ECOLE D'INGENIEURS DE GENEVE

(EIHES-GE)

PompEnTu

V.1.0.2

User's Manual

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CONTENTS

1. INTRODUCTION

This program predicts the turbine performance of a pump operating as turbine. It is based in the modeling of hydraulic losses in pump operating with the help of pump geometry. The model has been experimentally verified with the pump characteristics given by the manufacturer. Then, the model of losses has been applied to calculate losses in turbine mode. A turbine characteristic can be drawn and the head at the best operating point can be predicted.

Because incidence losses off-design point in turbine operating can't be predicted by this method, so the flow rate at best operating point, the program uses the Chapallaz's curves to asses the optimum flow rate in turbine mode.

The program has been tested on four double volute pumps with different specific speed and dimensions. The results have been compared to experimental tests performed by manufacturers in test rig. The comparison of prediction and experiments shows a spread of results up to +\- 5 %.

This program is mainly addressed to pump manufacturers who would like to propose to their customers the turbine prediction of their pumps for energy production applications and also for users who would want to verify the performances promised by the manufacturer.

The code source is open and can be modified in order to adapt to a particular machine.

2. STRUCTURE OF THE PROGRAM

The EXCEL program is divided in two parts:

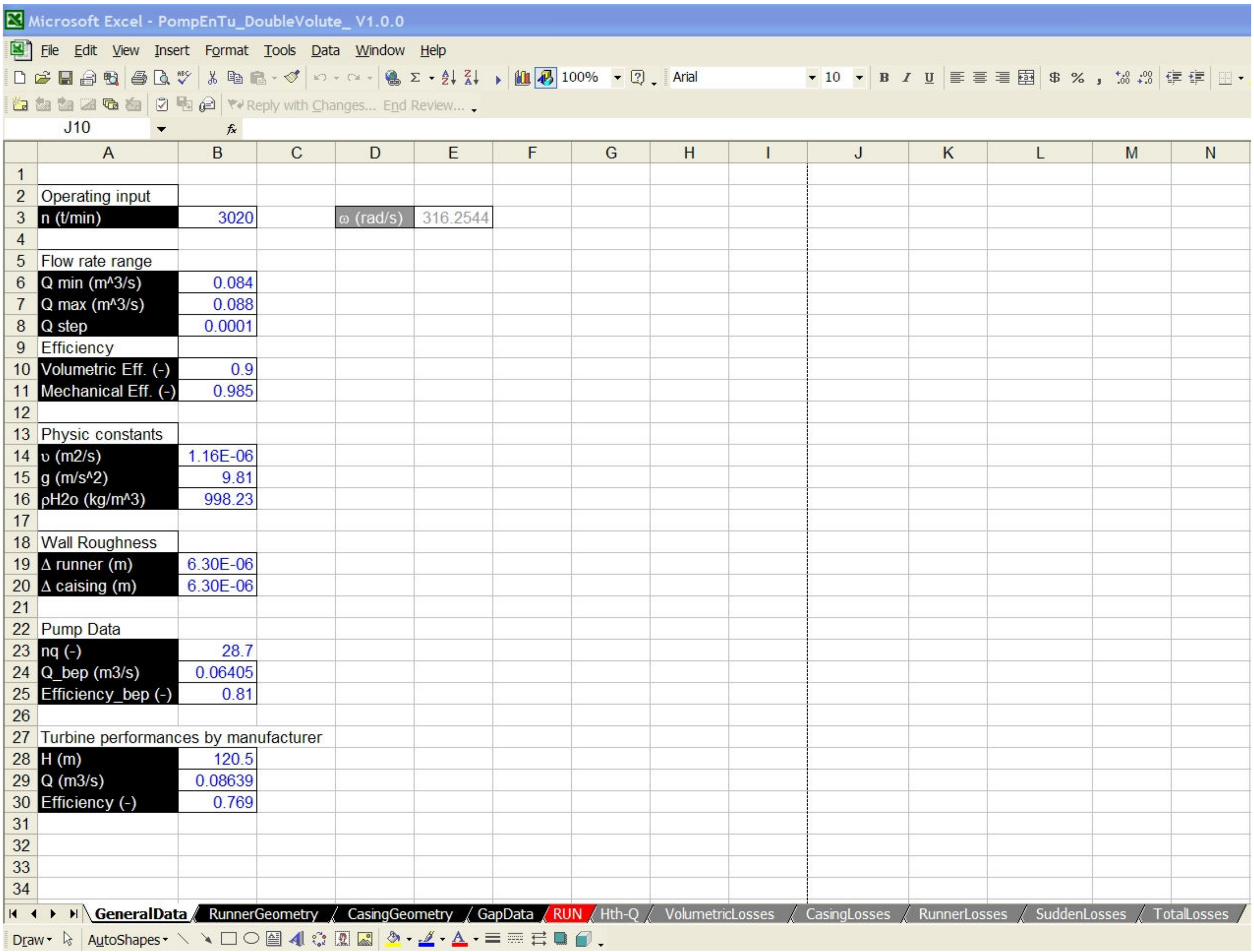
- Sheets for input data (physics constants and pump geometry)
- Sheets for the output results

Sheets for input data have black tabs and the sheets of the output data have grey tabs. All formulas in the Worksheets have been locked to prevent modifications inadvertently.

2.1 Sheets of inputs data

2.1.2 Sheet: GeneralData

Write the main data in turbine operation.
- The turbine speed in RPM
- A range of flow rate around the BEP expected
- A first value of the leakage efficiency (to correct afterwards)
- An approximation of the mechanical efficiency
- The physics constants of water
- Roughness of the impeller and of the casing
- The pump data at the BEP: specific speed, flow rate and efficiency
- For the users: write the turbine performances promised by the manufacturer



Microsoft Excel - PompEnTu_DoubleVolute_ V1.0.0

	A	B	C	D	E
1					
2	Operating input				
3	n (t/min)	3020		ω (rad/s)	316.2544
4					
5	Flow rate range				
6	Q min (m^3/s)	0.084			
7	Q max (m^3/s)	0.088			
8	Q step	0.0001			
9	Efficiency				
10	Volumetric Eff. (-)	0.9			
11	Mechanical Eff. (-)	0.985			
12					
13	Physic constants				
14	υ (m2/s)	1.16E-06			
15	g (m/s^2)	9.81			
16	ρH2o (kg/m^3)	998.23			
17					
18	Wall Roughness				
19	Δ runner (m)	6.30E-06			
20	Δ caising (m)	6.30E-06			
21					
22	Pump Data				
23	nq (-)	28.7			
24	Q_bep (m3/s)	0.06405			
25	Efficiency_bep (-)	0.81			
26					
27	Turbine performances by manufacturer				
28	H (m)	120.5			
29	Q (m3/s)	0.08639			
30	Efficiency (-)	0.769			

GeneralData / RunnerGeometry / CasingGeometry / GapData / RUN / Hth-Q / VolumetricLosses / CasingLosses / RunnerLosses / SuddenLosses / TotalLosses

Figure 1: GeneralData sheet

2.1.3 Sheet: RunnerGeometry

Write the impeller geometry and some data of the interface between the casing and the runner (section 3).

- Number of vanes, dimensions of the low pressure side of the turbine (section 1), dimensions of the high pressure side (section 2) and dimensions of the section 3 related to the casing.

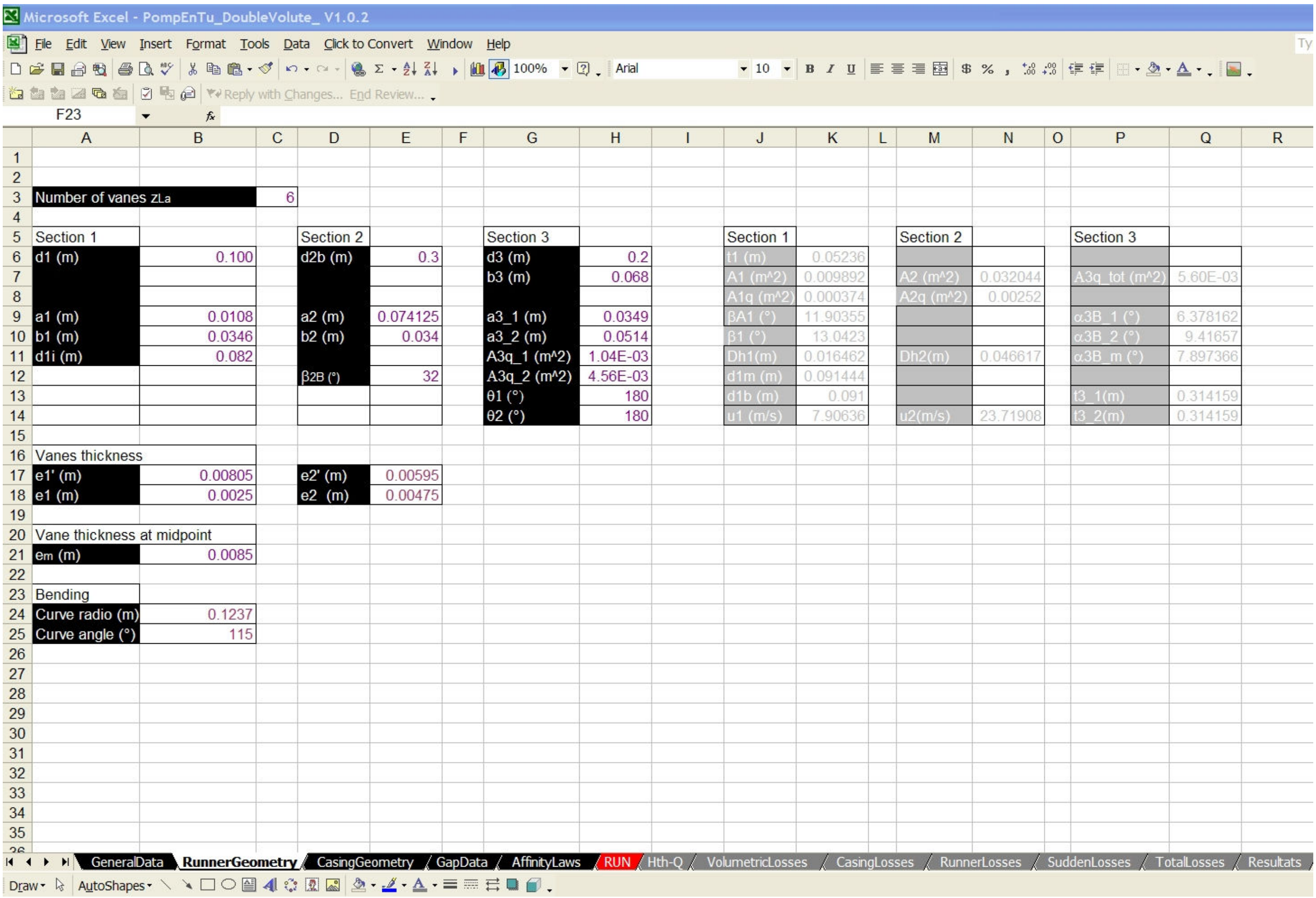


Figure 2: Impeller geometry and casing geometry

2.1.4 Sheet: CasingGeometry

Writing the data of the volute is the more tedious work and need careful treatment. Figure 3 shows the case of a double volute.

The volute is divided in several elements from the inlet (discharge section) to the exit (spiral part of the volute).

For each element, dimensions must be introduced in the Sheet, as for instance:

- The angle of the each bent element
- Top and bottom radius at the inlet and outlet section of each element.
- Surfaces and wet perimeters of the inlet and outlet sections of each element

The nomenclature of the elements of the volute shown in the Figure 3 must not be changed because those terms are used in the program. More elements can be added if needed but respecting the nomenclature proposed.

For a double volute:

Outer volute:

> **OuterDisch** : discharge section (it is the inlet in turbine mode)
> **OSK** : volute channel
> **OuterSpiral** : spiral part of the volute

Inner Volute:

> **InnerDisch** : discharge section (it is the inlet in turbine mode)
> **InnSpiral** : spiral part of the volute

For a single volute:

> **Disch** : sections discharge section (inlet in turbine mode)
> **Spiral** : spiral part of the volute

Element		angle [°]	Rtop in (m)	Rbot in (m)	Rtop out (m)	Rbot out (m)	A in (m2)	p* in (m)	A out (m2)	p* out (m2)	Ro average (m)	ΔL Average (m)	ΔU Average (m)	Dh in (m)	Dh out (m)
1	OuterDisch	15	0.330082	0.223459	0.330082	0.223459	0.017368	0.527118	0.014426	0.476388	0.276771	0.072458	0.501753	0.131798	0.121125
2	OuterDisch	24	0.210533	0.118961	0.210533	0.118961	0.014426	0.476388	0.010586	0.402261	0.164747	0.069009	0.439324	0.121125	0.105266
3	OuterDisch	15	0.331135	0.255046	0.210533	0.255046	0.010586	0.402261	0.010586	0.342613	0.262940	0.068838	0.372437	0.105266	0.123592
2	OSK	15	0.314700	0.245400	0.210533	0.263100	0.007673	0.342613	0.010586	0.331973	0.258433	0.067658	0.337293	0.089585	0.127553
4	OSK	15	0.314700	0.263100	0.326200	0.259700	0.007228	0.331973	0.007065	0.327473	0.290925	0.076164	0.329723	0.087097	0.086291
6	OSK	30	0.314700	0.259700	0.317200	0.252600	0.007065	0.327473	0.006741	0.318360	0.286050	0.149775	0.322916	0.086291	0.084693
8	OSK	30	0.314700	0.252600	0.308200	0.252600	0.006741	0.318360	0.006337	0.307142	0.282025	0.147668	0.312751	0.084693	0.082530
10	OSK	30	0.308200	0.245200	0.294900	0.252600	0.006337	0.307142	0.005472	0.287517	0.275225	0.144107	0.297329	0.082530	0.076131
11	OSK	30	0.294900	0.237800	0.273000	0.221600	0.005472	0.287517	0.004564	0.259605	0.256825	0.134473	0.273561	0.076131	0.070329
12	OuterSpiral	15	0.273000	0.237800	0.269400	0.198500	0.004564	0.287517	0.005860	0.221691	0.244675	0.064056	0.254604	0.063502	0.105725
13	OuterSpiral	15	0.269400	0.237800	0.265700	0.198500	0.005860	0.287517	0.005486	0.213248	0.242850	0.063578	0.250383	0.081520	0.102900
14	OuterSpiral	30	0.265700	0.237800	0.258200	0.198500	0.005486	0.287517	0.004738	0.195855	0.240050	0.125690	0.241686	0.076320	0.096762
15	OuterSpiral	30	0.258200	0.198500	0.250600	0.198500	0.004738	0.195855	0.004000	0.177782	0.226450	0.118569	0.186818	0.096762	0.089989
16	OuterSpiral	30	0.250600	0.198500	0.242800	0.198500	0.004000	0.177782	0.003293	0.159554	0.222600	0.116553	0.168668	0.089989	0.082552
17	OuterSpiral	30	0.242800	0.198500	0.234800	0.198500	0.003293	0.159554	0.002609	0.140587	0.218650	0.114485	0.150071	0.082552	0.074242
18	OuterSpiral	30	0.234800	0.198500	0.234800	0.198500	0.002609	0.140587	0.001919	0.120475	0.216650	0.113438	0.130531	0.074242	0.063705
0	OuterSpiral	30	0.226800	0.198500	0.234800	0.207000	0.001919	0.120475	0.000000	0.082117	0.216775	0.113503	0.101296	0.063705	0.000000
24	InnerDisch	15	0.218800	0.342145	0.234800	0.342145	0.010996	0.456262	0.008470	0.392942	0.284472	0.074475	0.424602	0.096398	0.086221
22	InnerDisch	24	0.281633	0.222619	0.281633	0.222619	0.008470	0.392942	0.004920	0.392942	0.252126	0.105610	0.392942	0.086221	0.050082
20	InnerDisch	15	0.381258	0.343428	0.381258	0.343428	0.004920	0.300034	0.003040	0.392942	0.362343	0.094861	0.346488	0.065590	0.030942
1	InnSpiral	15	0.233400	0.198500	0.251100	0.198500	0.003040	0.239200	0.004323	0.200375	0.220375	0.057694	0.219788	0.050829	0.086307
3	InnSpiral	15	0.251100	0.198500	0.247700	0.198500	0.004323	0.200375	0.003980	0.190806	0.223950	0.058630	0.195591	0.086307	0.083428
5	InnSpiral	30	0.247700	0.198500	0.240600	0.198500	0.003980	0.190806	0.003286	0.169988	0.221325	0.115885	0.180397	0.083428	0.077314
7	InnSpiral	30	0.247700	0.198500	0.233200	0.198500	0.003286	0.190806	0.002592	0.146230	0.219475	0.114917	0.168518	0.068878	0.070892
9	InnSpiral	30	0.247700	0.198500	0.226100	0.198500	0.002592	0.190806	0.001967	0.126684	0.217700	0.113987	0.158745	0.054330	0.062107
8.5	InnSpiral	30	0.226100	0.198500	0.213600	0.203855	0.001967	0.126684	0.000000	0.079450	0.210514	0.110225	0.103067	0.062107	0.000000

Figure 3: Complete casing geometry

2.1.5 Sheet: GapData

The leakage efficiency computation of the turbine needs to know the geometry of the wear ring, as for instance the diameter, the clearance and the length.

Leave empty the columns 2 and 3 if there is a single gap.

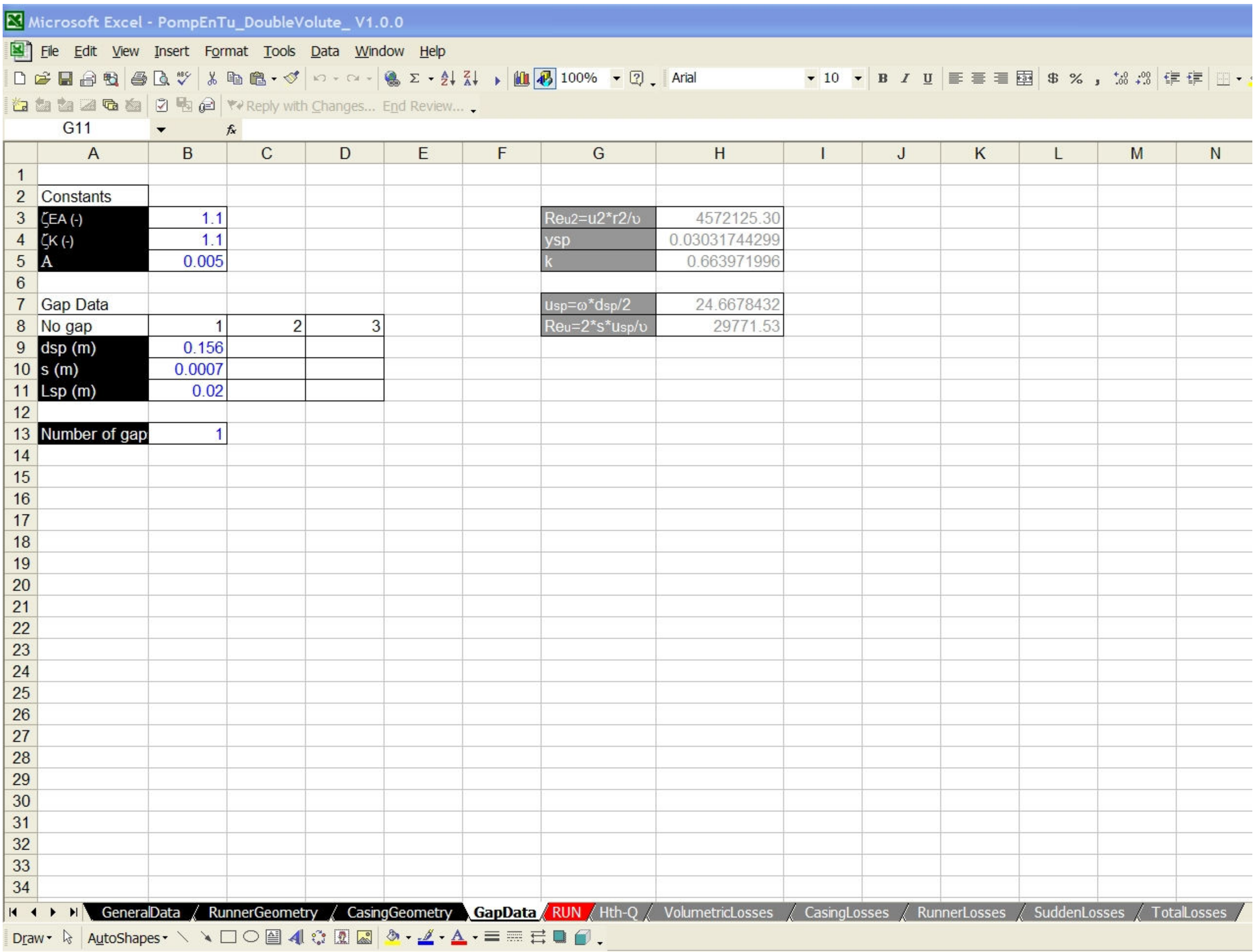


Figure 4: sheet of the clearance data

Figure 5: sheet to predict performances at other speed and/or other runner diameter

2.1.6 Sheet: RUN

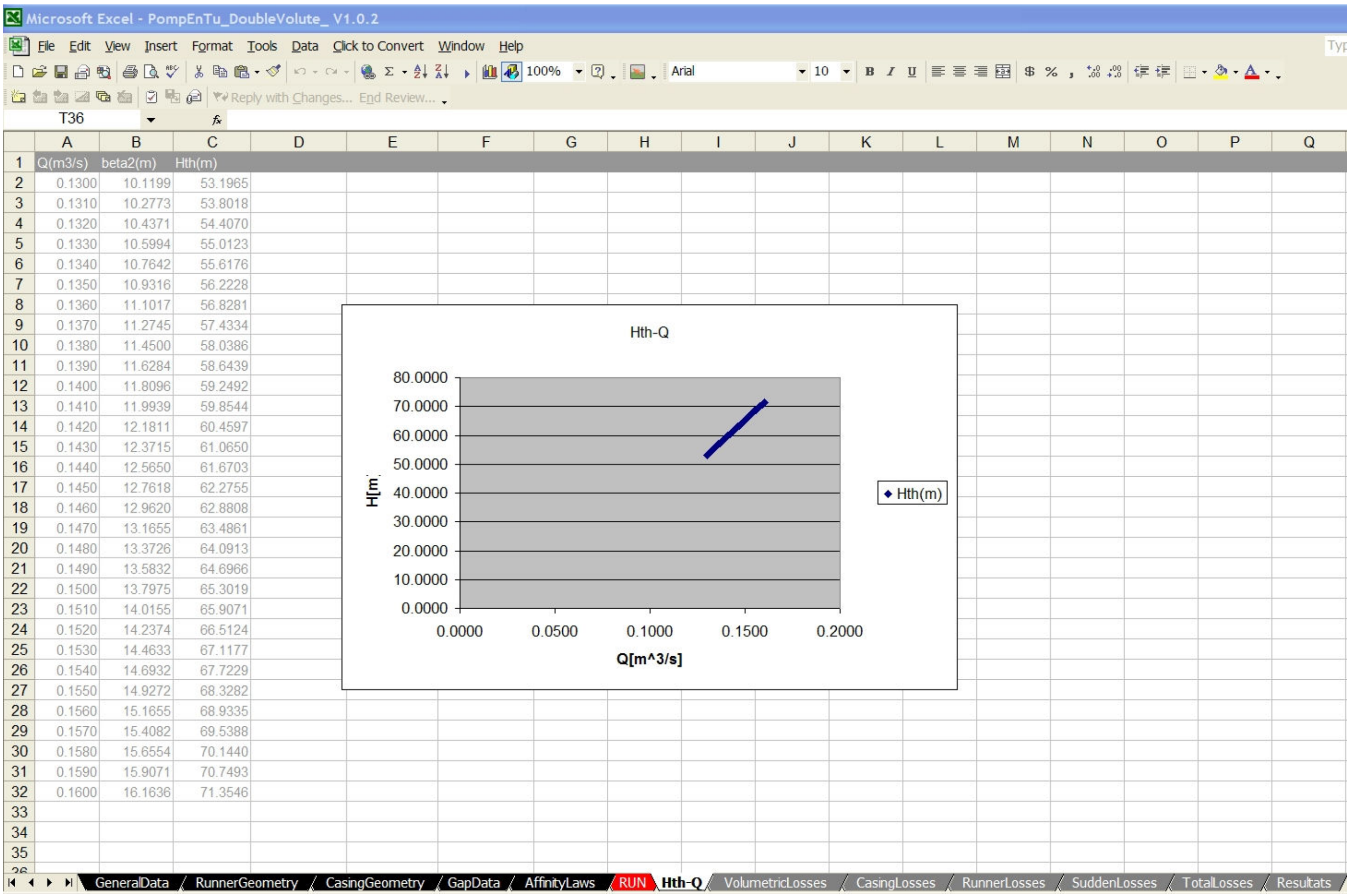
In that Sheet there is a button called RUN to launch and execute the VBA Excel macro. It is possible to add the command “Run Macro” in the toolbars of the Excel worksheet (blue arrow) as shown in Figure 5.

2.2 Sheets of outputs data

These sheets are used as monitors of the program and as controls and are useful for the code developers.

2.2.1 Sheet: Hth-Q

In this sheet (Figure 6) the theoretical curve Hth-Q is plotted and the assessment of the flow angle at the impeller entry (at section 2) is done.



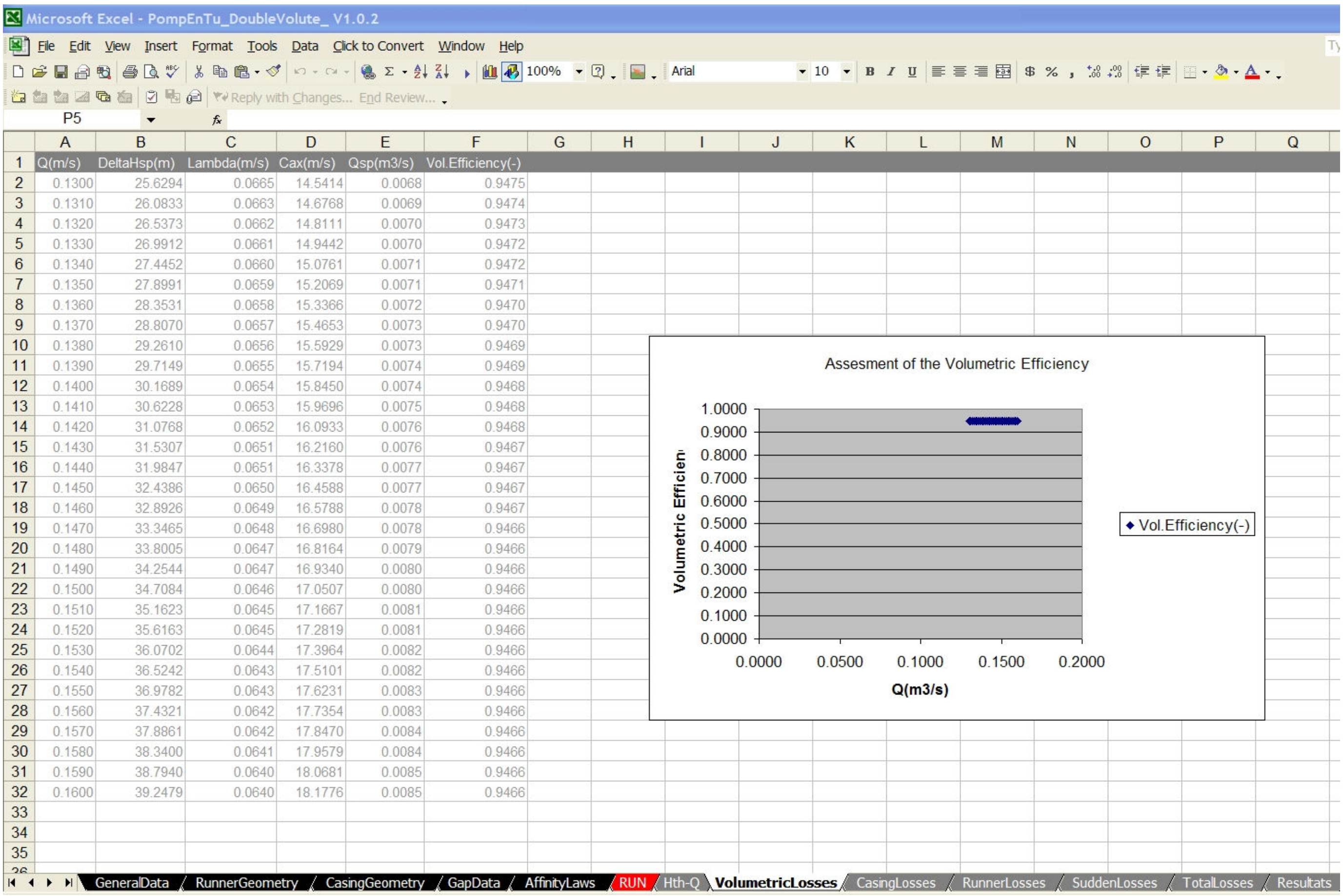
Q(m3/s)	beta2(m)	Hth(m)
0.1300	10.1199	53.1965
0.1310	10.2773	53.8018
0.1320	10.4371	54.4070
0.1330	10.5994	55.0123
0.1340	10.7642	55.6176
0.1350	10.9316	56.2228
0.1360	11.1017	56.8281
0.1370	11.2745	57.4334
0.1380	11.4500	58.0386
0.1390	11.6284	58.6439
0.1400	11.8096	59.2492
0.1410	11.9939	59.8544
0.1420	12.1811	60.4597
0.1430	12.3715	61.0650
0.1440	12.5650	61.6703
0.1450	12.7618	62.2755
0.1460	12.9620	62.8808
0.1470	13.1655	63.4861
0.1480	13.3726	64.0913
0.1490	13.5832	64.6966
0.1500	13.7975	65.3019
0.1510	14.0155	65.9071
0.1520	14.2374	66.5124
0.1530	14.4633	67.1177
0.1540	14.6932	67.7229
0.1550	14.9272	68.3282
0.1560	15.1655	68.9335
0.1570	15.4082	69.5388
0.1580	15.6554	70.1440
0.1590	15.9071	70.7493
0.1600	16.1636	71.3546

Figure 6: sheet showing the curve Hth-Q

2.2.2 Sheet: VolumetricLosses

In this sheet (Figure 7), the graphic of the volumetric efficiency related to the flow rate Q can be observed, as well as the axial flow velocity at the clearance (Cax) and so the flow rate (Qsp).

If the volumetric efficiency value entered in the *GeneralData* sheet does not fit the results shown in the graphic of Figure 7, correct it until obtained similar values.

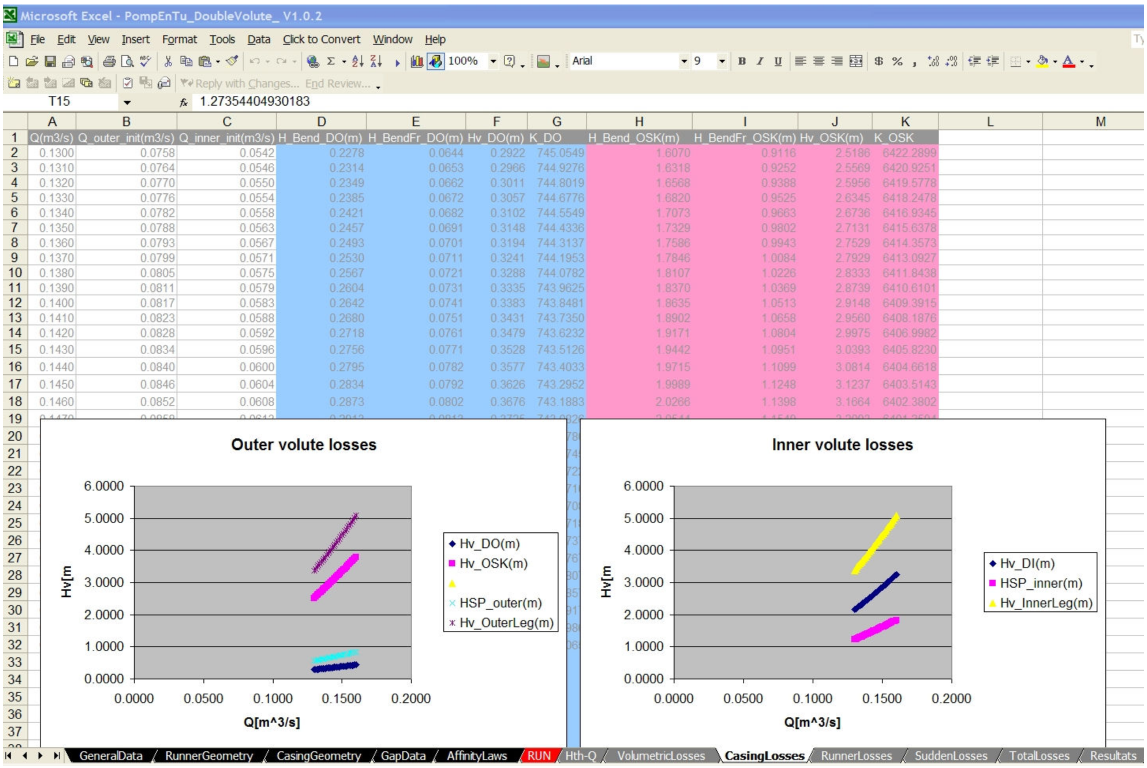


Q(m/s)	DeltaHsp(m)	Lambda(m/s)	Cax(m/s)	Qsp(m3/s)	Vol.Efficiency(-)
0.1300	25.6294	0.0665	14.5414	0.0068	0.9475
0.1310	26.0833	0.0663	14.6768	0.0069	0.9474
0.1320	26.5373	0.0662	14.8111	0.0070	0.9473
0.1330	26.9912	0.0661	14.9442	0.0070	0.9472
0.1340	27.4452	0.0660	15.0761	0.0071	0.9472
0.1350	27.8991	0.0659	15.2069	0.0071	0.9471
0.1360	28.3531	0.0658	15.3366	0.0072	0.9470
0.1370	28.8070	0.0657	15.4653	0.0073	0.9470
0.1380	29.2610	0.0656	15.5929	0.0073	0.9469
0.1390	29.7149	0.0655	15.7194	0.0074	0.9469
0.1400	30.1689	0.0654	15.8450	0.0074	0.9468
0.1410	30.6228	0.0653	15.9696	0.0075	0.9468
0.1420	31.0768	0.0652	16.0933	0.0076	0.9468
0.1430	31.5307	0.0651	16.2160	0.0076	0.9467
0.1440	31.9847	0.0651	16.3378	0.0077	0.9467
0.1450	32.4386	0.0650	16.4588	0.0077	0.9467
0.1460	32.8926	0.0649	16.5788	0.0078	0.9467
0.1470	33.3465	0.0648	16.6980	0.0078	0.9466
0.1480	33.8005	0.0647	16.8164	0.0079	0.9466
0.1490	34.2544	0.0647	16.9340	0.0080	0.9466
0.1500	34.7084	0.0646	17.0507	0.0080	0.9466
0.1510	35.1623	0.0645	17.1667	0.0081	0.9466
0.1520	35.6163	0.0645	17.2819	0.0081	0.9466
0.1530	36.0702	0.0644	17.3964	0.0082	0.9466
0.1540	36.5242	0.0643	17.5101	0.0082	0.9466
0.1550	36.9782	0.0643	17.6231	0.0083	0.9466
0.1560	37.4321	0.0642	17.7354	0.0083	0.9466
0.1570	37.8861	0.0642	17.8470	0.0084	0.9466
0.1580	38.3400	0.0641	17.9579	0.0084	0.9466
0.1590	38.7940	0.0640	18.0681	0.0085	0.9466
0.1600	39.2479	0.0640	18.1776	0.0085	0.9466

Figure 7: Sheet showing the Volumetric losses related to the flow rate

2.2.3 Sheet: CasingLosses

That sheet allows monitoring the losses according to the flow rate, through each part of the casing and in each leg of the volute (if double volute).

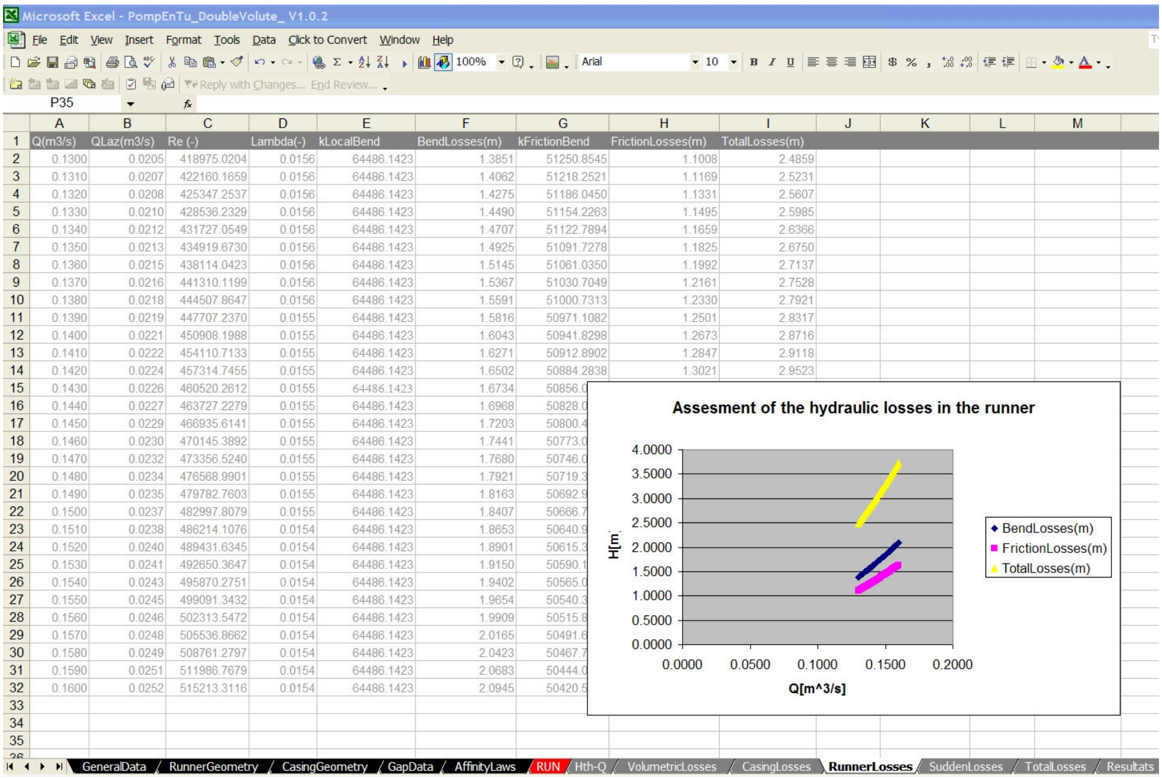


Q(m3/s)	Q_outer_init(m3/s)	Q_inner_init(m3/s)	H_Bend_DO(m)	H_BendFr_DO(m)	Hv_DO(m)	K_DO	H_Bend_OSK(m)	H_BendFr_OSK(m)	Hv_OSK(m)	K_OSK
0.1300	0.0758	0.0542	0.2278	0.0644	0.2922	745.0549	1.6070	0.9116	2.5186	6422.2899
0.1310	0.0764	0.0546	0.2314	0.0653	0.2966	744.9276	1.6318	0.9252	2.5569	6420.9251
0.1320	0.0770	0.0550	0.2349	0.0662	0.3011	744.8019	1.6568	0.9388	2.5956	6419.5778
0.1330	0.0776	0.0554	0.2385	0.0672	0.3057	744.6776	1.6820	0.9525	2.6345	6418.2478
0.1340	0.0782	0.0558	0.2421	0.0682	0.3102	744.5549	1.7073	0.9663	2.6736	6416.9345
0.1350	0.0788	0.0563	0.2457	0.0691	0.3148	744.4336	1.7329	0.9802	2.7131	6415.6378
0.1360	0.0793	0.0567	0.2493	0.0701	0.3194	744.3137	1.7586	0.9943	2.7529	6414.3573
0.1370	0.0799	0.0571	0.2530	0.0711	0.3241	744.1953	1.7846	1.0084	2.7929	6413.0927
0.1380	0.0805	0.0575	0.2567	0.0721	0.3288	744.0782	1.8107	1.0226	2.8333	6411.8438
0.1390	0.0811	0.0579	0.2604	0.0731	0.3335	743.9625	1.8370	1.0369	2.8739	6410.6101
0.1400	0.0817	0.0583	0.2642	0.0741	0.3383	743.8481	1.8635	1.0513	2.9148	6409.3915
0.1410	0.0823	0.0588	0.2680	0.0751	0.3431	743.7350	1.8902	1.0658	2.9560	6408.1876
0.1420	0.0828	0.0592	0.2718	0.0761	0.3479	743.6232	1.9171	1.0804	2.9975	6406.9982
0.1430	0.0834	0.0596	0.2756	0.0771	0.3528	743.5126	1.9442	1.0951	3.0393	6405.8230
0.1440	0.0840	0.0600	0.2795	0.0782	0.3577	743.4033	1.9715	1.1099	3.0814	6404.6618
0.1450	0.0846	0.0604	0.2834	0.0792	0.3626	743.2952	1.9989	1.1248	3.1237	6403.5143
0.1460	0.0852	0.0608	0.2873	0.0802	0.3676	743.1883	2.0266	1.1398	3.1664	6402.3802

Figure 8: sheet showing the results of losses in the casing

2.2.4 Sheet: RunnerLosses

The graphic showing the total losses in the impeller related to the flow rate is shown in this sheet (Figure 9). The part of the local losses and the friction losses can also be observed.

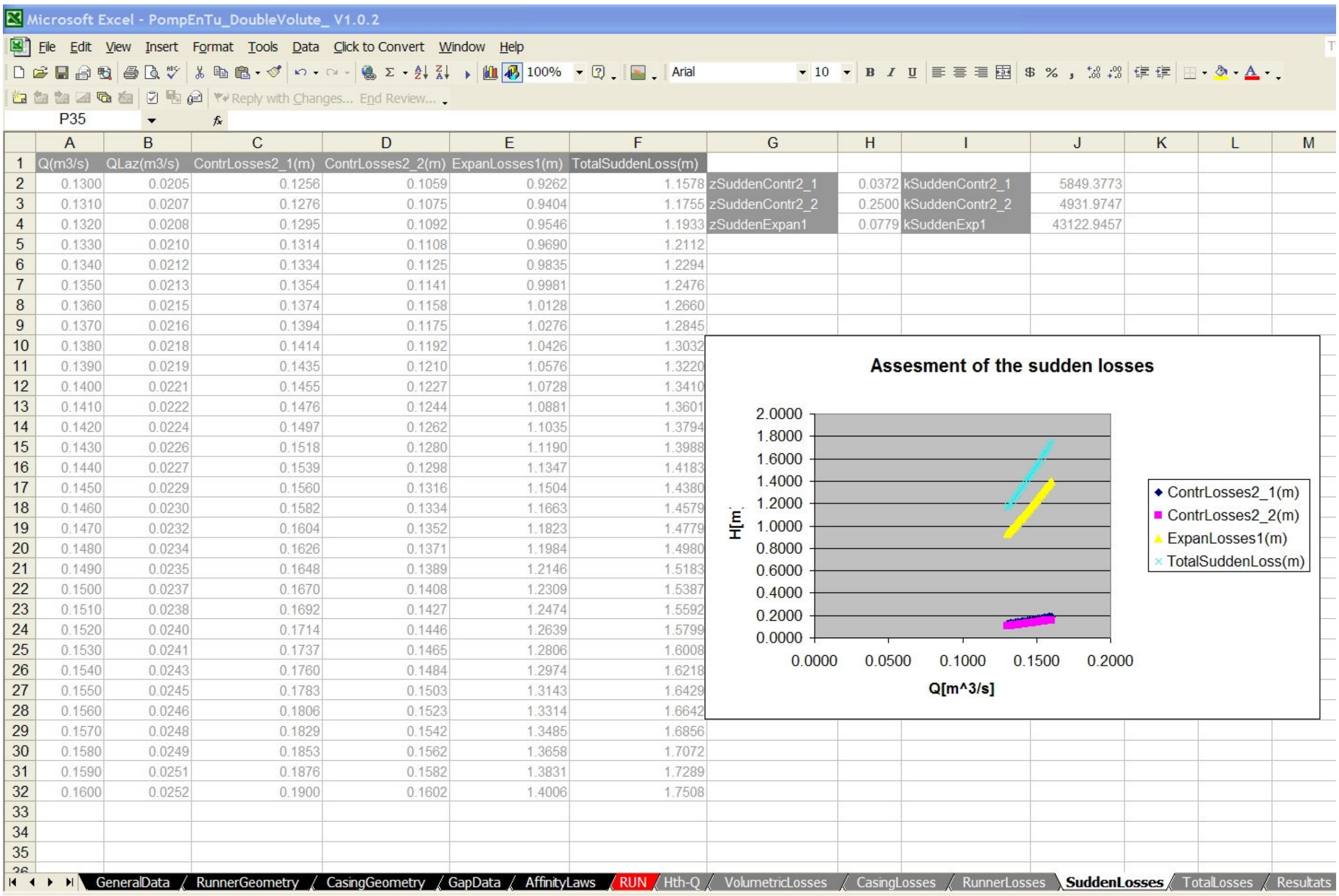


Q(m3/s)	QLaz(m3/s)	Re (-)	Lambda(-)	kLocalBend	BendLosses(m)	kFrictionBend	FrictionLosses(m)	TotalLosses(m)
0.1300	0.0205	418975.0204	0.0156	64486.1423	1.3851	51250.8545	1.1008	2.4859
0.1310	0.0207	422160.1659	0.0156	64486.1423	1.4062	51218.2521	1.1169	2.5231
0.1320	0.0208	425347.2537	0.0156	64486.1423	1.4275	51186.0450	1.1331	2.5607
0.1330	0.0210	428536.2329	0.0156	64486.1423	1.4490	51154.2263	1.1495	2.5985
0.1340	0.0212	431727.0549	0.0156	64486.1423	1.4707	51122.7894	1.1659	2.6366
0.1350	0.0213	434919.6730	0.0156	64486.1423	1.4925	51091.7278	1.1825	2.6750
0.1360	0.0215	438114.0423	0.0156	64486.1423	1.5145	51061.0350	1.1992	2.7137
0.1370	0.0216	441310.1199	0.0156	64486.1423	1.5367	51030.7049	1.2161	2.7528
0.1380	0.0218	444507.8647	0.0156	64486.1423	1.5591	51000.7313	1.2330	2.7921
0.1390	0.0219	447707.2370	0.0155	64486.1423	1.5816	50971.1082	1.2501	2.8317
0.1400	0.0221	450908.1988	0.0155	64486.1423	1.6043	50941.8298	1.2673	2.8716
0.1410	0.0222	454110.7133	0.0155	64486.1423	1.6271	50912.8902	1.2847	2.9118
0.1420	0.0224	457314.7455	0.0155	64486.1423	1.6502	50884.2838	1.3021	2.9523
0.1430	0.0226	460520.2612	0.0155	64486.1423	1.6734	50856.0		
0.1440	0.0227	463727.2279	0.0155	64486.1423	1.6968	50828.0		
0.1450	0.0229	466935.6141	0.0155	64486.1423	1.7203	50800.4		
0.1460	0.0230	470145.3892	0.0155	64486.1423	1.7441	50773.0		
0.1470	0.0232	473356.5240	0.0155	64486.1423	1.7680	50746.0		
0.1480	0.0234	476568.9901	0.0155	64486.1423	1.7921	50719.3		
0.1490	0.0235	479782.7603	0.0155	64486.1423	1.8163	50692.9		
0.1500	0.0237	482997.8079	0.0155	64486.1423	1.8407	50666.7		
0.1510	0.0238	486214.1076	0.0154	64486.1423	1.8653	50640.9		
0.1520	0.0240	489431.6345	0.0154	64486.1423	1.8901	50615.3		
0.1530	0.0241	492650.3647	0.0154	64486.1423	1.9150	50590.1		
0.1540	0.0243	495870.2751	0.0154	64486.1423	1.9402	50565.0		
0.1550	0.0245	499091.3432	0.0154	64486.1423	1.9654	50540.3		
0.1560	0.0246	502313.5472	0.0154	64486.1423	1.9909	50515.8		
0.1570	0.0248	505536.8662	0.0154	64486.1423	2.0165	50491.6		
0.1580	0.0249	508761.2797	0.0154	64486.1423	2.0423	50467.7		
0.1590	0.0251	511986.7679	0.0154	64486.1423	2.0683	50444.0		
0.1600	0.0252	515213.3116	0.0154	64486.1423	2.0945	50420.5		

Figure 9: Sheet showing the losses in the runner

2.2.5 Sheet: SuddenLosses

The losses caused by the abrupt changes of section at the entry and exit of the impeller are shown in this sheet (Figure 10).



Q(m3/s)	QLaz(m3/s)	ContrLosses2_1(m)	ContrLosses2_2(m)	ExpanLosses1(m)	TotalSuddenLoss(m)
0.1300	0.0205	0.1256	0.1059	0.9262	1.1578
0.1310	0.0207	0.1276	0.1075	0.9404	1.1755
0.1320	0.0208	0.1295	0.1092	0.9546	1.1933
0.1330	0.0210	0.1314	0.1108	0.9690	1.2112
0.1340	0.0212	0.1334	0.1125	0.9835	1.2294
0.1350	0.0213	0.1354	0.1141	0.9981	1.2476
0.1360	0.0215	0.1374	0.1158	1.0128	1.2660
0.1370	0.0216	0.1394	0.1175	1.0276	1.2845
0.1380	0.0218	0.1414	0.1192	1.0426	1.3032
0.1390	0.0219	0.1435	0.1210	1.0576	1.3220
0.1400	0.0221	0.1455	0.1227	1.0728	1.3410
0.1410	0.0222	0.1476	0.1244	1.0881	1.3601
0.1420	0.0224	0.1497	0.1262	1.1035	1.3794
0.1430	0.0226	0.1518	0.1280	1.1190	1.3988
0.1440	0.0227	0.1539	0.1298	1.1347	1.4183
0.1450	0.0229	0.1560	0.1316	1.1504	1.4380
0.1460	0.0230	0.1582	0.1334	1.1663	1.4579
0.1470	0.0232	0.1604	0.1352	1.1823	1.4779
0.1480	0.0234	0.1626	0.1371	1.1984	1.4980
0.1490	0.0235	0.1648	0.1389	1.2146	1.5183
0.1500	0.0237	0.1670	0.1408	1.2309	1.5387
0.1510	0.0238	0.1692	0.1427	1.2474	1.5592
0.1520	0.0240	0.1714	0.1446	1.2639	1.5799
0.1530	0.0241	0.1737	0.1465	1.2806	1.6008
0.1540	0.0243	0.1760	0.1484	1.2974	1.6218
0.1550	0.0245	0.1783	0.1503	1.3143	1.6429
0.1560	0.0246	0.1806	0.1523	1.3314	1.6642
0.1570	0.0248	0.1829	0.1542	1.3485	1.6856
0.1580	0.0249	0.1853	0.1562	1.3658	1.7072
0.1590	0.0251	0.1876	0.1582	1.3831	1.7289
0.1600	0.0252	0.1900	0.1602	1.4006	1.7508

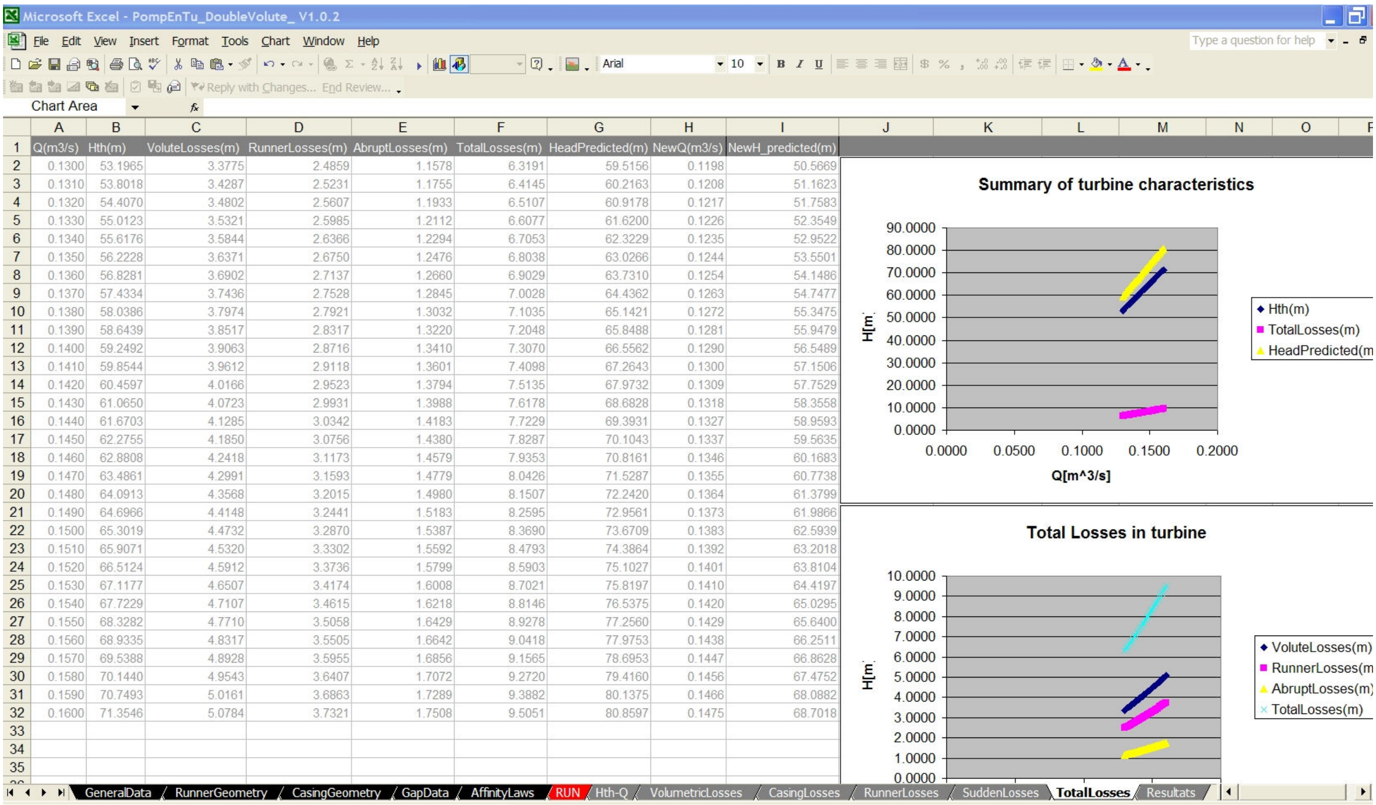
zSuddenContr2_1	0.0372	kSuddenContr2_1	5849.3773
zSuddenContr2_2	0.2500	kSuddenContr2_2	4931.9747
zSuddenExpan1	0.0779	kSuddenExp1	43122.9457

Figure 10: sheet showing the sudden losses at the inlet and runner outlet.

2.2.6 Sheet: TotalLosses

That sheet (Figure 11) shows a summary of all results observed in the output data sheets, as for instance, the part of the impeller losses, the part of the volute losses and the part of the abrupt losses. The total losses in the turbine are then obtained by the sum of all these losses.

There is also a graphic showing the determination of the predicted curve around the BEP which is obtained by the sum of the theoretical curve Hth-Q and the predicted losses curve.

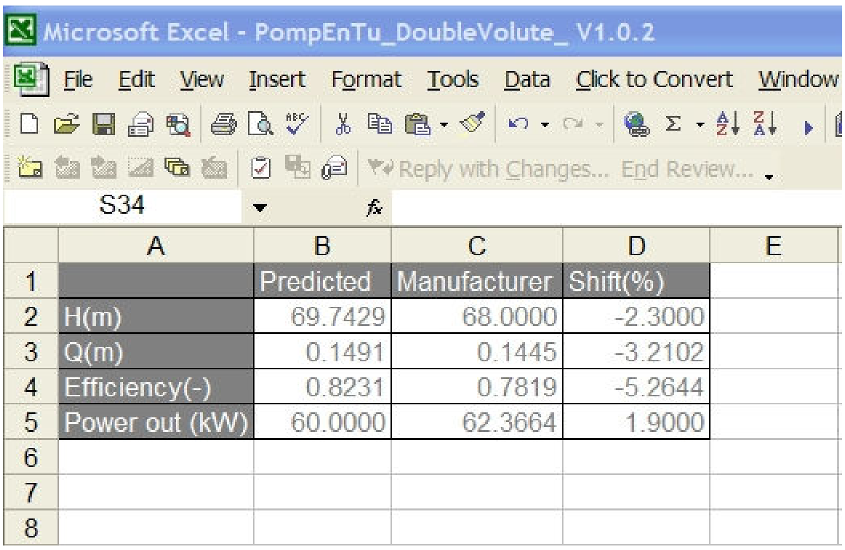


	Q(m3/s)	Hth(m)	VoluteLosses(m)	RunnerLosses(m)	AbruptLosses(m)	TotalLosses(m)	HeadPredicted(m)	NewQ(m3/s)	NewH_predicted(m)
2	0.1300	53.1965	3.3775	2.4859	1.1578	6.3191	59.5156	0.1198	50.5669
3	0.1310	53.8018	3.4287	2.5231	1.1755	6.4145	60.2163	0.1208	51.1623
4	0.1320	54.4070	3.4802	2.5607	1.1933	6.5107	60.9178	0.1217	51.7583
5	0.1330	55.0123	3.5321	2.5985	1.2112	6.6077	61.6200	0.1226	52.3549
6	0.1340	55.6176	3.5844	2.6366	1.2294	6.7053	62.3229	0.1235	52.9522
7	0.1350	56.2228	3.6371	2.6750	1.2476	6.8038	63.0266	0.1244	53.5501
8	0.1360	56.8281	3.6902	2.7137	1.2660	6.9029	63.7310	0.1254	54.1486
9	0.1370	57.4334	3.7436	2.7528	1.2845	7.0028	64.4362	0.1263	54.7477
10	0.1380	58.0386	3.7974	2.7921	1.3032	7.1035	65.1421	0.1272	55.3475
11	0.1390	58.6439	3.8517	2.8317	1.3220	7.2048	65.8488	0.1281	55.9479
12	0.1400	59.2492	3.9063	2.8716	1.3410	7.3070	66.5562	0.1290	56.5489
13	0.1410	59.8544	3.9612	2.9118	1.3601	7.4098	67.2643	0.1300	57.1506
14	0.1420	60.4597	4.0166	2.9523	1.3794	7.5135	67.9732	0.1309	57.7529
15	0.1430	61.0650	4.0723	2.9931	1.3988	7.6178	68.6828	0.1318	58.3558
16	0.1440	61.6703	4.1285	3.0342	1.4183	7.7229	69.3931	0.1327	58.9593
17	0.1450	62.2755	4.1850	3.0756	1.4380	7.8287	70.1043	0.1337	59.5635
18	0.1460	62.8808	4.2418	3.1173	1.4579	7.9353	70.8161	0.1346	60.1683
19	0.1470	63.4861	4.2991	3.1593	1.4779	8.0426	71.5287	0.1355	60.7738
20	0.1480	64.0913	4.3568	3.2015	1.4980	8.1507	72.2420	0.1364	61.3799
21	0.1490	64.6966	4.4148	3.2441	1.5183	8.2595	72.9561	0.1373	61.9866
22	0.1500	65.3019	4.4732	3.2870	1.5387	8.3690	73.6709	0.1383	62.5939
23	0.1510	65.9071	4.5320	3.3302	1.5592	8.4793	74.3864	0.1392	63.2018
24	0.1520	66.5124	4.5912	3.3736	1.5799	8.5903	75.1027	0.1401	63.8104
25	0.1530	67.1177	4.6507	3.4174	1.6008	8.7021	75.8197	0.1410	64.4197
26	0.1540	67.7229	4.7107	3.4615	1.6218	8.8146	76.5375	0.1420	65.0295
27	0.1550	68.3282	4.7710	3.5058	1.6429	8.9278	77.2560	0.1429	65.6400
28	0.1560	68.9335	4.8317	3.5505	1.6642	9.0418	77.9753	0.1438	66.2511
29	0.1570	69.5388	4.8928	3.5955	1.6856	9.1565	78.6953	0.1447	66.8628
30	0.1580	70.1440	4.9543	3.6407	1.7072	9.2720	79.4160	0.1456	67.4752
31	0.1590	70.7493	5.0161	3.6863	1.7289	9.3882	80.1375	0.1466	68.0882
32	0.1600	71.3546	5.0784	3.7321	1.7508	9.5051	80.8597	0.1475	68.7018

Figure 11: sheet summarizing all results and showing a small table comparing the prediction and the manufacturer data

2.2.7 Sheet: Results

In this sheet (Figure 12) comparisons are done between the prediction and the performances given by the manufacturer.



	Predicted	Manufacturer	Shift(%)
H(m)	69.7429	68.0000	-2.3000
Q(m)	0.1491	0.1445	-3.2102
Efficiency(-)	0.8231	0.7819	-5.2644
Power out (kW)	60.0000	62.3664	1.9000

Figure 12: sheet with the final results of the prediction

3. TAKING THE PUMP GEOMETRY

Figure 13 and 14 show the dimensions to take from a pump drawing (impeller and casing) to use in the program PompEntu.

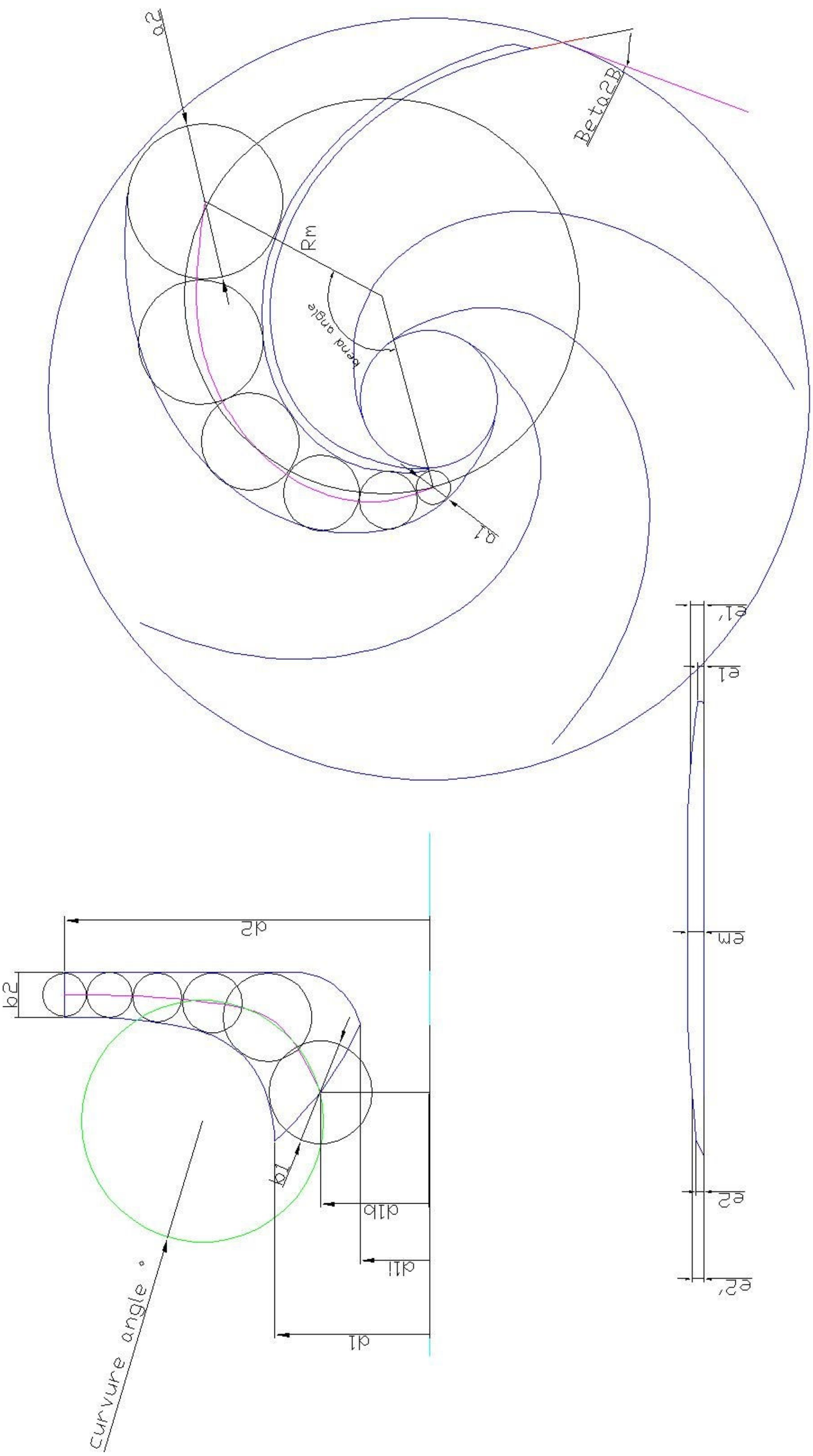


Figure 13: symbols of the impeller dimensions needed for the VBA Excel macro PumpsAsTurbines

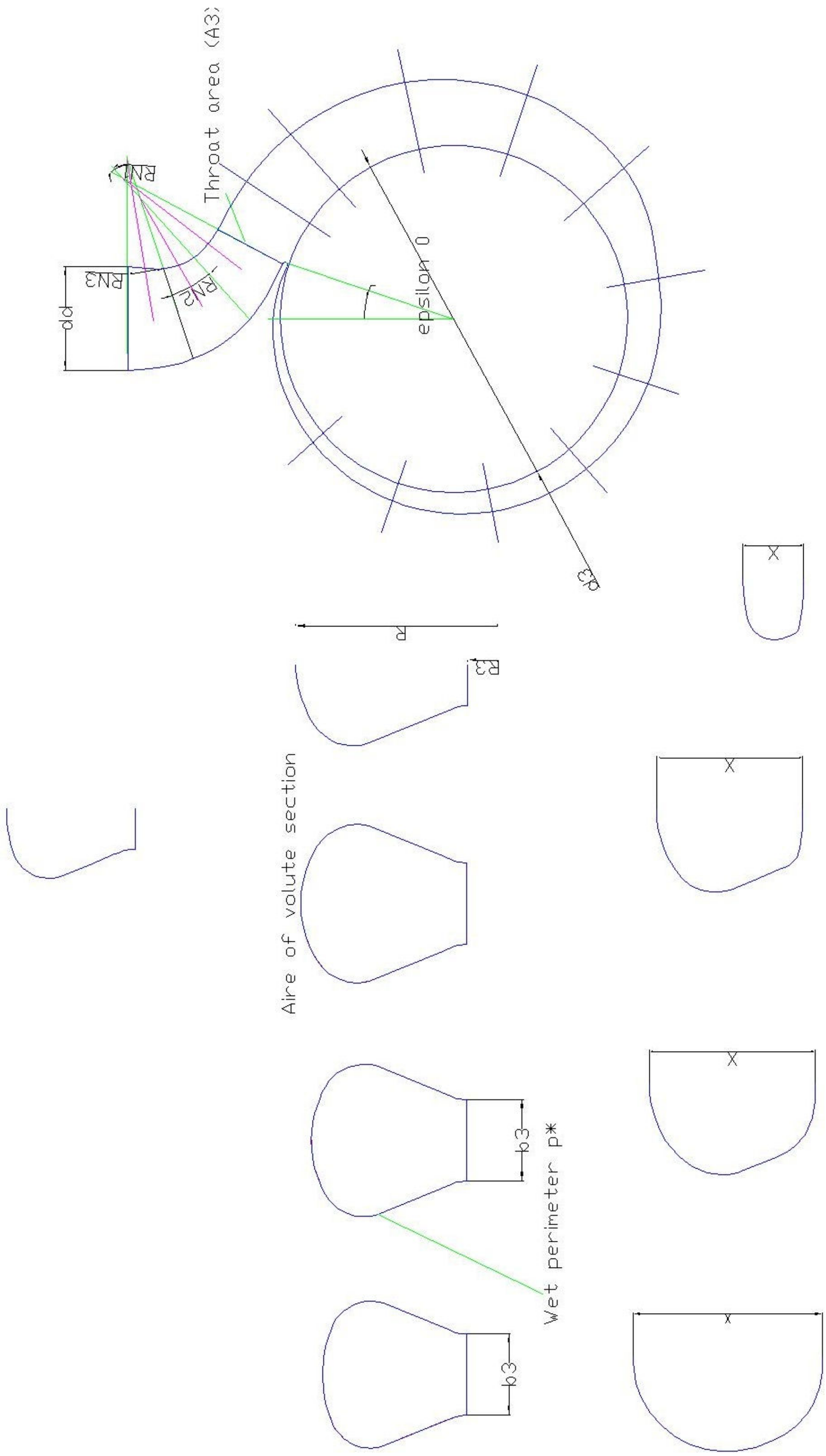


Figure 14: symbols of the volute elements needed for the VBA Excel macro PumpsAsTurbines

3.1 Symbols used

A	area, cross section
A3	throat area
a	distance between vanes
b	width of vane
b2	impeller outlet width
D, d	diameter
d_{sp}	gap diameter
d_d	discharge nozzle diameter
d_b	arithmetic average of diameters at impeller or diffuser e.g. $d_{1b} = 0.5\,(d_1 + d_{1i})$; defined such that: $A1 = \pi d_{1b}\, b_1$
d_m	geometric average of diameters at impeller or diffuser, e.g. $d_{1m} = \sqrt{0.5(d_{1a}^2 + d_{1i}^2)}$
e	vane thickness
H	head
L	length
L_{sp}	gap length
n	rotational speed (revolutions per minute)
n_q	specific speed
p^*	wet perimeter
Q	flow rate, volumetric flow
R_N	bend radius
r	radius
s	gap width
Z_{La}	number of impeller blades
Z_{Le}	number of diffuser vanes (volute: number of cutwaters)
θ	angle used for the law section of the spiral casing
λ_{La}	angle between vanes and side disks (impeller or diffuser)
β_{2B}	blade angle at the pump outlet
ε_o	angular position of the cutwater
$\Delta_{runner,volute}$	roughness of the runner and volute

Subscripts

1	impeller blade leading edge (low pressure)
2	impeller blade trailing edge (high pressure)
3	diffuser vane leading edge or volute cutwater
La	impeller
Le	diffuser
opt	operation at maximum efficiency (BEP)
sp	gap, leakage flow