



Avtomatiziran dizajn turbinskih strojev

Radialne črpalke

Univerza v Novem mestu
Fakulteta za strojništvo
2024

Dizajn radialnih črpalk

VISTA AFD

VISTA CCD

VISTA CPD

VISTA RTD

Radialne črpalke

Črpalke so najbolj razširjen energetska stroj, saj se uporabljajo v skoraj vseh industrijskih panogah.

Spadajo med delovne energetske stroje in obratujejo v zelo različnih obratovalnih pogojih.

Ker so velik potrošnik električne energije je njihov razvoj zelo pomemben, če želimo, da obratujejo z visokimi izkoristki, imajo nizke stroške vzdrževanja in dolgo življenjsko dobo.

Oblikovanje hidravličnih oblik pretočnega trakta in lopatic gonilnika radialne črpalke je lahko zahtevna naloga.

Naloge se lahko lotimo s poznavanjem osnovnih teoretičnih osnov obratovanja radialnih črpalk ali pa si delo olajšamo z uporabo dostopnih programskih paketov.

Radialne črpalke

V programskem paketu ANSYS Workbench imamo na razpolago modul z imenom VISTA CPD (Centrifugal Pump Design), ki nam omogoča osnovni dizajn radialnih črpalk.

Programsko orodje ANSYS je za študente in dijake prosto dostopno, saj so le ti opravičeni do uporabe študentske licence.

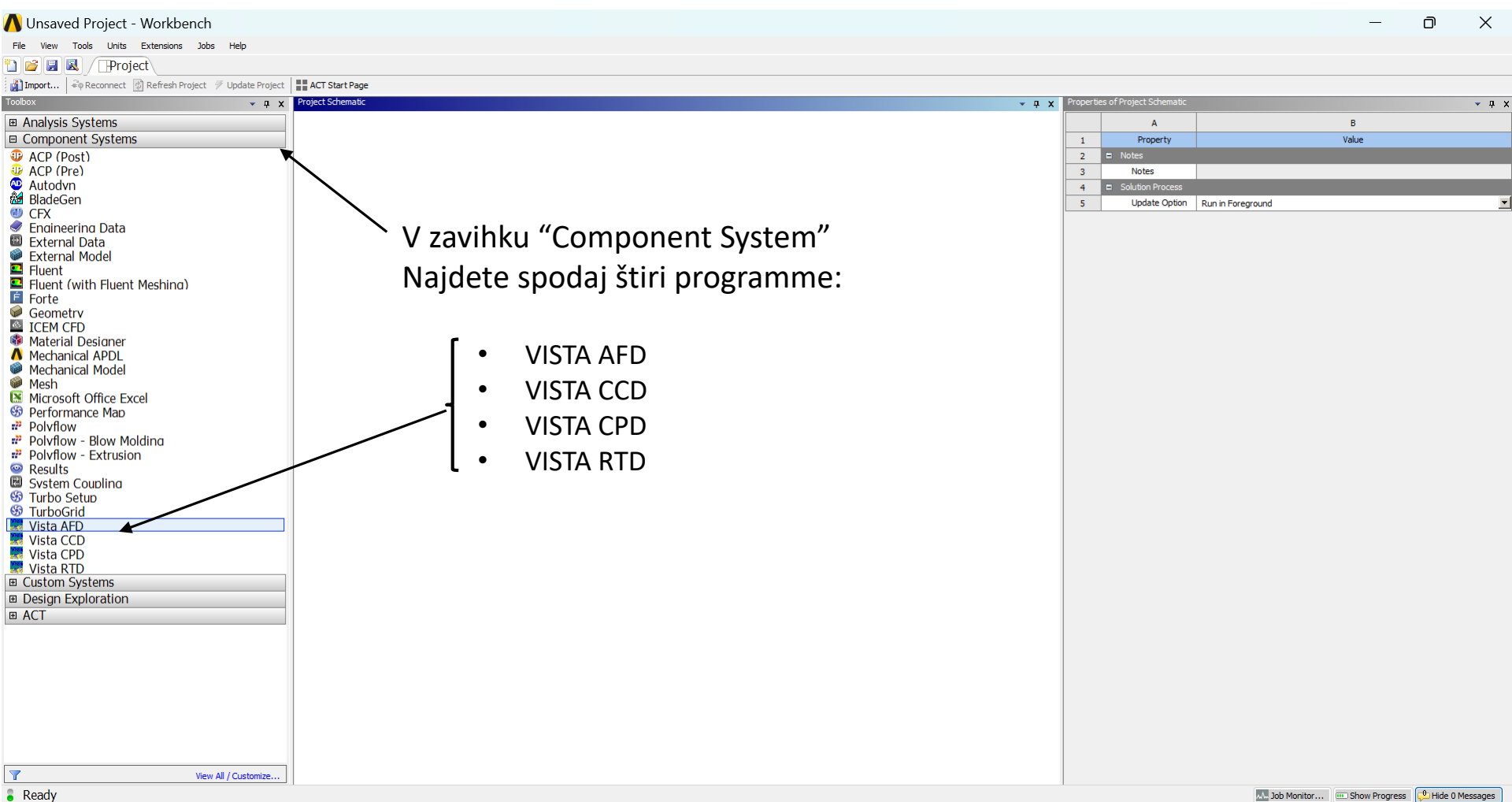
Tako imenovane učne licence imajo določene kvantitativne omejitve glede števila uporabljenih elementov, nimajo pa omejitev glede izbirnih modulov.

Z uporabo programa VISTA CPD lahko hitro in preprosto definiramo 3-D obliko pretočnega trakta radialne črpalke, hidravlično obliko lopatic gonilnika in spiralnega ohišja.

Dobljena 3-D geometrija nam predstavlja dober začetni približek za nadaljnjo optimizacijo z uporabo programa za numerično dinamiko tekočin.

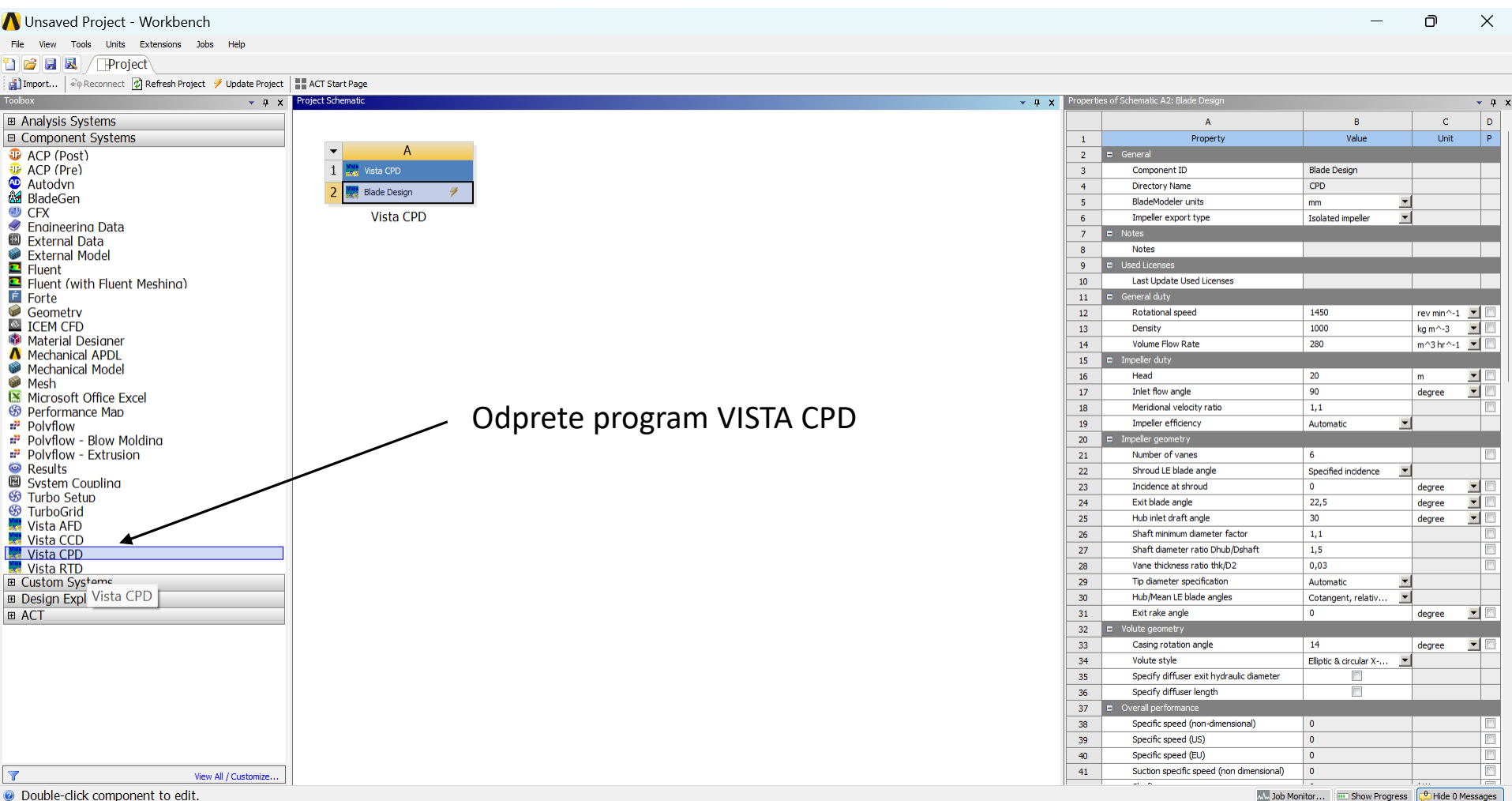
Zagon programa ANSYS Workbench

- odpre se okno

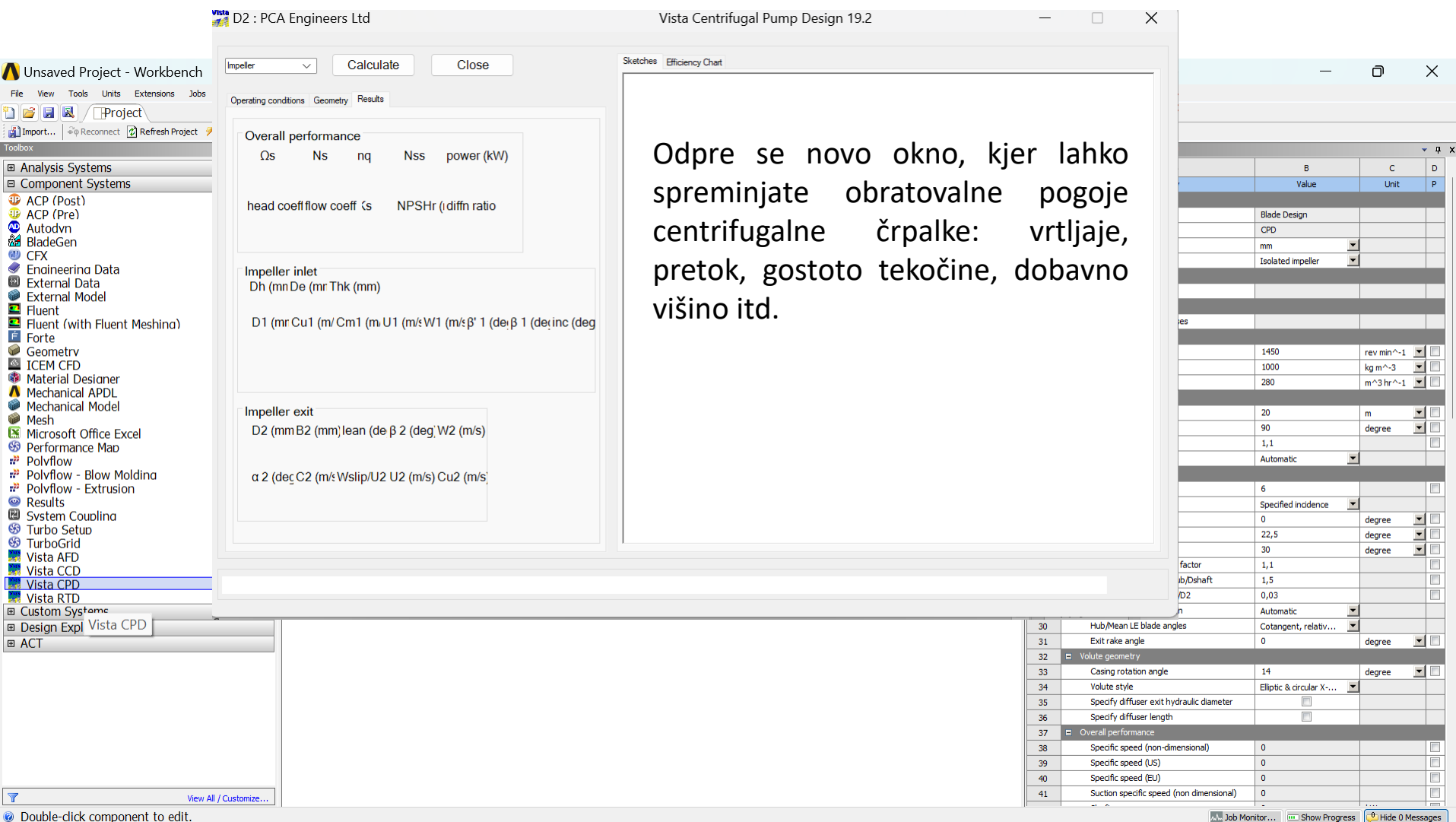


Zagon programa VISTA CPD

- Odpre se okno “VISTA Centrifugal Pump Design”
- Program omogoča oblikovanje radialnih črpalk za določene obratovalne pogoje



- Okno “VISTA Centrifugal Pump Design”



Zagon programa VISTA CPD

- Okno “VISTA Centrifugal Pump Design”

The screenshot displays the VISTA CPD software interface. On the left, a 'Toolbox' panel lists various analysis systems, with 'Vista CPD' highlighted. In the center, a 'Project Schematic' window shows a tree view with 'Vista CPD' and 'Blade Design' components. An arrow points from the text 'Zaženete program VISTA CPD' to the 'Vista CPD' component. On the right, a 'Properties of Schematic A2: Blade Design' window is visible, showing a table with columns A, B, C, and D. The main window, titled 'Vista Centrifugal Pump Design 19.2', contains a 'Calculate' button, a 'Close' button, and a 'Sketches' tab. An arrow points from the text 'Ko ste določili obratovalne pogoje, kliknete okno “Calculate” in dobite začetno obliko črpalke prikazano v meridianskem preseku (naslednja slika).' to the 'Calculate' button. Below the 'Calculate' button, there are input fields for 'Rotational speed', 'Volume flow rate', 'Density', 'Head rise', 'Inlet flow angle', and 'Merid velocity'. A section titled 'Efficiencies' shows a dropdown menu set to 'Automatic' and four input fields for 'Hydraulic', 'Volumetric', 'Mechanical', and 'Pump' efficiencies.

	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	Blade Design		
4	Directory Name	CPD		

Zaženete program VISTA CPD

Ko ste določili obratovalne pogoje, kliknete okno “Calculate” in dobite začetno obliko črpalke prikazano v meridianskem preseku (naslednja slika).

Operating conditions | Geometry | Results

Units
☒ SI ☐ Imperial

Duty
Rotational speed: rpm
Volume flow rate: m³/hr
Density: 1000 kg/m³
Head rise: 20 m
Inlet flow angle: 90 deg
Merid velocity: 1.1

Efficiencies
Automatic

Hydraulic: 0.874
Volumetric: 0.97
Mechanical: 0.948
Pump: 0.804

Program VISTA CPD

- Za izbrane pogoje dobimo 3-D obliko gonilnika radialne črpalke.

Unsaved Project - Workbench

File View Tools Units Extensions Jobs Help

Project

Import... Reconnect Refresh Project Update Project ACT Start Page

Toolbox

- Analysis Systems
- Component Systems
 - ACP (Post)
 - ACP (Pre)
 - Autodyn
 - BladeGen
 - CFX
 - Engineering Data
 - External Data
 - External Model
 - Fluent
 - Fluent (with Fluent Meshing)
 - Forté
 - Geometrv
 - ICEM CFD
 - Material Designer
 - Mechanical APDL
 - Mechanical Model
 - Mesh
 - Microsoft Office Excel
 - Performance Map
 - Polvflow
 - Polvflow - Blow Moldina
 - Polvflow - Extrusion
 - Results
 - System Couplina
 - Turbo Setuo
 - TurboGrid
 - Vista AFD
 - Vista CCD
 - Vista CPD**
 - Vista RTD
 - Custom Systems
 - Design Expl
 - Vista CPD
 - ACT

Project Schematic

A

- Vista CPD
- Blade Design

Vista CPD

Properties of Schematic A2: Blade Design

	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	Blade Design		
4	Directory Name	CPD		
5	BladeModeler units	mm		
6	Impeller export type	Tabulated impeller		

Vista A2 : PCA Engineers Ltd

Vista Centrifugal Pump Design 19.2

Impeller Calculate Close

Operating conditions Geometry Results

Overall performance

Ω s	Ns	η_q	Nss	power (kW)
0,82	2242	43,4	3,15	19,5

head coeff flow coeff ζ_s NPSHr (diffn ratio

0,461	0,053	1,009	3,32	0,040	

Impeller inlet

Dh (mm) De (mm) Thk (mm)

39,3	170,6	8,2					

D1 (mm) Cu1 (m/Cm1) (m/U1 (m/s) W1 (m/s) β 1 (deg) β 1 (deg) inc (deg)

83,1	0,00	3,55	6,31	7,24	34,52	29,37	5,15
127,3	0,00	3,95	9,67	10,44	24,19	22,21	1,98
171,5	0,00	4,34	13,02	13,72	18,44	18,44	0,00

Impeller exit

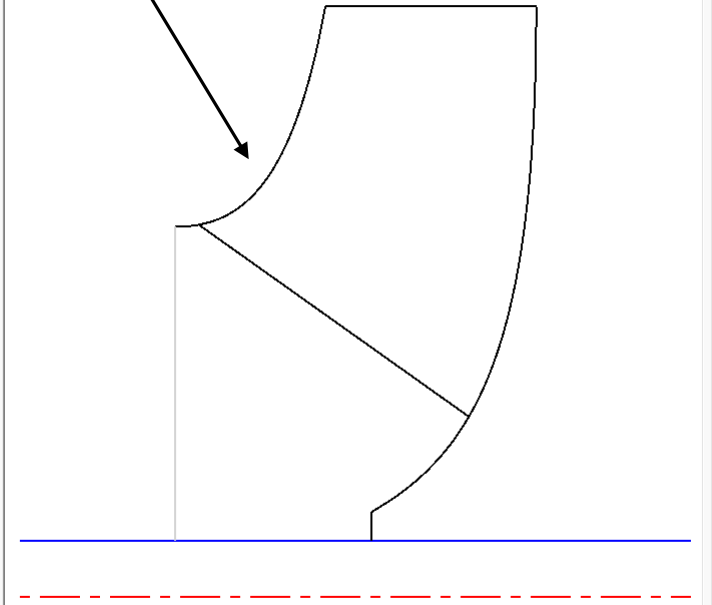
D2 (mm) B2 (mm) lean (deg) β 2 (deg) W2 (m/s)

271,9	48,6	0,0	13,11	10,03	

α 2 (deg) C2 (m/s) Wslip/U2 U2 (m/s) Cu2 (m/s)

11,81	11,11	0,21	20,64	10,87	

Sketches Efficiency Chart



Program VISTA CPD

- Obratovalne pogoje lahko poljubno izbirate in spreminjate

Vista A2 : PCA Engineers Ltd

Vista Centrifugal Pump Design 19.2

Impeller

Operating conditions Geometry Results

Units
☒ SI ☐ Imperial

Duty

Rotational speed rpm

Volume flow rate m³/hr

Density kg/m³

Head rise m

Inlet flow angle deg

Merid velocity

Efficiencies

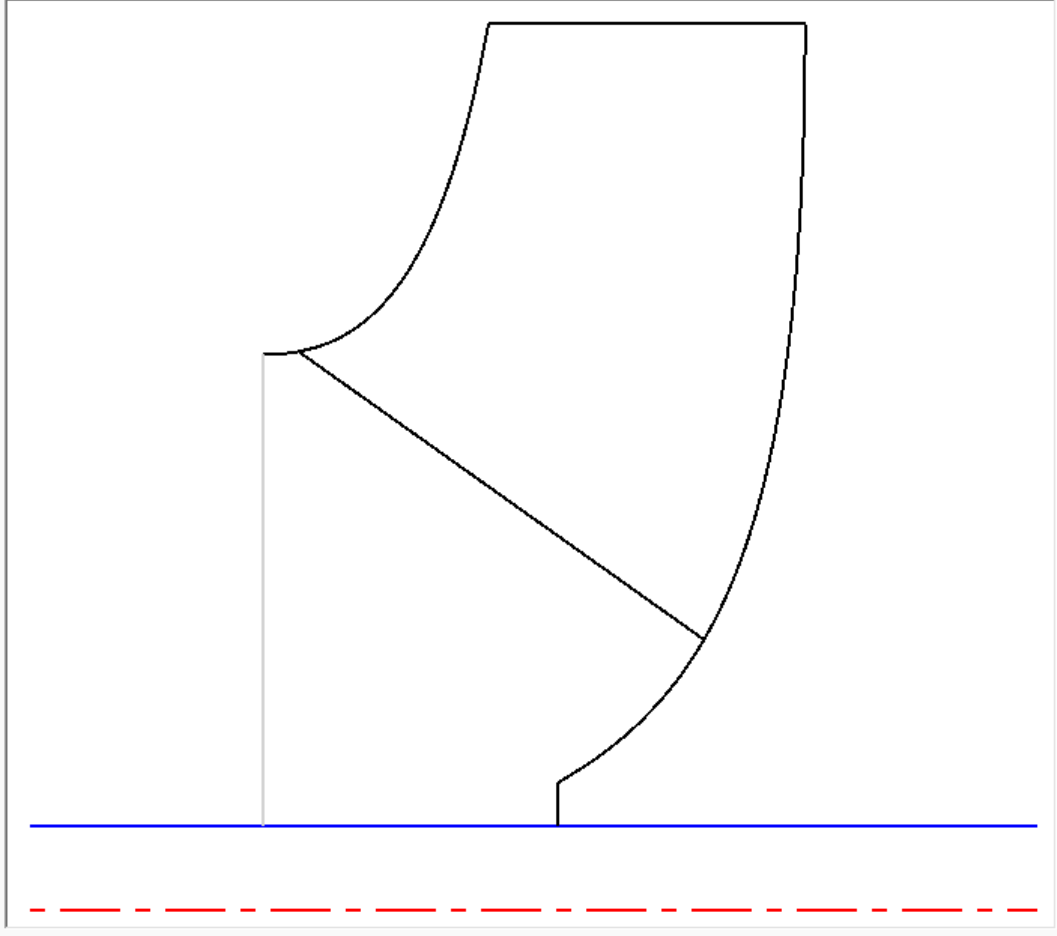
Hydraulic

Volumetric

Mechanical

Pump

Sketches Efficiency Chart



Program VISTA CPD

- Za izbrane pogoje dobimo 3-D obliko spiralnega ohišja.

Unsaved Project - Workbench

File View Tools Units Extensions Jobs Help

Project

Import... Reconnect Refresh Project Update Project ACT Start Page

Toolbox

- Analysis Systems
- Component Systems
- ACP (Post)
- ACP (Pre)
- Autodyn
- BladeGen
- CFX
- Engineering Data
- External Data
- External Model
- Fluent
- Fluent (with Fluent Meshing)
- Forté
- Geometrv
- ICEM CFD
- Material Designer
- Mechanical APDL
- Mechanical Model
- Mesh
- Microsoft Office Excel
- Performance Map
- Polvflow
- Polvflow - Blow Molding
- Polvflow - Extrusion
- Results
- System Coupling
- Turbo Setup
- TurboGrid
- Vista AFD
- Vista CCD
- Vista CPD**
- Vista RTD
- Custom Systems
- Design Explorer
- ACT

Project Schematic

- A
- 1 Vista CPD
- 2 Blade Design

Vista CPD

Properties of Schematic A2: Blade Design

	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	Blade Design		
4	Directory Name	CPD		
5	BladeModeler units	mm		
6	Impeller export type	Translated impeller		

A2 : PCA Engineers Ltd

Vista Centrifugal Pump Design 19.2

Volume Calculate Close

Operating conditions Geometry Results

Inlet width 82.5 mm Cutwater clear. 14.8 mm
Base circle radius 150 mm Cutwater thickness 5.2 mm

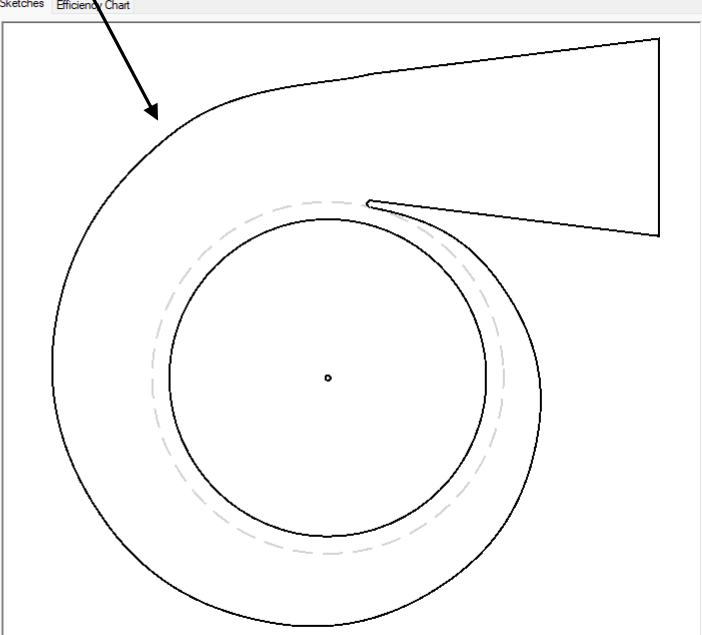
Sections, cutwater to throat

No.	Area mm ²	Centroid mm	ra mm	Outer radius mm	or radius mm	or radius mm
1	0	150,7	150,7	41,3	0,0	Cutwat
2	1093	157,9	167,6	41,3	16,9	
3	2296	165,8	186,2	41,3	35,4	
4	3595	173,1	202,4	42,3	42,3	
5	4971	179,5	215,7	45,6	45,6	
6	6418	185,4	227,6	49,5	49,5	
7	7931	190,9	238,7	53,6	53,6	
8	9505	196,1	249,0	57,8	57,8	
9	11217	202,5	260,4	62,1	62,1	Throat

Diffuser

Exit Area	176 mm ²	Length	247 mm
Exit Hyd Diam.	149 mm	Cone angle	7,0 deg

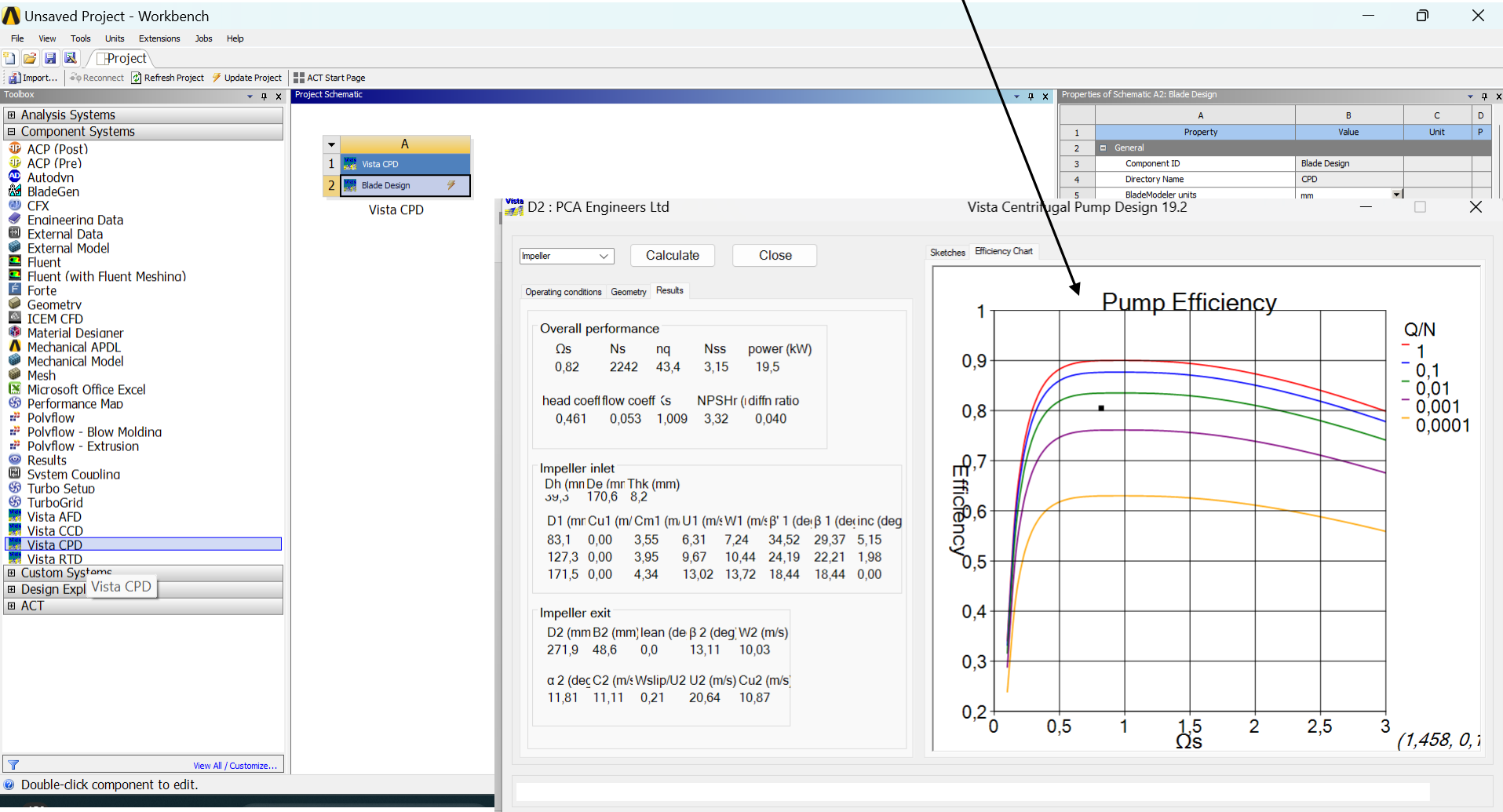
Sketches Efficiency Chart



Double-click component to edit.

Program VISTA CPD

- Za definirano 3-D geometrijo dobimo osnovne podatke o izoristkih.



Zagon programa BladeGen

- Z desno tipko na miški odprete novo okno, greste na “Create new” → “BladeGen”

The screenshot displays the Ansys Workbench software interface. On the left, the 'Toolbox' pane lists various analysis systems, including 'BladeGen'. In the center, the 'Project Schematic' shows a project named 'Vista CPD' with a 'Blade Design' component. A right-click context menu is open over the 'Blade Design' component, and the 'Create New' option is selected, leading to a sub-menu where 'BladeGen' is highlighted. On the right, the 'Properties of Schematic A2: Blade Design' table is visible, showing various design parameters and their values.

	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	Blade Design		
4	Directory Name	CPD		
5	BladeModeler units	mm		
6	Impeller export type	Isolated impeller		
7	Notes			
8	Notes			
9	Used Licenses			
10	Last Update Used Licenses	Not Applicable		
11	General duty			
12	Rotational speed	1450	rev min ⁻¹	
13	Density	1000	kg m ⁻³	
14	Volume Flow Rate	280	m ³ hr ⁻¹	
15	Impeller duty			
16	Head	20	m	
17	Inlet flow angle	90	degree	
18	Meridional velocity ratio	1,1		
19	Impeller efficiency	Automatic		
20	Impeller geometry			
21	Number of vanes	6		
22	Shroud LE blade angle	Specified incidence		
23	Incidence at shroud	0	degree	
24	Exit blade angle	22,5	degree	
25	Hub inlet draft angle	30	degree	
26	Shaft minimum diameter factor	1,1		
27	Shaft diameter ratio Dhub/Dshaft	1,5		
28	Vane thickness ratio thk/D2	0,03		
29	Tip diameter specification	Automatic		
30	Hub/Mean LE blade angles	Cotangent, relativ...		
31	Exit rake angle	0	degree	
32	Volute geometry			
33	Casing rotation angle	14	degree	
34	Volute style	Elliptic & circular X-...		
35	Specify diffuser exit hydraulic diameter			
36	Specify diffuser length			
37	Overall performance			
38	Specific speed (non-dimensional)	0,82019		
39	Specific speed (US)	2241,6		
40	Specific speed (EU)	43,404		
41	Suction specific speed (non dimensional)	3,1515		

Zagon programa BladeGen

- Dobite novo okno "BladeGen"

Unsaved Project - Workbench

File View Tools Units Extensions Jobs Help

Import... Reconnect Refresh Project Update Project ACT Start Page

Toolbox

- Analysis Systems
- Component Systems
 - ACP (Post)
 - ACP (Pre)
 - Autodyn
 - BladeGen
 - CFX
 - Engineering Data
 - External Data
 - External Model
 - Fluent
 - Fluent (with Fluent Meshing)
 - Forte
 - Geometrv
 - ICEM CFD
 - Material Designer
 - Mechanical APDL
 - Mechanical Model
 - Mesh
 - Microsoft Office Excel
 - Performance Map
 - Polvflow
 - Polvflow - Blow Molding
 - Polvflow - Extrusion
 - Results
 - System Coupling
 - Turbo Setup
 - TurboGrid
 - Vista AFD
 - Vista CCD
 - Vista CPD
 - Vista RTD
- Custom Systems
- Design Exploration
- ACT

Project Schematic

Vista CPD

- 1 Vista CPD
- 2 Blade Design ✓

BladeGen

Blade Design

Odprete program "Blade Design"

Properties of Schematic A2: Blade Design

	A	B	C	D
	Property	Value	Unit	P
1	General			
2	Component ID	Blade Design		
3	Directory Name	CPD		
4	BladeModeler units	mm		
5	Impeller export type	Isolated impeller		
6	Notes			
7	Used Licenses			
8	Last Update Used Licenses	Not Applicable		
9	General duty			
10	Rotational speed	1450	rev min ⁻¹	
11	Density	1000	kg m ⁻³	
12	Volume Flow Rate	280	m ³ hr ⁻¹	
13	Impeller duty			
14	Head	20	m	
15	Inlet flow angle	90	degree	
16	Meridional velocity ratio	1,1		
17	Impeller efficiency	Automatic		
18	Impeller geometry			
19	Number of vanes	6		
20	Shroud LE blade angle	Specified incidence		
21	Incidence at shroud	0	degree	
22	Exit blade angle	22,5	degree	
23	Hub inlet draft angle	30	degree	
24	Shaft minimum diameter factor	1,1		
25	Shaft diameter ratio Dhub/Dshaft	1,5		
26	Vane thickness ratio thk/D2	0,03		
27	Tip diameter specification	Automatic		
28	Hub/Mean LE blade angles	Cotangent, relativ...		
29	Exit rake angle	0	degree	
30	Volute geometry			
31	Casing rotation angle	14	degree	
32	Volute style	Elliptic & circular X...		
33	Specify diffuser exit hydraulic diameter			
34	Specify diffuser length			
35	Overall performance			
36	Specific speed (non-dimensional)	0,82019		
37	Specific speed (US)	2241,6		
38	Specific speed (EU)	43,404		
39	Suction specific speed (non dimensional)	3,1515		

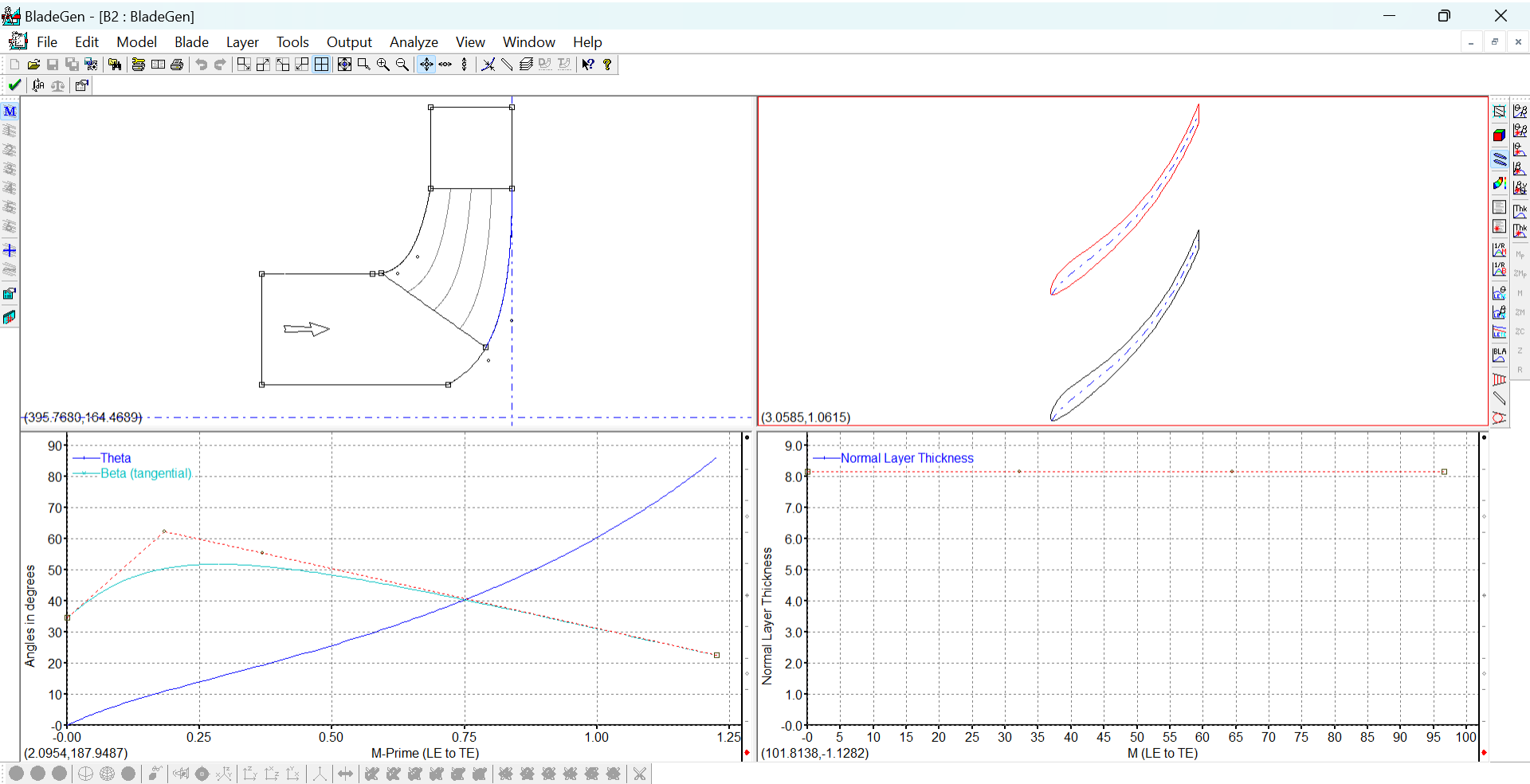
View All / Customize...

Double-click component to edit.

Job Monitor... Show Progress Hide 0 Messages

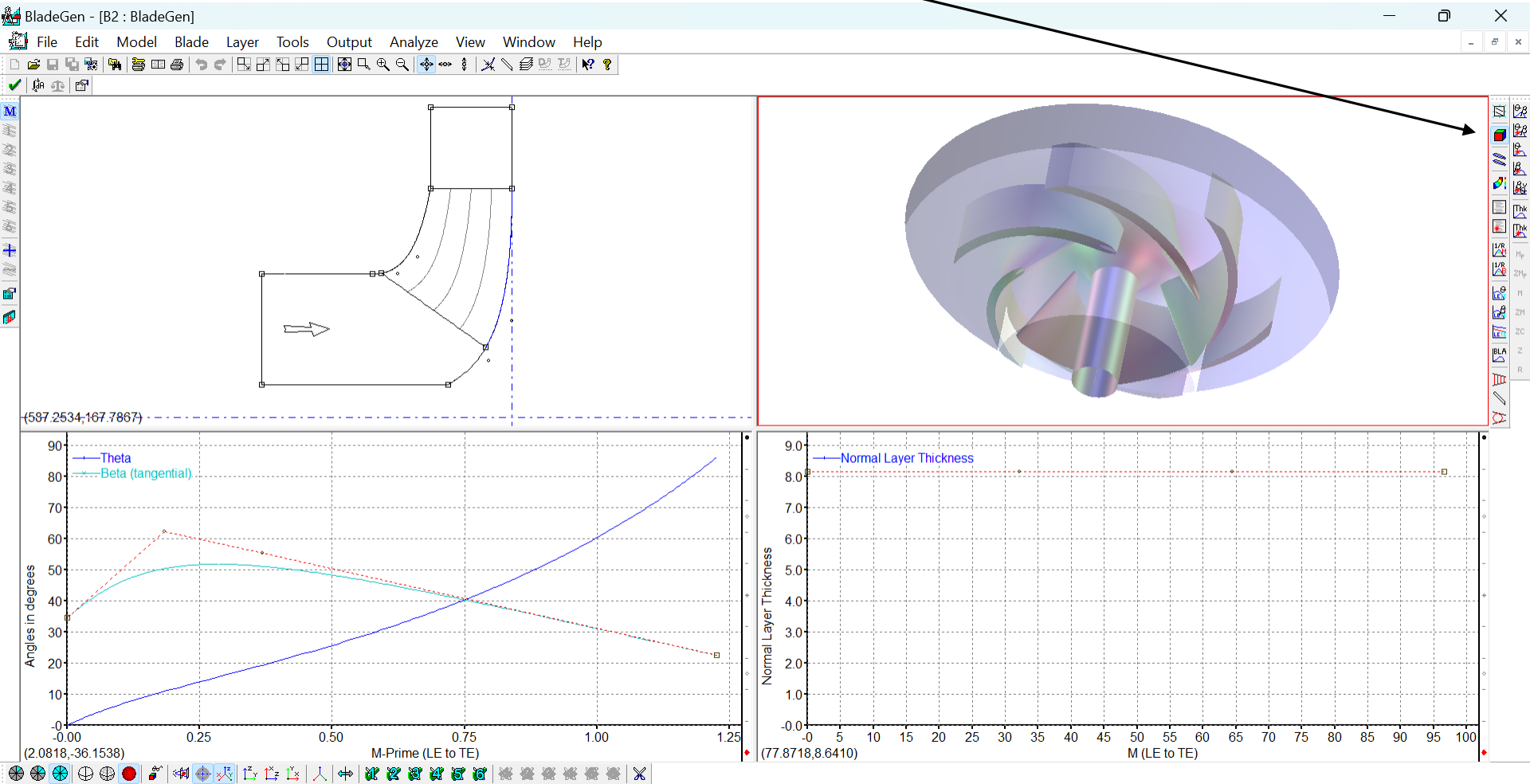
Program BladeGen

- Odpre se nov program za oblikovanje in spreminjanje hidravličnih oblik centrifugalnih črpalk



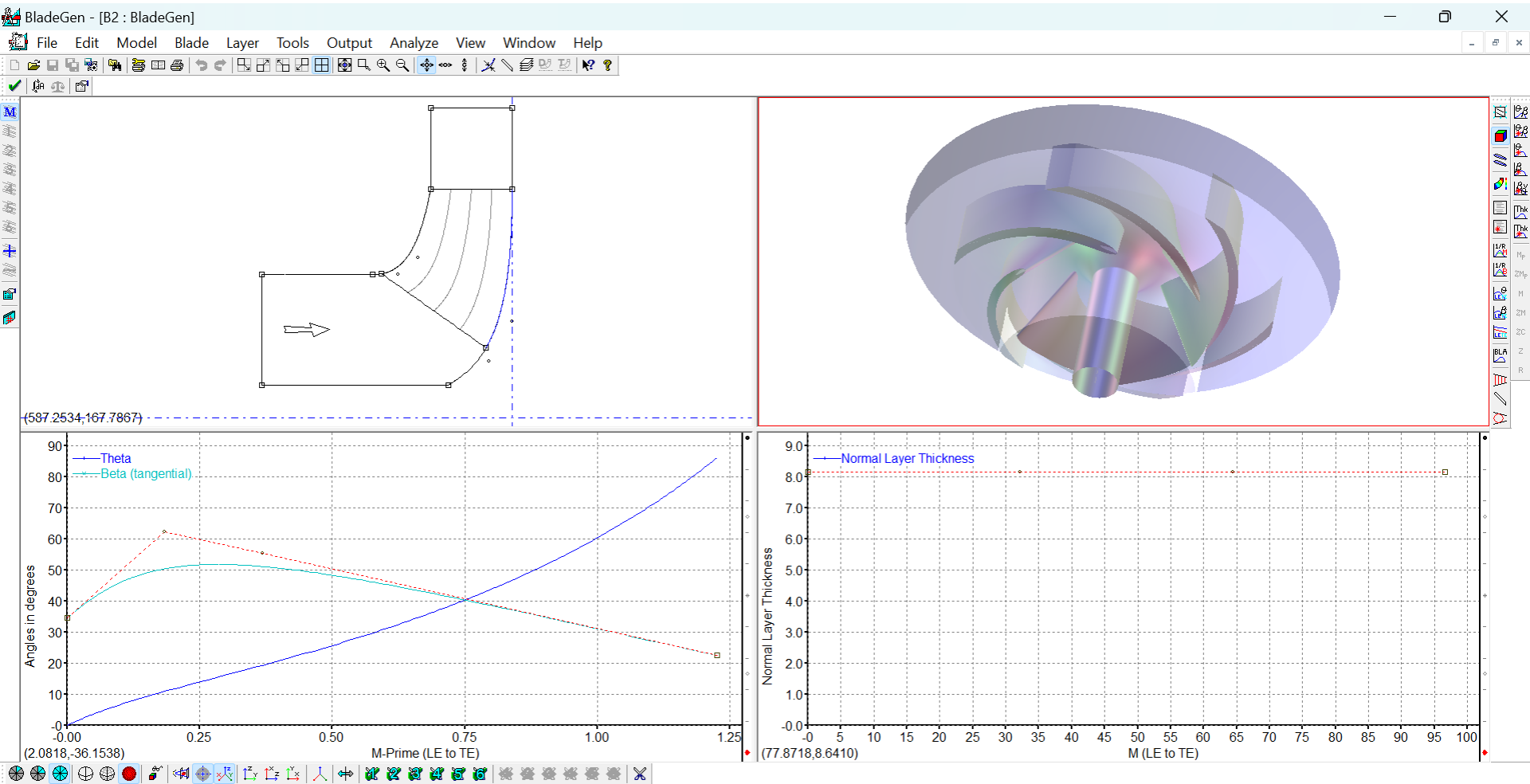
Program BladeGen

- S klikom na 3D view dobite 3D CAD model črpalke s predpisanimi obratovalnimi pogoji



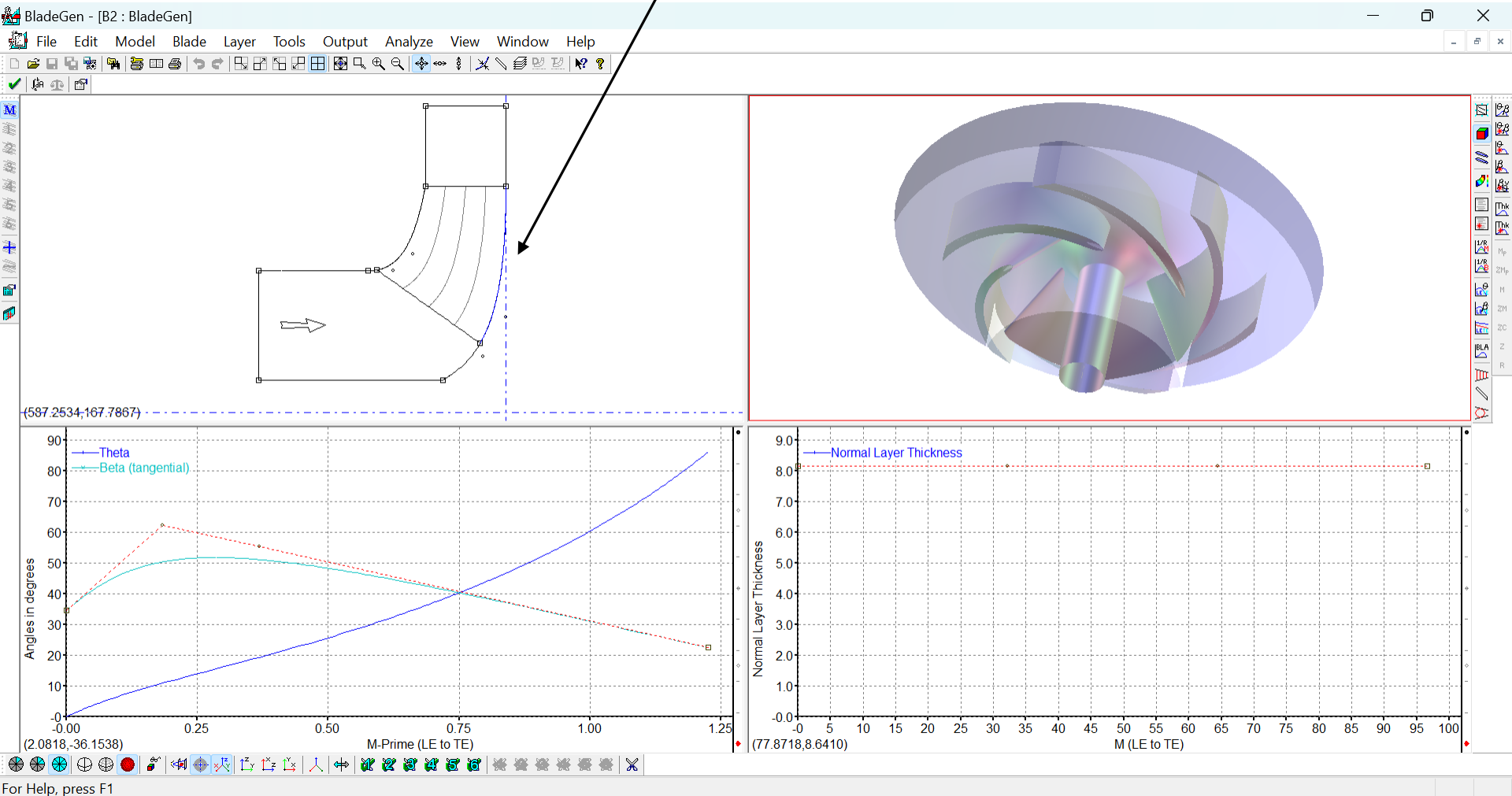
Program BladeGen

- Program "BladeGen" je odlično orodje za spreminjanje oblike črpalke
- Spreminjate lahko število lopatic, debelino lopatic, vstopne in izstopne kote ter obliko meridianskega preseka
- Vsaka sprememba se takoj pokaže na 3D modelu



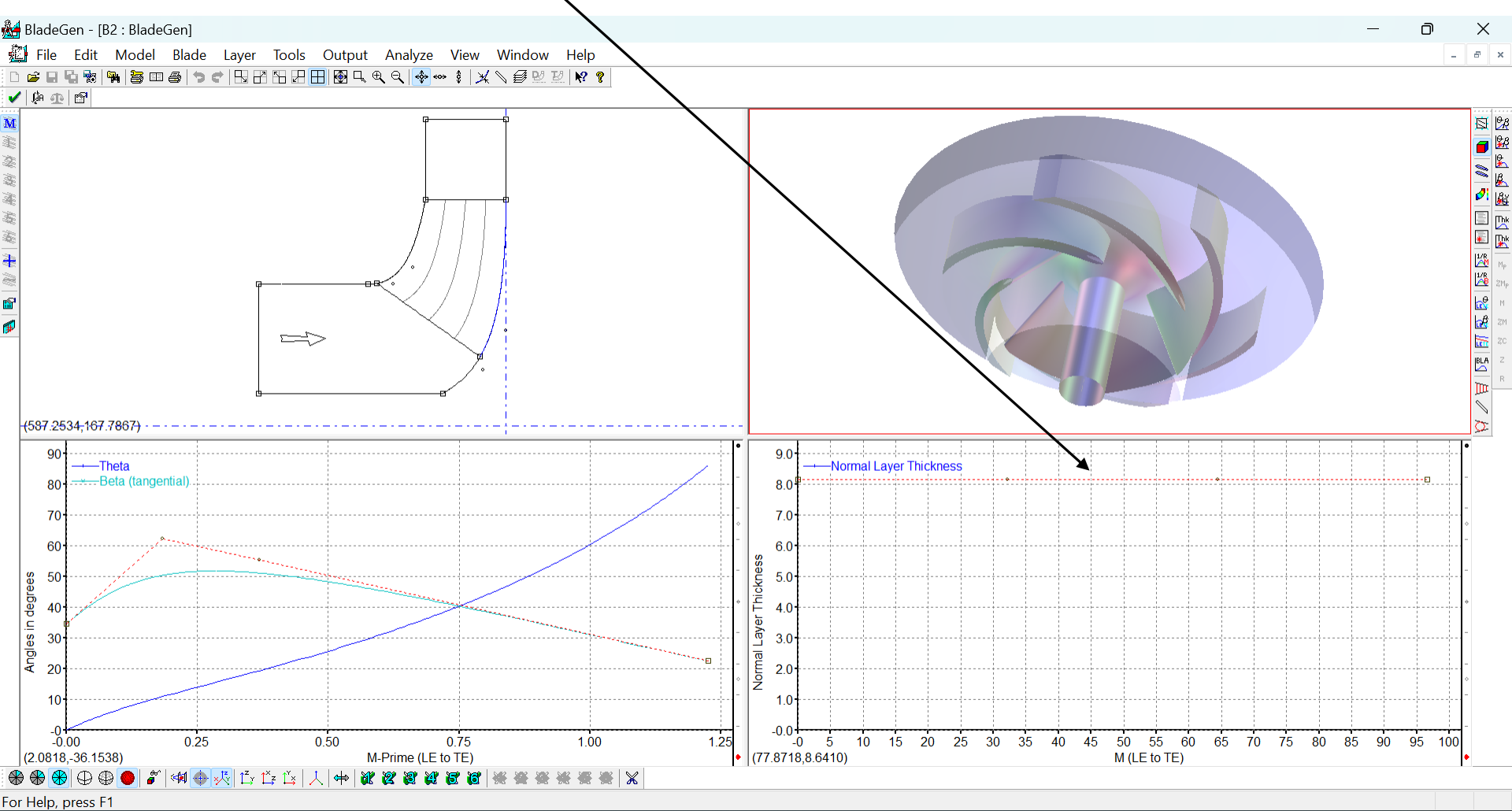
Program BladeGen

- Spreminjanje oblike pretočnega trakta se opravi v zgornjem levem oknu



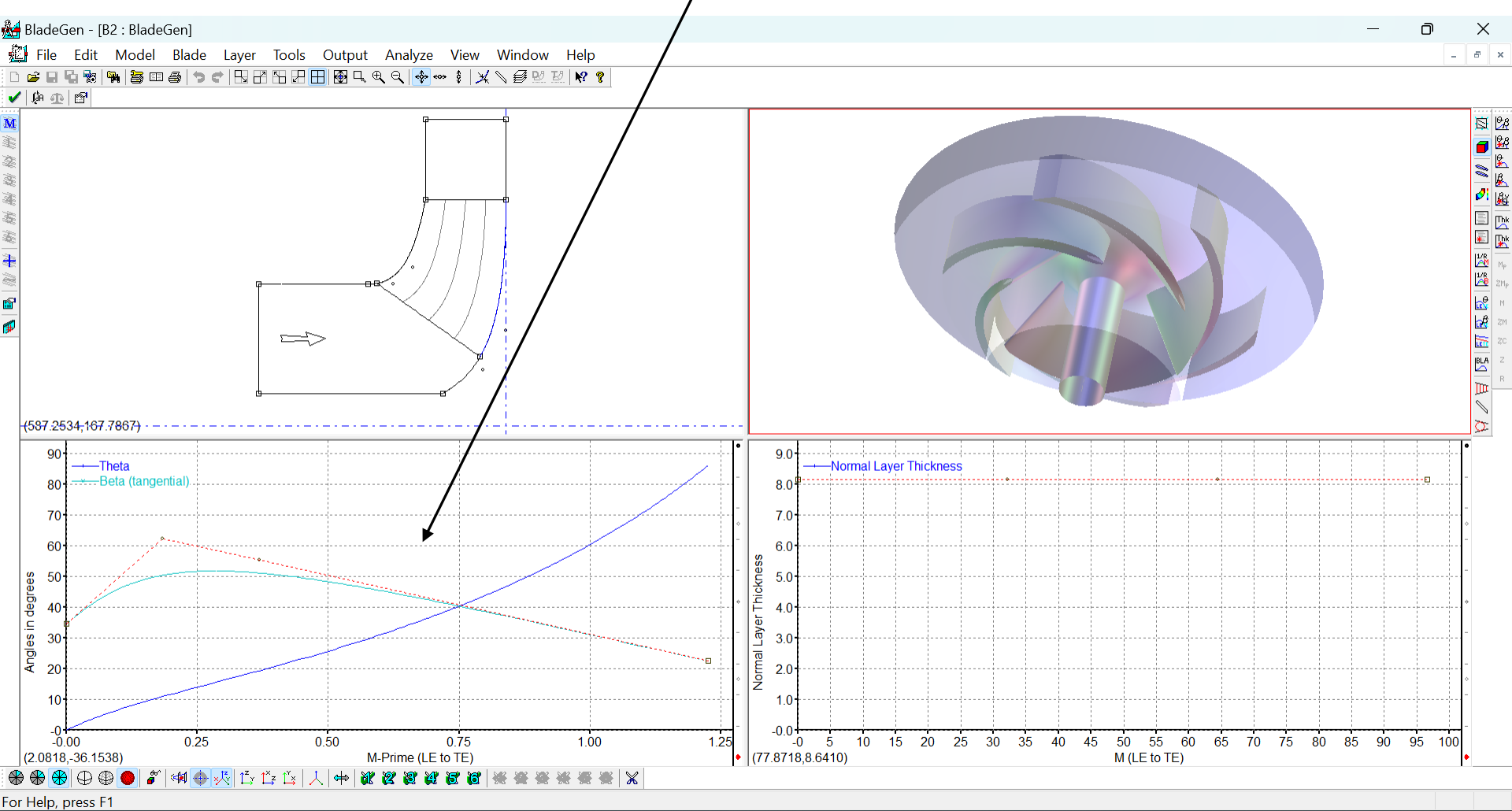
Program BladeGen

- Spreminjanje debeline lopatic se opravi v spodnjem desnem oknu



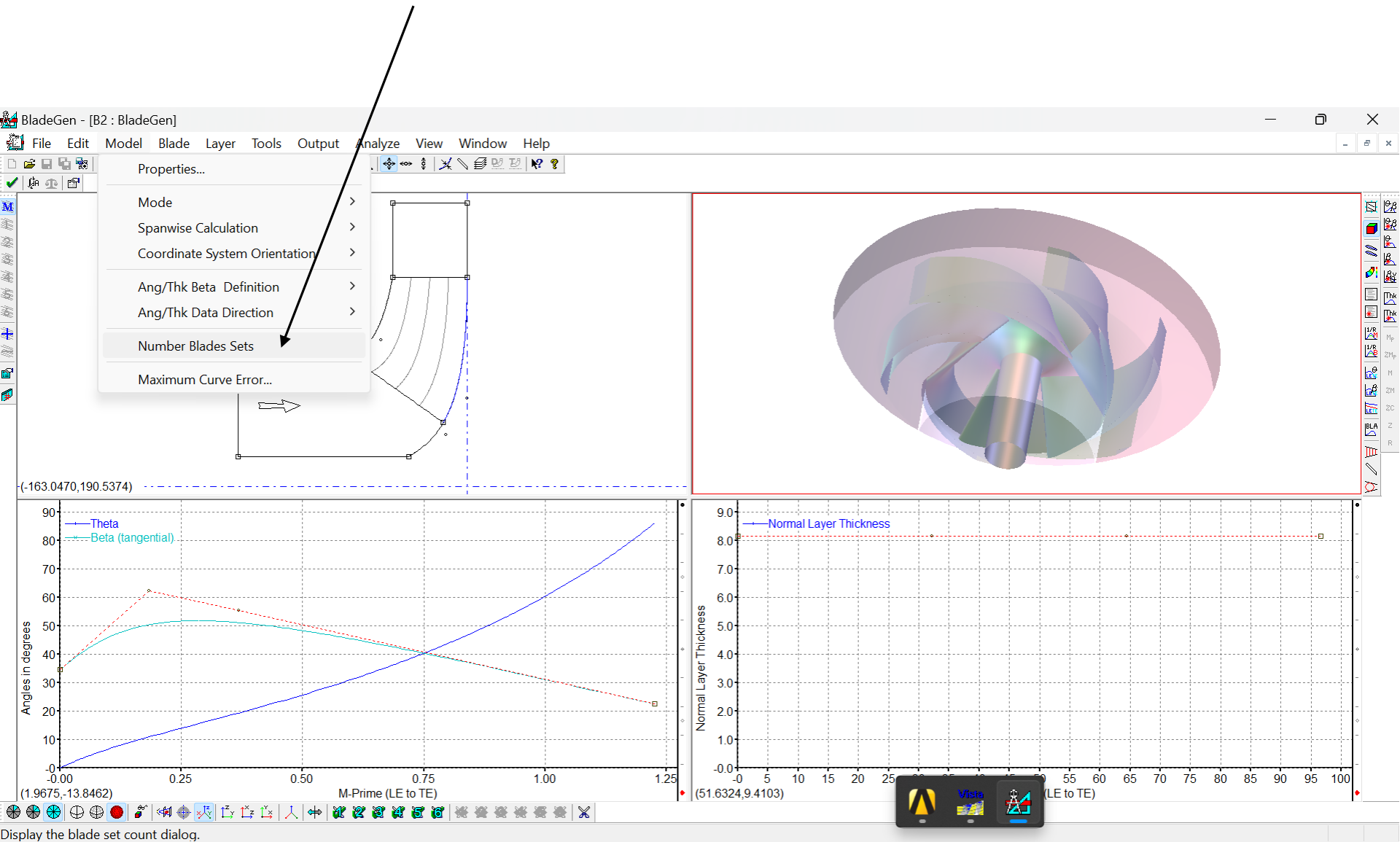
Program BladeGen

- Spreminjanje vstopnih in izstopnih kotov lopatic se opravi v spodnjem levem oknu



Program BladeGen

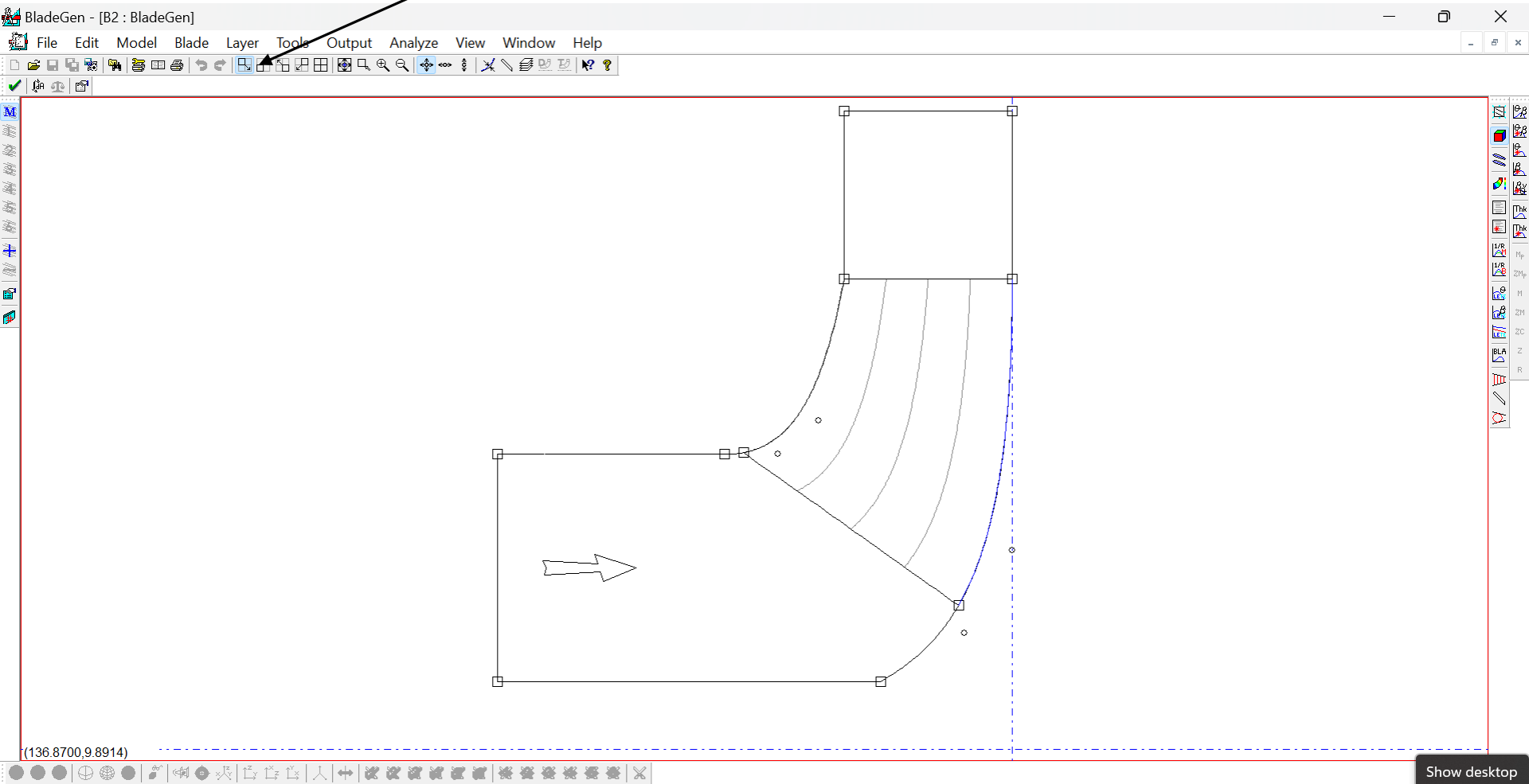
- Spreminjanje števila lopatic gonilnika lahko opravite v orodni vrstici.



Display the blade set count dialog.

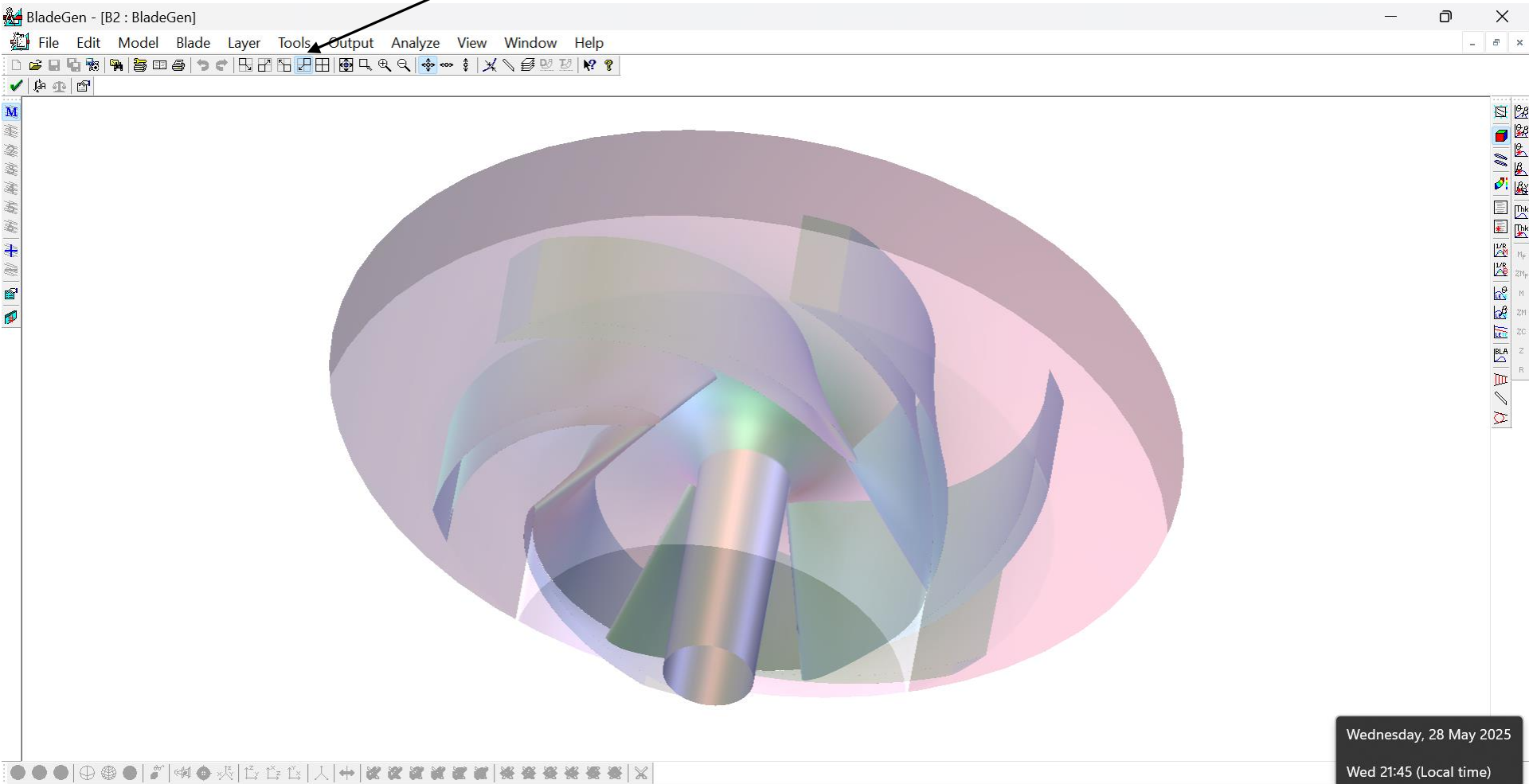
Program BladeGen

- Za lažje delo lahko posamezno okno povečate.



Program BladeGen

- Za lažje delo lahko posamezno okno povečate.

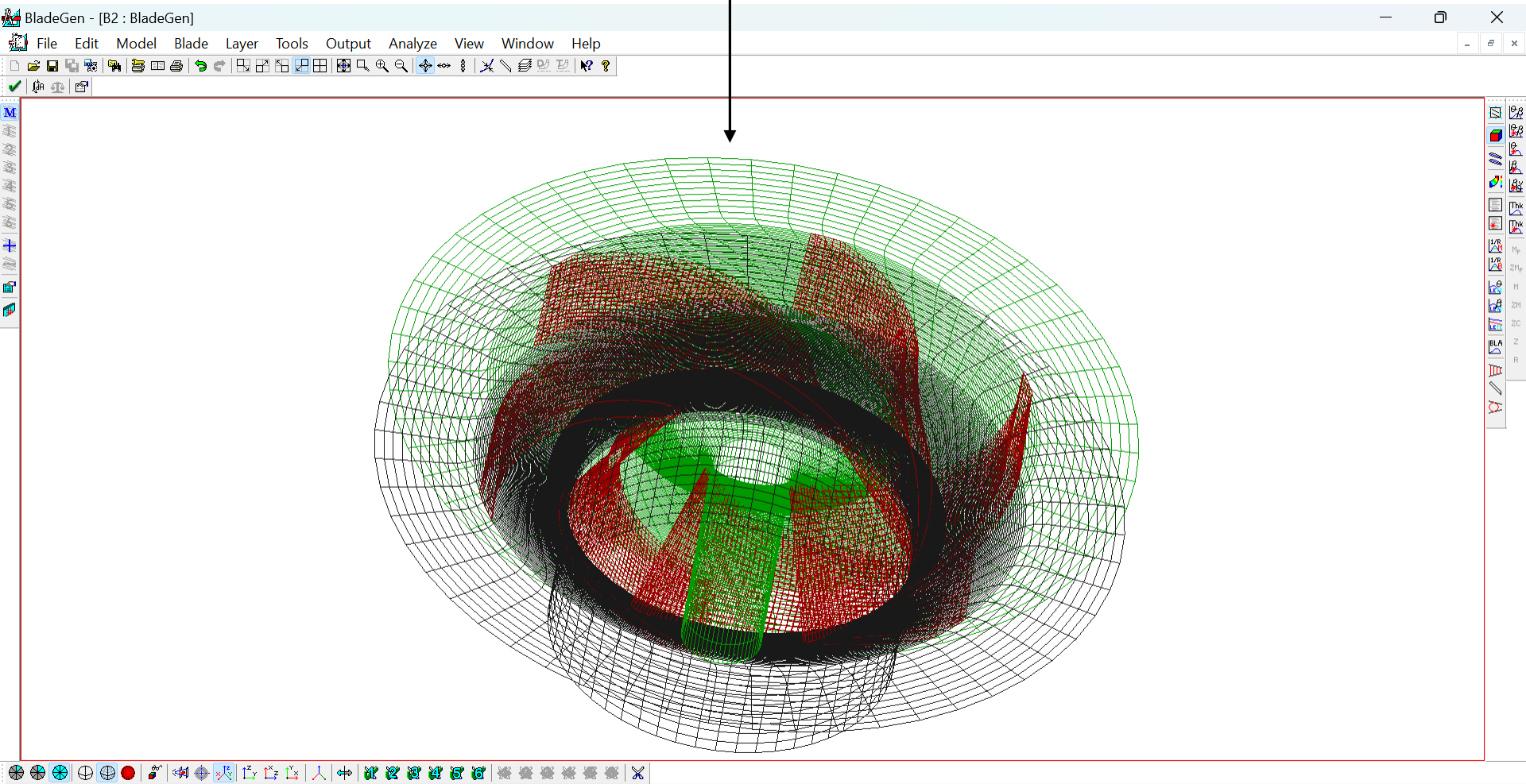


Wednesday, 28 May 2025

Wed 21:45 (Local time)

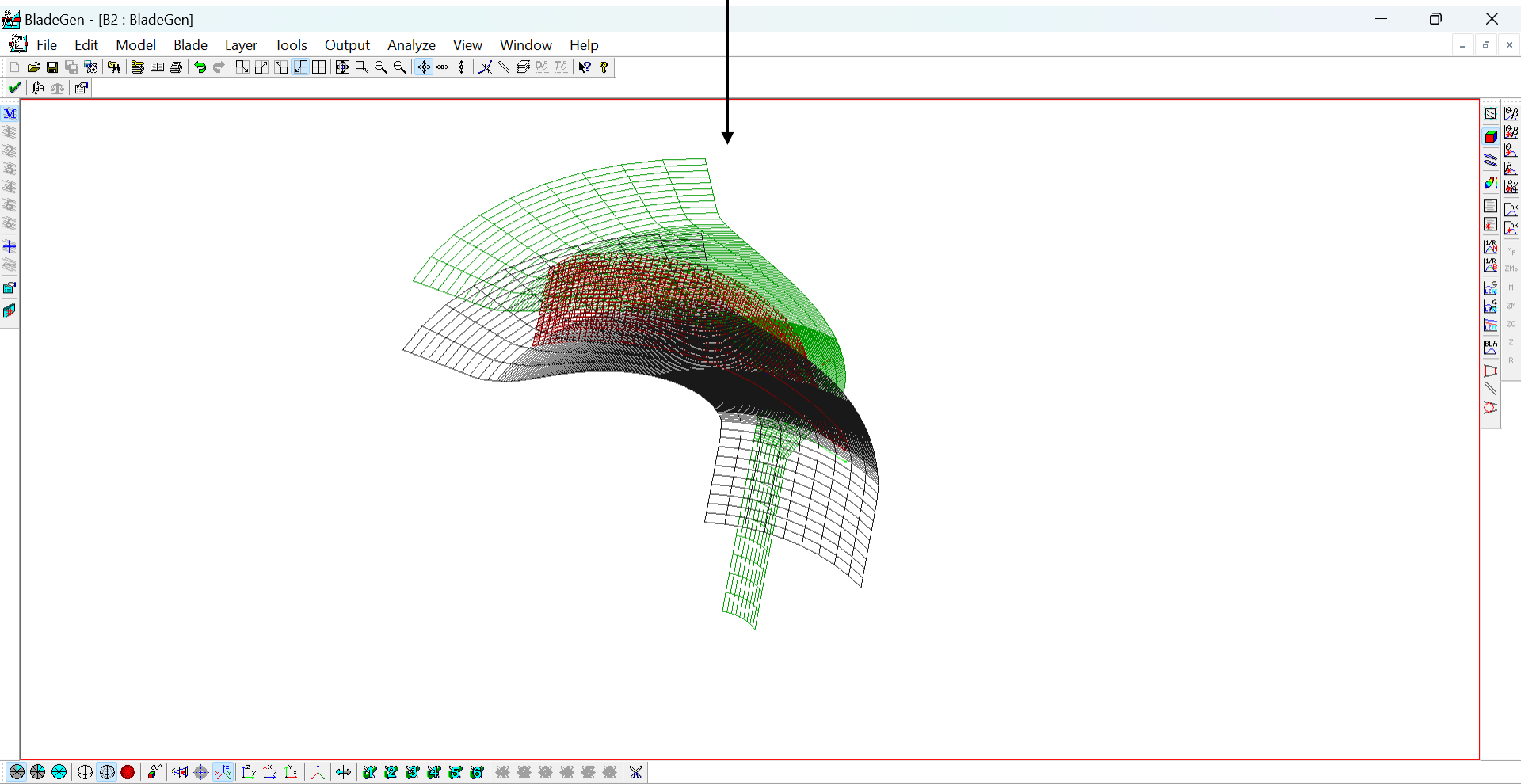
Program BladeGen

- Rotor lahko predstavite v obliki mreže.



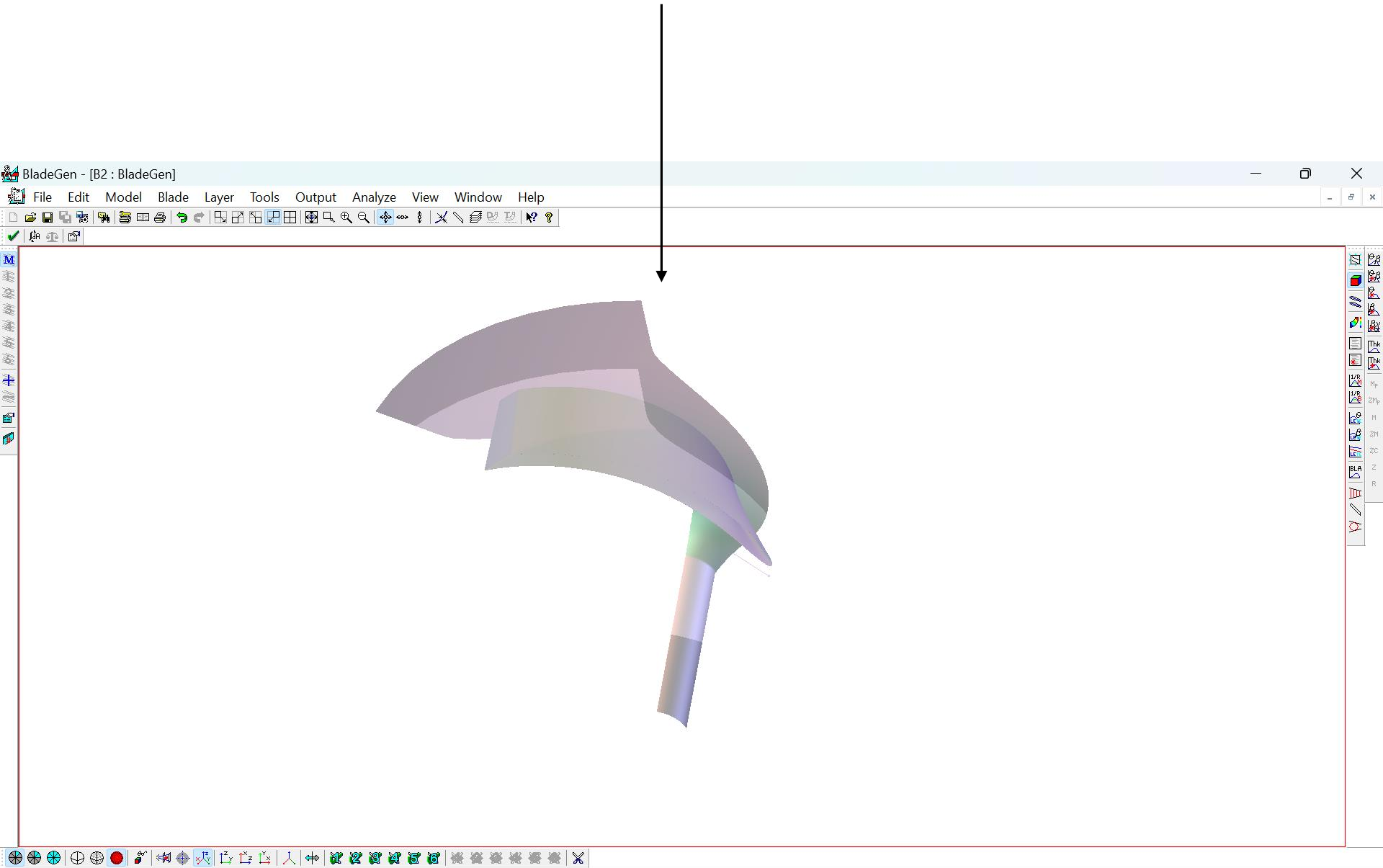
Program BladeGen

- Lahko je predstavljena samo ena lopatica gonilnika in območje ob lopatici .



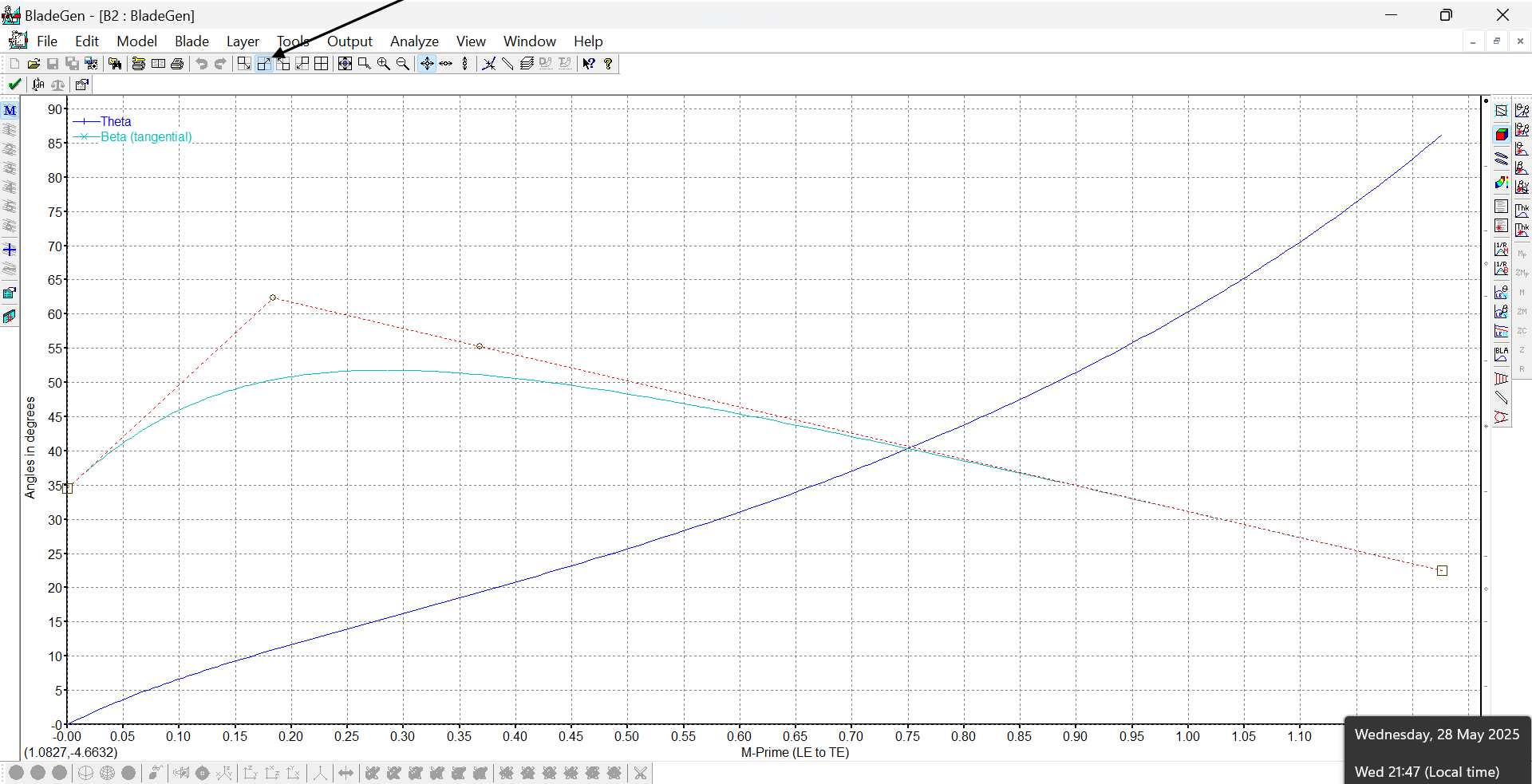
Program BladeGen

- Lahko je predstavljena samo ena lopatica gonilnika in območje ob lopatici .



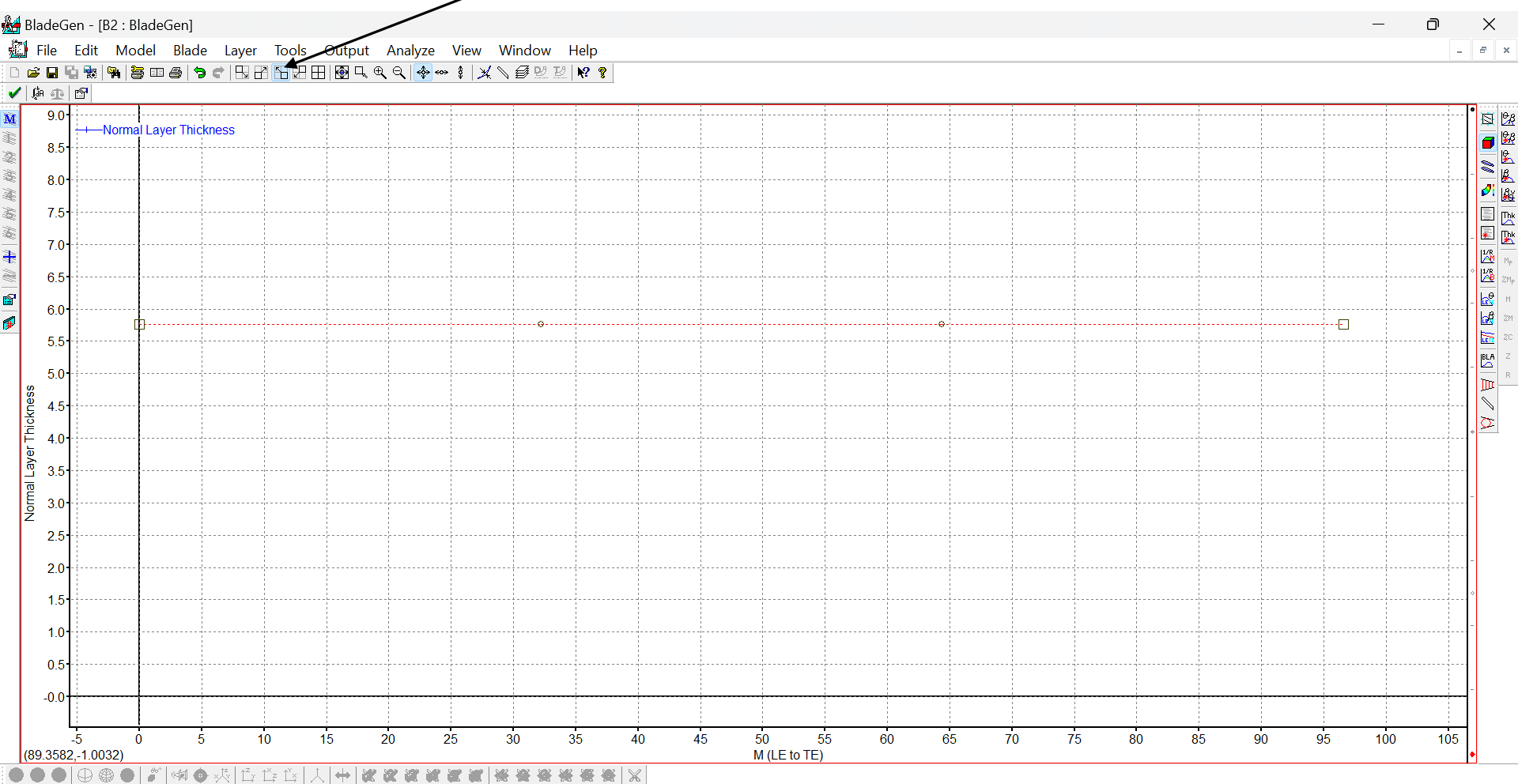
Program BladeGen

- Za lažje delo lahko posamezno okno povečate.



Program BladeGen

- Za lažje delo lahko posamezno okno povečate.



Zagon programa DesignModeler

- Z desno tipko na miški odprete novo okno, greste na "Create new" → "Geometry"
- Spreminjate lahko število lopatic, debelino lopatic, vstopne in izstopne kote ter obliko meridianskega preseka
- Vsaka sprememba se takoi pokaže na 3D modelu

The screenshot displays the ANSYS Workbench environment. On the left, the 'Toolbox' panel lists various analysis systems, with 'BladeGen' and 'Blade Design' highlighted. The central 'Project Schematic' shows a hierarchical structure with 'A' (Vista CPD) and 'B' (BladeGen) components. A right-click context menu is open over the 'BladeGen' component, showing options like 'Edit...', 'Duplicate', and 'Create New'. The 'Create New' option is selected, leading to a sub-menu where 'Geometry' is chosen. On the right, the 'Properties of Schematic A2: Blade Design' panel is visible, displaying a table of design parameters.

	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	Blade Design		
4	Directory Name	CPD		
5	BladeModeler units	mm		
6	Impeller export type	Isolated impeller		
7	Notes			
8	Notes			
9	Used Licenses			
10	Last Update Used Licenses	Not Applicable		
11	General duty			
12	Rotational speed	1450	rev min ⁻¹	
13	Density	1000	kg m ⁻³	
14	Volume Flow Rate	280	m ³ hr ⁻¹	
15	Impeller duty			
16	Head	20	m	
17	Inlet flow angle	90	degree	
18	Meridional velocity ratio	1,1		
19	Impeller efficiency	Automatic		
20	Impeller geometry			
21	Number of vanes	6		
22	Shroud LE blade angle	Specified incidence		
23	Incidence at shroud	0	degree	
24	Exit blade angle	22,5	degree	
25	Hub inlet draft angle	30	degree	
26	Shaft minimum diameter factor	1,1		
27	Shaft diameter ratio Dhub/Dshaft	1,5		
28	Vane thickness ratio thk/D2	0,03		
29	Tip diameter specification	Automatic		
30	Hub/Mean LE blade angles	Cotangent, relativ...		
31	Exit rake angle	0	degree	
32	Volute geometry			
33	Casing rotation angle	14	degree	
34	Volute style	Elliptic & circular X-...		
35	Specify diffuser exit hydraulic diameter			
36	Specify diffuser length			
37	Overall performance			
38	Specific speed (non-dimensional)	0,82019		
39	Specific speed (US)	2241,6		
40	Specific speed (EU)	43,404		
41	Suction specific speed (non dimensional)	3,1515		

Double-click component to edit.

Zagon programa DesignModeler

- Odpre se okno “Geometry”

Unsaved Project - Workbench

File View Tools Units Extensions Jobs Help

Import... Reconnect Refresh Project Update Project ACT Start Page

Toolbox

- Analysis Systems
- Component Systems
- ACP (Post)
- ACP (Pre)
- Autodyn
- BladeGen
- CFX
- Engineering Data
- External Data
- External Model
- Fluent
- Fluent (with Fluent Meshing)
- Forté
- Geometrv
- ICEM CFD
- Material Designer
- Mechanical APDL
- Mechanical Model
- Mesh
- Microsoft Office Excel
- Performance Map
- Polvflow
- Polvflow - Blow Moldina
- Polvflow - Extrusion
- Results
- System Couplina
- Turbo Setuo
- TurboGrid
- Vista AFD
- Vista CCD
- Vista CPD
- Vista RTD
- Custom Systems
- Design Exploration
- ACT

Project Schematic

A

- Vista CPD
- Blade Design ✓

Vista CPD

B

- BladeGen
- Blade Design ✓

BladeGen

C

- Geometry
- Geometry ✓

Geometry

Properties of Schematic A2: Blade Design

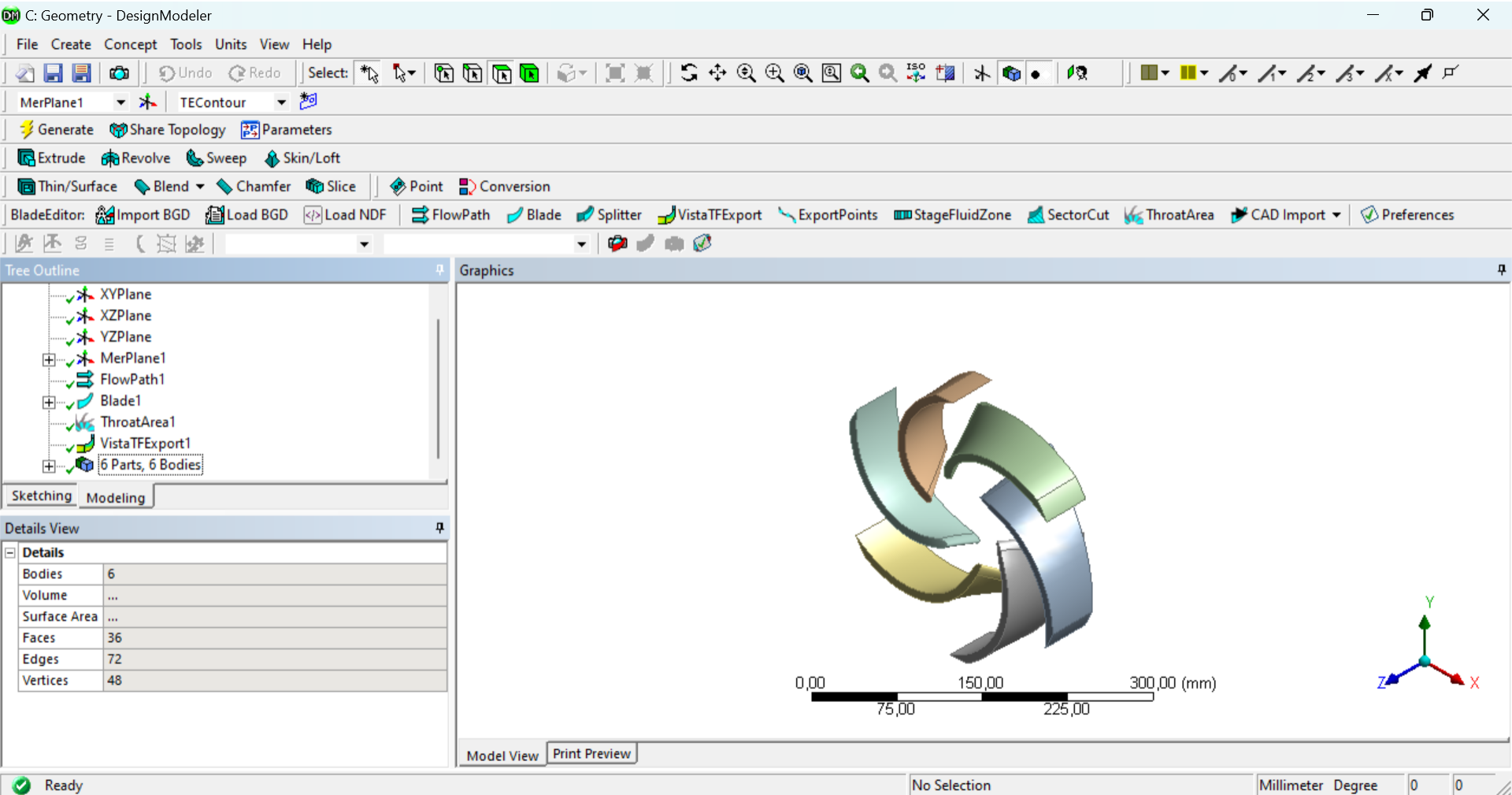
	A	B	C	D
1	Property	Value	Unit	P
2	General			
3	Component ID	Blade Design		
4	Directory Name	CPD		
5	BladeModeler units	mm		
6	Impeller export type	Isolated impeller		
7	Notes			
8	Used Licenses			
9	Last Update Used Licenses	Not Applicable		
10	General duty			
11	Rotational speed	1450	rev min ⁻¹	
12	Density	1000	kg m ⁻³	
13	Volume Flow Rate	280	m ³ hr ⁻¹	
14	Impeller duty			
15	Head	20	m	
16	Inlet flow angle	90	degree	
17	Meridional velocity ratio	1,1		
18	Impeller efficiency	Automatic		
19	Impeller geometry			
20	Number of vanes	6		
21	Shroud LE blade angle	Specified incidence		
22	Incidence at shroud	0	degree	
23	Exit blade angle	22,5	degree	
24	Hub inlet draft angle	30	degree	
25	Shaft minimum diameter factor	1,1		
26	Shaft diameter ratio Dhub/Dshaft	1,5		
27	Vane thickness ratio thk/D2	0,03		
28	Tip diameter specification	Automatic		
29	Hub/Mean LE blade angles	Cotangent, relativ...		
30	Exit rake angle	0	degree	
31	Volute geometry			
32	Casing rotation angle	14	degree	
33	Volute style	Elliptic & circular X-...		
34	Specify diffuser exit hydraulic diameter			
35	Specify diffuser length			
36	Overall performance			
37	Specific speed (non-dimensional)	0,820 19		
38	Specific speed (US)	2241,6		
39	Specific speed (EU)	43,404		
40	Suction specific speed (non dimensional)	3,1515		

Double-click component to edit.

Job Monitor... Show Progress Hide 0 Messages

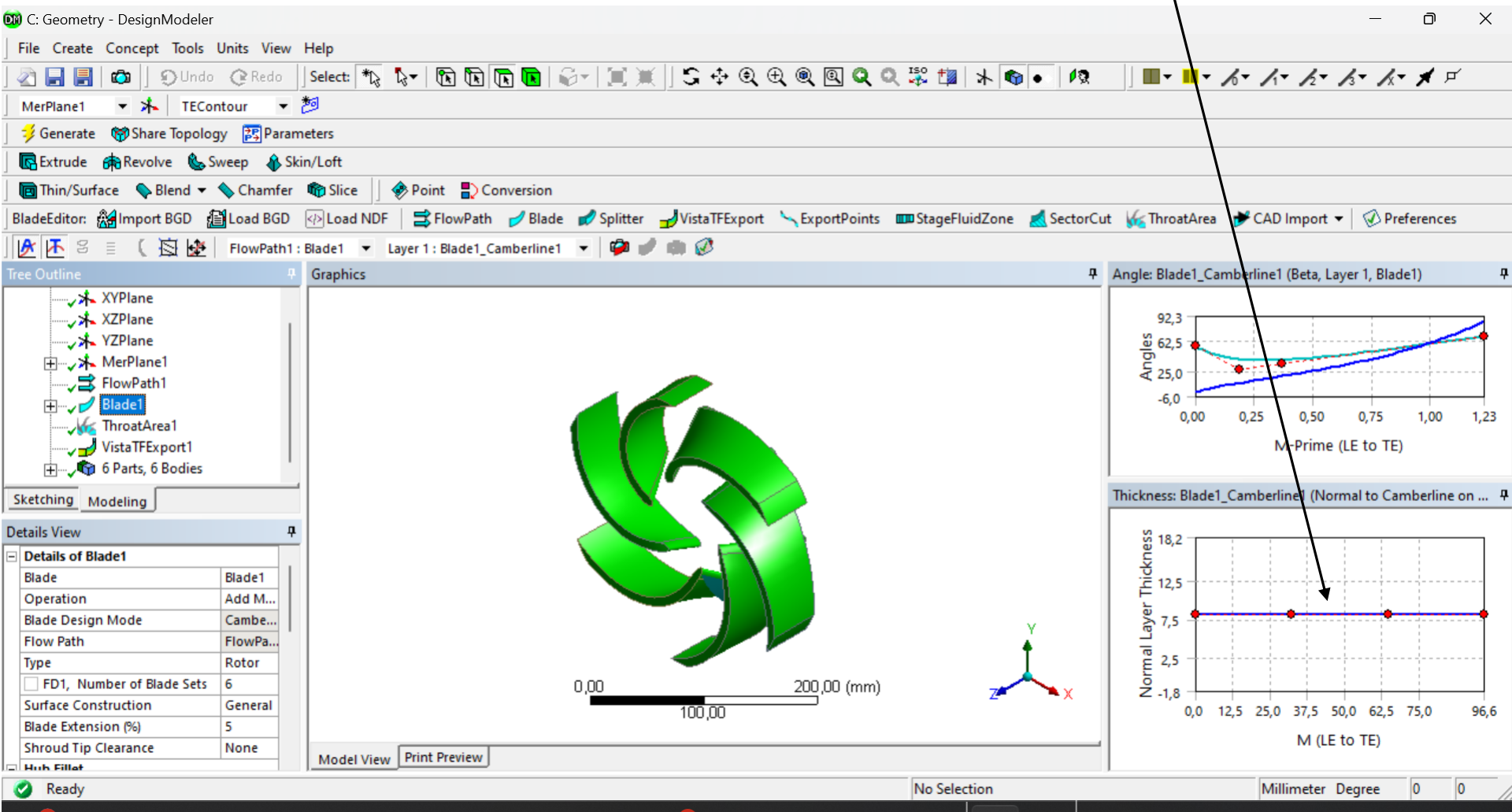
Program DesignModeler

- Odprete program "Geometry" in dobite novo okno
- Osrednji del predstavlja 3-D model lopatic gonilnika radialne črpalke



Program DesignModeler

- Tudi v programu Design Modeler lahko poljubno definirate debeline lopatic



Program DesignModeler

- Definirate lahko tudi vstopne in izstopne kote lopatic.

C: Geometry - DesignModeler

File Create Concept Tools Units View Help

MerPlane1 TEContour

Generate Share Topology Parameters

Extrude Revolve Sweep Skin/Loft

Thin/Surface Blend Chamfer Slice Point Conversion

BladeEditor: Import BGD Load BGD Load NDF FlowPath Blade Splitter VistaTFExport ExportPoints StageFluidZone SectorCut ThroatArea CAD Import Preferences

FlowPath1: Blade1 Layer 1: Blade1_Camberline1

Tree Outline

- ✓ XYPlane
- ✓ XZPlane
- ✓ YZPlane
- ✓ MerPlane1
- ✓ FlowPath1
- ✓ Blade1
- ✓ ThroatArea1
- ✓ VistaTFExport1
- ✓ 6 Parts, 6 Bodies

Sketching Modeling

Details View

Details of Blade1

Blade	Blade1
Operation	Add M...
Blade Design Mode	Cambe...
Flow Path	FlowPa...
Type	Rotor
☐ FD1, Number of Blade Sets	6
Surface Construction	General
Blade Extension (%)	5
Shroud Tip Clearance	None

Ready

Graphics

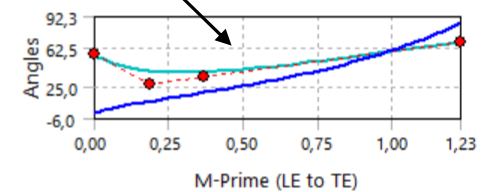


0,00 200,00 (mm)
100,00

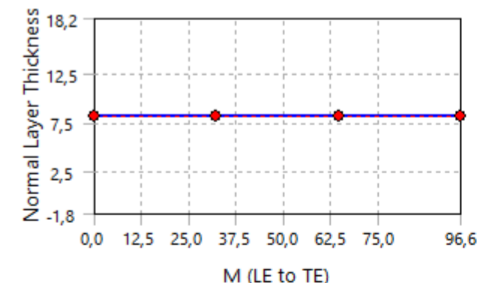


Model View Print Preview

Angle: Blade1_Camberline1 (Beta, Layer 1, Blade1)



Thickness: Blade1_Camberline1 (Normal to Camberline on ...)

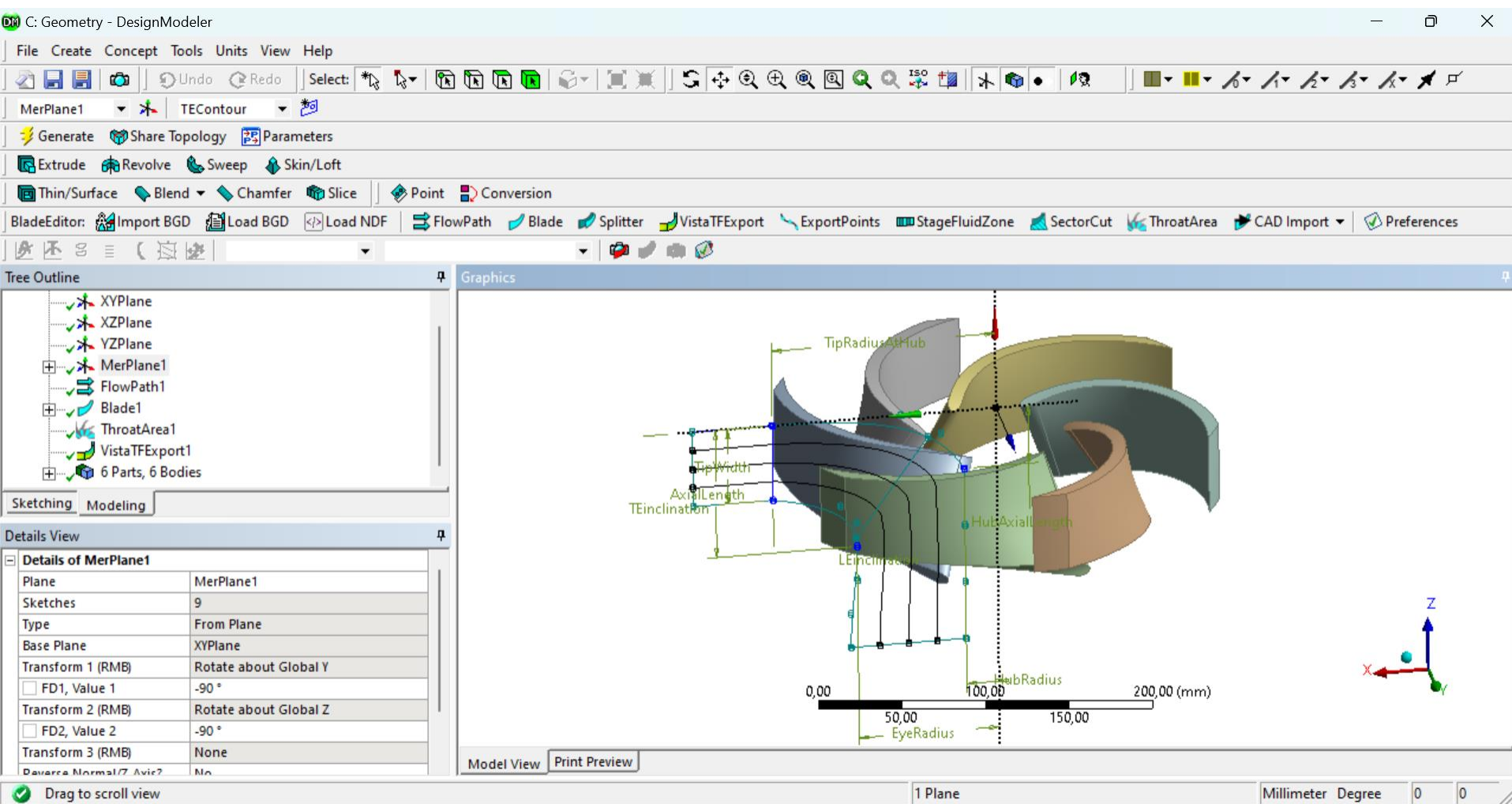


No Selection

Millimeter Degree 0 0

Program DesignModeler

- Program Design Modeler vam omogoča CAD modeliranje celotnega rotorja črpalke



Priprava na numerične analize

- Programi VISTA, BladeGen in Design Modeler vam omogočajo hitro pripravo hidravličnih oblik za numerično analizo tokovnih razmer v turbinskih strojih ali za numerične simulacije napetosti in deformacij posameznih delov energetskih strojev .