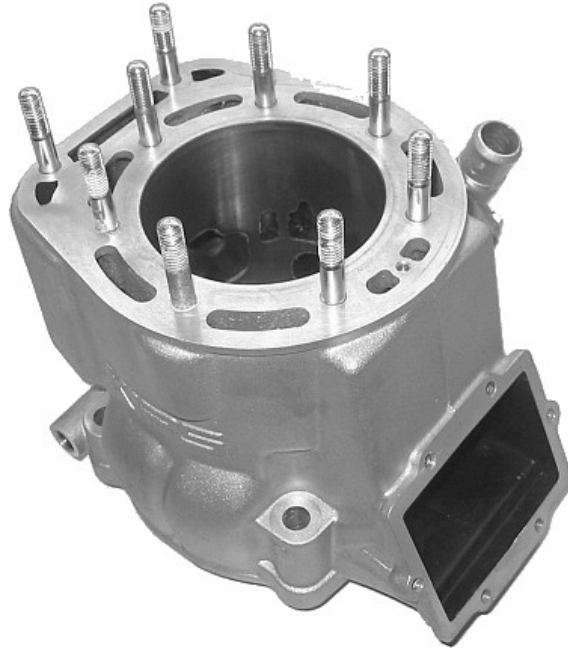


Bimotion Advanced Port & Pipe Case study A step by step guide about how to calculate a 2-stroke engine.

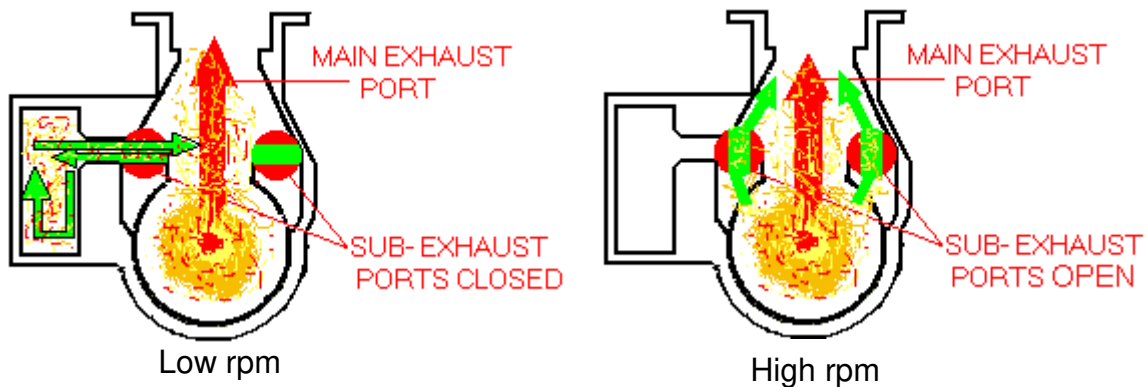
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KX500 2004

The Kawasaki KX500 motocross cylinder will be analyzed with the software Bimotion Advanced Port&Pipe in a case study which not only shows the ordinary mapping technique but also requires some special modeling approach. This engine produces massive torque at low rpm up to peak at 6500 rpm, a time-area calculation will show this in figures too. The KX500 cylinder is a true state of the art design of 2-strokes.

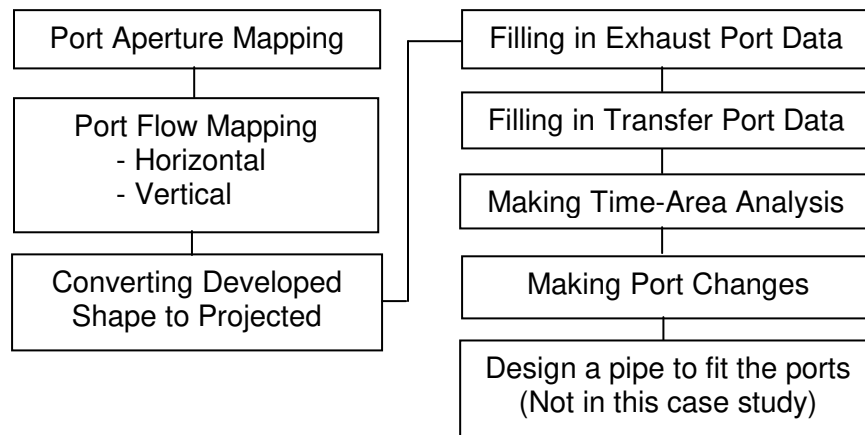
The brilliant KIPS exhaust system has an elevating upper valve, side sub port slide valves connected to a chamber which reduces the non-phased wave energy from the pipe at lower rpm.



The program can easily calculate both phases by disabling the sub exhaust ports with a single click, but we will first check peak power rpm.

Work Flow

As an overview, the different steps look like this:



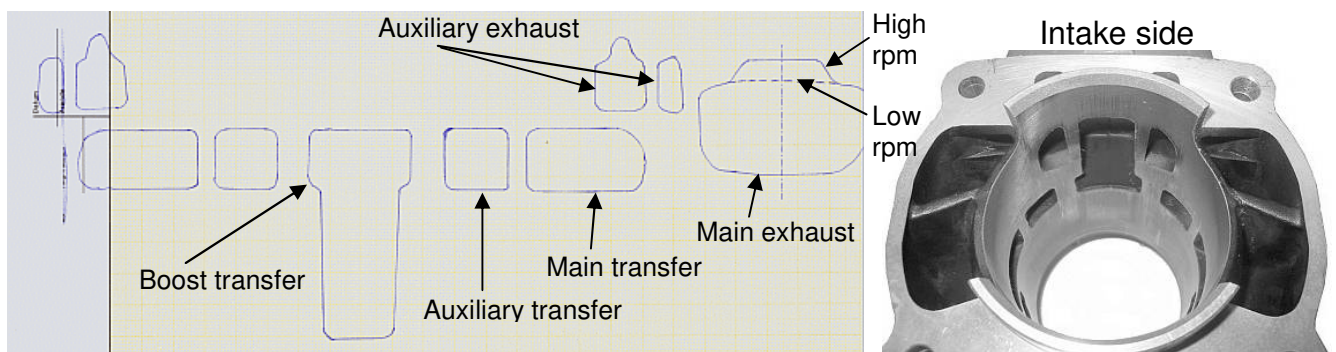
Port Aperture Mapping

The first step is to map the cylinder ports. A good advice is to use a special grid paper for best accuracy. (You will see why).

Print your own from e.g www.printfreegraphpaper.com. Place the paper in the cylinder and fix it with some tape, be sure to fit it straight and tight to the wall.

Use your fingers to massage the paper to the port edges, making reliefs. Remove and develop the paper and fill in the edges with a pen, be very accurate.

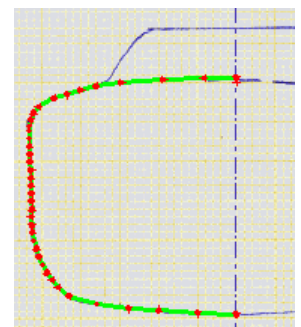
The result will look like this:



We will now measure the port width for each mm height, using Bottom Dead Center (BDC) as the height reference. Make a scan of the paper and work in a zoom view of the picture in the pc. As you can see, it's quite easy to get correct accuracy with the mm grid paper.

If the Exhaust main port is symmetric (which it should be) you only need to measure one side and double the width.

Make a table for each port starting from zero at BDC and fill in the width's to the top. At locations where the curve turns to the

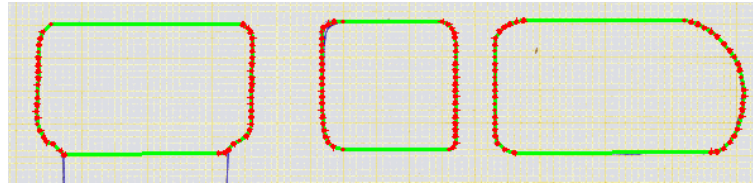


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horizontal direction, half mm height's or less can be measured to get a nice curvature.

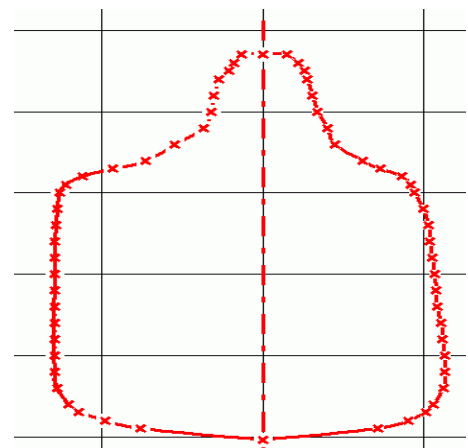
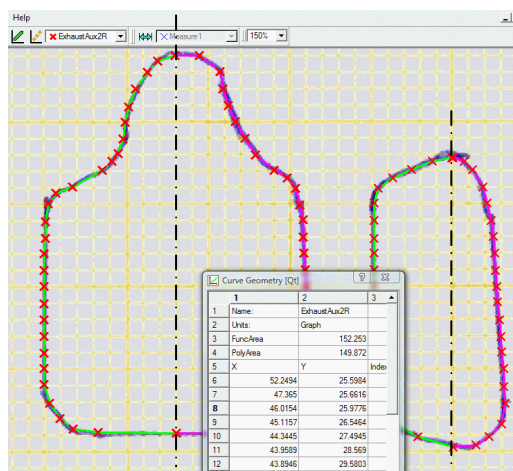
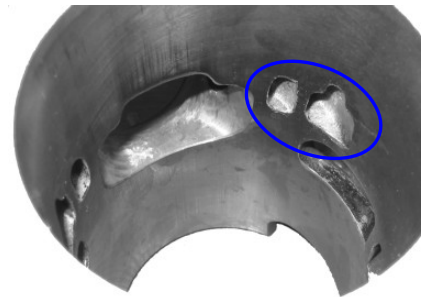
Do the same with the transfer ports, but with the complete way around since they are smaller. The main port is here non-symmetric, but that makes no different in the calculation, the actual modeling will always be symmetric.

The Exhaust sub auxiliary's needs to be treated in a somewhat different manner.



For better visibility, the port is modeled non-symmetric. The port is split in to two parts, in left and right side at the highest location by a vertical center line. Left and right width contours (green and blue lines) are measured individually to the center line at the same height values. Specify this in your table.

The KX500 cylinder has the very uncommon layout of two exhaust auxiliaries, so we need to cheat some to make that work. We simply add both left width values and both right width values, merging it to a single port (in two halves). As said before, the true non-symmetric shape has no influence on the calculation; it's only for a better layout visibility.



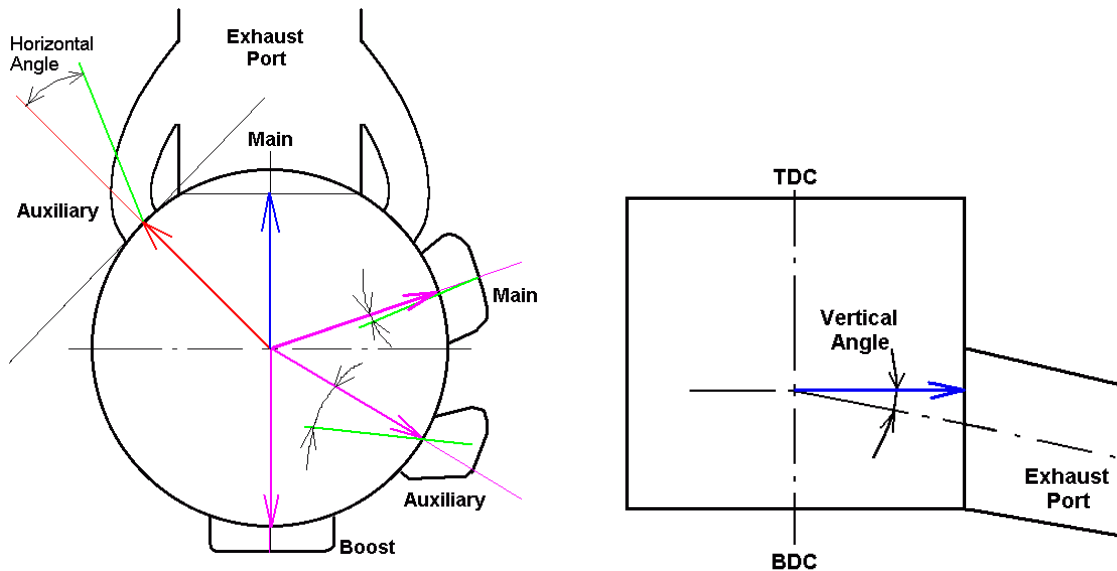
The exhaust auxiliary ports will be merged to one port in the program.

For the port mapping shown above we used the freeware *Engauge Digitizer* [1], but this can be made manually without problems.

This mapping is only a picture of the port aperture in the cylinder, perpendicular to the surface. It says nothing about the flow directions or the actual flow.

Port Flow Mapping

It is very important to understand the differences between port apertures and flow directions. The port time area is calculated from the perpendicular opened direction and reduced with the flow angle. Both horizontal and vertical angles should be measured. An example of the exhaust port directions are shown below:



Horizontal Directions

The easiest way to go for measuring horizontal angles is to take a picture of the ports from a central point from above like the picture below. We used the measuring tool in the freeware *IrfanView* [2] to measure angles in the picture.

Main Transfer:

The main transfer port is estimated to have a flow in 22 deg to the perpendicular direction.

The blue lines show the wall directions and the mean flow should be in the middle of these (white line).

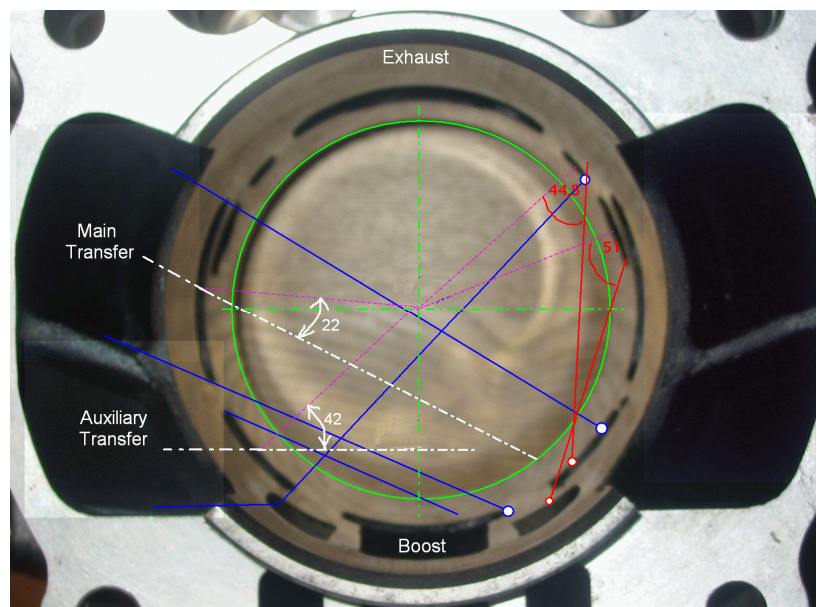
Auxiliary Transfers:

Flow direction: 42 deg.

The walls have very diverging directions, but this is part of the stratified porting close to the aperture. Flushing water into the ports will show the flow behavior and direction too.

Main Exhaust and Boost:

0 deg. (perpendicular)



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should be zero. (Here all but one is used since the port is very high). Repeat for all ports in the rest of the tables. Click "Copy" below the table, e.g. your main exhaust width data.

Click "Exhaust Port #1" tab and button "Paste" under the table Port#1; Main; Width. It's easiest to use these buttons since the cell formats are remained. If you by any reason choose to paste into any cells by any other way, be sure to use "Paste Special..." and "values" only.

Now fill in the height data as well. Repeat the procedure with the other ports from the Mapping page in "Exhaust Port #1" and "Transfer Ports".

("W.Out" and "W.In" refers to width inner and width outer.) Copy each table (click button) from "Exhaust Port #1" to "Exhaust Port #2".

Filling in Exhaust Port Data

When you make changes in "Exhaust Port #1" it will also affect the pipe calculation. Changes in "Exhaust Port #2" are now your reference as the original layout and are not connected to the pipe calculations.

In #2, fill in the original header dia, e.g. the inside dia of the cylinder flange. (Flange dia and header dia should match, if they don't, use the Flange dia.) In this case #2 flange dia is 46mm and the header 49mm, not so good. The relation between flange dia and port area is important, called "Factor K1" It should be within a certain value dependent on tuning degree (enduro mx, RR). The small red triangles in the cells give additional information, recommended values and ranges. 1.052 is slightly low for this application, indicating that the port area is a little bit low. However, the flange should match the header pipe so we need to grind it to 49mm to match the header. That will also match the K1 factor better. Without port modifications and with 49mm flange, K1 would be 1.121. We made some change to the port and went down to 1.061 which maybe is low but will do.

The angle (vertical only) was measured to 35 deg.

The x-location of the auxiliary port is only for layout mapping, it does not affect any calculation. The measured angles are entered too.

Max power is expected to be produced at 6500 rpm. Normally, a recommended duration at this rpm would be 163 deg, but this engine is special.

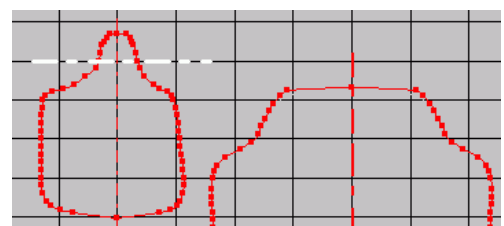
The auxiliaries are placed above the main port and that opening height is used as port height. However, since the auxiliary port has a 'decompression' upper shape for low rpm, we estimate the true height to 45 mm at peak rpm (white line). By clicking any of the option buttons either measure can be entered, mm, deg ATDC or duration. Or, if a desired duration is entered, the corresponding port height is returned.

Port #1				
Main		Auxiliary		
Height	Width	Height	W.Out	W.In
41,5	0,0	48,5	0,0	0,0
41,3	22,0	48,5	0,0	0,0
40,6	24,8	48,5	1,3	1,5
39,5	26,7	49,0	1,8	2,0
3,0	40,0	27,0	12,1	10,0
6,5	44,5	26,5	11,4	10,2
3,5	39,0	26,0	9,8	9,1
2,0	30,0	25,5	7,6	7,2
1,0	0,0	24,8	0,0	0,0
0	0	0	0	0
Copy	Copy	Copy	Copy	Copy
Paste	Paste	Paste	Paste	Paste

Main Port	#1	#2
Equiv. dia	46,2	43,7
Factor k1	1,061	1,052
Header dia	49,0	46,0
Width	47,6	47,6
%	55	55
Angle	35	35

Auxiliary Port		
X - location	40,0	40,0
Angle Vert.	5	5
Angle Hor.	47	47

Port Design Guide	
RPM	6500
Reco. Dur.	163
Duration	200
deg ATDC	80
Port height	45,0



Important to know about time-area and port design

The time-area measure is only a section flow measure of the port aperture as said earlier. This means that the actual t-a requirement for the calculated engine will vary dependent on the port layout, port channel shape and channel surface roughness. The nominal state is the untouched original design, in this case with a t-a target estimated to 13.9 s/mm. ($13.9 \cdot 10^{-3} \text{ mm}^2 \cdot \text{s/cc} = 13.9 \text{ s/mm}$). This measure is independent of cylinder size since it is divided by the cc, thus can be compared with other engines sizes with the same type of porting if we like. However, with a careful and well performed cylinder porting, only considering the port channels, the channel flow will increase significantly. From calculation point of view, this lowers the port aperture time area requirement to produce the estimated hp's, and the change can be as much as 1s/mm. By other means, the total flow and BMEP will increase at the nominal t-a. This cylinder was ported for maximum flow (and with a small exhaust port area and timing adjustment independent of that), so we can use 1s/mm for compensation. This is done by increasing the BMEP value from nominal 8.2 to 9.7, changing the target t-a from 13.7 to 14.7 s/mm. (You do not change the port t-a, only the target value !) The hp output will increase to about 71hp. This engine was not run in bench to confirm the figures, but an experienced test ride does confirm the change.

It should also be said that a bad port configuration and shape may lower the flow with the corresponding value of 1 s/mm. **This leaves the actual time-area target bounds to $\pm 1 \text{ s/mm}$ from nominal value.**

Making the port analysis

At this point we are ready to make some analysis of the power capability regarding the exhaust ports. According to the recommendations, the motocross tuning degree should be defined as approximately 9 bar bmep (braked mean efficiency pressure).

We also know that a 500cc mx engine produces about 62-65hp. That is usually the power the rear tire can transmit by traction on an average motocross circuit.

Now if we change the bmep value, the time-area target sum and hp will change. (Stock configuration is changed in 'Exhaust Port #2'). More hp requires more t-a.

If we adjust the bmep so the target t-a matches with the actual port t-a, we will get a good estimation of the actual peak power, assuming that everything else is well designed and state of the art. This simple time-area calculation says that the exhaust delivers about 60hp stock, which probably is very close to reality. The ride feeling of this engine is a massive bottom and midrange but without any distinctive upper peak, as it's holding back. This could be the evidence in figures !

Tuning State	
Bmep	8,2
Kw	44,4
hp	60,3
Vpiston mean	18,6
Vpiston max	31,1

Time-Area		
Port	#1	#2
Blow down	2,9	3,0
Auxiliary	4,9	4,9
Main	9,0	8,6
Sum	13,9	13,5
Target		
Blow down	0,8	0,8
Sum	13,9	13,5

Tuning State	
Bmep	8,6
Kw	46,5
hp	63,2
Vpiston mean	18,6
Vpiston max	31,1

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In order to increase the peak power we increase bmep in 'Exhaust Port #1' which tells us which corresponding t-a we need. About 3 more nominal hp's at top end would be desired and will probably not affect the low rpm power significantly. We can not increase the port area too much either since the K1 factor may change out of range that would cost us a new exhaust pipe...

Port #1				
Main		Auxiliary		
Height	Width	Height	W.Out	W.In
41,5	0,0	48,5	0,0	0,0
41,3	22,0	48,5	0,0	0,0
40,6	24,6	48,5	1,3	1,5
39,6	26,7	48,5	1,8	2,2
3,5	48,5	27,0	12,1	10,8
6,5	44,5	26,5	11,4	10,2
3,5	39,0	26,0	9,8	9,1
2,0	30,0	25,5	7,6	7,2
1,0	0,0	24,8	0,0	0,0
0	0	0	0	0
Copy	Copy	Copy	Copy	Copy
Paste	Paste	Paste	Paste	Paste

In order to increase the hp's even more we perform a skilled port shape work to increase the port channel flow capability. According to above discussion, this changes the t-a target by 1 s/mm, increasing the BMEP, thus hp to 71hp's.

When we make preview changes to the ports we don't need to change the port shape in the first place. By using the offset cells in the tables (marked blue in picture) we can estimate the effect of raising or widening the ports quickly. The effect of a different cylinder gasket will be revealed instantly.

Table #6	
Input values	Output values
-7	-9,0
8	6,0
13	11,0
18	16,0
23,5	21,5
26,5	24,5
26	24,0
24	22,0
21	19,0
Offset	-2
Paste	Copy

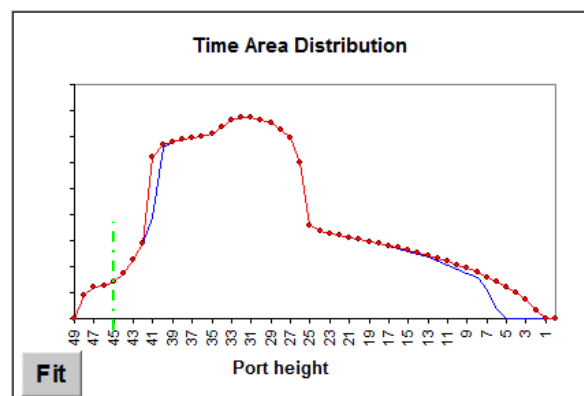
If a suitable offset value is found, then we don't have to change the whole table either to make it permanent with zero offset. Table #6 in the 'Port Mapping' will do this. Copy the table with the button and paste it into Table #6. Apply the offset and copy, paste back again.

If we would like to increase the peak rpm with more hp, we must keep the current time-area (mass flow) at the increased rpm. The time area will decrease as we enter a higher rpm (less time for flow), so we need to remove material somewhere.

At this point it's important to understand the t-a distribution over the port. The distribution chart (to the right) shows the relation. When we decided to choose 45 mm as the efficient port height for the auxiliary exhausts, we could see that this was a good point from total flow point of view in the distribution chart. Below 45mm (thin green line), the importance of the port flow increases dramatically. This is not easy to see by just watching the port itself.

A t-a distribution example: A 1mm high, 10mm wide (10mm²) area at the top of the port is opened for 0.0051 sek during one stroke which is equal to t-a 0.051mm²*s. At the bottom, at BDC, the piston opens the last mm for only 0.0014 sek, equal to t-a 0.014mm²*s.

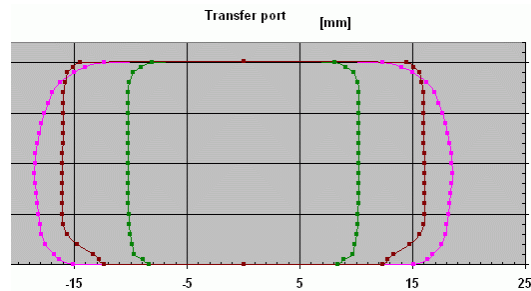
Removing 10mm² at the bottom of the port will *nominally* only increase the t-a flow capability by 27% compared to the top, but increasing the port area just as much (which affects factor K1 and the pipe). In reality, the difference is much larger since the pressure is much higher at the top of the port just as it opens. Maybe there is no pressure difference at all (no flow) as the port is fully opened and the lower part change will



make no difference at all... At this point the pipe influence must be considered, understanding when the pulses arrive and to what magnitude. Above 9000 rpm there is a low pressure secondary pulse arriving from the tailpipe which increases the scavenging efficiency. A lower port modification will in that case have just as much influence *to that pulse* as in the top region (not applicable on this engine). More details about time-area and time-area distribution can be studied on the Bimotion webpage in the 'Theory' section.

Filling in Transfer Port Data

We have 5 transfer ports which are modeled by symmetry for simplified and comparable viewing. The same procedure goes with the transfers as with the exhaust ports, making the projections and applying angles etc.



2- Port
3- Port
4- Port
5- Port

Port Height	
Duration	129
deg ATDC	116
Port height	20,0
Tuning State	
RPM	6500
Bmep	8,6
Kw	46,5
hp	63,2
Vpiston mean	18,6
Vpiston max	31,1

The port height of 20mm gives us 129 deg duration, which is ok for a good balance between midrange and peak power. The transfer 'Tuning State' table applies to the 'Exhaust Port #1' values, the same as referenced with the pipe calculations.

Now down to the interesting part again; time-area. We can see the target values for the different ports and actual values.

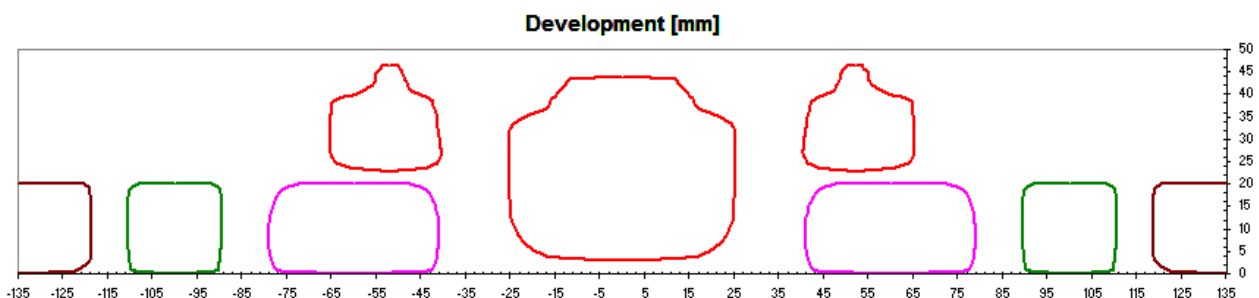
Everything is on target except the main transfer which is dimensioned for massive midrange torque... Even with the increased bmep giving 63 hp it will be over target, there is nothing we need to do here !

The blow down targets should be treated with care; it is not proved to be a perfect measure since it is widely dependent on pipe

Time-Area					
Port	Current	%	Target	%	Blowdown
Main	5,7	59	3,8	50,0	Current #1 2,9
Aux.	2,6	28	2,5	33,3	Current #2 3,0
Boost	1,3	13	1,3	16,7	Target 0,8
Sum	9,6		7,6		

design. Since big bore motocross engines needs a very wide power band, the pipe angles (read exhaust pulses) will not be in line with a smaller engines, tuned for peak power only. This is why this engine needs much more blow down charging to the pipe. We could also see this in the exhaust duration.

If we want to make a port change, then there is a development printout available for reverse port mapping in the 'Development Chart' sheet. Paste inside cylinder and start grinding.



References

- [1] Engauge Digitizer, <http://markummittchell.github.io/engauge-digitizer/>
- [2] Irfan View, www.irfanview.com, measuring tool accessible with short key F12
- [3] Bimotion Advanced Port & Pipe screenshots:

BIMOTION - Custom Racing Pipe

Engine: Test example (kx500-04)

Pipe Data		Length Data		Dia Data		Angle Data	
Temperature	500	LT (Total)	1426	d0	46,2	alfa0	0,5
BellyFact. k2	2,3	L1 (Header)	418	d1	49	alfa1	2,0
Flange Length	25	L2 (Diff. 1)	220	d2	56	alfa2	3,0
Header Length	393	L3 (Diff. 2)	180	d3	71	alfa3	4,0
Header Factor	8,5	L4 (Diff. 3)	162	d4	90	alfa4	4,5
Port Factor k1	1,061	L5 (Belly)	132	d5	113	alfa5	9,0
1-Stage Diffus or		Work Strategy		1-Stage Baffle			
2-Stage Diffus or		Cones		2-Stage Baffle			
3-Stage Diffus or							

Diffuser 1	
R1	800
R2	1020
Coord Length	223

Diffuser 3	
R1	646
R2	808
Coord Length	351

Diffuser 2	
R1	680
R2	861
Coord Length	282

Baffle 1	
R1	618
R2	718
Coord Length	350

Baffle 2	
R1	93
R2	310
Coord Length	292

Y - lines Axis Range
 X - lines Y 30
X 100

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BIMOTION - BLAIR Racing Pipe

Engine: Test example (kx500-04)

Pipe Data		Length Data		Dia Data		Angle Data	
Temp (C)	500	LT (Total)	1426	d0	46,2	alfa1	1,2
Kh	1,50	L1 (Header)	143	d1	49,0	alfa2	2,9
BellyFact. k2	2,3	L2 (Diff. 1)	392	d2	66	alfa3	4,5
StingerFact.	0,62	L3 (Diff. 2)	261	d3	92	alfa4	7,0
Flange Length	25	L4 (Diff. 3)	131	d4	113		
Header Length	118	L5 (Belly)	157	d5	113		
PortFact. k1	1,061	L6 (Baffle)	342	d6	29		
HeaderDia	49	L7 (Stinger)	342	d7	29		

Diffuser 1	
R1	1145
R2	1538
Coord Length	206

Diffuser 2	
R1	649
R2	910
Coord Length	289

Diffuser 3	
R3	594
R4	726
Coord Length	351

Baffle	
R1	117
R2	462
Coord Length	345

Y - lines Axis Range
 X - lines Y 20
X 100

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BIMOTION - Transfer Ports

Engine: Test example (kx500-04)

Height	Main	Aux.	Boost
20,1	0,0	0,0	0,0
20,1	0,0	0,0	0,0
20,1	0,0	0,0	0,0
20,1	0,0	0,0	0,0
20,1	0,0	0,0	0,0
20,1	0,0	0,0	0,0
20,1	0,0	0,0	0,0
20,0	24,6	16,2	28,9
19,5	28,0	18,1	30,2
19,0	30,1	19,5	31,3
18,0	32,5	20,3	31,5
17,0	33,9	20,5	31,9
16,0	34,7	20,5	32,0
15,0	35,3	20,5	32,0
14,0	35,9	20,5	32,0
13,0	36,2	20,5	31,9
12,0	36,5	20,5	31,9
11,0	36,9	20,5	32,1
10,0	37,0	20,5	32,2
9,0	37,0	20,5	32,2
8,0	37,0	20,5	32,2
7,0	36,8	20,5	32,2
6,0	36,6	20,5	32,2
5,0	36,3	20,3	32,2
4,0	36,1	20,2	31,9
3,0	35,8	20,0	31,2
2,0	35,1	19,7	29,5
1,0	33,6	19,3	26,6
0,5	32,7	17,9	25,6
0,0	30,2	16,7	24,6
0,0	0,0	0,0	0,0

Port Exit Angle			
Direction	Main	Aux.	Boost
Vertical	0	0	63
Horizontal	22	42	

Port Height	
Duration	129
deg ATDC	116
Port height	20,0

Tuning State	
RPM	6500
Bmep	8,6
Kw	46,5
hp	63,2
Vpiston mean	18,6
Vpiston max	31,1

2 - Port

3 - Port

4 - Port

5 - Port

Transfer port [mm]

Time-Area						
Port	Current	%	Target	%	Blowdown	
Main	5,7	59	3,8	50,0	Current #1	2,9
Aux.	2,6	28	2,5	33,3	Current #2	3,0
Boost	1,3	13	1,3	16,7	Target	0,8
Sum	9,6		7,6			

Auto Range
 Auto Range

Axis Range	
Y	X
21	25

1:1

OK

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BIMOTION - Exhaust Port #1

Engine: Test example (kx500-04)

Port #1			
Main		Auxiliary	
Height	Width	Height	W.Out
41,7	0,0	48,5	0,0
41,3	22,0	48,5	0,0
40,6	24,6	48,5	1,3
39,6	26,7	48,0	1,8
38,8	28,0	47,5	2,1
37,6	29,6	47,0	2,7
36,6	31,1	46,0	3,0
35,6	32,0	45,0	3,2
34,6	34,2	44,0	3,7
33,7	37,9	43,0	5,5
32,7	43,1	42,0	7,3
31,6	46,0	41,5	9,3
30,8	46,8	41,0	11,2
29,9	47,5	40,5	12,2
28,6	47,6	40,0	12,7
27,6	47,6	39,0	12,8
26,5	47,6	38,0	12,9
25,5	47,6	37,0	13,0
24,7	47,6	36,0	13,0
23,6	47,5	35,0	13,0
22,6	47,4	34,0	13,0
21,6	47,4	33,0	13,0
19,6	47,4	32,0	13,0
17,6	47,4	31,0	13,0
15,6	47,4	30,0	13,0
13,5	47,2	29,0	13,0
11,5	47,0	28,0	12,8
9,5	46,5	27,0	12,1
6,5	44,5	26,5	11,4
3,5	39,0	26,0	9,8
2,0	30,0	25,5	7,6
1,0	0,0	24,8	0,0
0,0	0,0	0,0	0,0

Tuning State	
Bmep	8,6
Kw	48,7
hp	66,2
Vpiston mean	18,6
Vpiston max	31,1

Engine Dim.	
Bore	86,0
Stroke	86,0
Rod length	172,0
Vol. [cc]	499,6

Port Design Guide	
RPM	6500
Reco. Dur.	163
Duration	208
deg ATDC	76
Port height	48,5

Main Port			
#1	#2		
Equiv. dia	48,0	43,9	
Factor k1	1,021	1,021	
Header dia	49,0	46,0	
Width	49,6	47,6	
%	58	55	
Angle	35	35	

Auxiliary Port	
X - location	40,0
Angle Vert.	5
Angle Hor.	47

Time-Area

Port	#1	#2
Blow down	2,9	2,7
Auxiliary	6,1	4,9
Main	9,4	6,7
Sum	15,5	13,7
Target		
Blow down	0,9	0,8
Sum	14,3	13,5

Show Port #2 Data

Show Port #2 Distribution

Show Port #2 Shape Plot

Time Area Distribution

Exhaust Port [mm]

Axis Range	
Y	X
50	60

1:1

OK

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