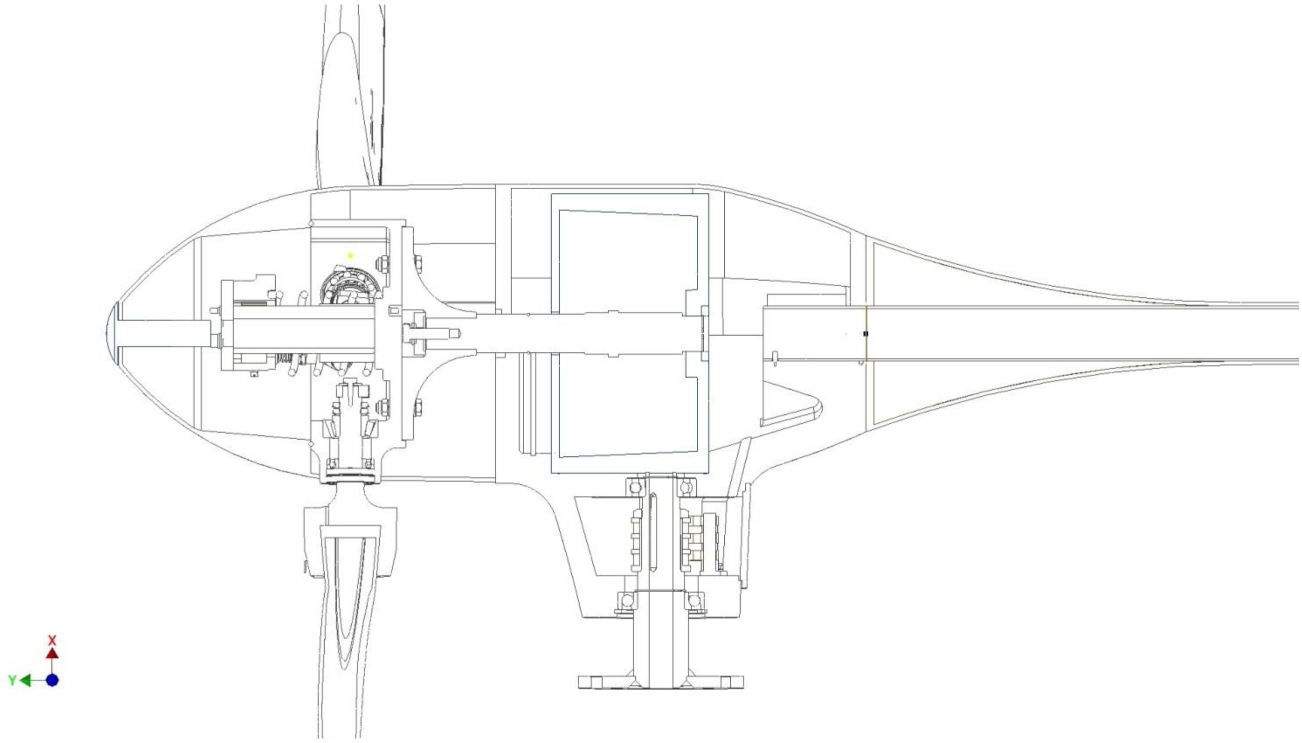
IEC 61400 JUSTIFICATION

E30/70 PRO



ENAIR ENERGY S.L.
Avda de Ibi, Nº 44 - 03420 - Castalla
Aptdo Correos 182 - Alicante - SPAIN

Tel: +34 96 556 00 18

e-mail: info@enair.es
Web: www.enair.es

INDEX

1.- SCOPE

This part of IEC 61400 deals with safety philosophy, quality assurance, and engineering integrity and specifies requirements for the safety of Small Wind Turbines (SWTs) including design, installation, maintenance and operation under specified external conditions. Its purpose is to provide the appropriate level of protection against damage from hazards from these systems during their planned lifetime.

This part of IEC 61400 is concerned with all subsystems of SWT such as protection mechanisms, internal electrical systems, mechanical systems, support structures, foundations and the electrical interconnection with the load.

While this part of IEC 61400 is similar to IEC 61400-1, it does simplify and make significant changes in order to be applicable to small turbines.

This part of IEC 61400 applies to wind turbines with a rotor swept area smaller than 200 m^2 generating at a voltage below 1 000 V a.c. or 1 500 V d.c. .

This part of IEC 61400 should be used together with the appropriate IEC and ISO standards.

2.- REFERENCES

Basis reference

"IEC 61400-2 Design requirements for small wind turbines"

3.- WIND TURBINE DESCRIPTION

The EPRO70 wind turbine is a wind turbine of 3,5 kW in nominal power, with a permanent magnet generator and a passive variable pitch system to control the power output and it can work as in isolated installations as in grid connected. In the next point some of the most important characteristics are specified.

3.1.-DATA SHEET

GENERAL	
Configuration	3 blades, horizontal axis, clockwise, upwind, passive yaw, variable pitch
Power [W]	5000
Rated speed [m/s]	11
Diameter [m]	4.25
Swept area [m2]	14.2
Annual energy yield [kWh] at 5ms	6000
Max. power [W]	5500
IEC Turbine Class	Class IV
Wind class	IEC / NVN I -A
Start rotation wind speed [m/s]	1.8
Cut-in wind speed [m/s]	2.8
Cut-out wind speed [m/s]	n/a
Noise [dB]	44
Nacelle weight [kg]	185
Operating temp. range [ºC]	-25/50
Nominal rotation speed [rpm]	225
Passive pitch start [rpm]	260
Design lifetime [years]	25
Supported speed [m/s]	> 60
GENERATOR	
Type	Direct drive permanent magnet synchronous
Generator	250 rpm | 24 poles | neodymium magnets
BLADES	
Material	Fiberglass epoxy resins and polyurethane core
CONVERTER	
Nominal efficiency [%]	95
Point tracking	MPPT algorithm
OTHER INFO	
Applications	Isolated connection batteries, electric grid connection
Brake	Electrical
Controller	Optional grid connection and battery charging
Noise	1% more than the environmental noise of the wind.
Anti-corrosive protection	Cataphoresis, epoxy painting
TOWER	
Configuration	12, 15 y 18m, folding, cable-stayed or lattice.

Table 1 – Data sheet

3.2.-PMG DATA SHEET

ELECTRICAL SPECIFICATION	
Rated output power [W]	3500
Rated rotation speed [rpm]	250
Rectified DC current at rated output [A]	ND
Number of poles	30
Required torque at rated power [Nm]	164
Phase resistance [Ohm]	1
Output wire square section [mm2]	2.5
Output wire length [mm]	700
Insulation	F
Generator configuration	Horizontal
Design lifetime	15
MECHANICAL SPECIFICATION	
Weight [kg]	100
Starting torque [Nm]	< 1
Rotor inertia [kg m2]	0.2
Front bearing	SKF 6309-2rsr
Rear bearing	SKF 6207-2rsr
MATERIAL SPECIFICATION	
Shaft material	F1252
Outer frame material	Aluminum alloy
Fasteners	Inox
Windings temperature rating [ºC]	130
Magnets material	Nd
Magnets temperature rating [ºC]	100
Magnets temperature until demagnetization [ºC]	150
Lamination stack	Non oriented magnetic steal

Table 2 – PMG Data sheet

PMG PERFORMANCE

The permanent magnet generator performance curves are next:

The open circuit voltage shows a linear behavior:

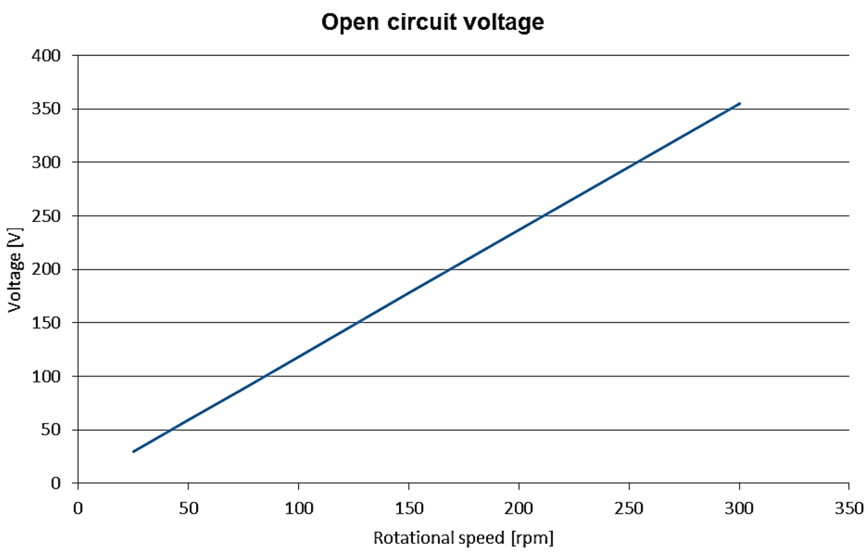


Figure 1 – PMG open circuit voltage

The output power is approximated by a straight line:

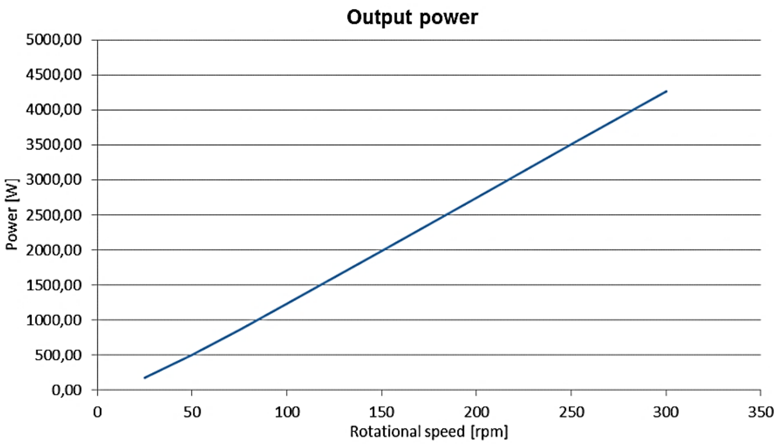


Figure 2 – PMG output power

The input torque needed for the continuous movement at the revolutions shown below:

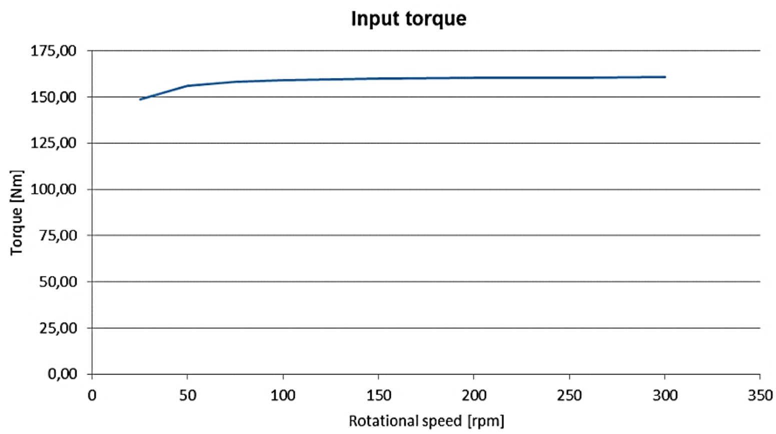


Figure 3 – PMG input torque

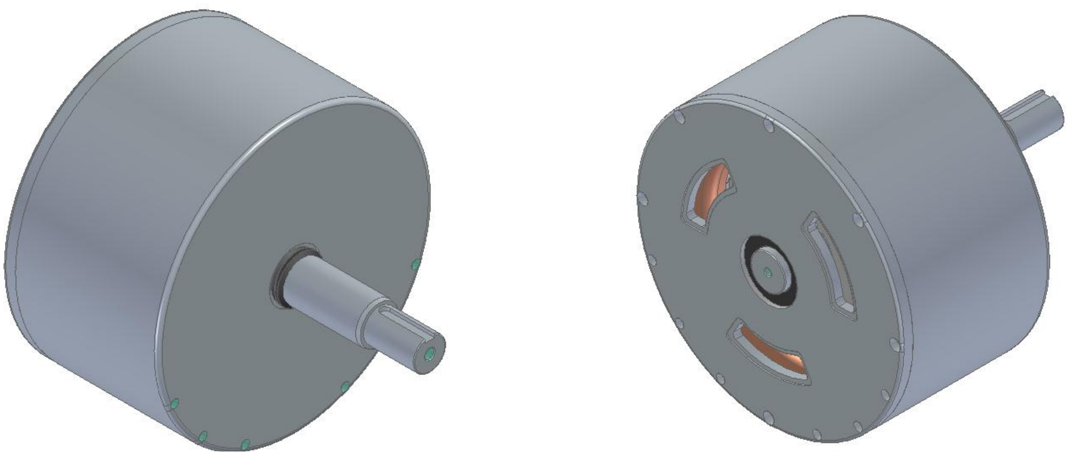


Figure 4 – PMG Schematic design

4.- SIMPLE LOAD MODEL

It has been performed a SLM (Simple Load Model) analysis according to the IEC 61400-2.

This is useful to get the real forces that appear in the wind turbine.

For certain turbine configurations, the loads can be derived using simple, conservative equations for a limited set of load cases. If the turbine configuration does not meet those configuration requirements, the simple equations cannot be used, instead the alternative aero elastic modelling or load measurements shall be used.

In Table 3 there are written all the necessary data to initialize the equations. All the parameters are about the geometry of the wind turbine and the operational behavior.

The Drag, Lift and Thrust coefficients are obtained according to the IEC 61400-2.

Along the overall process the equations used have been gotten from the IEC 61400-2 and each one is named before its use.

Table 1 Input data in the SLM method

INPUT DATA IN THE SLM METHOD			
Description	**Input value**	**Units**	**Symbol**
Air density	1.225	kg/m^3	ρ
Gravitational acceleration	9.81	m/s^2	g
Reference wind speed	30.0	m/s	V_ref
Average wind speed	6.0	m/s	V_ave
Number of blades	3	n/a	B
Blade tip radius	2.135	m	R
Total planform area of the blade	0.349	m^2	A_proj,B
Drag coefficient of the blades	1.5	n/a	C_d
Max lift coefficient of the blades	2.0	n/a	C_l,max
Thrust coefficient	0.5	n/a	C_T
Maximum rotor speed	400	rpm	n_max
Design rotor speed	250	rpm	n_design
Second moment of inertia for each blade	0.123	$kg\ m^2$	I_B
Single blade mass	4.95	kg	m_B
Rotor mass (All blades plus hub)	59.34	kg	m_r
Distance from blade centre of gravity to rotor axis	0.86	m	R_cog
Distance between rotor centre and the first bearing	0.28	m	L_rb
Distance between the rotor centre and the yaw axis	0.26	m	L_rt
Gearbox ratio	1.0	n/a	Gear
Brake torque	0	N m	M_brake
Design power	3.5	kW	P_design
Short circuit torque factor	2.0	n/a	G

Table 3 – Input data in the SLM method

The next parameters are intermediate data needed for the calculations of the loads in the SLM method. All of this parameters give us much information about the behavior of the wind turbine like the maximum wind speeds that are taking like a point of design for survival, not for operation.

PARAMETERS CALCULATED FROM THE INPUT DATA				
Description	**Equation**	**Value**	**Units**	**Symbol**
Design wind speed	IEC F	8.4	m/s	V_design
50 year extreme wind speed	IEC 10	42.0	m/s	V_e50
50 year extreme tip speed ratio	IEC F.2	2.13	n/a	λ_e50
Design tip speed ratio	IEC F.2	6.65	n/a	λ_design
Drive train efficiency	-	0.62	n/a	η
Design torque	-	216.5	N m	Q_design
Projected area (turbine swept area)	-	14.32	m2	A_proj
Design rotational speed of the rotor	-	26.18	rad/s	ωn,design
Maximum possible rotor speed	-	41.89	rad/s	ωn,max
Max yaw rate	-	2.88	rad/s	ωyaw,max
Eccentricity of the rotor centre of mass	-	0.0107	m	e_r
Effective brake torque	-	0.0	N m	M_brake

Table 4 – Intermediate parameters calculates from the input data

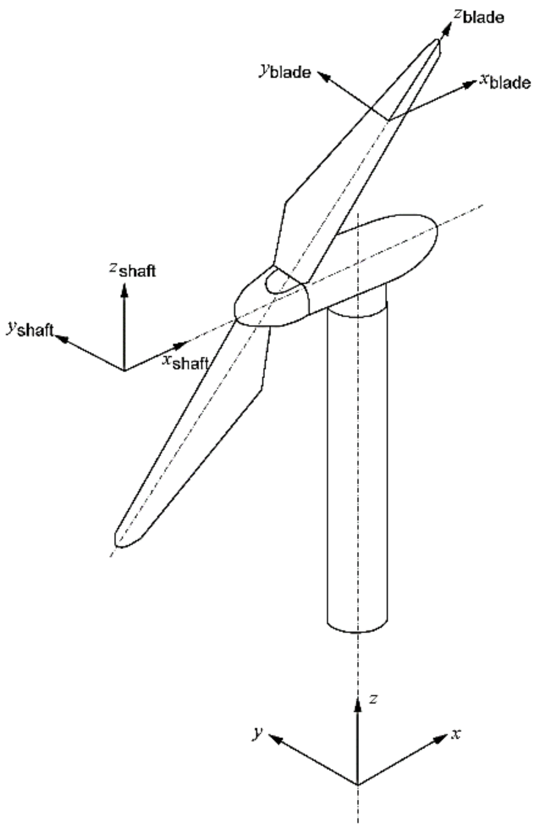


Figure 5 – Coordinate system

For the calculations it must be taken into account that there are different loads hypothesis. The IEC 61400-2 consider eight different load cases.

Load case A: Normal operation.

The design load for "normal operation" is a fatigue load. The load case assumes constant range fatigue loading for the blade and shaft, these ranges are given below. The ranges are to be considered in the fatigue assessment as peak-to-peak values. The mean values of the load ranges can be ignored.

The fatigue loading on the blade would be considered to occur at the airfoil – root junction or at the root – hub junction, whichever is determined to have the lowest ultimate strength. The calculated stresses are the combination of the centrifugal loading (F_{ZB}) and the bending moments (M_{XB} and M_{YB}).

The fatigue load on the rotor shaft shall be considered at the rotor shaft at the first bearing (nearest to the rotor). The range of the stress shall be calculated from the combination of the thrust loading ($F_{x\text{-shaft}}$), the torsion moment ($M_{x\text{-shaft}}$) and the bending moment (M_{shaft}).

Load case B: Yawing

For this load case, the ultimate loads (gyroscopic forces and moments) shall be calculated assuming the maximum yaw speed $\omega_{yaw,max}$ occurring with n_{design}.

Load case C: Yaw error

All turbines operate with a certain yaw error. In this load case, a yaw error of 30° is assumed.

Load case D: Maximum thrust

The SWT can be exposed to high thrust loads on the rotor. The thrust load acts parallel to the rotor shaft and has a maximum value.

The trust coefficient is equal to 0,5 by normative.

Load case E: Maximum rotational speed

The centrifugal load in the blade root F_{ZB} and the shaft bending moment M_{SHAFT} due to centrifugal load and rotor unbalance shall be calculated. The maximum possible rotor speed is directly related to the maximum rotational speed revolutions.

Load case F: Short at load connection

In the case of a direct electrical short at the output of the SWT or internal short in the generator, high moment is created about the rotor shaft due to the short circuit torque of the alternator. In the absence of any values proven to be more accurate, two times the Q_{DESIGN} is to be taken as the short circuit torque acting on the generator shaft.

In the absence of any values proven to be more accurate, G shall be 2,0.

Load case G: Shutdown (braking)

In the case of wind turbines with a mechanical or electrical braking system in the drive train, the braking moment can be greater than the maximum driving moment. In these cases, the braking moment M_{brake}, derived from testing or calculations, shall be used in the design calculations of the SWT. The maximum shaft torque is assumed to be equal to the brake plus the design torque (thus assuming that the brake is applied while the generator still delivers design torque).

Mbrake shall be multiplied by the gearbox ratio if the brake is on the high speed shaft.

Load case H: Parked wind loading

In this load case, the wind turbine is parked in the normal way. The loads on the exposed

parts of the SWT shall be calculated assuming wind speed of V_{e50}

The maximum tower bending moment shall be calculated using the thrust force. The drag or lift force on the tower and nacelle need to be taken into account as well. For free standing towers the maximum bending moment will occur at the tower base. For guyed towers, the maximum bending moment will occur at the upper guy wire attachment.

Load case I: Parked wind loading, maximum exposure

In the case of a failure in the yaw mechanism, the SWT can be exposed to the wind from all directions. Thus, for design purposes, the forces on the SWT blades, nacelle, tower, and tail (if applicable) shall be calculated for all possible exposures including winds from the front, side or rear of the rotor.

Load case J: Transportation, assembly, maintenance and repair

The manufacturer shall consider loads on the turbine system caused by the transportation, assembly, installation, and maintenance and repair of the system. Examples of such loads are:

– gravity loads on turbine during transportation in other than upright position

– loads caused by special installation tools

– wind loads during installation

– loads introduced by hoisting the turbine onto the foundation

– loads on a tilt up tower during erection

– load on a support structure from climbing it

LOADS FROM SLM				
Description	**Equation**	**SLM value**	**Units**	**Symbol**
Load case A – Fatigue loads on blades and rotor shaft				
Blade loads				
Centrifugal force at the blade root (z-axis)	IEC 21	5304.91	N	ΔF_zB
Lead-lag root bending moment (x-axis)	IEC 22	148.10	N m	ΔM_xB
Flapwise root bending moment (y-axis)	IEC 23	480.21	N m	ΔM_yB
Shaft loads				
Thrust on shaft (x-axis)	IEC 24	1012.15	N	ΔF_x-shaft
Shaft moment about x-axis	IEC 25	228.93	N m	ΔM_x-shaft
Shaft moment	IE 26	686.15	N m	ΔM_shaft
Load case B – Blade and rotor shaft loads during yaw				
Flapwise root bending moment (y-axis)	IEC 28	266.96	N m	M_yB
Bending moment on the shaft	IEC 29, 30	550.94	N m	M_shaft
Load case C – Yaw error loads on blades				
Flapwise root bending moment (y-axis)	IEC 31	871.86	N m	M_yB
Load case D – Maximum thrust on shaft				
Maximum thrust on shaft	IEC 32	986.74	N	F_x-shaft
Load case E – Maximum rotational speed				
Centrifugal force at the blade root (z-axis)	IEC 33	6790.29	N	F_zB
Bending moment on the shaft	IEC 34	474.20	N m	M_shaft
Load case F – Short at load connection				
Bending moment on shaft	IEC 35	433.00	N m	M_x-shaft
Lead-lag root bending moment (x-axis)	IEC 36	144.33	N m	M_xB
Load case G – Shutdown braking				
Bending moment on shaft	IEC 37	n/a	N m	M_x-shaft
Lead-lag root bending moment (x-axis)	IEC 38	n/a	N m	M_xB
Load case H – Parked wind loads during idling				
Flapwise root bending moment (y-axis)	IEC 39, 40	603.79	N m	M_yB
Maximum thrust on shaft	IEC 41, 42	1696.85	N	F_x-shaft

Table 5 – Loads from SML

In Table 6 there are considered the highest values for each part in which we must pay attention. The highest between all the load hypothesis have been taken. These values will be the input data for the FEM (Finite Element Method analysis)

MAXIMUM LOADS			
Description	**Hypothesis**	**Value**	**Symbol**
Blades loads			
Centrifugal force at the blade root (z-axis)	Load case E – Maximum rotational speed	6790.29N	F_zB
Lead-lag root bending moment (x-axis)	Load case A – Fatigue loads on blades and rotor shaft	148.10Nm	ΔM_xB
Flapwise root bending moment (y-axis)	Load case C – Yaw error on blades	871.86Nm	My_B
Shaft loads			
Maximum thrust on shaft	Load case H – Parked wind loads during idling	1696.85 N	F_x-shaft
Bending moment on shaft	Load case F – Short at load connection	433.00 N m	M_x-shaft
Shaft moment	Load case A - Fatigue loads on blades and rotor shaft	686.15 N m	ΔM_shaft

Table 6 – Maximum loads

4.1.- CALCULATION OF EQUIVALENT STRESSES

Handmade calculations were done before the FEM analysis for the different load hypothesis.

In Table 7 there are some necessary data for the calculations to the stresses which appear on the most critical parts in the wind turbine as the blades and the shaft are.

Other data that we have to fix are the fatigue parameters that we want the wind turbine to resist.

ADDITIONAL MECHANICAL DATA			
Description	**Value**	**Units**	**Symbol**
Diameter of the shaft	0.05	m	n/a
Cross sectional area of the shaft	1.9635E-3	m^2	A_shaft
Second moment of inertia for the shaft	3.068E-7	m^4	I_x-shaft
Section modulus for the shaft	1.2272E-5	m^3	W_shaft
Cross sectional area of the blade root	3.85E-3	m^2	A_B
Ixx for the blade	3E-7	m^4	I_xxB
x-distance from blade centroid to the maximum stress point	5E-3	m	c_xB
Iyy for the blade	4E-5	m^4	I_yyB
y-distance from blade entroid to the maximum stress point	3E-2	m	c_yB
Blade x-section modulus	6E-5	m^3	W_xB
Blade y-section modulus	1.33E-3	m^3	W_yB
Ultimate material strength for the blades	3445	MPa	f_kb
Ultimate material strength for the shaft	207	MPa	f_k-shaft
Additional data for fatigue calculations			
Design life of the turbine	25 788940000	Years s	- T_d
Number of fatigue cycles	9.86E+ 9	n/a	n_i
Number of cycles to failure as a function of stress (shaft)	1E+ 10	n/a	N_shaft
Number of cycles to failure as a function of stress (blade)	1.23E+ 3	n/a	N_blade

Table 7 – Additional mechanical data

Where

$$I_x - shaft = \pi D^4/_{64}$$

$$W_{shaft} = 2\frac{I_x\_shaft}{D}$$

$$W_{xB} = \frac{I\_xxB}{c\_xB}$$

$$W_{yB} = \frac{I\_yyB}{c\_yB}$$

Now we proceed to the calculations of the equivalent stress in the blade root and in the axis in the different load hypothesis.

The calculation method is always the same but changing the loads in each hypothesis.

$$\sigma[Pa] = \frac{F\ [N]}{S\ [m^2]}$$

$$\sigma[Pa] = \frac{M\ [Nm]}{W\ [m^3]}$$

ADDITIONAL MECHANICAL DATA	
Description	**Equivalent stress [MPa]**
Load case A – Fatigue loads on blades and rotor shaft	
Blades	4.21
Shaft	58.69
Load case B – Blade and rotor shaft loads during yaw	
Blades	0.20
Shaft	44.89
Load case C – Yaw error loads on blades	
Blades	0.65
Load case D – Maximum thrust on shaft	
Shaft	0.50
Load case E – Maximum rotational speed	
Shaft	1.76
Blades	38.64
Load case F – Short load connection	
Blades	2.41
Shaft	30.56
Load case G – Shutdown braking	
Blades	-
Shaft	-
Load case H – Parked wind loads during idling	
Blades	0.45
Shaft	0.86

Table 8 – Equivalent stresses

4.2.-MATERIAL CHARACTERIZATION

One of the most important things to guarantee the correct behavior of the wind turbine is to use the correct materials, and the mechanical properties of them.

In that point we have made the decision to full characterize all the materials for knowing the real properties of them and after that to oversize the wind turbine for getting more reliability.

For all the materials that we use we ask for the data sheet which has the full analysis to check if the material is the one we need for guaranteeing the mechanical performance that is needed and the safety factors.

ALUMINUM 356 T6		
Properties	**Value**	**Units**
Modulus of elasticity	4.21	N/m^2
Poisson coefficient in XY	58.69	N/D
Shear modulus XY	0.20	N/m^2
Mass density	44.89	Kg/m^3
Traction limit X	0.65	N/m^2
Traction limit Y	0.50	N/m^2
Elastic limit	1.76	N/m^2
Coefficient of thermal expansion X	38.64	/K
Thermal conductivity X	2.41	W/(m K)
Specific heat	30.56	J/(kg K)

Table 9 – Aluminum 356 T6

CERTIFIED MATERIAL TEST REPORT 材质报告

SUPPLIER工厂：		JINZHONG			MATERIAL材质:			AL356-T6			
ITEM NO.	PART NO. 部件号	HEAT NO. 炉号	MECHANICAL PROPERTIES 机械性能			CHEMICAL COMPONENTS 化学成分					
			TENSILE STRENGTH 抗拉强度 Mpa	YEILD STRENGTH 屈服强度Mpa	ELONGATION 延伸率%	Si	Fe	Cu	Mn	Mg	Zn
	20030019(AL356-T6)	21/09/2011	219	183	4,5	7,1	0,11	0,002	0,0055	0,39	0,006

STEEL F 114		
Properties	**Value**	**Units**
Modulus of elasticity	2.05 + 011	N/m^2
Poisson coefficient in XY	0.29	N/D
Shear modulus XY	8e+ 010	N/m^2
Mass density	7850	Kg/m^3
Traction limit X	665000000	N/m^2
Compression limit X		N/m^2
Elastic limit	400000000	N/m^2
Coefficient of thermal expansion X	1.15e-005	/K
Thermal conductivity X	49.8	W/(m K)
Specific heat	486	J/(kg K)
Damping coefficient		N/D

Table 10 – Steel F114

4.3.-SAFETY FACTORS

The most important parameters in a small wind turbine are safety and reliability.

According to IEC 61400-2 safety factors for this machines must be higher than 9 if the material properties are not characterized but if the material is full characterized as we have made with ours the safety factor must not be less than 3.

We have made the choice to full characterize the materials and despite of that we also get higher safety factors.

In the next tables the comparison between the safety factors which were obtained and the ones which are needed is done.

It is clear that each part of the wind turbine is according to the IEC 61400-2 and the safety factors are bigger than the mandatories ones because of we want to increase the safety of the machine.

According to the simple load model:

The safety study was first done using the simple load model to ensure that the IEC61400-2 was covered.

Simple Load Model Results			
Load Case A - Fatigue Loads on Blades and Rotor Shaft			
	Fatigue Damage Limit	Fatigue Damage	Conclusion
Blades	1,00	1,01E-06	**SAFE**
Shaft	1,00	Infinite Life	**SAFE**
Load Case B - Blade and Rotor Shaft Loads during Yaw			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Blades	382,78	0,20	**SAFE**
Shaft	205,00	48,9	**SAFE**
Load Case C - Yaw Error Load on Blades			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Blades	382,78	0,65	**SAFE**
Load Case D - Maximum Thrust on Shaft			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Shaft	382,78	0,50	**SAFE**
Load Case E - Maximum Rotational Speed			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Blades	382,78	38,64	**SAFE**
Shaft	205,00	17,6	**SAFE**
Load Case F - Short at Load Connection			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Blades	382,78	2,41	**SAFE**
Shaft	205,00	35,6	**SAFE**
Load Case G - Shutdown Braking			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Blades	382,78	n/a	n/a
Shaft	205,00	n/a	n/a
Load Case H - Parked Wind Loads during Idling			
	Material Stress Limit (MPa)	Calculated Stress (MPa)	Conclusion
Blades	382,78	0,86	**SAFE**
Shaft	205,00	4,5	**SAFE**

Table 11 – Simple Load Model Results

According to the Annex A and the Finite Element Method for the maximum loads.

In the IEC 61400-2 the FEM analysis is not mandatory, but we have decided to full study our wind turbine to ensure that not only in the parts which is mandatory to study the loads the safe factor is the correct one. We want to know all about our wind turbine and we want it to me as safe as we can, and the finite element method analysis reveals that the safety factors in every part of the wind turbine are higher than the mandatories as it could be seen in the next table.

Part	Material stress limit [MPa]	Calculated stress [MPa]	Safety factor	Conclusion
Framework	272	33.3	8.17	**SAFE**
Nacelle	272	45.3	6.01	**SAFE**
Blade holder	205	59.4	3.45	**SAFE**
Yaw axe	205	51.9	3.95	**SAFE**
Variable pitch support	272	68.5	3.97	**SAFE**
Rod	205	34.6	5.92	**SAFE**
Slider	205	24.1	8.5	**SAFE**

ANNEX A

FEM ANALYSIS

A.1.-EPRO_BASE

Analyzed File:	EPRO_BASE.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 9:54
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Material	Aluminum 356 T6
Density	2,8384 g/cm^3
Mass	8,09196 kg
Area	402876 mm^2
Volume	2850890 mm^3
Center of Gravity	x= 0,0569934 mm y= 73,0483 mm z= -0,0503049 mm

Data

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 9:51
Detect and Eliminate Rigid Body Modes	No

Mesh settings: These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,05
Min. Element Size (fraction of avg. size)	0,05
Grading Factor	1,1
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

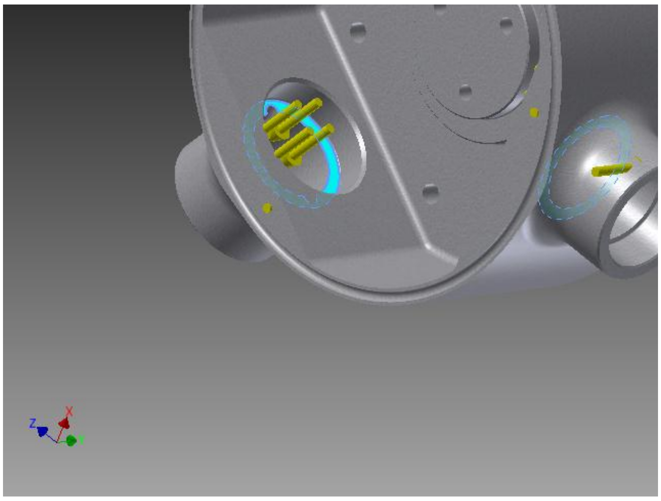
Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Pressure: 1

Load Type	Pressure
Magnitude	4.880 MPa

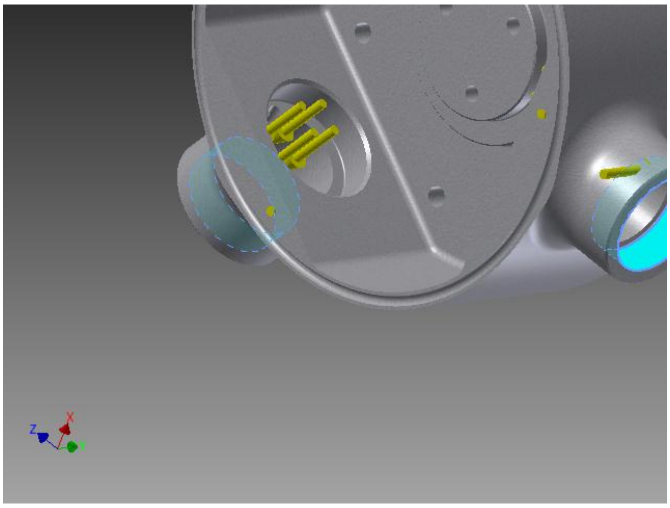
Selected Face(s)



Force: 1

Load Type	Force
Magnitude	452.000 N
Vector X	0.000 N
Vector Y	452.000 N
Vector Z	0.000 N

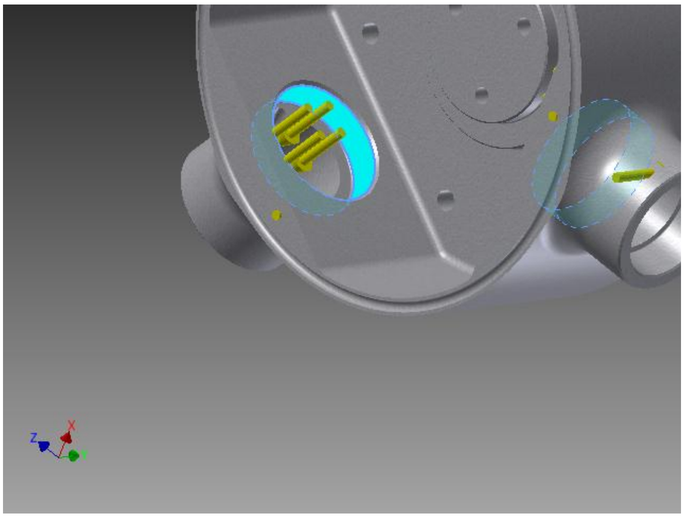
Selected Face(s)



Force: 2

Load Type	Force
Magnitude	113.000 N
Vector X	0.000 N
Vector Y	113.000 N
Vector Z	0.000 N

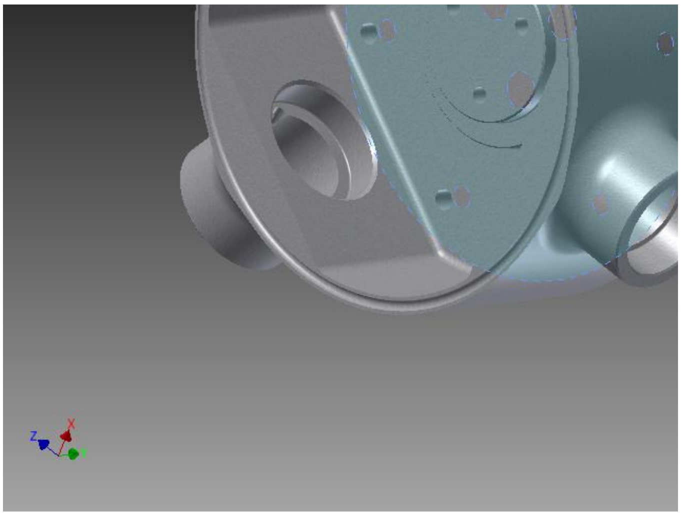
Selected Face(s)



Fixed Constraint: 1

Constraint Type	Fixed Constraint

Selected Face(s)



Results

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point

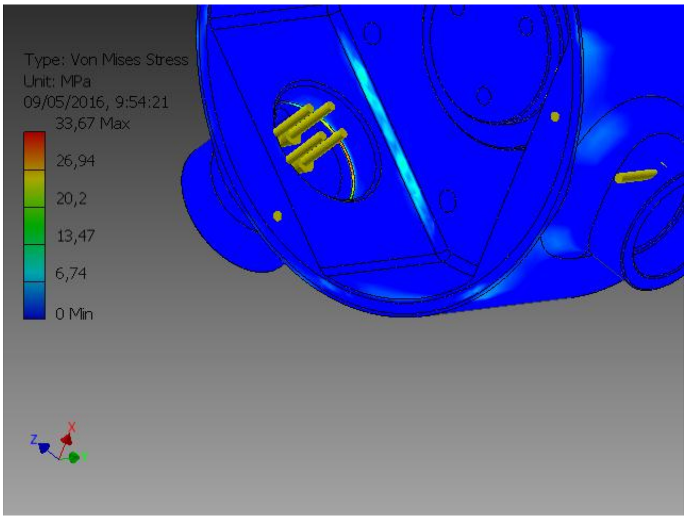
Result Summary

Name	Minimum	Maximum
Volume	2850890 mm^3	
Mass	8,09196 kg	
Von Mises Stress	0,00104139 MPa	33,6726 MPa
Displacement	0 mm	0,0406143 mm
Safety Factor	8,16687 ul	15 ul

Figures

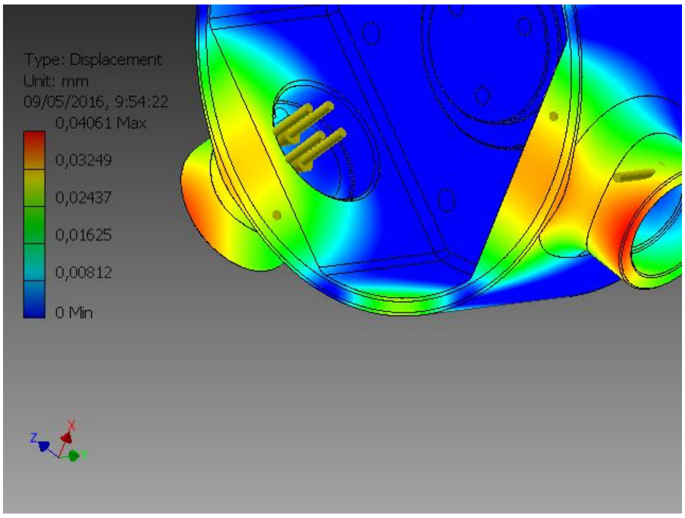
Von Mises Stress

Maximum combined stress point



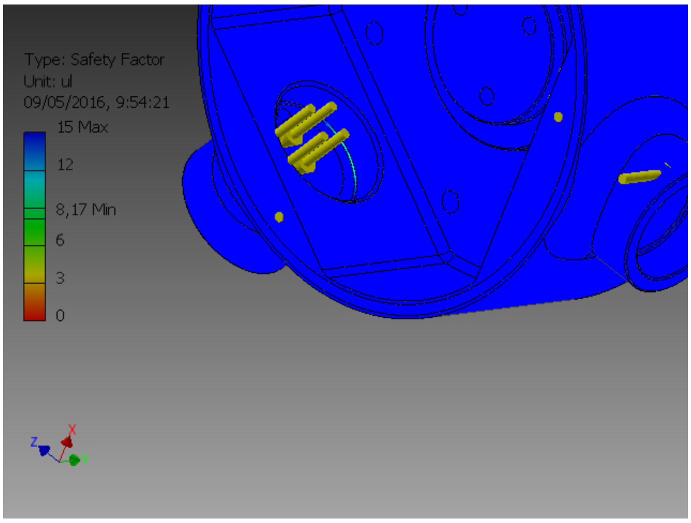
Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.



A.2.-EPRO_ BIELA

Analyzed File:	EPRO_BIELA.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 13:07
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Material	Steel F114
Density	7,85 g/cm^3
Mass	0,328713 kg
Area	11015,6 mm^2
Volume	41874,3 mm^3
Center of Gravity	x= 7,5 mm y= 12,104 mm z= -15,5365 mm

Simulation: 1

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 13:06
Detect and Eliminate Rigid Body Modes	No

Mesh settings: These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,01
Min. Element Size (fraction of avg. size)	0,01
Grading Factor	1,1
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s)

Name	Steel, Cast	
General	Mass Density	7,85 g/cm^3
	Yield Strength	250 MPa
	Ultimate Tensile Strength	300 MPa
Stress	Young's Modulus	210 GPa
	Poisson's Ratio	0,3 ul
	Shear Modulus	80,7692 GPa
Part Name(s)	EPRO_BIELA	

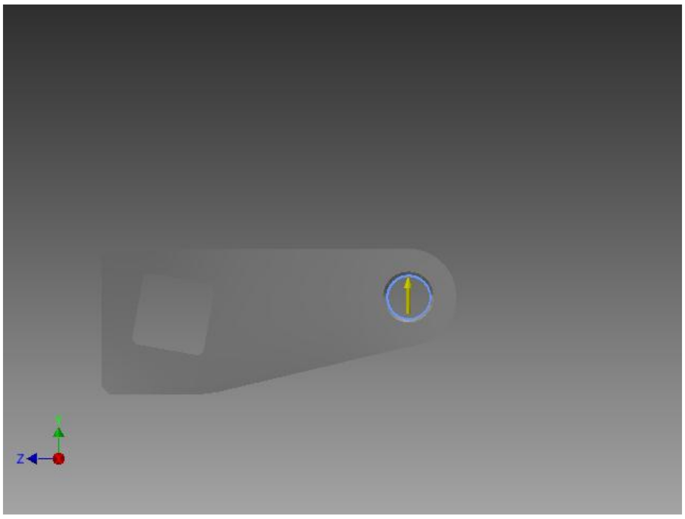
Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Force: 1

Load Type	Force
Magnitude	1255.000 N
Vector X	0.000 N
Vector Y	1255.000 N
Vector Z	0.000 N

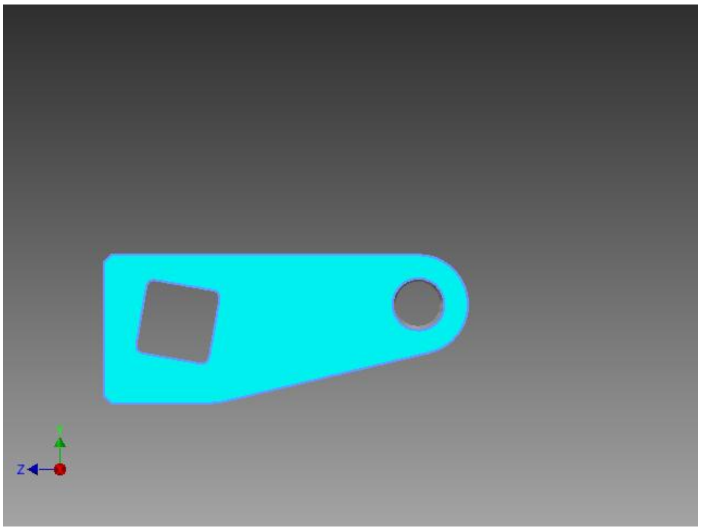
Selected Face(s)



Frictionless Constraint: 1

Constraint Type	Frictionless Constraint

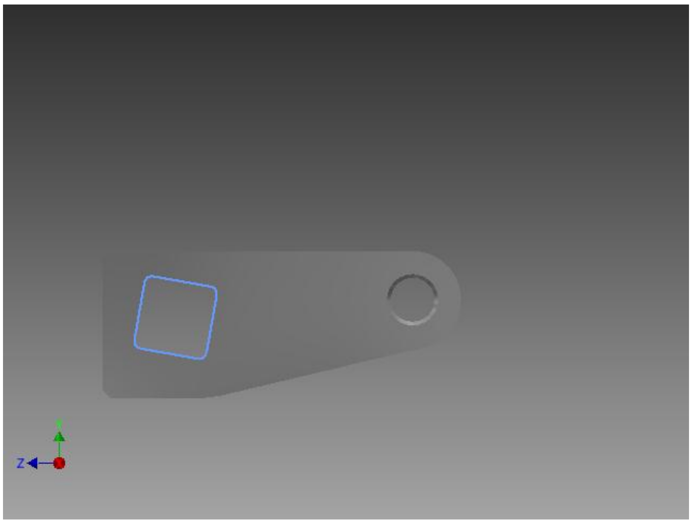
Selected Face(s)



Frictionless Constraint: 2

Constraint Type	Frictionless Constraint

Selected Face(s)



Results

Reaction Force and Moment on Constraints

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Frictionless Constraint:1	14,6695 N	0 N -14,6695 N 0 N	0,531348 N m	-0,531348 N m 0 N m 0 N m
Frictionless Constraint:2	1240,25 N	0 N -1240,25 N 0 N	80,4596 N m	-80,4596 N m 0 N m 0 N m

Result Summary

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

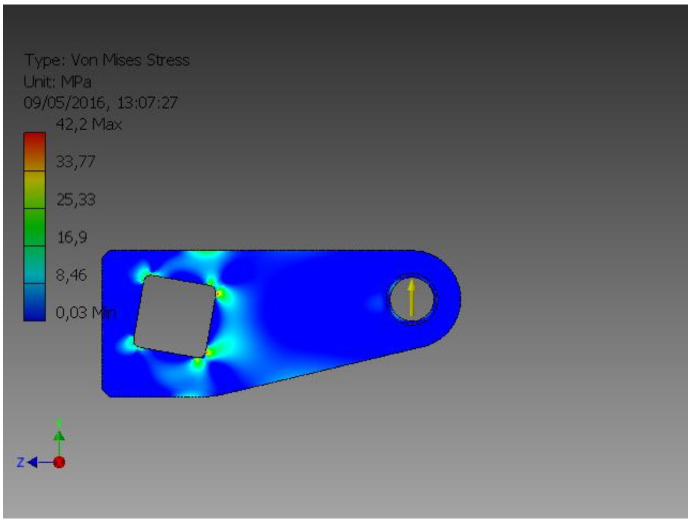
-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point.

Name	Minimum	Maximum
Volume	41874,3 mm^3	
Mass	0,328713 kg	
Von Mises Stress	0,0310979 MPa	42,1988 MPa
1st Principal Stress	-47,4164 MPa	93,4125 MPa
3rd Principal Stress	-93,5576 MPa	49,06 MPa
Displacement	0,000646734 mm	0,0189292 mm
Safety Factor	5,92433 ul	15 ul

Figures

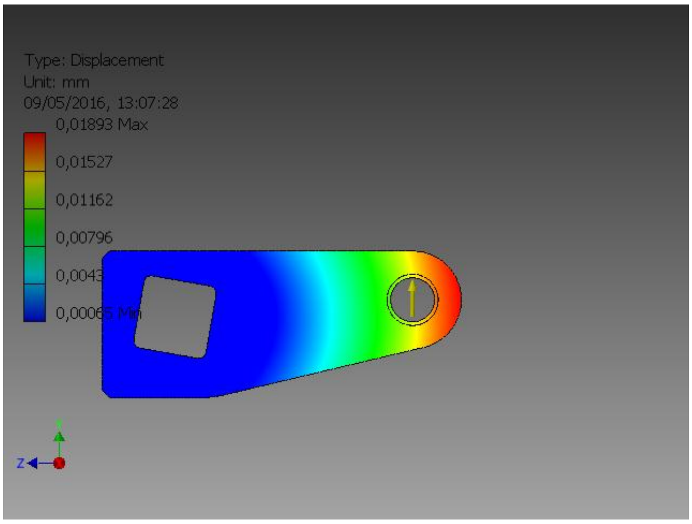
Von Mises Stress

Maximum combined stress point



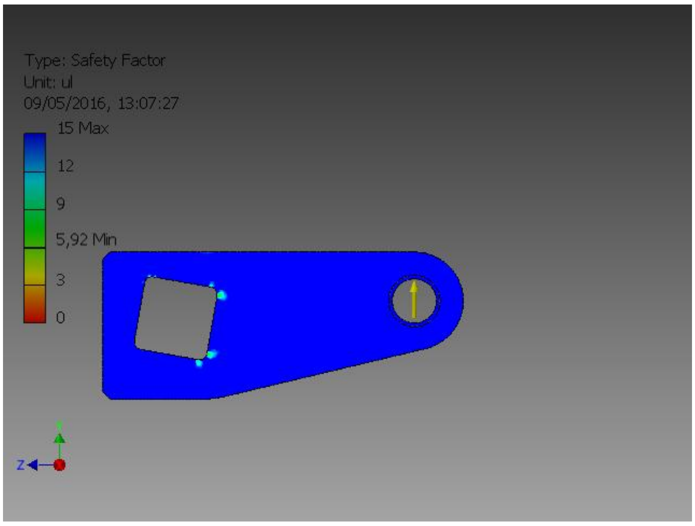
Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.



A.3.-EPRO_CORREDERA

Analyzed File:	EPRO_CORREDERA.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 15:46
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Material	Steel F114
Density	7,85 g/cm^3
Mass	2,44378 kg
Area	63602,1 mm^2
Volume	311309 mm^3
Center of Gravity	x= 80,0001 mm y= 24,3562 mm z= -46,188 mm

3070V2_Análisis_Deslizadora

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 15:44
Detect and Eliminate Rigid Body Modes	No

Mesh settings: These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,01
Min. Element Size (fraction of avg. size)	0,05
Grading Factor	1,2
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s)

Name	Steel, Cast	
General	Mass Density	7,85 g/cm^3
	Yield Strength	250 MPa
	Ultimate Tensile Strength	300 MPa
Stress	Young's Modulus	210 GPa
	Poisson's Ratio	0,3 ul
	Shear Modulus	80,7692 GPa
Part Name(s)	EPRO_BIELA	

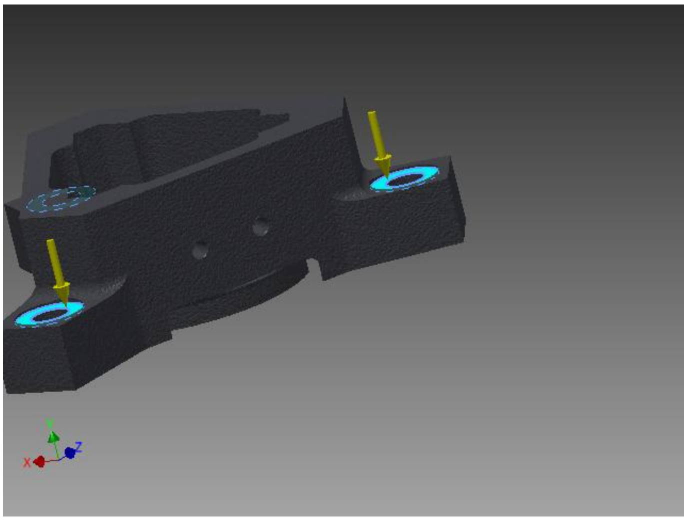
Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Force: 1

Load Type	Force
Magnitude	9145.000 N
Vector X	-0.000 N
Vector Y	-9145.000 N
Vector Z	0.000 N

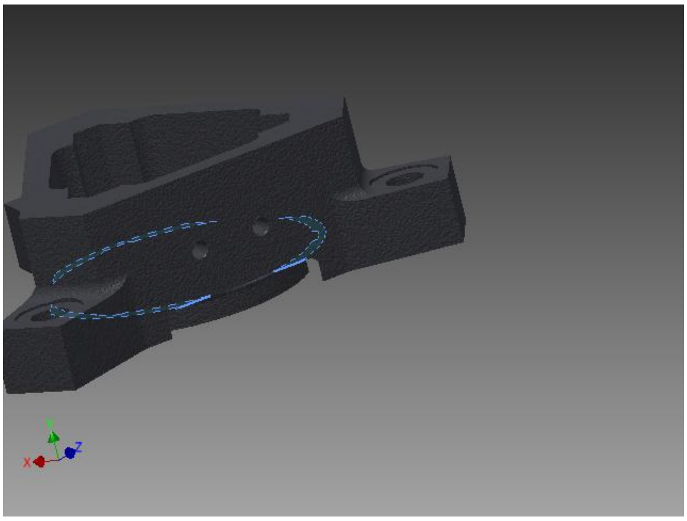
Selected Face(s)



Fixed Constraint: 1

Constraint Type	Fixed Constraint

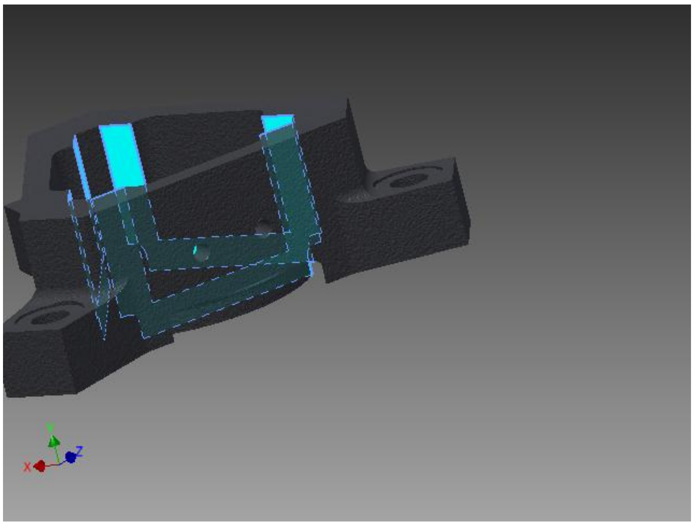
Selected Face(s)



Frictionless Constraint: 1

Constraint Type	Frictionless Constraint

Selected Face(s)



Results

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point.

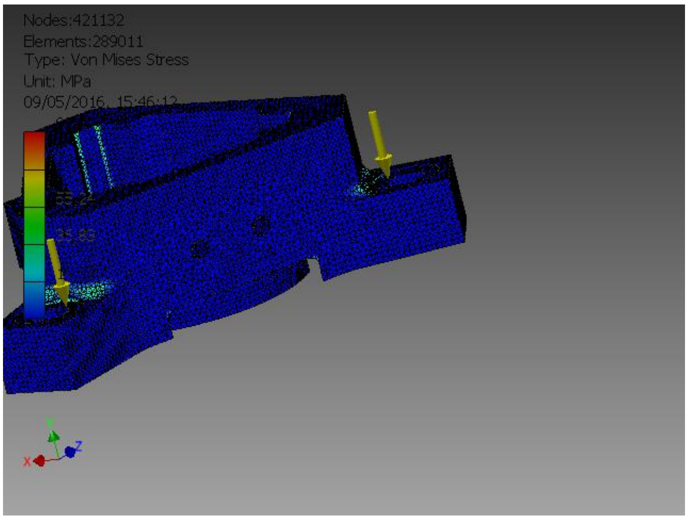
Result Summary

Name	Minimum	Maximum
Volume	311309 mm^3	
Mass	2,44378 kg	
Von Mises Stress	0,0104964 MPa	92,0673 MPa
Displacement	0 mm	0,0110634 mm
Safety Factor	2,7154 ul	15 ul

Figures

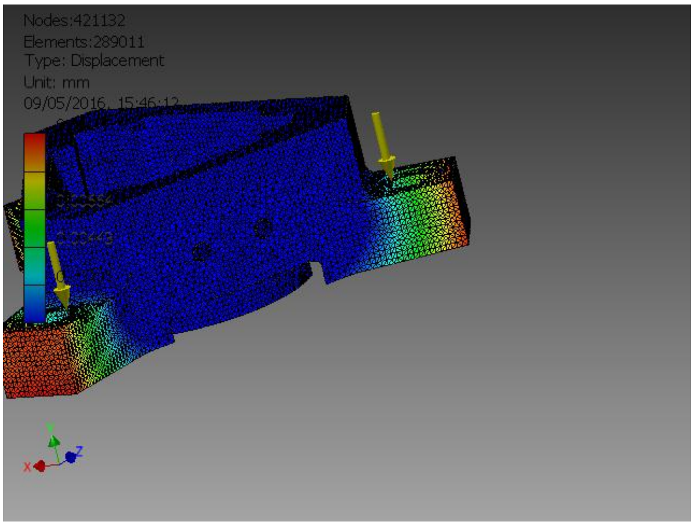
Von Mises Stress

Maximum combined stress point



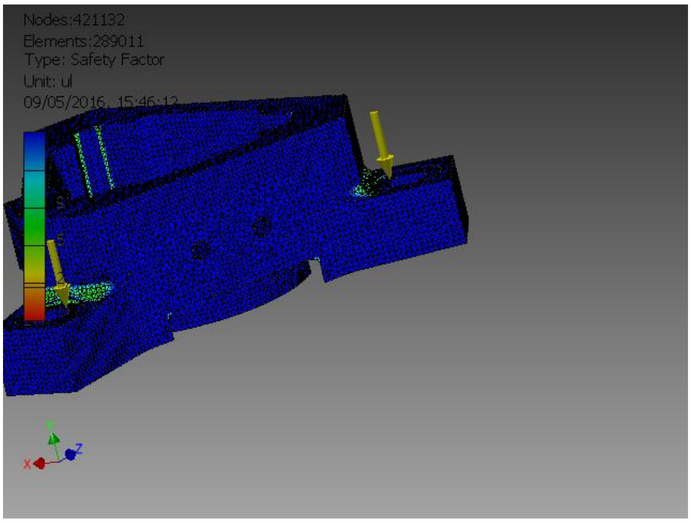
Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.



A.4.-EPRO_CUCHARA

Analyzed File:	EPRO_CUCHARA.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 11:42
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Material	Steel F114
Density	7,15 g/cm^3
Mass	3,52544 kg
Area	63907 mm^2
Volume	493069 mm^3
Center of Gravity	x= 17,5713 mm y= -0,00144994 mm z= 145,664 mm

Simulation: 1

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 11:42
Detect and Eliminate Rigid Body Modes	No

Mesh settings: These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,02
Min. Element Size (fraction of avg. size)	0,05
Grading Factor	1,1
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s)

Name	Steel F 114	
General	Mass Density	7,15 g/cm^3
	Yield Strength	758 MPa
	Ultimate Tensile Strength	884 MPa
Stress	Young's Modulus	120,5 GPa
	Poisson's Ratio	0,3 ul
	Shear Modulus	46,3462 GPa
Part Name(s)	EPRO_CUCHARA	

Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Force: 1

Load Type	Force
Magnitude	339.000 N
Vector X	0.000 N
Vector Y	0.000 N
Vector Z	339.000 N

Selected Face(s)

Force: 2

Load Type	Force
Magnitude	679.000 N
Vector X	0.000 N
Vector Y	0.000 N
Vector Z	679.000 N

Selected Face(s)

Force: 3

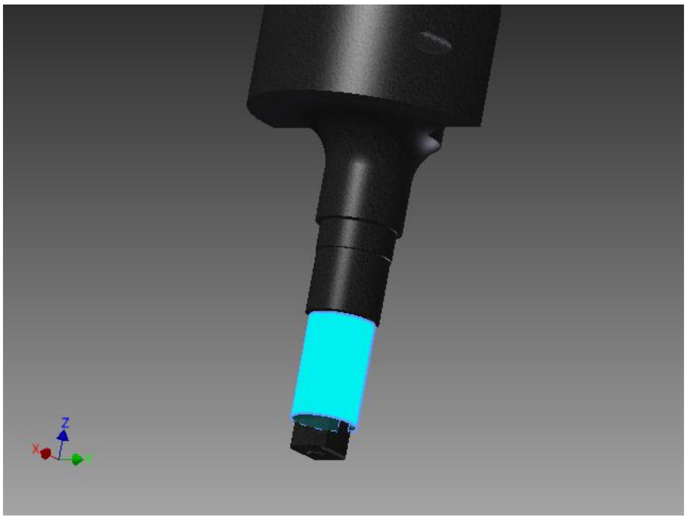
Load Type	Force
Magnitude	1764.000 N
Vector X	1764.000 N
Vector Y	0.000 N
Vector Z	0.000 N

Selected Face(s)

Fixed Constraint: 1

Constraint Type	Fixed Constraint

Selected Face(s)



Pin Constraint: 1

Constraint Type	Pin Constraint
Fix Radial Direction	Yes
Fix Axial Direction	Yes
Fix Tangential Direction	No

Selected Face(s)

Results

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point.

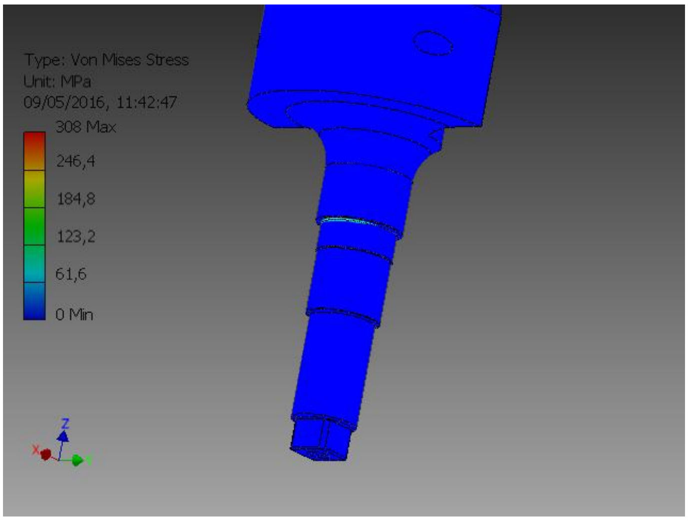
Result Summary

Name	Minimum	Maximum
Volume	493055 mm^3	
Mass	3,52534 kg	
Von Mises Stress	0,00000425949 MPa	307,96 MPa
Displacement	0 mm	0,0703671 mm
Safety Factor	2,46135 ul	15 ul

Figures

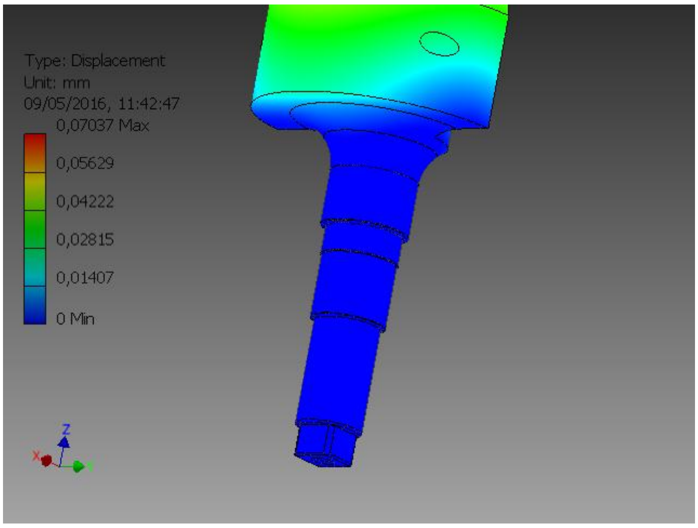
Von Mises Stress

Maximum combined stress point



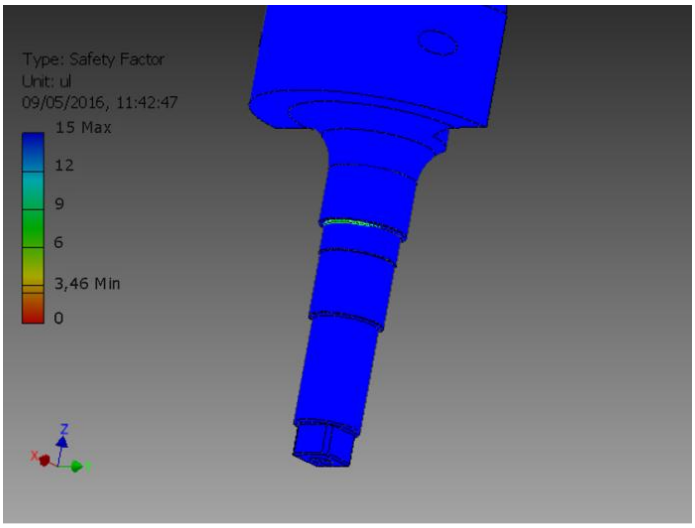
Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.



A.5.-EPRO_GIRATORIA

Analyzed File:	EPRO_GIRATORIATESTS.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 10:17
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Mass	7,48794 kg
Area	172973 mm^2
Volume	983138 mm^3
Center of Gravity	x= 0,00000486377 mm y= 43,8377 mm z= -0,15053 mm

Simulation: 1

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 15:47
Detect and Eliminate Rigid Body Modes	Yes
Separate Stresses Across Contact Surfaces	No
Motion Loads Analysis	No

Mesh settings: These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,01
Min. Element Size (fraction of avg. size)	0,1
Grading Factor	1,1
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes
Use part based measure for Assembly mesh	Yes

Material(s)

Name	Acero S355	
General	Mass Density	7,73 g/cm^3
	Yield Strength	355 MPa
	Ultimate Tensile Strength	600 MPa
Stress	Young's Modulus	205 GPa
	Poisson's Ratio	0,3 ul
	Shear Modulus	78,8462 GPa
Part Name(s)	EPRO_BRIDA EPRO_EJEGIRATORIA	

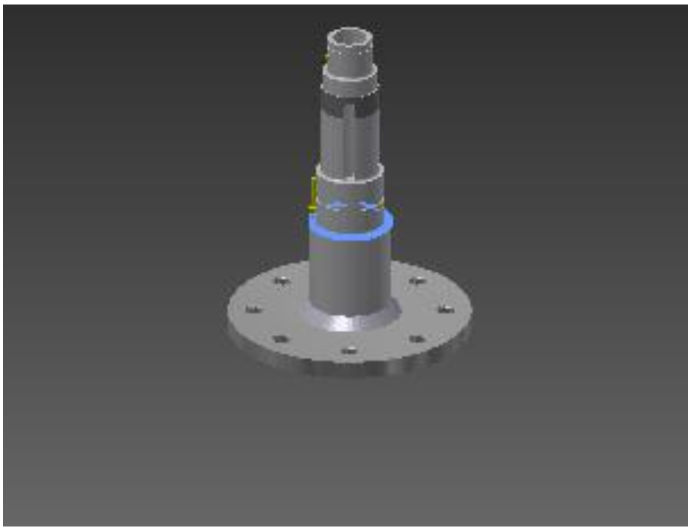
Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Force: 1

Load Type	Force
Magnitude	1873,700 N
Vector X	-0,000 N
Vector Y	-1873,700 N
Vector Z	0,000 N

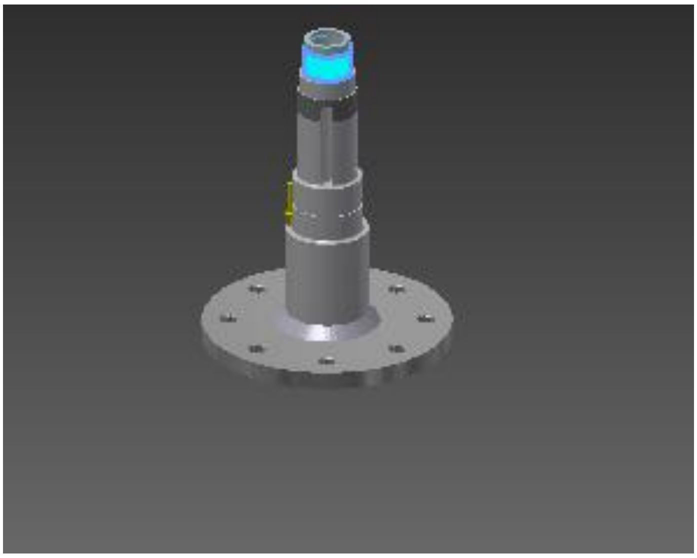
Selected Face(s)



Force: 2

Load Type	Force
Magnitude	1360,000 N
Vector X	1360,000 N
Vector Y	0,000 N
Vector Z	0,000 N

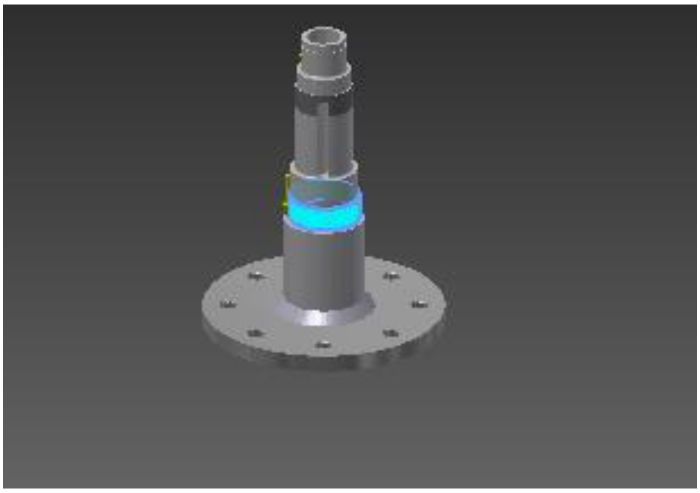
Selected Face(s)



Force: 3

Load Type	Force
Magnitude	339,000 N
Vector X	339,000 N
Vector Y	0,000 N
Vector Z	0,000 N

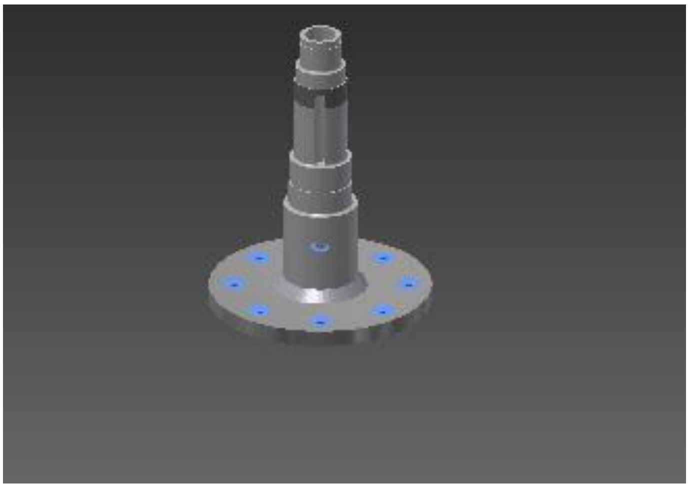
Selected Face(s)



Fixed Constraint: 1

Constraint Type	Fixed Constraint

Selected Face(s)



Results

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point.

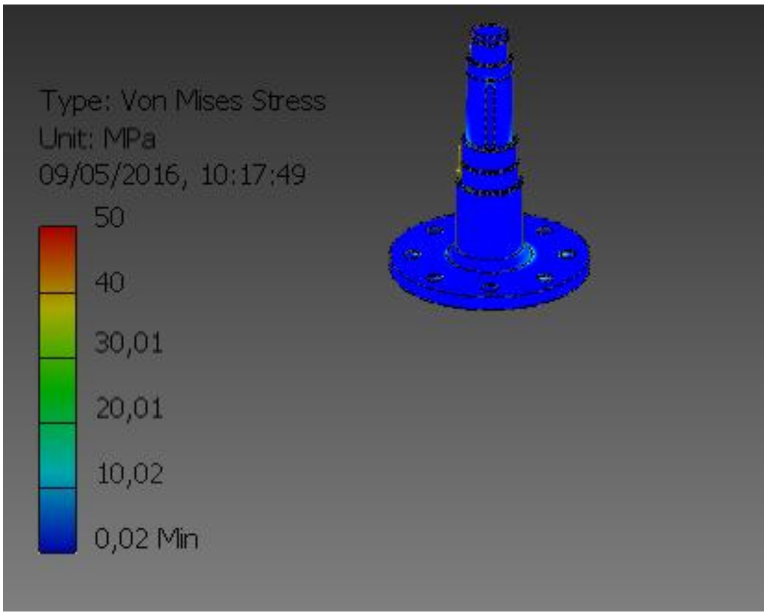
Result Summary

Name	Minimum	Maximum
Volume	983137 mm^3	
Mass	7,48794 kg	
Von Mises Stress	0,0232978 MPa	89,8774 MPa
Displacement	0 mm	0,113105 mm
Safety Factor	3,94982 ul	15 ul

Figures

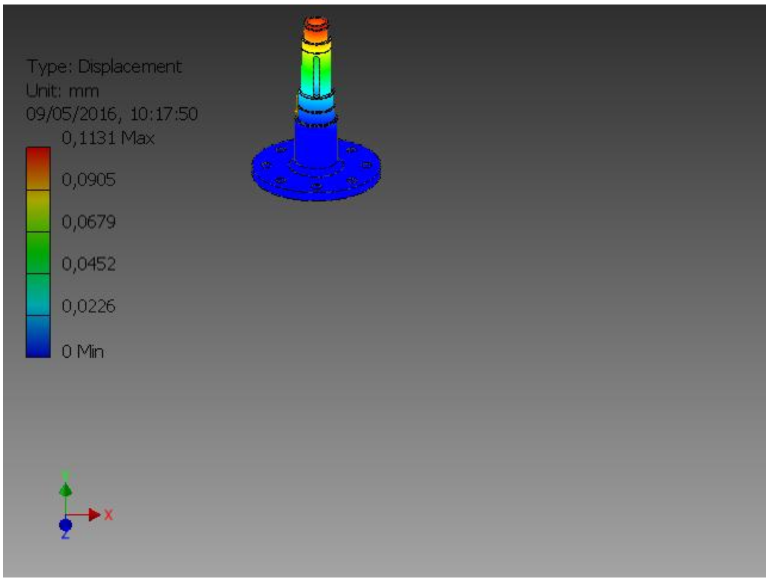
Von Mises Stress

Maximum combined stress point



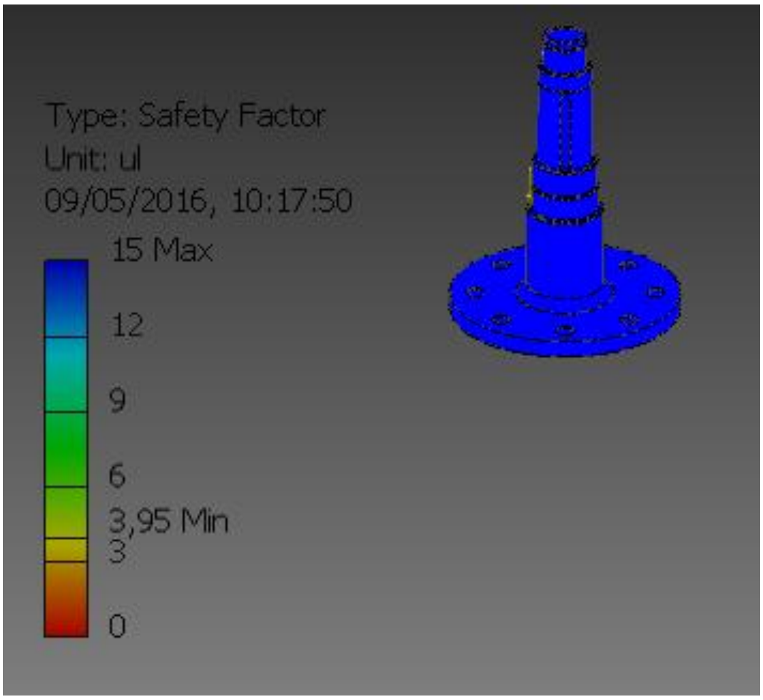
Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.



A.6.-EPRO_GONDOLA

Analyzed File:	EPRO_GONDOLA.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 12:30
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Material	Aluminum 356T6
Density	2,7 g/cm^3
Mass	34,1382 kg
Area	979287 mm^2
Volume	12643800 mm^3
Center of Gravity	x= -139,85 mm y= -14,6386 mm z= -0,0667279 mm

Simulation: 1

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 12:37
Detect and Eliminate Rigid Body Modes	No

Mesh settings:

These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,051
Min. Element Size (fraction of avg. size)	0,092
Grading Factor	1,5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s)

Name	Aluminum 6061	
General	Mass Density	2,7 g/cm^3
	Yield Strength	275 MPa
	Ultimate Tensile Strength	310 MPa
Stress	Young's Modulus	68,9 GPa
	Poisson's Ratio	0,33 ul
	Shear Modulus	25,9023 GPa
Part Name(s)	EPRO_GONDOLA	

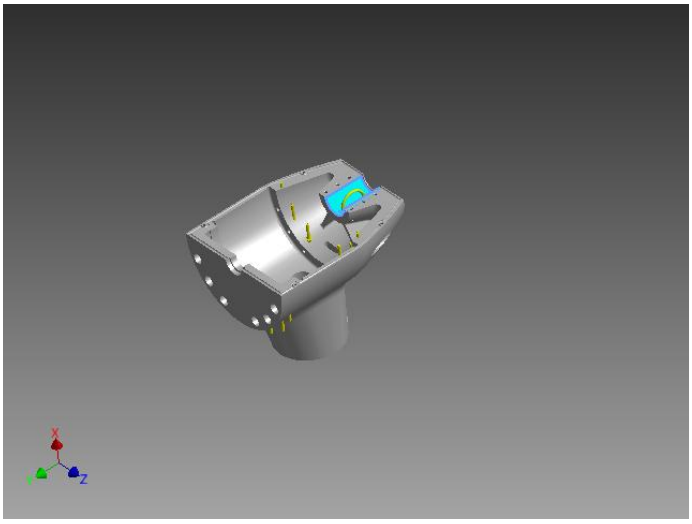
Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Moment: 1

Load Type	Moment
Magnitude	170000.000 N mm
Vector X	0.000 N mm
Vector Y	0.000 N mm
Vector Z	-170000.000 N mm

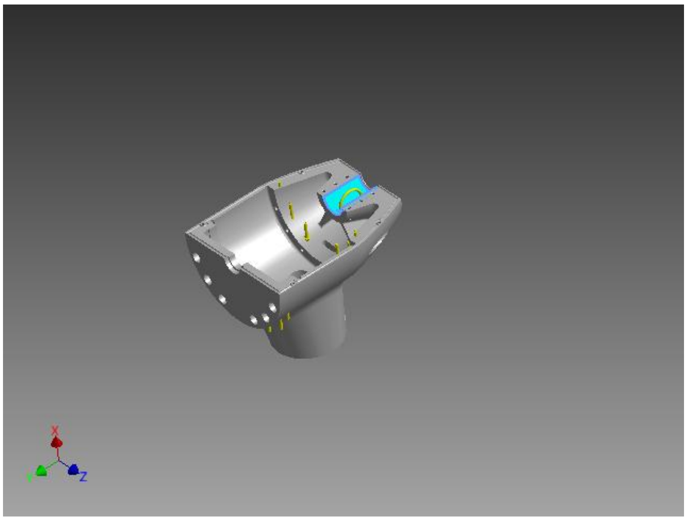
Selected Face(s)



Moment: 2

Load Type	Moment
Magnitude	2205000.000 N mm
Vector X	2205000.000 N mm
Vector Y	0.000 N mm
Vector Z	0.000 N mm

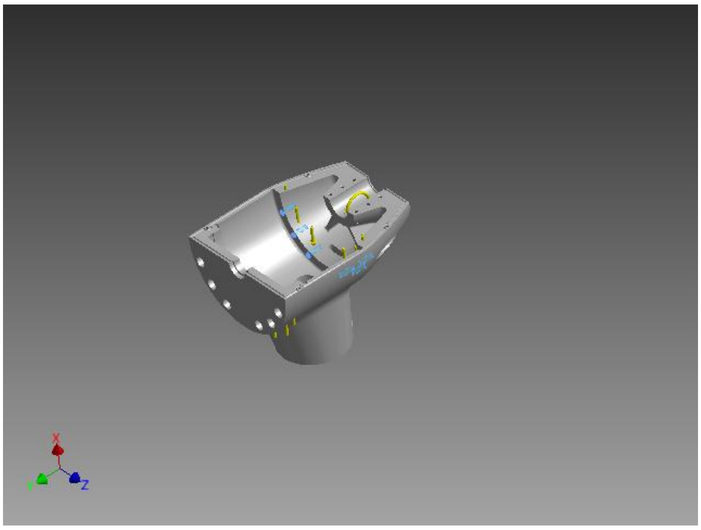
Selected Face(s)



Force: 1

Load Type	Force
Magnitude	702.000 N
Vector X	-702.000 N
Vector Y	0.000 N
Vector Z	0.000 N

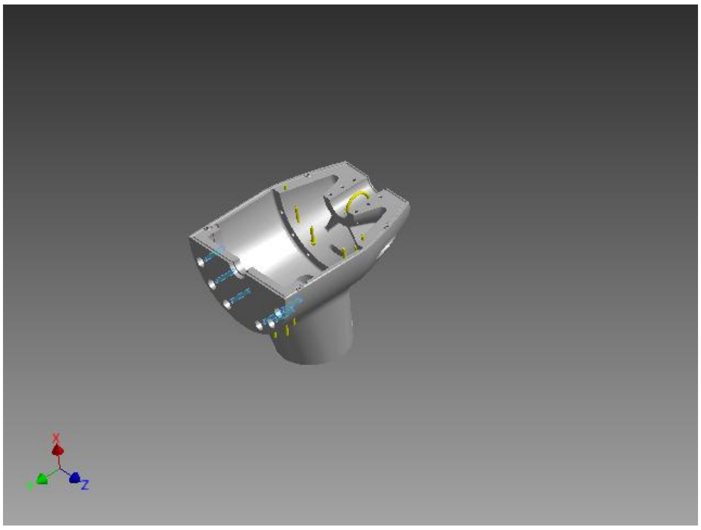
Selected Face(s)



Force: 2

Load Type	Force
Magnitude	702.000 N
Vector X	702.000 N
Vector Y	0.000 N
Vector Z	0.000 N

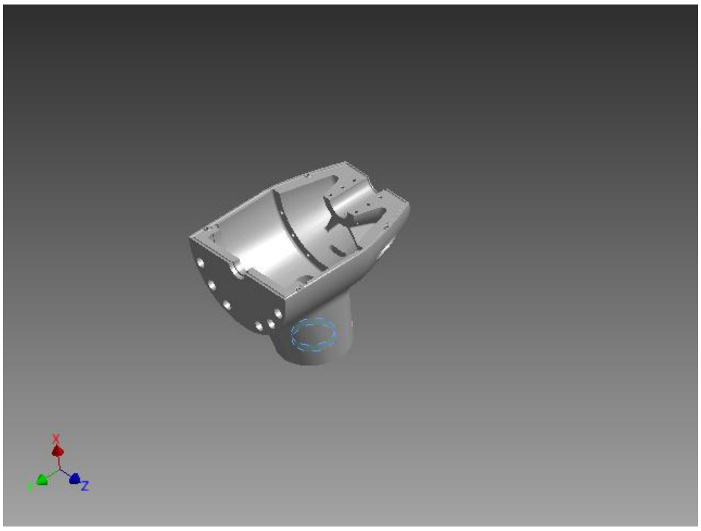
Selected Face(s)



Fixed Constraint: 1

Constraint Type	Fixed Constraint

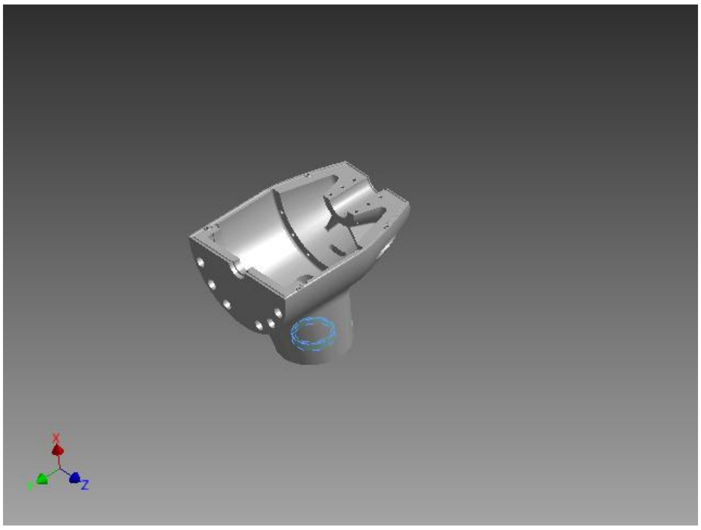
Selected Face(s)



Fixed Constraint: 1

Constraint Type	Fixed Constraint

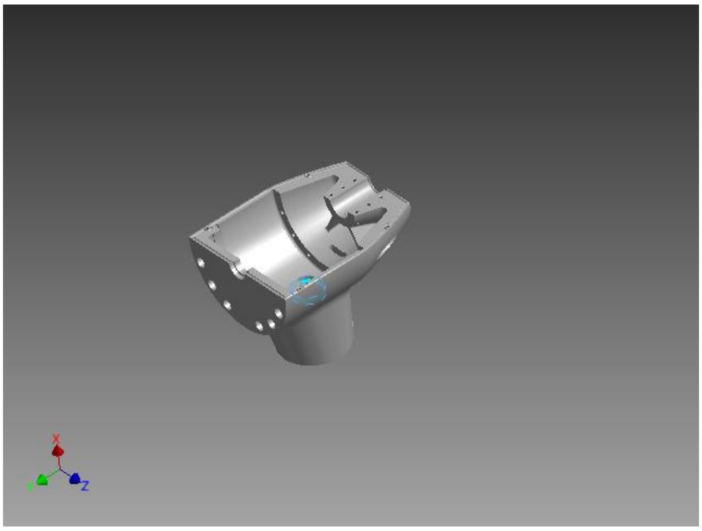
Selected Face(s)



Pin Constraint: 1

Constraint Type	Pin Constraint
Fix Radial Direction	Yes
Fix Axial Direction	Yes
Fix Tangential Direction	No

Selected Face(s)



Results

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point.

Reaction Force and Moment on Constraints

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Fixed restricction:1	1070,47 N	-257,835 N -849,721 N 597,822 N	828,343 N m	-781,212 N m 273,347 N m 33,7967 N m
Fixed Constraint:1	9121,15 N	-512,129 N -396,492 N -9098,12 N	1478,56 N m	-1423,61 N m 397,153 N m 41,6967 N m
Pin Constraint:1	8625,66 N	769,795 N 1246,81 N 8500,29 N	453,827 N m	0 N m 446,117 N m 83,2969 N m

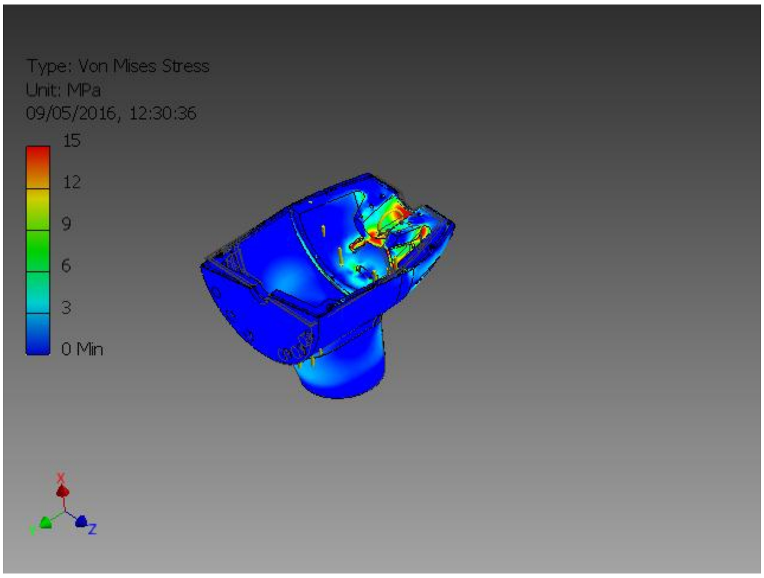
Result Summary

Name	Minimum	Maximum
Volume	12644300 mm^3	
Mass	34,1396 kg	
Von Mises Stress	0,00286847 MPa	45,7223 MPa
1st Principal Stress	-31,9007 MPa	53,2738 MPa
3rd Principal Stress	-78,6908 MPa	21,1258 MPa
Displacement	0 mm	0,104102 mm
Safety Factor	6,01457 ul	15 ul

Figures

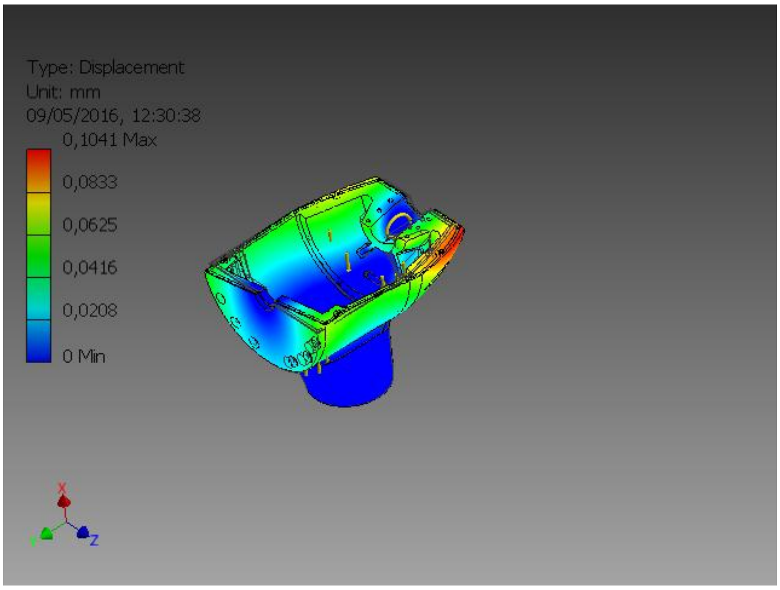
Von Mises Stress

Maximum combined stress point



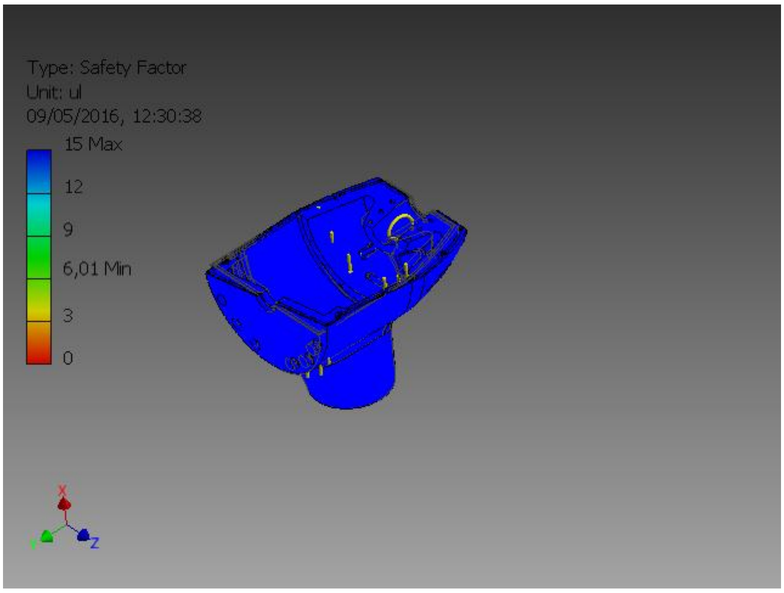
Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.



A.7.-EPRO_PLATO

Analyzed File:	EPRO_PLATO.ipt
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	09/05/2016, 12:54
Simulation Author:	Román Dato Cuadrado
Summary:	

Project Info (iProperties)

Physical

The most significant material specifications of this parts were defined below

Material	Aluminum 356T6
Density	2,7 g/cm^3
Mass	3,33473 kg
Area	150680 mm^2
Volume	1235090 mm^3
Center of Gravity	x= -0,0600538 mm y= -0,00108793 mm z= -17,0923 mm

Simulation: 1

General objective and settings: This kind of analysis is the necessary to get the strengths that appear in the studied part of the full wind turbine

The single point objective is for solving every point in the part, and the static analysis is opposite to the fatigue one, so the maximum loads act in certain moments.

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	09/05/2016, 12:54
Detect and Eliminate Rigid Body Modes	No

Mesh settings: These mesh settings were chosen according with the standards for that kind of analysis

Avg. Element Size (fraction of model diameter)	0,05
Min. Element Size (fraction of avg. size)	0,05
Grading Factor	1,1
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s)

Name	Aluminum 6061	
General	Mass Density	2,7 g/cm^3
	Yield Strength	275 MPa
	Ultimate Tensile Strength	310 MPa
Stress	Young's Modulus	68,9 GPa
	Poisson's Ratio	0,33 ul
	Shear Modulus	25,9023 GPa
Part Name(s)	EPRO_PLATO	

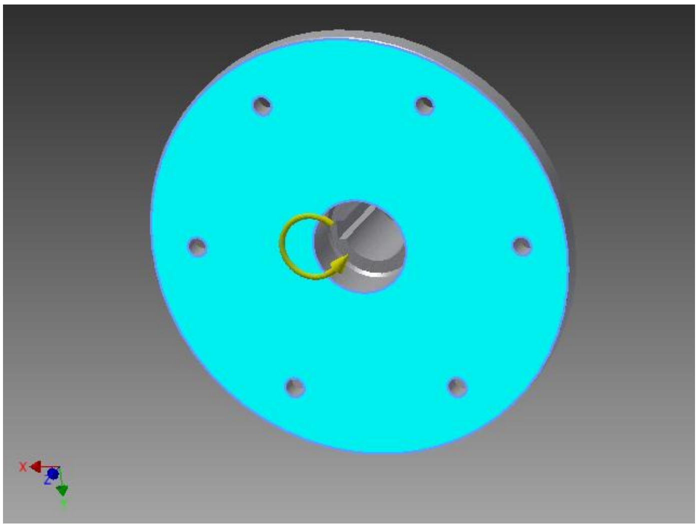
Operating conditions

In the next steps it is shown what and where the loads are put. The pictures are clear enough to understand what kind of loads are actuating in its face.

Moment: 1

Load Type	Moment
Magnitude	433000,000 N mm
Vector X	0,000 N mm
Vector Y	0,000 N mm
Vector Z	433000,000 N mm

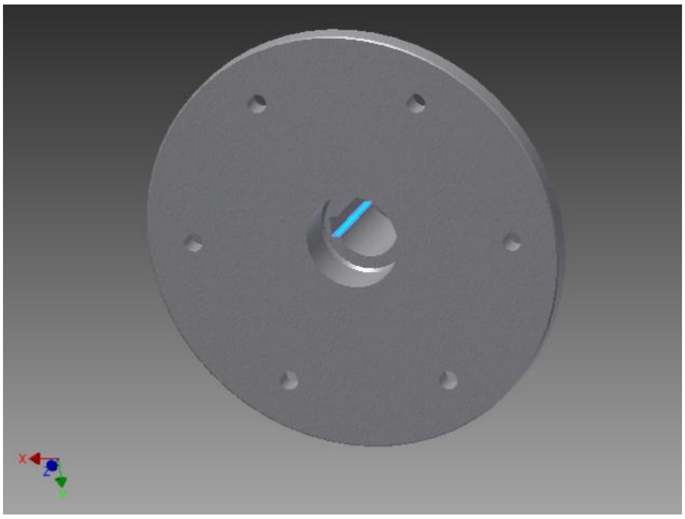
Selected Face(s)



Fixed Constraint: 1

Constraint Type	Fixed Constraint

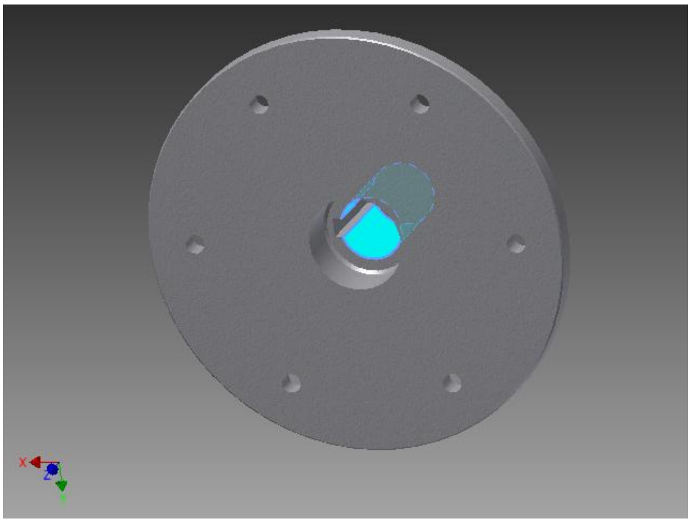
Selected Face(s)



Frictionless Constraint: 1

Constraint Type	Frictionless Constraint

Selected Face(s)



Results

The results obtained are shown using three magnitudes of control

-Von Mises Stress: It reveals a combination of all kind of tensions that appear in each point of the part

-Displacement: It shows how much the part is deformed

-Safety factor: Using the material given as a reference it makes the comparison between the maximum stress admitted and the stress obtained in each point.

Reaction Force and Moment on Constraints

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Fixed Constraint:1	17620,1 N	2736,19 N -17406,3 N 34,8316 N	135,509 N m	129,943 N m 24,8565 N m -29,3202 N m
Frictionless Constraint:1	17623,4 N	-2733,21 N 17410,1 N -35,4464 N	134,927 N m	-130,347 N m -24,1337 N m 25,1464 N m

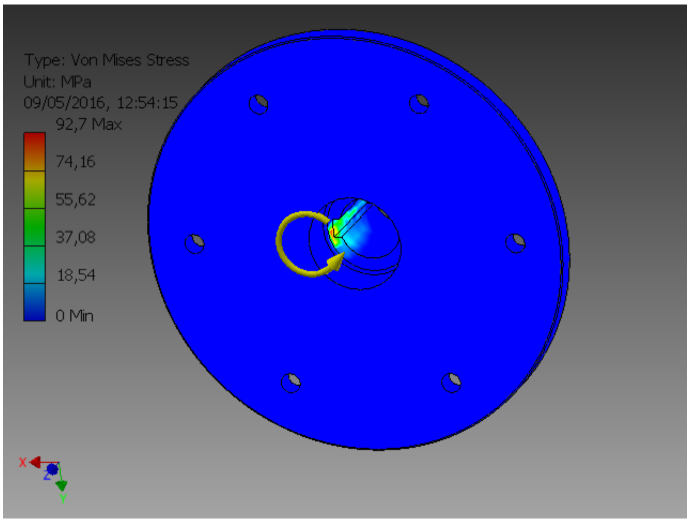
Result Summary

Name	Minimum	Maximum
Volume	1235130 mm^3	
Mass	3,33485 kg	
Von Mises Stress	0,00410328 MPa	0,00410328 MPa
1st Principal Stress	-10,2799 MPa	83,8409 MPa
3rd Principal Stress	-96,7552 MPa	18,5053 MPa
Displacement	0 mm	0,0596551 mm
Safety Factor	2,96667 ul	15 ul

Figures

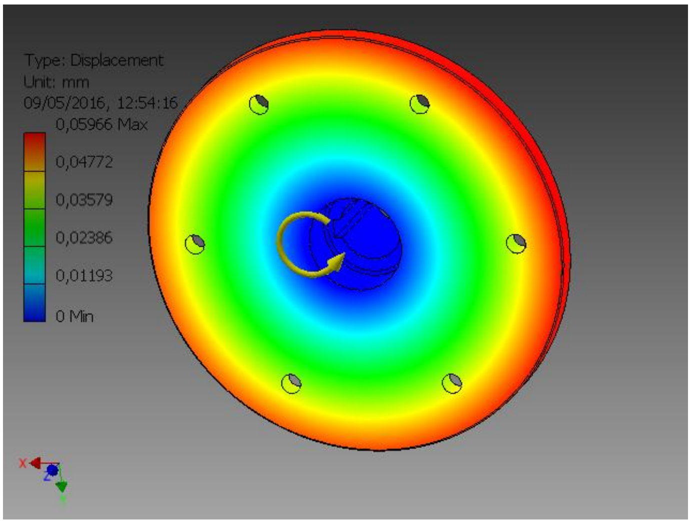
Von Mises Stress

Maximum combined stress point



Displacement

Points which will be deformed when the maximum loads are applied



Safety Factor

The most important parameter, it shows the safety factor in each point of the part when the maximum loads are applied. That analysis does not make difference between the most critical points like the SLM because it takes the overall points of the part to make the analysis.