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UNIVERSIDAD POLITÉCNICA DE MADRID

Escuela Universitaria de
Ingeniería Técnica Aeronáutica

HELICOPTERS

Professors: ***Miguel A. Barcala Montejano***
Ángel A. Rodríguez Sevillano

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ROTOR BLADES

AIRFOIL SELECTION

- The choice of airfoil used is determined by the operational requirements of the helicopter.
- The operating conditions of the airfoil are highly dependent on the flight configurations.
- It is impossible to define an optimal airfoil without encountering a conflict in requirements.

AIRFOIL SELECTION

- It depends on the section along the span of the blade.
- Combine:
  - Advancing blade characteristics (high value of divergence Mach resistance for low values of C_L), with
  - Retreating blade characteristics (high value of $C_{L\ max}$, for low Mach).

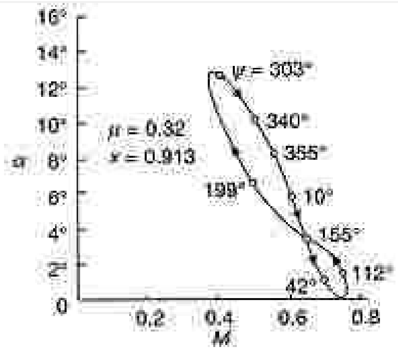

Fig. 6.31 'Figure-of-eight' variation of incidence and Mach number

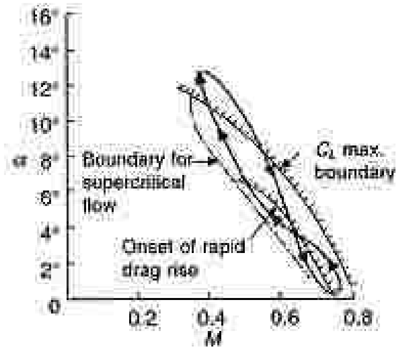

Fig. 6.32 Stall and compressibility boundary

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Ángel A. Rodríguez Sevillano

AIRFOIL SELECTION

- It should also maintain good lift drag ratio L/D to the intermediate values of C_l and Mach in the blade that moves back and forth in vertical flight.
- Furthermore, the low moment coefficient should be of interest (C_m of the order of 0.01 to minimise the twist of the blade and the stresses in the controls of the pitch variations).

AIRFOIL SELECTION

- Initially, conventional airfoils were used, well known for their use in aviation, such as the **NACA** 0012 or the **NACA** 23012, were used until the 70s.
- Subsequently, development started on their own family of airfoils fulfilling the new requirements and adapted to the particular operating conditions of rotary winged vehicles.
  - For example, the family **Oa**xxx involves the collaboration *ONERA/Aérospatiale.*
  - airfoils **VR**xx have been developed by *Boeing Vertol* or **DM-H**x by *DFVLR y MBB*.
- This development also allows airfoils designed with the objective of reducing drag and, consequently, the power needed for the helicopter.

AIRFOIL SELECTION

- Thus different types were developed, such as the type BERP.
- The new designs of blade tips are the results of airflow study in this area and the attempt to adapt the velocity of supersonic flow in certain areas, to subsonic by the occurrence of shock waves.

AIRFOIL SELECTION

- On the actual rotor blade there is a variation of airfoils along its span in order to optimise the performance.
- Criteria:
  - Maximum lift coefficient $\mathbf{c_{lmáx}}$ high – greater than or equal to 1.6 – for Mach numbers around 0.4.
  - Drag divergence Mach number M_{DD} high – more than 0.75 or 0.80 - for small lift coefficients, i.e., close to zero.
  - Moment coefficient about the aerodynamic centre of the airfoil c_{mCA} low – lower in absolute terms than 0.01 – in the range of Mach numbers expected on the blade.
  - Relative thickness of the airfoil around 12% or 13%.

AIRFOIL SELECTION

- Summary table.

	airfoil	C_{lmax} to M=0.4	Mdd to Cl=0	Cd to M=0.6 and Cl=0.6
1	NACA 64A608	1.400	0.7550	0.0060
2	NACA 64A(4.5)12	1.430	0.7350	0.0085
3	NACA 64A612	1.450	0.6900	0.0080
4	NACA 64A516	1.470	0.6850	0.0089
5	V23010-1.58 0º TE tab	1.460	0.7940	0.0108
6	V23010-1.58 3º TE tab	1.420	0.7980	0.0110
7	VR-7 0º TE tab	1.500	0.7420	0.0081
8	VR-7 -3º TE tab	1.460	0.7500	0.0084
9	VR-7 -6º TE tab	1.410	0.7570	0.0090

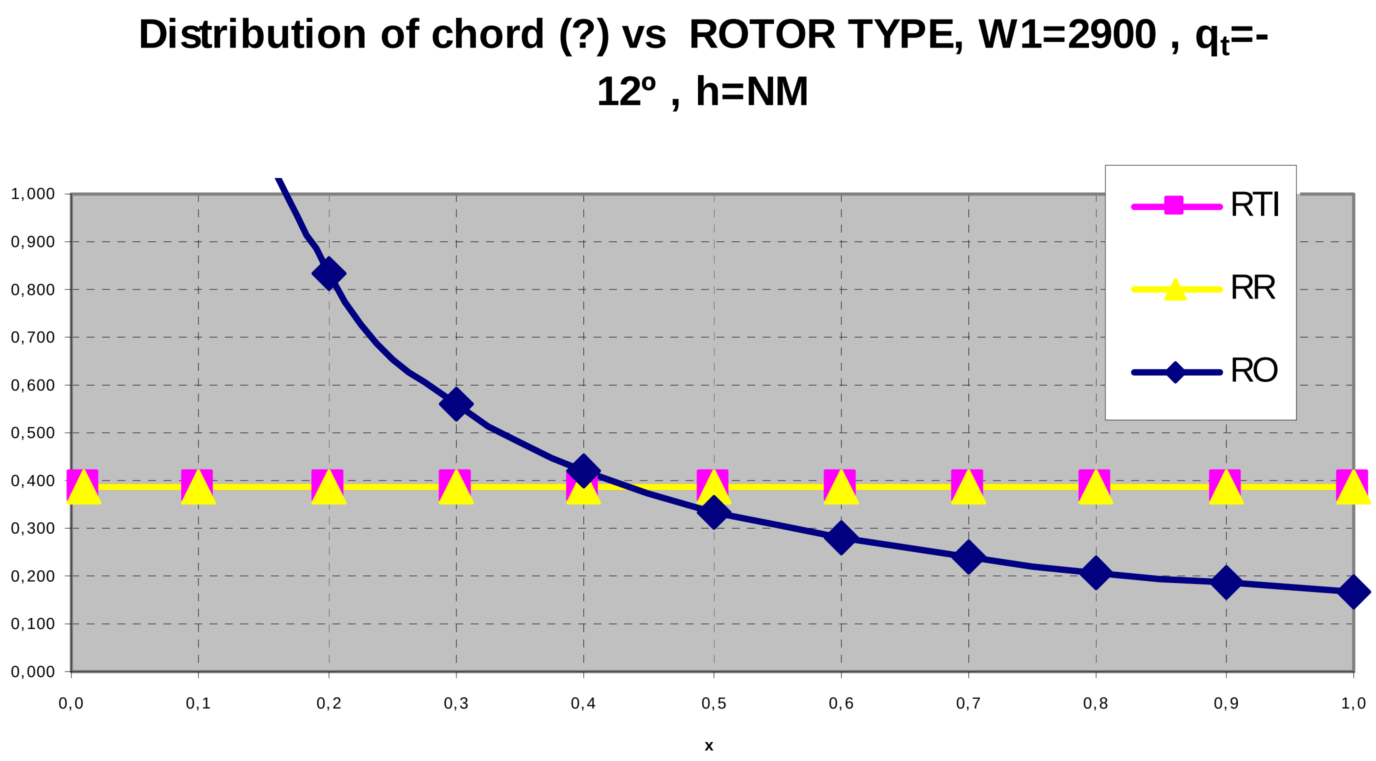
AIRFOIL SELECTION

- Among the various curves shown for each coefficient as a function of the Mach number, our interest lies in corresponding Mach numbers in the characteristic section of the blade, located in 70% of its span (x=0.70).
- When in hover, a condition which will be discussed later, the tip Mach number is taken as 0.6, in the characteristic section it will be 70% of this value, i.e. 0.45.

PLANFORM

- The blade tips are important and support the higher dynamic pressures.
- They are the source of vortices formation on the blade tips.
- They generate most of the drag and the rotor noise.

PLANFORM



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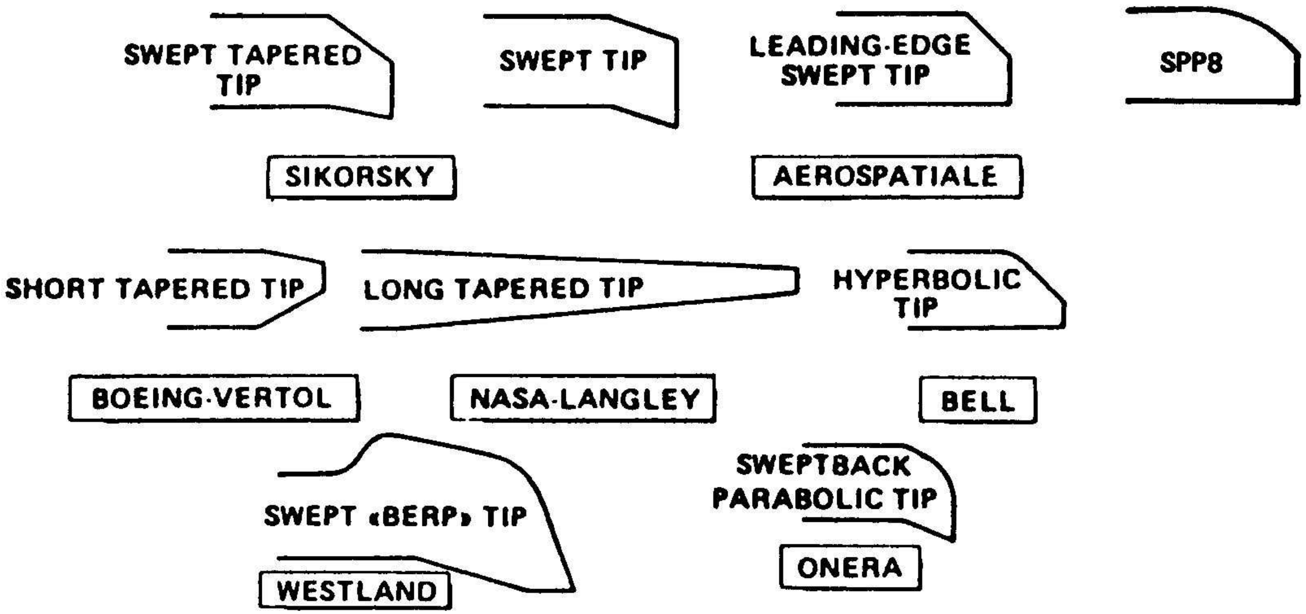
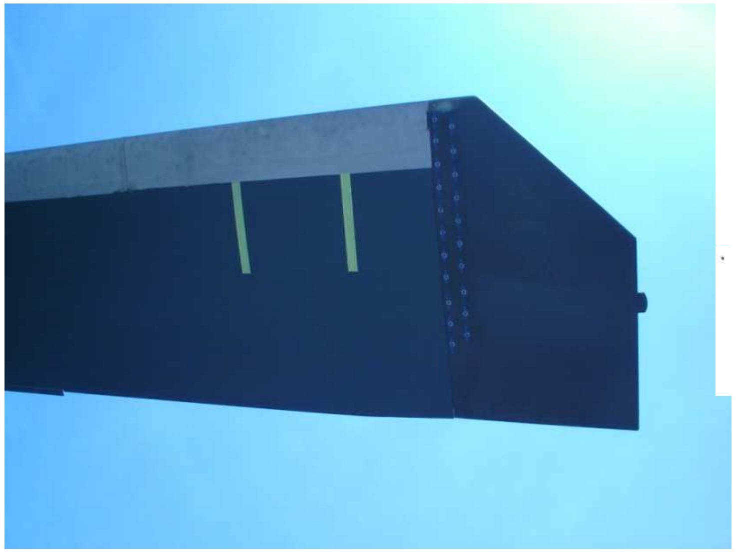
PLANFORM

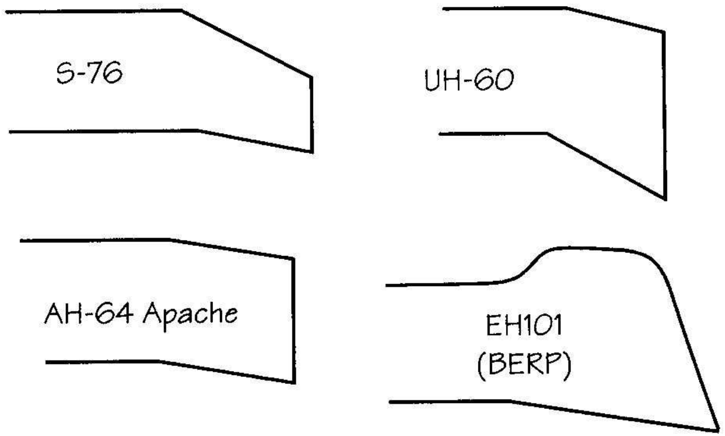
- Figures 12-3 y 12-4 show some of the main designs in production and development.
- Figure 12-3.



PLANFORM

- Figure 12-4.





PLANFORM

- An example of these developments is ***BERP*** *(British Experimental Rotor Program)* used in the *Westland Lynx* and shown in the figures 12-4 and 12-5.
- This design is characterised by a large extension of chord immediately after the tip.
- Among other effects, it delays the transonic flow on the advancing blade and creates a favourable effect on high angles of attack on the retreating blade.

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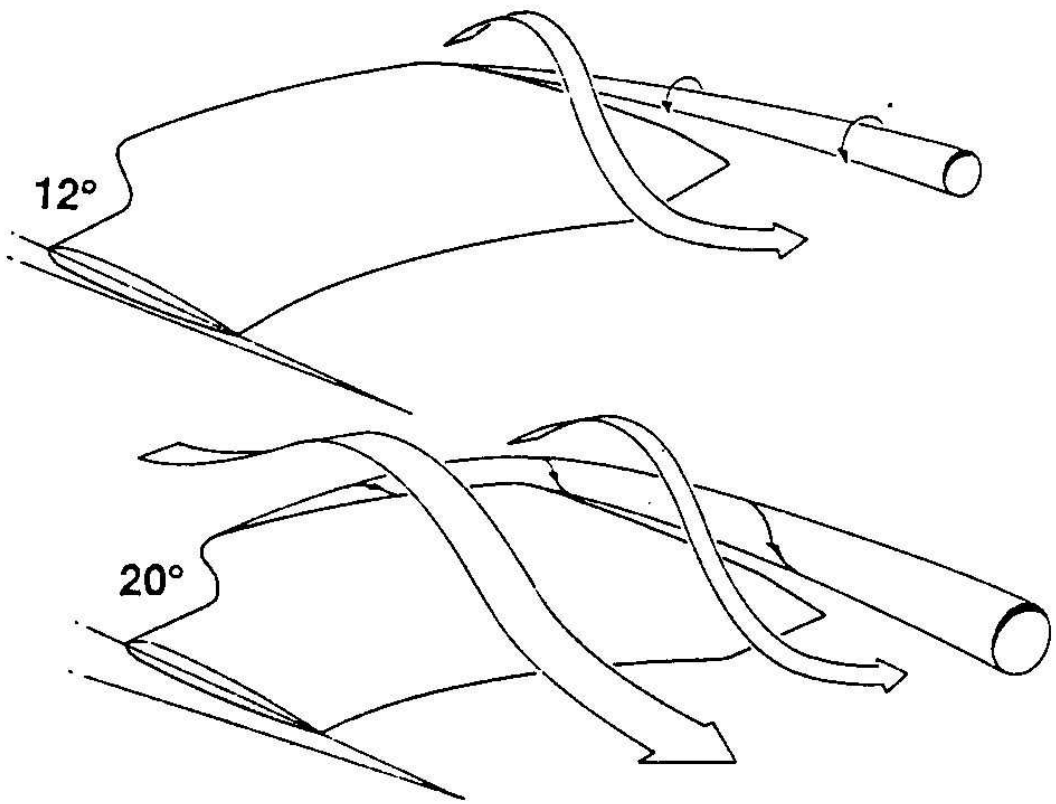
Ángel A. Rodríguez Sevillano

PLANFORM

- Figure 12-5



BERP Tip High Angle of Attack Behaviour

TWISTING

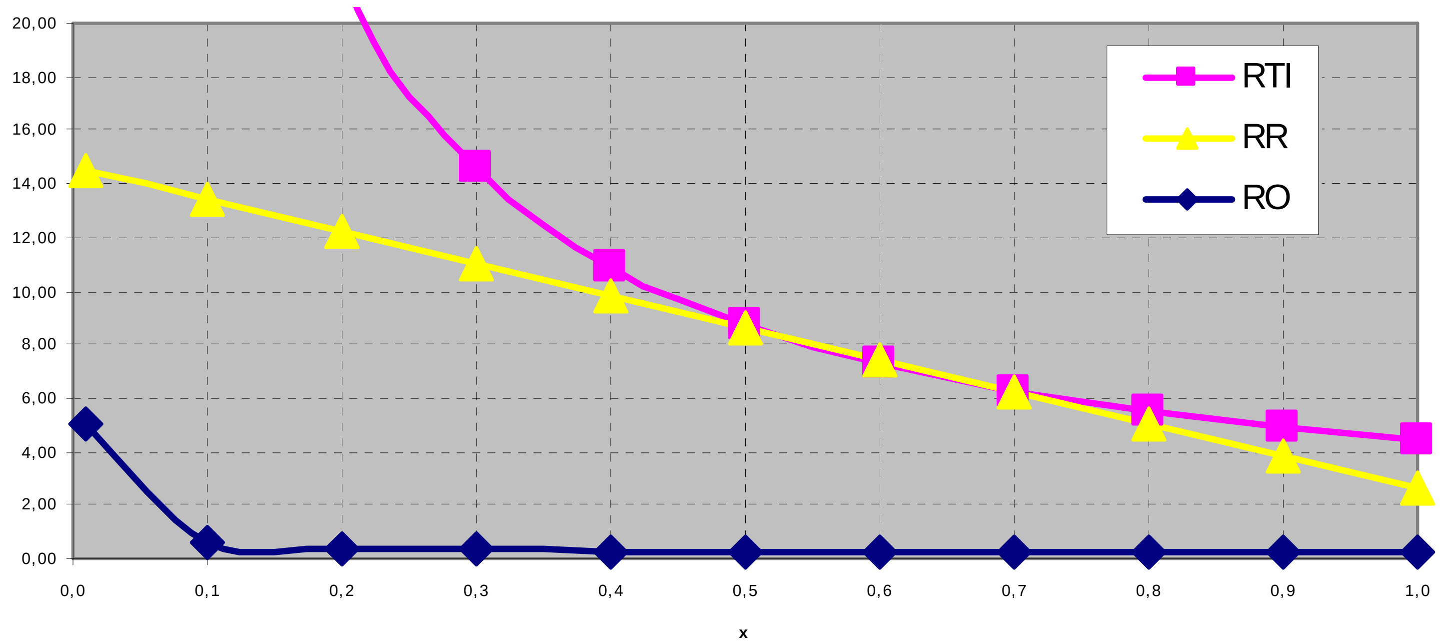
- For hovering it is recommended that the twisting values of the blade are between -12° and -14°.
  - Provide an induced velocity field more uniform over the rotor to ensure the blade tip sections operate below the drag divergence Mach number.
- We know the tip vortices drastically affect the distribution of lift along the span, especially near the tips, increasing the angle of attack on the outside and decreasing it on the inside.
- It is possible to use a non-linear distribution twist to minimise the detrimental effect of the interaction of the vortices and modify the variation on the angle of attack along the whole wing span.

TWISTING

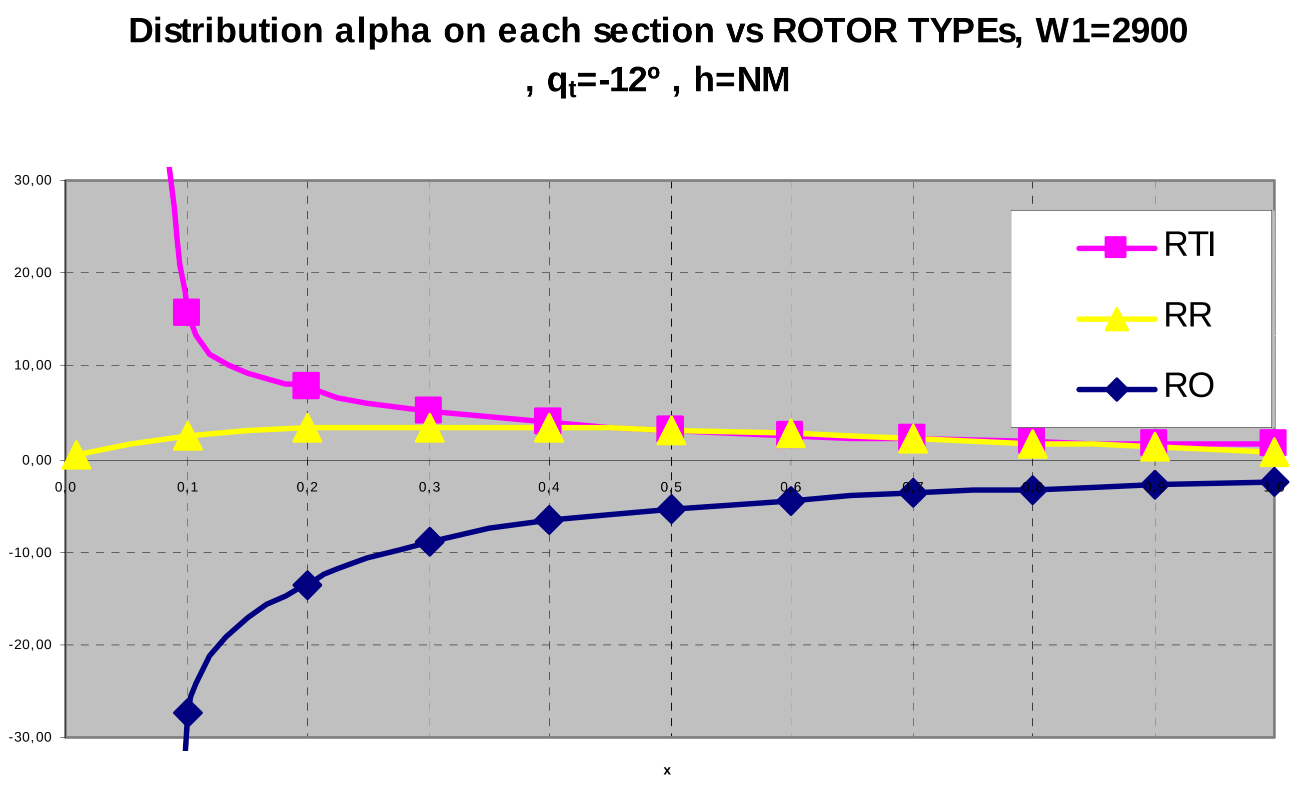
- In the interest of further development in hover flight it is possible to combine the high twisting values with sweptback on the tips and dihedral angle.

TWISTING

Distribution of Twisting vs ROTOR TYPES, W1=2900 , q_t=-12º , h=NM

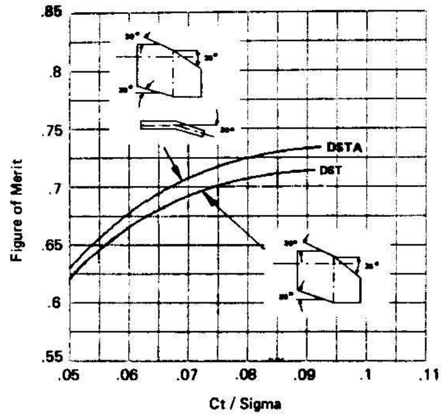


TWISTING

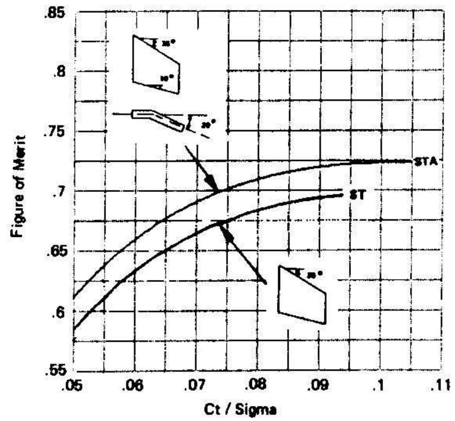

Distribution alpha on each section vs ROTOR TYPEs, W1=2900 , qt=-12º , h=NM
30,00
20,00
10,00
0,00
-10,00
-20,00
-30,00
0,0
0,1
0,2
0,3
0,4
0,5
0,6
x
RTI
RR
RO

TWISTING

- Figure 12-2. In the figure 12-2 shows a study by ONERA on the improvements on the figure of merit with increasing twisting in two different directions.

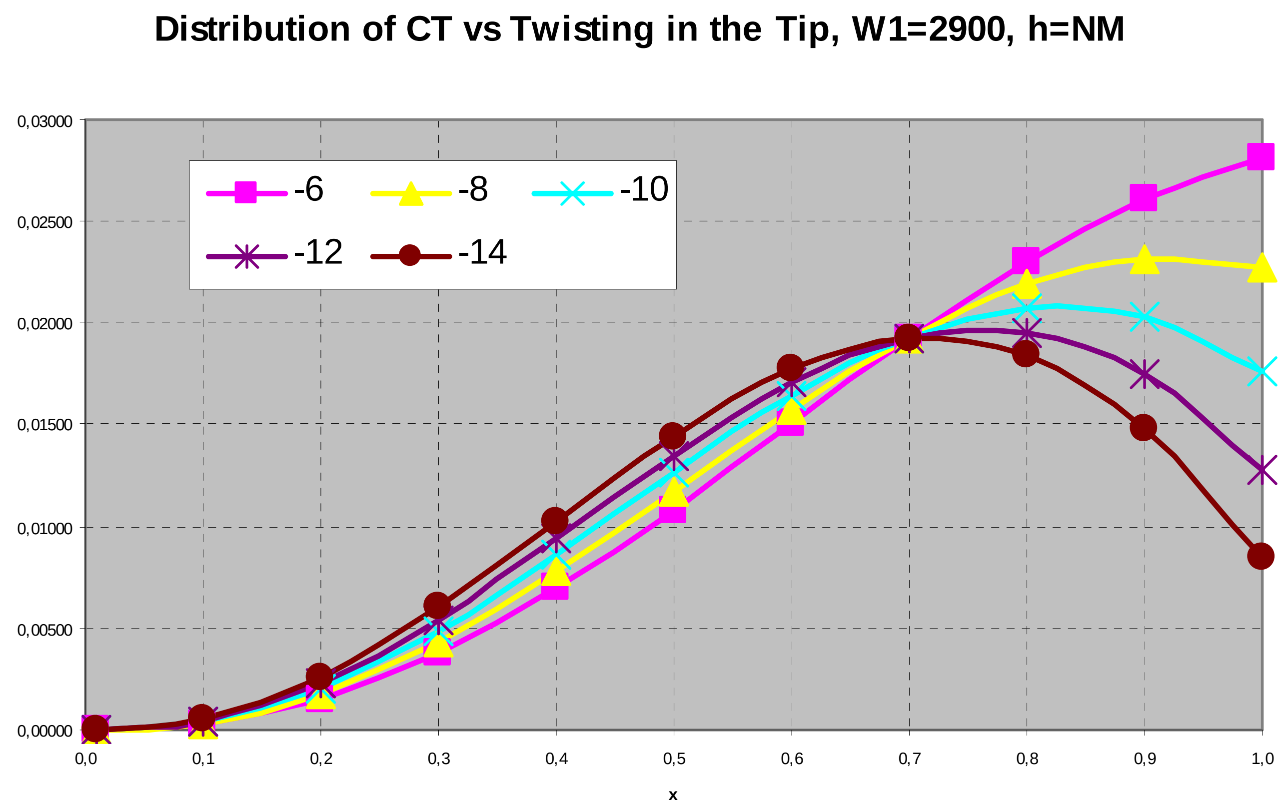


Effect of blade tip anhedral on BLACK-HAWK hover performance, Mtip=0.6

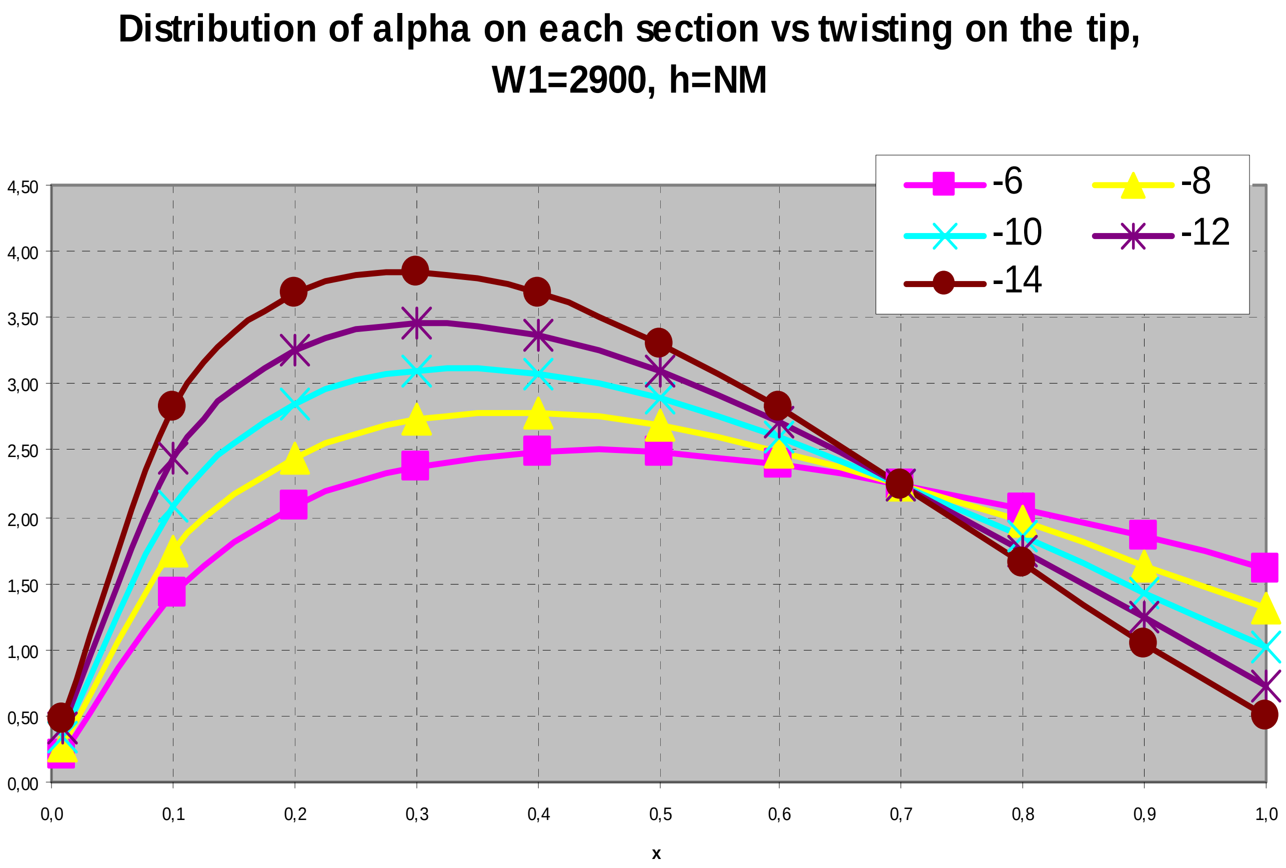


Effect of blade tip anhedral on S-76 hover performance, Mtip=0.6

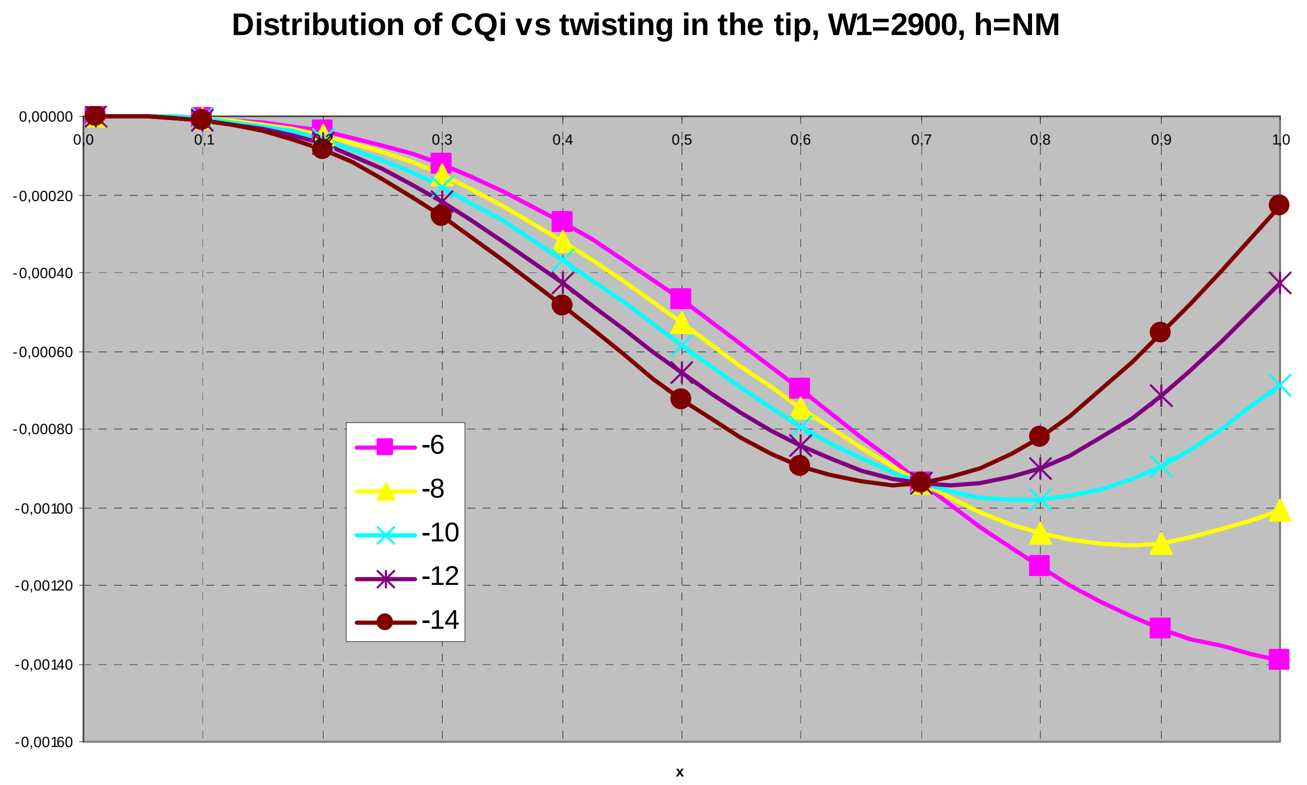
TWISTING


Distribution of CT vs Twisting in the Tip, W1=2900, h=NM
0,03000
0,02500
0,02000
0,01500
0,01000
0,00500
0,00000
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
x
-6
-8
-10
-12
-14

TWISTING


Distribution of alpha on each section vs twisting on the tip,
W1=2900, h=NM
-6
-8
-10
-12
-14
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
x

TWISTING


Distribution of CQi vs twisting in the tip, W1=2900, h=NM
0,00000
-0,00020
-0,00040
-0,00060
-0,00080
-0,00100
-0,00120
-0,00140
-0,00160
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
x
-6
-8
-10
-12
-14

BLADE ENGINEERING

- Material composites:
  - Composed of long and straight fibres, situated inside a matrix which holds the fibres together and distributes the forces.
- The fibres support most of the load while the matrix is responsible for damage tolerance (impact) and fatigue behaviour.
- The fibres are placed in layers or in superimposed sheets in the thickness direction obtaining a structure called laminates.
- Varying the stacking sequence and orientation can allow radically different behaviours to be achieved in strenght, stiffness, damage tolerance, dimensional stability or delamination.
- In general, the biggest disadvantage of composite materials is the price.

- The characteristics of the materials and the processes can make the product a lot of more expensive.
- For certain application the optimum mechanical characteristics, such as high specific stiffness (E/D), good dimensional stability, high tolerance to temperatures, high resistance to corrosion, lightness or greater resistance to fatigue than traditional materials, compensate the high price.

- The construction of the blades using composite materials also have repercussions in the maintenance and preservation, for example before an impact, the blades do not splinter, or before a moderate shock on startup fragments do not jump that could affect the rest of the blades or structural elements.
- Delamination is one of the biggest problems for composite materials. If it is internal it produces drastic decrease in the mechanical properties of the damage zone which has to be detected and evaluated using non destructive testing which is quite expensive.

- The main rotor essentially consists of blades joined together by means of the head.
- The rotating blades create lift and necessary traction for flight in helicopters.
- Basically, the stresses the blades are subjected to will be:
  - Centrifugal forces,
  - Aerodynamical forces - as it is a moving airfoil,
  - Inertial forces – due to the blade movement during flapping, drag, etc.,
  - And gravitational forces.

BLADE ENGINEERING

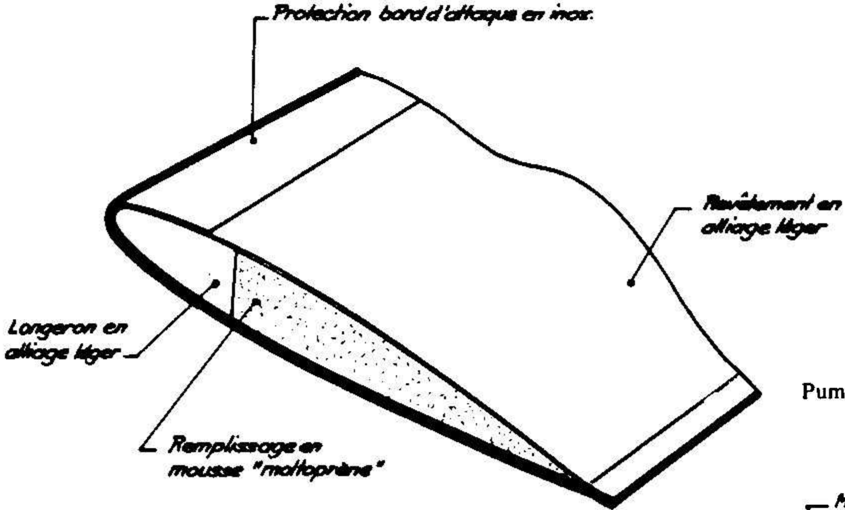
- The combinations of all these forces generate forces and moments along the blades and determine the status of those forces.
- Therefore, the distribution of the mass of the blade will be important.
- Basically all the blades consist of a strut, a thin coating, a core, and the blade tip.
- There is a lot of development in metalic materials like/similar to composite materials.

HELICOPTER BLADES IN USE

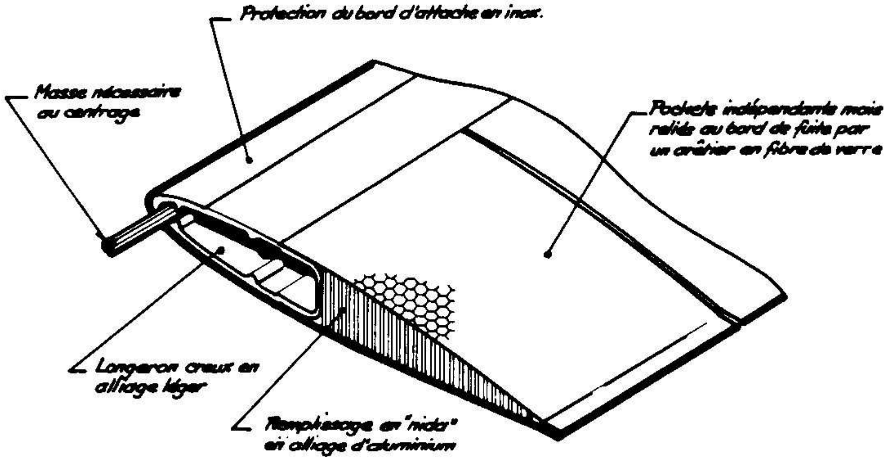
- This section shows some examples of designs chosen by different manufacturers.

HELICOPTER BLADES IN USE

Alouette II

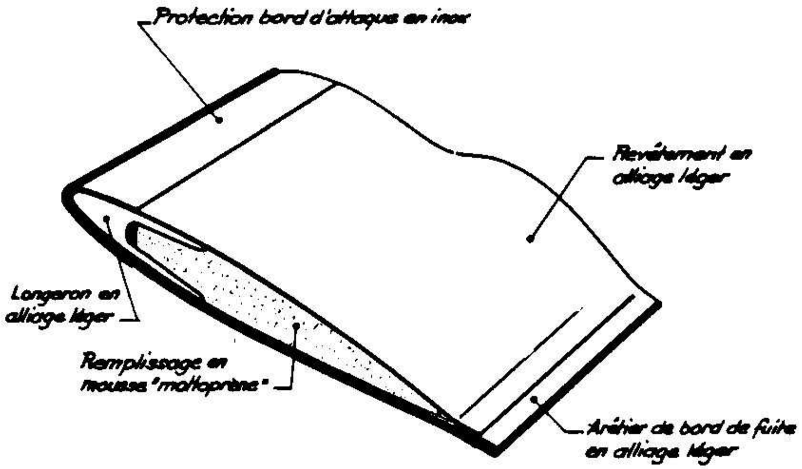


Puma 330 (métallique)

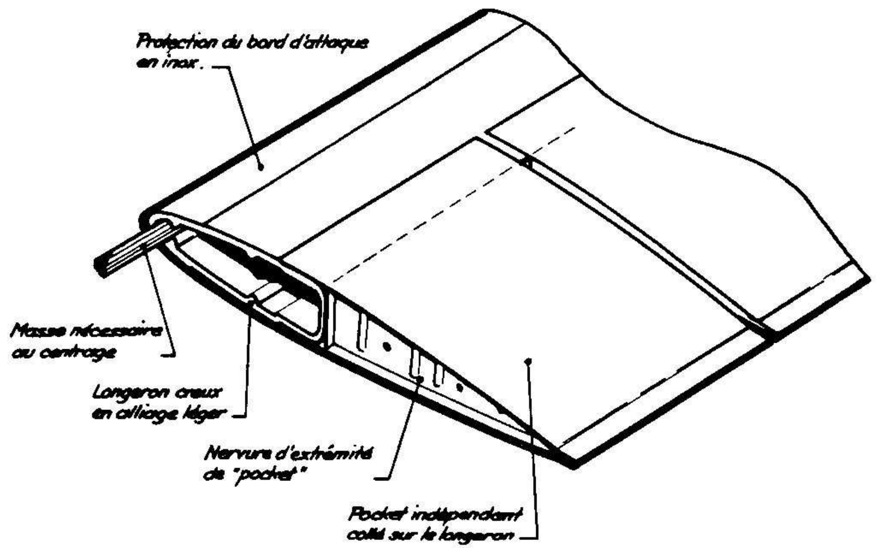


HELICOPTER BLADES IN USE

Alouette III

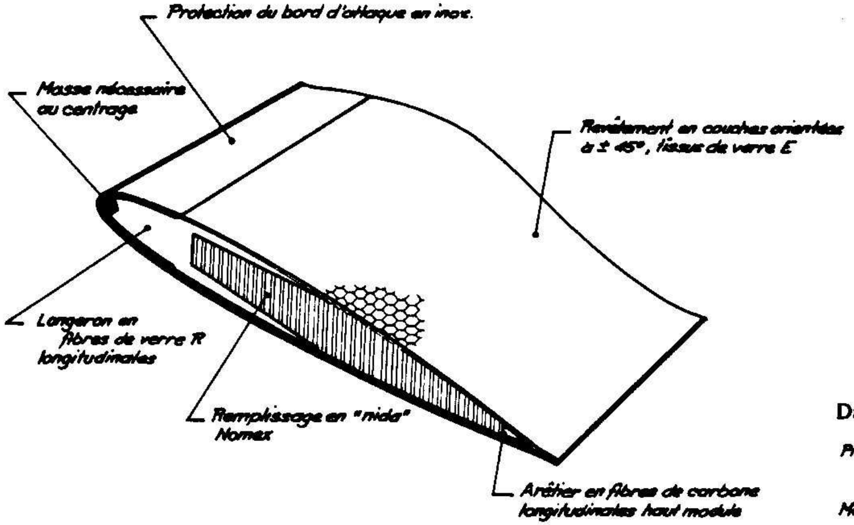


Super Frelon 321 (métallique)

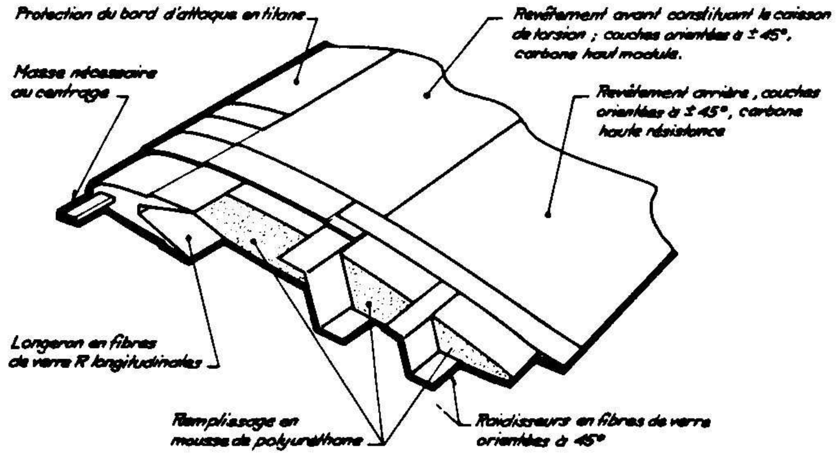


HELICOPTER BLADES IN USE

Gazelle 341

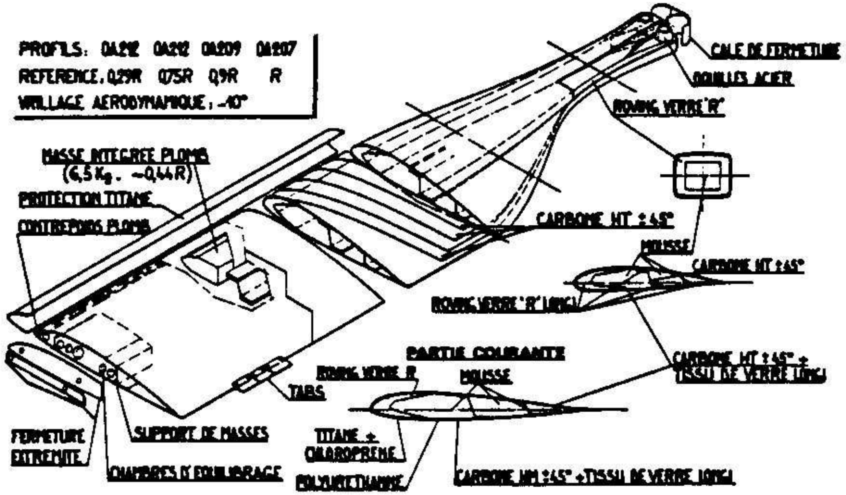


Dauphin 365 N

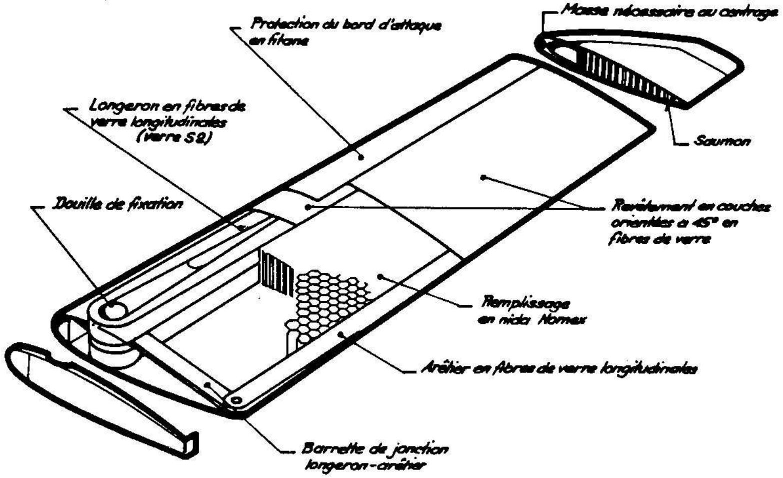


HELICOPTER BLADES IN USE

SA 365 N - Pale composite



Bell 214



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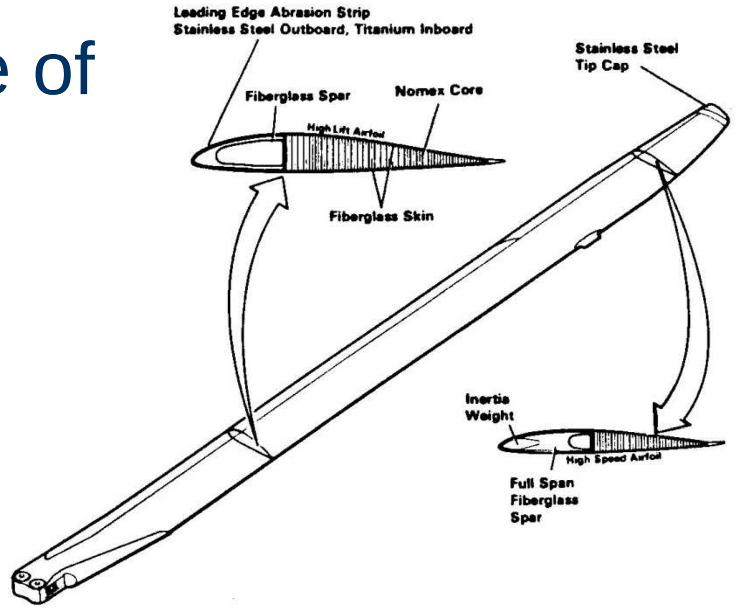
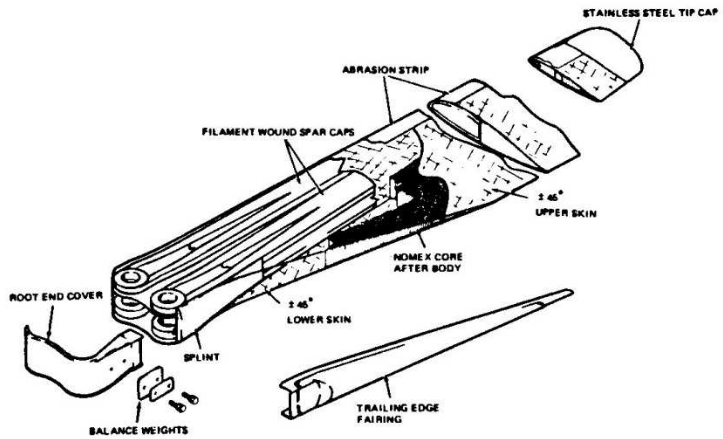
Ángel A. Rodríguez Sevillano

HELICOPTER BLADES IN USE

- In figure 12-6 the blade of the Bell 412 is shown.





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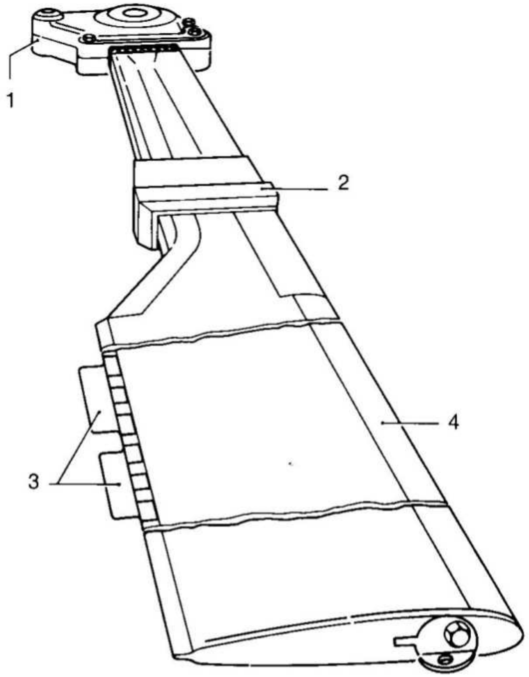
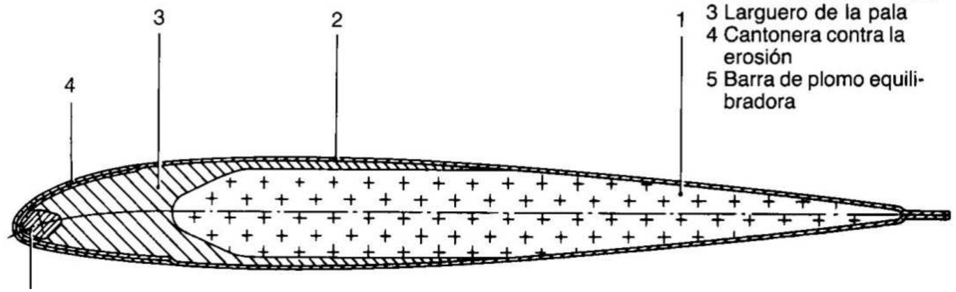
HELICOPTER BLADES IN USE

- The blade of the BO 105 can be analysed in figure 12-7.



Pala del rotor principal

1 Pieza de protección de la raíz de la pala
2 Manguito
3 Aletas de compensación dinámica
4 Cantonera contra la erosión



Sección de la pala

1 Relleno de espuma rigida
2 Revestimiento der PRV
3 Larguero de la pala
4 Cantonera contra la erosión
5 Barra de plomo equilibradora

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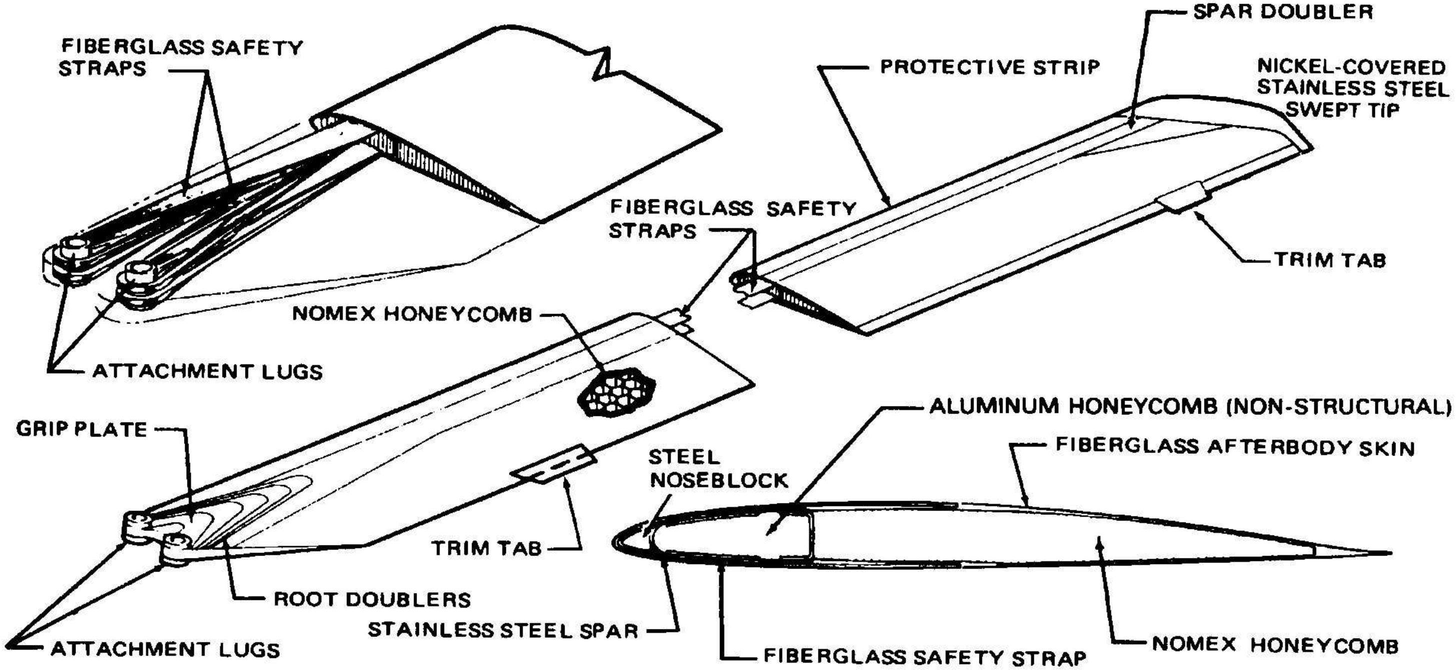
Ángel A. Rodríguez Sevillano

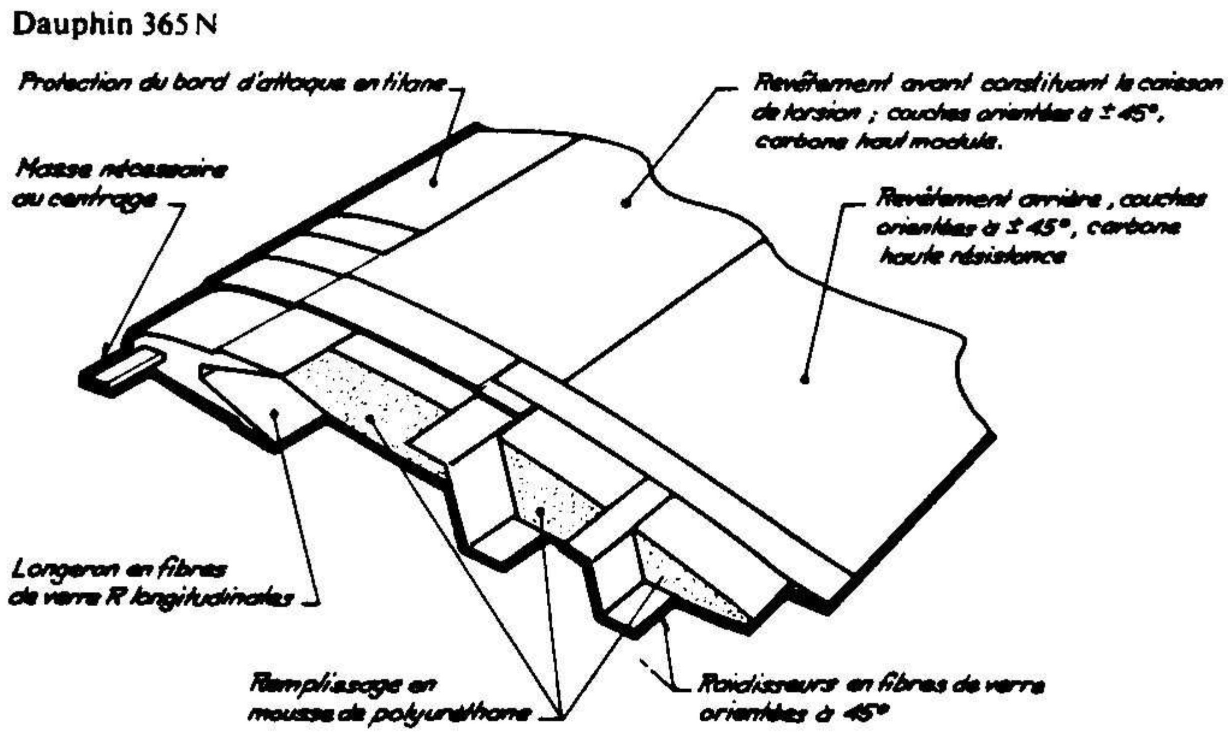
HELICOPTER BLADES IN USE

- Figure 12-8 shows the blade of the Bell 230.



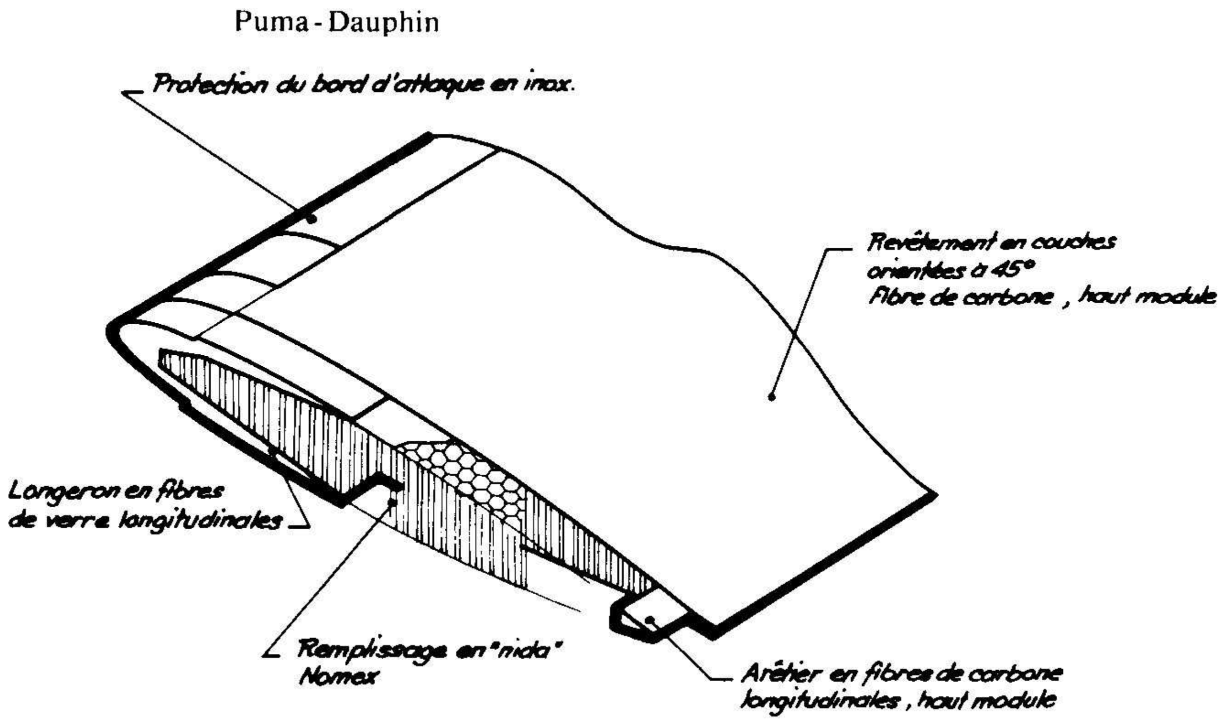
HELICOPTER BLADES IN USE

- Included is an example of a metalic blade (12-9).



HELICOPTER BLADES IN USE

- A composite material blade (12-10).



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