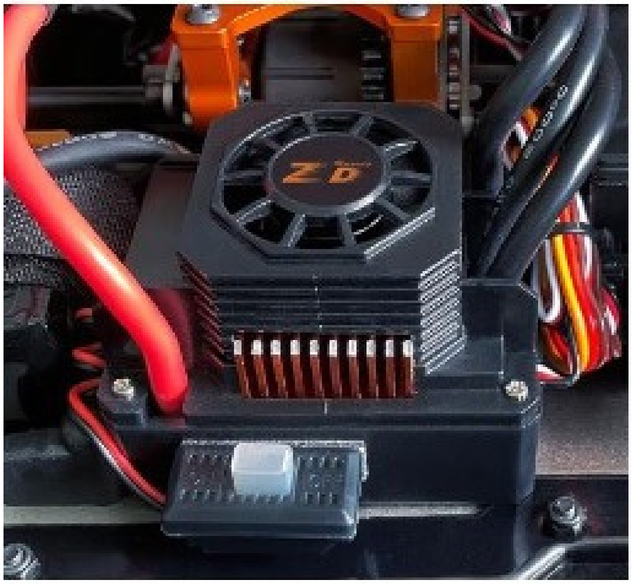
ESC Fire Investigation

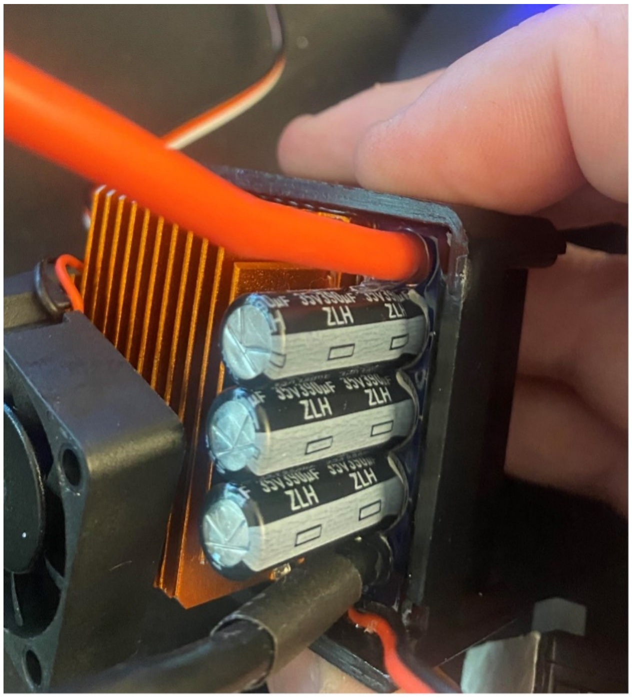
150A Brushless ESC Part for ZD Racing EX07 1/7 RC Car
SKU 6721365

Video of RC car and ESC fire scenario:
https://www.youtube.com/watch?v=Wi4VRdVBz6E

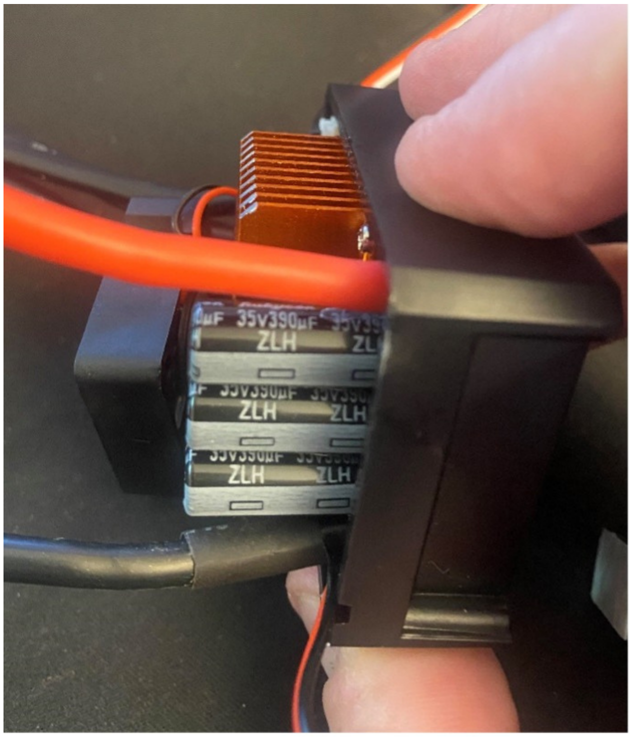


Analyzing the video, we noted that the fire originated in the corner where the RED lead (input +) is located.

We removed the plastic housing to inspect the RED lead area.



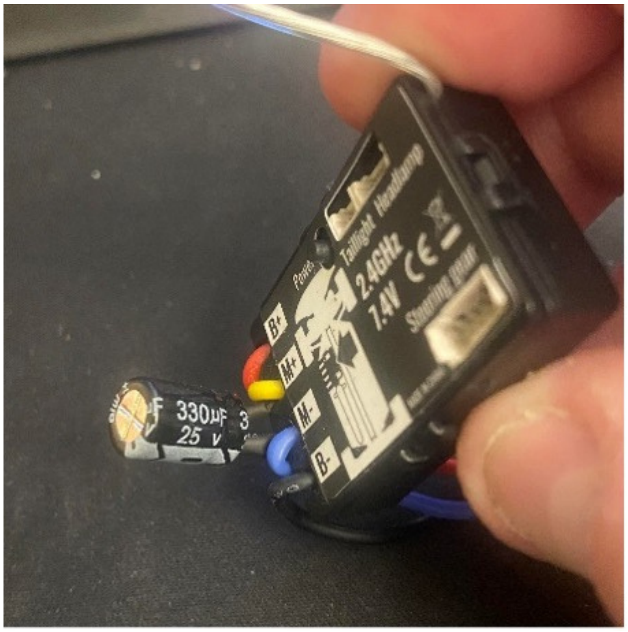
We revealed the input CAPs and found them to be Rubycon ZLH series 390uF rated for 35V, these are fairly common within RC ESC applications.



This immediately became our primary suspect and here are 2 working theories:

1. High AMP usage exceeded the thermal rating of the CAP and caused damage to the internal layers. The damage created a short between POSITIVE and NEGATIVE CAP LEADS. This short caused heat and fire.
2. High AMP usage caused a high ripple current exceeding the cap rating. This resulted in CAP destruction that caused a short, leading to heat and fire

It's worth noting the extremely low safety margin in the CAP max voltage rating versus max input rating for the ESC- 25V (6s lipo) versus 35V max CAP rated voltage 1.4X safety margin.

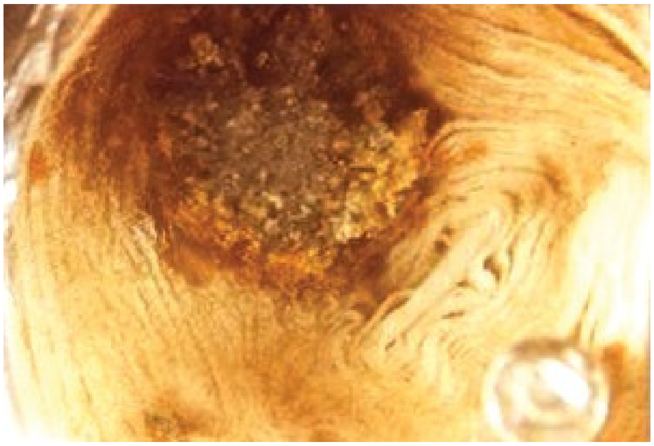


Here's an example from UDI 1601 ESC, rated for 2S lipo (8.4V) and has a 25V input CAP (3X safety margin).

Working Theory 1

Looking at the CAP's impedance (0.029ohm), assuming 150A usage, this will generate 4.35watt. However, because we have 3 of these caps in parallel, this will generate 1.5W of heat. This is enough to cause thermal failure in the CAP.

Typical PCB damage due to failed CAP.



Typical damage inside the CAP.

Source:
https://www.ee.co.za/article/thermal-stress-capacitors-failure-prevention.html#.YGp_8sBHbDv

Working Theory 2

The max ripple current allowed is 1500mA but because an RC ESC is very low frequency, the allowed ripple is only 0.55*1500 = 825mA. At 150A a few quick large throttle changes can cause 3 times that ripple value. I.E multiple full-throttle—full break—full-throttle applications can have substantial ripple current through the CAP.

Potential Solutions

- These can be solved from a design perspective by selecting a higher voltage cap (higher voltage safety margin), higher ripple current capability, and better thermal handling.
- Another option is to add more of the same CAPs to reduce each CAP stress\load.
- The most practical solution for a user would be to mitigate the risk of CAP failure by adding an external CAP pack.

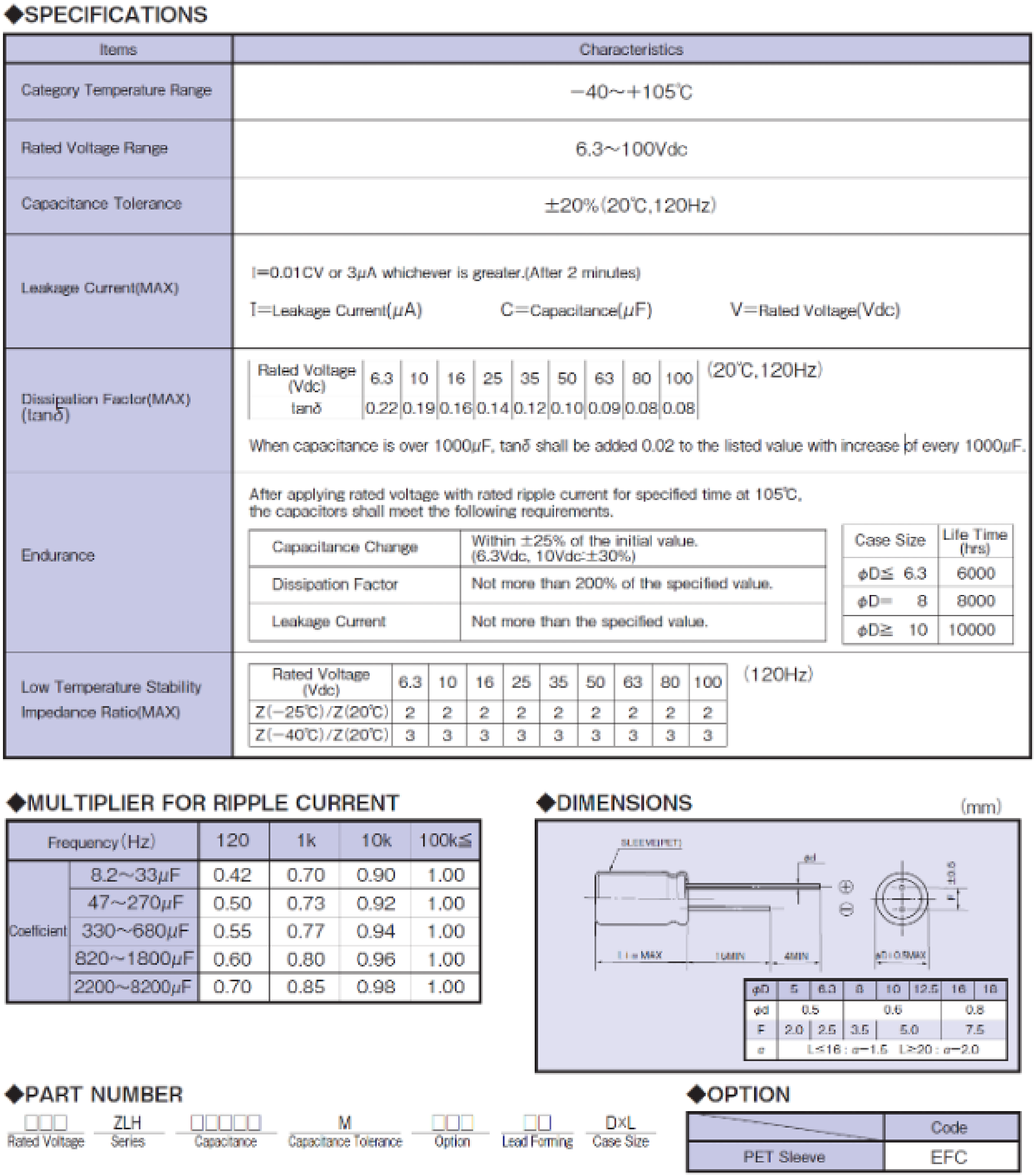
Conclusions

- We recommend lower current applications (I.E with lower C rating battery) or MAX 5S lipo if using the ESC ‘as is’ out of the box.
- We would estimate that using a 6S application without a CAP pack will result in CAP failure. It’s only a matter of time\battery cycles, external temperature, and user behavior (throttle\break application) until a 6S application fails.

Ofer Maltiel
Principal Engineer, Hudson Street Solutions

Appendix A

CAP Specs



◆SPECIFICATIONS

<table>
<tr><th>Items</th><th>Characteristics</th></tr>
<tr><td>Category Temperature Range</td><td>−40~+105℃</td></tr>
<tr><td>Rated Voltage Range</td><td>6.3~100Vdc</td></tr>
<tr><td>Capacitance Tolerance</td><td>±20%(20℃,120Hz)</td></tr>
<tr><td>Leakage Current(MAX)</td><td>I=0.01CV or 3μA whichever is greater.(After 2 minutes)
I=Leakage Current(μA) C=Capacitance(μF) V=Rated Voltage(Vdc)</td></tr>
<tr><td>Dissipation Factor(MAX)
(tanδ)</td><td>
<table>
<tr><td>Rated Voltage (Vdc)</td><td>6.3</td><td>10</td><td>16</td><td>25</td><td>35</td><td>50</td><td>63</td><td>80</td><td>100</td></tr>
<tr><td>tanδ</td><td>0.22</td><td>0.19</td><td>0.16</td><td>0.14</td><td>0.12</td><td>0.10</td><td>0.09</td><td>0.08</td><td>0.08</td></tr>
</table>
(20℃,120Hz)
When capacitance is over 1000μF, tanδ shall be added 0.02 to the listed value with increase of every 1000μF.</td></tr>
<tr><td>Endurance</td><td>After applying rated voltage with rated ripple current for specified time at 105℃, the capacitors shall meet the following requirements.
<table>
<tr><td>Capacitance Change</td><td>Within ±25% of the initial value. (6.3Vdc, 10Vdc:±30%)</td></tr>
<tr><td>Dissipation Factor</td><td>Not more than 200% of the specified value.</td></tr>
<tr><td>Leakage Current</td><td>Not more than the specified value.</td></tr>
</table>
<table>
<tr><th>Case Size</th><th>Life Time (hrs)</th></tr>
<tr><td>φD≤ 6.3</td><td>6000</td></tr>
<tr><td>φD= 8</td><td>8000</td></tr>
<tr><td>φD≥ 10</td><td>10000</td></tr>
</table></td></tr>
<tr><td>Low Temperature Stability
Impedance Ratio(MAX)</td><td>
<table>
<tr><td>Rated Voltage (Vdc)</td><td>6.3</td><td>10</td><td>16</td><td>25</td><td>35</td><td>50</td><td>63</td><td>80</td><td>100</td></tr>
<tr><td>Z(−25℃)/Z(20℃)</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>Z(−40℃)/Z(20℃)</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
</table>
(120Hz)</td></tr>
</table>

◆MULTIPLIER FOR RIPPLE CURRENT

Frequency(Hz)		120	1k	10k	100k≦
Coefficient	8.2~33μF	0.42	0.70	0.90	1.00
	47~270μF	0.50	0.73	0.92	1.00
	330~680μF	0.55	0.77	0.94	1.00
	820~1800μF	0.60	0.80	0.96	1.00
	2200~8200μF	0.70	0.85	0.98	1.00

◆DIMENSIONS

(mm)

φD	5	6.3	8	10	12.5	16	18
φd	0.5		0.6			0.8	
F	2.0	2.5	3.5	5.0		7.5	
α	L≤16 : α=1.5 L≥20 : α=2.0						

◆PART NUMBER

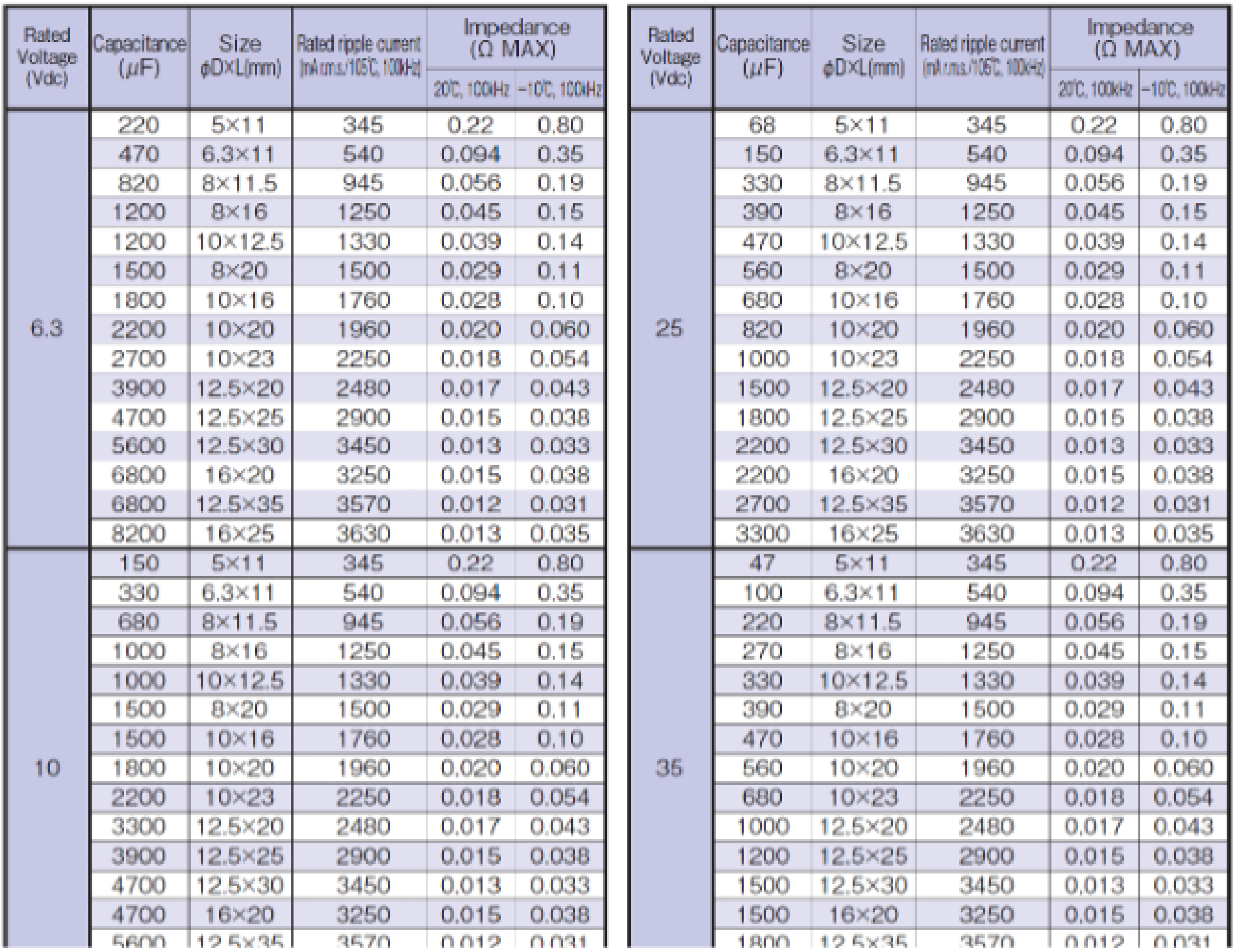
□□□	ZLH	□□□□□	M	□□□	□□	DxL
Rated Voltage	Series	Capacitance	Capacitance Tolerance	Option	Lead Forming	Case Size

◆OPTION

	Code
PET Sleeve	EFC

Appendix A

CAP Specs



Rated Voltage (Vdc)	Capacitance (μF)	Size φD×L(mm)	Rated ripple current (mA r.m.s./105℃, 100kHz)	Impedance (Ω MAX)	
				20℃, 100kHz	−10℃, 100kHz
6.3	220	5×11	345	0.22	0.80
	470	6.3×11	540	0.094	0.35
	820	8×11.5	945	0.056	0.19
	1200	8×16	1250	0.045	0.15
	1200	10×12.5	1330	0.039	0.14
	1500	8×20	1500	0.029	0.11
	1800	10×16	1760	0.028	0.10
	2200	10×20	1960	0.020	0.060
	2700	10×23	2250	0.018	0.054
	3900	12.5×20	2480	0.017	0.043
	4700	12.5×25	2900	0.015	0.038
	5600	12.5×30	3450	0.013	0.033
	6800	16×20	3250	0.015	0.038
	6800	12.5×35	3570	0.012	0.031
	8200	16×25	3630	0.013	0.035
10	150	5×11	345	0.22	0.80
	330	6.3×11	540	0.094	0.35
	680	8×11.5	945	0.056	0.19
	1000	8×16	1250	0.045	0.15
	1000	10×12.5	1330	0.039	0.14
	1500	8×20	1500	0.029	0.11
	1500	10×16	1760	0.028	0.10
	1800	10×20	1960	0.020	0.060
	2200	10×23	2250	0.018	0.054
	3300	12.5×20	2480	0.017	0.043
	3900	12.5×25	2900	0.015	0.038
	4700	12.5×30	3450	0.013	0.033
	4700	16×20	3250	0.015	0.038
	5600	12.5×35	3570	0.012	0.031

Rated Voltage (Vdc)	Capacitance (μF)	Size φD×L(mm)	Rated ripple current (mA r.m.s./105℃, 100kHz)	Impedance (Ω MAX)	
				20℃, 100kHz	−10℃, 100kHz
25	68	5×11	345	0.22	0.80
	150	6.3×11	540	0.094	0.35
	330	8×11.5	945	0.056	0.19
	390	8×16	1250	0.045	0.15
	470	10×12.5	1330	0.039	0.14
	560	8×20	1500	0.029	0.11
	680	10×16	1760	0.028	0.10
	820	10×20	1960	0.020	0.060
	1000	10×23	2250	0.018	0.054
	1500	12.5×20	2480	0.017	0.043
	1800	12.5×25	2900	0.015	0.038
	2200	12.5×30	3450	0.013	0.033
	2200	16×20	3250	0.015	0.038
	2700	12.5×35	3570	0.012	0.031
	3300	16×25	3630	0.013	0.035
35	47	5×11	345	0.22	0.80
	100	6.3×11	540	0.094	0.35
	220	8×11.5	945	0.056	0.19
	270	8×16	1250	0.045	0.15
	330	10×12.5	1330	0.039	0.14
	390	8×20	1500	0.029	0.11
	470	10×16	1760	0.028	0.10
	560	10×20	1960	0.020	0.060
	680	10×23	2250	0.018	0.054
	1000	12.5×20	2480	0.017	0.043
	1200	12.5×25	2900	0.015	0.038
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