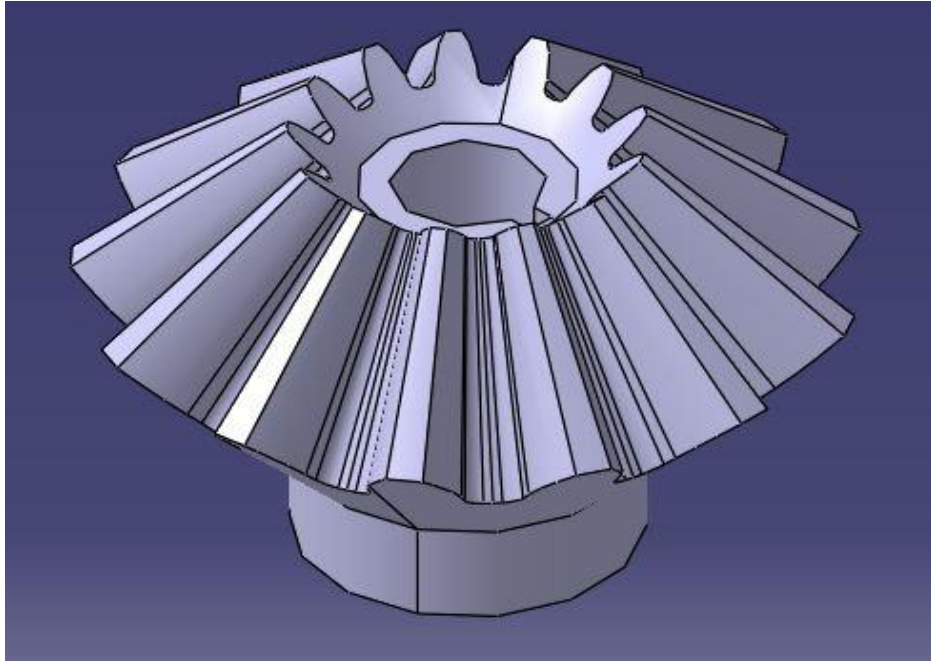


Designing parametric bevel gears with Catia V5



This tutorial shows how to make a basic bevel gear that you can freely re-use in your assemblies.

1 Sources, credits and links

- The conventional formulas and their names in French come from the page 100 of the book "Précis de construction mécanique" by R. Quatremer and J.P. Trotignon, Nathan publisher, 1983 edition.
- I found a clear explanation of bevel gears in the pages 258 to 280 of the book "Les mécanismes des machines y compris les automobiles" by H. Leblanc, Garnier publisher, 1930 edition.
- For an exhaustive analysis, we could also use the famous old book "Les engrenages" written by Mr Henriot.

The principle for designing a bevel gear consists in drawing two primitive conical surfaces:

- The front cone, parallel to the edges of the teeth.
- The rear cone, used for designing the profile of a tooth.

The half angle δ of the front cone depends on:

- The module m .

- The number of teeth of the gear Z_1 .
- The number of teeth of the other gear Z_2 .
- The angle between the axis of the two gears.

In most applications using bevel gears, the angle between the axis of the two gears is equal to $\pi/2$. In that case, the half angle δ of the front cone is defined by the formula:

$$\delta = \arctan(Z_1 / Z_2)$$

2 Table of gear parameters and formulas

The following table contains:

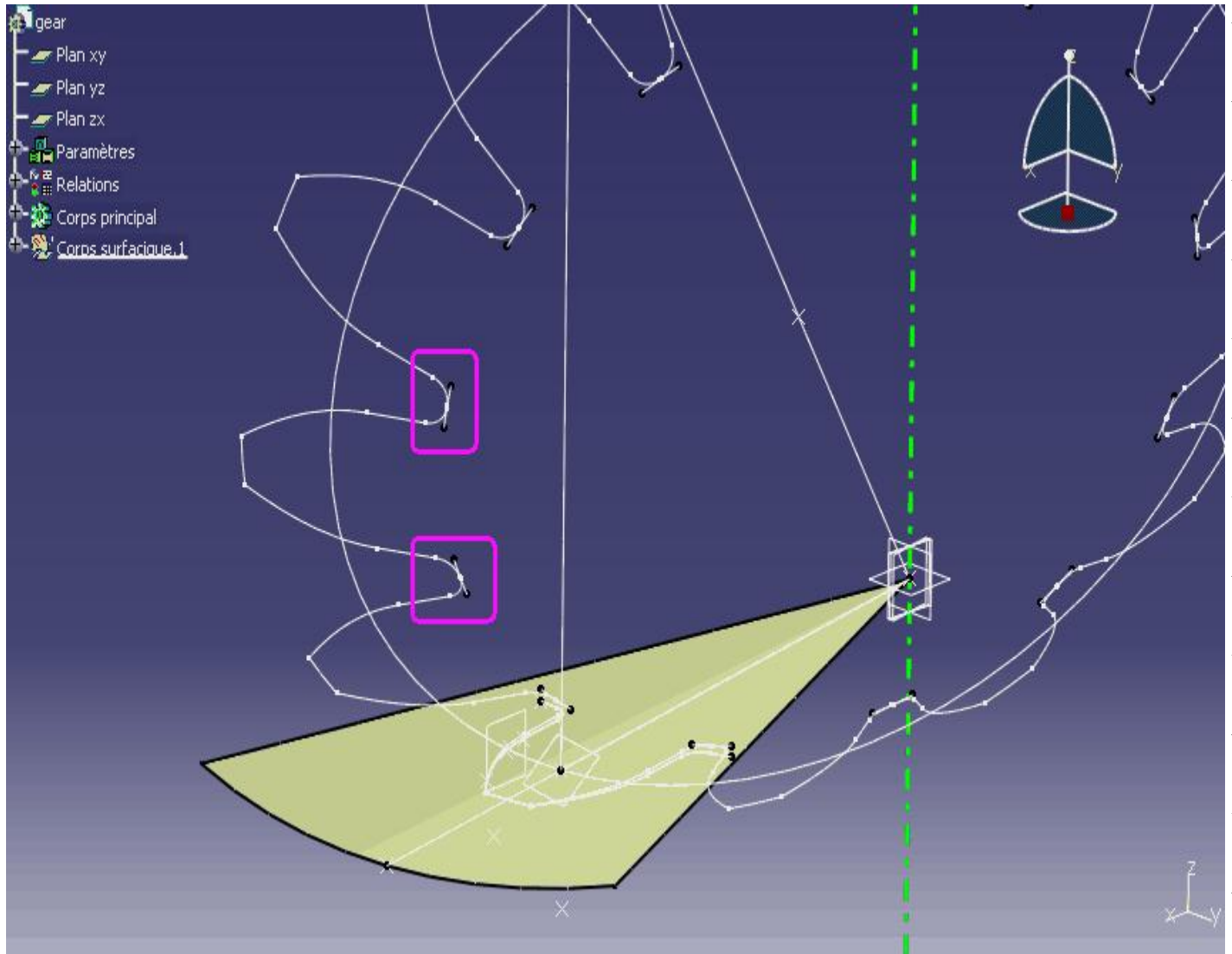
- The parameters and formulas used for standard spur gears.
- The specific parameters and formulas added for bevel gears (in the cells colored in pink).

#	Parameter	Type or unit	Formula	Description	Name in French
1	a	angular degree	20deg	Pressure angle: technologic constant ($10\text{deg} \leq a \leq 20\text{deg}$)	Angle de pression.
2	m	millimeter	—	Modulus.	Module.
3	Z_1	integer	—	Number of teeth ($11 \leq Z_1 \leq 200$).	Nombre de dents.
4	Z_2	integer	—	Number of teeth of the complementary bevel gear.	Nombre de dents de la roue conique complémentaire.
5	δ	angular degree	$\arctan(Z_1 / Z_2)$	Half angle of the front primitive cone.	Demi angle au sommet du cône primitif avant
6	ld	millimeter	—	Length of the teeth on the front primitive cone.	Longueur des dents sur le cone primitif avant.
7	ratio		$1 - ld / (lc * \cos(\delta))$		pour calculer les homothéties du flanc intérieur
8	dZ	millimeter	0mm	Translation offset of the generative geometry on the Z axis.	Décalage des constructions géométriques suivant l'axe Z.
9	p	millimeter	$m * \pi$	Pitch of the teeth on a straight generative rack.	Pas de la denture sur une crémaillère génératrice rectiligne.

10	e	millimeter	$p / 2$	Circular tooth thickness, measured on the pitch circle.	Epaisseur d'une dent mesurée sur le cercle primitif.
11	ha	millimeter	m	Addendum = height of a tooth above the pitch circle.	Saillie d'une dent.
12	hf	millimeter	$m * 1.25$	Dedendum = depth of a tooth below the pitch circle.	Creux d'une dent.
13	rp	millimeter	$m * Z / 2$	Radius of the pitch circle.	Rayon du cercle primitif.
14	rc	millimeter	$rp / \cos(\delta)$		Rayon du cône primitif arrière
15	ra	millimeter	$rp + ha$	Radius of the outer circle.	Rayon du cercle de tête.
16	rf	millimeter	$rp - hf$	Radius of the root circle.	Rayon du cercle de fond.
17	rb	millimeter	$rc * \cos(\alpha)$	Radius of the base circle.	Rayon du cercle de base.
18	rr	millimeter	$m * 0.38 =$ "arc cercle fond" * 0.7763	Radius of the root concave corner. ($m * 0.38$) is a normative formula.	Congé de raccordement à la racine d'une dent. ($m * 0.38$) vient de la norme.
19	t	floating point number	$0 \leq t \leq 1$	Sweep parameter of the involute curve.	Paramètre de balayage de la courbe en développante.
20	tc	angular degree	$-\text{atan}(\text{yd}(\alpha / 180\text{deg}) / \text{xd}(\alpha / 180\text{deg}))$	Trim angle used to put the contact point in the ZX plane.	Angle d'ajustement pour placer le point de contact dans le plan ZX.
21	xd	millimeter	$rb * (\cos(t * \pi) + \sin(t * \pi) * t * \pi)$	X coordinate of the involute tooth profile, generated by the t parameter.	Coordonnée X du profil de dent en développante de cercle, généré par le paramètre t.
22	yd	millimeter	$rb * (\sin(t * \pi) - \cos(t * \pi) * t * \pi)$	Y coordinate of the involute tooth profile.	Coordonnée Y du profil de dent en développante de cercle.

1 First attempt: a simple projection on the rear primitive cone

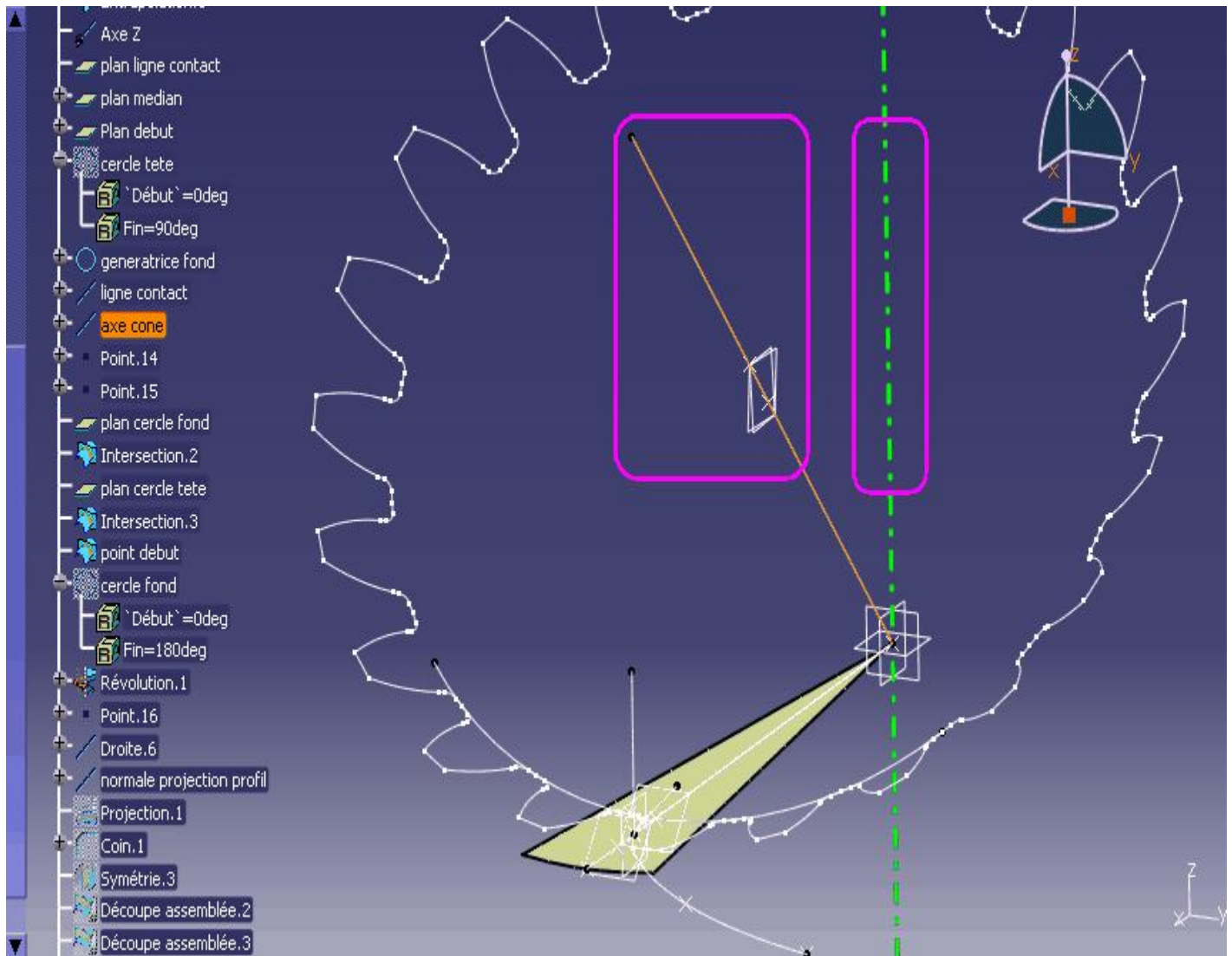
This view shows that the whole geometry must be rebuilt, because the simple projection on a cone implies interferences between the root circles:



2 Projection of the involute on the rear primitive cone

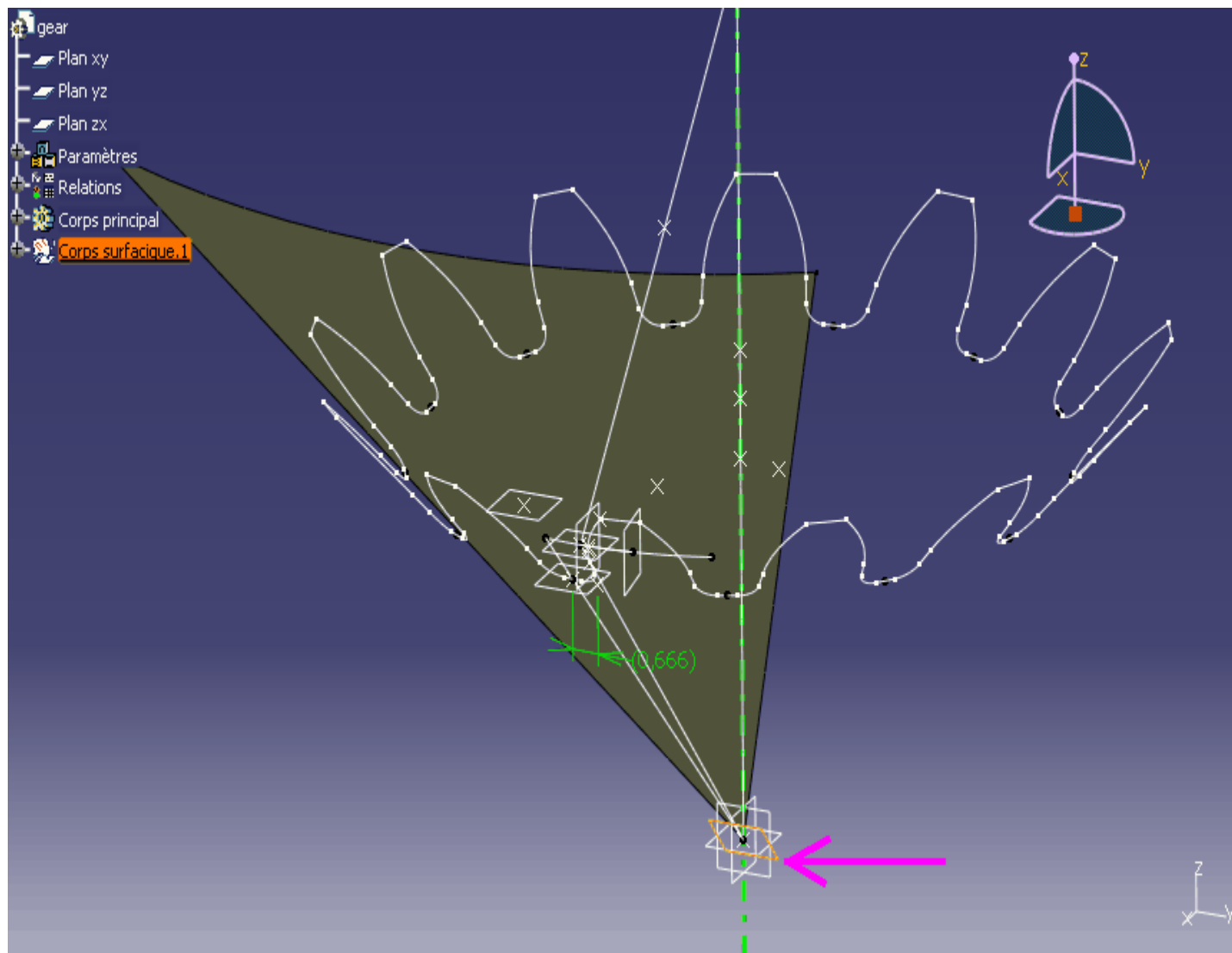
Now, the tooth is actually designed on a cone:

- The involute is still designed on the XY plane.
- Then it is projected on the rear primitive cone.
- The root circle and outer circle are defined in planes orthogonal to the axis of the cone.
- The tooth profile is made with "cut and assemble" operations on the root circle, the projection of the involute curve on the cone, and the outer circle.
- The whole profile is a circular repetition around axis of the cone.
- The profile is good, but it has a major drawback: the axis of the cone (in red) is not parallel to X, Y or Z (in green).



3 Designing the involute curve on an inclined plane

In order to make the gear aligned with the Z axis (shown in green), the involute curves is designed on an inclined plane (shown in red):

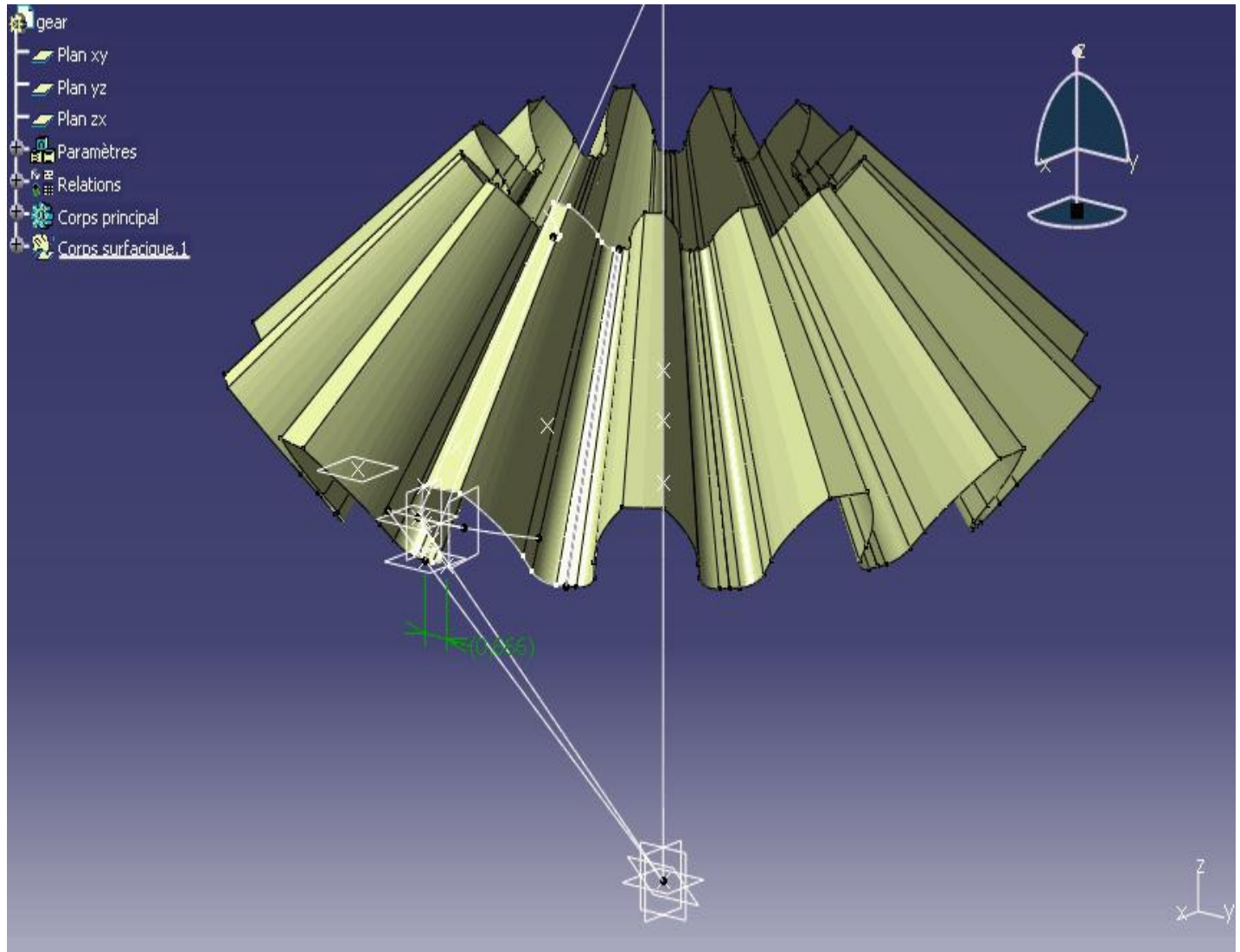


4 Making the tooth profile

- The inner tooth profile is generated by a scale operation on the outer tooth profile.
- The scale factor is computed by the ratio between the length of the front cone and the length of the teeth:

$$\text{ratio} = 1 - \text{teeth length} / \text{front cone length}.$$

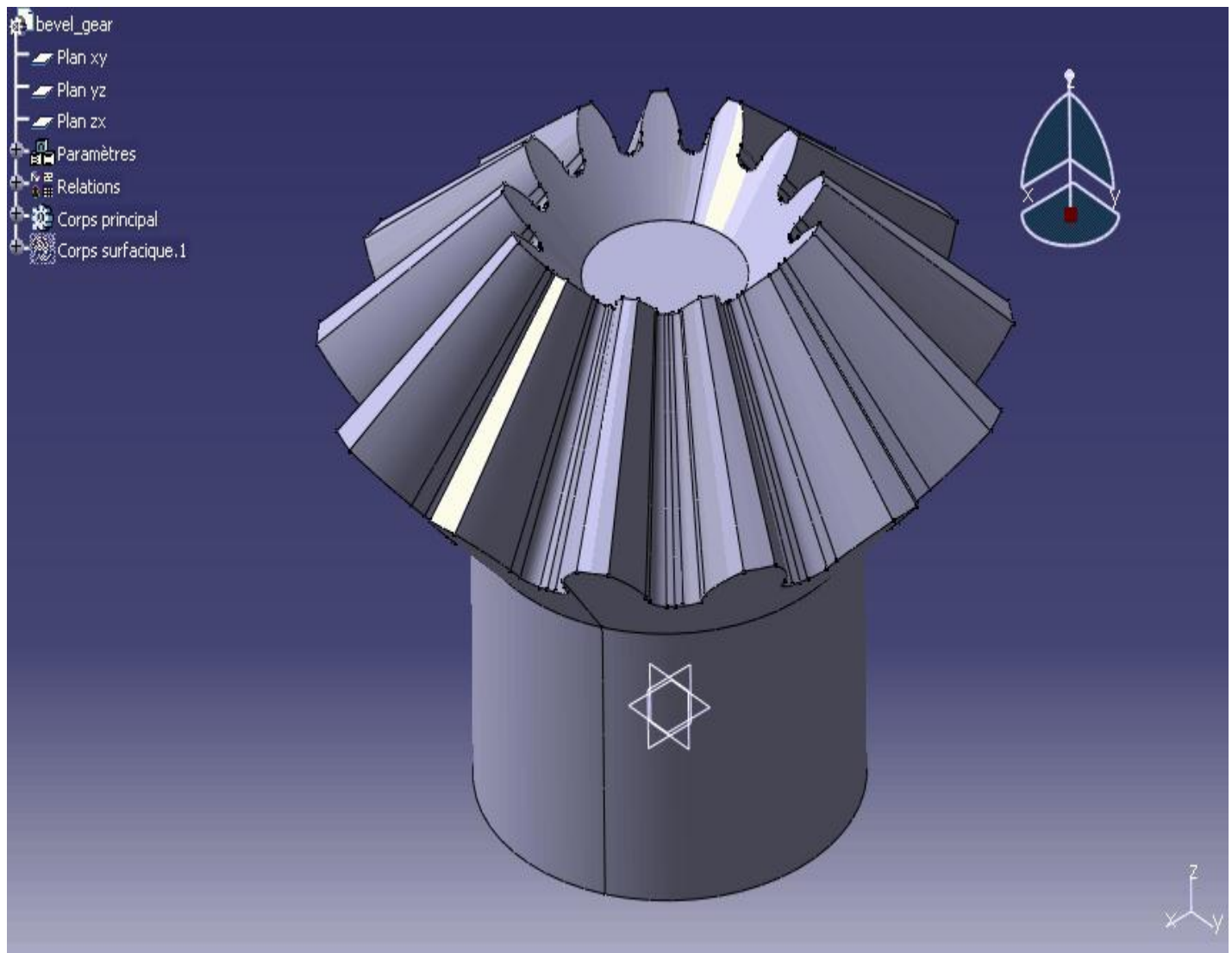
- The tooth is generated by a multi-section surface, guided by 2 line segments connected to the end points of the outer tooth profile and inner tooth profile.
- The whole profile is a circular repetition of the tooth profile around the Z axis.
- Now the teeth surface is ready, but the generation parameters are not well defined yet.



5 Making the outer and inner side cones

On most bevel gears, the teeth are delimited by an exterior cone and an interior cone. In order to build these cones:

- The tooth profile is duplicated on the whole circle.
- That profile is then used for cutting the rear cone.
- The remaining part of the rear cone makes the outer side of the teeth.
- The inner side is made by a scale-down operation on the outer side surface.
- Then we can merge the inner side cone, the teeth surfaces and the outer side cone.
- The resulting surface can be converted to a solid body in the Mechanical Part workshop.

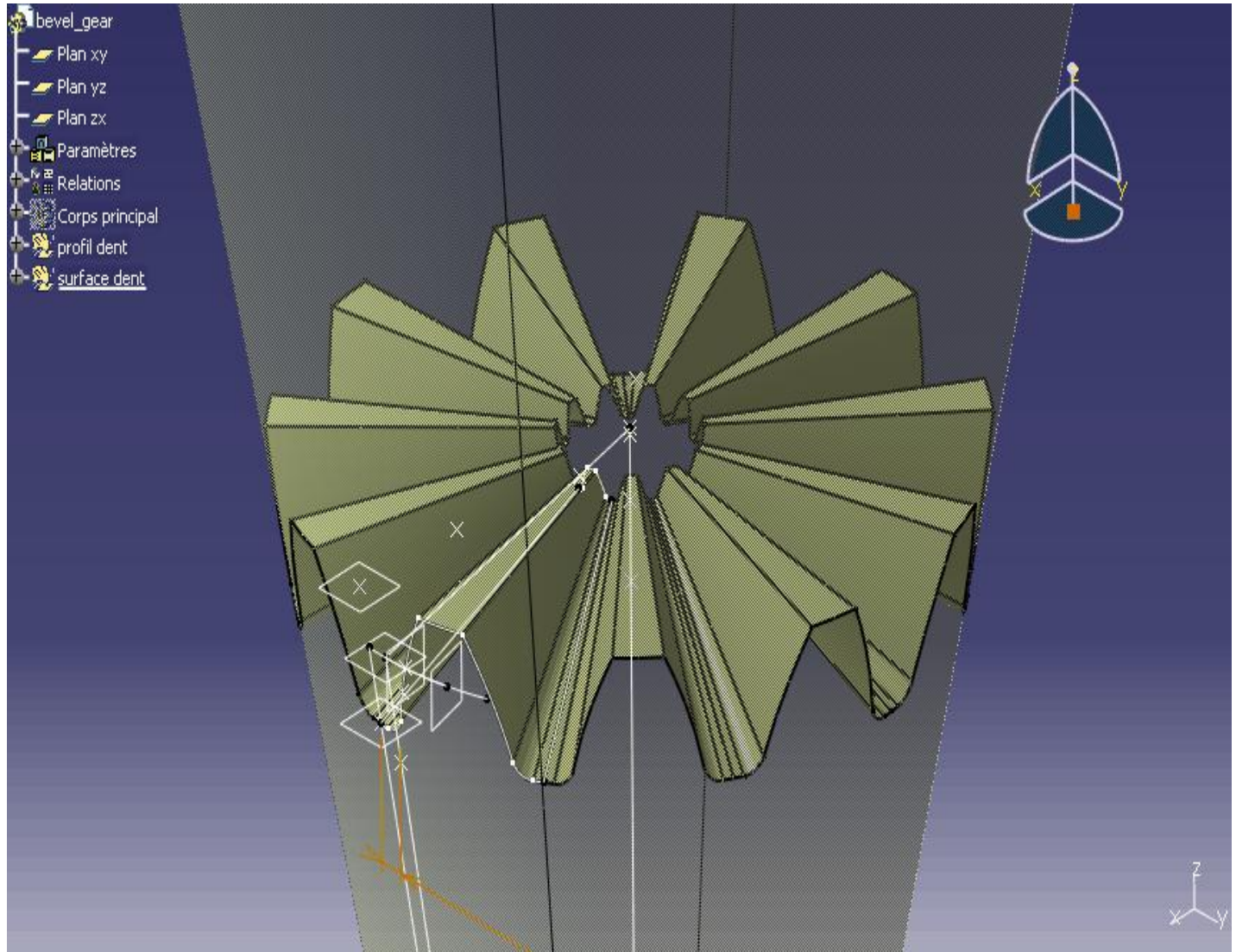


6 Checking and improving the robustness of the theet surface

The parametric gear show in the previous section fails when the `delta` angle is greater than 70degrees.

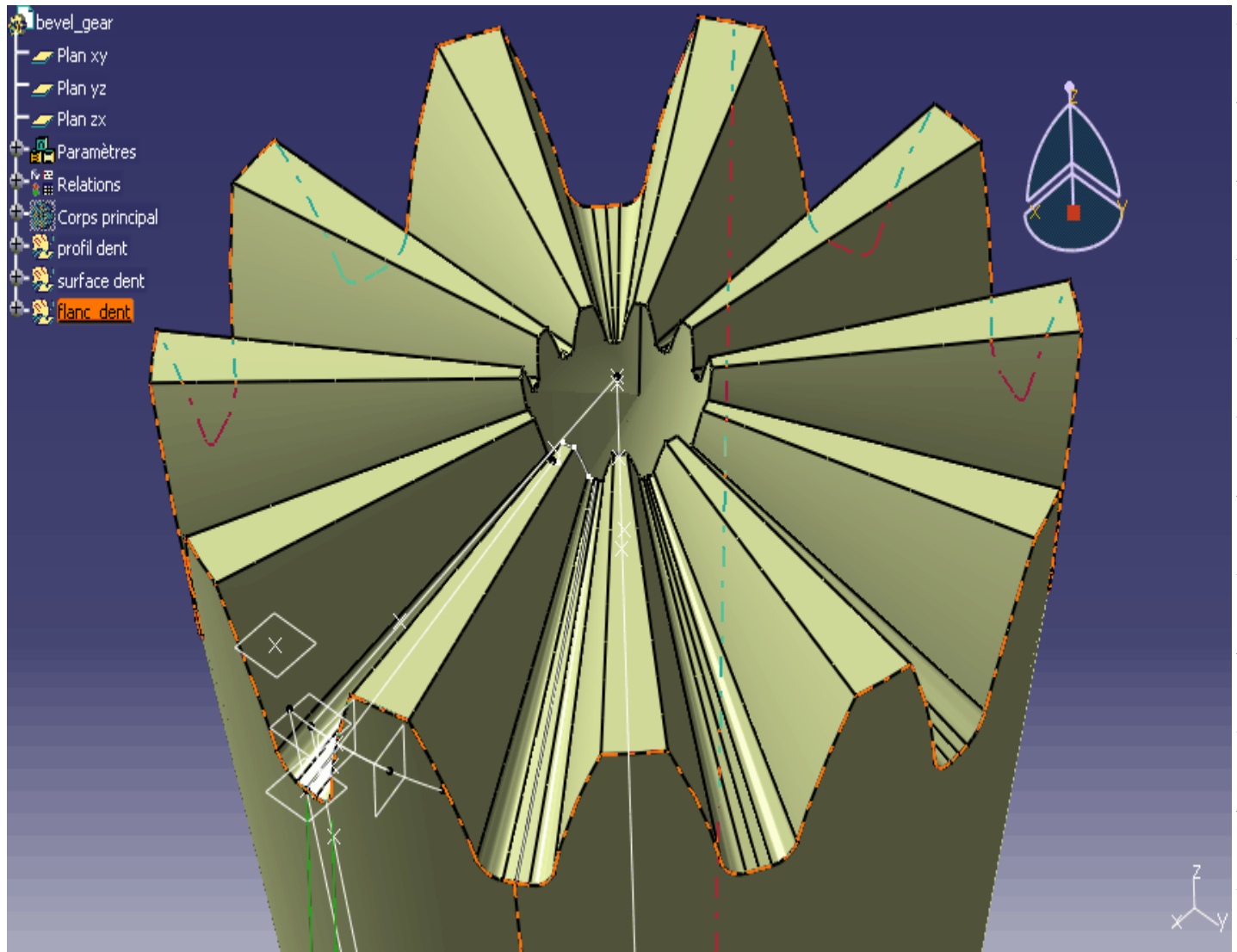
After hacking some parameters, the following image shows an improved extreme geometry:

- Minimal number of teeth `z1` = 11.
- Maximal `delta` angle = 79degrees.



7 Checking the generation of the side surface

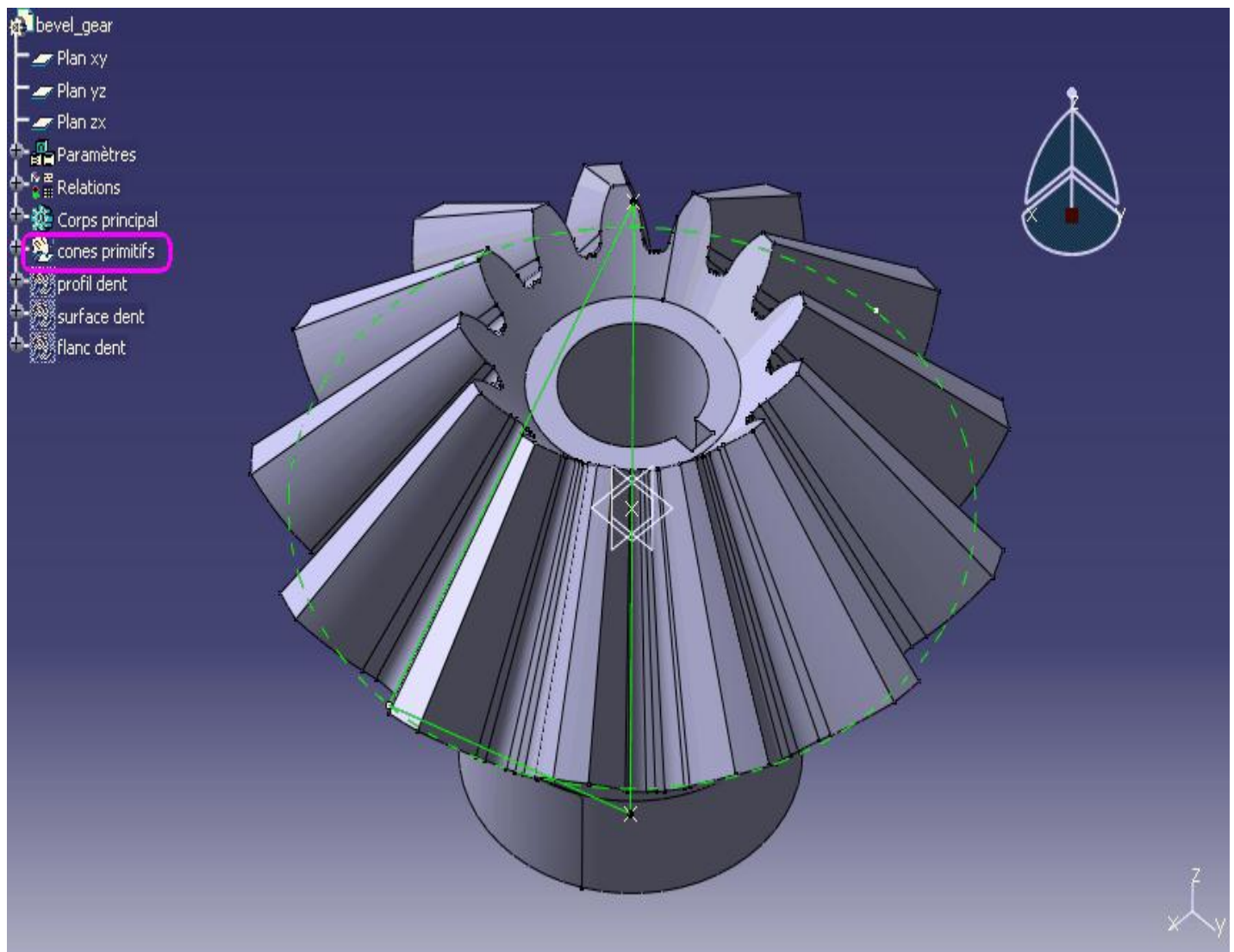
- We do the same work on the generation of the side surfaces.
- Of course, this geometry should never be used in a real mechanism.



8 Putting the primitive cones in a separate group of surfaces

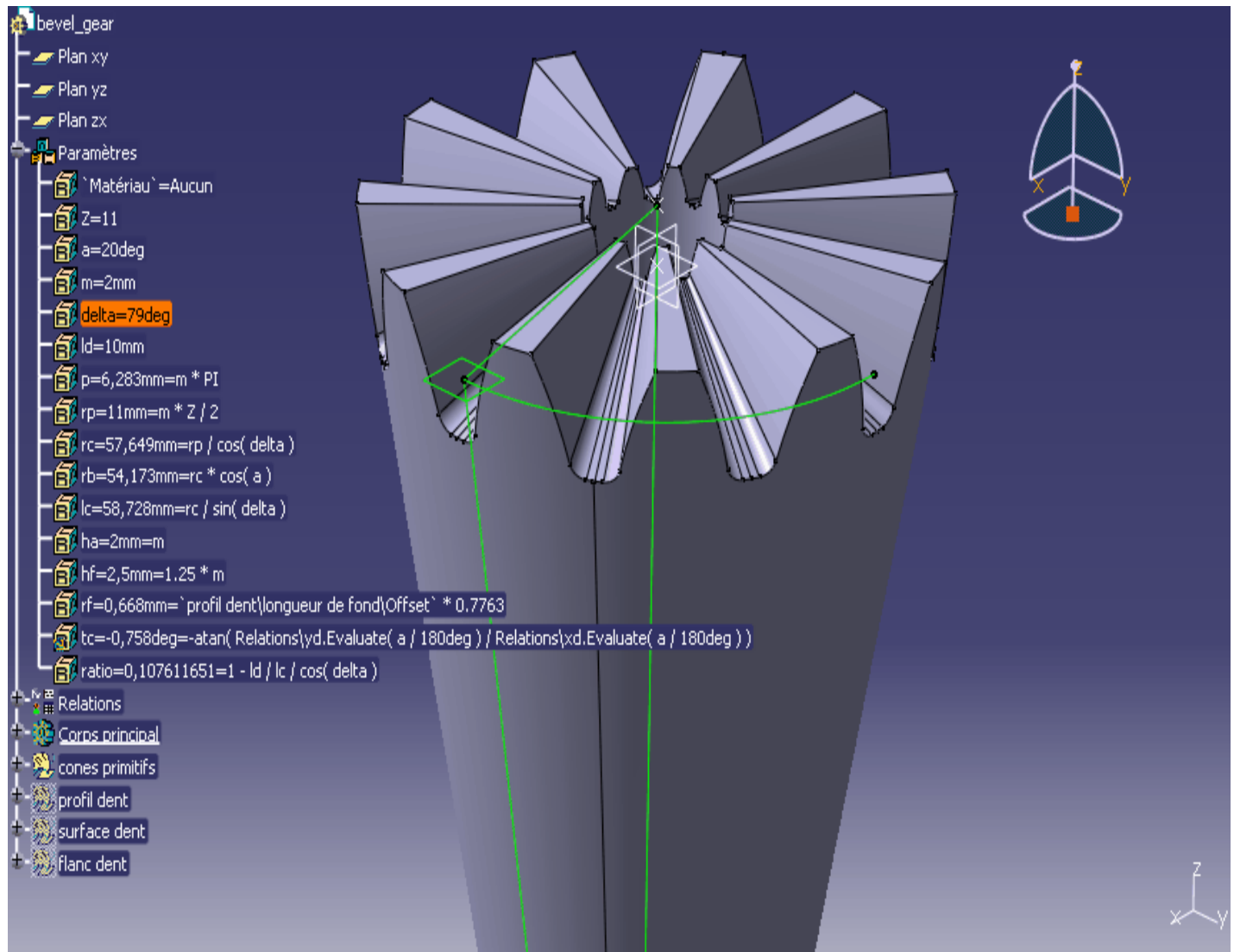
Now that the gear design is completed, we can put the fundamental geometric elements in a separate group and display them in green.

- The following image show the rotation axis, the primitive circle, the front and rear primitive cones.
- These elements can be useful for checking the position of the bevel gears in the mechanical assembly workshop.



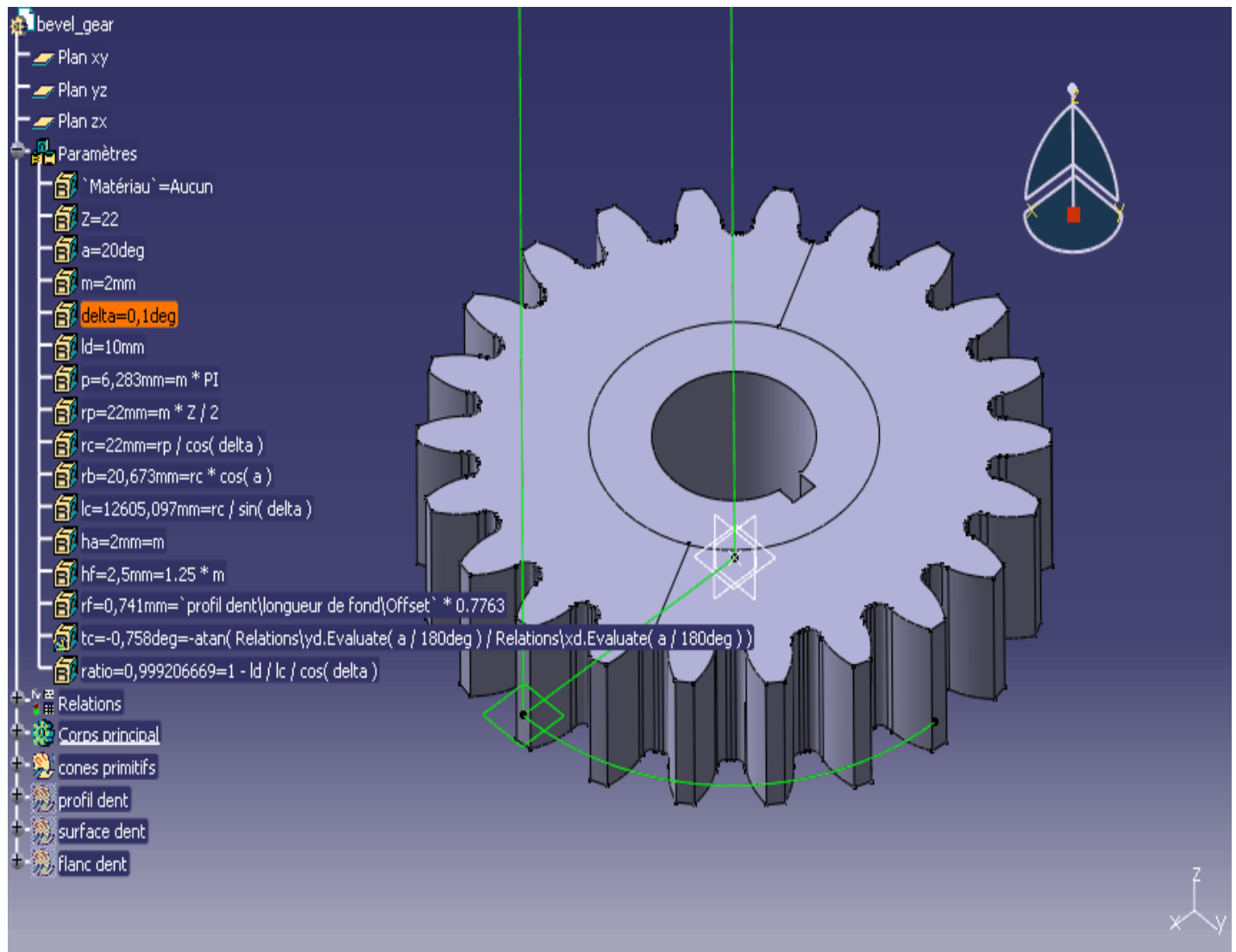
9 Flat gear

This figure shows a gear generated with the widest front cone:



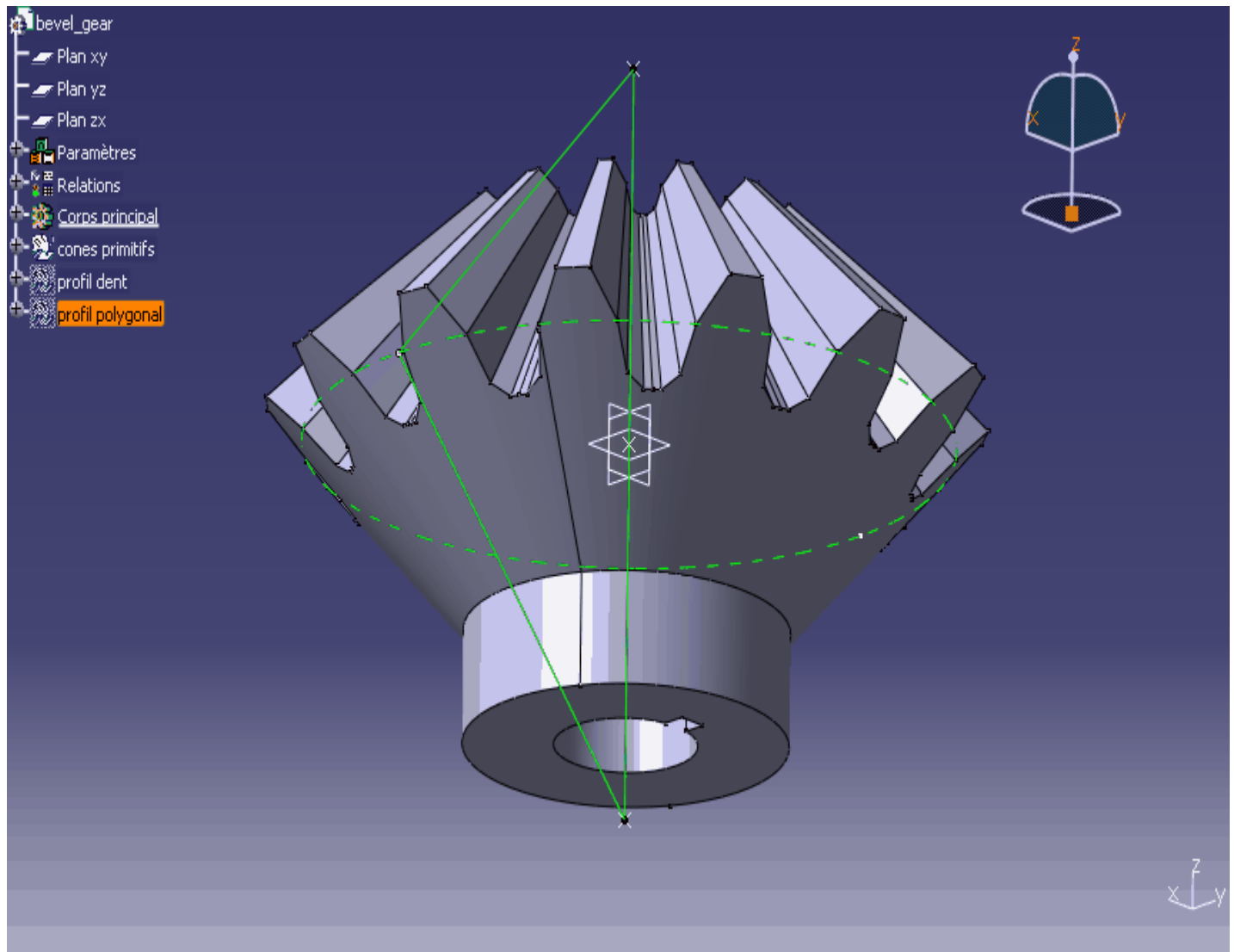
10 Normal gear

On the opposite, we can check that we go back to the ordinary spur gear when the `delta` angle tends to zero:



11 Check if the curved surfaces could be simplified

- The final bevel gear file is large: 950 KB for 13 teeth.
- So we can wonder if the file could be smaller with simpler surfaces.
- In order to check that, I replace all the surfaces generated by circles, arcs or involute curves with surfaces generated by straight lines.
- The file size only decreased to 890KB, so the curved surfaces of the bevel gear are not worth being simplified.



The End