Competence Center for Gas Exchange

CCGEx

”Charging for the future”

Energimyndigheten

SCANIA

VOLVO

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KTH ROYAL INSTITUTE
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Unconventional Diffuser design for extended compressor range

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Thomas Lischer – Borg Warner

Objectives

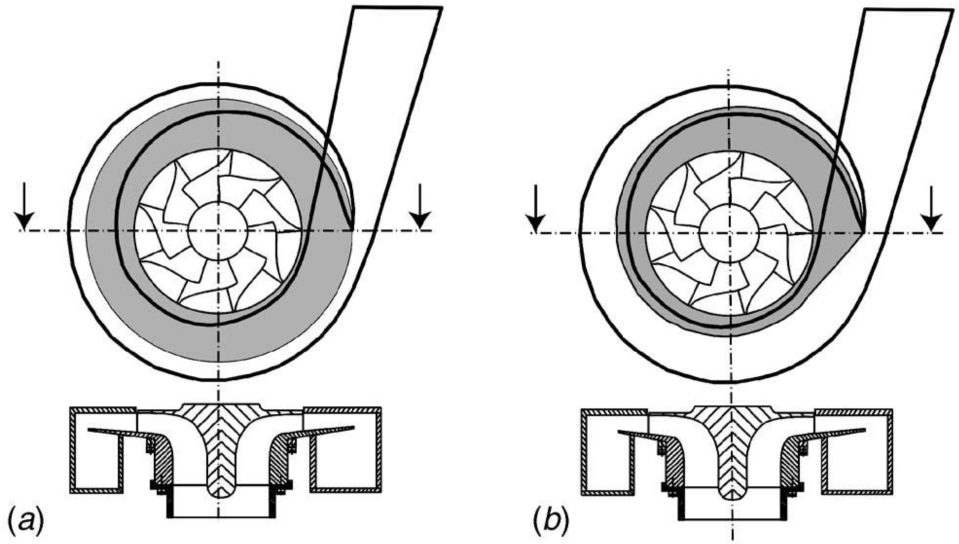
ASME GT-2005-68894

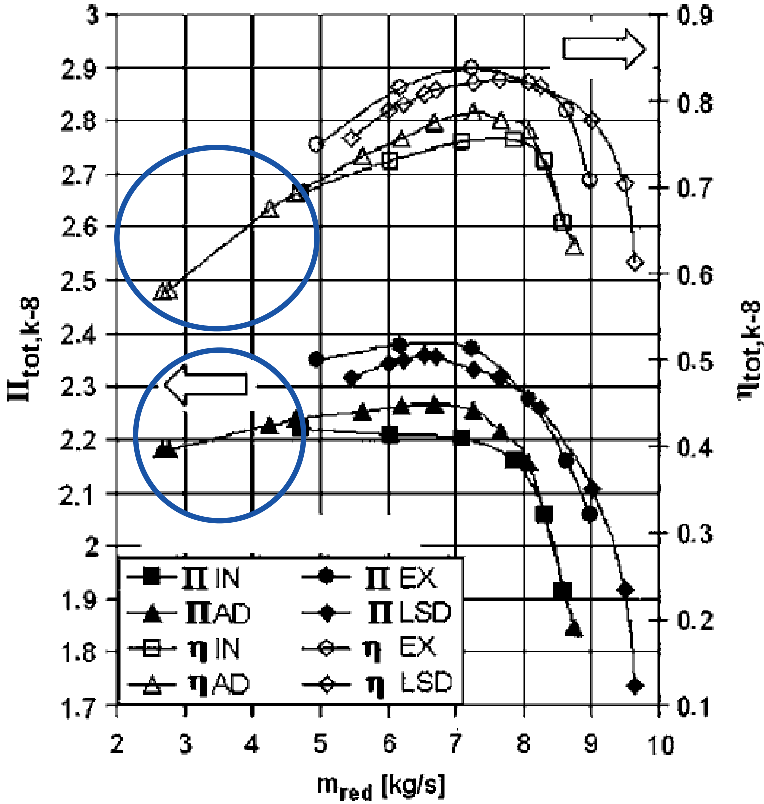
-Greater range at higher speedlines

-Improved efficiency

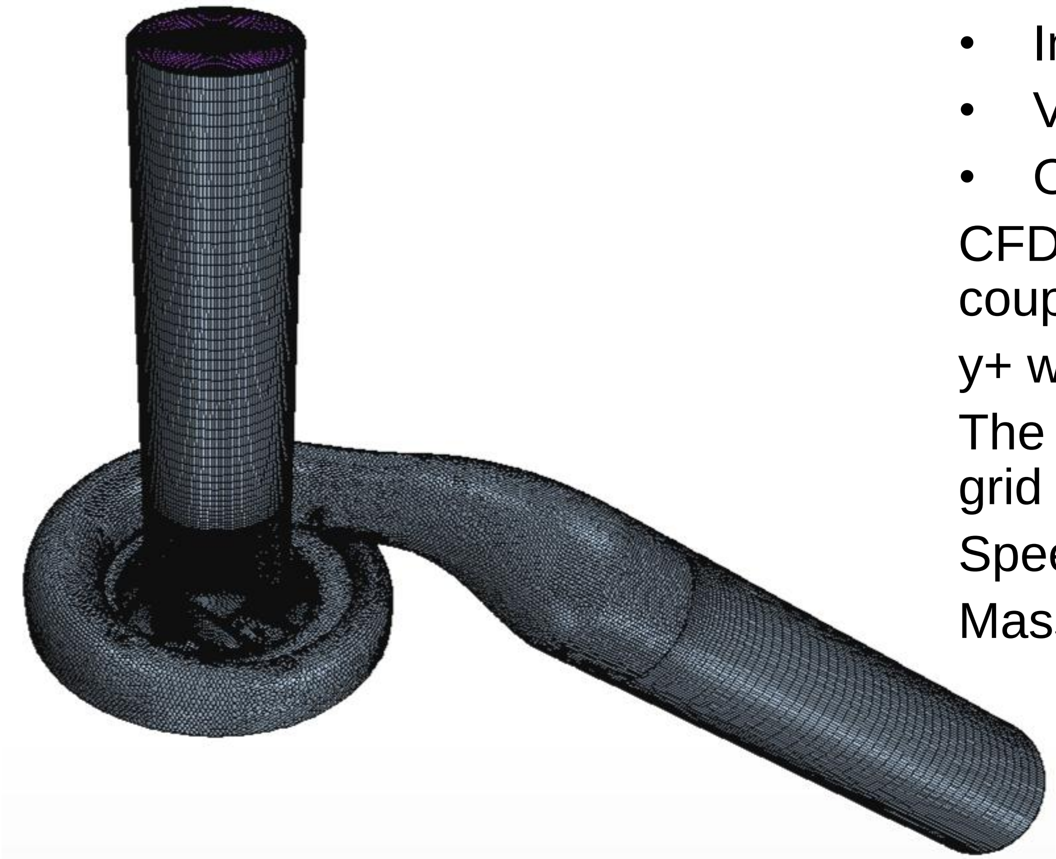
Other findings:

-” […] more pronounced circumferential static pressure variation at the impeller outlet […]”





Current case and methodology



The stage is divided into 4 regions:

- Inlet duct
- Impeller
- Volute
- Outlet duct

CFD Model RANS, SARC model, coupled, second order upwind.

y+ was kept below one unit

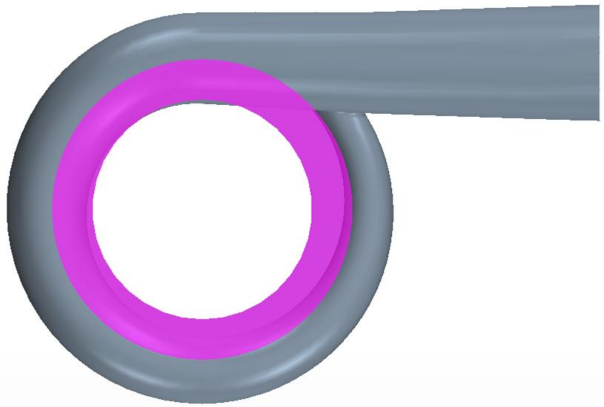
The overall mesh resulted following a grid sensitivity study

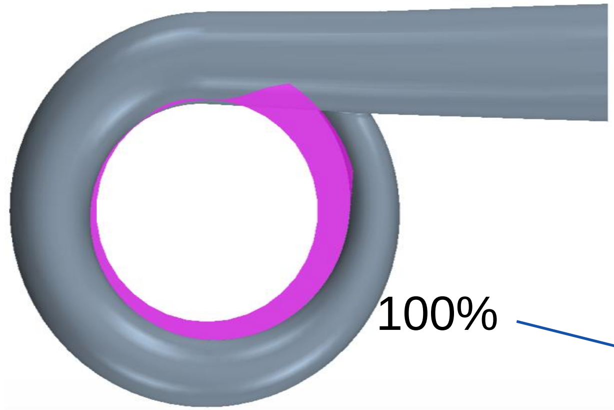
Speedline137274.3131 RPM

Massflow 0.24582 kg/s

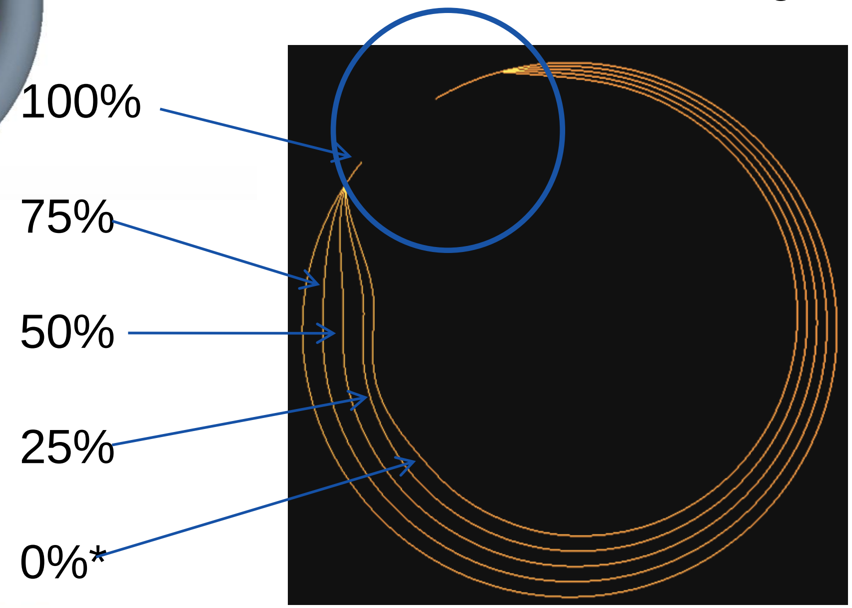
The modified geometry

Current study volute
provided by BW

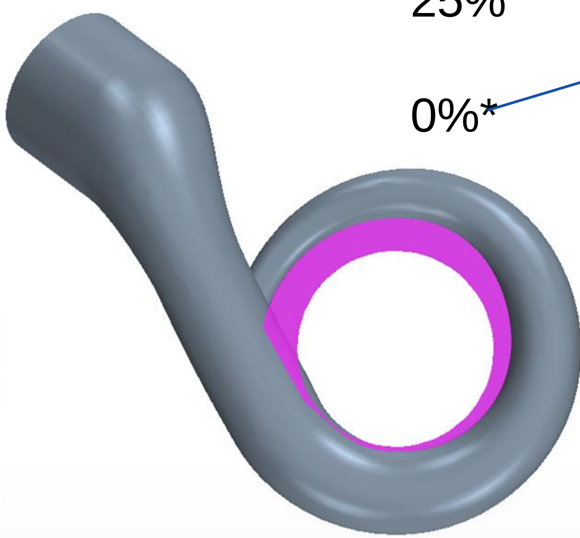




Tongue region
is not changed



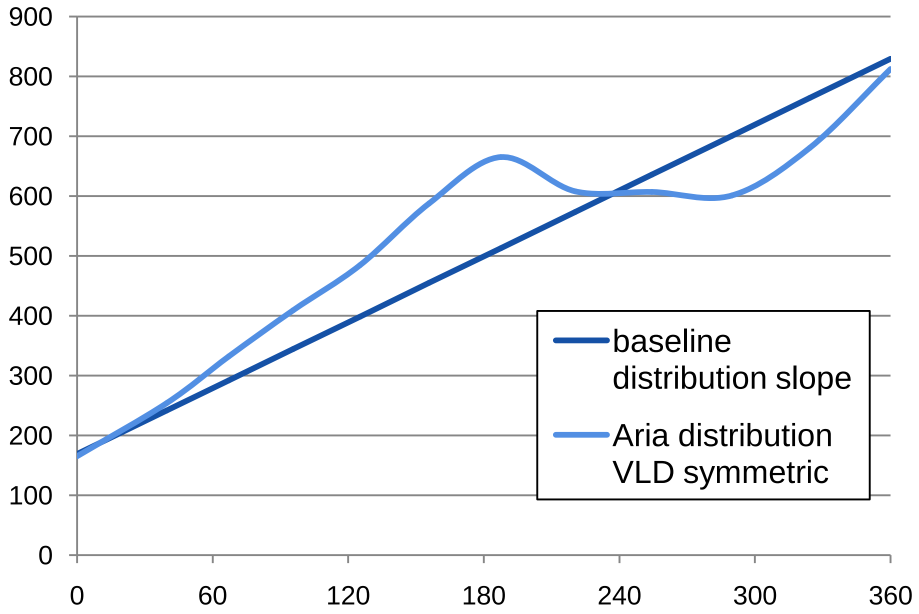
The baseline volute (right) is modified by trimming the protruding part of the VLD by various percentage. The flush volute (left) has the VLD fully trimmed.

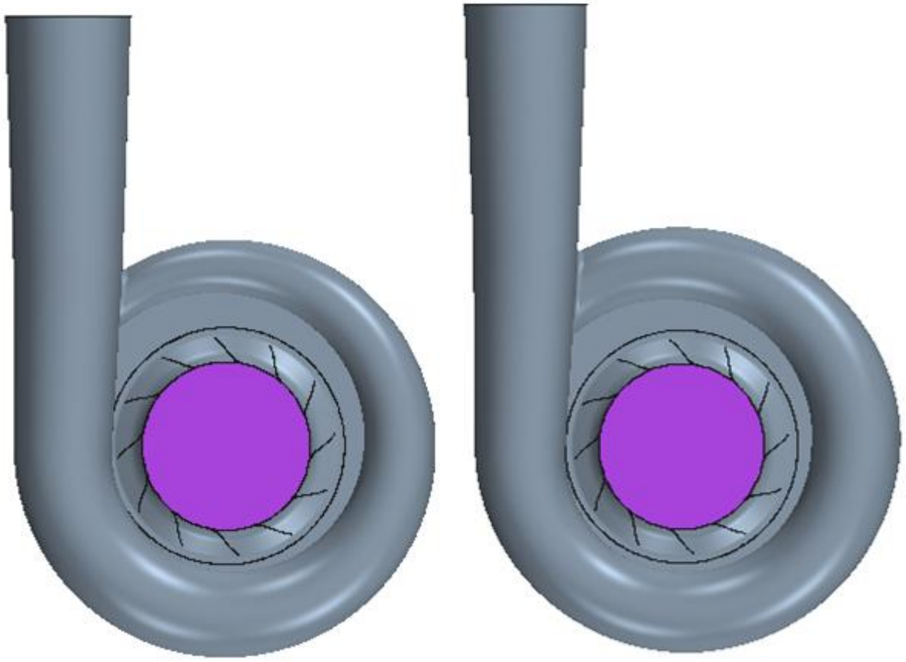


Actual application volute
provided by BW

Unconventional design volute

Having the exact same baseline VLD, a new distribution of crossectional arias is proposed in order to obtain the same flow distortion but with less aerodynamic penalty.



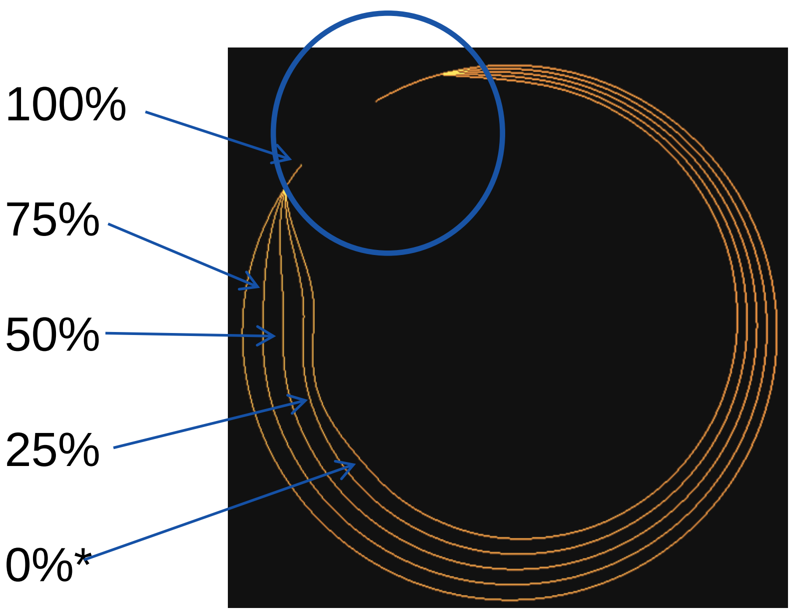


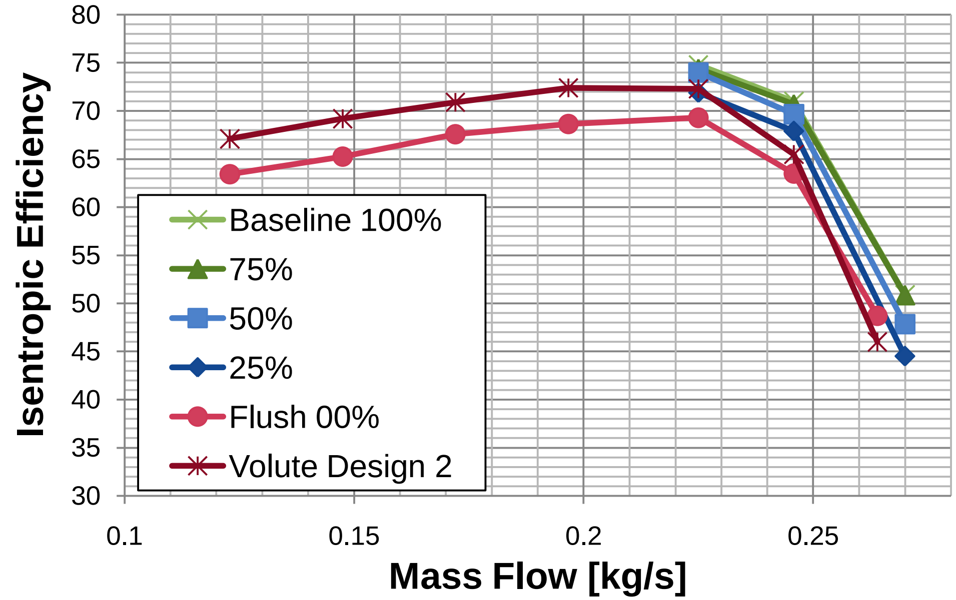
Baseline

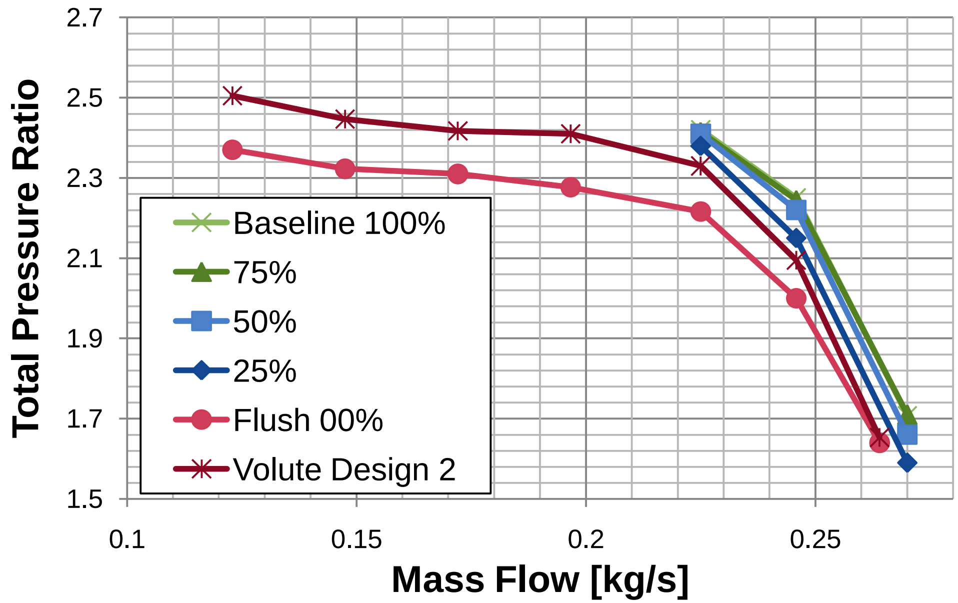
Volute Design 2

In RANS simulations, the only geometrical variation stable across the whole mass flow range is the flush volute

The choke line is altered since the throughflow is accelerated.





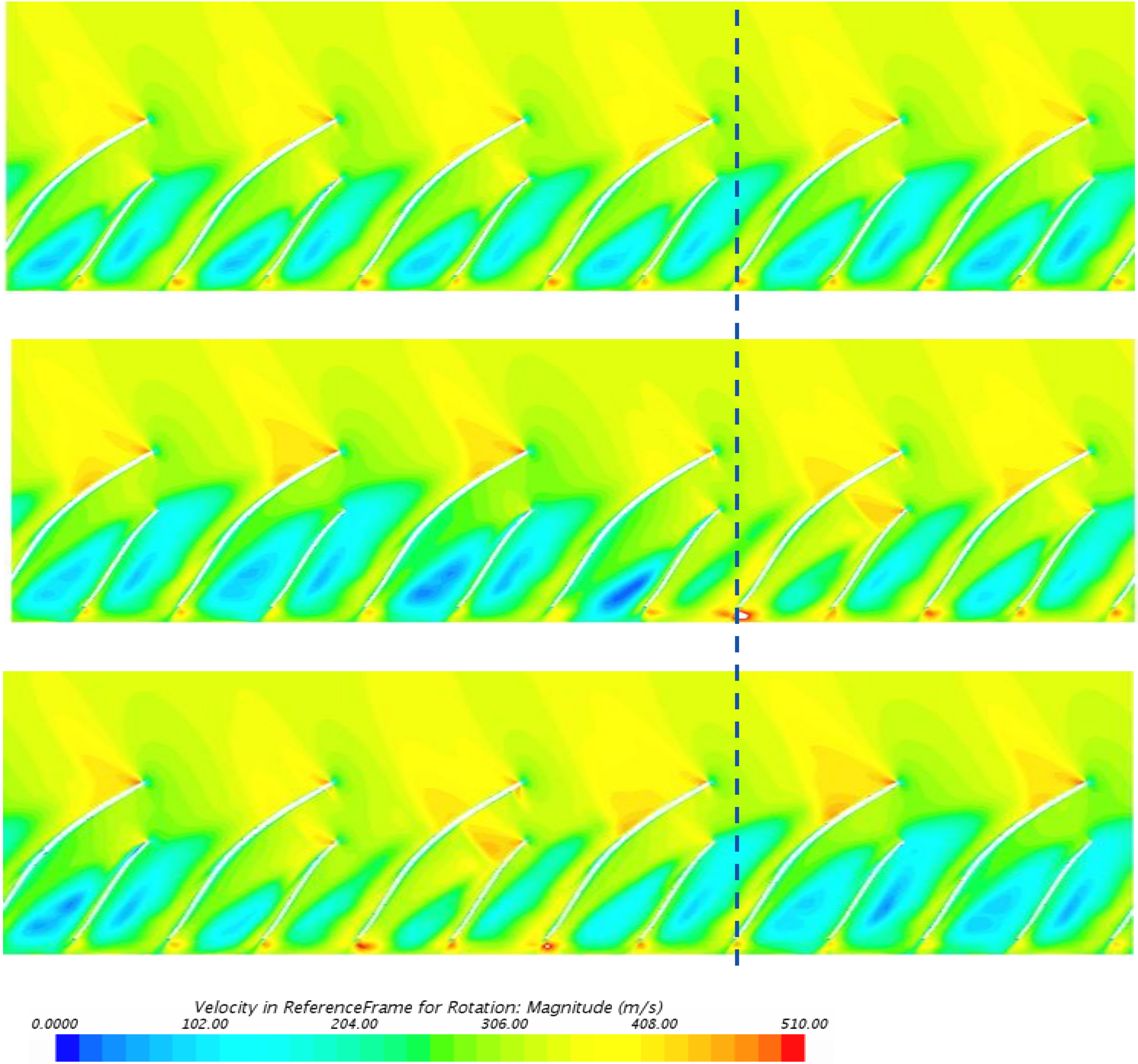


Comments on current findings

Characteristics	Flush Volute 0% VLD	Lower trimmed VLD	Volute Design 2	ASME GT-2005-68894
Nominal speed	high	high	high	low
Nominal mass flow	low	low	low	high
Extended stall range	yes	no	yes	yes
Choke margin loss	yes	no	yes	no
VLD trim	00%	00%	No trim	25%
Efficiency impact	-6%	-0.3%	-3%	+0.5%
Pressure loss [bar]	-0.25	-0.05	-0.155	+0.06

Circumferential pressure distribution becomes more biased with VLD trim percentage

Volute throughflow velocity increases (due to radial velocity component)

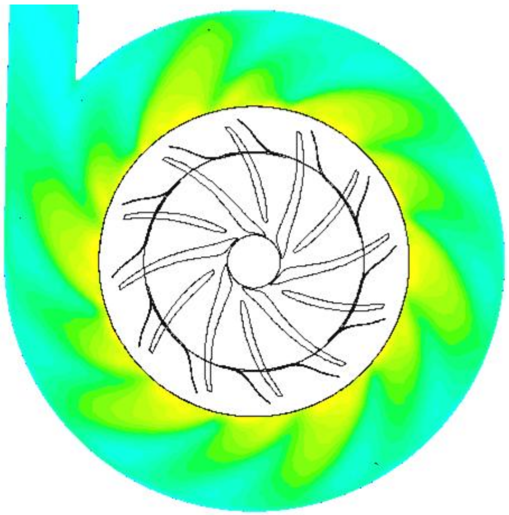


Baseline volute leads to almost symmetrical loading on impeller

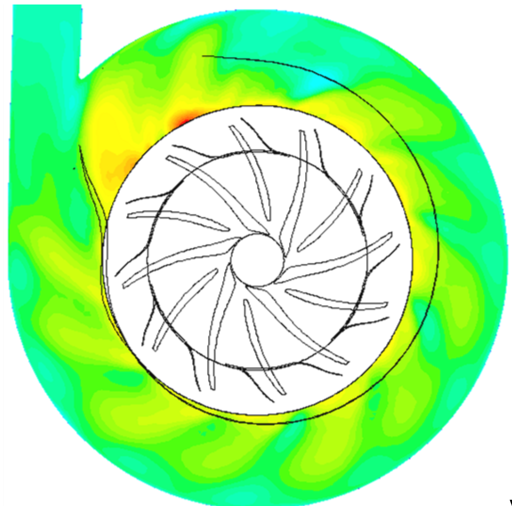
Flush volute overall accelerated throughflow.
Visible at VLD inlet
Less symmetrical loading on impeller.

Volute Design 2 induced a similar effect to the trimmed volute in terms of stability and pressure distribution

Diffuser midspan velocity distribution



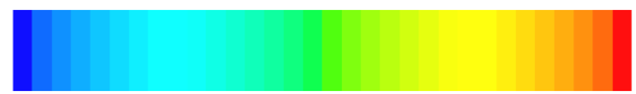
Baseline

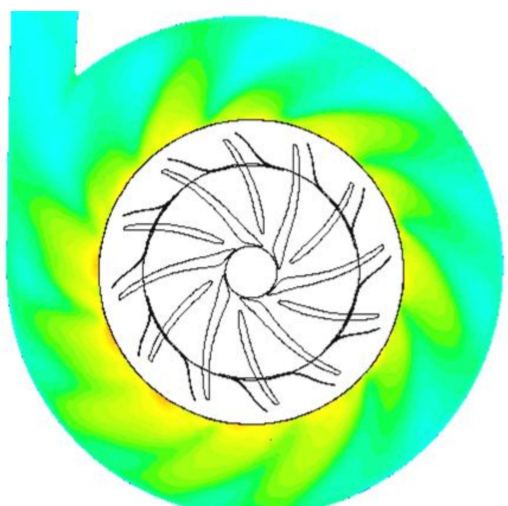


Flush

Allowing for proper diffusion inside the VLD we can reduce losses even if the circumferential pressure is not constant.

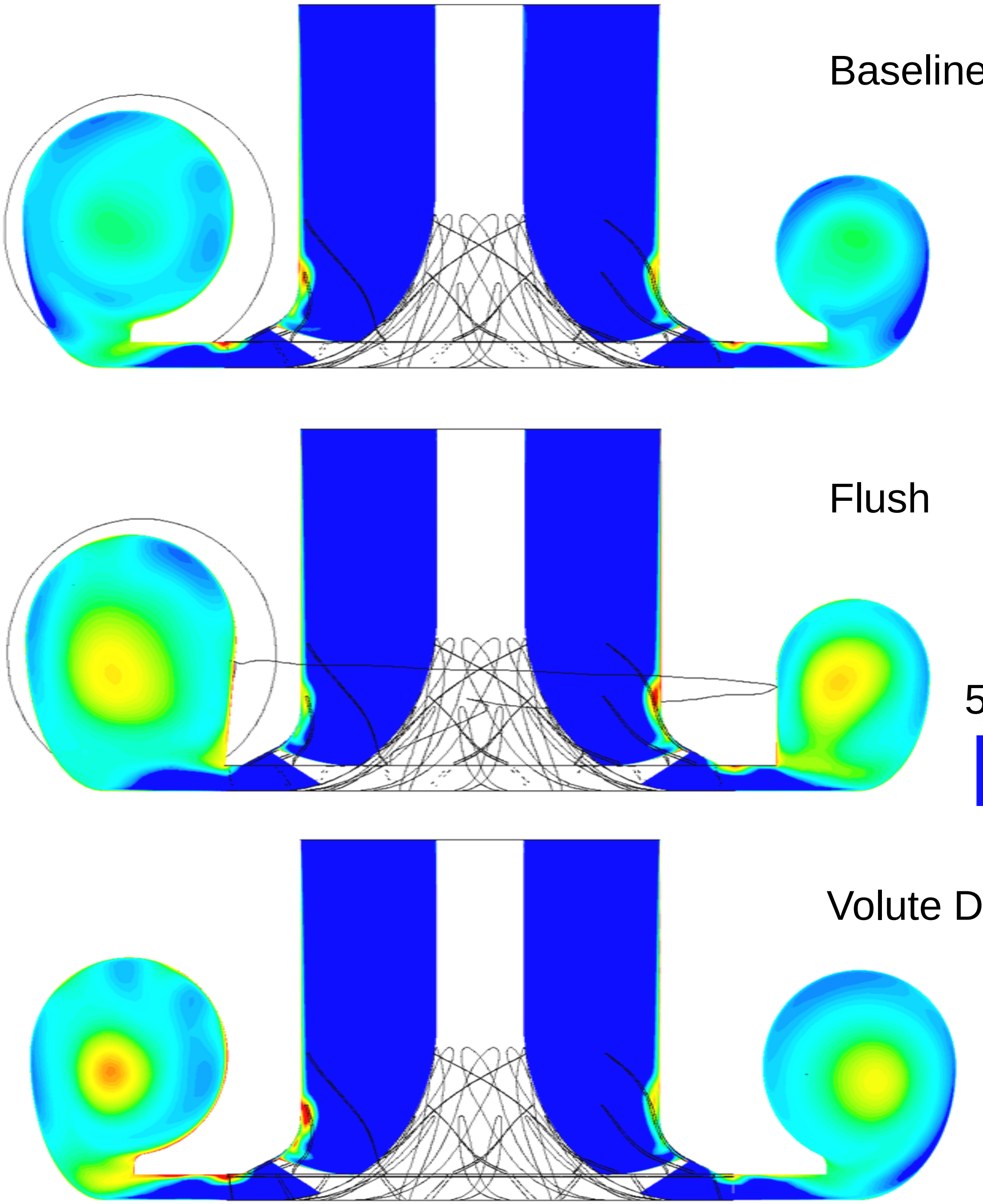
0 **Velocity magnitude** 485 [m/s]



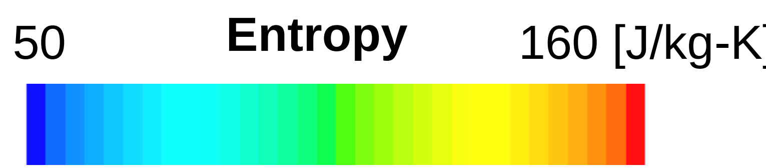


Volute Design 2

Transversal section entropy



The losses associated with the VLD interaction can be eliminated but reacceleration inside the scroll will impact efficiency at high flow conditions.



Conclusions and Highlights

Trimming the VLD of an interior volute can extend compressor range

The stabilizing mechanism was identified in the circumferential pressure distribution near the impeller

Size matters, lower Re machines will display significant losses of efficiency

By shaping the volute it is possible to obtain similar effects in terms of stability with lower losses

Combining a slightly trimmed VLD with an appropriate volute could result in better high mass flow behavior while retaining the gained stall range

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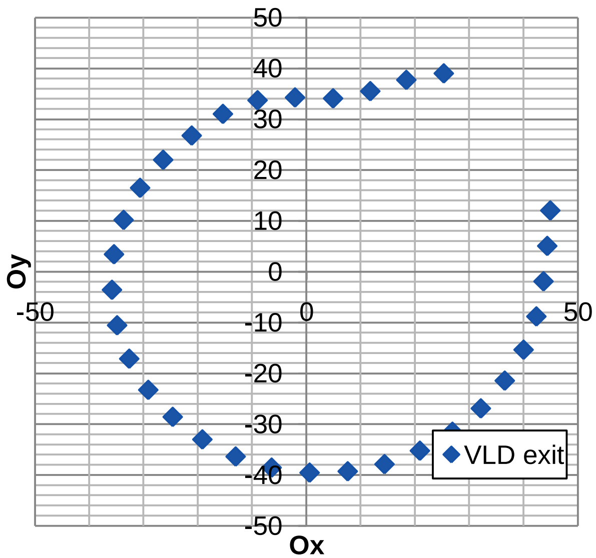
Unconventional volute #1

X [m]	Y [m]	Alpha_3 (VLD exit angle) [deg]	Velocity magnitude [m/s]
0.0252937	0.026294	-54.6124	319.8415961
0.004902283	0.0341	-45.6828	366.5473291
-0.01539398	0.031042	-62.3424	489.3535176
-0.03065039	0.016489	-49.8131	390.6988796
-0.03583316	-0.00358	-50.4079	293.9347825
-0.02914526	-0.02328	-41.2268	282.9783823
-0.01304824	-0.03639	-41.3705	261.5435831
0.007595611	-0.0393	-46.1753	224.1775288
0.02688813	-0.03151	-44.9786	250.30309
0.03999403	-0.01538	-45.6201	226.5971523
0.04435123	0.005054	-50.8566	218.5682634



x [mm]	y [mm]
25.2937	39.01922
18.39356	37.73476
11.75316	35.51772
4.902283	34.10035
-2.11049	34.27784
-9.01595	33.72984
-15.394	31.04224
-21.1439	26.77859
-26.4024	22.00315
-30.6504	16.4891
-33.684	10.17229
-35.4588	3.415769
-35.8332	-3.58462
-34.8869	-10.5642
-32.6548	-17.1391
-29.1453	-23.2762
-24.6415	-28.5885
-19.1819	-33.0258
-13.0482	-36.3874
-6.42323	-38.5774
0.575889	-39.5642
7.595611	-39.3008
14.37607	-37.8963
20.88783	-35.2477
26.88813	-31.5148
32.12008	-26.9178
36.52586	-21.4621
39.99403	-15.3753
42.34882	-8.81773
43.66422	-1.91042
44.35123	5.053929
44.91588	12.03518

Comparison with conventional benchmarks

Constant pinch VLD leads to marginal increase in range but significant (+10%) increase in efficiency losses.

In order to dissociate the pressure distribution from the increased throghflow velocity two setups were further proposed:

-A shelf VLD with deliberate stalling (primarily increases throughflow velocity)

-A conventional VLD with an unconventional aria distribution (primarily mimics uneven pressure distribution)

Further work

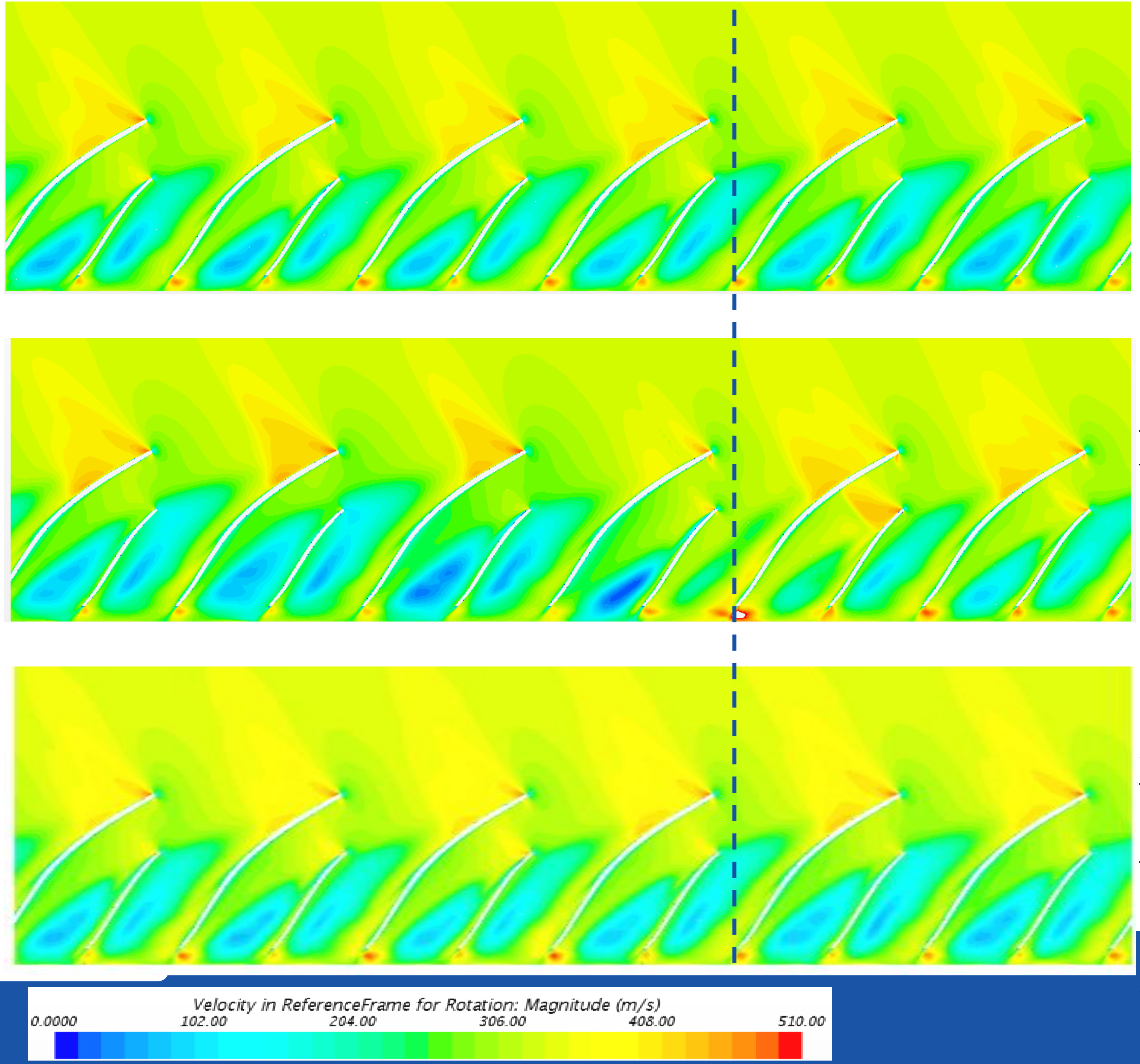
URANS simulations started on the last stable operating point of the baseline vs flush volute

RANS simulations started on the 370 and 520 m/s speedlines

Further assessment of the reasons for which the flush volute is more stable and try to separate them from the loss generating mechanisms

Probably a classic diffuser with a tailored volute be more efficient while having the same benefits

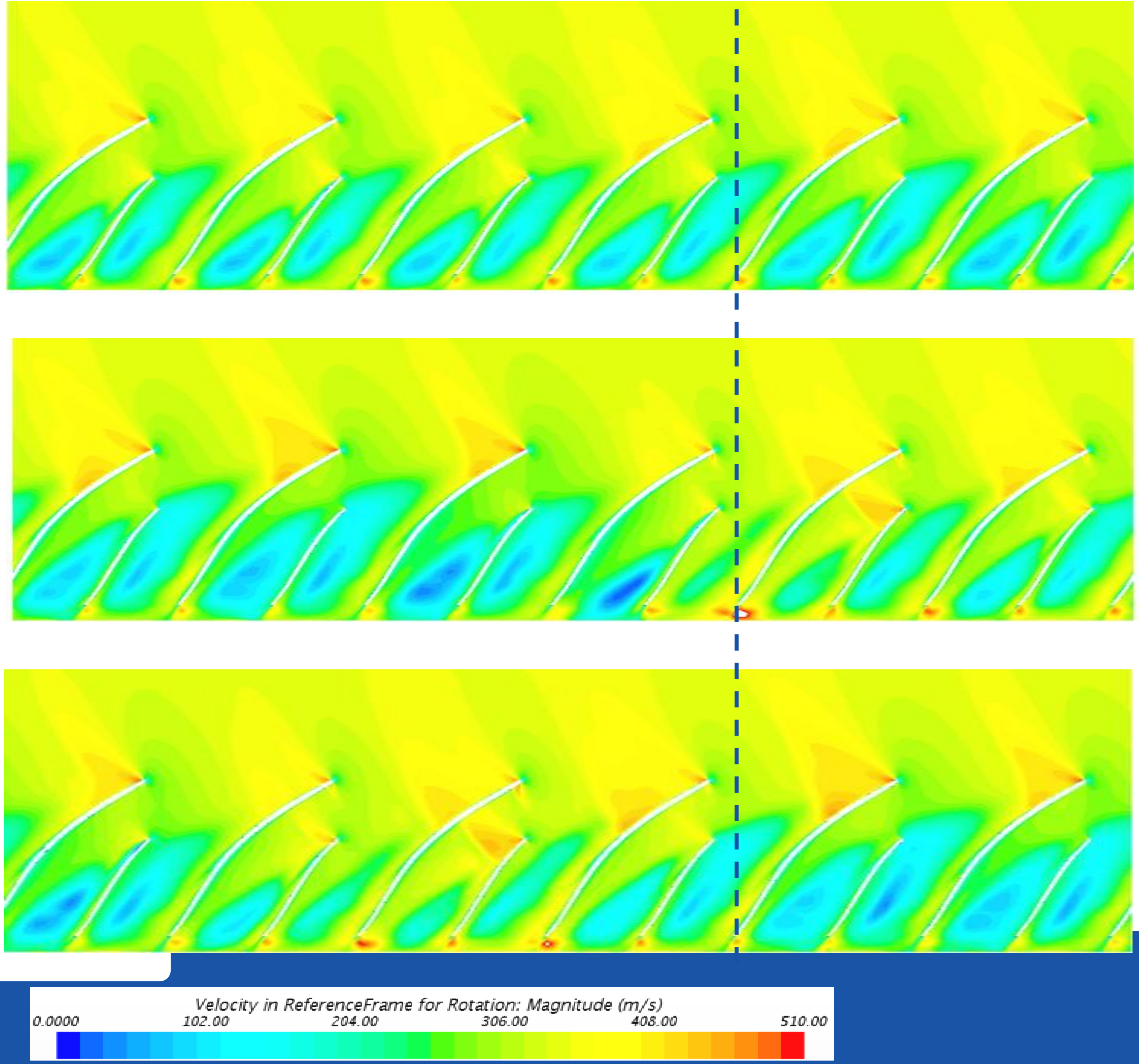
Additional slides



Baseline volute leads to almost symmetrical loading on impeller

Flush volute overall accelerated throughflow. Visible at VLD inlet Less symmetrical loading on impeller.

Symmetrically shelved VLD leads to significantly decelerated throghflow. The passage loading is largely symmetrical



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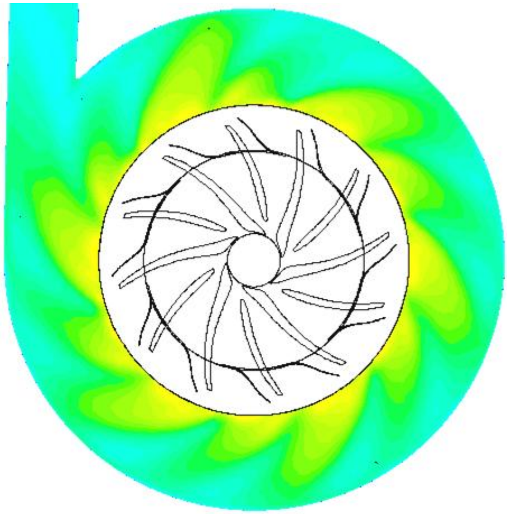
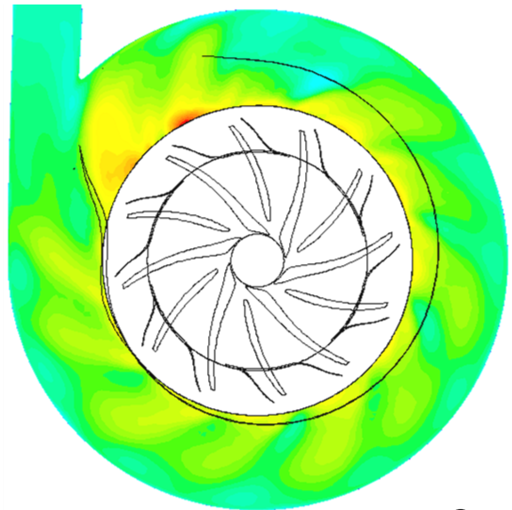
The unconventionally shaped volute induced a similar effect to the trimmed volute in terms of stability and pressure distribution

Diffuser midspan velocity distribution



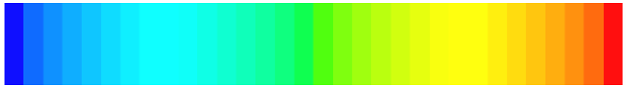
baseline

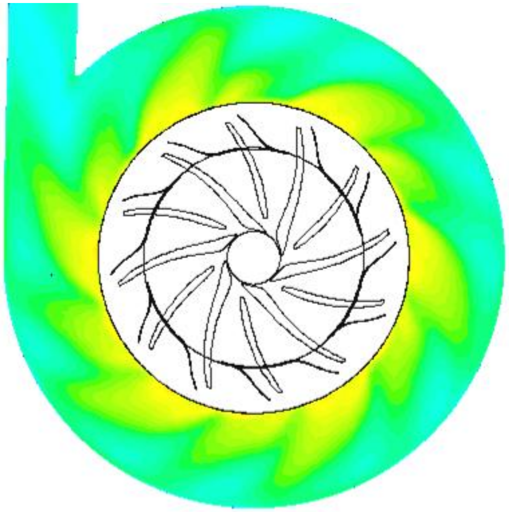


flush

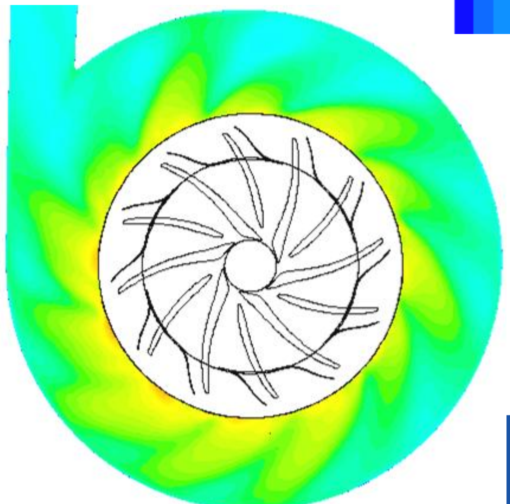
Allowing for proper diffusion inside the VLD we can reduce losses even if the circumferential pressure is not constant.

0 **Velocity magnitude** 485 [m/s]



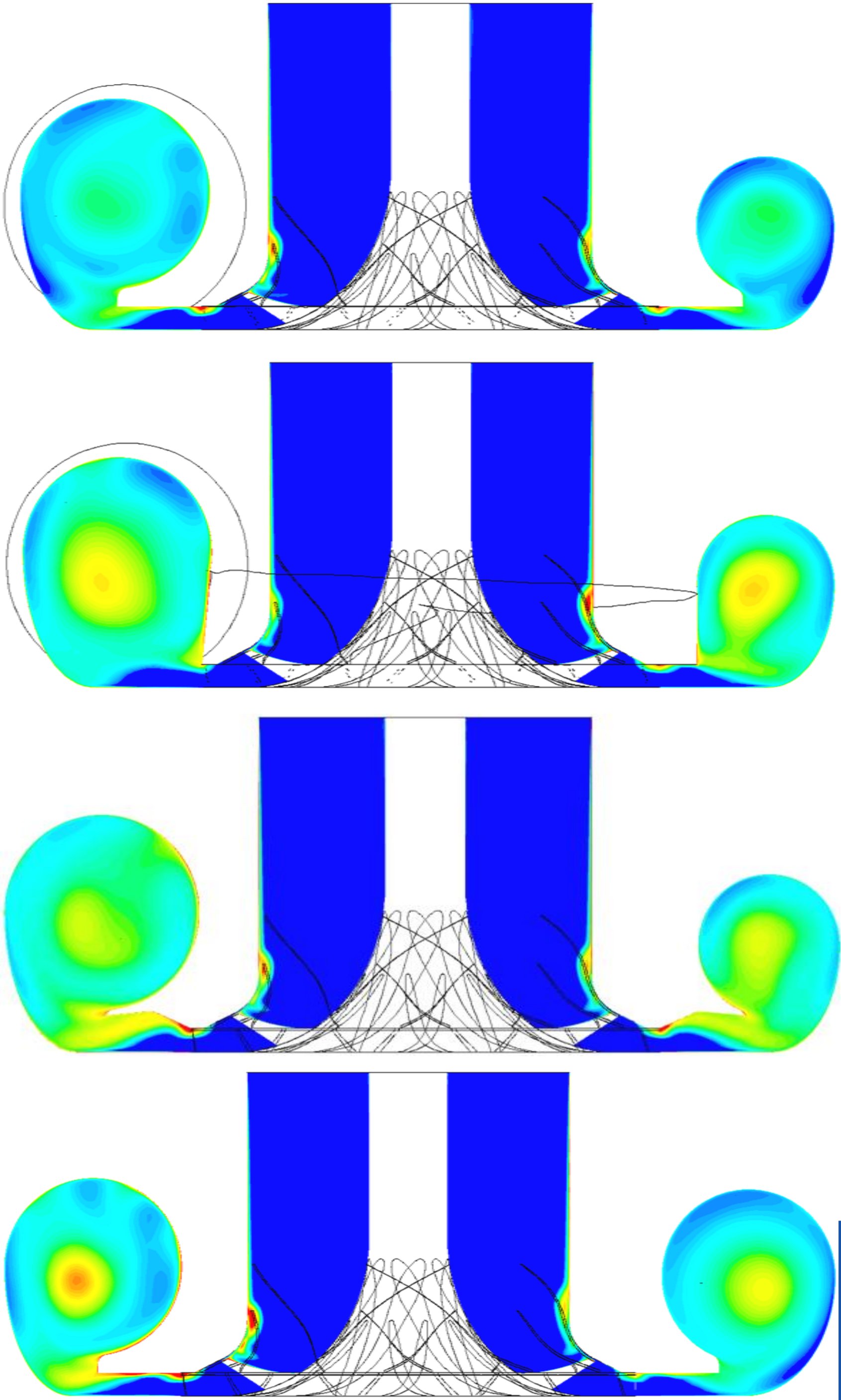


shelved



Unconventional volute

Transversal section entropy



baseline

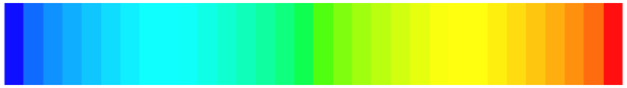
flush

shelved

Unconventional volute

The losses associated with the VLD interaction can be eliminated but reacceleration inside the scroll will impact efficiency at high flow conditions.

50 **Entropy** 160 [J/kg-K]



Maps of asymmetric vs symmetrical VLD for a centrifugal compressor

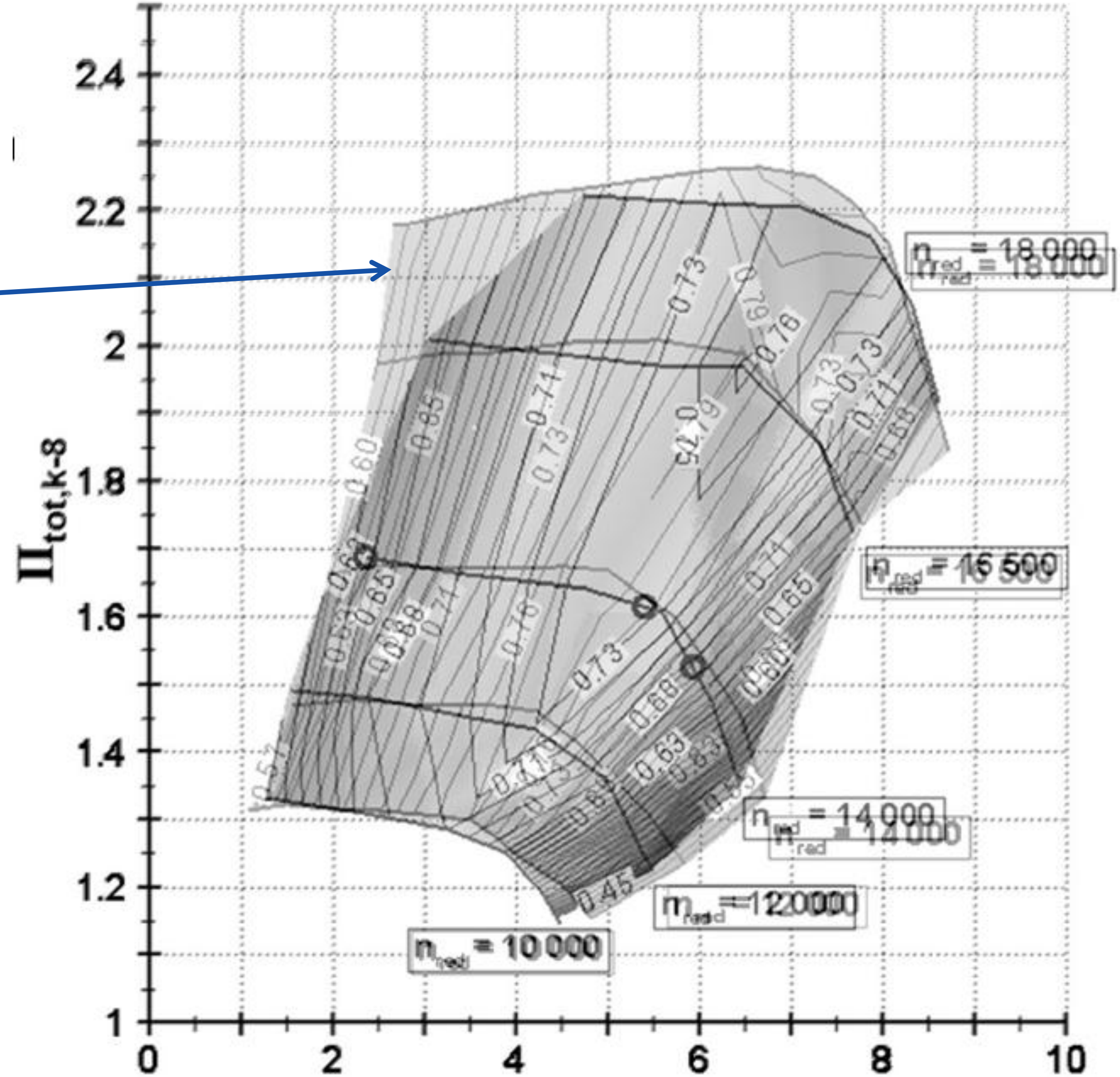
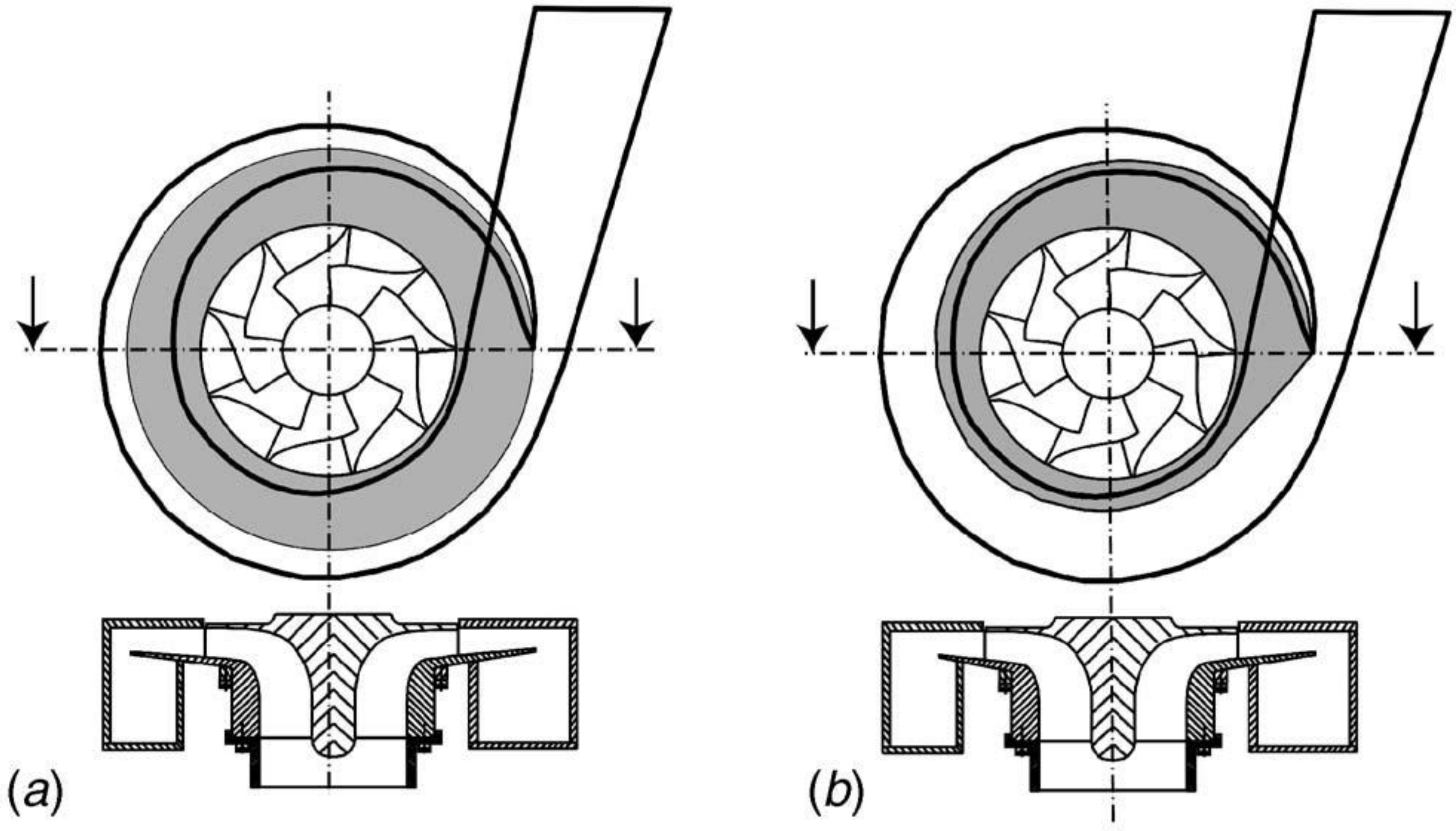


Fig. adapted from T. Steglich, J. Kitzinger,J. R. Seume, R. A. Van den, Braembussche, J. Prinsier, Improved Diffuser/Volute Combinations for Centrifugal, Compressors, Journal of TurbomachineryJANUARY 2008, Vol. 130 / 011014-1

The VLD geometries



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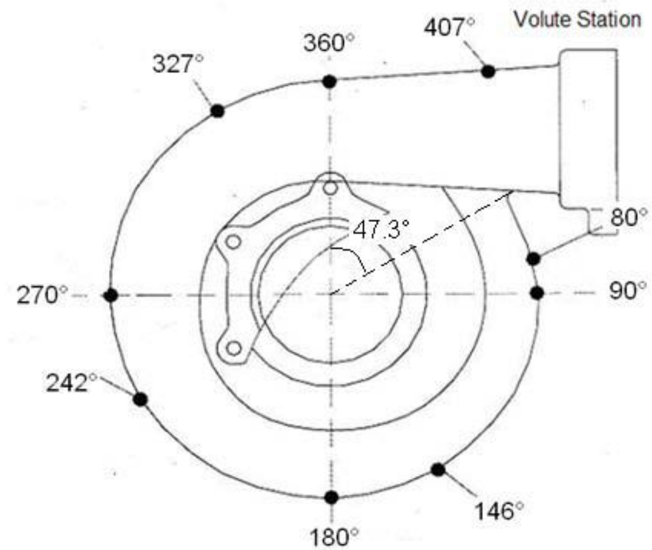
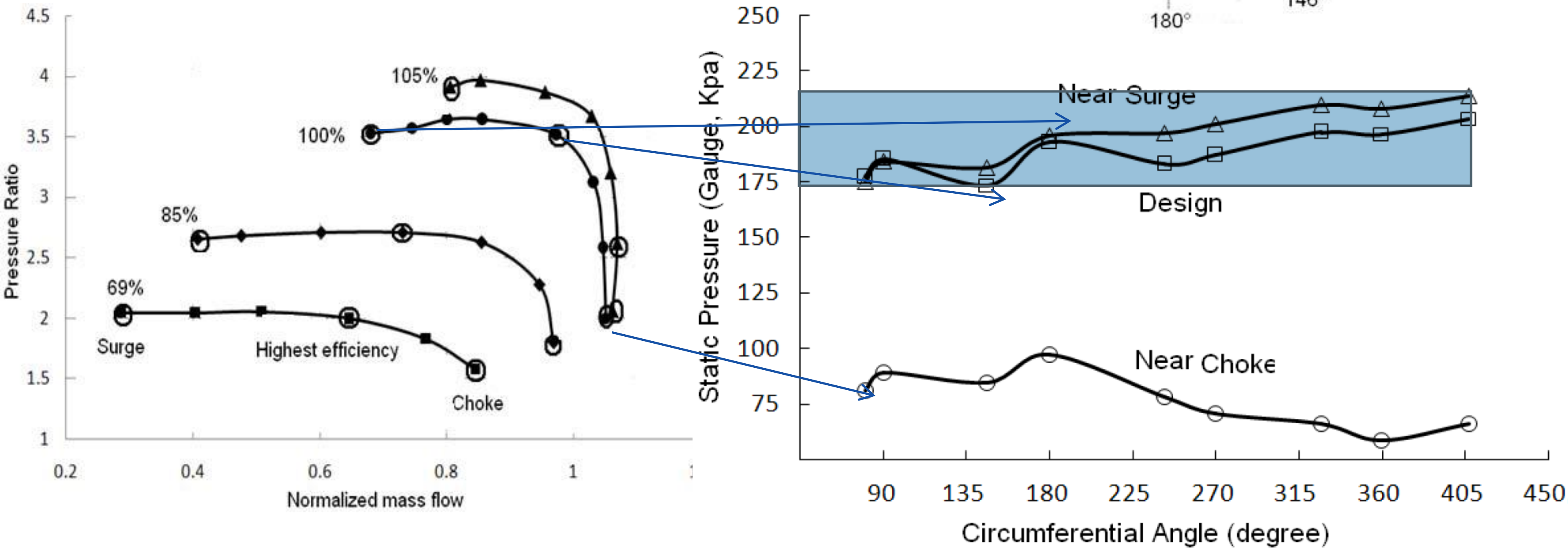
- Both Stepanoff and Pfleiderer methods lead to uneven pressure across the circumference





Figs. From ASME paper GT2010-22581

The natural trend is that at low flow coefficients, even an ideal volute will start to diffuse the flow

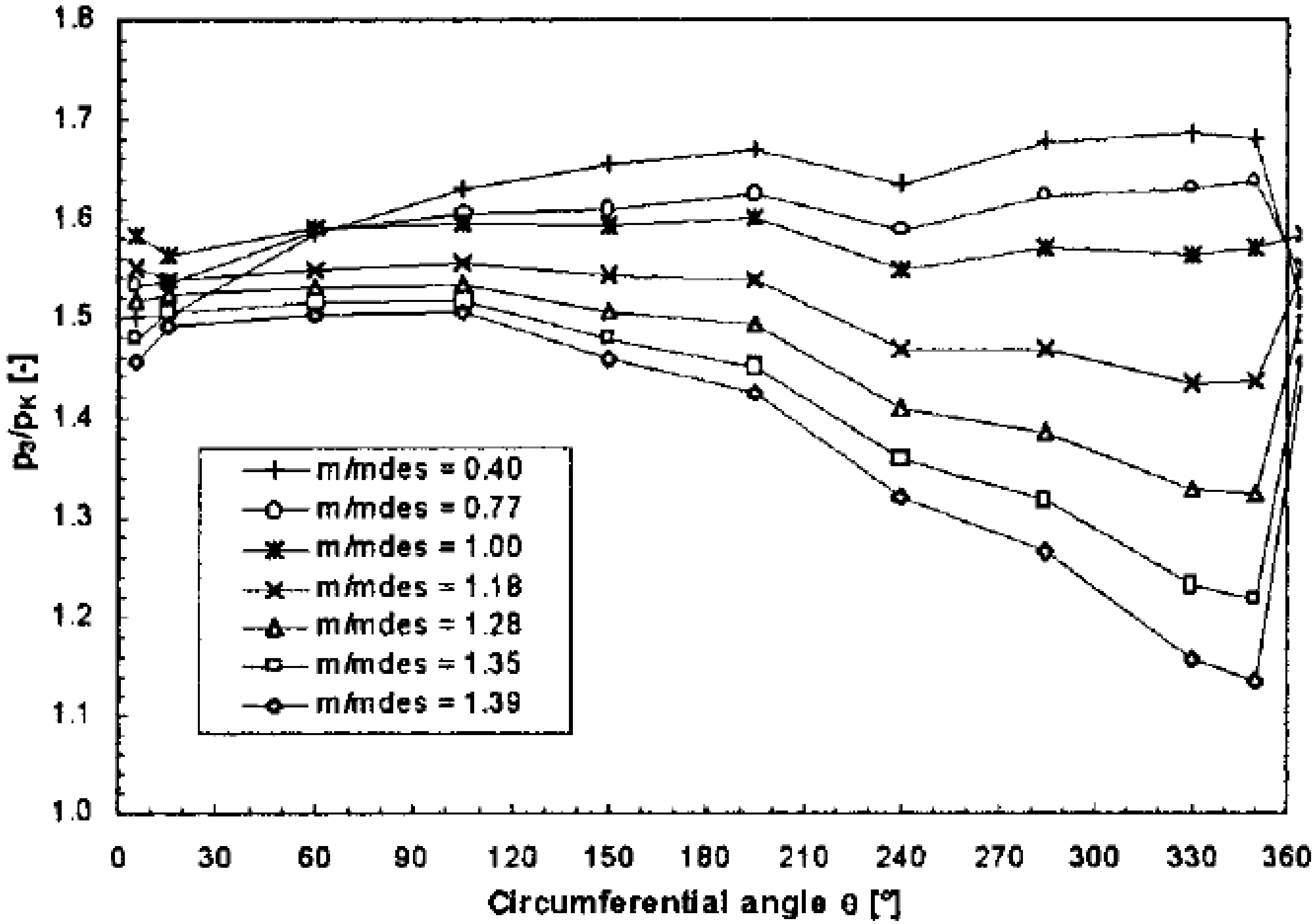


Fig. from ASME Paper No. 99-GT-79

Using shelved diffusers

Shelves can provide both choke and surge extensions

Their interacting mechanisms varies with the outlet Mach number

Authors have reported stall margin extensions of up to 10% for certain mid-speed speedlines, making his method a good complementary for NAS VLDs.

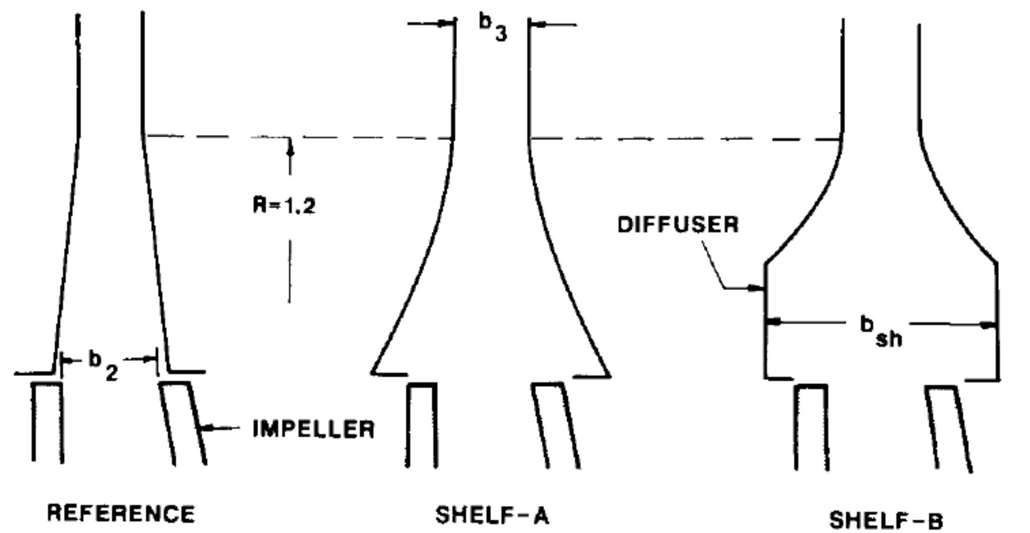
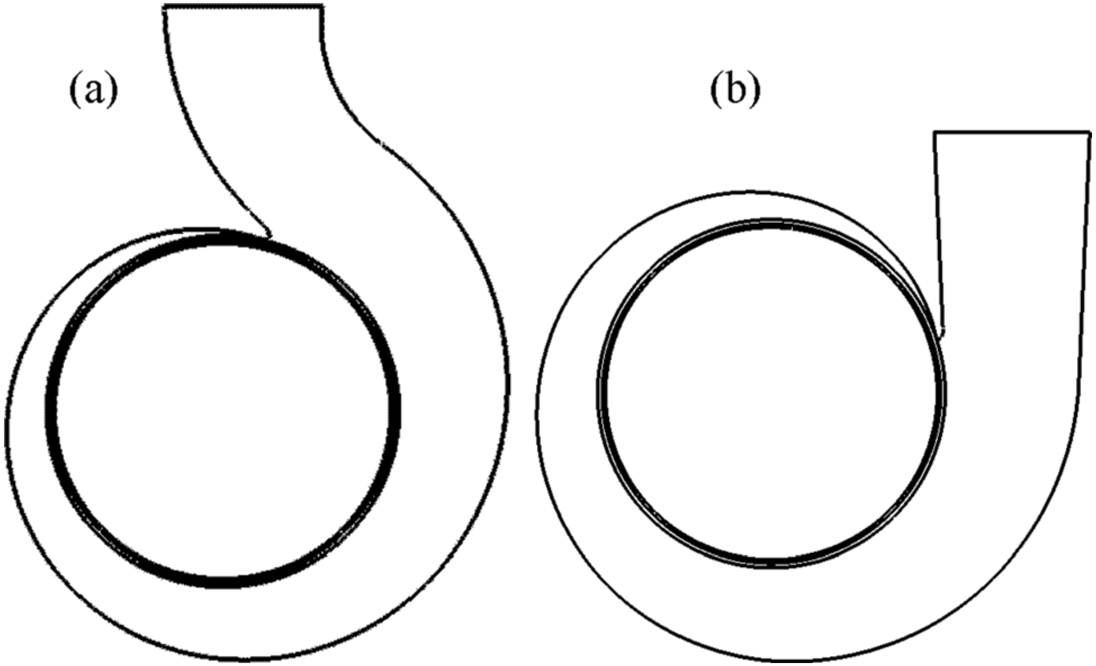


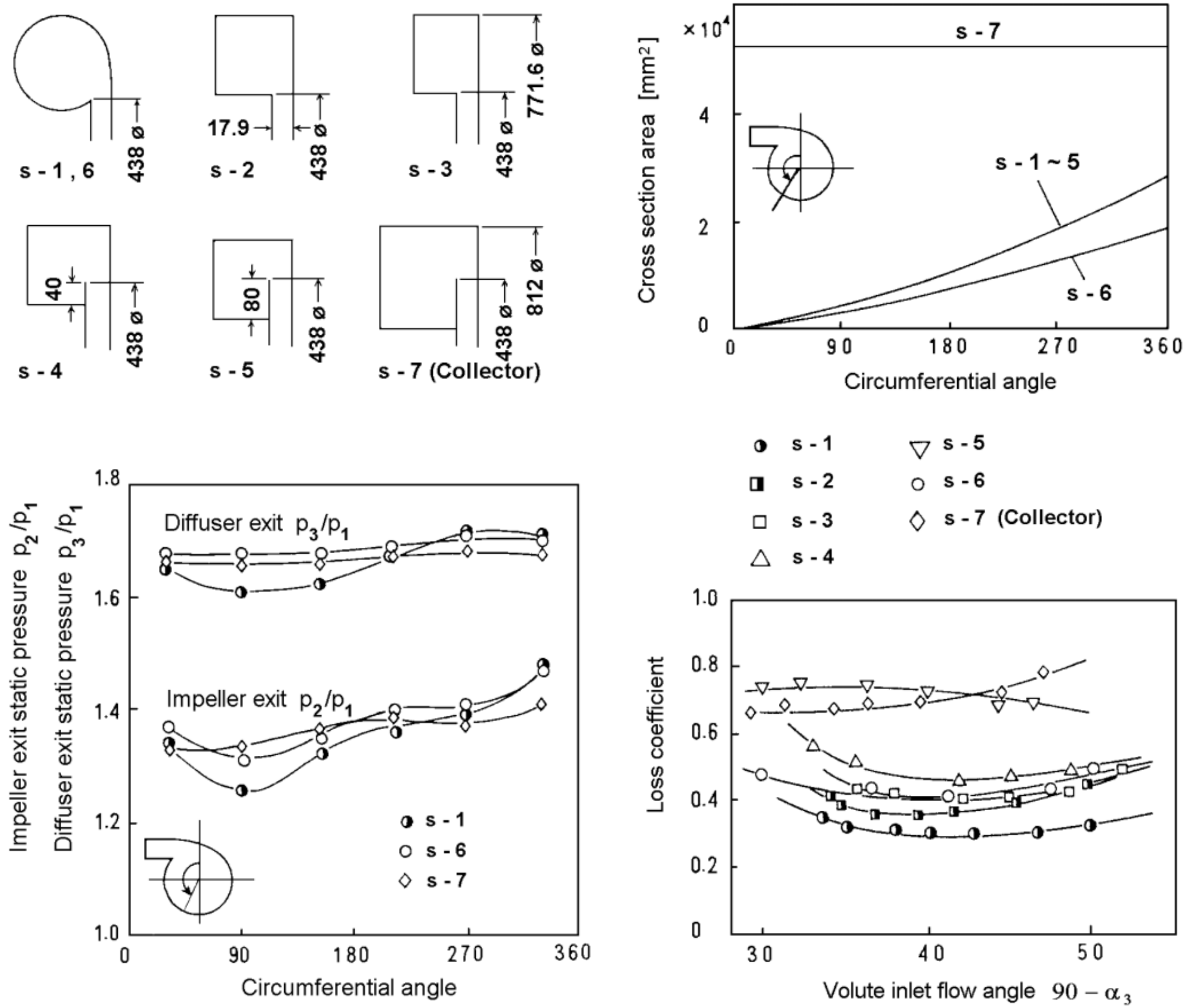
Fig. from G. J. HANUS, Characteristics of a Centrifugal Compressor With a Radial
Shelf Diffuser, ASME 87-GT-192

Volute diffuser influence

ASME paper 041009-4 concludes that a radial volute diffuser (a) would lead to less radial force on the impeller, indicating a more even distribution of pressure across the rotor.



The scroll (or collector) shape matters only in terms of efficiency, the trends remain the same.



Figs. from Mishina & Gyobu 1978

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