Material Thickness Control through Manufacturing Process Refinement

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Controlling the thickness of materials and coatings to more precise limits can yield increased vehicle performance through lowered weight at minimum or no cost increase. Historically, the processing of materials has tended to produce thicknesses of parts above the nominal thickness dimension specified. The control of machined parts, rolled mill sheet, and chemically milled parts is discussed. Specific examples and means are given explaining how increased control and closer-to-nominal thicknesses were obtained on the C-5A Program. The essential features of target establishment, communication of requirements, and process operator motivation are given.

Introduction

FOR the attainment of increased performance in aerospace structures, technology has been pushed increasingly forward but at the expense of an increase in cost. The search for higher performance has led to the development of new materials and methods of construction, which often have lead to sophisticated approaches. Existing technology can generate additional dividends by further examination and refinement. One such area is the control of material thickness. Material producing or removing processes have tended to produce component or part thicknesses on the structurally conservative side. The reason for this is simply that any mill, metal working shop, or manufacturing process is guided by economic considerations in trying to avoid producing material "too thin," with resulting scrap.

Purpose and Objectives

A body of knowledge has been developed through actual experience which lends itself to further extension and application. The techniques and means of achieving component thicknesses for all materials and process forms are very similar and constitute a common approach. An advancement in technology can be stimulated which bears directly upon performance, in terms of weight control, achieved at minimum cost.

Scope

Machined parts, chemically milled parts, rolled sheet, anodic coatings, organic finishes, and sealants involve the human element in setting thickness goals, and the process operators then are challenged to meet those goals. By specifying the stress-calculated nominal thickness as the manufacturing goal, the historical statistical thickness trend, occuring at above nominal, can be altered to bring actual part thicknesses nearer to the desired nominal thickness.

Presented as Paper 74-375 at the AIAA/ASME/SAE 15th Structures, Structural Dynamics, and Materials Conference, Las Vegas, Nev., April 17-19, 1974; submitted April 16, 1974; revision received May 30, 1975. Appreciation is extended to all of the many Lockheed-Georgia Company team members who contributed to this technical paper and to John R. Delbridge of the C-5A Weights Organization in particular. Additionally, the real success of the program was dependent upon the Manufacturing Process Operators of the Lockheed-Georgia Company and its suppliers and subcontractors. Encouragement for preparation was given by J.R. Roquemore, C-5 Materials and Processes Department Manager, and S.C. Rogers, C-5 Structures Division Manager.

Index categories: Aircraft Fabrication; Aircraft Structural Design (including Loads).

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Methodology and Approach

Where vast quantities of materials are used in aircraft, such as in the C-5A, a small percent over nominal thickness takes on tremendous importance. Recognition of the C-5A size and the stringent performance objectives established by the Air Force led to a thorough evaluation of every aspect of design and manufacture for the attainment of least weight to achieve the function desired.

An initial weight and tolerance study concerned the integrally stiffened, extruded, and machined wing panels forming a structural box with wing plan form area of 6200 ft.[2] The analytical approach to resolve the wing panel weight problem is outlined as follows:

1) Survey-data collection: Past programs were surveyed to ascertain the exact weight/thickness/tolerance relationships.

2) Statistical performance: It was established that actual part weight refleced an average part thickness midway between nominal and maximum dimensions.

3) Projection of past performance: A projection of past statistical performance, applied to the C-5 wing skin panels, indicated that 520 lb of excess weight (over nominal) would result, unless the past manufacturing trend was altered.

4) Methodology: It was determined that strength analyses are based upon nominal dimensions per MIL-A-8860, and that weight projections are based upon the best indication of actual final weight.

5) Manufacturing policy: The stated manufacturing policy was to produce to nominal dimensions, but inherent conservatism and lack of thickness control measures caused policy not to be implemented and put into practice.

6) Nominal thickness policy impact: Recognition was given to the fact that any managerial direction to apply the nominal thickness concept would require an evaluation of the risks involved, such as a) increased scrappage, b) the addition of more machine cuts, and c) the use of chemical milling as a sizing operation.

7) Implementation: The attainment of part thicknesses more nearly corresponding to the strength nominal thickness was achieved through a) training of operators, b) communicating engineering requirements to the people controlling the process, c) creating a nonpunitive climate, d) establishing incentives for nominal thickness attainment, e) improving thickness measuring devices, f) improving metal cutting equipment, and g) communicating the weight savings significance to the process operator.

Program Implementation

The most difficult part of any new program is to communicate clearly to the right people what needs to be accomplished, how it relates to overall objectives, and the

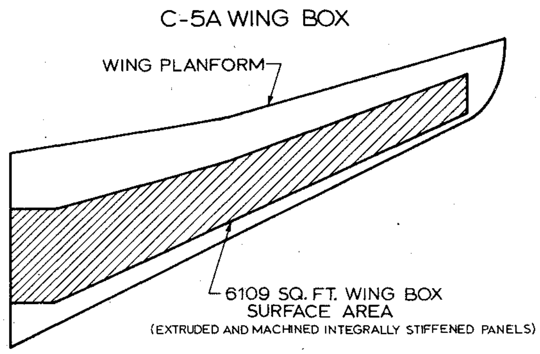

Fig. 1 C-5A wing box.

means for achieving implementation. In 1965, at the outset of the C-5A program, the thickness control concept was established. This marked the beginning point of an organized program that was to have impact upon every facet of design, manufacturing, quality control, and procurement.

It was appreciated readily that even 0.001 in. closer dimensional control would result in a substantial weight saving, considering such a large wing surface area as depicted in Fig. 1. Additionally, integrally stiffened wing panel design had undergone much process refinement at Lockheed, as several aircraft programs had employed this design concept. Therefore, a significant amount of data were available for review and analysis. The fact that the Lockheed-Georgia Company had stringent weight/performance guarantees to meet, recognition that a huge potential existed in the thickness control concept, and that data were available with which to prove the point all led to the acceptance of the concept.

Review of past program data, such as shown in Table 1 and Figs. 2-4, became the basis for constructive effort. Implementation of the thickness control concept and policy was carried out through engineering drawing callout of weight limits based upon either nominal dimensions or nominal plus some allowance for manufacturing latitude. Planing documents, tool designs, facilities, and equipment all reflected the engineering requirement. Since a major portion of the C-5A manufacture was subcontracted, subcontract source documents and contractual arrangements were negotiated. In some instances specific incentive clauses were built into the contract. The success of the program is reflected in the subcontractor manufactured empennage integrally stiffened and machined skin panels, as shown in Table 2.

Thickness Control Concept Expanded

In a manner similar to that applied to the machined wing panels, the Lockheed-Georgia Company expanded the nominal thickness control approach to include the following:

1) All major machined parts: Both in-house and subcontractors were participants in a formal program. The concept was applied where the weight savings potential was large enough and the ease of accomplishment was such as to justify the increased cost at a reasonable cost per pound of weight saved. Complex and intricate shaped machined parts obviously were not the place to apply the thickness control approach. Much discretion had to be applied at the design stage, on an individual component basis, to consider all of the various parameters. Where the concept was applied judiciously, weight saving results were favorable.

2) Sheet material: Through proper measurement and statistical analysis of incoming sheet material, understanding of the mill rolling process, and exact specification of the desired thickness distribution curve, the C-5A aircraft was able to save some 900 lb of stuctural weight, at no appreciable increase in cost. This weight savings was based upon a usage of some 60,000 lb of aluminum sheet material per aircraft. The approach to the sheet material thickness control problem was much the same as for the machined parts. Actual thickness data were gathered, and a statistical analysis was conducted to define the magnitude of potential savings.

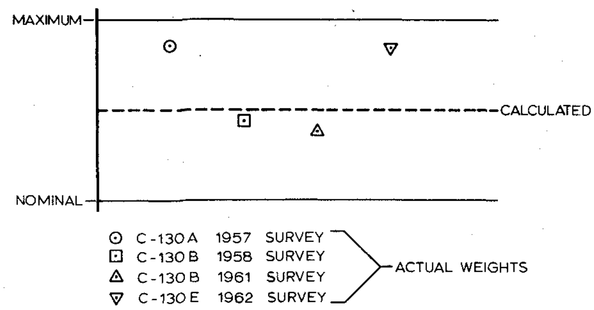

Fig. 2 C-130 wing panel weight.

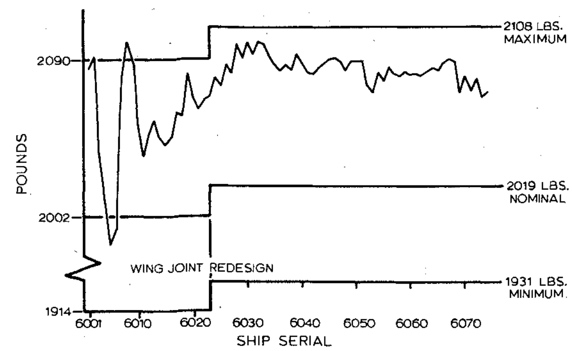

Fig. 3 C-141 actual center wing panel weights.

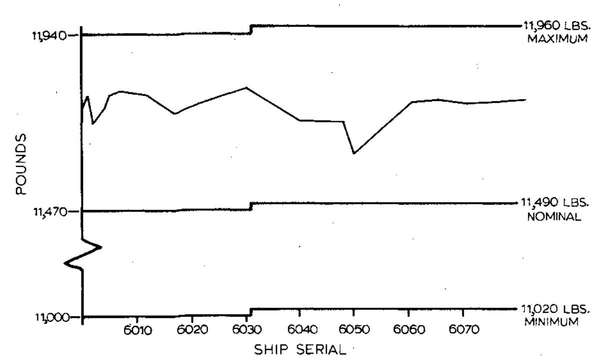

Fig. 4 C-141 actual IW + OW panel weights.

Table 1 Lockheed wing panel tolerance evolution

C-130	+0.010 −0.005
Jetstar	+0.008 −0.003
P3V	+0.006 −0.006
Electra	+0.005 −0.007
C-141A	+0.006 −0.006

Table 2 Example of results actually achieved on C-5A machined parts (empennage skin panels)

C-5A ship number	Weight set at target of nominal +0.001 in.,lb	Actual measured weight, lb
0002	4089.0	4056.7
0006	4094.0	4070.8
0007	4094.0	4081.3
0040	4114.2	4112.7

Table 3 C-5A sheet metal survey (summary of results)

Description order number	No. pieces	Total weight, nominal, lb	Total weight, actual, lb	Act./nom.
$0.063 \times 68 \times 100$	28	1,112	1,204	1.083
$0.090 \times 80 \times 130$	55	4,911	4,412	0.898
$0.086 \times 48 \times 144$	99	5,690	5,816	1.022
$0.020 \times 48 \times 144$	312	4,003	4,270	1.067
$0.125 \times 36 \times 230$	42	4,285	4,350	1.016
$0.068 \times 26 \times 420$	72	5,176	5m245	1.013
$0.016 \times 48 \times 144$	307	3,162	3,234	1.022
Totals[a]		705,916	716,553	1.015

[a]Totals shown are for 133 orders.

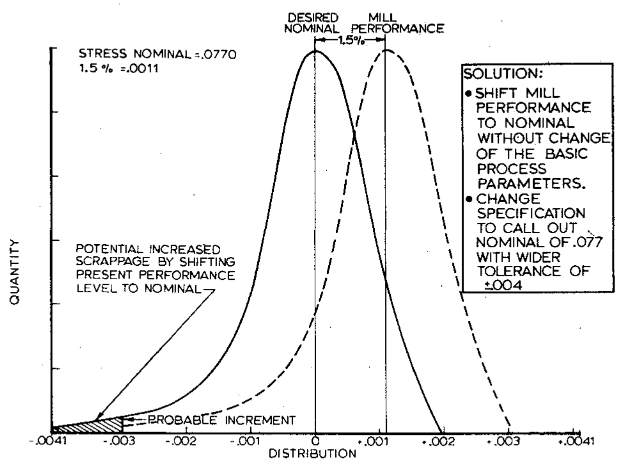

Fig. 5 Aluminum sheet thickness control (typical C-5A sheet: 0.080 × 60 in., ds 30007, tolerance + 0.000 − 0.006.

Typical results are shown in Table 3. A distribution curve was developed which defined the mill thickness performance in the rolling process, as shown in Fig. 5. These data became the basis for an agreement negotiated between the aluminum sheet suppliers and the Lockheed-Georgia Company, which communicated the objective and accounted for the variables involved.

3) Chemically milled parts: An objective to lower aircraft weight by some 200 lb was conducted successfully. A program plan for achieving thickness control of chem-milled parts was established which set up a shop system of control whereby every chemically milled part and each "cut" were carefully measured to ascertain further the "cut" needed to achieve nominal thickness. Features essential to the implemetation of the plan consisted of careful analysis of the following factors: a) alternative approaches, b) variables in the process, c) customary shop practices, d) segregation and classification of parts, e) specification requirements, f) procedure for adjustments, g) recording of data, and, h) responsibility.

4) Anodic coatings, organic finishes, and sealants: For reasons of weight control, cost savings, and functional performance, thickness control is applicable to coatings in a manner similar to that for metallic parts. Significant reductions were implemented in these areas. In each instance it is necessary to effect control of the process operator if the desired results are to be obtained. Experience has shown that control is applied best and yields the most results if it is in the form of individual desire from within (motivation). This involves communicating what is needed, and then helping everyone involved become members of the team.

Conclusions

The significance of the Lockheed-Georgia Company C-5A Thickness Control program is that major weight savings were achieved through proper analysis of the potential, institution of control measures, and motivation of process operators. Several features stand out in this process refinement experience, as follows:

1) Scientific analysis of all material thickness trends resulting from manufacturing processes can be meaningful.

2) In the case of sheet material, paint, sealant, and similar items, a weight reduction results in a cost reduction, since the material is purchased by the pound.

3) For machined and chemically milled parts, additional control adds cost at a reasonable expenditure, if common sense and selectivity are applied.

4) Goal setting and motivation of operators are the key factors in performance attainment.

5) Attainment of exactly specified thicknesses results in a better correlation of engineering analysis and actual aircraft fleet performance.

6) Performance-oriented objectives, structural efficiency, weight savings, and cost/producibility disciplines can and should work in concert with each other.

Although the individual facets of this thickness control system are not new, the collection and organization of the various elements into a body of knowledge, as presented herein, can result in a transfer of technology to new applications.