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# Parametrics Investigation on Material selection for Outlet guide vane (OGV)

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**Abstract**- Design solutions for intermediate cases with integrated outlet guide vanes, which has the job to both carry load and direct the bypass air, are considered competitive for the future. The different concepts have also been evaluated with respect to material selection. Various design parameters by fatigue load consideration are described in order to design the outlet guide vane. Possible design solutions are discussed by considering fatigue load considerations. Critical factors when designing integrated outlet guide vanes are weight, cost, structural stiffness, sound damping and operating life. A solid vane design will make the target weight for the outlet guide vanes to be exceeded, especially when engines are getting larger in diameter due to a desire to increase the by-pass flow. Author concludes that Ti-6A1-4V is best alloy for the manufacturing of outlet guide vane from structural and chemical composition point of view
**Keywords** – Outlet Guide Vane, by-pass flow, Low Cycle Fatigue.

## 1 Introduction

The use of outlet guide vane arrangement is to remove the swirl from the flow coming from the fan. It connects the engine core structurally with the bypass duct and the engine mounts. For that reason, the outlet guide vanes have to fulfill aerodynamic requirements such as low pressure loss and large working range and turning of the absolute flow to 0 degree as well as the structural requirement to withstand the engine loads in all operating conditions. The real advantage is that additional struts downstream of the fan outlet guide vane become obsolete, which provides advantage for the engine length and weight and therefore the engine specific fuel consumption. At the same time the structural and aerodynamic requirements on such an outlet guide vane are intuitively contradictory. Hence, the design is more complex than for a conventional purely aerodynamic guide vane. In order to achieve the different requirements, the traditional iterative design process has been replaced by a multi-disciplinary approach, which delivers an aero mechanically optimized fan outlet guide vane geometry based on aerodynamic and mechanical boundary conditions and constraints [1].

## 2 Investigation on Material

Aerospace industry material demands include improved toughness, lower density, increased resistance to fatigue and corrosion. The boundaries of what materials can withstand are being constantly extended as manufacturers strive to improve the performance of the next generation of aircrafts.

Titanium and aluminum are two of the key materials facing these demands. These material alloys are used in a large number of aerospace applications, from lightly loaded components to load carrying structures in aircrafts and aircraft engines

The choice of material for the outlet guide vane involves a wide range of considerations including manufacturing processes, material costs, and availability.

When comparing the materials, the following properties were investigated:

Strength and stiffness - yield- and ultimate strength have to be high as the intermediate case- structure is one of the main load carrying structures in the engine

Manufacturability- can be manufactured by forging, casting and welding. If not, the result is often a more complex and expensive manufacturing.

Corrosion and oxidation- The rate of reaction at room temperature is low and the oxide layer that forms on the surface acts as a barrier to further oxidation.

Creep- Selected materials must have a high opposition to creep at the operating temperature to avoid failure in the engine,

The titanium and aluminum possesses all these properties to be used for aerospace structures. By comparing the mechanical and chemical composition of the alloys for the aluminum and titanium, we get to know that titanium alloy Ti-6A1-4V provides better solution for making the aerospace parts.

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The relationship between microstructure and mechanical properties of Ti-6A1-4V will now be addressed in more detail-

This alloy is an α+β alloy, with 6 wt.% aluminum stabilizing the α phase and 4 wt.% vanadium stabilizing the β phase. At room temperature, the microstructure at equilibrium consists mainly of the α phase (hcp) with some retained β phase (bcc). Depending on cooling rate and prior heat treatment the micro constituents and microstructures are divided into several types, namely grain boundary allotriomorph α, globular or primary α

Beginning with the fatigue properties, the dominating factor for high cycle fatigue (HCF) is the resistance to crack nucleation, whereas for low cycle fatigue (LCF) the resistance to propagation of the small surface cracks (micro cracks).

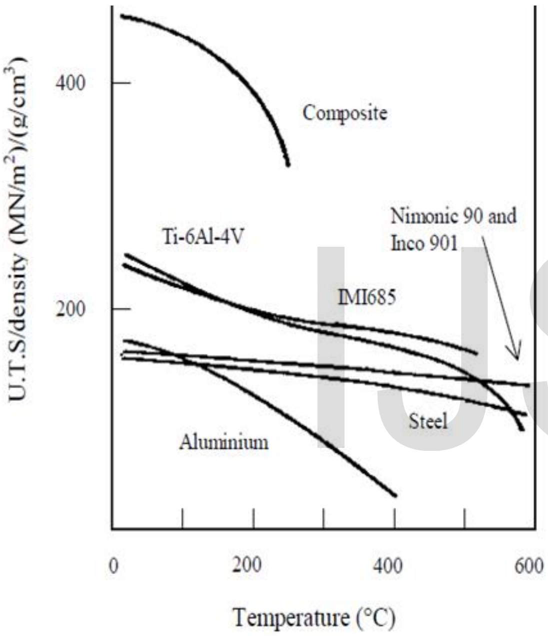


Fig No.1 Comparison of specific tensile strength vs. temperature [5]

Colony boundaries and martensitic plates are strong obstacles to micro crack propagation. Consequently, LCF strength generally improves with increasing cooling rate (decreasing colony size). The most important micro structural parameter determining the mechanical properties, for α+β titanium alloys, is the α colony size. With decreasing a colony size (decreasing slip length) the yield strength, the ductility, the crack propagation resistance (together with the crack nucleation resistance determining the LCF strength) are improved, whereas only the macro crack propagation resistance and fracture toughness are improved by a large a colony size. The latter effects are probably due to increased crack roughness and crack closure phenomena. The α colony size depends on the cooling rate from the β phase field and the β grain size, which limits the maximum a colony dimensions [5].

Another important parameter also shown to affect the mechanical properties for this alloy is the alloying element partitioning effect. The β phase contains lower concentration of those elements (especially oxygen) that promote age hardening by formation of coherent Ti3Al particles. This partitioning has the consequence that the α plates (lamellaes) formed from the β phase upon cooling will not respond as well to age hardening as globular (primary) a. Since for Ti-6A1-4V, the Ti3Al solvus temperature is about 550°C aging at 500°C will precipitate Ti3Al particles whereas heat treatment at 600°C or above will only lead to stress-relief. The alloy partitioning effect increases with the volume fraction globular a, leading to a lower strength within the platelet region of the bi-modal microstructure as compared to that in fully platelet structure. The partitioning effect has a negligible influence on ductility, on the propagation behavior of micro- and macrocracks and on fracture toughness, there being determined mainly by the α colony size. The dependence of yield strength on αp volume fraction, is determined both by the α colony size effect and the alloy element partitioning effect and usually shows a maximum between 10 and 20 vol% otp. For small volume fractions of αp the colony size effect dominates and for large volume fractions of αp the alloy element partitioning effect dominates.

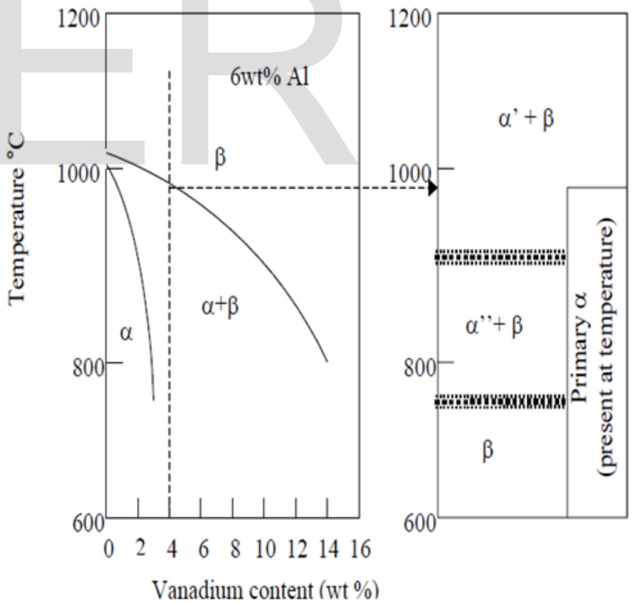


Fig No.2 A schematic illustration of microstructures occurring in Ti-6A1-4V after quenching from different temperatures [5]

The mechanical properties of Ti-6A1-4V are also affected by the texture of the alpha phase. Forming processes are usually performed by hot rolling or hot forging in the β phase field or in the α+β phase field which generally induces relatively sharp textures in the α phase formed upon cooling. Thus, adaptation of properties for a given application requires good control of the induced texture. Various investigations have been carried out to study the influence the deformation parameters (temperature, degree and rate) on microstructures and texture.

## 3 PARAMETRIC WORKDONE

The intermediate case and the integrated outlet guide vanes needs to fulfil several design criteria, all found in the design specification for an intermediate case structure.
The outlet guide vane should be able to transfer loads from the intermediate case fan hub frame and to the forward engine mounts. Furthermore, the outlet guide vanes need to withstand oxidation, corrosion as well as flight induced loads. The different design requirements are described in the following.

### 3.1. HCF (High Cycle Fatigue)

To achieve full engine life high cycle fatigue phenomena should be avoided by fulfilment of following criteria's:
1. No global Eigen mode below 2'nd order of Low Pressure Turbine
2. No local Eigen mode below 5'th order of Low Pressure Turbine
3.No local eigenmode in range of 1'st order of the fan blade passing frequency ±15%, based on Low Pressure Turbine speed
The resistance to HCF is in general determined by modal analysis and this would give the first global eigenmode of the outlet guide vane. The first eigenmode must be above 325 Hz to avoid the first five multipliers of the frequency caused by the low-pressure rotor. The low-pressure rotor is spinning at approximately 3900 revolutions per minute which is equivalent to a frequency of 65 Hz. The calculations can be seen below. [2]
F =3900/60 = 65Hz 1'st eigenmode of LPT
F = 65*5 = 325Hz 5'th eigenmode of LPT

### 3.2 Limit load capability

The limit load cases are to be considered as typical loads during a flight cycle and in ground handling of the engine. Examples of these load sets are when the engine runs at max thrust and decelerating while landing (thrust reverse). During these situations, specified deformation limits must not be exceeded. The intermediate case should withstand these limit loads without any permanent deformation, meaning that the local stress levels must not be above the yield strength of the material.

The limit load cases are:

1.Take of rotation: Max thrust, 2g downward, and lateral gyroscopic forces

2. Arbitrary Gust: Max thrust, 5g downward and l g laterally

3. Thrust reverse: Max revere thrust, l g downward

It is not only the thrust force that is imposed on the outlet guide vane during take-off but also gyroscopic forces due to the rotating engine shaft. When the shaft is spinning, gyroscopic effects will create an additional resultant force acting in the radial direction. Figure 4 illustrates this phenomenon when a moment around x and y will create an additional force, P, acting in the z-direction [2]. This is however not the most severe load case which the outlet guide vanes are subjected to. An even more severe load case is produced in the Landing sequence when the breaks on the aircraft not are efficient enough so a need for additional method for bringing the aircraft to stop is required. Additional braking force is accomplished by reversing the exhaust gas stream and thereby using the engines power for decelerating. The use of thrust reverse has a huge influence on the aircrafts landing distance. Also, the arbitrary gust load case is of more interest compared to the other two since this will create the worst limit load case.

### 3.3. LCF

A simplified flight cycle diagram, see Fig.3, is used to study low cycle fatigue, LCF. Fatigue occurs when a material is subjected to alternating stresses, over a long period of time. The most common type of loading cycle found in engineering applications is where the maximum stress (σmax) and minimum stress (σmin) are asymmetric (the curve is a sine wave) not equal and opposite. Since LCF calculations are time consuming and to simplify the work, LCF capability is evaluated by ensuring that the maximum stresses during a limit load case does not exceed 50% of the yield strength

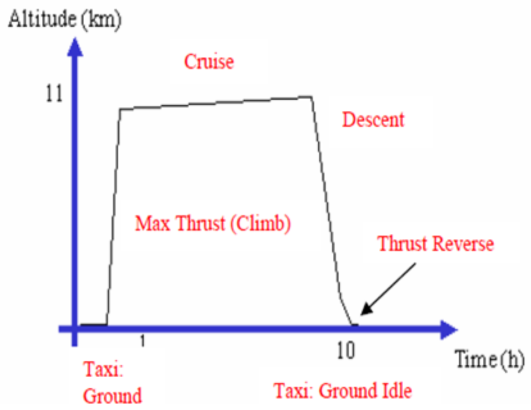


Fig 3 Typical Flight Cycle [2]

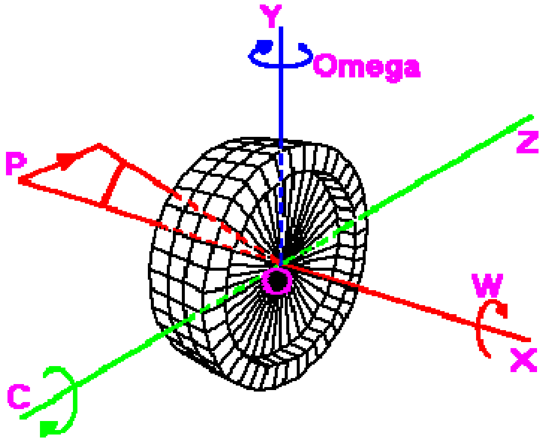


Fig.4 Forces created by the spinning moments of engines during takeoff [2]

### 3.4 Ultimate load capability

In certain situations, abnormal loads may act on the intermediate case-structure. These loads are defined as ultimate load cases. These extreme load cases must be considered when designing the intermediate case and examples of ultimate load cases are

| | |
|---|---|
| Emergency landing | 9 g in axial direction |
| Arbitrary Gust×1.5 | 1.5 x (Max thrust, 5g downward and l g laterally) |
| Thrust reverse x 1.5 | 1.5 x (Max revere thrust, l g downward) |
| Rotation imbalance | Rotating imbalance of 600 kN at fan CofG |

Fan blade out is considered as an ultimate load case. When a fan blade for some reason escapes from the fan root and hits the fan case a large turning momentum is induced on the fan case and on the intermediate case. The fan blade out scenario has been analyzed by imposing forces represent the unbalance created of the fan rotor. This force will approximately be 600 kN at the fan Centre of gravity. After a fan blade out accident, the component should have sufficient residual capability to withstand wind milling operation for 2,5h. [2]

During these ultimate load situations, plasticity is allowed only at small areas of the component but the ultimate tensile strength can never be exceeded anywhere in the structure.

A buckling analysis must also be made to evaluating the sheet thickness of the outlet guide vane. The buckling requirement for this kind of model is 3. Therefore, a buckling load factor of 3 must be obtained during the buckling analysis with a buckling force of 100 kN, since this force is estimated to rise during a fan blade out.

### 3.5 Hail ingestion

The engine is subjected to two hail ingestion scenarios and should withstand ingestion of both 25mm and 50 mm hailstones. The aim is to investigate if rupture will occur in the structure during an impact load. The 25-mm hail is considered to produce a limit load and should hence not cause any plasticity in the structure while the 50-mm hailstone is considered to give rise to an ultimate load case where small amounts of local plasticity can be tolerated.

To investigate this, a transient analysis must be done with forces for each of the concepts, material, sheet thickness and diameter of the ice hails. [2]

## 4 Result and Discussion

Historically, the outlet guide vane configuration has consisted of solid vanes manufactured in materials like aluminum and titanium. However, with a solid vane solution, the total weight for the outlet guide vanes will be too high, especially when the engines are getting larger in diameter. The trend towards large-diameter jet engines is driven by the fact that a larger diameter increases the by-pass flow in the jet engine, which is a desirable characteristic. One solution to reduce the weight of the outlet guide vane design is thus to make the vanes hollow. Making the outlet guide vane's hollow will however cause some manufacturing difficulties. Traditionally, solid vanes have been casted but since the configuration will be too complicated for a one-piece casting this is not an option for hollow vanes. Therefore, a fabrication manufacturing technique must be developed to make hollow vanes a reality. Different outlet guide vane design concepts have been developed. If a simple hollow vane does not fulfil the mechanical requirements that an outlet guide vane must withstand, a concept with a foam core has also been suggested. The reason to add a foam core is that the core will contribute to the configuration by adding extra stiffness and little extra weight.

## 5 Conclusions

Solid vanes with leading and trailing edges provide better solution for designing the outlet guide vane. Forging process is best for manufacturing the outlet guide vane as casting & other manufacturing process provides difficulty while manufacturing.

Titanium alloy Ti-6A1-4V provides better high specific strength ratio Colony boundaries as well as martensitic plates in Ti-6A1-4V gives strong resistance to micro crack propagation. The combination of high strength-to-weight ratio, excellent mechanical properties, and corrosion resistance makes titanium 6-4 the best material choice for many critical applications.

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