The estimation technique of the airframe design for manufacturability

A Govorkov and A Zhilyaev
Institute of Aircraft Construction, Mechanical Engineering and Transport, National Research Irkutsk State Technical University, 83, Lermontova st., Irkutsk, 664074, Russia
E-mail: anton@el.istu.edu

Abstract. This paper discusses the method of quantitative estimation of a design for manufacturability of the parts of the airframe. The method is based on the interaction of individual indicators considering the weighting factor. The authors of the paper introduce the algorithm of the design for manufacturability of parts based on its 3D model.

1. Introduction
There is a high variety of technical publications and guides that describe designs for manufacturability (DFM) for the aircraft industry [1, 3], particularly, the methodical basis of its support and evaluation. Nowadays, it is reasonable to consider DFM evaluation from early design stages when using CAD/CAM/CAE/PDM solutions. Therefore, to reduce the period of documentation preparation and to hasten the product launch, design engineers should do the following tasks:
- choose modern design solutions, an optimal fabrication variant and a structural configuration;
- choose part's design depending on its functions;
- use standard library features when designing the airframe (for example in Siemens NX);
- consider typical manufacturing processes for airframe parts;
- decrease the complexity of parts manufacture.

During the DFM process for an airframe, design engineers should take into account the scale of the manufacture, the production type, and the specifics of the plant to be sure that every part is manufacturable. In the pre-production stages, it is hard to evaluate DFM [2, 4] due to the lack of information (time rates, equipment list). To assure high DFM levels, one can make a qualitative evaluation using DFM properties and a quantitative evaluation by the indicators. Final DFM evaluations on pilot airframe manufacture are described below and were done by comparison of the author’s and manufacturer parts. While there is no analog for the part, the complex indicator must be set above 0.5. It is the value, which is determined by expert evaluations on an unfavorable combination of factors.

This paper proposed the method of DFM evaluation in the aircraft industry that focused on formalization of the process and customization of DFM indicators.

2. The method of quantitative estimation of design for manufacturability
Initial data for calculation of technological design parts are listed below (in Table 1).
Figure 1. Diaphragm of the airplane's brake flap

Table 1. Initial data for DFM evaluation

| № | Data title                               | Value                        |
|---|------------------------------------------|------------------------------|
| 1 | Data for geometric parameters            | Model parts, specification   |
| 2 | Amount of issue production per year      | 0-100 units.                 |
| 3 | Details' weight                          | Less than 0,100 kg           |
| 4 | Amount of element part                   | More than 3                  |
| 5 | Contacting with a theoretical contour    | yes                          |
| 6 | Material                                 | D16AT                        |
| 7 | Admission to the aerodynamic contour     | +/-1.0                       |

The quantitative DFM evaluation of the technological parts of the ‘aperture’ in the design phase and a comparison of technology options were realized using complex indicator [2]:

$$p = \frac{\sum_{i=1}^{n} k_i \varphi_i}{\sum_{i=1}^{n} \varphi_i},$$  \hspace{1cm} (1)

where  
- $k_i$ – value of $i$ – st quantitative DFM indicator;
- $\varphi_i$ – weight rate $i$ – st quantitative DFM indicator;
- $n$ – number of indicators defined by the expert, shall be more than 4

Table 2. DFM calculating summary

| № | DFM private indicator                  | Value | Weight, $\varphi_i$ | $k_i \varphi_i$ |
|---|----------------------------------------|-------|---------------------|-----------------|
| 1 | Amount of issue production per year, $k_{year}$ | 0,30  | 0,06                | 0,018           |
| 2 | DFM for split operation, $k_{tm}$       | 1,00  | 0,12                | 0,12            |
| 3 | DFM for shaping operation, $k_{fm}$     | 0,90  | 0,13                | 0,117           |
| 4 | Repeatability of products' element of construction, $k_{el}$ | 0,90  | 0,12                | 0,108           |
| 5 | Weight, $k_M$                          | 1,00  | 0,07                | 0,07            |
| 6 | Size, $k_{tm}$                         | 0,80  | 0,08                | 0,064           |
| 7 | Shape of the contours, $k_{f,ob}$       | 0,75  | 0,06                | 0,045           |
| 8 | Shape of the circuit, $k_{f,con}$       | 0,60  | 0,05                | 0,03            |
| 9 | Curvature level, $k_{l,cr}$             | 0,9   | 0,11                | 0,099           |
| 10| Contacting with a theoretical contour, $k_{aer}$ | 0,40  | 0,05                | 0,02            |
| 11| Contacting with a perimeter, $k_{TK}$   | 0,5   | 0,08                | 0,04            |
| 12| Details location in relation to conditional plane parts, $k_N$ | 0,8   | 0,07                | 0,056           |
| Total |                                     |       |                     | 1,00            | 0,787           |
Moreover, the values of DFM indicators are conditional. The amount of issue production per year ($k_{\text{year}}$) is described in chart 3 and evaluates the possibility of mechanization and automation of the parts manufacture process. The higher the amount, the more efficient mechanization and automation implementation, and thus reducing complexity will reduce the production price.

| №  | Amount of airframe production per year | $k_{\text{year}}$ |
|----|---------------------------------------|------------------|
| 1  | 1-10                                  | 0,1              |
| 2  | 10-50                                 | 0,2              |
| 3  | 50-100                                | 0,3              |
| 4  | 100-200                               | 0,4              |
| 5  | 200-300                               | 0,5              |
| 6  | 300-400                               | 0,6              |
| 7  | 400-600                               | 0,7              |
| 8  | 600-800                               | 0,8              |
| 9  | 800-1000                              | 0,9              |
| 10 | 1000 and more                         | 1,0              |

DFM indicator depends on the type of ($k_{\text{m}}$) split operation for the part manufacture process (Table 4) and on the technological cost of a blank.

| №  | DFM for split operation | $k_{\text{m}}$ |
|----|-------------------------|----------------|
| 1  | On milling machines     | 1,0            |
| 2  | On a milling machine from a template | 0,8 |
| 3  | The stamp               | 0,6            |
| 4  | Guillotine scissors      | 0,4            |
| 5  | Roller scissors         | 0,2            |

The DFM value depends on the type of the molding ($k_{\text{m}}$) operation in the production of shaped parts from sheets metal and on DFM properties: technological cost of a blank, technological simplicity.

While there are many types of molding operations for the 1-st part, the average value is determined by formula

$$k_{\text{m}} = \frac{\sum_{i=1}^{n} k_{\text{m}} p_{i}}{p}$$

where $p$ – total number of molding operations for details manufacture;

$k_{\text{m}}$ – DFM indicator value by $i$ – st parameter;

$p_{i}$ – number of $i$ – st type operations.

The indicators describing repeatability of the part' elements of construction ($k_{\text{el}}$), are taken from the DFM guides.

When the amount of elements of the construction is more than 40, the indicator value is considered within the range of 0,40…0,10.

Indicator $k_{\text{M}}$ depends on the weight of the part and can be determined in the DFM guides. The indicator takes into account DFM properties suitable only for airframe parts.

The indicator describing size of the parts $k_{\text{m}}$ can be determined in the DFM guides.

Indicator $k_{\text{f,ob}}$ takes into account the shape of the contours and depends on the purpose of whole part or its elements. The indicator is described in the DFM guides.
Indicator $k_{f,con}$ takes into account the shape of the circuit and depends on the purpose of whole part or its elements. The indicator is described the DFM guides.

Indicator $k_{iv,cr}$ takes into account the level of part curvature. The indicator is described the DFM guides.

Indicator $k_{ae}$ takes into account the aerodynamic contour allowance and is based on the detail's objective function.

Indicator $k_{T}$ takes into account the fact that the detail is contacting with a theoretical contour.

Indicator $k_{N}$ takes into account the details location in relation to conditional plane parts.

By using the method mentioned above, the values of $k_{i}$ and $k_{i}g_{i}$ can be found. These DFM indicators are estimated by experts' evaluation. The sum of the selected coefficients is equal to one.

Therefore the complex DFM value can be calculated by formula (1):

$$p = \frac{0.787}{1.0} = 0.787.$$  

The resulting DFM value for the aircraft part, namely diaphragm:

- new detail: 0.5;
- calculated by the formula (1): 0.787.

3. Conclusion

Comparing a comprehensive indicator, calculated by the method described above, and the basic indicator for a new part we can conclude that the engineering design is manufacturable and can be accepted for manufacture. This method is use-proven on the design of the aircraft parts stamped from sheet and fully describes the designing and manufacturing process.

Consequently, this method of DFM evaluation can be adapted in practice for the aircraft's parts that are hard to evaluate by the basic indicators due to the lack of information and to the fact that optional indicators can only describe the elements of the construction. Utilization of the method in the authors' DSS “DFM analysis system” at the early design stages for aircraft industry allows easy customization of 3D models. Even when the technological dictionary is changing rapidly, the design dictionary is consistent.

The time rate is changed by the improvement of technological and design engineering methods. ‘DFM analysis system’ can make it easier for a design engineer when the time rate is changing, but at the same time allows user to utilize these new technological improvements.

Thereby, utilizing “DFM analysis system” can ease the adaptation of the method for a specific manufacturer and accumulate technological knowledge. This provides the method's ability to adapt to the variety manufactures and its peculiarities. The method of feature recognition is suitable for 3D models based on hard-body elements, which are made independently of the model's creation technique.

References

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