AN EXPANSION OF THE IMPROVEMENT CURVE TO ALLOW ITS USE WITH A COMMON/PECULIAR PRODUCTION MIX

W. W. Baker
General Engineer
Cost Analysis Division
Aeronautical Systems Division
Air Force Systems Command

J. Silver
Operations Research Analyst
Cost Analysis Division
Aeronautical Systems Division
Air Force Systems Command

March 1967

21

AN EXPANSION OF THE IMPROVEMENT CURVE TO ALLOW ITS USE WITH A COMMON/PECULIAR PRODUCTION MIX

Presenter: W. W. Baker
General Engineer
Cost Analysis Division, Aeronautical Systems Division, Air Force Systems Command

Co-author: J. Silver, Operations Research Analyst, Cost Analysis Division, Aeronautical Systems Division, Air Force Systems Command

INTRODUCTION

After WW II there occurred a considerable period filled with glowing reports on the value of the Improvement Curve Technique. Of late, however, it has become popular for some personnel to write brusque little papers for trade magazines emphasizing the faults of the Improvement Curve concepts and minimizing any importance. One recent paper, by a management consultant, devoted some space to the thesis that all curves merely reflect the manufacturers budget practices, provided no other significant information and should be abandoned. There are even jokes. Many may have seen the cartoon of an 80% slope on log-log paper with the caption, "the greatest thing since the invention of the crystal ball."

Other criticisms have been made to the effect that contractors always "sell" the Department of Defense high starting points and thereafter find no difficulty in achieving high rates of improvement in cost. The detractors, as is often the case, generally stop just short of providing constructive help. Almost all criticisms of the improvement curve have some basis in fact. However, to put the problem in proper perspective, the cited disadvantages must be weighed against alternate techniques of projecting resources. Fortunately for this exercise, there is no problem. Alternate or competitive techniques are conspicuously absent.

As is the case in the field of Education, many users berate and batter their best tool without regard to the availability of a substitute, thus, the IQ test and the Improvement Curve share the same stigma; "they are only used because no one can think up anything better." This statement is in itself a most powerful reason to support the Improvement Curve. It is agreed additional refinement effort is required with changing times. Also, as will be outlined, the original concept was based on

NON-HOMOGENOUS NATURE OF AIRFRAME CONSTRUCTION

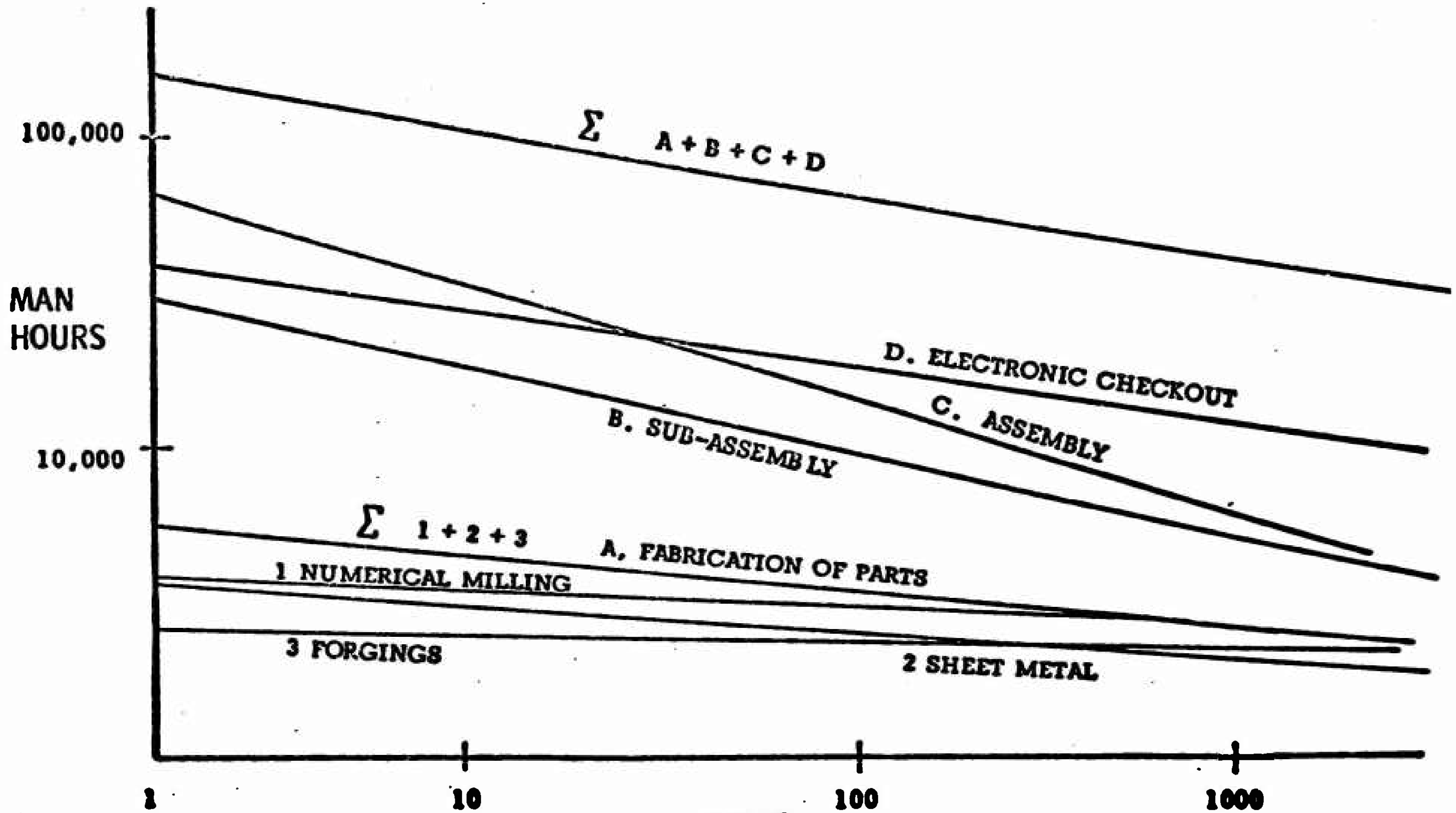


Figure 1

certain premises which if not met, tend to create serious doubts in the mind of the user as to the overall applicabilities of the techniques. These premises are:

a. Low Engineering Changes

b. Homogeneous Article Construction

c. Sequential Model Production

A low ratio of engineering change cost to total cost is fundamental if we are to use historical experience as a base on which to project future costs. Certainly, the projection of experience from a limited number of articles to calculate the cost of thousands of articles without considering the possible technical instability of the item being projected is foolhardy. This is one reason data banks runneth over with noncomparable cost data. Suffice it to say, it can be argued that an article with a 7% design change each year (unless the same portions are being redesigned over and over) cannot be defended as realistically projectable on a single curve. New portions certainly should not carry the same unit learning as their fellow portions which have been unchanged for many units. When the volume of new to old becomes significant, incompatibilities arise. It is recognized that in most cases, "comparable" historical data is also diluted by the engineering change factor. Thus, any comparisons made against historical data with a supposedly like rate of change may not be too noticeable. This still doesn't make it right. The question of how much alike makes one uneasy at least.

Secondly, it goes without saying that homogeneous articles simply do not occur as a natural phenomenon in an aircraft program. No portion of an airframe is homogeneous, or manufactured of many identically sized pieces. Labor needs vary by weight and complexity of major structural sections and within portions of these sections. They vary by task and there is no common denominator. The projection of all labor trends by a single curve, as shown by Figure 1, thus reflects a highly optimistic picture since obviously, management and labor should be able to effect labor savings on some portions with far more ease than on others. For example, those portions of the aircraft weight composed of forgings, due to the nature of the process, cannot be produced at a sharply reduced cost per sequential unit. Conversely, those sections wherein the work tasks are primarily sheet metal fabrication, or assembly, may have a very high potential for improvement due to management innovation, improved tools, redesign, etc. As a consequence, all the labor trends of fabrication, subassembly, assembly and electronic check-out and field operations may become a part of a single curve which is a summarization of the many individual specialized labor elements which make up the total. Comparisons of cost of this heterogeneous mixture with the historical cost of other aircraft mixtures, or even between models of the same aircraft, often leave something to be desired.

The third and final criteria, sequential production of models, formerly did not pose too much of a problem. In the past, as a general rule, new aircraft models displaced old models in the classic Detroit automotive pattern. One pattern of former aircraft production e visioned the development of a good basic aircraft design with built-in capability for improvement to take advantage of growth in engine power or the customers' needs. As advanced subsystems became available, and significantly changed the weapon or support system capabilities, a new model letter was assigned and production of the old model was discontinued. Improvement curve techniques generally allowed for the increase due to the new model by "bumping" the curve upward to reflect the new work and establishing a new start point at the point of introduction of the new model. It is critical to that technique that the new model entirely supercede the old, otherwise a joint curve would occur which would have relatively little management relevance as to slope and individual model learning.

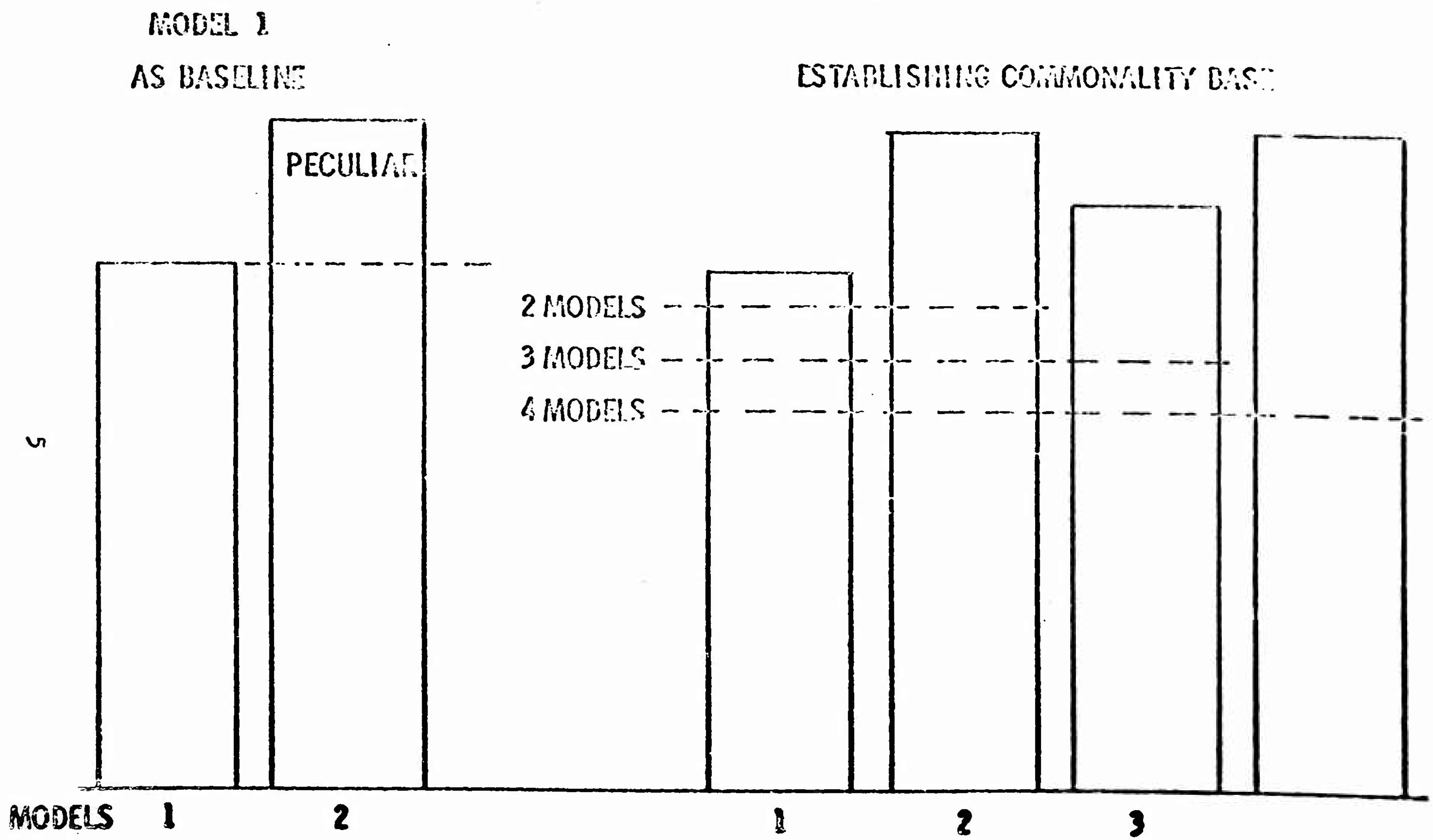
DISCUSSION

It is in the sequential model concept that the greatest change has occurred in recent years and thus caused the introduction of more complexity in cost procedures than either of the other critical elements. This paper is addressed to cost estimation of a common/peculiar mix of airframes in simultaneous production.

OSD policies limiting the number of aircraft to be developed for the special use of one service and the encouragement of the procurement of aircraft with the capability of satisfying the requirements of two or more services, or missions, has made the multiple aircraft assembly line a routine rather than a unique sight.

For example, the F-4 contractor is currently delivering six models to the inventory, the F-111 schedule requires the contractor to deliver five models of the aircraft simultaneously, and the A-7 program anticipates simultaneous production of two and probably more models. The OV-10 Coin Aircraft is scheduled for simultaneous delivery to all three services. There are many others. Some of these models are quite close in technical configuration of the airframe. Others are considerably different with substitutions of engines, wings, fuselage sections and landing gear. In many cases, the avionics or aeronautical details are quite different and these cause substantial structural changes in the airframe. Some parts may be common on all models and some may be peculiar to one or more.

COMMONALITY BASE



The condition described is not unknown to many cost analysts. Many attempts have been made to develop commonality indices which are representative of the degree of difference or the degree of commonality between models. Some of these indices have attempted to make use of common and peculiar counts of Engineering Drawings. Tool counts have also been used for the same purpose. In all cases studied, whenever single percentage indices were developed to describe the common/peculiar model relationships the indices have not been directly translatable to cost. Further, the value of some of these techniques is highly questionable since most have no sensitivity to schedule and some have no sensitivity to major configuration changes.

No small part of the problem with using some of these techniques lies in establishing the scope of applicability of the expressed percentage. As an example, if a count of engineering drawings discloses a 20% change for a new model, is it reasonable to assume that the manufacturing labor costs should exactly parallel the number of new drawings? The answer is obvious. A drawing change could either increase or decrease the manufacturing complexity of a part.

As a matter of fact, much of the learning which occurs in manufacturing stems from the engineering refinement which allows faster, cheaper and more simple manufacturing practices. Thus, a 20% redesign arrived at by a drawing count could not necessarily be extrapolated to support a similar increase in manufacturing labor, tooling cost or material.

The percentage of AMPR weight change is another technique with dubious bases in fact. In simple terms, AMPR weight is defined as basic airframe less engines, wheels, tires, avionics, etc. As a typical example, let us suppose a current fighter type aircraft for interceptor application is to be redesigned for tactical uses in close support. (There have been instances where the entire nose of an aircraft was removed along with the included avionics and a new nose and avionics substituted to support the different weapons delivery capability required for the new mission.) If the AMPR weight savings due to structural deletions are substantially balanced off by the added airframe then the apparent AMPR weight difference could be very low. Using only AMPR weight as a basis, an entirely erroneous cost conclusion could result from dependence solely on the AMPR weight differences between concurrent models.

In a number of previous studies which were examined, a commonality base was usually established with Model 1 as the reference. All labor or cost increases for Model 2 above this amount were considered as peculiar. Figure 2 illustrates the fact that basic common learning between models would almost always be less than the total of any model. Further, overall commonality between all models can be expected to decrease as additional models are added.

It can be safely concluded from review of various studies of commonality between models that a judgment on commonality between models which does not directly relate to cost of manufacture is of little value to detailed cost analysis in the acquisition period. This is not to say such an index may not have some value in determining system cost effectiveness and for use in comparative studies of total R&D, investment and operating costs.

The preceding discussion thus indicates that projections of labor changes for a new model which are based on differences in drawings, AMPR weight, or other, to secure a new start point may cause considerable errors to be introduced, and lead to a general lack of credibility in the results. This is so even though the preceding production item was discontinued in favor of a new model.

As previously mentioned, the introduction of a new model often has been portrayed by "bumping" the improvement curve at the point of introduction of the new model. Actually, the "bump" produced is the sum of the existing learning on those components tasks carried over from the preceding model production plus the mnaufacturing labor costs for the new and peculiar portions less the cost of those old portions no longer a part of the new model.

Mathematically, this can be expressed as:

$$uc\ (x) = (a + a')\ x^{b} \quad ; 1 \leq x \leq n$$

$$uc\ (y) = a(n+y)^{b} + a''(y)^{b'} ; \quad n < n+y \leq n + n'$$

$$1 \leq y \leq n'$$

Where x is the cumulative unit number of the old model and y is the cumulative unit number of the new model

n is the total number of units of old model
n' is the total number of units of new model
a is the first cost of tasks carried over
a' is the first cost of tasks dropped
a" is the first cost of new tasks for new model

The above pertains if the old model is discontinued with the introduction of the new. A more complicated problem arises if the older model is continued in production and delivered concurrently with the new model.

In that case, instead of a "bump" it becomes necessary to project two curves, one for each model. The curve for the old model is a composite of common and old peculiar effort.

SIMULTANEOUS PRODUCTION

(3 MODELS WITH SIGNIFICANT DIFFERENCES)

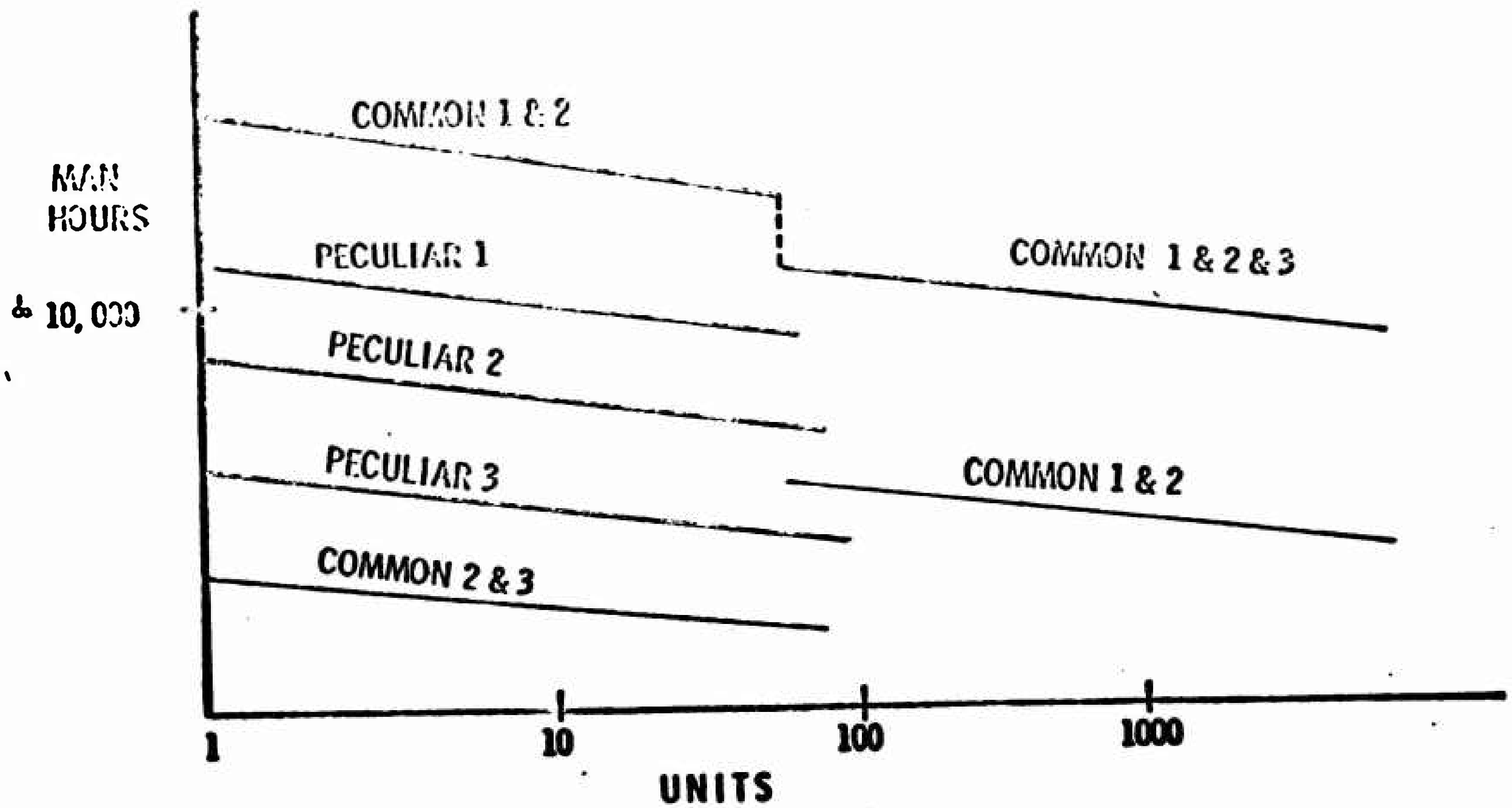


Figure 3

The curve for the new model is a composite of common and new peculiar effort. It should be noted the curve can only be used in conjunction with the overall manufacturing schedule since it is necessary to account for each unit of the total in order to ascertain the unit take-off location on each curve. Since the common is a part of both model curves, it logically can be identified and separately plotted as shown. This results in three curves: common, new peculiar and old peculiar. These can be expressed mathematically as:

$$uc\ (x) = a\ (x + y)^b$$

$$uc\ (y) = a\ (x + y)^b \qquad \text{Common}$$

$$uc\ (x) = a'\ (x)^{b'} \qquad \text{Old Peculiar}$$

$$uc\ (y) = a''\ (y)^{b''} \qquad \text{New Peculiar}$$

Where x is the cumulative unit for 1st model

When y is the cumulative unit for 2nd model and vice-versa

Theoretically, a third model could be easily handled using this technique by adding only a new curve for its peculiar. However, in practice, it is not reasonable to expect a new mission or design to require the exact common which resulted from the examination of the first and second models. The following curves, shown graphically on Figure 3, could conceivably result from the introduction of a third model:

Peculiar #1 Common All
Peculiar #2 Common #1 and #2
Peculiar #3 Common #1 and #3
Common #2 and #3

Mathematically, these can be expressed as:

$$uc_1(x_J) = a^{(1)}\ (x_1 + x_2 + x_3)^{b(1)} \qquad \text{Common All}$$

$$uc_2(x_J) = a^{(2)}\ (x_1 + x_2)^{b(2)} \qquad \text{Common \#1 and \#2}$$

$$uc_3(x_J) = a^{(3)}\ (x_1 + x_3)^{b(3)} \qquad \text{Common \#1 and \#3}$$

$$uc_4(x_J) = a^{(4)}\ (x_2 + x_3)^{b(4)} \qquad \text{Common \#2 and \#3}$$

$$uc_5(x_1) = a^{(5)}\ (x_1)^{b(5)} \qquad \text{Peculiar \#1}$$

$$uc_6(x_2) = a^{(6)} (x_2)^{b^{(6)}}$$ Peculiar #2

$$uc_7(x_3) = a^{(7)} (x_3)^{b^{(7)}}$$ Peculiar #3

Where: x_J is the cumulative unit number of model J

$x_1 + x_2 + x_3$ is the total cumulative unit number of all models at the schedule position of x_J.

$x_1 + x_2$ is the total cumulative unit number of models #1 and #2 at the schedule position of x_J, etc.

Using this form, there is no theoretical limit to the number of models which can be introduced if proper data is available.

Several problems arose during the development and use of this technique on a recent analysis. Since the cost separation of models by previously stated assumptions as to AMPR weights, drawings, etc. was found to be unsatisfactory, a better and more accurate method was sought.

An attempt was made to develop the manufacturing impact at total model level due to differences in design. It was found not practicable to perform an assessment at the total model level since it was necessary to consider the impact on each major component of each model. At the component level, many major differences became apparent. There is an even more cogent reason to analyze each model at the component level. Development of data at that level allows the total model labor to be developed as the sum of the individual component learning slopes.

A survey was made to determine if labor data was available for fabrication and sub-assembly of each major portion of the aircraft and for the Final Assembly and Electronics and Field Operations on the complete aircraft. Data on current production was not readily available which differentiated between the Fabrication and Sub-assembly areas.

In lieu thereof, data was available by component from the nearly 100 separate component labor accounts which had been established for each model. This was consolidated to reflect 16 major components and final assembly and check out.

Basically, each labor account identified one or more stations on the assembly line. At each station, some portion of the aircraft was fabricated or assembled using smaller components or sections produced in other departments. All the direct labor prior to that point was charged to that account. This data was available by aircraft component which represented the sum of all fabrication and sub-assembly. Final assembly and electronics and field operation was also available by model.

MAN-HOURS – ACTUAL PRODUCTION DATA UNIT

	COMPONENT	COMMON	PECULIAR 1	PECULIAR 2
A	PYLON	615	2,768	2,879
B	ELECT & F.O.	[illegible]	43,100	47,000
C	FINAL ASSEMBLY	7,697	7,692	10,030
D	A/C MATE	4,69[illegible]	16,572	18,000
E	VERT STABILIZER	1,020	560	499
F	ENGINE B.U.	7,079	1,581	1,361
G	WING STRUCTURE	29,835	2,653	7,000
H	FWD ELECT BAY	1,543	15,424	3,412
I	FWD & AFT CENTER FUSELAGE	44,231	22,995	4,935
J	STABILIZERS	5,306	745	332
K	AFT FUSELAGE	36,102	0	0
L	ESCAPE SUBSYSTEM	21,075	0	0
M	FIN & RUDDER	4,741	250	446
N	LANDING GEAR	350	200	180
O	OUTSIDE PRODUCTION	45,000	2,000	6,000
	TOTAL	202,339	116,401	102,642

Actual labor data by aircraft unit number was summarized for each major component for the two models in simultaneous production. This was identified as common, peculiar to #1 and peculiar to #2. Figure 4 shows the differences between models.

The segregation was established by the contractor from analysis of fabrication and sub-assembly costs. The Final Assembly and Electronics Field Operation labor was maintained by aircraft unit number. By analysis of task and man-loading schedules a segregation was available as to the common and the peculiar labor hours required for each model. Thus, basic data was available upon which to base common/peculiar labor projections of the two models.

As previously mentioned, it is the policy of the Secretary of Defense to minimize the number of aeronautical systems with very similar characteristics. In addition to the existing two models, two additional new models with changed missions were projected for this aircraft program. Only broad technical mission changes and new armament had been identified at the time of the study.

Each new model was analyzed and a technical comparison made by major aircraft component with the equivalent components already in production. This analysis first considered the obvious structural differences between models including the number of parts, their size and complexity which would be eliminated. In the second phase of this analysis, the new technical requirements were analyzed and an estimate made of the percentage of new work which would be introduced. This analysis considered fabrication, sub-assembly, assembly and electronic check out and field operations.

An example of the effect of a simple change in a new aircraft model was the substitution of a complete component, such as a heavier landing gear for the old. This required that the existing landing gear slope not be utilized for that model and that a new landing gear component slope be established and used.

A representative of a more difficult type of change to include in a new model was the main bulkhead included in one of the fuselage components, and which incorporated the attach points for the above landing gear. If properly designed for a lower gross take-off weight, the new bulkhead will require redesign to take the stresses transmitted through the new and heavier landing gear. This requires the thickening of web sections of the bulkhead with no change in overall dimensions of the bulkhead. The remainder of the fuselage of which this bulkhead was a part was changed only slightly.

The estimation of the effect of this latter change required an assessment of the change in fabrication time and labor for the new bulkhead and also the effect on the entire fuselage sub-assembly, and assembly operations since all are included in the total man-hours for the fuselage component. This new work

TYPICAL COMPONENT CURVES

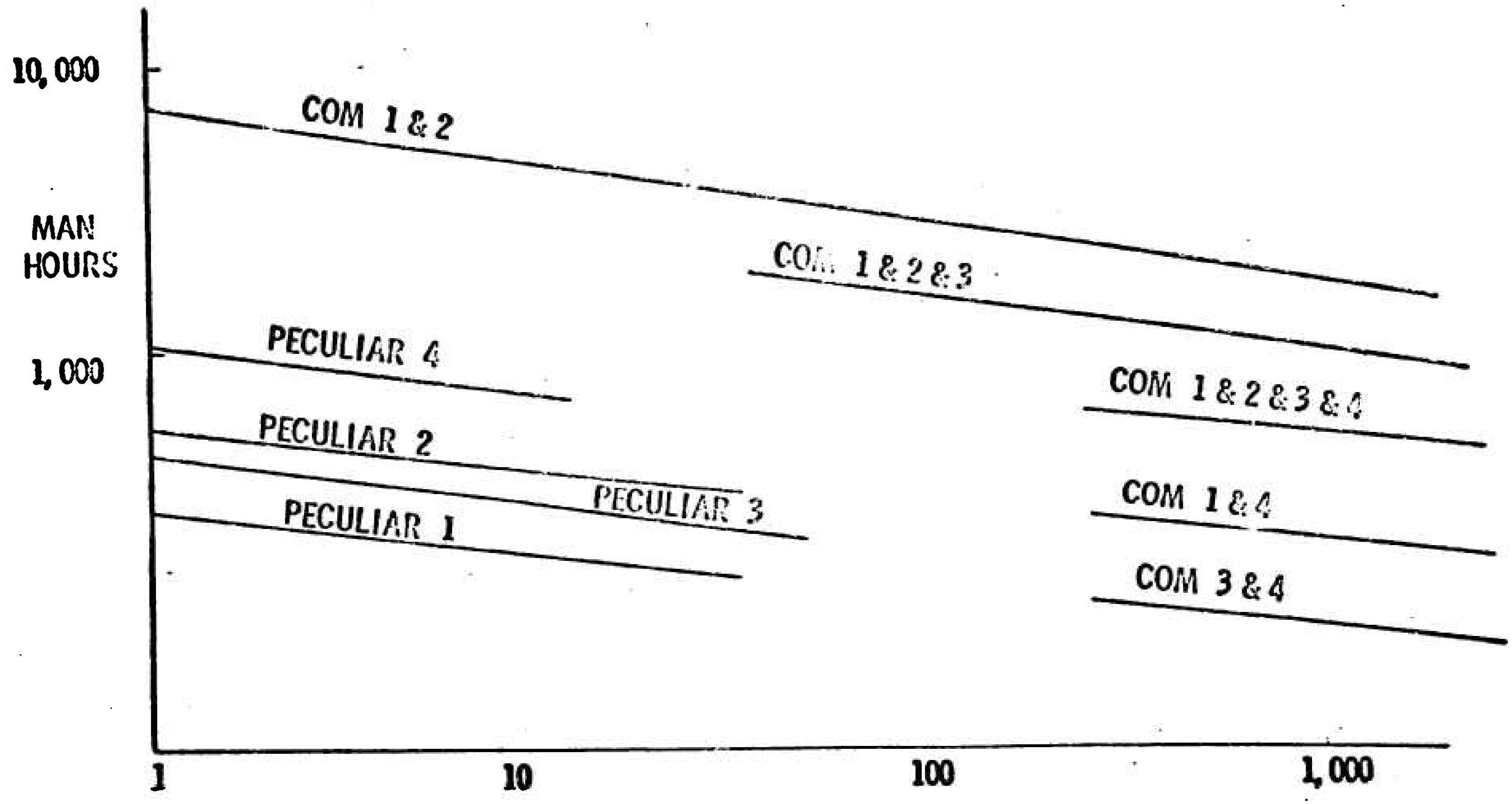


Figure 5

GENERAL FORMULATION

UNIT COST = $a_i (x + e_i)^{b_i}$ WHERE $X_{u_{i-1}} < x \leq X_{u_i}$

and x IS UNIT NUMBER BETWEEN $X_{u_{i-1}}$ AND X_{u_i}

a_i IS VALUE OF THEORETICAL UNIT NO. 1

e_i IS ADJUSTMENT TO x. NOTE: $e_i \geq -X_{u_{i-1}}$

b_i IS SUCH THAT 2^{b_i} = SLOPE

X_{u_i} IS UPPER LIMIT OF SEGMENT

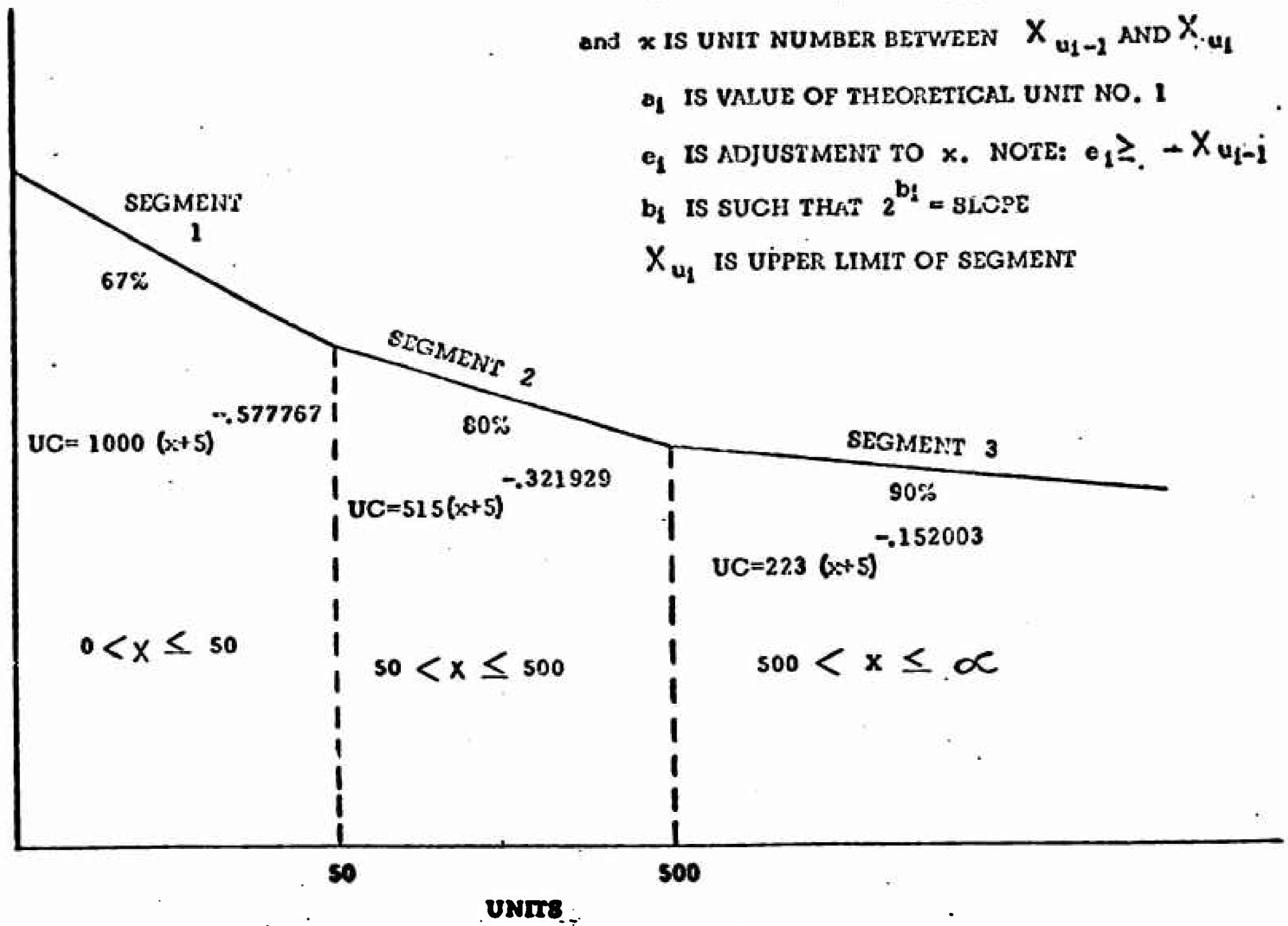


Figure 6

was projected from a new slope starting from the #1 production position while the unchanged portion of that fuselage component was continued on its improvement curve at a value equal to the original less the portion no longer required. If a portion of the work included in the component for this model is the same as the peculiar for another model, then this results in the creation of a common slope composed of a portion of the former peculiar and the peculiar from the new component. This "common peculiar" is a true common and is so considered. Figure 5 illustrates the resulting family of slopes for a typical component. Each of the major components of the two new models were analyzed in this fashion and an estimate made of the effect. The following had to be answered:

- the amount of reduction to the previous commonality level,
- the value to be assigned to any new common curves composed of two or more peculiars or any new common/peculiar mixes,
- the value to be assigned any new peculiar.

This technique is relatively easy to use for two models. Three models introduces more complications. Four were handled without strain, however, in the case being reported upon, many of the probable combinations of common/peculiar did not have an assigned value or were of such small value that they could be eliminated. After four models, the possible number of combinations becomes awesome and in the case of a program with a large variation on each component for each model all probable combinations might occur and the overall complexity could cause the problem to become unmanageable, in a practical sense.

A count of the curve segments and models indicated some 200 overall slope equations would have to be established. In addition, in order to obtain the proper learning by model and componen it would be necessary to perform individual computations for each monthly delivery quantity by model after the basic data was available.

The use of a computer to perform these calculations was an obvious solution. Figure 6 indicates the formulation used and is general enough to handle any practical problem.

This figure shows a unit progress curve following a 67% curve up to unit 50 with unit 1 redefined as #6, an 80% curve to 500, with unit 51 redefined as unit 56, and a 90% curve after unit 500, with unit 501 redefined as 506. The redefinition was on the assumption that 5 RDT&E units were produced and contribute to the learning process. The cumulative average progress curve can be formulated as:

$$uc(x) = a_i \left[(x+e_i)^{1+b_i} - (x-1+e_i)^{1+b_i} \right] ; \quad x_{ui-1} < x \leq x_{ui}$$

In this case the value of the xth unit is determined by the total value of all units up to and including unit x minus the total value of all units up to but not including unit x.

Using the previous example (the unit curve), let us suppose that it describes a common effort associated with 3 models. If the exact delivery position of each model is known, it is a trivial exercise to read off the uc(x) of each position and sum for each of the three models.

$$TC_j = \sum_{1}^{n} f(x)$$

Where $f(x)$ = uc if x is a jth delivery
$f(x)$ = o if x is not a jth delivery
TC_j = total cost of jth model

However, if the exact delivery position of each model is not known, an approximation to this can be made by utilization of the delivery schedule. Let $X.(t)$ be the total delivery quantity for all relevant models in time period t, and $x_j(t)$ be the total delivery quantity for the model in time period t.

$$\text{Then:} \quad TC(X_j(t)) = \frac{X_j(t)}{X.(t)} \sum f(m); \quad X.(t-1) < m \leq X.(t)$$

The above formulation assumes that the production positions for each model are equally distributed throughout the time period. This assumption is valid if the time period is relatively short, say a month (or less) for aircraft.

This formulation is equivalent to:

$$uc(X_j) = \frac{X_j(t)}{X.(t)} f(m); \quad X.(t-1) < m \leq X.(t)$$

and

$$TC(X_j(t)) = \sum uc(X_j)$$

Formulation 1 above is more convenient if manual computation is performed. However, formulation 2 is more convenient for computer manipulation since it permits more straight-forward programming. In particular, if there is a break in the slope of the learning curve during a month (t), formulation 2 is desirable.

After the computer program is available, the inputs required of a cost analyst are quite simple once he has developed the necessary data to differentiate between components of the models.

Computer Logic

In the case being reported upon, it was desirable to calculate the cumulative costs by contract for each of the four models. The computer program has available to it the cumulative monthly delivery schedule $X_j(t)$ for each model, and the cumulative quantity by "block" (e.g., Fiscal Year Buy, Contract) for each model, e.g., Y_{jl}, where l is the sequence number of the contract.

Define an "input set" as a collection of parameters that stipulates:

a. Model Identification
b. Title (e.g., Airframe Component)
c. Unit or cumulative average curve
d. Identity of models sharing this curve
e. Number of segments
f. For each segment
   (1) Number 1 value
   (2) Slope
   (3) Upper and lower limits
   (4) Quantity adjustment to unit number

Associated with each model schedule is a set of storage locations to accumulate costs, $Z_j(t)$.

The input set is read in, and a combined schedule $(X.(t))$ is formed by adding the schedules of the models stipulated. The $X.(t)$ schedule is costed, using the parameters specified in c through f above. Each time a unit is costed, it is multiplied by $\frac{X_j(t)}{X.(t)}$ and the result added to $Z_j(t)$.

Another input set is read in, and the process repeated. In this way, any number of input sets can be processed. No particular order is required, since the accumulation of costs is independent of order.

It should be pointed out that the above system requires as many input sets for a particular learning curve as there are models involved. However, the additional input required is compensated for by the additional flexibility and ease of programming permitted. For example, it may be desired to adjust one of the models (even though common) for special considerations. This methodology permits this to be done.

Finally, with the cost accumulation completed into $Z_j(t)$ for all j, the summarization of costs into "blocks" is accomplished by matching the schedule for each model with the unit number specified by "block" and accumulating. For example, "Block" 2 for model 2 calls for units 50 - 98. Time period 12 shows a total of 48, 13 shows 53, 19 shows 96 and 20 shows 100 for model 2 schedule. The cost for "block" 2 would be 4/5 of the cost in

COMPUTER READ-OUT

COMPUTER READ-OUT

PRODUCTION LABOR DOLLARS	FY 1	FY 2	FY 3	TOTAL
MODEL 1 - COMMON TO 2, 3	1.5	.7	1.2	3.4
MODEL 1 - COMMON TO 4	.5	.4	.6	1.5
MODEL 1 - PECULIAR	4.7	3.2	2.5	10.4
MODEL 1 - TOTAL	6.7	4.3	4.3	15.3
MODEL 2 - COMMON TO 1, 3				
⌇	⌇	⌇	⌇	⌇
TOTALS				
MODEL 1	6.7	4.3	4.3	15.3
MODEL 2	1.1	0.9	0.8	2.8
MODEL 3	2.2	1.7	1.2	5.1
MODEL 4	3.4	3.0	2.8	9.2
ALL	13.4	9.9	9.1	32.4

Figure 7

time period 13 plus the cost in all time periods through 19, plus 2/4 of the cost in 20.

In this way, subdivisions of the program can be shown, and cumulative totals used to show the total program. An example of such an output is shown in figure 7.

There are four major advantages of the technique. It has greater inherent accuracy due to the intense scrutiny of each component and the changes required for each model. Secondly, configuration changes are directly relatable to components and thus are reflected in the cost. Thirdly, there is an immediate benefit from the mandatory requirement that a computer program be used to perform the necessary calculations. This provides quick reaction capability for obtaining the cost effect of schedule and technical changes. Lastly, commonality indices are eliminated and all aspects of commonality are directly relatable to cost.

The procedure is not without disadvantages, or at least some problems. First, greatly increased data must be obtained on the technical details by model and component and on the cost of these changes in man-hours. Secondly, the examination of component differences requires the support of personnel highly skilled in relating technical changes to cost. These are not always available. Thirdly, computer support must be available and preferably the computer programming should be accomplished by those scarce individual(s) who are expert at both cost estimating and computer programming. Fourthly, greater detail must be reckoned with in updating an initial estimate prepared in this manner and the time and talent required will be substantially more than required for conventional estimates. Lastly, the procedure is of no assistance in furnishing a simple expression of commonality by model. Data from the output indicates that the commonality ratio changes continuously by model throughout the program. This precludes the support of a single index.

CONCLUSIONS AND RECOMMENDATIONS

The technique developed in the course of the study and which has been reported herein appears to have distinct advantages in the development and maintenance of a more accurate estimate of the labor required for a multi-model program.

Some of the disadvantages of the technique such as requirements for increased data and electronic computer support are not too significant in view of the great cost of most multi-model programs and the benefits to be derived. The obtaining of technically qualified personnel to accomplish the detailed component review could pose a larger problem.

The advantage of the technique would appear to considerably outweigh the disadvantages. The probability of schedule changes and technical configuration changes increases rapidly as more models are added to a multi-model program. This technique offers a way to anticipate in advance the cost interrelationship of these changes between models. In view of this almost constant change, or threat of change, on programs of this type, the quick reaction programming capability offered by the automated technique becomes almost mandatory for efficient program management and support of decision making.

In summation, available data indicates the technique should be utilized in either limited or full form, on all multi-model aeronautical airframe programs with a high dollar value.

The applications of this technique to other cost elements which make up the total airframe cost such as Engineering, Tooling and Materials should be productive, however, this application may be expected to present some problems due to the characteristics of those cost elements.

Finally, it is suggested the technique be considered for applications other than airframes where significant component learning has been observed and there is a high ratio common/peculiar component mix.