NASA
SPACE VEHICLE
DESIGN CRITERIA
(CHEMICAL PROPULSION)

SP-8120

LIQUID ROCKET ENGINE NOZZLES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Table I. – Chief Features of Nozzles Used in Operational High-Thrust Liquid Rocket Engines

Engine	System application	Thrust, lbf	Chamber pressure, psia	Specific impulse, lbf-sec/lbm	Propellants			A_c/A_t	Chamber/nozzle joint	Entrance half-angle, deg
					Oxidizer	Fuel	MR			
RS-1801	Lunar Excursion Module ascent engine	3500 vac	120 vac	310 vac	N_2O_4	50:50	1.60	2.9	Integral	30.0
AJ 10-118	Delta second stage	7575 alt	206 alt	267 alt	IRFNA	UDMH	2.8	3.27	Welded	25
AJ 10-138	Titan III transtage	8000 alt	105 alt	302 alt	N_2O_4	50:50	2.0	2.54	Integral	7.5
VTR-10	Lunar Excursion Module descent engine	9850 vac	104 vac	305 vac	N_2O_4	50:50	1.6	2.52	–	–
RL10A-3-3	Centaur upper stage	15 000 alt	400 alt	444 alt	LOX	LH_2	5.0	4	Integral	10.5
YLR81-BA-11	Agena upper stage	15 800 vac	506 vac	298 vac	IRFNA	UDMH	2.57	5.335	Welded	–
AJ10-137	Apollo Service Module	20 500 vac	97 vac	310 vac	N_2O_4	50:50	1.6	2.00	Bolted	7.5
YLR99-RM-1	X-15 aircraft; Pioneer spacecraft	49 390 alt	600 alt	236 alt	LOX	NH_3	1.25	4.10	Integral	31.5
YLR113-AJ-1	Rocket sled	50 000 to 150 000 sl	235 to 595 sl	195 to 240 sl	N_2O_4	UDMH	2.1	2.04	Integral	25
LR91-AJ-5	Titan II second stage	100 000 alt	827 alt	321 alt	N_2O_4	50:50	1.80	2.51	Integral	30
LR89-NA-7	Atlas MA-5 booster engine	330 000 sl (2 thrust chambers)	578 sl	254 sl	LOX	RP-1	2.28	1.67	Integral	–
LR79-NA-11	Thor MB-3	169 500 sl	588 sl	256 sl	LOX	RP-1	2.15	1.67	Integral	10
H-1C and H-1D	S-1 stage of Saturn 1B launch vehicle	204 300 sl 228 800 alt	705 sl 707 alt	269 sl 301 alt	LOX	RP-1	2.23	1.62	Integral	–
LR87-AJ-5	Titan II first stage	214 400 sl 236 400 alt	783 sl 783 alt	263 sl 289 alt	N_2O_4	50:50	1.93	2.04	Integral	25
J-2	S-II and S-IV stages of Saturn V	230 000 alt	725 (nozzle stagnation)	423 alt 294 sl	LOX	LH_2	5.5	1.58	Integral	13.73
F-1	S-1C stage of Saturn V	1 522 000 sl 1 748 000 alt	1126 injector 983 throat	274 sl 315 alt	LOX	RP-1	2.27	1.307	Integral	13

(continued)

Table I. – Chief Features of Nozzles Used in Operational High-Thrust Liquid Rocket Engines (concluded)

Engine	D_t, in.	A_t, in.^{2}	Length, throat to exit, in.	Exit type	Divergence half-angle, deg	D_e, in.	A_e, in.^{2}	A_e/A_t	Nozzle extension	Extension/ nozzle joint	Method of cooling nozzle and extension
RS-1801	4.578	16.5	35.27	72% bell	–	30.9	750	45.6	None	NA	Film and ablation
AJ10-118	5.25	21.64	23.1	Complex contour	–	23.5	432.8	20	Optional	Clamped flange	Regenerative to 20:1; radiation to 30:1 or 40:1
AJ10-138	7.48	43.9	49.61	Bell	–	47.33	1758.5	40	Yes	Bolted flange	Ablation to extension; radiation thereafter
VTR-10	8.320	54.34	62.11	72.3% bell, round entrance	–	57.26	2574.0	47.5	Yes	–	Ablation to 16:1; radiation to 47.5:1
RL10A-3-3	5.14	20.75	46.3	Bell	32.5	38.8	1182.75	57	None	NA	Regenerative
YLR81-BA-11	4.670	17.13	39.8	Bell	25.7	31.326	770.32	45	Yes	Bolted flange	Regenerative to 13:1; radiation to 45:1
AJ10-137	12.447	121.675	111.8	Bell	–	98.40	7605	62.5	Yes	Bolted flange	Ablation to 6:1; radiation to 62.5:1
YLR99-RM-1	8.64	58.6	–	Conical	20	27.20	574.3	9.8	None	NA	Regenerative
YLR113-AJ-1	15.25	182.56	35.41	Conical	17	36.41	1040.66	5.7	None	NA	Film
LR91-AJ-5	9.12	65.41	72	Bell	17	64.0	3217	49.2	Yes	Bolted flange	Regenerative to 13:1; ablation to 49.2:1
LR89-NA-7	16.2	206.0	58	100% bell	–	45.83	1648.8	8	None	NA	Regenerative
LR79-NA-11	16.2	206.0	58	100% bell	–	45.8	1646.6	8	None	NA	Regenerative
H-1C and H-1D	16.16	205	55	Bell	–	45.49	1630	8	Yes	Bolted flange	Regenerative
LR87-AJ-5	15.25	182.56	42.46	Bell	23	43.14	1461.6	8	None	NA	Film and regenerative
J-2	14.7	169.6	90	Bell	4.226 min 27.5 max	77	4656.6	27.5	None	NA	Combined fluid and regenerative
F-1	35	961.4	158	Bell	–	140	15 400	16	Yes	Bolted flange	Regenerative to 10:1; turbine exhaust to 16:1

NA = not applicable

Table II. – Chief Features of Nozzles Used in Operational Low-Thrust Liquid Rocket Engines

Engine	System application	Thrust, lbf	Chamber pressure, psia	Specific impulse, lbf-sec/lbm	Propellants			A_c/A_t	Chamber/ nozzle joint	Entrance half-angle, deg
					Oxidizer	Fuel	MR			
Model 8093	Centaur ACS and ullage orientation	1.5 vac	198 vac	155 vac	90% H_2O_2 (mono)		–	17.4	Welded	(0.06 in. radius)
M2A	Comsat positioning and orientation	1.9 to 3.0 vac	117 to 185 vac	225 vac	N_2H_4 (mono)		–	44.8	Integral	60
Model 8250 Unit I	Agena-Gemini target vehicle SPS	16 vac	78 vac	252 vac	MON	UDMH	1.1	15.8	Integral	40
SE-7	Gemini attitude control	23 vac	132 vac	258 vac	N_2O_4	MMH	0.7	3.8	Integral	31.5
PD6000179	Titan III transtage ACS	16.0 vac 26.7 vac	120 vac 200 vac	221 vac 225 vac	N_2H_4 (mono)		–	33.7	Welded	50
Model TD-339	Surveyor vernier propulsion system	30 to 104 vac	70 to 250 vac	287 vac	MON	MMH:H_2O (72:28)	1.5	10	Welded	47
MC-4-610	Ranger and Mariner propulsion	50 vac	190 vac	235 vac	N_2H_4 (mono)		–	37	Welded	60
R-4D	Apollo Service Module RCS	60 sl 100 vac	96.5 sl 96.5 vac	168 sl 280 vac	N_2O_4	50:50	2.03	4.2	Integral	53
SE-7-1	Saturn SIV-B ullage	72 vac	101 vac	274 vac	N_2O_4	MMH	1.27	3.1	Integral	31.5
SE-8	Apollo Command Module ACS	93 vac	137 vac	274 vac	N_2O_4	MMH	2.0	3.1	Integral	26.1
Model 700800	Saturn SI-B and SIV-B ACS	147 vac	101 vac	292 vac	N_2O_4	MMH	1.64	5.8	Integral	45
Model 8250 Unit II	Agena-Gemini target vehicle SPS	200 vac	94 vac	257 vac	MON	UDMH	1.15	7.9	Integral	40
RS-2101	Mariner Mars 1971 spacecraft	300 vac	117 vac	283 vac	N_2O_4	MMH	1.55	4.9	Clamp	44.7
Model 7161 (500 lbf)	Lunar landing training vehicle ACS	500 sl	325 sl	122 sl	90% H_2O_2 (mono)		–	12.7	Integral	45
LR101-NA-15 Mod. 2	Atlas MA-5 vernier engine	913 sl	337 sl	205 sl	LOX	RP-1	1.8	3.0	Integral	10

(continued)

Table II. – Chief Features of Nozzles Used in Operational Low-Thrust Liquid Rocket Engines (concluded)

Engine	D_t, in.	A_t, in.^{2}	Length, throat to exit, in.	Exit type	Divergence half-angle, deg	D_e, in.	A_e, in.^{2}	A_e/A_t	Nozzle extension	Extension/ nozzle joint	Method of cooling nozzle and extension
Model 8093	0.075	0.0044	0.344	Conical	18	0.293	0.0674	15	None	NA	Radiation
M2A	0.105	0.0086	0.9	Conical	15	0.662	0.34	40	None	NA	Radiation
Model 8250 Unit I	0.377	0.1118	3.715	80% bell	29	2.832	6.28	56.2	None	NA	Radiation
SE-7	0.358	0.1008	2.599	80% bell (scarfed)	31.6	2.27	4.05	40.2	None	NA	Ablation
PD6000179	0.313	0.0772	3.	Optimized bell	15	2.20	3.8	49	None	NA	Radiation
Model TD-339	0.54	0.23	6.5	Overturned bell	37	5.09	19.7	86	Yes	Welded	Regen. to extension; radiation thereafter
MC-4-610	0.437	0.15	4.05	Bell	23.6	2.904	6.623	44	None	NA	Radiation
R-4D	0.868	0.592	6.98	Bell	8	5.46	23.41	40	Yes	Bolted flange	Radiation
SE-7-1	0.710	0.3959	–	80% bell (scarfed)	–	4.49	15.85	40	None	NA	Ablation
SE-8	0.710	0.3959	2.190	82% bell	36 entrance 10.6 exit	2.13	3.563	9	Yes	Bolted flange	Ablation
Model 700800	1.040	0.849	6.350	Bell	32	6.06	28.84	33.9	None	NA	Ablation
Model 8250 Unit II	1.423	1.59	–	80% bell	27	4.9	18.85	11.86	None	NA	Radiation
RS-2101	1.354	1.44	–	80% bell	44.75	8.56	57.5	40	Yes	Clamp	Film and radiation
Model 7161 (500 lbf)	1.195	1.121	1.640	80% bell	15	2.078	3.39	3	None	NA	Radiation
LR101-NA-15 Mod. 2	1.63	2.09	4.75	Conical	15	3.86	11.70	5.6	None	NA	Regenerative

ACS = attitude control system
RCS = reaction control system
SPS = secondary propulsion system
NA = not applicable