

# UEI CONCEVOIR

## Usinage Formes Complexes



# INTRODUCTION

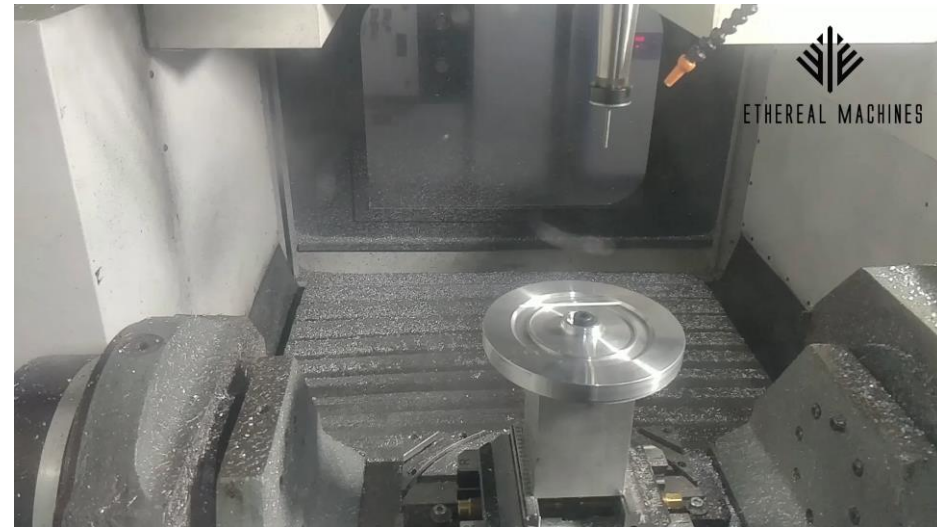
Manufacturing parts with complex geometries (Aerospace, Biomedical, Naval...)

- ❖ **CAM (Computer-Aided Manufacturing)**
- ❖ **FAO (Fabrication Assistée par Ordinateur)**

- ❖
  - Calculate tool path
  - Check the accessibility of the tool/surfaces
  - Avoid tool/workpiece, tool/mounting, tool/machine collisions
  - Check if the geometry of the machined part is correct
  - Estimate the machining times
  - Generate the CNC program (via the postprocessor)

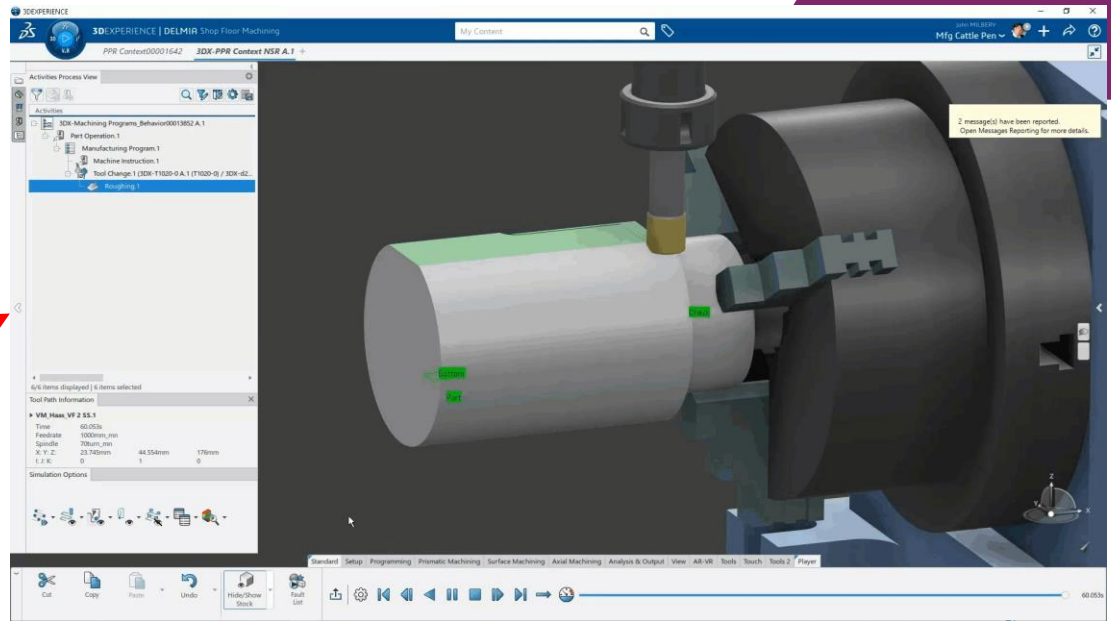
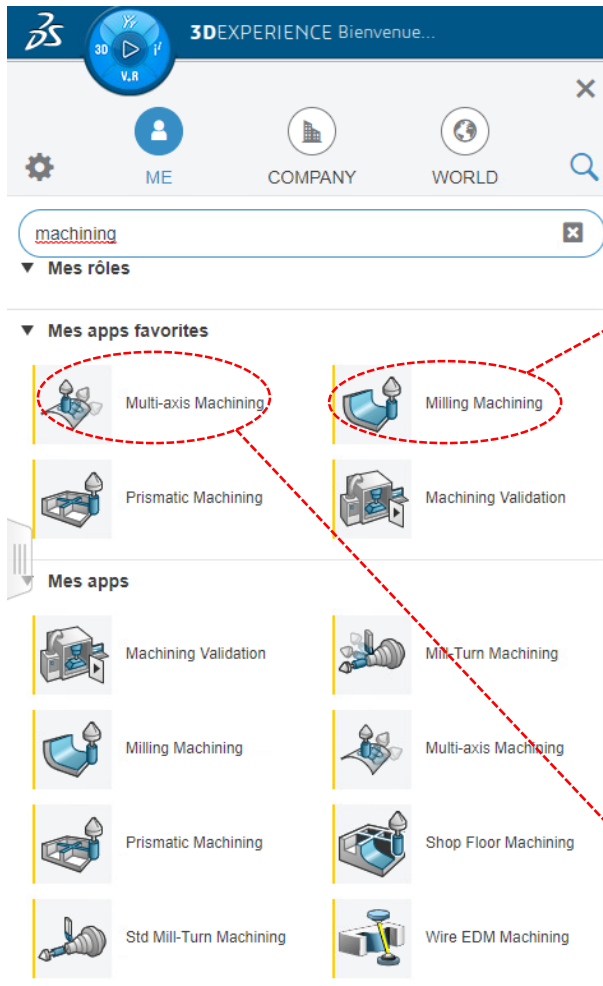


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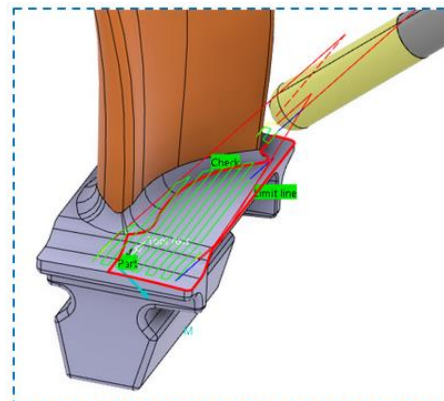
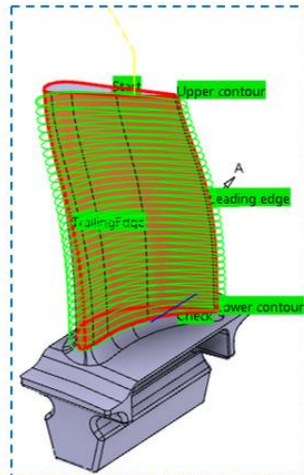


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# PRESENTATION OF THE CAM MODULE

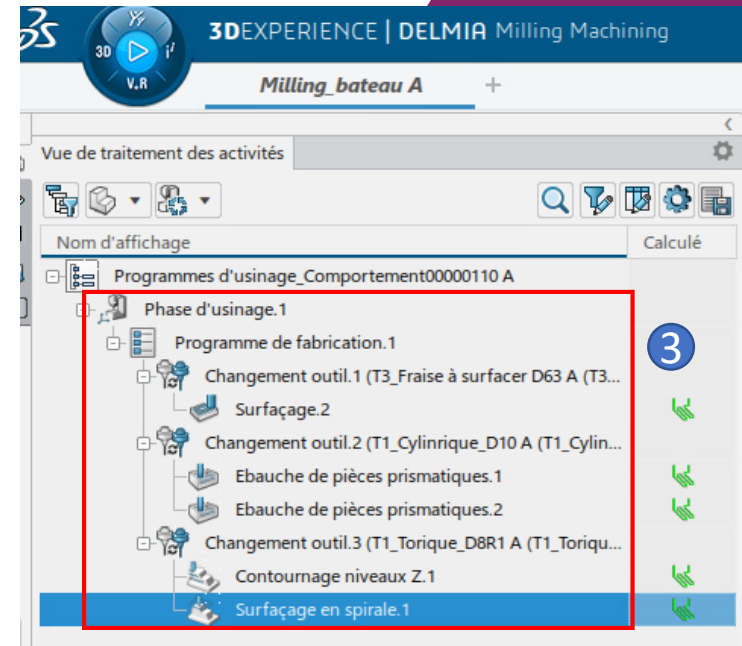
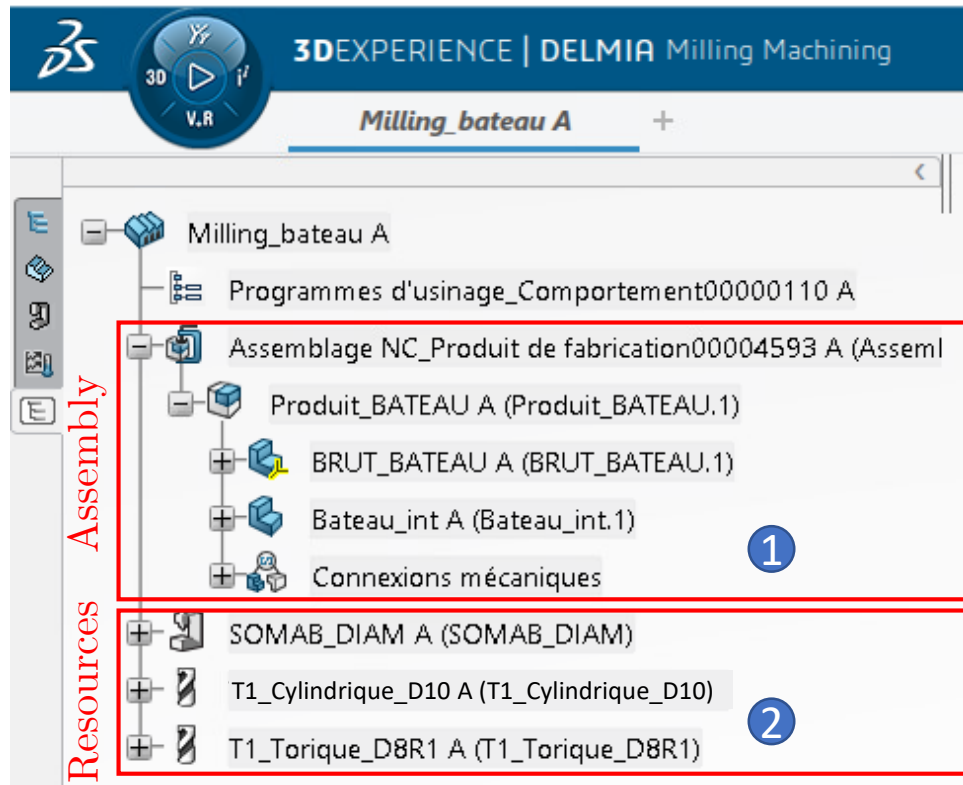


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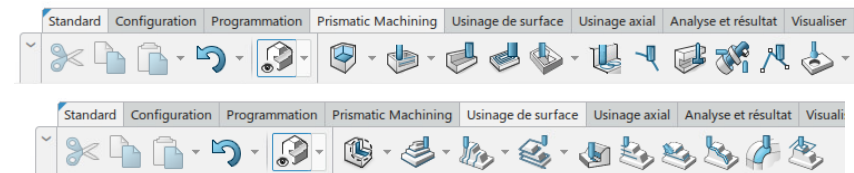
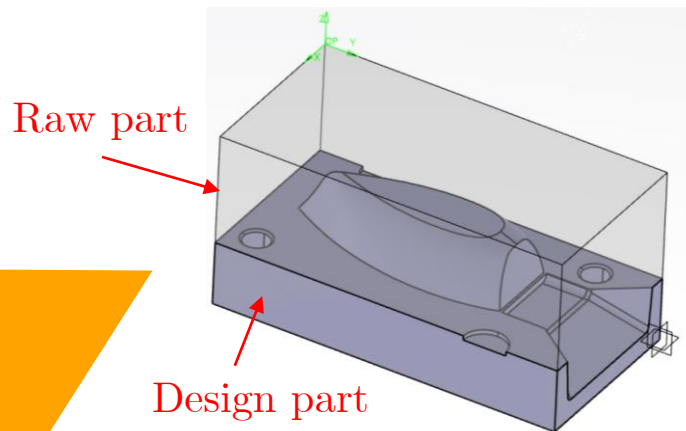


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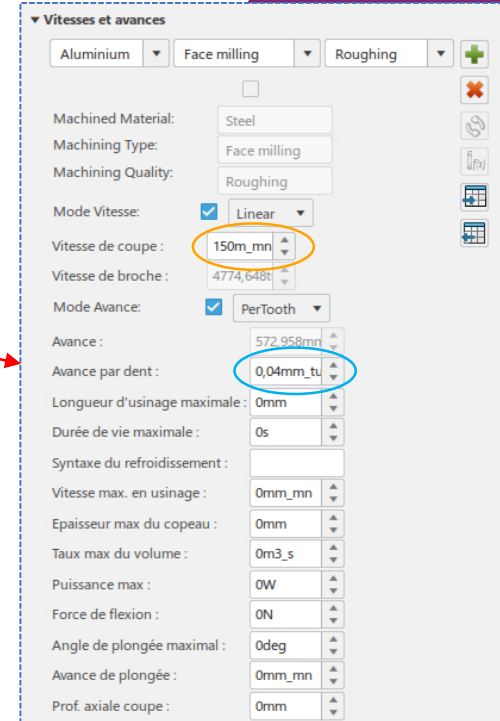
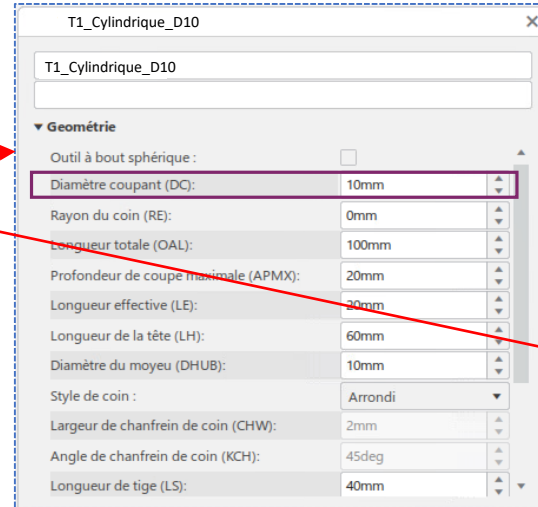
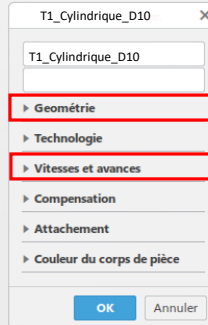
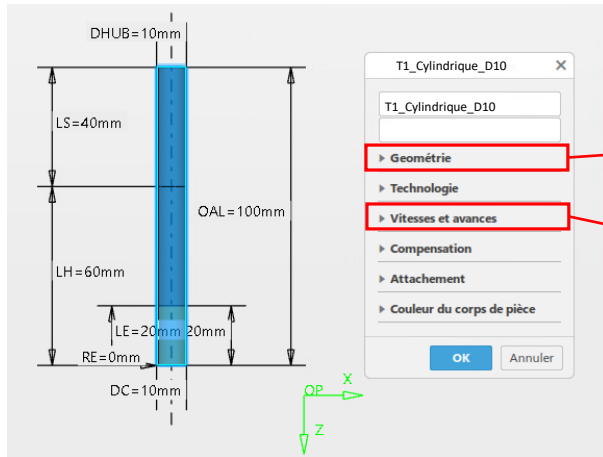


Manufacturing sequence



Machining operations

# PRESENTATION OF THE CAM MODULE



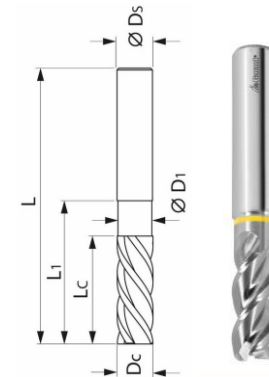
Cutting tool geometry & Cutting conditions

To be defined from a catalog



| Application/<br>$v_c$ [m/min] | Alu     | Alu     | Fonte<br>d'Alu<br>> 10% Si | PMMA<br>Acryl | PE-HD | PA 66 | PEEK | PF 31 | AFK<br>Aramide | PVDF | POM | PA 66 | PEEK | PTFE | PEEK | Honey-<br>comb<br>Sandwich | Cu  | CuZn |     |  |  |  |
|-------------------------------|---------|---------|----------------------------|---------------|-------|-------|------|-------|----------------|------|-----|-------|------|------|------|----------------------------|-----|------|-----|--|--|--|
| Code ISO                      | N       | N       | N                          | N             | N     | N     | N    | N     | N              | N    | N   | N     | N    | N    | N    | N                          | N   | N    |     |  |  |  |
| 20 2243–20 2249               | 190     | 150     | 120                        | 180           | 130   | 150   | 130  | 110   |                |      |     |       |      |      |      |                            | 180 | 120  | 150 |  |  |  |
| $\varnothing D_c$             | 20 2243 | 20 2244 | 20 2249                    |               |       |       |      |       |                |      |     |       |      |      |      |                            |     |      |     |  |  |  |
|                               | mm      | mm      | mm                         |               |       |       |      |       |                |      |     |       |      |      |      |                            |     |      |     |  |  |  |
|                               | 10      | 63,11   | 63,11                      | 70,75         | 22    | 30    | 9,2  | 72    | 10             | HA   | 0,2 | 0,04  | 0,05 |      |      |                            |     |      |     |  |  |  |

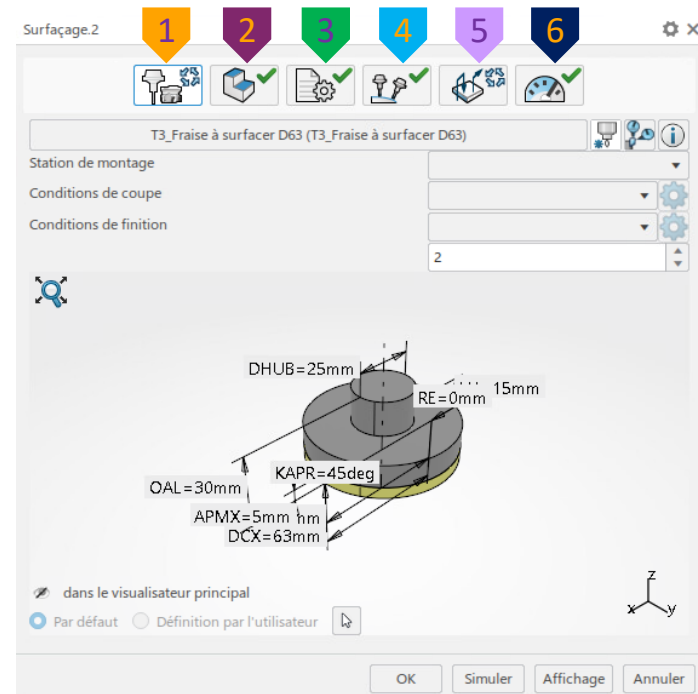
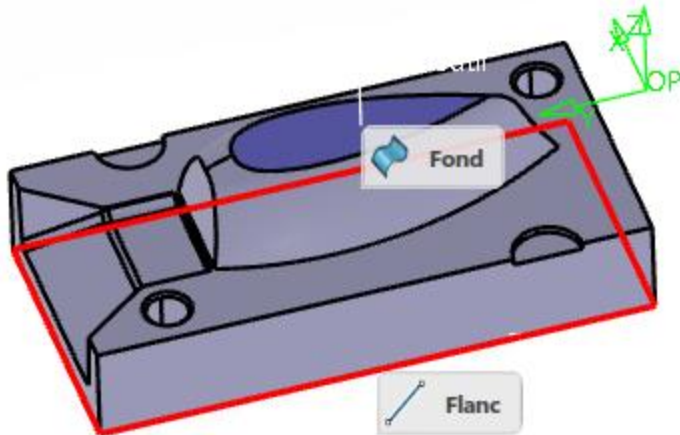
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# PRESENTATION OF THE CAM MODULE

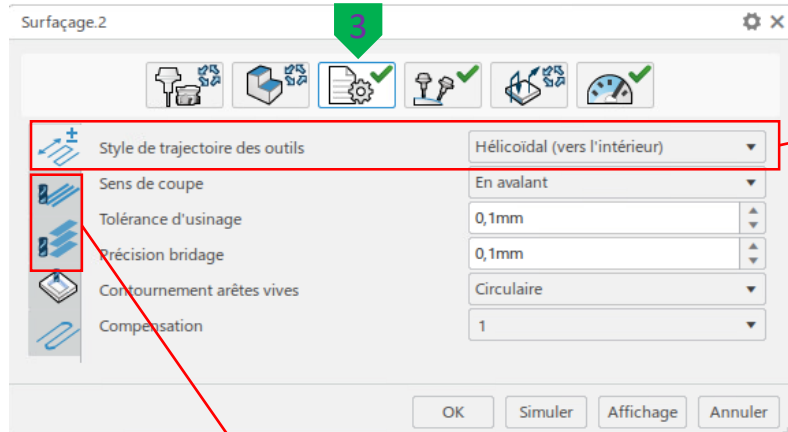
## Typical operation definition

- 1- Tool selection
- 2- Geometry : Concerned surfaces
- 3- Machining strategy
- 4- Tool axis
- 5- Approach/retraction path
- 6- Approach/retraction path speed

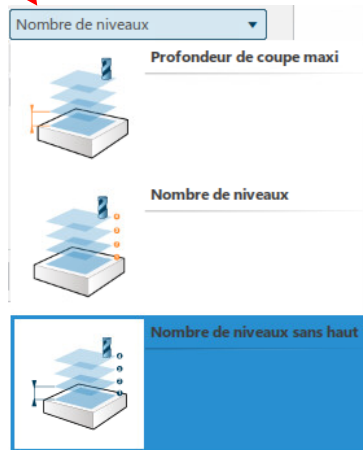


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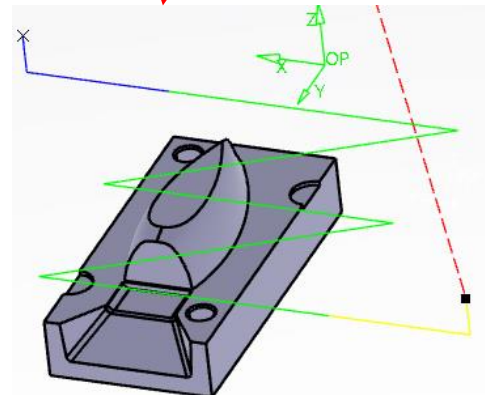
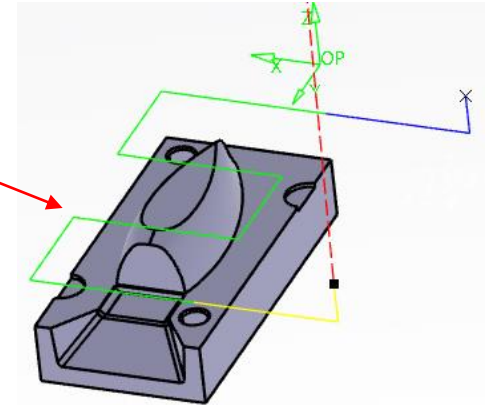
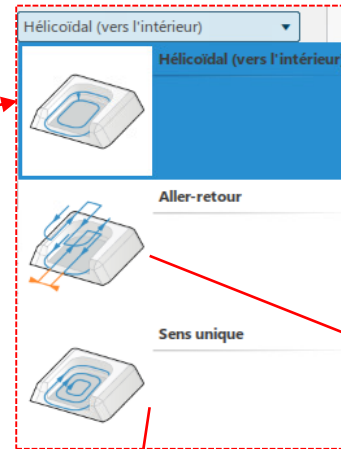
## Typical operation definition



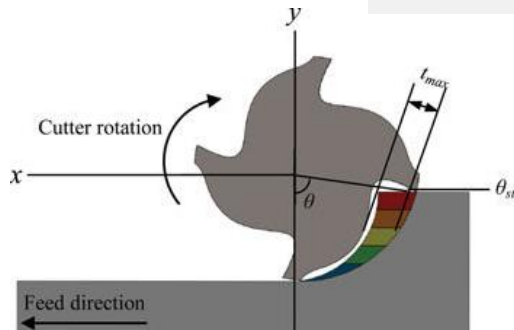
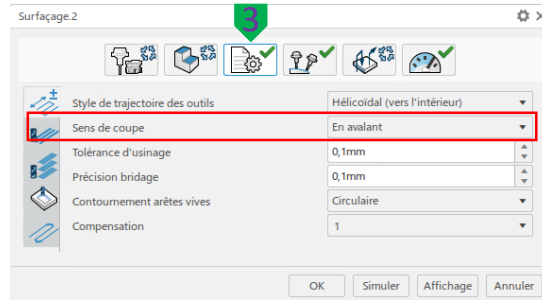
Operation parameters configuration  
(axial pass  $ap$ , radial pass  $ae$  ...)



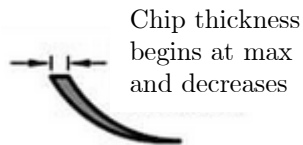
## Tool path



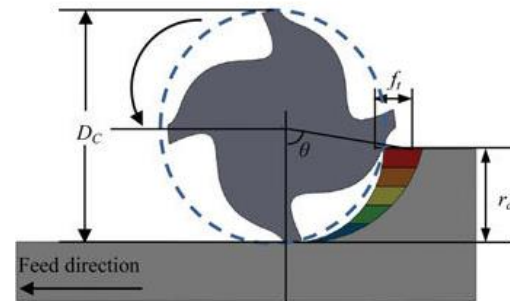
# IMPACT OF TOOL PATH ON SURFACE QUALITY



Down milling (en avalant)



- \* Good surface roughness
- \* Cutting force is directed downwards
- \* Higher cutting force at the beginning
  - > Not suitable for brittle materials



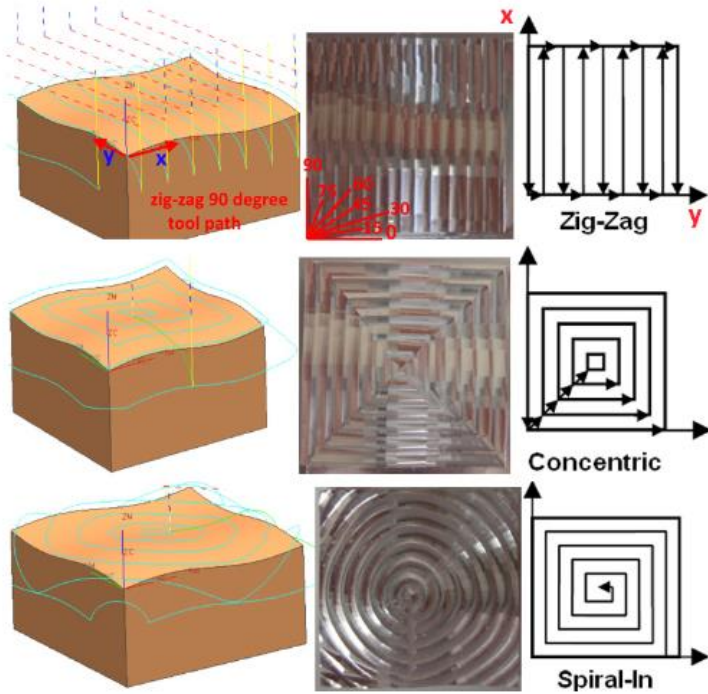
Up milling(en opposition)

Chip thickness  
begins at zero  
and increases



- \* Poor surface roughness
- \* Cutting force is directed upwards
  - > Needs strong clamping
- \* Material work hardening and more heat generation

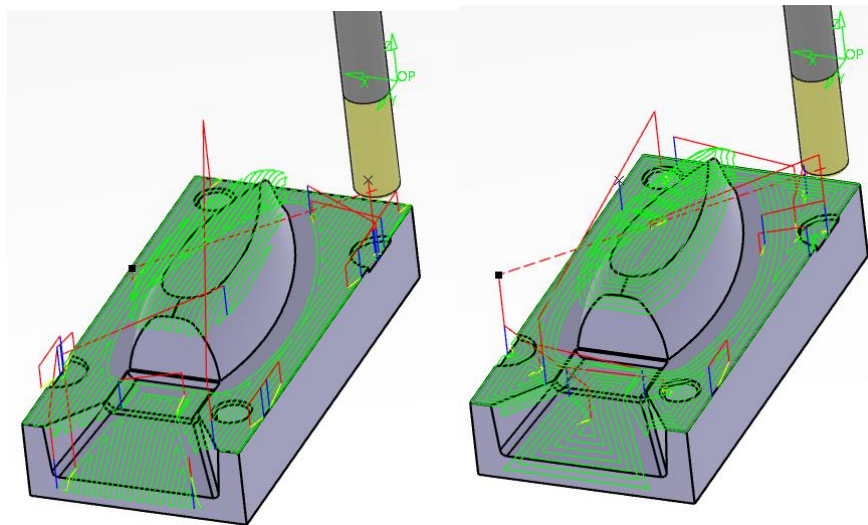
# IMPACT OF TOOL PATH ON SURFACE QUALITY



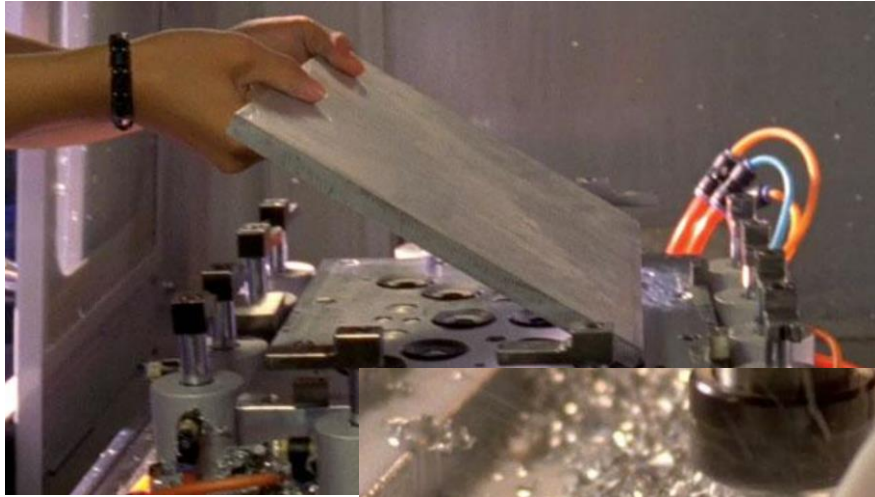
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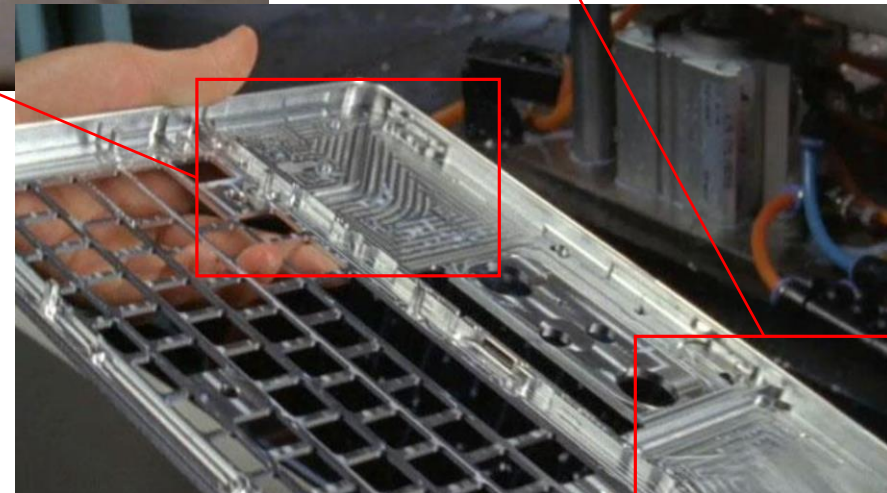
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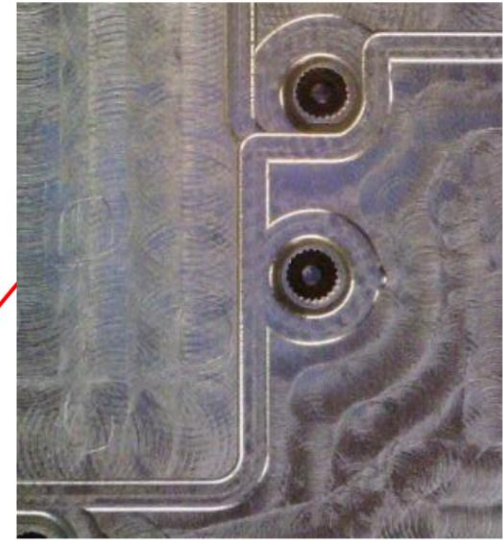
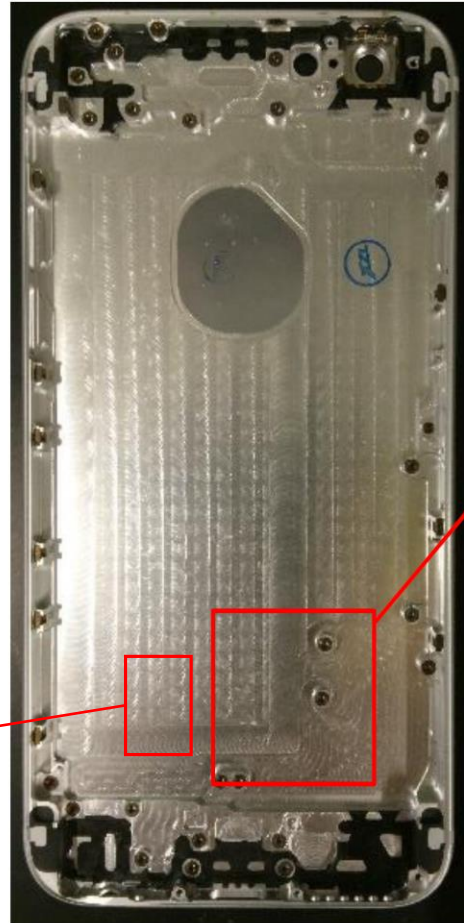
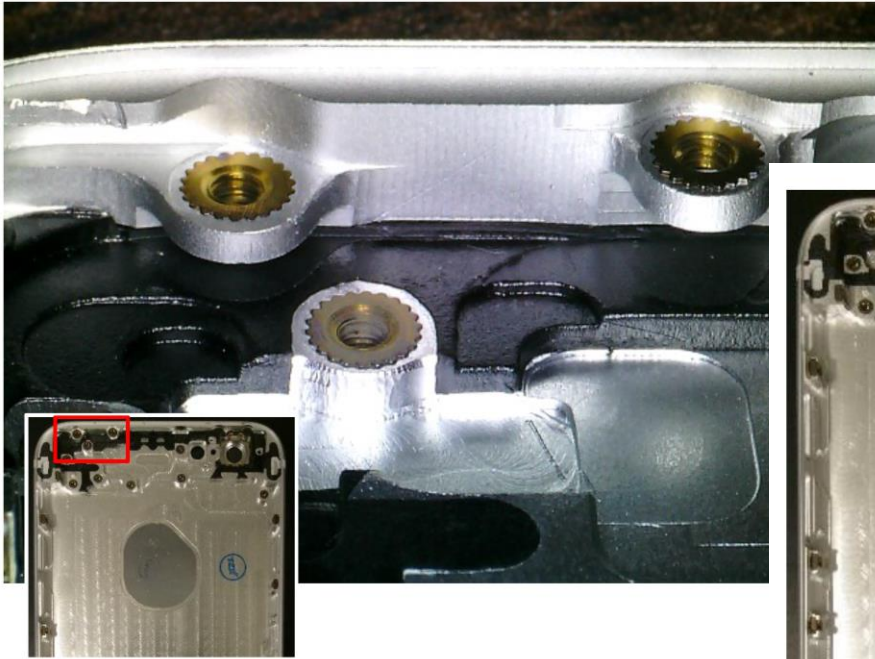
# IMPACT OF TOOL PATH ON SURFACE QUALITY



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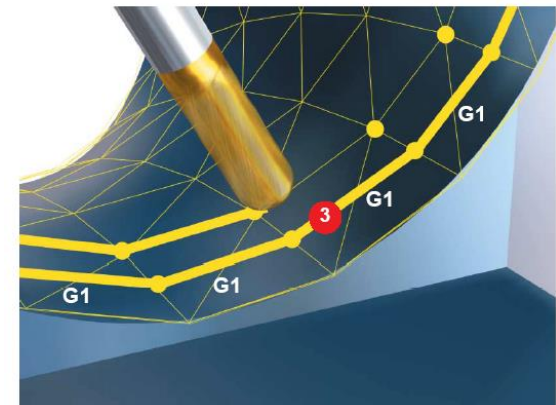
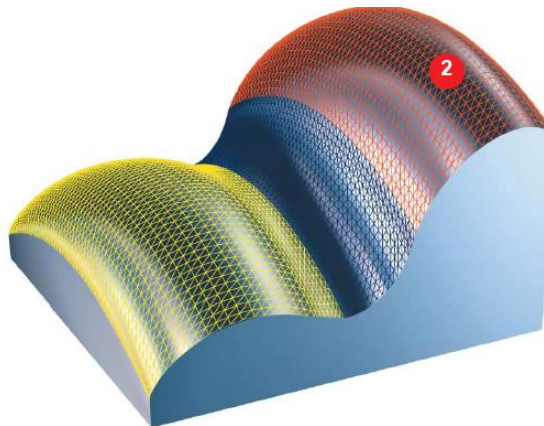
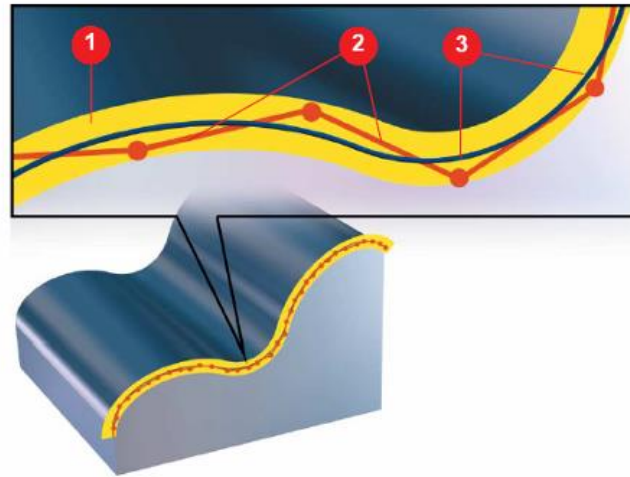
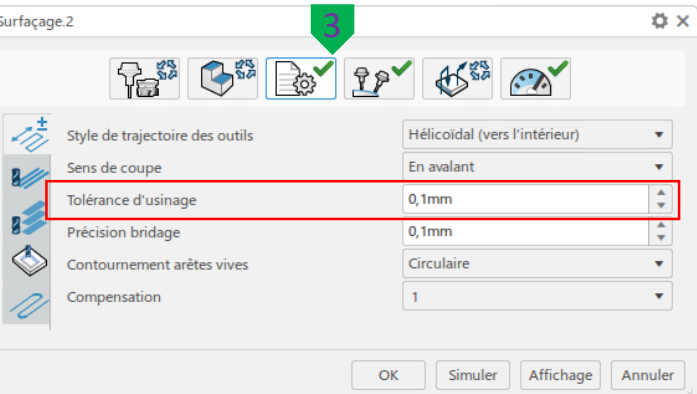
# IMPACT OF TOOL PATH ON SURFACE QUALITY



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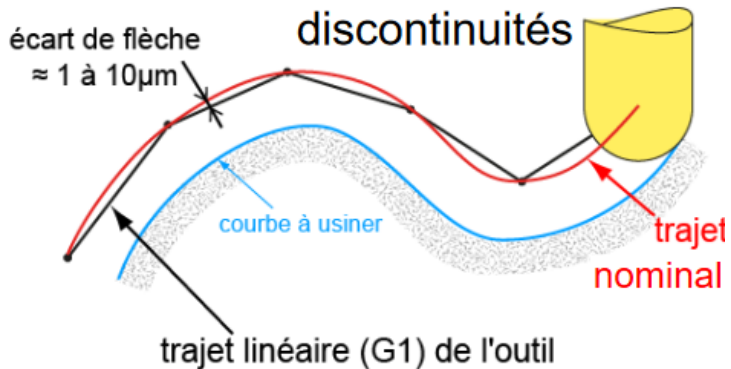
# TOOL PATH DISCRETIZATION (CHORD ERROR)

Orange bar

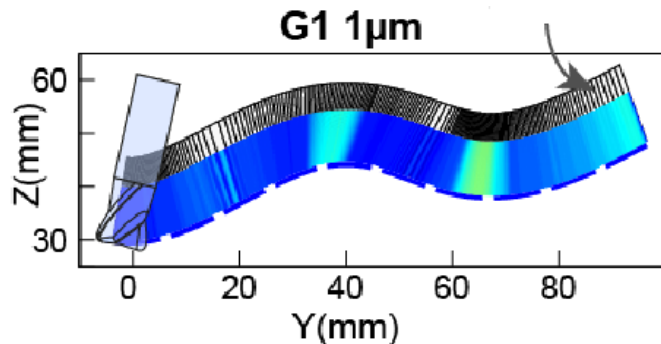


# TOOL PATH DISCRETIZATION (CHORD ERROR)

## Linear interpolation

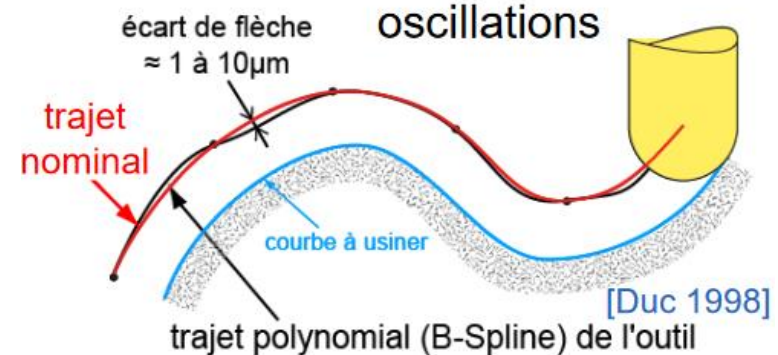


-> Not recommended for high feed rates



$Ra=1,11 \mu\text{m}$   
 $Rt=9,62 \mu\text{m}$

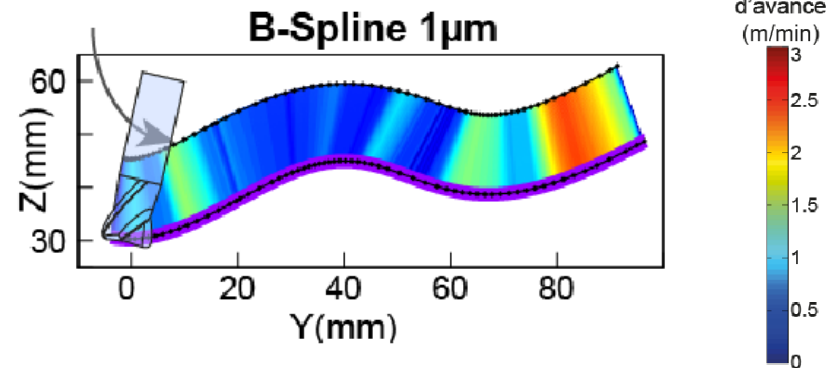
## Polynomial interpolation (Bspline, NURBS ...)



[Source](#)

[Duc 1998]

-> Smooth tool path



$Ra=1,1 \mu\text{m}$   
 $Rt=7,72 \mu\text{m}$

# MILLING STRATEGIES

## \* *Thin-Walled Workpiece*

Poor rigidity (stiffness) -> Workpiece vibration and deformation

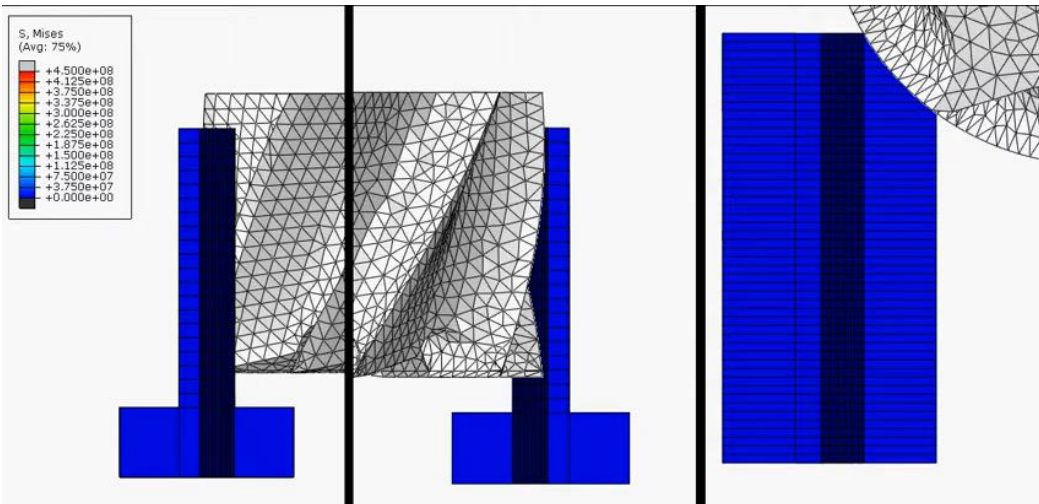


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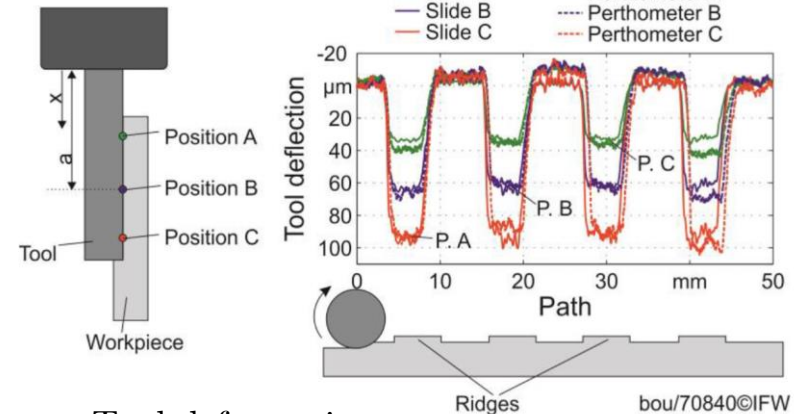


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- Specific fixture/clamping system
- Tool path optimization



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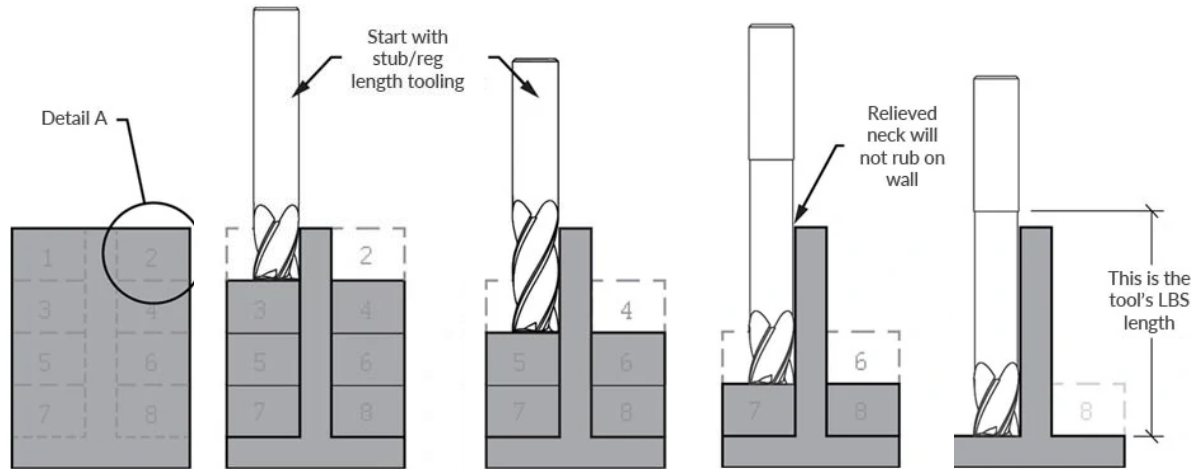
Tool deformation

[Source](#)

Workpiece vibration and deformation

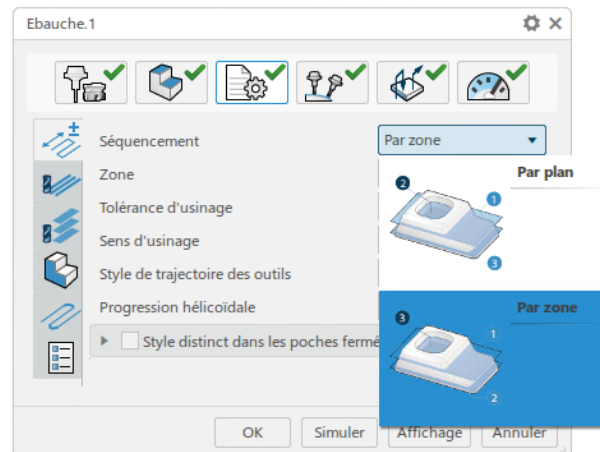
## \* Thin-Walled Workpiece

- *Work by zone*: avoids going back and forward between the different zones
- *Work by plane*: balance the deformations of the workpiece (Jump-to-jump toolpath strategy)



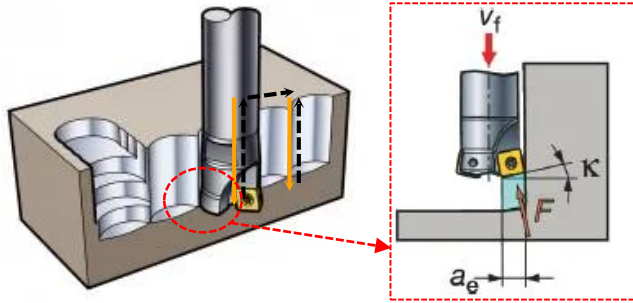
© Harvey Performancecompany, LLC.

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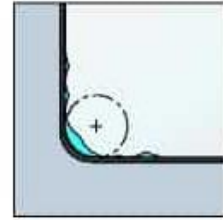
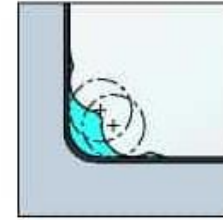
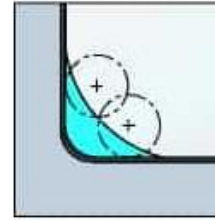
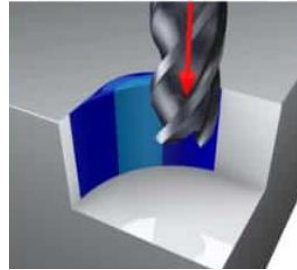


# MILLING STRATEGIES

## \* *Rough machining: plunge milling (trèflage)*

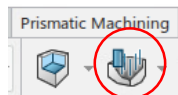
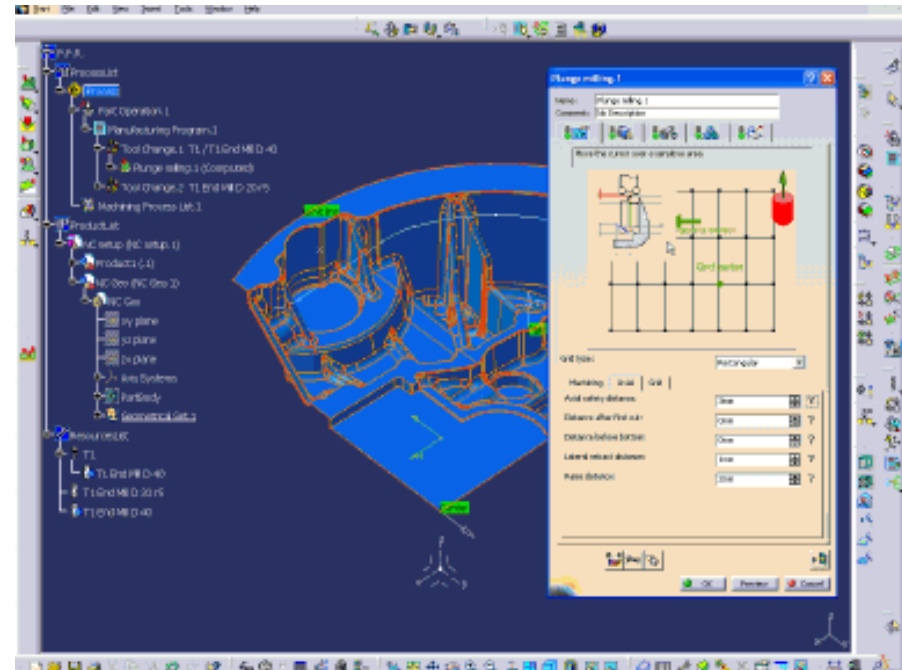
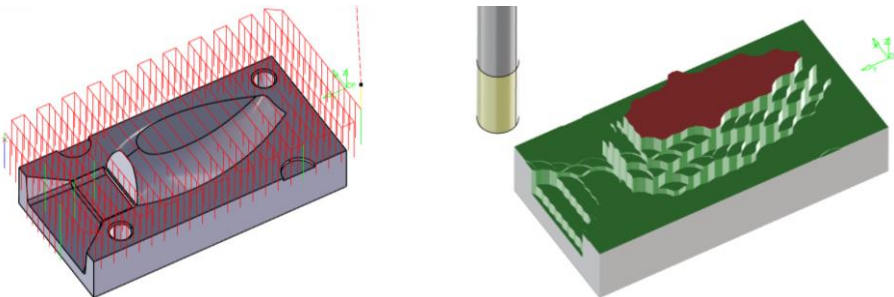


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- + High material removal rates
- + limited tool deflexion (low radial forces)
- + Corners machining
- High axial force
- High machine rigidity is required

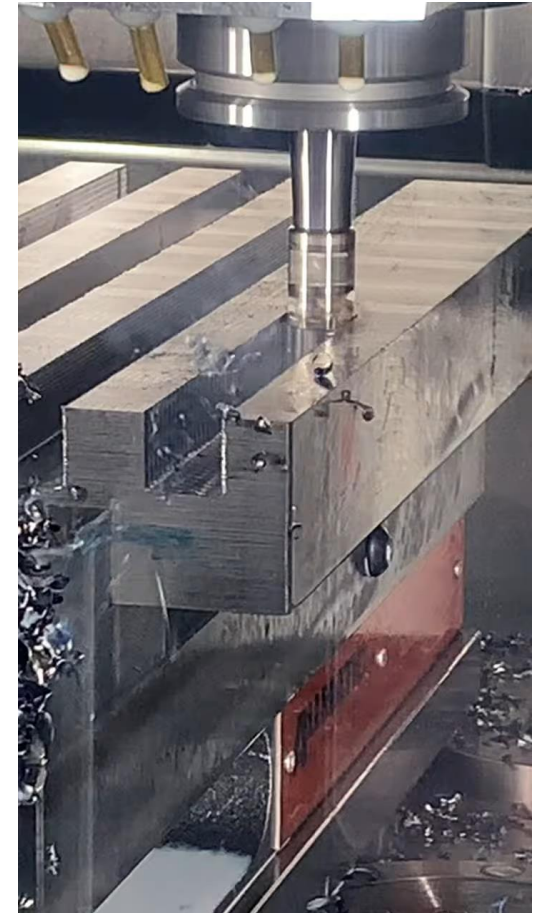


# MILLING STRATEGIES

*\* Rough machining: plunge milling (trèflage)*

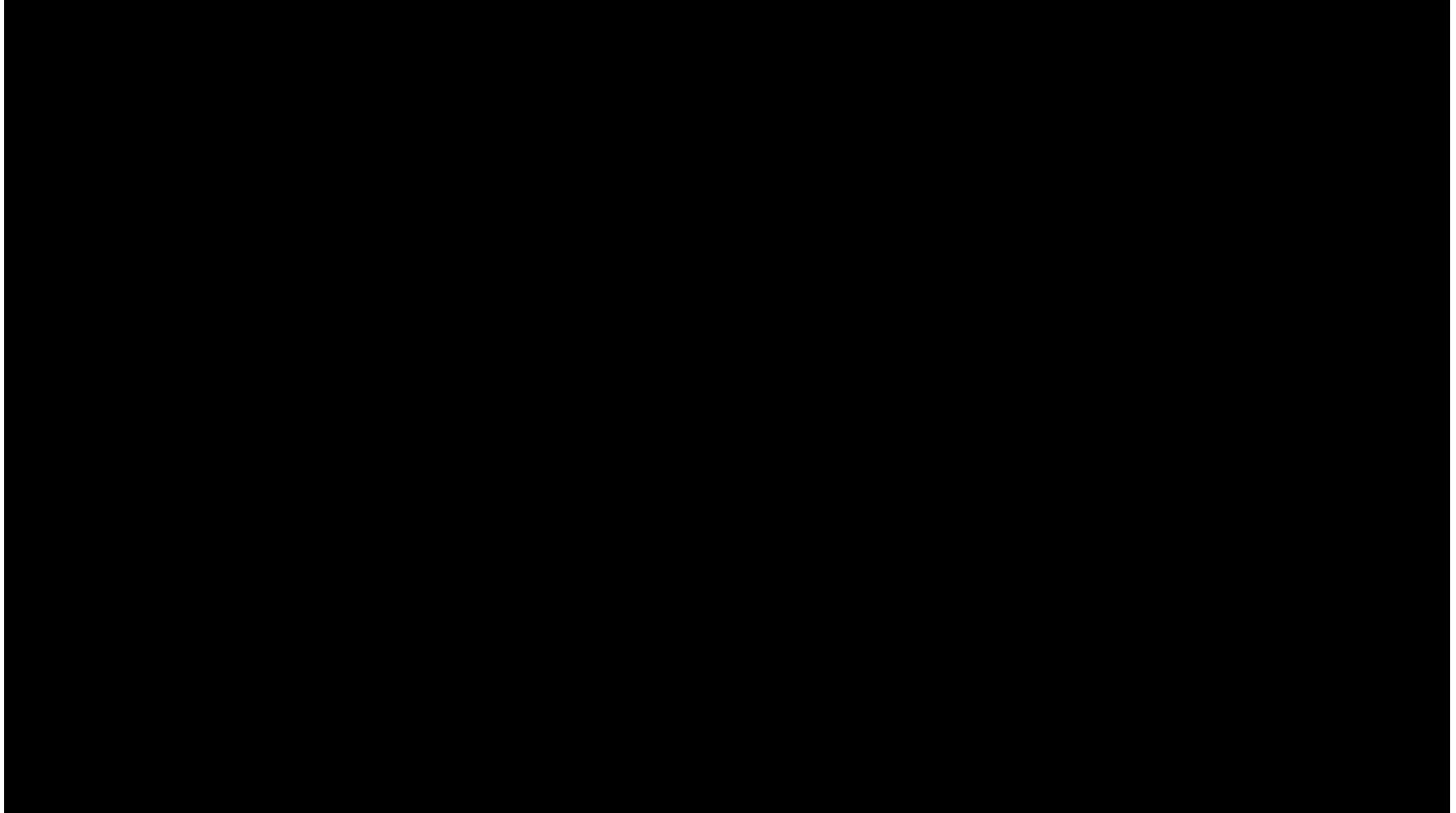


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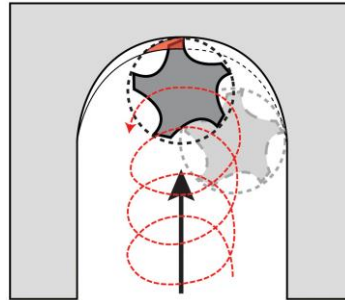
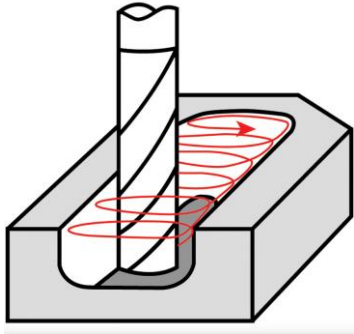


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\* *Rough machining: plunge milling (trèflage)*

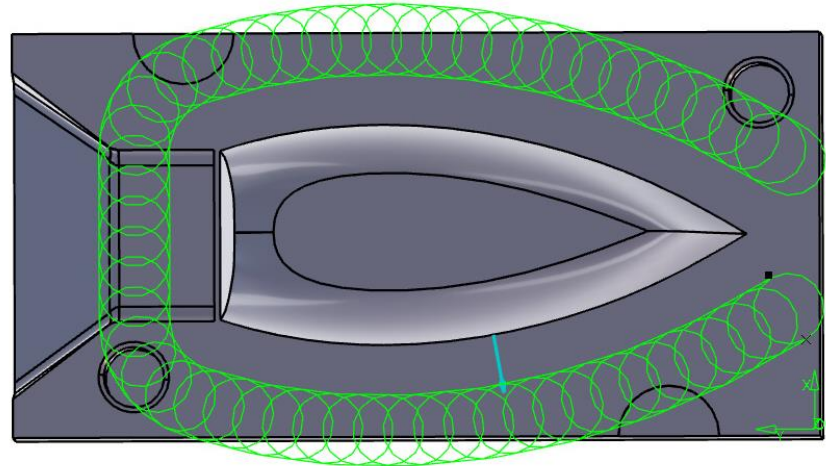
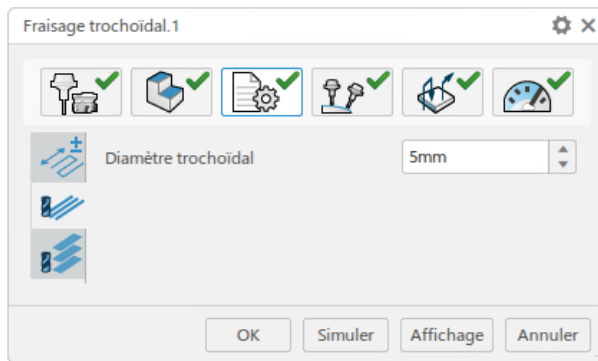
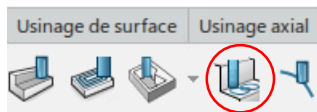


## \* *Rough machining: Trochoidal milling*

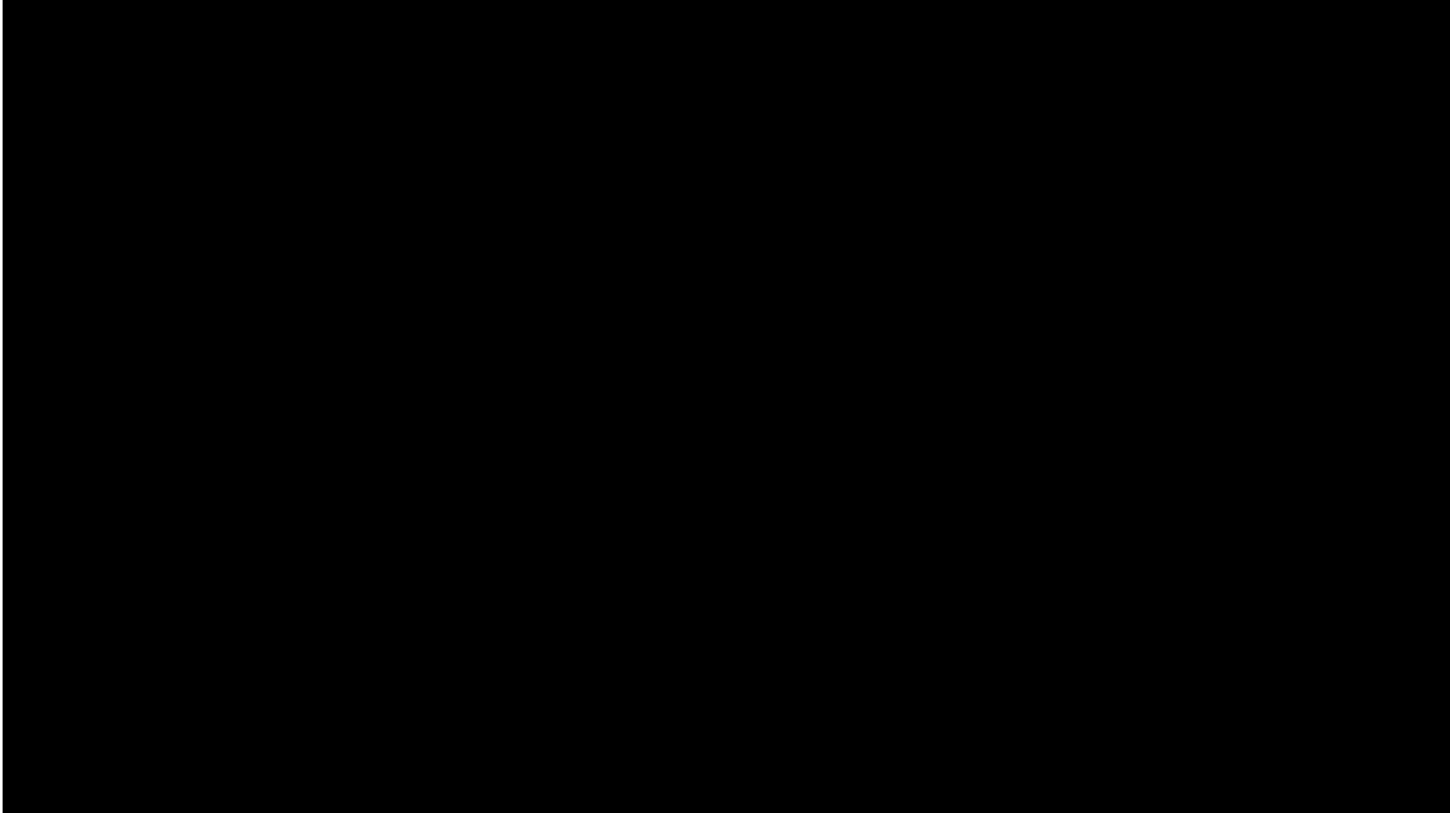


[Source](#)

- + Cutting forces reduction (up to 70%)
- + Lower cost (smaller cutting tools)
- + High removal rate
- + Lower heat generation
- + Lower tool wear evolution
- CAM Software features
- High kinematic performance of the milling machine



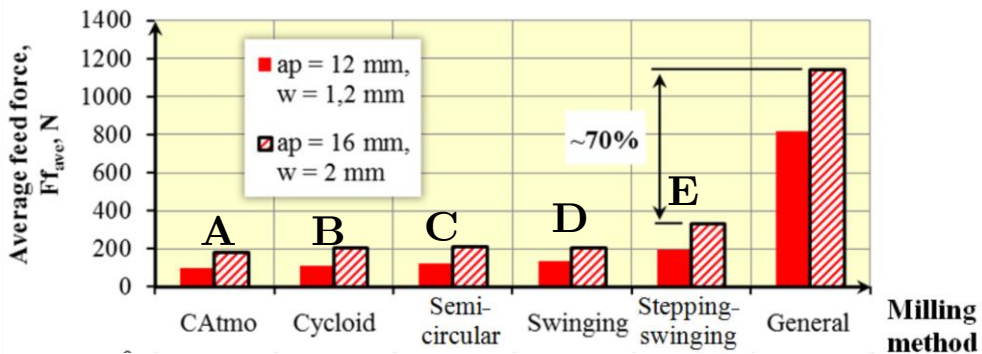
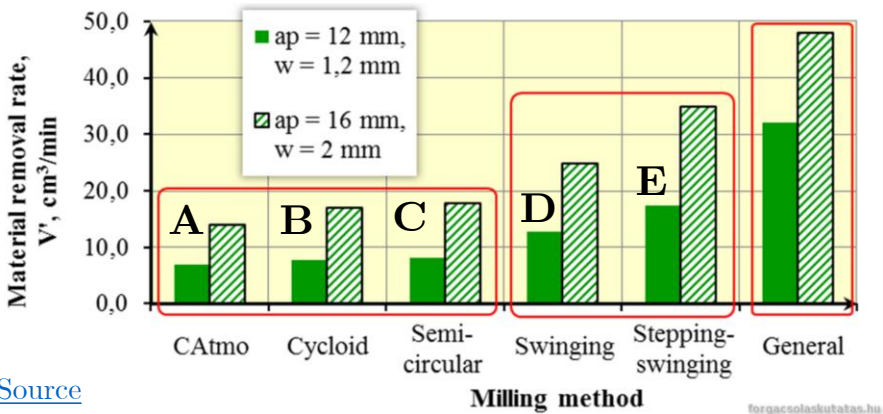
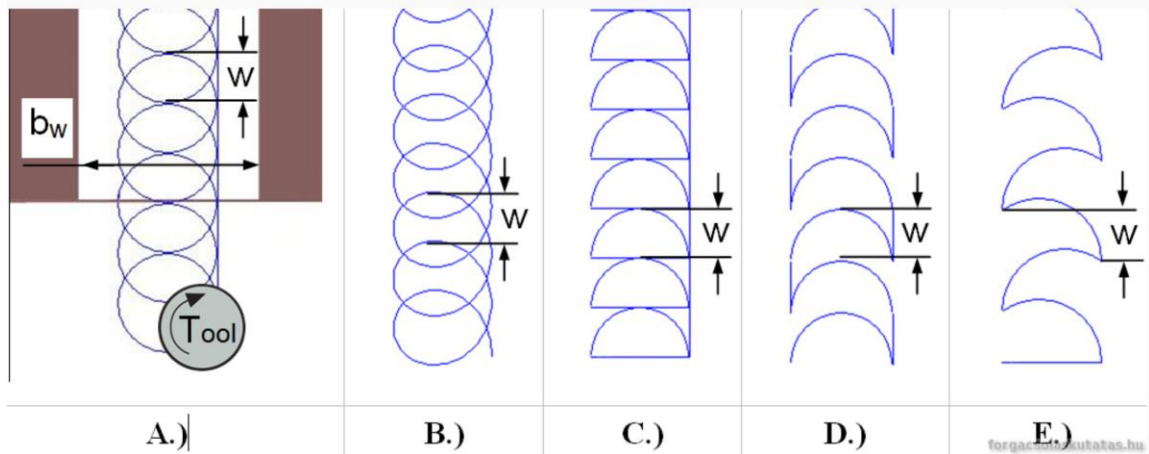
*\* Rough machining: Trochoidal milling*



[Source](#)

# MILLING STRATEGIES

\* *Rough machining: Trochoidal milling*

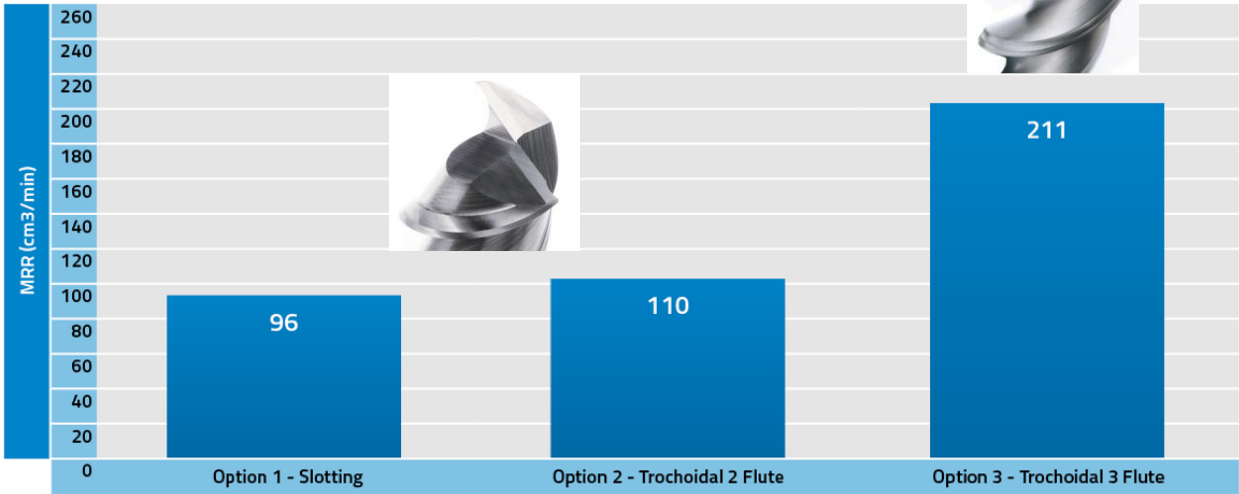


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# MILLING STRATEGIES

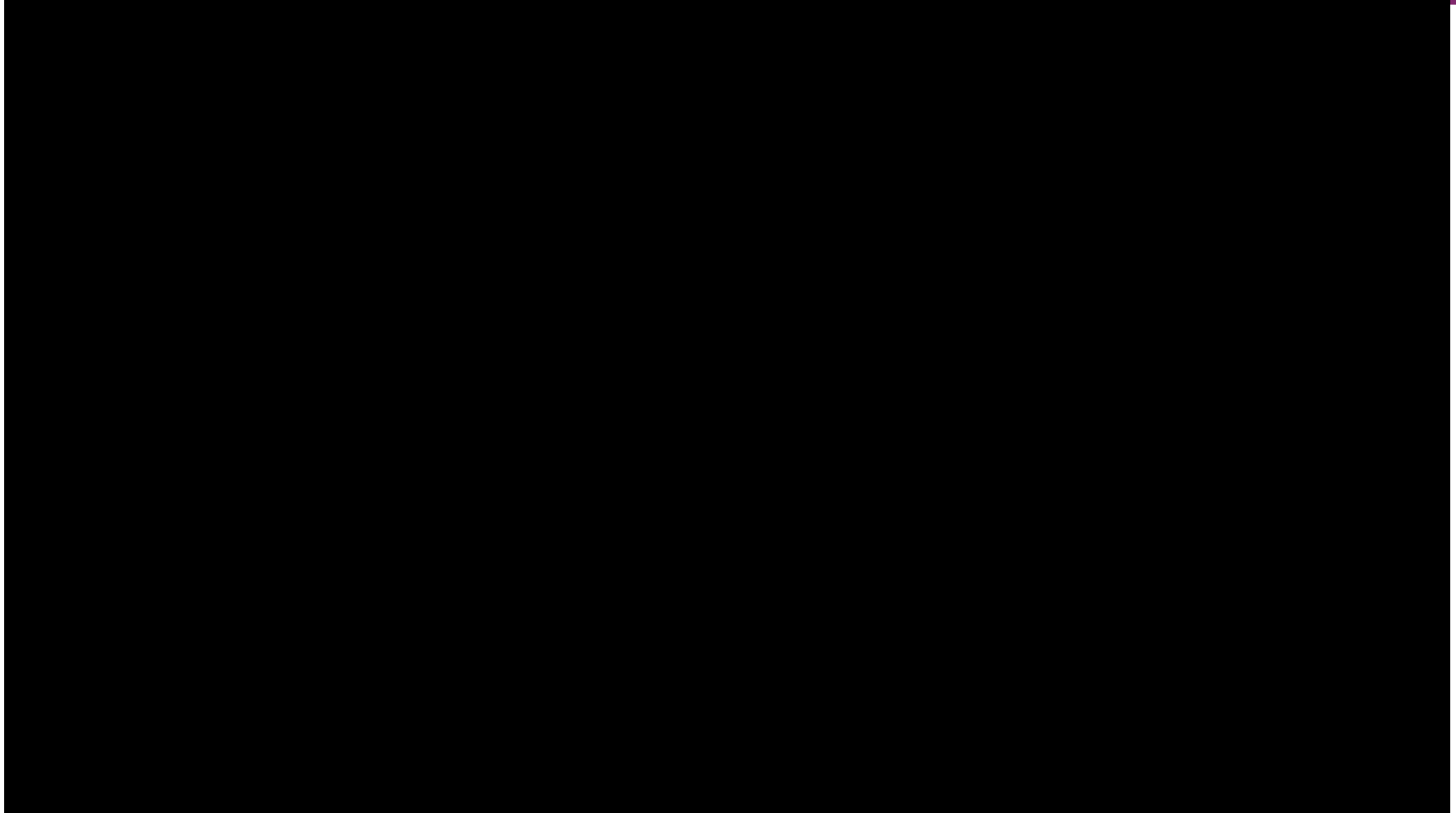
## \* *Rough machining: Trochoidal milling*

| Test Data              | Option 1 - Slotting | Option 2 – Trochoidal – 2 Flute | Option 3 – Trochoidal – 3 Flute |
|------------------------|---------------------|---------------------------------|---------------------------------|
| Brand                  | Sutton              | Sutton                          | Sutton                          |
| Tool                   | R40 AI              | R40 AI                          | R42/43/44 HARMONY AI            |
| Part No. / Reference   | E3102000            | E3101200                        | E4001200                        |
| Tool Material Grade    | VHM                 | VHM                             | VHM                             |
| Tool Holder            | ER Collet chuck     | Shrink fit                      | Shrink fit                      |
| Tool Diameter (mm)     | 20                  | 12                              | 12                              |
| Tool Cost (Approx.)    | \$220.00            | \$77.00                         | \$80.00                         |
| Z (teeth number)       | 2                   | 2                               | 3                               |
| a e (mm)               | 20                  | 2                               | 2                               |
| a p (mm) / depth       | 12 + 12 (2 passes)  | 24 (single pass)                | 24 (single pass)                |
| Cutting Speed V(m/min) | 100                 | 200                             | 250                             |
| RPM                    | 1600                | 5300                            | 6600                            |
| Feed Rate (mm/min)     | 200                 | 2300                            | 4400                            |
| Feed f(mm/flute)       | 0.05                | 0.22                            | 0.22                            |



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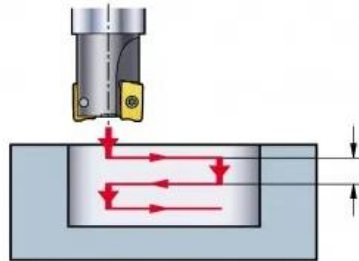
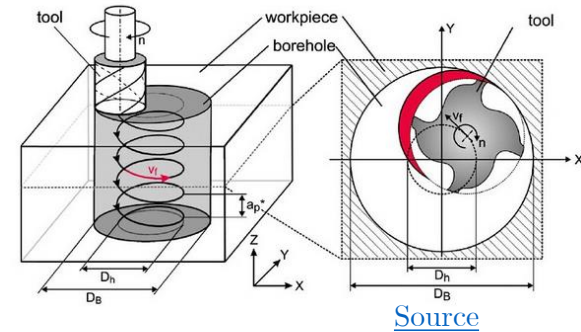
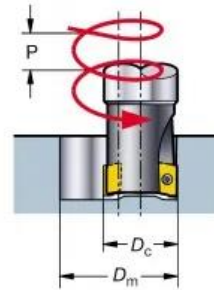
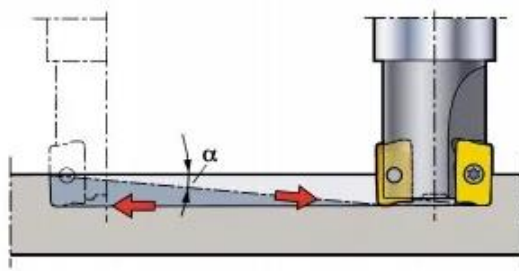
*\* Rough machining: Trochoidal milling*



[Source](#)

100%

-Ramping/helical ramping strategy-



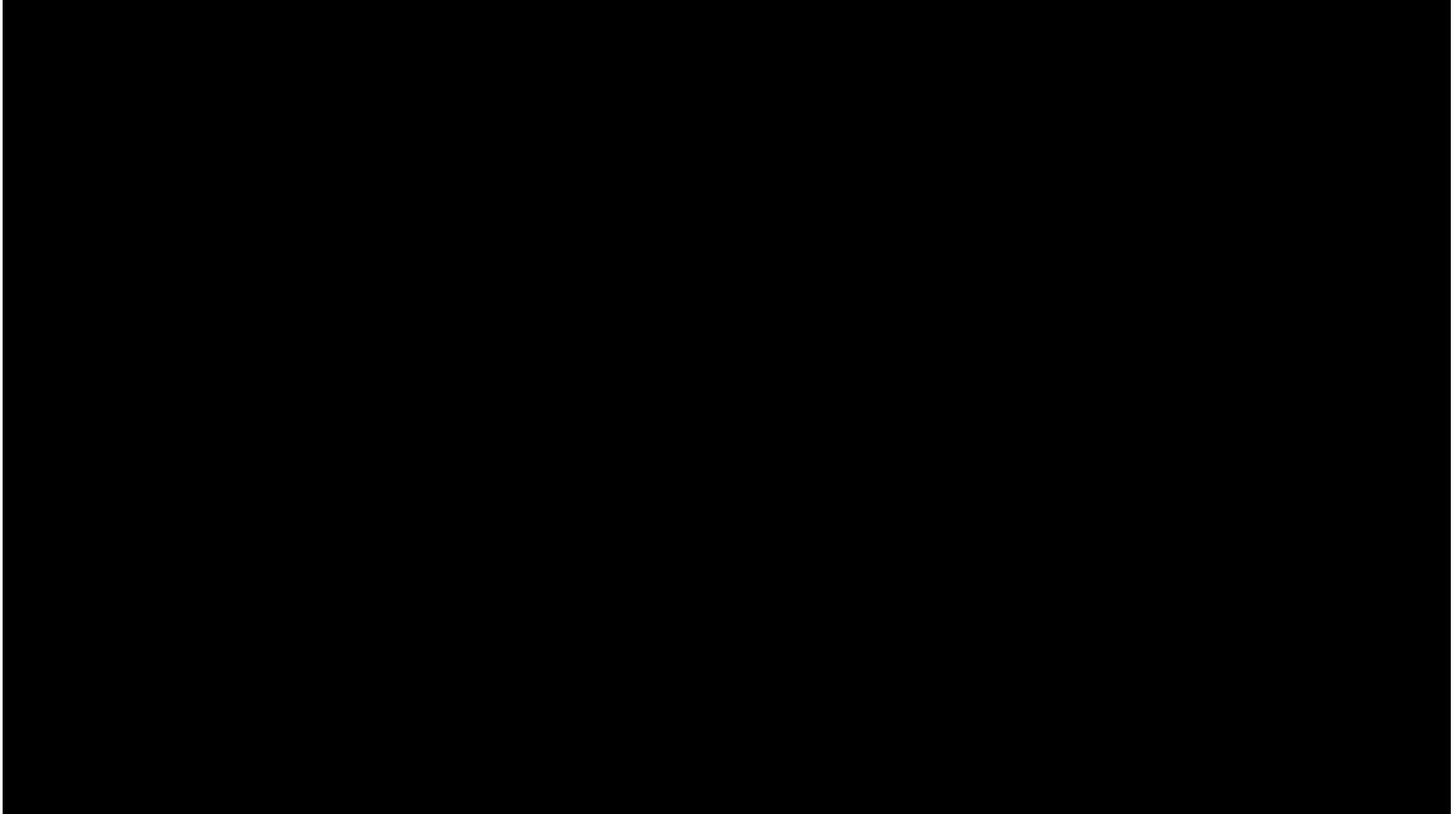
## High power requirement

- > Use only when it remains the only possible option

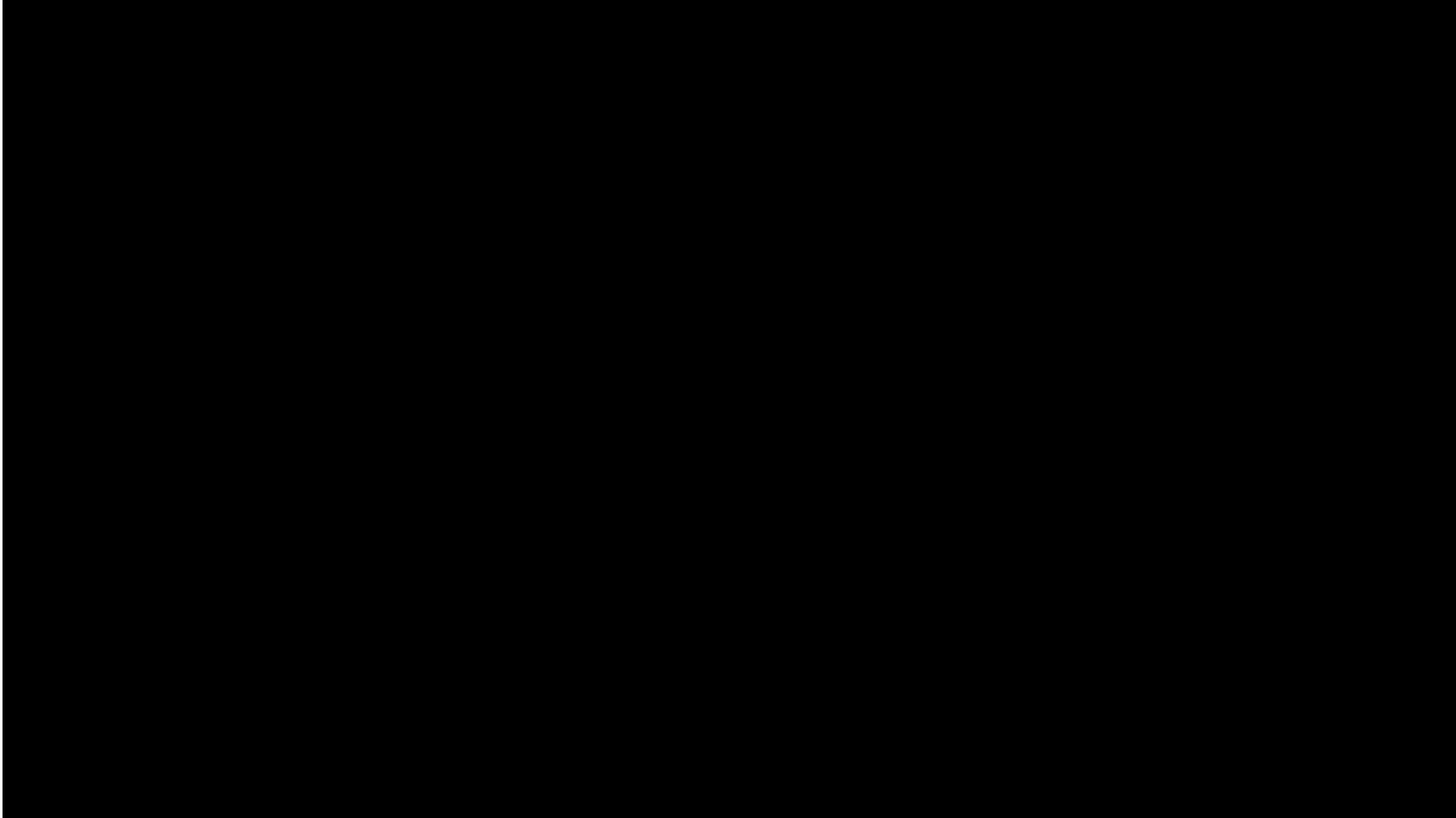
# MILLING STRATEGIES

\* Milling cavities/pockets

-Ramping/helical ramping strategy-



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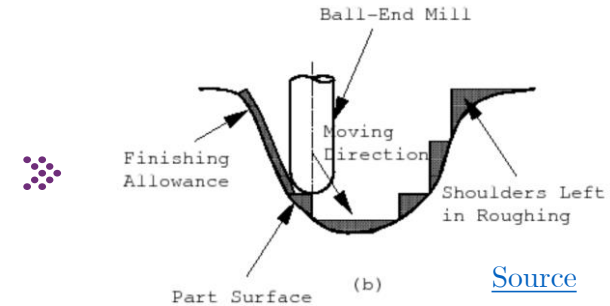
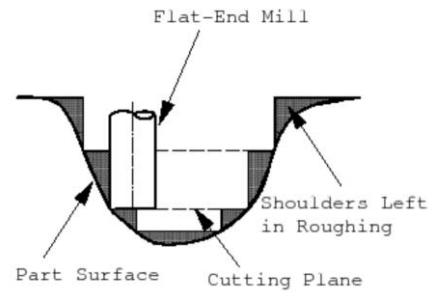
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# MILLING STRATEGIES

## *\* Finish machining strategies*



[Source](#)

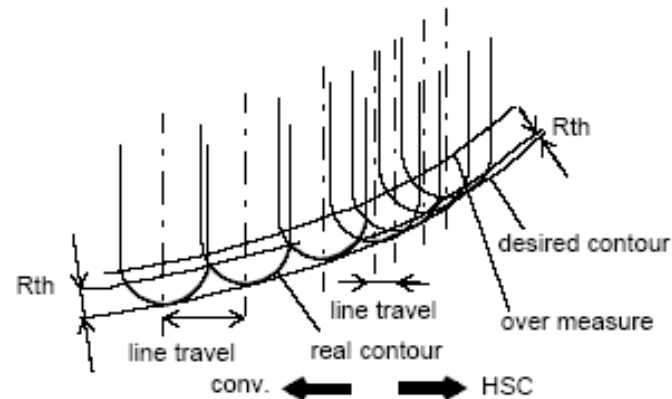
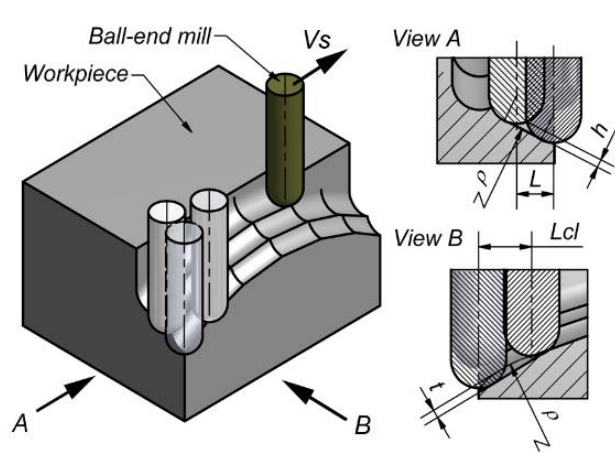


[Source](#)

# OSG PHOENIX

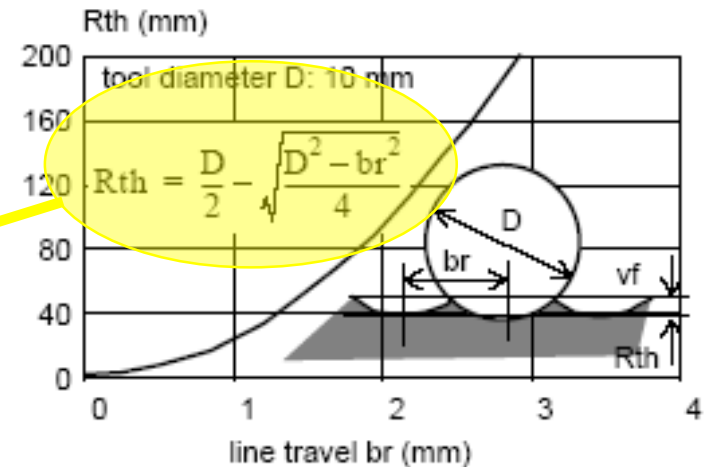
# MILLING STRATEGIES

## \* Finish machining strategies



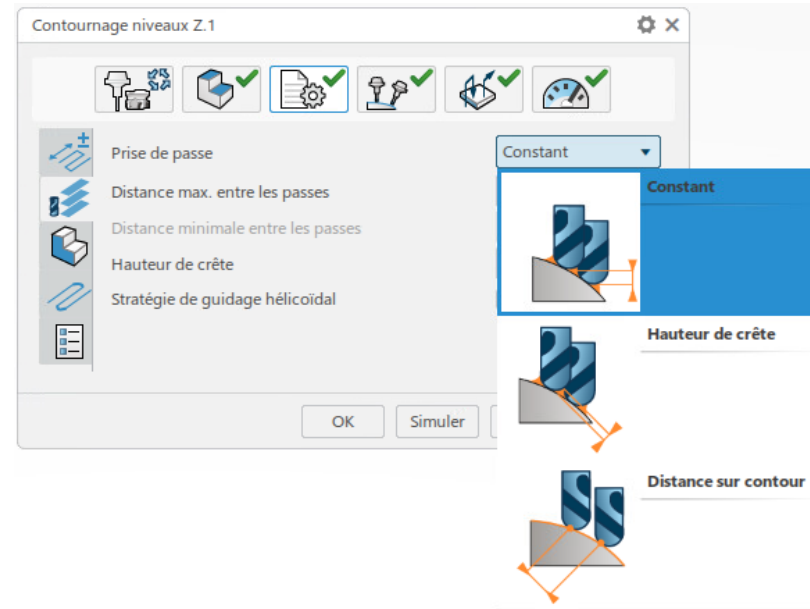
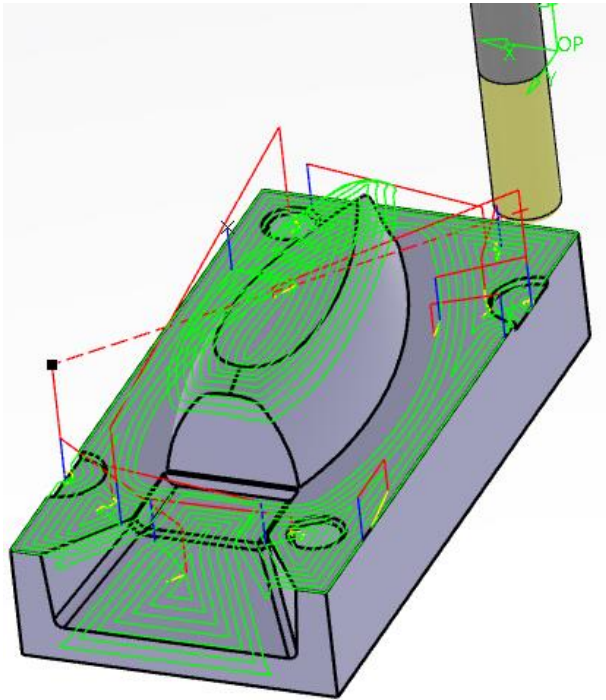
[Source](#)

$$R_{th} = \frac{D}{2} - \frac{D}{2} \sqrt{1 - \left(\frac{br}{D}\right)^2} \approx \frac{br^2}{4D}$$



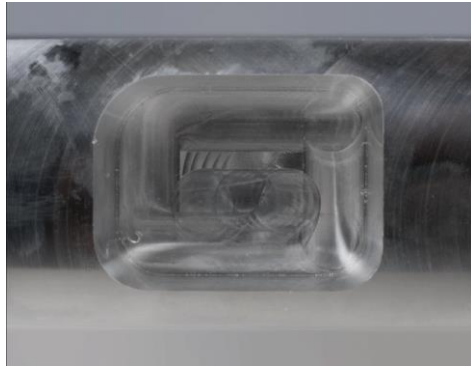
## \* Finish machining strategies

Scallop height ( hauteur de crête)

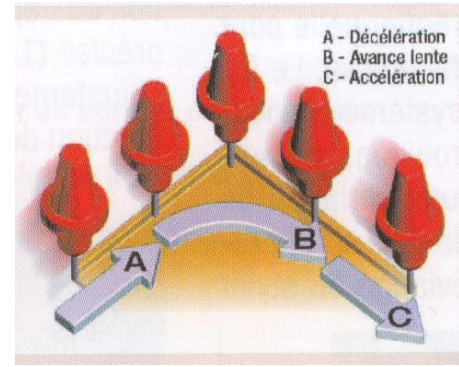
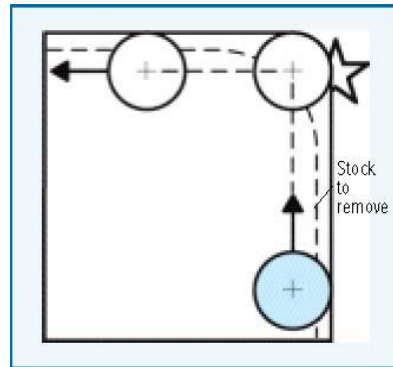


# MILLING STRATEGIES

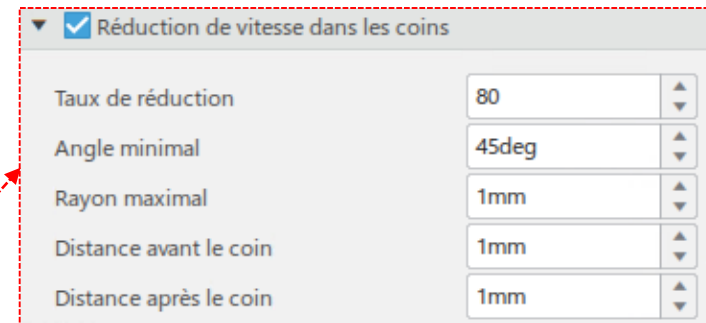
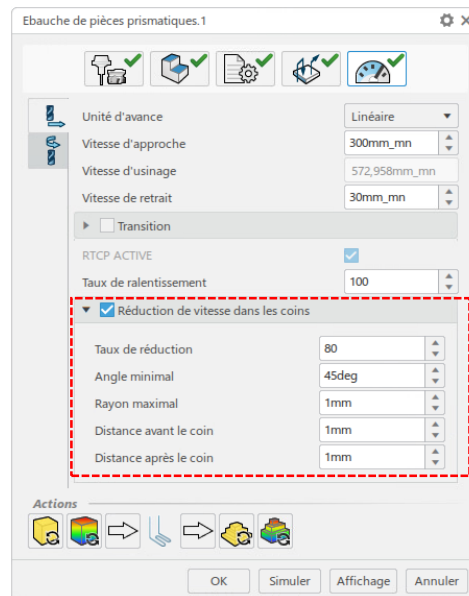
## \* Finish machining strategies



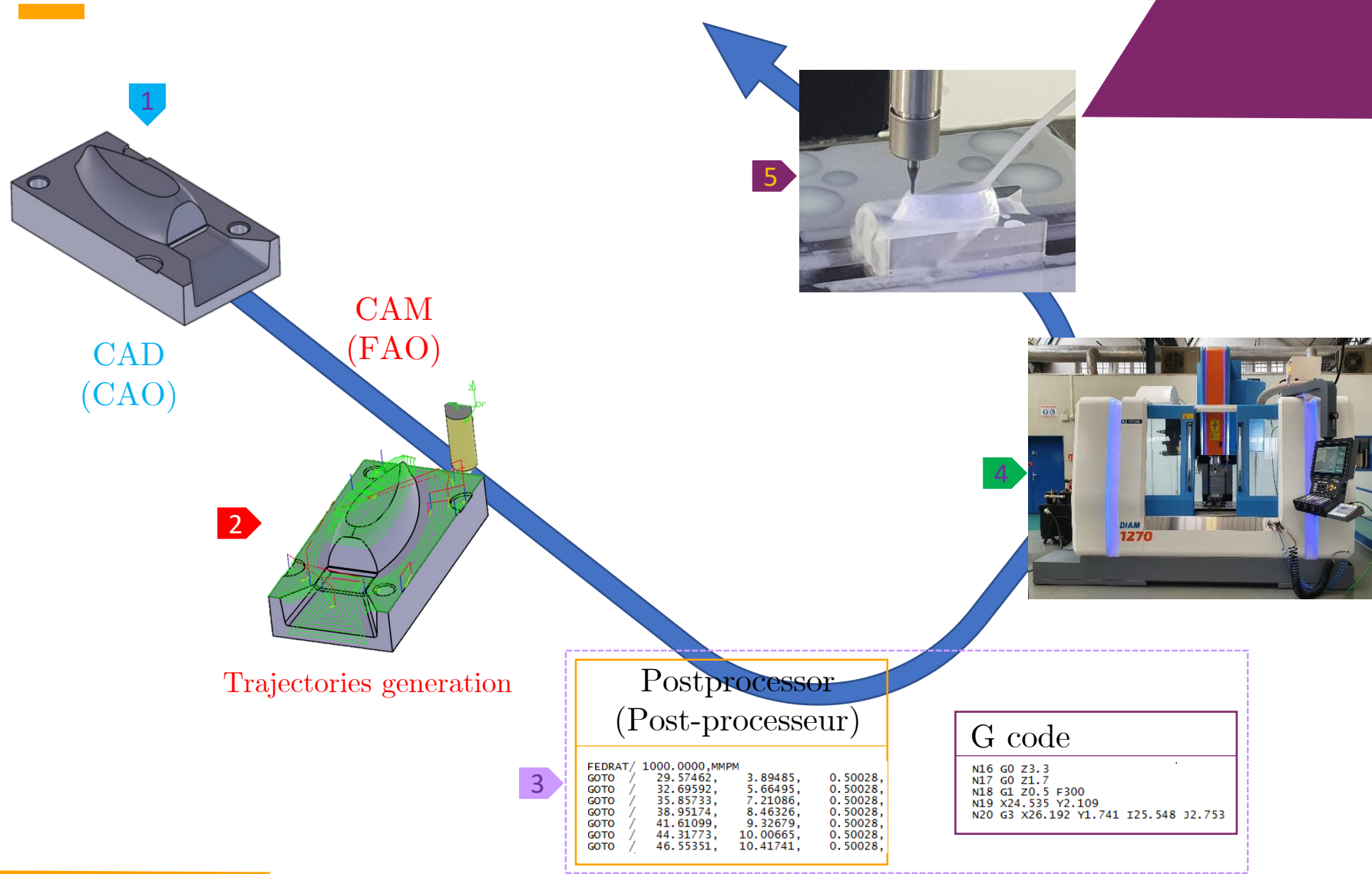
[Source](#)



Variation of the chip thickness in the corners => Shock, vibration  
=> Reduction of the feed rate in the corners



# G CODE GENERATION



APT Source

```
MSYS/ 0.83717, 0.54694, 0.00000, 1091.36447,$
0.00000, 0.00000, 1.00000, -756.89991,$
0.54694, -0.83717, 0.00000, -564.15320
$$CATIAV5-SGPOST.pptable-(NCISOFT)
PPRINT Phase d'usinage.1
PARTNO Programme de fabrication.1
$$ OPERATION NAME : Changement outil.1
$ Début de génération de: Changement outil.1
MULTAX/ON
$$ TOOLCHANGEBEGINNING
CUTTER/ 28.000000, 0.000000, 14.000000, 0.000000, 0.000000,$
0.000000, 50.000000
MODE/MILL
TPRINT/T1 Fraise 2 tailles D28
LOADTL/2
$$ TOOLCHANGEEND
$ Fin de génération de: Changement outil.1
OPTYPE/3AXES,Contournage niveaux Z
PPRINT Contournage niveaux Z.1
$$ OPERATION NAME : Contournage niveaux Z.1
$ Début de génération de: Contournage niveaux Z.1
$$ PPTABLE : NC_COMPENSATION 1
SPINDL/ 70.0000,RPM,CLW
RAPID
GOTO / 24.90375, 3.76862, 3.30028, 0.000000, 0.000000, 1.000000
RAPID
GOTO / 24.90375, 3.76862, 1.78828, 0.000000, 0.000000, 1.000000
FEDRAT/ 300.0000,MMPM
GOTO / 24.90375, 3.76862, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 24.53534, 2.10902, 0.50028, 0.000000, 0.000000, 1.000000
INTOL / 0.03000
OUTTOL/ 0.00000
AUTOPS
INDIRV/ 0.53707, -0.84354, 0.00000
TLON,GOFWD/ (CIRCLE/ 25.54759, 2.75350, 0.50028,$
1.20000),ON,(LINE/ 25.54759, 2.75350, 0.50028,$
26.19207, 1.74125, 0.50028)
FEDRAT/ 1000.0000,MMPM
GOTO / 29.57462, 3.89485, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 32.69592, 5.66495, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 35.85733, 7.21086, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 38.95174, 8.46326, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 41.61099, 9.32679, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 44.31773, 10.00665, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 46.55351, 10.41741, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 49.13488, 10.73025, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 52.13315, 10.88408, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 55.33895, 10.81488, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 58.85936, 10.48475, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 61.96674, 9.99450, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 65.41061, 9.25747, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 68.83897, 8.33173, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 70.85900, 7.63799, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 71.98863, 7.11840, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 73.31569, 6.33349, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 74.59268, 5.40897, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 75.90653, 4.18669, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 77.09247, 2.77441, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 78.03877, 1.31423, 0.50028, 0.000000, 0.000000, 1.000000
GOTO / 78.79521, -0.23309, 0.50028, 0.000000, 0.000000, 1.000000
```

Langage ISO

```
% Process1_Programme_de_fabrication_1 G71
N1 G30 G17 X-10.226 Y-43.489 Z-85.058
N2 G90 G31 X80.321 Y11.488 Z0.5
N3 G80 A0 C0
N4 G80
N5;T2 T1 Fraise 2 tailles D28
N6;T3 T1 Fraise hemi sphérique D10
; Phase d usinage.1
N7 G0 Z450 M91
N8 G0 A0 C0 M91 M94
N9; T1 Fraise 2 tailles D28
N10 G17 T2 DR-14 S70
N11 G51 Z3
; Contournage niveaux Z.1
N12 M3
N13 G80 A0 C0
N14 G0 AQ120 CQ122 M94
N15 G90 G40 G0 X24.904 Y3.769
N16 G0 Z3.3
N17 G0 Z1.7
N18 G1 Z0.5 F30
N19 X24.535 Y2.
N20 G3 X26.192
N21 G1 X29.575
N22 X32.696 Y5.
N23 X35.857 Y7.
N24 X38.952 Y8.
N25 X41.611 Y9.
N26 X44.318 Y10
N27 X46.554 Y10
N28 X49.135 Y10
N29 X52.133 Y10
N30 X55.339 Y10
N31 X58.859 Y10
N32 X61.967 Y9.
N33 X65.411 Y9.
N34 X68.839 Y8.
N35 X70.859 Y7.
N36 X71.989 Y7
O BEGIN PGM process1_programme_de_fabrication_1 MM
1 BLK FORM 0.1 Z X-10.226 Y-43.489 Z-85.058
2 BLK FORM 0.2 X+80.321 Y+11.488 Z+0.5
3; Programme de fabrication.1
4 CYCL DEF 19.0 PLAN D'USINAGE
5 CYCL DEF 19.1 A+0 C+0
6 CYCL DEF 19.0 PLAN D'USINAGE
7 CYCL DEF 19.1
* -Phase d usinage.1
8 L X+450 FMAX M91
9 L A+0 C+0 FMAX M91
10 M94
11* -T1 Fraise 2 tailles D28
12 TOOL CALL 2 Z S70
13 TOOL DEF 3
* -Contournage niveaux Z.1
14 L M3
15 CYCL DEF 19.0 PLAN D'USINAGE
16 CYCL DEF 19.1 A+0 C+0
17 L AQ120 CQ122 FMAX M94
18 L X+24.904 Y+3.769 R0 FMAX
19 L Z+3.3 FMAX
20 L Z+1.7 FMAX
21 L Z+0.5 F300
22 L X+24.535 Y+2.109
23 CC X+25.548 Y+2.753
24 C X+26.192 Y+1.741 DR+
25 L X+29.575 Y+3.895 F1000
26 L X+32.696 Y+5.665
27 L X+35.857 Y+7.211
28 L X+38.952 Y+8.463
29 L X+41.611 Y+9.327
30 L X+44.318 Y+10.007
31 L X+46.554 Y+10.417
32 L X+49.135 Y+10.73
33 L X+52.133 Y+10.884
34 L X+55.339 Y+10.815
35 L X+58.859 Y+10.485
36 L X+61.967 Y+9.995
```

Langage Heidenhain

```
O BEGIN PGM process1_programme_de_fabrication_1 MM
1 BLK FORM 0.1 Z X-10.226 Y-43.489 Z-85.058
2 BLK FORM 0.2 X+80.321 Y+11.488 Z+0.5
3; Programme de fabrication.1
4 CYCL DEF 19.0 PLAN D'USINAGE
5 CYCL DEF 19.1 A+0 C+0
6 CYCL DEF 19.0 PLAN D'USINAGE
7 CYCL DEF 19.1
* -Phase d usinage.1
8 L X+450 FMAX M91
9 L A+0 C+0 FMAX M91
10 M94
11* -T1 Fraise 2 tailles D28
12 TOOL CALL 2 Z S70
13 TOOL DEF 3
* -Contournage niveaux Z.1
14 L M3
15 CYCL DEF 19.0 PLAN D'USINAGE
16 CYCL DEF 19.1 A+0 C+0
17 L AQ120 CQ122 FMAX M94
18 L X+24.904 Y+3.769 R0 FMAX
19 L Z+3.3 FMAX
20 L Z+1.7 FMAX
21 L Z+0.5 F300
22 L X+24.535 Y+2.109
23 CC X+25.548 Y+2.753
24 C X+26.192 Y+1.741 DR+
25 L X+29.575 Y+3.895 F1000
26 L X+32.696 Y+5.665
27 L X+35.857 Y+7.211
28 L X+38.952 Y+8.463
29 L X+41.611 Y+9.327
30 L X+44.318 Y+10.007
31 L X+46.554 Y+10.417
32 L X+49.135 Y+10.73
33 L X+52.133 Y+10.884
34 L X+55.339 Y+10.815
35 L X+58.859 Y+10.485
36 L X+61.967 Y+9.995
```

# CONCLUSION

## CAD software ensures:

- Tool path optimization
- Accessibility, collisions verification
- Machining time estimation
- APT source/G code generation

## It can not predict:

- Surface roughness
- Vibration/chatter
- Workpiece/tool deformation
- Cutting parameters validation

❖ An optimization of the machining strategies (tool path) is crucial to obtain a high quality machined parts and to obtain a high level of productivity

❖ However, the tool selection and operating parameters optimization must not be neglected (COM approach).