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AIR FORCE REUSABLE ROCKET ENGINE PROGRAM

**XLR129-P-1
FINAL REPORT
AFRPL-TR-71-1 VOL I
JANUARY 1971**

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Pratt & Whitney Aircraft
Division of United Aircraft Corporation
Florida Research and Development Center**

**Prepared Under
Contract F04611-68-C-0002 for
Air Force Rocket Propulsion Laboratory
Edwards Air Force Base, California 93523**

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Table II. Demonstrator Engine Operating Characteristics, Booster (Concluded)

	100% Thrust r = 5.0	100% Thrust r = 6.0	100% Thrust r = 7.0	75% Thrust r = 5.0	75% Thrust r = 6.0	75% Thrust r = 7.0
Configuration						
Thrust, lb	244,000	244,000	244,000	183,000	183,000	183,000
Vacuum Specific Impulse, sec ϵ = 75	450	450	444	451	448	441
Sea Level Specific Impulse, sec ϵ = 35	387	386	380	370	367	364
Envelope:						
Diameter, in.	69.25	69.25	69.25	69.25	69.25	69.25
Length: Nozzle Extended/Retracted, in.	131.7/80.0	131.7/80.0	131.7/80.0	131.7/80.0	131.7/80.0	131.7/80.0
Nozzle Area Ratio: Extended/Retracted	75/35	75/35	75/35	75/35	75/35	75/35
Fuel Flow, lb/sec	90.3	77.5	68.8	67.7	58.4	51.8
Oxidizer Flow, lb/sec	431.5	465.2	481.4	338.4	350.1	362.8
Total Propellant Flow, lb/sec	541.9	542.8	550.1	406.1	408.5	414.6
Main Burner Chamber						
Throat Total Pressure, psia	2806	2740	2676	2101	2059	2002
Mixture Ratio (injector)	5.56	6.68	7.94	5.53	6.77	8.06
Specific Impulse Efficiency, %	96.7	97.0	96.9	96.9	96.8	96.7
Fuel Injector Pressure Loss, psi	164	134	125	97.7	89.7	86.3
Oxidizer Injector Pressure Loss, psi	851	910	979	496	532	572
Momentum Pressure Loss, psi	-1.6	0.8	-0.4	15.2	9.7	6.4
Transpiration Coolant Flow, lb/sec	6.42	5.36	5.49	4.24	4.34	4.50
Throat Diameter, in.	7.68	7.68	7.68	7.68	7.68	7.68
Preburner						
Total Pressure, psia	4778	4332	4152	3256	3100	3003
Mixture Ratio (preburner injector)	1.08	1.12	1.28	0.98	1.06	1.23
Temperature, °R	2026	2095	2345	1715	1984	2274
Fuel Injector Pressure Loss, psi	320.8	248.0	200.5	201.9	158	129
Oxidizer Injector and Control Valve Pressure Loss, psi	1141	944	599	1385	1065	966
Total Injector Propellant Flow, lb/sec	157.8	138.1	128.2	108.6	98.6	92.4
Combustion Efficiency, %	100	100	100	100	100	100
Primary Nozzle						
Transpiration Supply Section:						
Coolant Flow, lb/sec	7.75	6.44	6.59	5.06	5.17	5.36
Coolant Inlet Pressure, psia	5279	4723	4830	3595	3701	3836
Coolant Inlet Temperature, °R	142	133	139	114	120	129
Coolant Pressure Loss, psi	142	120	126	89	94	100
Coolant Temperature Rise, °R	266	338	341	336	350	349
Preburner Supply Section:						
Coolant Flow, lb/sec	76.5	65.5	56.7	57.7	48.4	41.7
Coolant Inlet Pressure, psia	5271	4712	4455	3561	3341	3199
Coolant Inlet Temperature, °R	142	133	142	114	121	131
Coolant Pressure Loss, psi	147	112	90.1	90	69	56.4
Coolant Temperature Rise, °R	35.7	44.2	48.5	40.7	48.8	53.4

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Table II. Demonstrator Engine Operating Characteristics, Booster (Continued)

	50% Thrust r = 5.0	50% Thrust r = 6.0	50% Thrust r = 7.0	20% Thrust r = 5.0	20% Thrust r = 6.0	20% Thrust r = 7.0
Configuration						
Thrust, lb	122,000	122,000	122,360	48,860	48,800	48,800
Vacuum Specific Impulse, sec $\epsilon = 75$	449	446	438	444	439	429
Sea Level Specific Impulse, sec $\epsilon = 35$	344	339	334	269	264	262
Envelope:						
Diameter, in.	69.25	69.25	69.25	69.25	69.25	69.25
Length: Nozzle Extended/Retracted, in.	131.7/80.0	131.7/80.0	131.7/80.0	131.7/80.0	131.7/80.0	131.7/80.0
Nozzle Area Ratio: Extended/Retracted	75/35	75/35	75/35	75/35	75/35	75/35
Fuel Flow, lb/sec	45.2	39.1	34.8	19.3	15.9	14.2
Oxidizer Flow, lb/sec	226.2	234.7	243.7	91.5	95.3	99.6
Total Propellant Flow, lb/sec	261.4	273.8	278.5	109.8	111.2	113.8
Main Burner Chamber						
Throat Total Pressure, psia	1396	1360	1329	552	537	526
Mixture Ratio (injector)	5.61	6.92	8.25	5.99	7.45	8.93
Specific Impulse Efficiency, %	96.8	96.6	96.4	96.3	96	95.9
Fuel Injector Pressure Loss, psi	543	53.5	52.8	17.4	16.0	18.3
Oxidizer Injector Pressure Loss, psi	230	246	265	13.1	42	45.6
Momentum Pressure Loss, psi	15.2	11.6	9.5	9.0	7.6	7.1
Transpiration Coolant Flow, lb/sec	2.95	3.23	3.36	1.45	1.57	1.62
Throat Diameter, in.	7.68	7.68	7.68	7.68	7.68	7.68
Preburner						
Total Injector Pressure, psia	2026	1970	1926	741	728	719
Mixture Ratio (preburner injector)	0.80	1.01	1.21	0.76	1.00	1.24
Temperature, °R	1548	1901	2223	1464	1883	2255
Fuel Injector Pressure Loss, psi	106	86	74	30.687	27.810	22.382
Oxidizer Injector and Control Valve Pressure Loss, psi	1093	1105	1102	583	652	677
Total Injector Propellant Flow, lb/sec	67.3	62.2	58.8	23.8	22.24	21.3
Combustion Efficiency, %	100	100	100	100	100	100
Primary Nozzle						
Transpiration Supply Section:						
Coolant Flow, lb/sec	3.43	3.81	3.95	1.66	1.80	1.86
Coolant Inlet Pressure, psia	2474	2668	2779	1156	1251	1302
Coolant Inlet Temperature, °R	93.8	105	116	75.6	84.8	92.6
Coolant Pressure Loss, psi	60.7	67.9	71.9	28.7	31.5	33.2
Coolant Temperature Rise, °R	375	365	365	392	387	392
Preburner Supply Section:						
Coolant Flow, lb/sec	37.7	31.3	26.9	13.7	11.2	9.6
Coolant Inlet Pressure, psia	2185	2100	2035	785	768	750
Coolant Inlet Temperature, °R	95.4	107	117	75.0	82.0	87.6
Coolant Pressure Loss, psi	44.8	35.8	30.0	10.9	9.6	7.8
Coolant Temperature Rise, °R	45.9	55.8	60.8	53.0	72.0	74.9

Table II. Demonstrator Engine Operating Characteristics, Booster (Continued)

	100% Thrust r = 5.0	100% Thrust r = 6.0	100% Thrust r = 7.0	75% Thrust r = 5.0	75% Thrust r = 6.0	75% Thrust r = 7.0
Low-Speed Inducer						
Fuel Inducer:						
Flowrate, lb/sec	90.31	77.5	68.8	67.67	58.4	51.8
Speed, rpm	19,823	18,146	17,699	16,150	15,742	15,618
Pressure Rise, psi	90.0	88.7	100.1	74.8	86.7	97.5
NPSH, ft	60.2	60.2	60.2	60.2	60.2	60.2
Efficiency, %	61.6	60.1	56.7	60.0	55.2	50.7
Oxidizer Inducer:						
Flowrate, lb/sec	451.5	465.2	481	338.4	377.9	362.8
Speed, rpm	5417	4935	4904	4857	4659	4989
Pressure Rise, psi	258	197	186	254	224.2	257
NPSH, ft	16.0	16.0	16.0	16.0	16.0	16.0
Efficiency, %	57.2	60.7	61.4	52.9	55.8	54.1
Fuel Low-Speed Inducer Turbine						
Pressure Ratio	1.48	1.43	1.46	1.42	1.45	1.49
Flowrate, lb/sec	5.55	5.62	4.73	3.64	3.72	3.87
Speed, rpm	19,823	18,146	17,699	16,150	15,742	15,618
Efficiency, %	63.1	60.3	58.8	57.4	55.1	53.7
Oxidizer Low-Speed Inducer Turbine						
Pressure Drop, psi	772	523.0	478	940	727.6	875
Flowrate, lb/sec	568	391	408	286	298	310
Speed, rpm	5417	4935	4904	4857	4659	4989
Efficiency, %	68.5	72.7	73.8	52.9	63.7	62.5
Preburner Fuel Valve						
Flow, lb/sec	77	66	57	58.0	49.0	42.5
Pressure Drop, psi	270	200	550	162	475	745
Effective Area, in ²	3.48	3.48	1.83	3.45	1.69	1.20
Preburner Oxidizer Valve						
Flow, lb/sec	75	66	68	43	42	44
Pressure Drop, psi	670	580	230	1220	900	795
Effective Area, in ²	0.54	0.49	0.82	0.215	0.260	0.286
Main Chamber Oxidizer Valve						
Flow, lb/sec	370	390	410	283	300	310
Pressure Drop, psi	630	1120	1520	520	947	1100
Effective Area, in ²	1.74	2.13	2.96	1.58	1.96	2.49

Table II. Demonstrator Engine Operating Characteristics, Booster (Continued)

	50% Thrust r = 5.0	50% Thrust r = 6.0	50% Thrust r = 7.0	20% Thrust r = 5.0	20% Thrust r = 6.0	20% Thrust r = 7.0
Low-Speed Inducer						
Fuel Inducer:						
Flowrate, lb/sec	45.2	39.1	34.8	18.3	15.9	14.2
Speed, rpm	12,473	12,630	12,663	7748	7978	8043
Pressure Rise, psi	58.0	70.3	77.5	32.3	37.2	39.5
NPSH, ft	60.2	60.2	60.2	60.2	60.2	60.2
Efficiency, %	54.6	47.8	42.9	35	30.2	26.9
Oxidizer Inducer:						
Flowrate, lb/sec	226.2	234.7	243.7	91.5	95.3	99.6
Speed, rpm	3745	3906	4115	1971	2077	2163
Pressure Rise, psi	176	192	213	54	60	65
NPSH, ft	16.0	16.0	16.0	16.0	16.0	16.0
Efficiency, %	48.9	48.8	48.2	36.0	36.1	36.4
Fuel Low-Speed Inducer Turbine						
Pressure Ratio	1.44	1.49	1.52	1.51	1.55	1.57
Flowrate, lb/sec	2.51	2.75	2.96	1.20	1.30	1.35
Speed, rpm	12,473	12,630	12,663	7748	7978	8043
Efficiency, %	50.3	48.7	47.5	34.5	34.4	33.9
Oxidizer Low-Speed Inducer Turbine						
Pressure Drop, psi	835	923.2	1062	573	650.1	695.4
Flowrate, lb/sec	195	202	210	80.6	83.5	87.1
Speed, rpm	3745	3906	4115	1971	2077	2163
Efficiency, %	48.6	48.2	47.3	28.8	28.3	28.5
Preburner Fuel Valve						
Flow, lb/sec	38.5	32.0	27.5	14	12	10
Pressure Drop, psi	348	628	808	380	500	570
Effective Area, in ²	1.55	0.98	0.76	0.56	0.43	0.35
Preburner Oxidizer Valve						
Flow, lb/sec	23	24	25	5	5.5	6
Pressure Drop, psi	1020	1040	1040	580	640	680
Effective Area, in ²	0.150	0.140	0.140	0.04	0.04	0.04
Main Chamber Oxidizer Valve						
Flow, lb/sec	194	202	210	80	85	90
Pressure Drop, psi	360	530	640	120	140	150
Effective Area, in ²	1.42	1.60	2.02	1.22	1.29	1.46

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Table II. Demonstrator Engine Operating Characteristics, Booster (Continued)

	100% Thrust r = 5.0	100% Thrust r = 6.0	100% Thrust r = 7.0	75% Thrust r = 5.0	75% Thrust r = 6.0	75% Thrust r = 7.0
Two-Position Nozzle						
Coolant Flow, lb/sec	2.33	2.24	2.24	2.02	2.02	1.99
Thrust, lb	901	905	922	760	783	792
Fuel Turbopump						
Pump:						
Number of Pump Stages	2	2	2	2	2	2
Speed, rpm	48,043	44,548	44,490	38,783	38,724	39,404
Pressure Rise, psi	5493	4845	4915	3686	3723	3841
Overall Efficiency, %	65.9	65.3	63.7	650	63.1	60.6
Impeller Tip Velocity, 1st Stage, ft/sec	2226	2064	2061	1797	1794	1826
Impeller Tip Velocity, 2nd Stage, ft/sec	2641	2449	2446	2132	2129	2166
Temperature Rise, °R	91.3	83.1	89.6	66.1	71.9	80.5
Inlet Flow, lb/sec	91.3	78.5	69.7	67.7	58.4	51.8
Turbine:						
Number of Stages	2	2	2	2	2	2
Pressure Ratio	1.59	1.49	1.47	1.46	1.43	1.42
Inlet Temperature, °R	2011	2079	2326	1702	1967	2252
Inlet Pressure, psia	4721	4283	4106	3220	3066	2971
Temperature Drop, °R	177	157.0	165	124	131.7	144
Mean Wheel Velocity, ft/sec	1488	1380	1378	1201	1200	1221
Efficiency, %	78.1	77.9	77.8	76.5	76.3	76.2
Inlet Flow, lb/sec	110.6	96.6	89.5	76.1	68.9	64.5
Oxidizer Turbopump						
Pump:						
Number of Stages	1	1	1	1	1	1
Speed, rpm	25,727	23,399	22,612	20,839	19,972	19,555
Pressure Rise, psi	5732	5139	4628	4397	3952	3726
Efficiency, %	55.6	65.5	66	61.8	63.0	63.8
Impeller Tip Velocity, ft/sec	952	866	837	771	739	725
Temperature Rise, °R	40.1	31.7	28.1	29.2	25.3	23.4
Inlet Flow, lb/sec	619.4	545.9	558.2	413.0	421.2	432.1
Turbine:						
Number of Stages	2	2	2	2	2	2
Pressure Ratio	1.59	1.49	1.46	1.45	1.42	1.42
Inlet Flow, lb/sec	48.1	42.3	39.4	33.2	30.3	28.5
Inlet Temperature, °R	2011	2079	2326	1702	1967	2252
Inlet Pressure, psia	4730	4290	4113	3226	3071	2975
Temperature Drop, °R	156.1	137	142.0	109	114	122
Mean Wheel Velocity, ft/sec	1123	1021	987	912	871	855
Efficiency, %	69.4	68.5	67.6	67.5	66.3	65.2

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Table II. Demonstrator Engine Operating Characteristics, Booster

	50% Thrust r = 5.0	50% Thrust r = 6.0	50% Thrust r = 7.0	20% Thrust r = 5.0	20% Thrust r = 6.0	20% Thrust r = 7.0
Two-Position Nozzle						
Coolant Flow, lb/sec	1.77	1.75	1.70	1.42	1.35	1.27
Thrust, lb	625	640	640	406	408	402
Fuel Turbopump						
Pump:						
Number of Pump Stages	2	2	2	2	2	2
Speed, rpm	31,195	32,474	33,591	20,843	22,262	23,357
Pressure Rise, psi	2450	2630.6	2736	1092	1183	1233
Overall Efficiency, %	61.8	58.2	55.3	49	44.9	42.0
Impeller Tip Velocity, 1st Stage, ft/sec	1445	1505	1556	966	1032	1082
Impeller Tip Velocity, 2nd Stage, ft/sec	1715	1785	1847	1146	1224	1284
Temperature Rise, °R	47.4	58.2	68.1	28.6	37.1	44.3
Inlet Flow, lb/sec	45.2	39.1	34.8	18.8	16.4	14.7
Turbine:						
Number of Stages	2	2	2	2	2	2
Pressure Ratio	1.37	1.37	1.37	1.27	1.28	1.29
Inlet Temperature, °R	1534	1881	2197	1442	1850	2211
Inlet Pressure, psia	2004	1949	1905	734	721	712
Temperature Drop, °R	92.2	108.5	123	60.2	76.3	89.9
Mean Wheel Velocity, ft/sec	966	1006	1041	646	690	724
Efficiency, %	74.0	73.6	73.6	66.4	65.7	65.6
Inlet Flow, lb/sec	47.2	43.6	41.1	16.8	15.7	15.0
Oxidizer Turbopump						
Pump:						
Number of Stages	1	1	1	1	1	1
Speed, rpm	16,576	16,476	16,365	10,431	10,650	10,712
Pressure Rise, psi	2921	2862	2796	1229	1279	1291
Efficiency, %	58.5	59.4	60.3	44.9	45.5	46.5
Impeller Tip Velocity, ft/sec	613	610	605	385	394	396
Temperature Rise, °R	20.1	19.3	18.5	11.0	11.3	11.2
Inlet Flow, lb/sec	287.7	295.7	304.1	132.5	137.0	141.5
Turbine:						
Number of Stages	2	2	2	2	2	2
Pressure Ratio	1.37	1.36	1.37	1.27	1.3	1.28
Inlet Flow, lb/sec	20.7	19.2	18.2	7.4	6.9	6.66
Inlet Temperature, °R	1534	1881	2197	1442	1850	2211
Inlet Pressure, psia	2008	1952	1908	735	722	713
Temperature Drop, °R	79.8	91.8	102	49.4	61.1	70.0
Mean Wheel Velocity, ft/sec	723	719	714	455	465	467
Efficiency, %	64.6	62.8	61.6	55.3	53.5	52.1