Firefighting Nozzle Reaction

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In 1990 I completed a research project (Fire Magazine UK - November 1992) that evaluated the operational capability of fire fighting hand-line streams as used by London Fire Brigade. At that time we had main-line options of 45mm (1 3/4") hose-lines with 12.5mm (1/2") nozzles and 70mm (2 3/4") hose-lines with either 20mm (3/4") or 25mm (1") nozzle options. One of the basic laws of physics - Newton's third law - states that for every action there is an equal and opposite reaction. Quite simply, to the firefighter this means that as water is projected from a nozzle to form a 'jet' or firefighting stream, the nozzle tends to recoil in the opposite direction. This effect, termed nozzle or jet reaction (or kick-back) requires the firefighters at the nozzle to exert sufficient effort into over-coming this reaction force. The entire force of this reaction takes place as the water leaves the nozzle and whether or not the fire stream strikes a nearby object has no effect on the reaction. Thus, whether or not a hose-line's stream is allowed to strike a wall whilst a firefighter is working it from the top of a ladder is immaterial to his stability on the ladder, which is governed solely by the reaction at the nozzle.

By evaluating maximum flow capability for a hose-line that could be effectively directed and safely handled whilst *advancing and working* inside a fire-involved structure It was observed that there was a maximum nozzle reaction force that could be handled by one, two and three firefighters as follows -

One firefighter - 266N (60 lbf)

Two firefighters - 333N (75 lbf)

Three firefighters - 422N (95 lbf)

These were interesting findings and from these I was able to establish baseline flows for interior firefighting operations. To achieve this it became necessary to take acceptable pumping practice into consideration without contravening the limitations placed upon european pumps, hoses and equipment available at that time. This resulted in baseline flows of 277 lpm (73 gpm) on 45mm hose-lines with 12.5mm nozzles, 650 lpm (172 gpm) on 70mm hose-lines with 20mm nozzles and 750 lpm (200 gpm) on 70mm hose-lines with 25mm nozzles, as *advanced* by two-man crews.

However, these 'base-line' flows were rarely, if ever, achieved in practice as tradition had established a base-line pumping pressure of 3-4 bars (45-60 lbs psi) to which a small adjustment may have sometimes been made for frictional loss and pressure head. Actual firefighting flow-rates were in fact far lower than had been previously thought. - Ref: SRDB Codes of the period.

Interestingly, similar research has been carried out by other fire departments, notably San Francisco, Los Angeles and Chicago, who proposed that a safe and practical baseline flow for a workable firefighting hand-line would be around 550 lpm (150 gpm). More recently (1996), the City of St. Petersburg in Florida USA have established that, for their purposes, the ideal baseline flow is around 600 lpm (160 gpm) using a 7/8" (22mm) nozzle with a 50 lbs psi nozzle pressure on a 45mm (1 3/4") hose-line. This set-up will create an acceptable reaction force of 266N (60 lbf) and offers a hose-line that is easily advanced and maneuvered for interior position.

However, the change to combination fog/straight-stream or automatic nozzles brings a demand for higher nozzle pressures to achieve similar flows and with that comes an increased reaction force. A baseline flow of 600 lpm (160 gpm) being discharged from a combination/automatic type nozzle operating at 7 bars (100 psi) NP will produce a reaction force of 356N (80 lbs lbf) which would cause a two-man team to struggle with any workable advance of the line. There are combination/automatic nozzles available that have been adjusted to provide rated flows at lower nozzle pressures but be sure to test these yourself as manufacturer's 'rated' flows are sometimes unachievable! Top US branded nozzles must meet the stringent demands of NFPA standards and *Low-Pressure* combination nozzles are able to achieve their rated flow-rates at factory-set nozzle pressures of just 5 bars. This would enable a flow of 600 lpm (160 gpm) to be

achieved with a reaction force of just 303N (68 lbs lbf) which is more easily handled and advanced by a two-man team.

The firefighter is able to calculate the amount of nozzle reaction (NR) by resorting to various formulae -

NR (Newtons) = 1.57 x NP x d squared/10 (European Smooth-bore), or;

NR (Newtons) = 0.22563 x lpm x Sq.root of NP (European Combination fog/jet or automatic Nozzles)

These are metric formulae where P = Nozzle Pressure; d = Nozzle Diameter; lpm = Flow in Litres Per Minute and NR is in Newtons.

In the USA different formulae are used as follows -

NR (lbf) = 1.57 x d squared x NP (US Smooth-bore), or;

NR (lbf) = 0.0505 x gpm x square root of NP (US Combination fog/straight or automatic Nozzles)

FOG NOZZLES																	
GPM SETTING	GALLONS PER MINUTE (GPM)									POUNDS REACTION FORCE† (RF)							
	NOZZLE PRESSURE AT INLET IN PSI																
	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	
13	9 3	10 4	10 4	10 4	11 5	11 5	12 5	12 6	12 6	13 6	13 7	13 7	14 7	14 8	14 8	15 8	gpm rf
20	14 5	15 6	15 6	16 7	17 7	17 8	18 8	18 9	19 9	19 10	20 10	20 11	21 11	21 12	22 12	22 13	gpm rf
25	18 6	19 7	19 7	20 8	21 9	22 10	22 10	23 11	24 11	24 12	25 13	26 13	26 14	27 15	27 15	28 16	gpm rf
30	21 8	22 8	23 9	24 10	25 11	26 11	27 12	28 13	28 14	29 14	30 15	31 16	31 17	32 17	33 18	34 19	gpm rf
40	28 10	30 11	31 12	32 13	33 14	35 15	36 16	37 17	38 18	39 19	40 20	41 21	42 22	43 23	44 24	45 25	gpm rf
60	42 15	44 17	46 18	48 20	50 21	52 23	54 24	55 26	57 27	58 29	60 30	61 32	63 33	64 35	66 36	67 38	gpm rf
95	67 24	70 26	74 29	77 31	79 34	82 36	85 38	88 41	90 43	93 46	95 48	97 50	100 53	102 55	104 58	106 60	gpm rf
100	71 25	74 28	77 30	81 33	84 35	87 38	89 40	92 43	95 45	97 48	100 51	102 53	105 56	107 58	110 61	112 63	gpm rf
125	88 32	93 35	97 38	101 41	105 44	108 47	112 51	115 54	119 57	122 60	125 63	128 66	131 69	134 73	137 76	140 79	gpm rf
150	106 38	111 42	116 45	121 49	125 53	130 57	134 61	138 64	142 68	146 72	150 76	154 80	157 83	161 87	164 91	168 95	gpm rf
200	141 51	148 56	155 61	161 66	167 71	173 76	179 81	184 86	190 91	195 96	200 101	205 106	210 111	214 116	219 121	224 126	gpm rf

250	177 63	185 69	194 76	202 82	209 88	217 95	224 101	230 107	237 114	244 120	250 126	256 133	262 139	268 145	274 152	280 158	gpm rf
300	212 76	222 83	232 91	242 98	251 106	260 114	268 121	277 129	285 136	292 144	300 152	307 159	315 167	322 174	329 182	335 189	gpm rf
375	265 95	278 104	290 114	302 123	314 133	325 142	335 152	346 161	356 170	366 180	375 189	384 199	393 208	402 218	411 227	419 237	gpm rf
500	354 126	371 139	387 152	403 164	418 177	433 189	447 202	461 215	474 227	487 240	500 253	512 265	524 278	536 290	548 303	559 316	gpm rf
700	495 177	519 194	542 212	564 230	586 247	606 265	626 283	645 300	664 318	682 336	700 354	717 371	734 389	751 407	767 424	783 442	gpm rf
750	530 189	556 208	581 227	605 246	627 265	650 284	671 303	691 322	712 341	731 360	750 379	769 398	787 417	804 436	822 455	839 473	gpm rf
1000	707 253	742 278	775 303	806 328	837 354	866 379	894 404	922 429	949 455	975 480	1000 505	1025 530	1049 556	1072 581	1095 606	1118 631	gpm rf
1250	884 316	927 347	968 379	1008 410	1046 442	1083 473	1118 505	1152 537	1186 568	1218 600	1250 631	1281 663	1311 694	1340 726	1369 758	1398 789	gpm rf
1500	1061 379	1112 417	1162 455	1209 492	1255 530	1299 568	1342 606	1383 644	1423 682	1462 720	1500 758	1537 795	1573 833	1609 871	1643 909	1677 947	gpm rf
1750	1237 442	1298 486	1356 530	1411 574	1464 619	1516 663	1565 707	1613 751	1660 795	1706 840	1750 884	1793 928	1835 972	1877 1016	1917 1061	1957 1105	gpm rf
2000	1414 505	1483 556	1549 606	1612 657	1673 707	1732 758	1789 808	1844 859	1897 909	1949 960	2000 1010	2049 1061	2098 1111	2145 1162	2191 1212	2236 1263	gpm rf

References: National Fire Protection Association (NFPA) Fire Protection Handbook - 17th Edition
International Fire Service Training Association (IFSTA) Fire Protection Publications - Fire Stream Practices - 7th Edition

* Nozzle Pressure Measured with Pitot Gauge, † Reaction force measured in pounds

SOLID BORE NOZZLES																	
NOZZLE PRESSURE*	GALLONS PER MINUTE (GPM)									POUNDS REACTION FORCE† (RF)							
	SOLID BORE DIAMETER (INCHES)																
	3/8"	1/2"	5/8"	3/4"	7/8"	15/16"	1"	1 1/8"	1 1/4"	1 3/8"	1 1/2"	1 3/4"	2"	2 1/4"	2 1/2"	2 3/4"	
40	26 9	47 16	73 25	106 35	144 48	165 55	188 63	238 79	294 98	355 119	423 141	575 192	752 251	951 318	1174 393	1421 475	gpm rf
45	28 10	50 18	78 28	112 40	153 54	175 62	199 71	252 89	311 110	377 134	448 159	610 216	797 283	1009 358	1246 442	1507 534	gpm rf
50	30 11	53 20	82 31	118 44	161 60	185 69	210 79	266 99	328 123	397 148	473 177	643 240	840 314	1064 397	1313 491	1589 594	gpm rf
55	31 12	55 22	86 34	124 49	169 66	194 76	220 86	279 109	344 135	417 163	496 194	675 264	881 345	1115 437	1377 540	1666 653	gpm rf
60	32 13	58 24	90 37	129 53	176 72	202 83	230 94	291 119	360 147	435 178	518 212	705 288	921 377	1165 477	1438 589	1740 712	gpm rf
65	34 14	60 26	94 40	135 57	183 78	211 90	240 102	303 129	374 159	453 193	539 230	734 313	958 408	1213 517	1497 638	1811 772	gpm rf
70	35 15	62 27	97 43	140 62	190 84	218 97	249 110	315 139	388 172	470 208	559 247	761 337	994 440	1258 556	1554 687	1880 831	gpm rf
75	36 17	64 29	101 46	145 66	197 90	226 103	257 118	326 149	402 184	486 223	579 265	788 361	1029 471	1303 596	1608 736	1946 890	gpm rf
80	37 18	66 31	104 49	149 71	203 96	234 110	266 126	336 159	415 196	502 237	598 283	814 385	1063 502	1345 636	1661 785	2010 950	gpm rf
85	39 19	68 33	107 52	154 75	210 102	241 117	274 133	347 169	428 209	518 252	616 300	839 409	1096 534	1387 676	1712 834	2071 1009	gpm rf
90	40 20	70 35	110 55	159 79	216 108	248 124	282 141	357 179	440 221	533 267	634 318	863 433	1127 565	1427 715	1762 883	2132 1069	gpm rf
95	41 21	72 37	113 58	163 84	222 114	255 131	290 149	366 189	452 233	547 282	652 336	887 457	1158 597	1466 755	1810 932	2190 1128	gpm rf
100	42 22	74 39	116 61	167 88	227 120	261 138	297 157	376 199	464 245	562 297	668 353	910 481	1188 628	1504 795	1857 981	2247 1187	gpm rf
105	43 23	76 41	119 64	171 93	233 126	268 145	304 165	385 209	476 258	576 312	685 371	932 505	1218 659	1541 835	1903 1030	2302 1247	gpm rf

110	44 24	78 43	122 67	175 97	239 132	274 152	312 173	394 219	487 270	589 327	701 389	954 529	1246 691	1577 874	1948 1079	2356 1306	gpm rf
115	45 25	80 45	124 71	179 102	244 138	280 159	319 181	403 229	498 282	602 341	717 406	976 553	1274 722	1613 914	1991 1128	2409 1365	gpm rf
120	46 26	81 47	127 74	183 106	249 144	286 166	325 188	412 238	509 294	615 356	732 424	997 577	1302 754	1648 954	2034 1178	2461 1425	gpm rf
125	47 28	83 49	130 77	187 110	254 150	292 172	332 196	420 248	519 307	628 371	747 442	1017 601	1329 785	1682 994	2076 1227	2512 1484	gpm rf
130	48 29	85 51	132 80	191 115	259 156	298 179	339 204	429 258	529 319	640 386	762 459	1037 625	1355 816	1715 1033	2117 1276	2562 1544	gpm rf
135	49 30	86 53	135 83	194 119	264 162	303 186	345 212	437 268	539 331	653 401	777 477	1057 649	1381 848	1748 1073	2157 1325	2611 1603	gpm rf
140	49 31	88 55	137 86	198 124	269 168	309 193	352 220	445 278	549 343	665 416	791 495	1077 673	1406 879	1780 1113	2197 1374	2658 1662	gpm rf
145	50 32	89 57	140 89	201 128	274 174	314 200	358 228	453 288	559 356	676 430	805 512	1096 697	1431 911	1811 1152	2236 1423	2706 1722	gpm rf
150	51 33	91 59	142 92	205 132	279 180	320 207	364 236	461 298	569 368	688 445	819 530	1114 721	1455 942	1842 1192	2274 1472	2752 1781	gpm rf
175	55 39	98 69	154 107	221 155	301 210	345 241	393 275	497 348	614 429	743 519	884 618	1204 841	1572 1099	1990 1391	2456 1717	2972 2078	gpm rf
200	59 44	105 79	164 123	236 177	322 240	369 276	420 314	532 397	657 491	794 594	945 707	1287 962	1681 1256	2127 1590	2626 1963	3177 2375	gpm rf

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