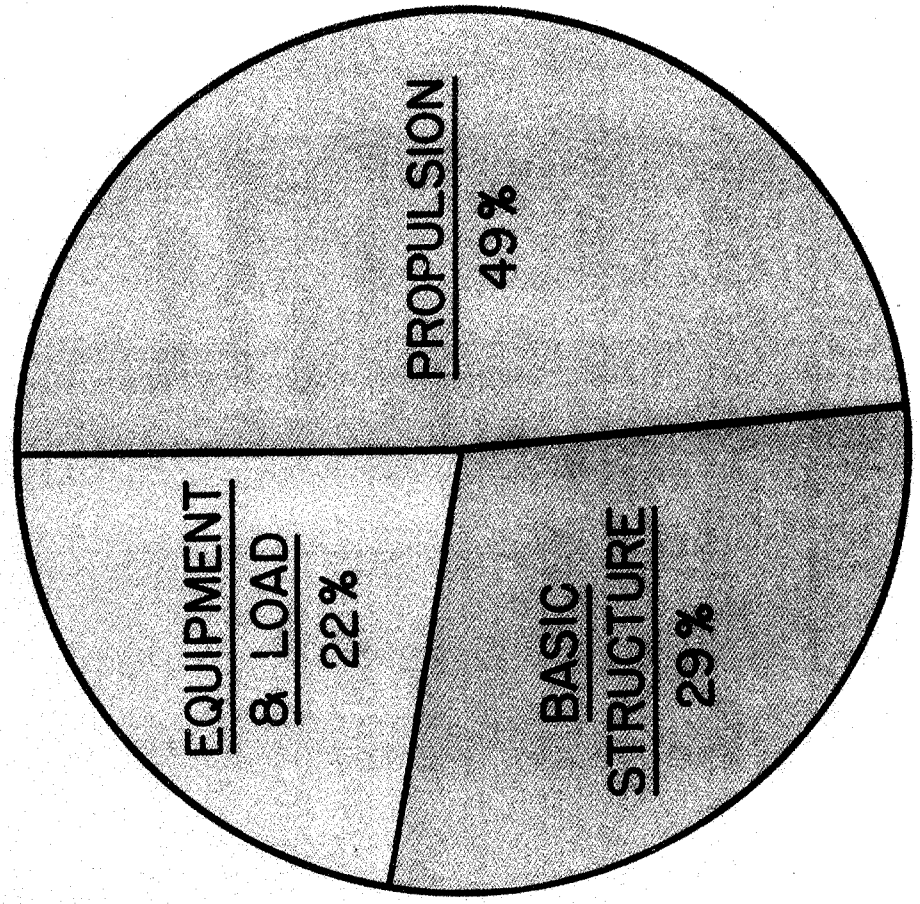
Chart 16, page 30, is a breakdown of the equipment and load weight distribution. This is the load and weight of the items that actually determine the size of the airplane. Any saving in this equipment would have greatly influenced the size of the airplane. It is interesting to note that electronics equipment in this airplane weighs 27 percent of all equipment and load, or more than the armament itself.

Chart 17, page 31, illustrates the distribution of weight chargeable to propulsion. It shows that with the modern jet engine, the engine itself is a small percentage of the total propulsion weight.


F3D TIME SPAN
F3D HISTORY
TYPICAL COMBAT AIRCRAFT (BASED ON 1948 PREDICTIONS)
PRODUCTION AUTHORIZATION DATE
PROTOTYPE AUTHORIZATION DATE
ENGINEERING PROPOSAL
CUSTOMER EVALUATION
MOCKUP
ENGINEERING DESIGN
LIAISON ENGINEERING
PLANNING & TOOLING
STATIC TEST ARTICLE
MANUFACTURING
FLIGHT TEST
ENGINEERING
MANUFACTURING
DELIVERY
SQUADRONS FORMED
DEVELOPMENT
PROTOTYPE
PRODUCTION
1945
1946
1947
1948
1949
1950
1951
1952
YEARS

1400

GROSS WEIGHT DISTRIBUTION
F3D-2 AIRPLANE



STRUCTURAL WT. DISTRIBUTION

F3D-2 AIRPLANE

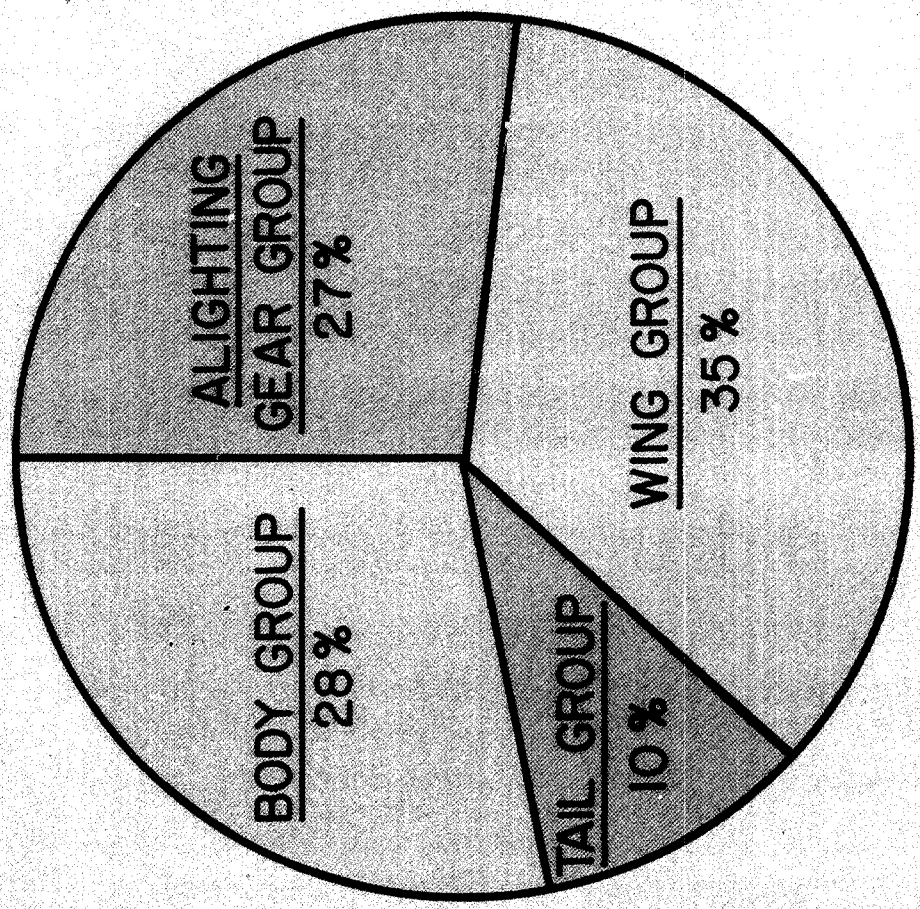


CHART 16

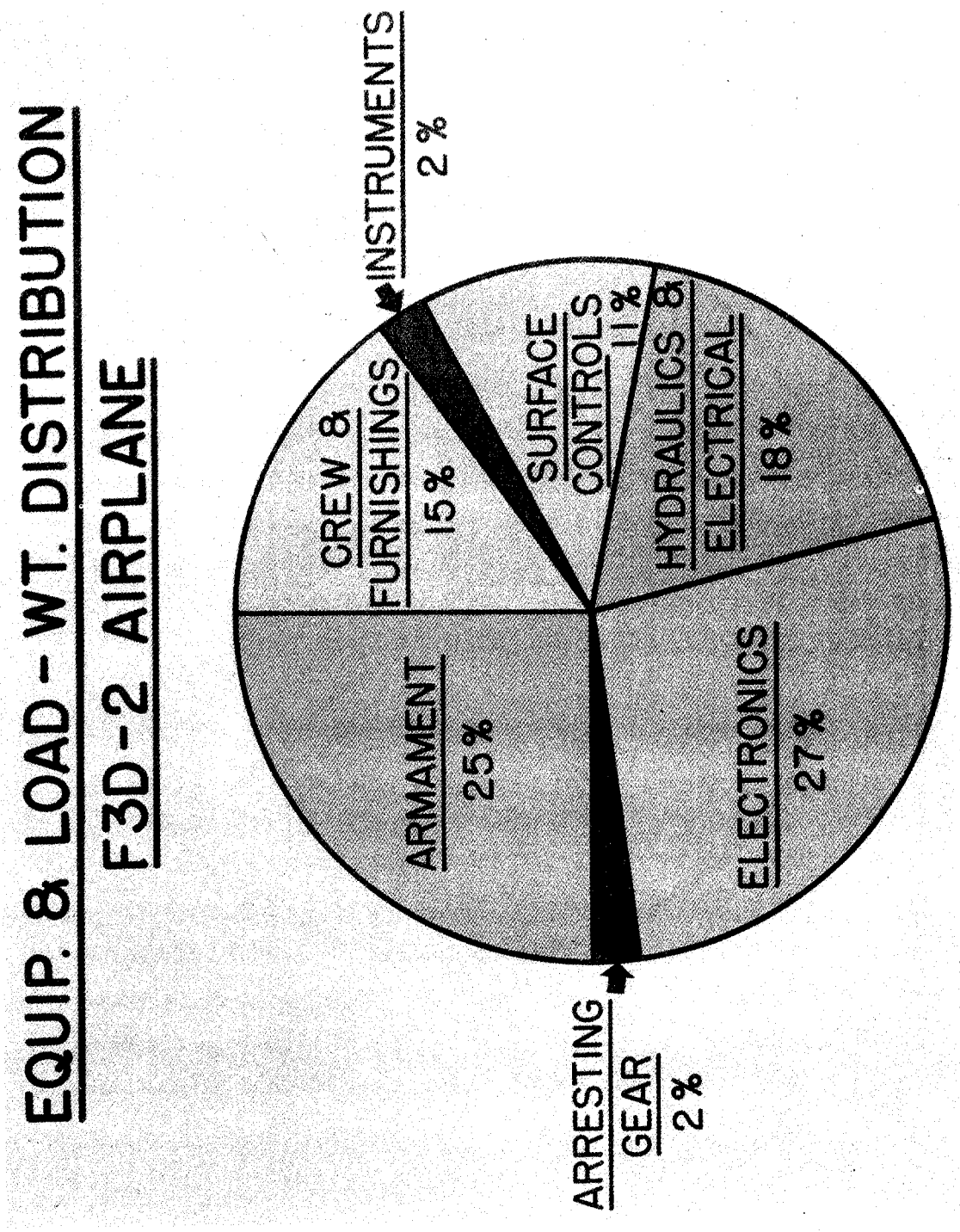


Figure 16.

1403

PROPULSION WT. DISTRIBUTION
F3D-2 AIRPLANE

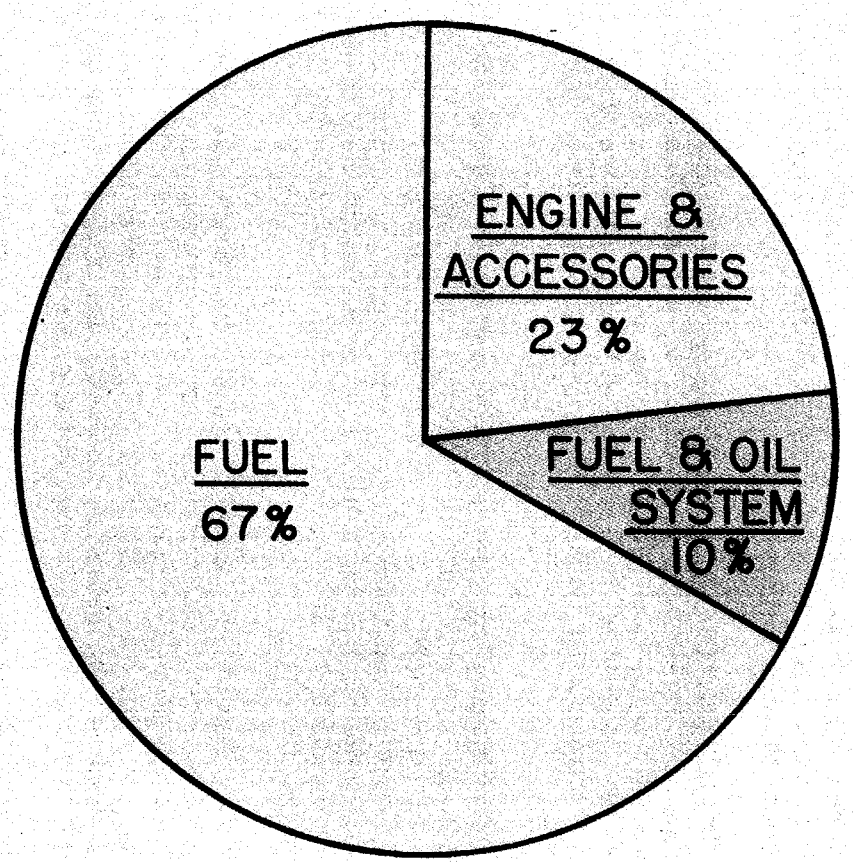


Figure 17.

In the case of the F3D the fuel amounts to 67 percent of the total weight chargeable to the propulsion system. Thus great gains could be made in airplane design by further improvement in fuel consumption. This, of course, would also have a favorable influence on the 10 percent chargeable to fuel and oil system, of which the greater percentage consists of fuel tank weight.

There have been numerous recent requests from various agencies regarding the relative use of materials for various planning purposes. Chart 18, following page, illustrates the distrubution of materials by form of the material stock. It is interesting to note that sheet metal accounts for over 51 percent of the weight of this airplane structure; also that forgings were kept down to 6.3 percent and castings were held to less than 1 percent. This includes all materials, both ferrous and nonferrous.

The distribution of materials of the F3D is shown on chart 19, page 34. It shows that 75 percent of the airplane weight is aluminum, 21 percent steel, 1.9 percent copper (mostly wiring), 1.3 percent magnesium (only used in portions of the structure where space did not permit conventional construction), and .8 percent lead--used for balance weights.

On this airplane every effort was made to keep forgings to a minimum and to use, instead, sheet, extrusions, and plate. The effort was quite successful, as it can be seen that only 1.8 percent of the material is in the form of aluminum forgings. Steel forgings run a little higher at 4.3 percent inasmuch as many landing gear parts could not be practicably made of sheet metal or plate, and forgings were a necessity.

With respect to labor distribution, chart 20, page 35, is a breakdown of the direct labor hours for the construction of the three experimental XF3D-1 airplanes. This shows that for an experimental contract of this kind, manufacturing consumed about half the total hours; whereas engineering, tooling, and flight test the other half--engineering consuming approximately one-quarter of the total.

Chart 21, page 36, shows how these percentages shifted for the first two production contracts of 96 airplanes. Manufacturing increased materially 60 percent, engineering reduced to 10.3 percent, flight test reduced to 1.7 percent, and tooling increased to 27.7 percent.

Since manufacturing requires the largest amount of manpower, chart 22, page 37, shows a further breakdown of manufacturing man-hours. This shows that fabrication requires only 38 percent of the man-hours; whereas assembly requires 61 percent. This points to the advisability of designing wherever possible to reduce installation time and assembly time. This chart also shows that of the total manufacturing man-hours

CHART 18

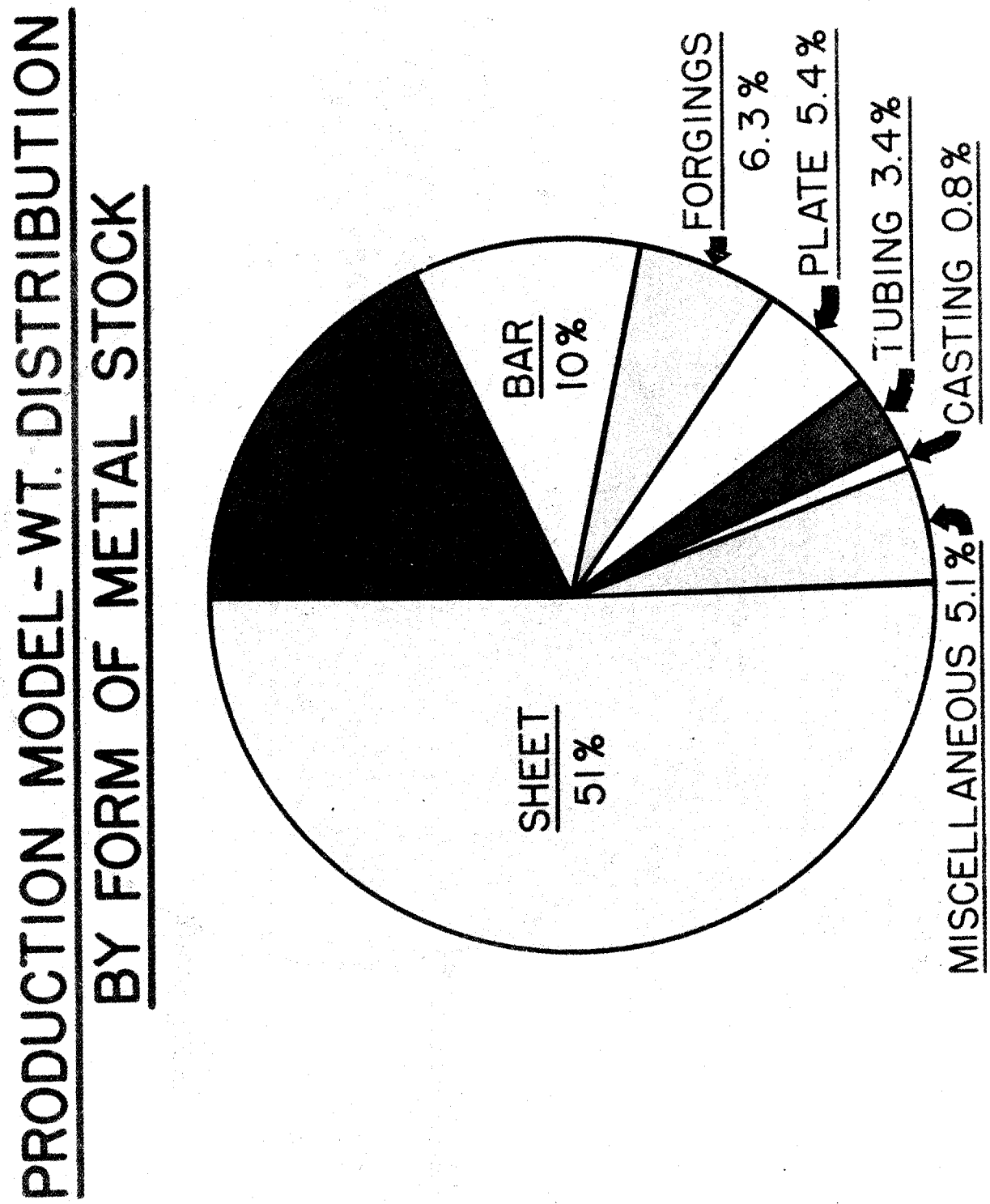
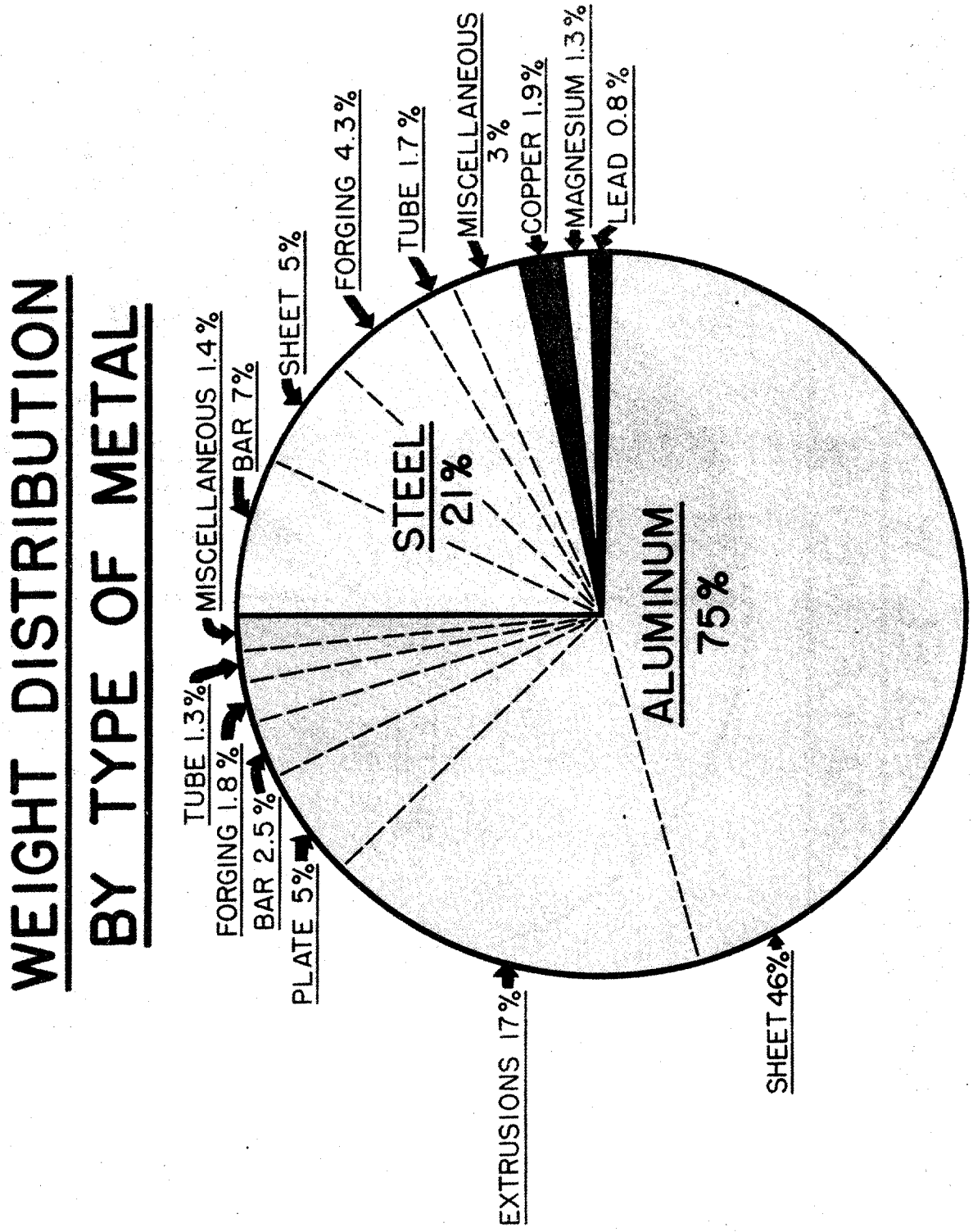

PRODUCTION MODEL-WT. DISTRIBUTION
BY FORM OF METAL STOCK
SHEET
51%
BAR
10%
FORGINGS
6.3%
PLATE 5.4%
TUBING 3.4%
CASTING 0.8%
MISCELLANEOUS 5.1%

CHART 19


WEIGHT DISTRIBUTION
BY TYPE OF METAL
STEEL
21%
ALUMINUM
75%
MISCELLANEOUS 1.4%
BAR 7%
SHEET 5%
FORGING 4.3%
TUBE 1.7%
MISCELLANEOUS
3%
COPPER 1.9%
MAGNESIUM 1.3%
LEAD 0.8%
TUBE 1.3%
FORGING 1.8%
BAR 2.5%
PLATE 5%
EXTRUSIONS 17%
SHEET 46%

XF3D-1 DIRECT LABOR HOURS

3 AIRPLANES + STATIC TEST ARTICLE

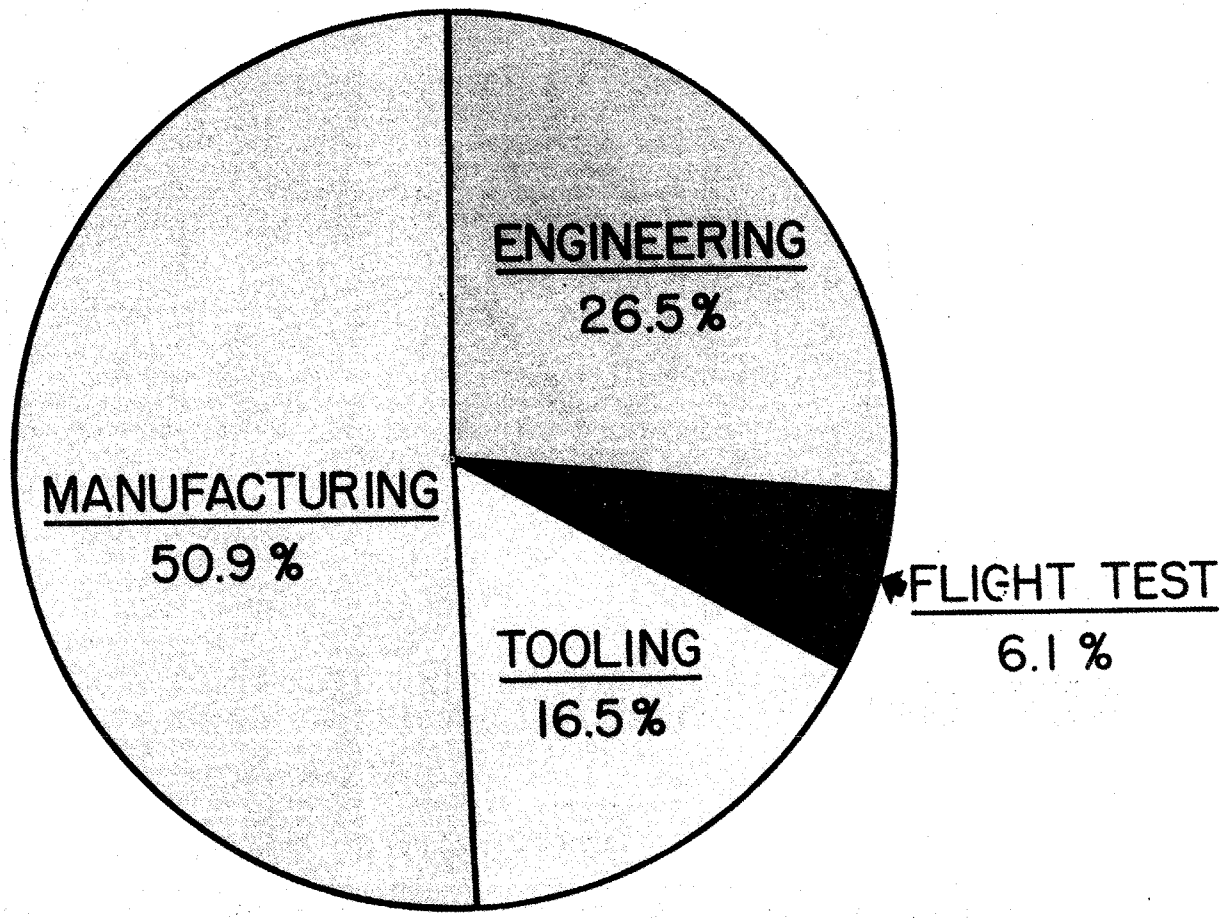


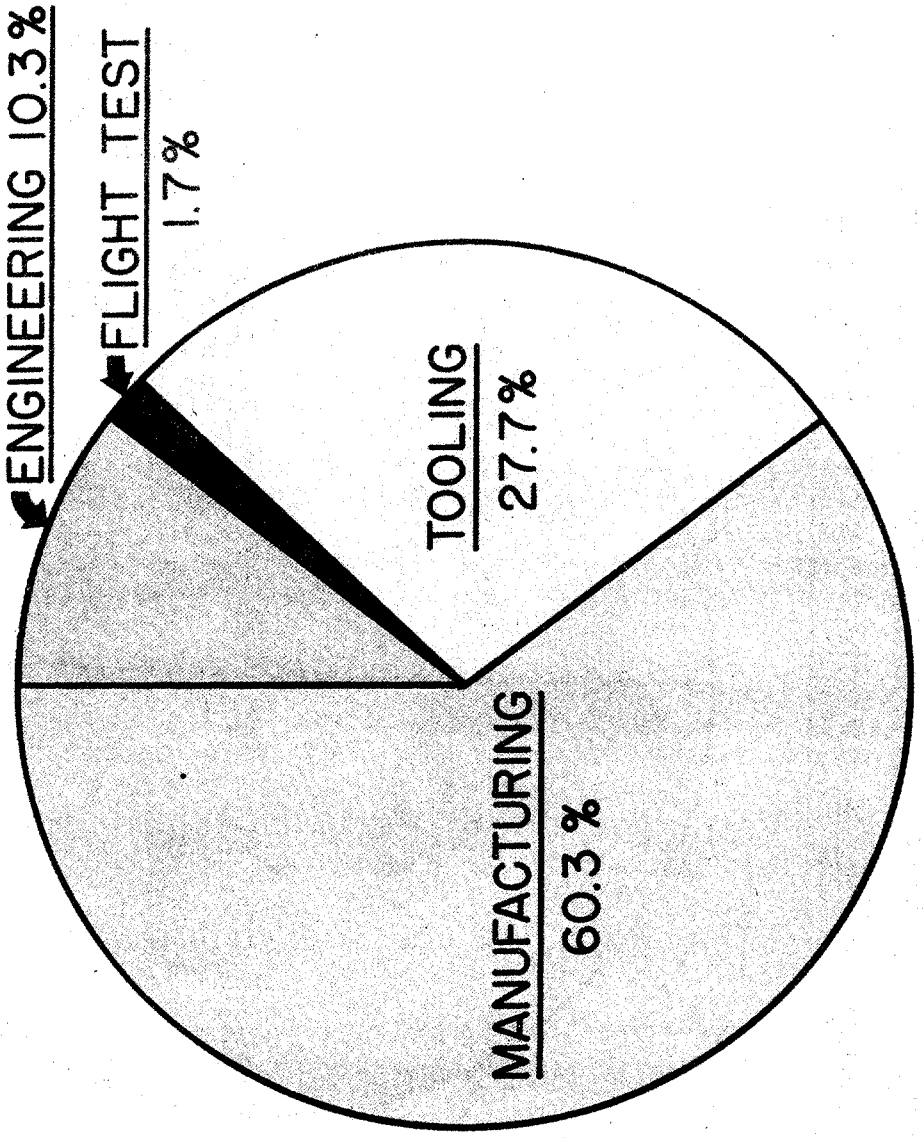
CHART 20

1402

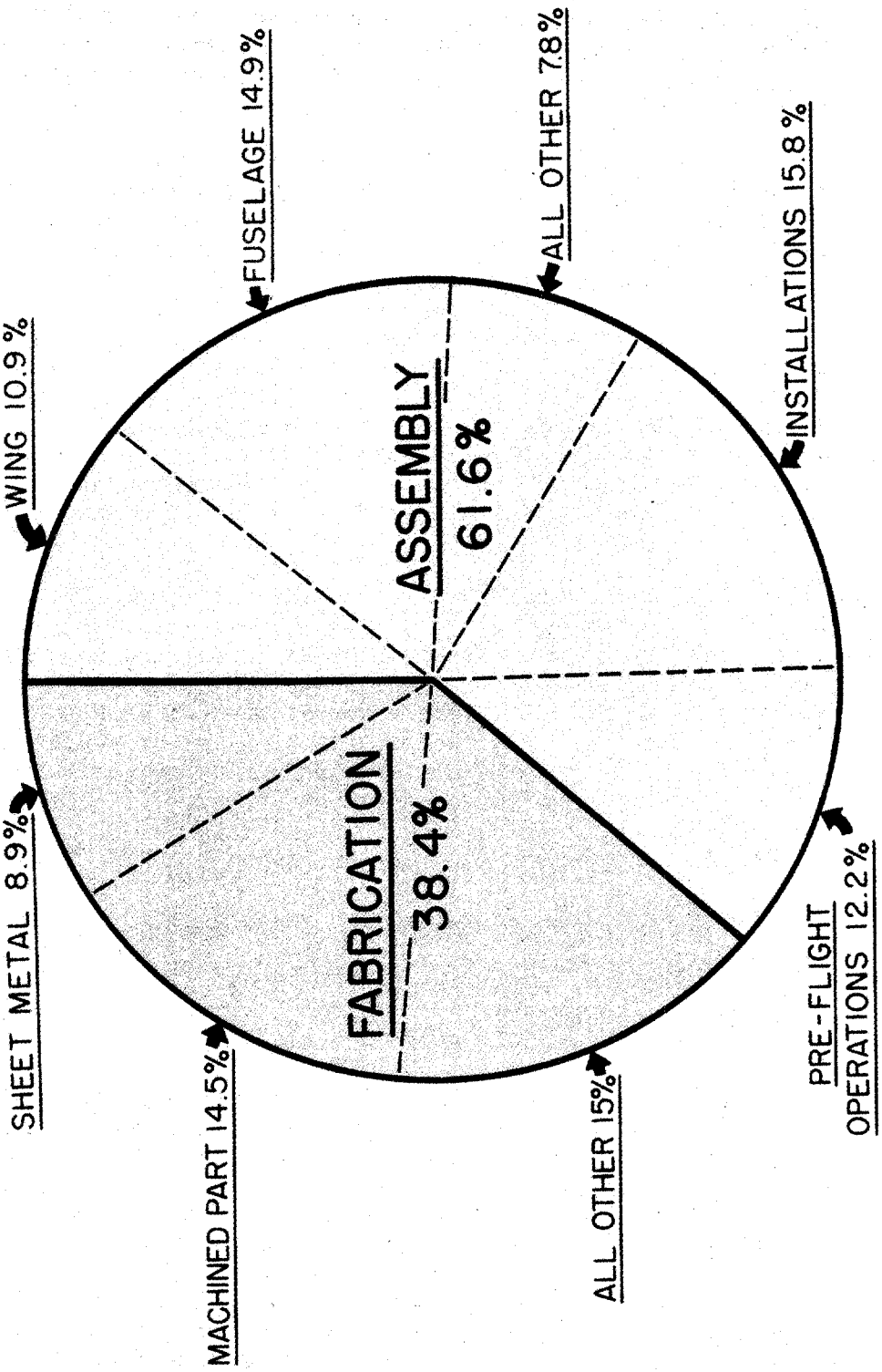
CHART 21

F3D DIRECT LABOR HOURS

96 AIRPLANES



MANUFACTURING MAN-HOUR DISTRIBUTION AT 250TH F3D-2



consumed, machined parts consist of only 14 percent and sheet metal parts 8.9 percent. These two operations employ a high percentage of mechanical production methods. The remainder of the man-hours are predominantly hand operations, which account largely for the high expense of aircraft construction.

Chart 23, following page, shows how the various skills vary from the experimental stage through the various production stages. This shows that flight testing and engineering diminish materially, tooling reaches its peak at the first production order, and manufacturing reaches its peak during the last production order.

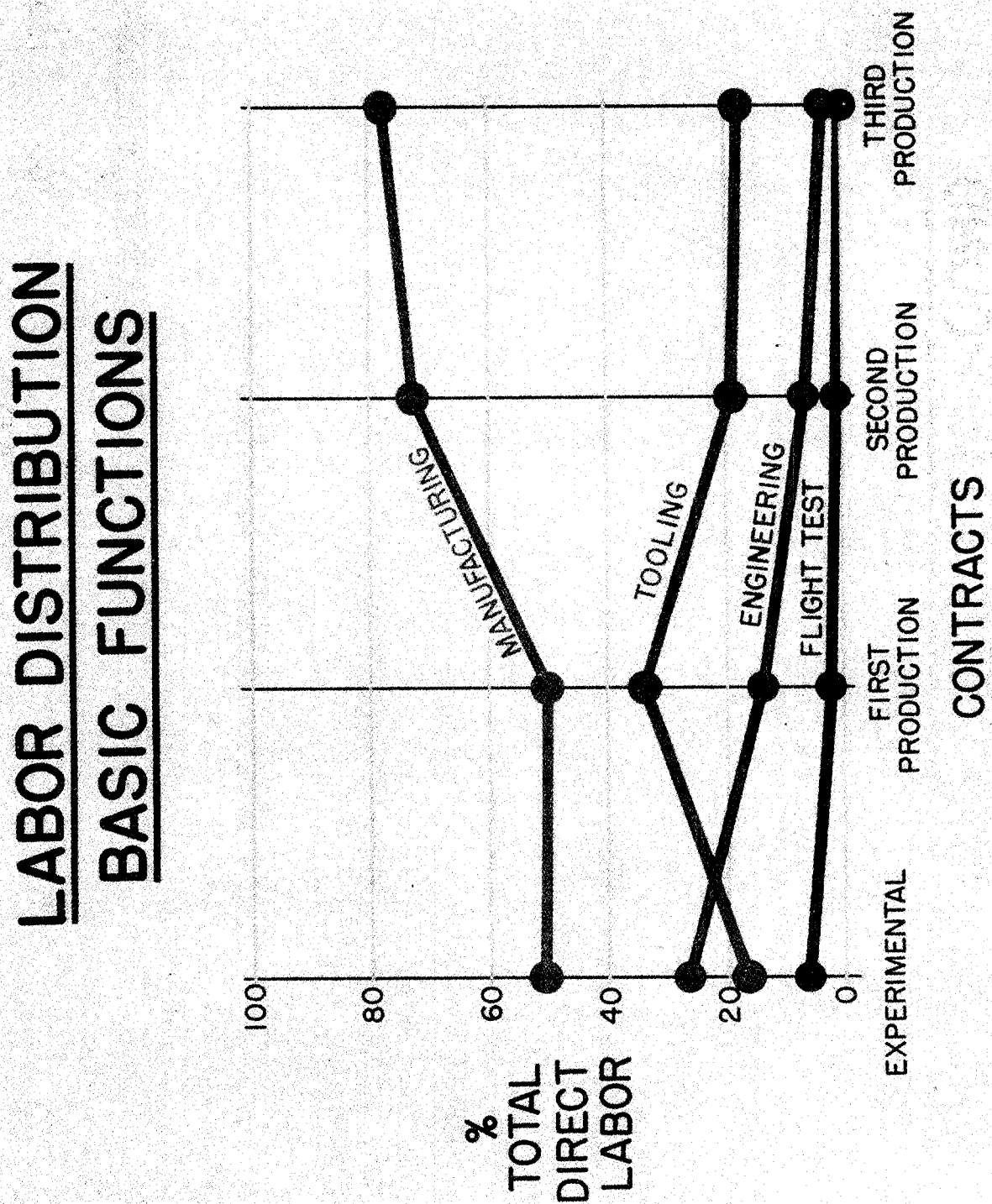
While these distributions probably haven't changed a great deal in recent years, it will probably be found that the amount of tooling required to put an airplane into production has increased the most--since, as the density of the airplane increases, heavier materials and manufacturing methods are employed which, in turn, require more complete tooling. Furthermore, as quantity increases, more tooling is required to permit assembly by unskilled personnel.

Chart 24, page 40, illustrates the difference in cost per pound between mechanisms and structures by departmental function. This is a very significant chart inasmuch as it shows that static structure is far less expensive than mechanisms, such as control system, landing gears, and so on. This shows that engineering costs for mechanisms run 14.65 dollars a pound; whereas structure only 2.96 dollars. Tooling for mechanisms is 6.99 dollars; for structures 4.46 dollars a pound. Manufacturing costs for mechanisms are 20.10 dollars a pound; whereas structures are only 7.35 dollars a pound. The total of engineering, tooling, and manufacturing runs 41.74 dollars a pound for mechanisms and for structures only 14.77 dollars a pound.

The maintenance of mechanisms amounts to 84.73 dollars per pound; whereas for structures only 3.37 dollars per pound. This brings the total to 126.47 dollars a pound for mechanisms and 18.09 dollars for structures. This is based on costs checked at the 205th F3D airplane with a weight empty of 14,000 pounds.

Chart 25, page 41, is a typical learning curve, with which you are no doubt somewhat familiar. It shows how airplane unit cost varies with airplane quantity. These curves, for most aircraft in the quantities procured during World War II, were assumed to be of 80 percent slope, that is, the second hundred airplanes cost 80 percent of the first hundred and so forth.

For the F3D, the curve turned out to be considerably less than 80 percent, probably for two reasons. The first, the initial development costs were high because of the large amount of new electronic


LABOR DISTRIBUTION
BASIC FUNCTIONS
% TOTAL DIRECT LABOR
100
80
60
40
20
0
MANUFACTURING
TOOLING
ENGINEERING
FLIGHT TEST
EXPERIMENTAL
FIRST PRODUCTION
SECOND PRODUCTION
THIRD PRODUCTION
CONTRACTS

LABOR COSTS PER POUND
14000 LB. (WT. EMPTY) MILITARY AIRFRAME
AT THE 205TH AIRPLANE

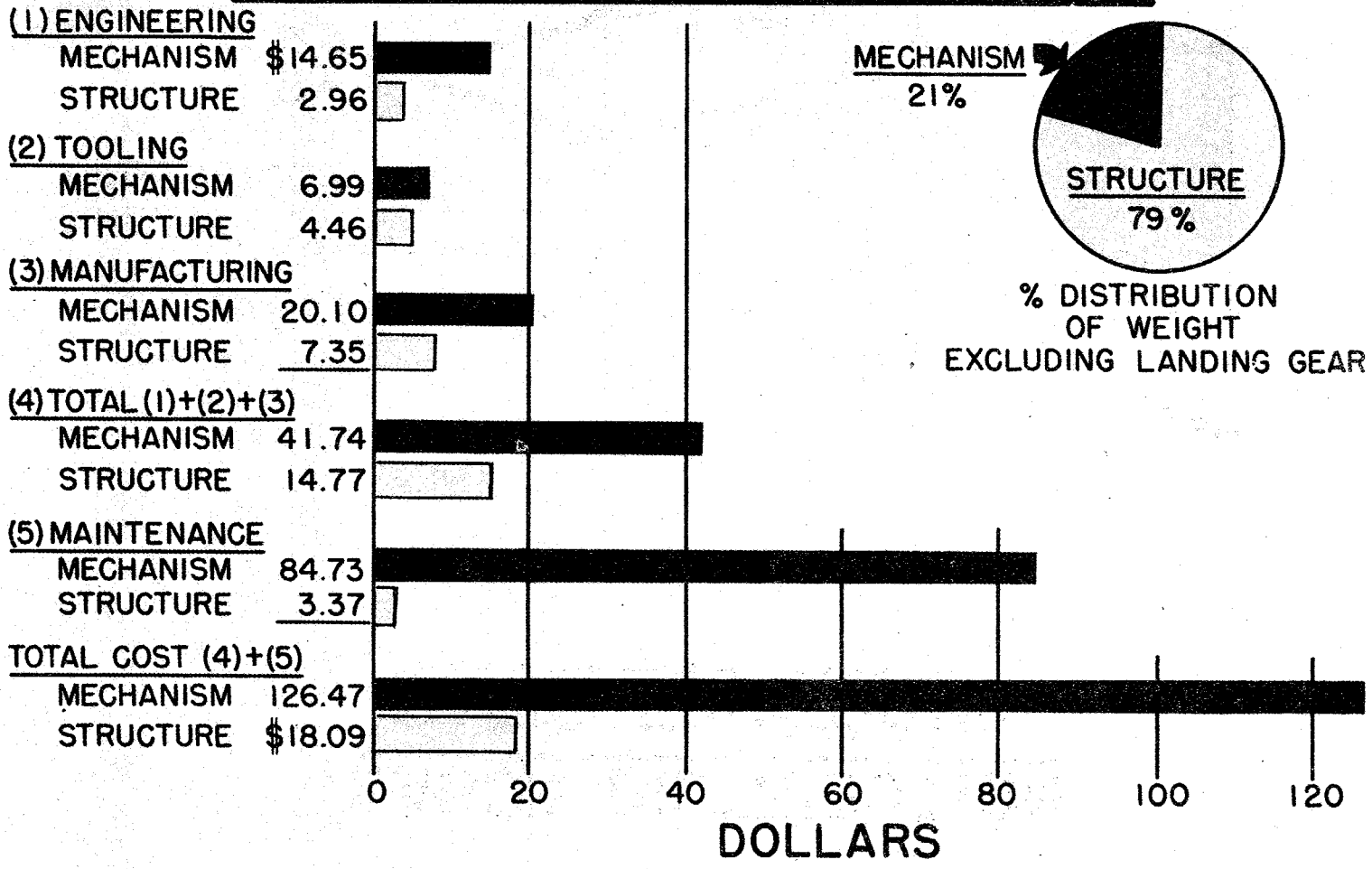
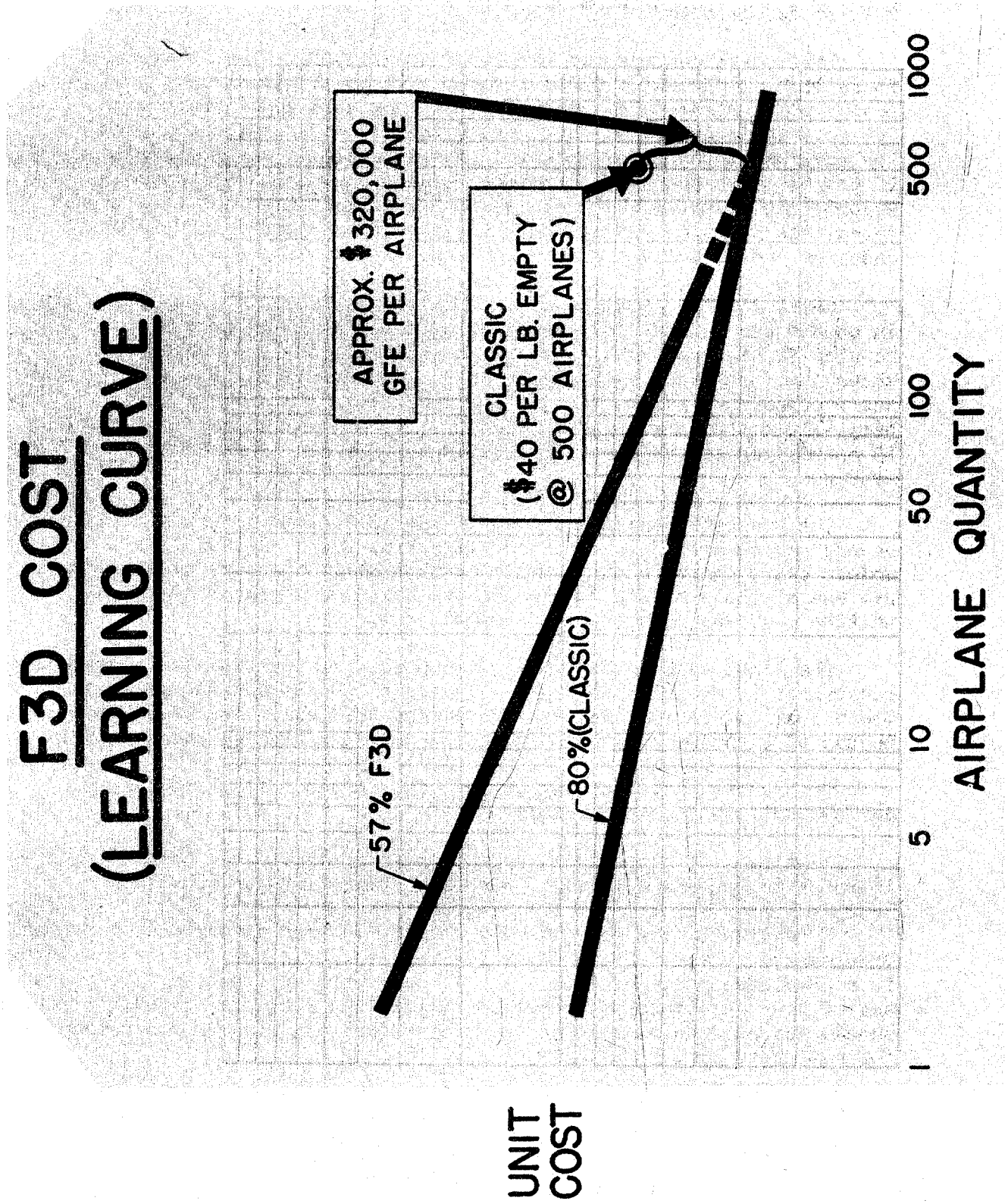


CHART 24


F3D COST
(LEARNING CURVE)
APPROX. $320,000
GFE PER AIRPLANE
CLASSIC
($40 PER LB. EMPTY
@ 500 AIRPLANES)
57% F3D
80%(CLASSIC)
UNIT
COST
1
5
10
50
100
500
1000
AIRPLANE QUANTITY

gear and new engines resulting in much testing. Also the structural design turned out to be favorable for large production. The learning curve for the F3D based on best available data now indicates that it will be in the order of 57 percent.

This chart conveys two very important points. The first, that it is very expensive to build airplanes in small quantities; the second point that--based upon the best available cost information for government-furnished equipment--the cost of the airframe plus the government-furnished equipment would result in an airplane cost if projected to the 500th airplane, equal to 40 dollars a pound. Beyond that quantity the curve would probably flatten out to a higher percentage learning curve. This is however, another fairly accurate check on the 40 dollars a-pound cost previously discussed.

Chart 26, following page, illustrates the annual plant production in pounds per square foot, considering total building area of the Douglas-El Segundo Division at various dates. The upper black bar shows that the average of the aircraft industry during the wartime peak was 9 pounds per square foot of building area. The second, light colored bar, illustrates that the El Segundo wartime peak reached approximately 15 pounds per square foot, or more than 50 percent greater than industry average.

The present scheduled output of the El Segundo Division is only four pounds per square foot. This low figure is the result of five different models being constructed in small quantities at the same time, and all but one of these models is high on the learning curve; whereas the wartime peak was based upon one model only.

The light colored bar is a plant potential for the models now under construction, assuming they are all carried to the optimum point on their learning curve. All the figures of this chart are based upon pounds of airframe produced within the plant, excluding subcontracting.

This chart indicates why ample space is necessary, especially during early production periods.

Gentlemen, I hope the material I have presented has been of some interest to you and will be of some assistance in your studies.

I realize I have touched only lightly on many of our most important problems and that it is almost impossible to cover the subject completely in a 45-minute prepared talk. I will be very happy, however, to answer any of your questions or to discuss any of the subjects in further detail should you care to have me do so, either now or during this afternoon's informal sessions.

ANNUAL PLANT PRODUCTION
POUNDS PER SQ. FT. TOTAL AREA

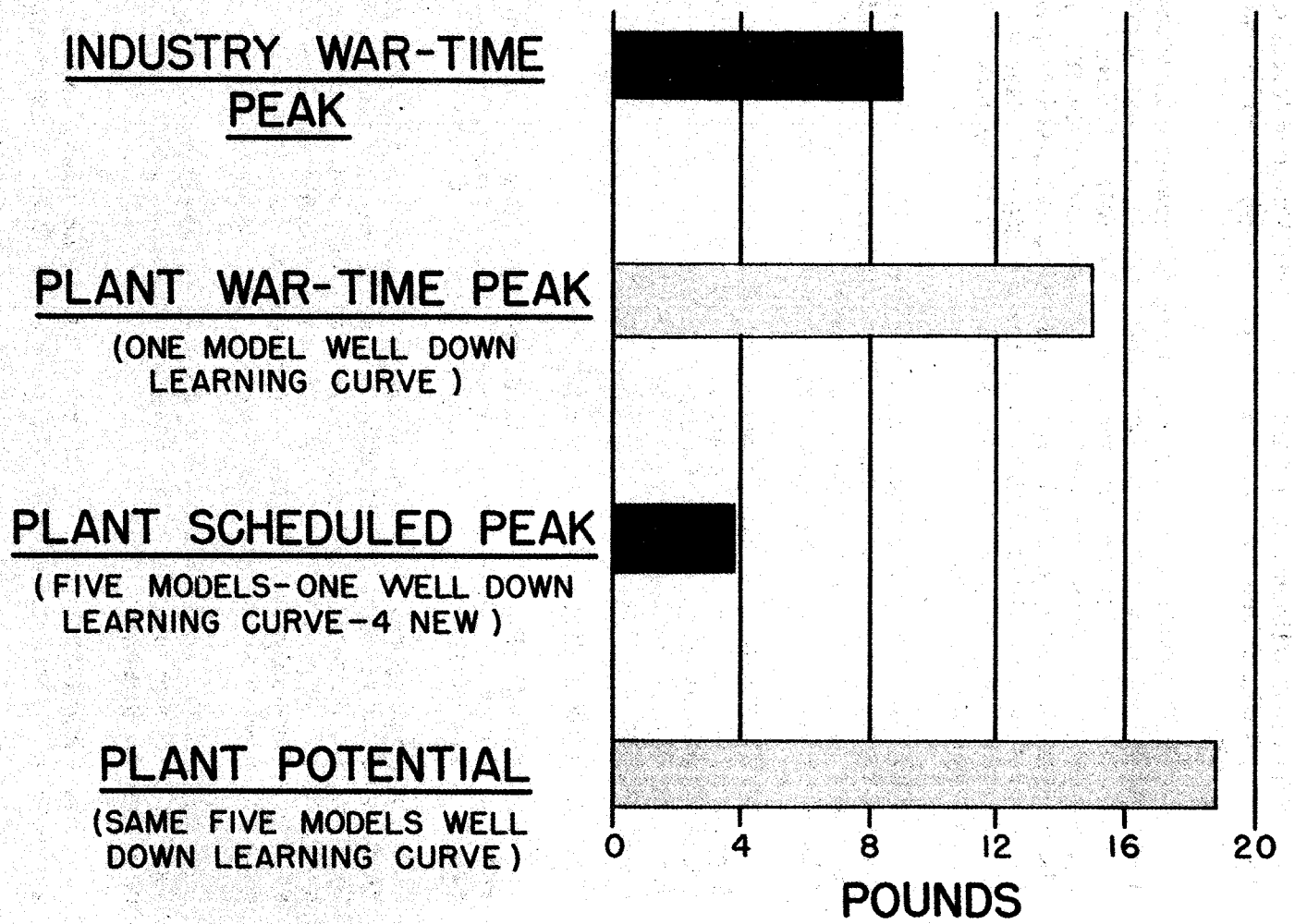


CHART 26

1445

It has indeed been a pleasure and a privilege to be with you and I wish to thank you for the opportunity of being here today.

QUESTION: In your example of those couplings, you indicated that as an example of overstandardization. It appears to me that it is an example of understandardization, in that the standardization activity hadn't been kept virile enough to keep up with improvement in design.

MR. HEINEMANN: Yes. I used the word "overstandardization" because that is the way the designers had used it. It is just that standardization is such a tremendous problem, it is awfully hard for the people having to do with it to watch all these little things. This is where responsibility comes back to industry. We have to point the way. It is particularly true that once a thing like that becomes obvious, it takes so long to put it into effect. I think we should be trying to improve the system.

QUESTION: In your material lead-time table, there seems to be a little discrepancy. Lead time on forgings was 12 to 14 months; on castings and extrusions, 3 months. That doesn't correspond to anything I have seen. Is that right for castings and extrusions?

MR. HEINEMANN: Yes. We make our own patterns as most plants do. A pattern can be made in a matter of days, two weeks at the most. Castings are usually poured in local foundries, and there is no reason for long lead time for castings because the mould doesn't take more than a day or two to make.

QUESTION: What about extrusions?

MR. HEINEMANN: Extrusion dies are very simple. The average doesn't run over 40 or 50 hours time, whereas forging dies may take a month or two of a die sinker's time and may be confined to the work of one man.

Forgings appear to be very simple production methods and I think that is where we made our biggest design mistakes during the last war. We thought for years that when M-day came, we could turn loose and forge everything. A good many people did that--we made our share of mistakes at our plant--only to find that everyone was doing the same thing. Diesinkers were scarce and we couldn't get die blocks.

QUESTION: In your cost comparison on forgings you had 600 parts and forging was considered to be uneconomical. Where would the cut-off point be on quantity?

MR. HEINEMANN: The cut-off point doesn't always occur at the same quantity. It varies considerably. We will find it is sometimes as many

as 100 parts. As a general rule, we try to limit forgings to quantities of half the number that we have. If we have 100 airplanes for which we need 200 parts, we try to make forging economical for 100 parts in order to anticipate changes which are bound to occur. But the cross-over point is anywhere from 100 to 1,000 according to the nature of the part.

QUESTION: You mentioned that growth factor and show the load in the F3D at about 22 percent of the gross weight. What did we lose in performance in adding that load?

MR. HEINEMANN: As I remember it, the 22 percent was the percentage of gross weight in the pilot and equipment, armament and electronic equipment, and so forth. We couldn't have taken it all out. If we had taken the radar out and used a simple sight, we could have saved about 1,000 pounds of weight. Had we applied the growth factor to that and built a smaller airplane, it would have weighed considerably less than it did. We couldn't do anything about engines in that particular case. If we just took the radar out alone, there would have been from six to eight knots difference in speed.

But in any new design, during the bid invitation stage, it is important to keep equipment down because every pound of equipment you call for does increase the gross weight by 10 pounds if performance, range, and strength are held constant.

CAPTAIN HALE: Mr. Heinemann, it is time for the luncheon and we must close. I wish to thank you for a very interesting and well-organized lecture.

(2 Apr 1953--750)S/ss