EVALUATION OF EJECTOR SYSTEMS FOR ETS-1
INTERIM REPORT

1 OCTOBER 1962 TO 31 JANUARY 1963

REPORT 729:R0002 22 FEBRUARY 1963
CONTRACT SNP-1 Mod. 6 W.C. 0716-31

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

KEYPUNCHED

EVALUATION OF EJECTOR SYSTEMS FOR ETS-1

INTERIM REPORT

1 OCTOBER 1962 TO 31 JANUARY 1963

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

Report 729:R0002
Contract SNP-1 Mod. 6

22 February 1963
W.O. 0716-31

REFERENCE COPY

Do not remove from
REON

Technical Information Center
Aerojet-General Corporation

Written by:

R. E. Nelson

R. E. Nelson

G. O. Patmore

G. O. Patmore

Approved for Distribution:

B. L. McFarland

B. L. McFarland
Department Manager
NERVA Thermodynamics

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

X-3203

This report presents a summary of the work done between the CY 1962 test program and the CY 1963 test program to define a duct configuration for ETS-1. Runs D-252-LQ:420 to 435 were conducted during the CY 1962 test program but were included herein for reference in comparing the ejector configurations.

Tests were performed during the interim, utilizing four basic ejector systems, namely (1) LRC-2, (2) LRC-3, (3) AGC-2 and (4) LRC-3S. These ejector systems are shown in Figures 1 through 4 with Figures 3 through 6 giving the instrumentation coverage. A summary of the tests performed is given in Table I.

Ejector performance curves (P_v/P_a vs P_{p_c}/P_a) are shown for the three LRC configurations in Figures 7 through 9. The effect on performance caused by removing the secondary duct and by removing the downstream contraction section of LRC-3 were investigated. The results are shown as Figures 10 and 11 and can be compared with Figure 9 which is the performance of the complete LRC-3 configuration. It should be noted that the pull-in and minimum operating points for the geometric variations tested are nearly identical (15 atmospheres pull-in and 13.5 minimum operating).

Figures 12 and 13 show selected wall pressures for various values of engine chamber pressure in the LRC-3 configuration. The $P_{ss(1-4)}$ pressures shown in Figure 12 are located just prior to the secondary ejector nozzle. Figure 13 shows a comparison between the elbow pressure and the pressures in the constriction just downstream of the elbow. To have this much variation in pressure it seems apparent that a shock system still exists in the elbow portion of the ejector. This elbow shock seems similar to previous 90° turn ejectors tested in that it appears to be a curved shock near and parallel to the elbow with subsonic high pressure on the wall impingement side and

supersonic flow still existing in the major portion of the elbow.

To further check on the supersonic aspect of the LRC-3 configuration the LRC-3 ejector was modified by replacing the elbow with an equivalent straight section. This modification enabled the flow characteristics of the ejector to be determined without the hindrance of two-dimensional flow effects and if supersonic flow did exist after the expansion section it could be more readily determined. Figure 14 shows local static pressure as a function of chamber pressure at various locations in the straight ejector system. Three things are of primary importance and should be noted: First, near the starting chamber pressure - all the pressures with the exception of (P_{D23}) are subsonic. In fact, by the behavior of (P_{D23}) it is apparent that this pressure tap is just at the end of the initial shock system and at the beginning of the turbulent mixing region. Secondly, as the chamber pressure is increased toward NERVA steady state conditions, one-by-one all the pressures show a pulled-in condition which indicates the shock system has extended past the pressure pickup. This applies also to P_{SD-1} in the secondary ejector region. Thirdly, P_{D36} , P_{D38} and P_{D40} all become stabilized or pulled-in at the same value of P_c/P_a .

Figure 15 shows the computed one-dimensional Mach numbers at selected stations as a function of chamber pressure. The expansion section is not forcing a termination shock prior to or in the divergent section of the ejector but instead an oblique shock located at the wall between P_{36} and P_{38} terminates the supersonic flow regime. The gas then re-expands in the contraction section and at $P_c \approx 32$ atm becomes choked at the minimum flow area (just aft of P_{15} and P_{43}).

The local wall pressures as a function of chamber pressure for the one-

dimensional flow model (straight LRC-3) with the secondary ejector operating are shown in Figure 16.

A secondary ejector consisting of 24 individual nozzles was constructed and tested to determine the performance difference between it and the annulus concept which has been used on all previous secondary ejector systems tested in conjunction with the ETS-1 test program. The secondary duct area to secondary nozzle throat area ratio was given the same value as secondary ejector N, that is, 24.3 (see AGC Report No. 2409).

The results of the tests showed that there was no significant difference between the annulus type of injection and the 24 multiple nozzle injection.

A preliminary investigation of the air backflow into the ejector system during rapid engine shutdown was made. This backflow is initiated when the established shock structure in the ejector suddenly collapses due to rapid cessation of engine flow. Air backflow is undesirable for two reasons: (1) an air-hydrogen explosion in the ejector could do considerable damage and (2) transmitting the backflow is a pressure surge which if allowed to reach the cell could cause over-pressurization. Two methods were utilized for detection: (1) pressure taps in the ejector and (2) transparent ejector with water fog at the ejector exit being photographed with high speed motion pictures.

After the first series of tests using both AGC-2 and LRC-3, it was found that the backflow occurred too rapidly to be detected with any accuracy using the pressure pickups and therefore visual means were relied upon. The high speed movies (2000 frames/sec) in conjunction with LRC-3 and a plastic secondary duct (Configuration H from AGC Report 2409) showed distinctly the backflow via water fog droplets as it permeated the secondary ejector duct.

This same test was repeated for various values of secondary ejector chamber pressure in an attempt to provide a means of preventing backflow and

cell over-pressurization. When the secondary ejector flow rate equaled 20.5% of the engine flow, all backflow and over-pressurization were arrested (see Aerojet-General Movie (M-388) "Preliminary Visual Investigation of Secondary Purge Flow Requirements for Backflow Prevention During Rapid Engine Shutdown"). It should be noted that the above series of tests was only preliminary and the 20.5% value quoted applies only to a nitrogen primary-nitrogen secondary case with an $A_{(\text{sec ejec.})}/A_{(\text{nozzle throat})} = 43.6$, and for the specific system tested.

The oscillations in the cell pressure were also monitored during this series of tests and it was qualitatively observed that the secondary purge eliminated the cell over-pressure at the same flow rates required to prevent backflow of air into the duct. This is shown in Figures 17 through 21 for the LRC-3 configuration.

These effects will be investigated in detail during the CY 1963 test program to develop a 25/1 ejector system for ETS-1.

Figure 22 shows the pumping capabilities of the secondary ejector (24 multiple nozzles #1) in conjunction with LRC-3. Ambient temperature hydrogen and nitrogen were used as the primary fluid and ambient temperature nitrogen was used as the secondary ejector working fluid. The optimum secondary ejector chamber pressure for pumping ambient temperature nitrogen with ambient temperature nitrogen is approximately 24 atm which coincides with the secondary ejector starting pressure. Ambient temperature nitrogen was then used successfully to pump unheated hydrogen. The secondary ejector chamber pressure required for optimum performance (minimum $P_c/P_{a_{\text{start}}}$) in this case was between 30 and 31 atmospheres.

The pumping capabilities of the secondary ejector (24 multiple nozzles #1) in conjunction with the straight LRC-3 is shown in Figure 23. The lowest primary starting pressure, 3 atm, was obtained with ambient temperature nitrogen pumping ambient temperature nitrogen. The primary starting pressure increased as the velocity of the secondary fluid relative to the velocity of the primary fluid decreased, as found previously. A comparison between the LRC-3 and straight LRC-3 as to the pumping capabilities of the secondary ejector (24 multiple nozzles #1) indicates no noticeable difference in performance (see Figures 22 and 23) for the same chamber conditions.

Figure 24 shows the performance of the LRC-3 with ambient temperature hydrogen as the primary fluid and exhaust gases from a hydrogen-oxygen gas generator as the secondary ejector working fluid. The difference in starting pressures of the two curves in Figure 24 is not due to the different temperatures or molecular weight of the secondary gases but is caused from the different secondary ejector chamber pressures. The starting pressures shown in Figure 24 coincides with the nitrogen-nitrogen curve of Figure 22.

The effect of the fluid temperatures and molecular weights are not fully understood and are being investigated further.

Heat transfer coefficients for LRC-2 and LRC-3 are tabulated in Tables II and III and shown graphically in Figures 25 and 26. The heat transfer rates over the majority of the ejectors are reasonable. In the 45° portion of the elbow, however, the heat transfer rates became excessive which corresponds to the earlier conclusion concerning supersonic flow in the elbow.

TABLE II

HEAT TRANSFER COEFFICIENTS FOR LRC-2 EJECTOR

T. C. #	P _{ps} (psia)	603	607
	Run #	423	420
	L/D	$h \times 10^5$	$h \times 10^5$
1	.4		
2	1.1	8.62	8.50
3	1.7	6.97	6.97
4	10.4	1.56	1.76
5	10.9	6.27	6.72
6	11.2		
7	11.8	1.75	1.69
8	12.1	1.85	1.92
9	12.6	1.71	1.50
10	13.1	2.43	3.66
11	13.4	5.47	5.89
12	18.8	6.07	6.50
13	.4	7.41	7.65
14	1.1	7.36	7.22
15	1.7	6.39	6.38
16	2.7	3.16	3.29
17	3.3	7.04	7.78
18	4.0	7.80	8.20
19	4.5	6.12	6.34
20	5.1		
21	5.7	8.14	7.99
22	6.3	7.94	7.97
23	7.1		
24	7.4	6.27	6.59
25	8.0	4.65	5.03
26	8.6	5.99	6.61
27	9.2	6.46	6.74
28	10.3	3.11	3.25
29	10.8	7.23	7.271
30	11.2		
31	11.5	15.68	16.05
32	11.9	23.07	23.15
33	12.2		
34	12.4	30.18	28.93
35	12.8	10.49	10.57
36	13.1	33.44	33.39
37	13.4		
38	13.8		
39	14.1		
40	14.3		

Note: $h \longrightarrow \frac{\text{BTU}}{\text{in}^2 \text{sec}^\circ \text{R}}$

TABLE III
HEAT TRANSFER COEFFICIENTS FOR LRC-3 EJECTORS

T. C. #	P_{pc} (psia)		615	689
	Run #		430	433
	L/D		$h \times 10^5$	$h \times 10^5$
1	.4		7.41	7.78
2	1.1		8.83	9.25
3	1.7		6.54	6.88
4	10.6		4.62	5.12
5	11.4		5.21	4.88
6	12.1		7.11	6.72
7	12.4		7.13	8.05
8	12.8		9.03	9.37
9	13.0		9.63	10.26
10	13.4		10.32	10.87
11	13.6		10.46	
12	14.1		10.42	
13	14.3		10.35	
14	15.9		10.52	
15	16.3		9.27	9.71
16	.4		7.39	7.96
17	1.1		8.55	
18	1.7		6.34	6.48
19	2.7		3.24	3.51
20	3.3			
21	4.0		8.30	8.60
22	4.5		7.03	7.32
23	5.1		5.27	5.22
24	5.7		5.91	6.83
25	6.3		7.07	7.57
26	7.1		6.49	6.78
27	7.4		6.87	7.10
28	8.0		4.63	5.10
29	8.6		5.27	6.32
30	9.2		6.14	6.63
31	10.6			6.14
32	11.4		5.93	6.11
33	12.1		9.48	9.33
34	12.3		9.48	9.22
35	12.5			
36	12.9		25.13	27.96
37	13.1			
38	13.3		45.65	46.80
39	13.7		24.07	27.26
40	13.9		28.61	32.13
41	14.1		29.58	32.07
42	14.6		21.04	22.72
43	14.8			27.93
44	15.0			22.82
45	15.9			28.29
46	16.3			14.77

SUMMARY OF TESTS PERFORMED

RUN NO.	TITLE	TEST GROUP	PRIM. CONF.	S. E. CONF.	PURPOSE	P. PSIA	T. °C	P. PSIA	OTHER TEST CONDITIONS	REMARKS
1	Multiple Secondary Ejector Nozzle	D-264-LQ	2	24 MN	To check out multiple nozzle ejector concept	-	Ambient	0-400-0	40:1 Conical Nozzle (TYP Ejector 2)	
2	" "	"	"	"	"	-	"	"		
3	" "	"	"	"	"	0-600-0	"	315	Primary=GH ₂ Secondary=H ₂ -O ₂	
5	" "	"	"	"	"	-	"	261	"	
6	" "	"	"	"	"	0-300-0	"	261	"	
7	" "	"	"	"	"	0-300-0	"	300	"	
8	" "	"	"	"	To determine via pressure measurement in the secondary ejector if backflow exists during rapid shutdown	500-0	Ambient	-		
9	" "	"	"	"		"	"	40		
10	" "	"	"	"		"	"	40		
11	" "	"	"	"		"	"	-		
12	" "	"	"	"		"	"	40		
13	" "	"	"	"		"	"	65		
14	" "	"	"	"		"	"	90		
15	" "	"	"	"		"	"	115		
16	" "	"	"	"		"	"	-		
17	" "	"	"	"		"	"	-		
18	" "	"	"	"		"	"	40		
19	" "	"	"	"		"	"	65		
20	" "	"	"	"		"	"	90		
21	" "	"	"	"		"	"	115		

SUMMARY OF TESTS PERFORMED

LRC-2 and LRC-3

RUN NO.	TITLE	TEST GROUP	PRIV. CONF.	S. E. CONF.	PURPOSE	P. P. I. A.	T. P. C.	P. P. I. A.	REMARKS
420	LRC-2	D-252-IQ	LRC-2	N	Heat Transfer	607	1630	-	
421	"	"	"	"	Startup	0-600-0	1514	-	
422	"	"	"	"	Combined Flow	0-600-0	1448	361	
423	"	"	"	"	Heat Transfer	603	1600	-	
424	"	"	"	"	Startup	0-600-0	1600	-	
425	"	"	"	"	Combined Flow	0-600-0	1600	355	
430	LRC-3	D-252-IQ	LRC-3	N	Heat Transfer	615	1600	-	$\epsilon = 25$
431	"	"	"	"	Startup	0-600-0	"	-	Conical Nozzle
432	"	"	"	"	Combined Flow	0-600-0	"	355	$A_{D1}/A^* = 47$
433	"	"	"	"	Heat Transfer	689	"	-	$X = .83$
434	"	"	"	"	Startup	0-600-0	"	-	(TYP LRC-3)
435	"	"	"	"	Combined Flow	0-600-0	"	365	
22	"	D-264-IQ	LRC-3	H	To determine via pressure measurements in the secondary ejector if backflow exists during rapid engine shutdown	550-0	Ambient	-	
23	"	"	"	"		"	"	-	
24	"	"	"	"		"	"	40	
25	"	"	"	"		"	"	65	
26	"	"	"	"		"	"	90	
27	"	"	"	"		"	"	115	
28	"	"	"	"		"	"	165	
29	"	"	"	"		"	"	135	
30	"	"	"	"	To compare ejector performance with and without secondary ejector in system	0	Ambient	-	
31	"	"	"	"		"	"	-	Secondary Ejector removed from system
32	"	"	"	W	To determine if visual observation of ejector backflow is possible	550-0	"	-	1200 frame/sec Fastex Camera
33	"	"	"	"		"	"	-	"
34	"	"	"	"		"	"	65	"
35	"	"	"	"		"	"	65	"
36	"	"	"	"		"	"	-	2000 frame/sec
37	"	"	"	"		"	"	65	"
38	"	"	"	"		"	"	40	"
39	"	"	"	"		547-0	"	-	"
40	"	"	"	"		537-0	"	42	"

No Data Reduction Required

No Data Reduction Required

(W) Secondary Ejector is an H Model Nozzle with Plastic Duct.

Movies poor due to incorrect lighting

Lighting and camera angle changed
Good movies

SUMMARY OF TESTS PERFORMED

RUN NO.	TITLE	TEST GROUP	PRIM. CONF.	S. E. CONF.	PURPOSE	P. PSIA	T °C	P. PSIA	FLUID	REMARKS
42	LRC-3	D-204-L	LRC-3	"	To determine if visual observation of ejector is possible	537-0	Ambient	65		
42	"	"	"	"	"	539-0	"	31		Lighting and camera angle changed Good movies
43	"	"	"	"	"	"	"	47		
44	"	"	"	"	"	261-0	"	-	GH ₂ in Primary	
45	"	"	"	"	Performance of ejector with various fluids used in primary and secondary chambers	O-pull-in-0	"	88	GH ₂ Primary GN ₂ Secondary	
46	"	"	"	"	"	"	"	139	"	
47	"	"	"	"	"	"	"	185	"	
48	"	"	"	"	"	"	"	351	"	
49	"	"	"	"	"	"	"	345	"	
50	"	"	"	"	"	"	"	182	GN ₂ Primary GN ₂ Secondary	
51	"	"	"	"	"	"	"	134	"	
52	"	"	"	"	"	"	"	93	"	
53	"	"	"	"	"	O-400-0	"	425	"	
54	"	"	"	"	"	"	"	533	"	
55	"	"	"	"	"	O-pull-in-0	"	433	"	
56	"	"	"	"	"	"	"	512	"	
57	"	"	"	"	"	-	"	275	GH ₂ Primary H ₂ O ₂ Secondary	
58	"	"	"	"	"	O-pull-in-0	"	313	"	
59	"	"	"	"	"	-	"	365	"	Nozzle Capped Off to Check Pull-in of Secondary Ejector
60	"	"	"	"	"	-	"	365	"	
61	"	"	"	"	"	O-pull-in-0	"	395	"	
62	"	"	"	"	"	"	"	395	"	Shutdown prior to pull-in due to overheating
63	"	"	"	"	"	"	"	301	"	
64	"	"	"	"	To find performance of LRC-3 without post elbow convergence	O-175-0	"	-	-	

TABLE I

SUMMARY OF TESTS PERFORMED

RUN NO.	TITLE	TEST GROUP	PRIM. CONF.	S. E. CONF.	PURPOSE	P _{PO} PSIA	T _{PO} °R	P _{SC} PSIA	OTHER TEST CONDITIONS	REMARKS
65	LRC-3S Performance	D-264-L	LRC-3S	24 MN	To determine performance, combined flow characteristics and supersonic aspects of the LRC-3 ejector with the elbow replaced by a straight section.	0-600-0	Ambient	-	GN ₂ Secondary GN ₂ Primary	
66	"	"	"	"	"	"	"	-		
67	"	"	"	"	"	"	"	373		
68	"	"	"	"	"	"	"	-		
69	"	"	"	"	"	"	"	125		
70	"	"	"	"	"	"	"	240		
71	"	"	"	"	"	"	"	355		
72	"	"	"	"	"	"	"	475		
73	"	"	"	"	"	"	"	595		
74	"	"	"	"	"	0-175-0	"	-	GN ₂ Secondary GH ₂ Primary	
75	"	"	"	"	"	0-150-0	"	130		No pull-in due to insufficient GH ₂
76	"	"	"	"	"	0-100-0	"	245		
77	"	"	"	"	"	0-100-0	"	360		
78	"	"	"	"	"	0-200-0	"	-		
79	"	"	"	"	"	0-175-0	"	353		
80	"	"	"	"	"	0-220-0	"	124		
81	"	"	"	"	"	0-205-0	"	240		
82	"	"	"	"	"	0-110-0	"	475		
83	"	"	"	"	"	0-120-0	"	585		GH ₂ ignition delayed, P _v jumped when GH ₂ ignited outside of duct
84	"	"	"	"	"	0-100-0	"	130	GH ₂ Primary 1600°R GN ₂ Secondary	No pull-in, heater did not regulate at 1600°R
85	"	"	"	"	"	0-280-0	"	120		
86	"	"	"	"	"	0-180-0	"	250		
87	"	"	"	"	"	0-240-0	"	355		
88	"	"	"	"	"	0-140-0	"	470		
89	"	"	"	"	"	0-60-0	"	560		
90	"	"	"	"	"	0-600-0	"	-	GN ₂ Primary GN ₂ Secondary	
91	"	"	"	"	"	0-600-0	"	123		
92	"	"	"	"	"	0-600-0	"	182		
93	"	"	"	"	"	0-600-0	"	255		
94	"	"	"	"	"	0-600-0	"	95	GH ₂ Primary	
95	"	"	"	"	"	0-600-0	"	187	GN ₂ Secondary	
96	"	"	"	"	"	0-690-0	"	234		

PRIMARY EJECTOR LRC-2

NOTES:

1. ALL DIMENSIONS ARE MULTIPLES OF "D"
2. DIAMETERS ARE INTERNAL
3. $A_D / A^* = 19.8$

PRIMARY EJECTOR LRC-3

NOTES:

1. ALL DIMENSIONS ARE MULTIPLES OF "D"
2. DIAMETERS ARE INTERNAL
3. $A_0 / A^* = 19.8$

FUNCTION	L/D	FUNCTION	L/D
PD 1	0.9	PD 47	12.4
PD 2	1.7	PD 48	12.8
PD 3	2.5	PD 49	13.2
PD 4	2.9	PD 50	13.6
PD 5	3.8	PD 51	14.0
PD 6	4.7	PD 52	14.5
PD 7	5.6	PD 53	14.9
PD 8	6.5	PD 54	15.3
PD 9	7.3	PD 55	15.9
PD 10	8.2	PD 56	1.7
PD 11	9.1	PD 57	2.5
PD 12	10.0	PD 58	0.8
PD 13	10.9	PD 59	1.7
PD 14	11.8	PD 60	2.5
PD 15	12.7	PD 61	0.2
PD 16	13.6	PD 62	0.4
PD 17	14.4	PD 63	0.5
PD 18	15.3	PD 64	0.4
PD 19	0.8	PD 65	0.4
PD 20	1.3	PD 66	9.1
PD 21	1.7	PD 67	9.1
PD 22	2.1	PD 70	15.3
PD 23	2.5	PD 71	15.3
PD 24	2.9	PD 72	0.2
PD 25	3.3	PD 73	0.7
PD 26	3.7	PD 74	1.2
PD 27	4.1	PD 75	1.6
PD 28	4.5	PD 76	2.1
PD 29	4.9	PD 77	2.6
PD 30	5.4	PD 78	3.1
PD 31	5.8	PD 79	3.6
PD 32	6.2	PD 80	4.1
PD 33	6.6	PD 81	4.6
PD 34	7.0	PD 82	5.1
PD 35	7.4	PD 83	5.6
PD 36	7.8	PD 84	6.0
PD 37	8.2	PD 85	6.5
PD 38	8.7	PD 86	7.0
PD 39	9.1	PD 87	7.5
PD 40	9.5	PD 88	8.0
PD 41	9.9	PD 89	8.5
PD 42	10.3	PD 90	9.0
PD 43	10.7	PD 91	9.5
PD 44	11.1	PD 92	10.0
PD 45	11.5	PD 93	10.5
PD 46	12.0	PD 94	11.0
		PD 95	11.5
		PD 96	12.0
		PD 97	12.5
		PD 98	13.0
		PD 99	13.5
		PD 100	14.0
		PD 101	14.5
		PD 102	15.0
		PD 103	15.5
		PD 104	16.0
		PD 105	16.5
		PD 106	17.0
		PD 107	17.5
		PD 108	18.0
		PD 109	18.5
		PD 110	19.0
		PD 111	19.5
		PD 112	20.0
		PD 113	20.5
		PD 114	21.0
		PD 115	21.5
		PD 116	22.0
		PD 117	22.5
		PD 118	23.0
		PD 119	23.5
		PD 120	24.0
		PD 121	24.5
		PD 122	25.0
		PD 123	25.5
		PD 124	26.0
		PD 125	26.5
		PD 126	27.0
		PD 127	27.5
		PD 128	28.0
		PD 129	28.5
		PD 130	29.0
		PD 131	29.5
		PD 132	30.0
		PD 133	30.5
		PD 134	31.0
		PD 135	31.5
		PD 136	32.0
		PD 137	32.5
		PD 138	33.0
		PD 139	33.5
		PD 140	34.0
		PD 141	34.5
		PD 142	35.0
		PD 143	35.5
		PD 144	36.0
		PD 145	36.5
		PD 146	37.0
		PD 147	37.5
		PD 148	38.0
		PD 149	38.5
		PD 150	39.0
		PD 151	39.5
		PD 152	40.0
		PD 153	40.5
		PD 154	41.0
		PD 155	41.5
		PD 156	42.0
		PD 157	42.5
		PD 158	43.0
		PD 159	43.5
		PD 160	44.0
		PD 161	44.5
		PD 162	45.0
		PD 163	45.5
		PD 164	46.0
		PD 165	46.5
		PD 166	47.0
		PD 167	47.5
		PD 168	48.0
		PD 169	48.5
		PD 170	49.0
		PD 171	49.5
		PD 172	50.0
		PD 173	50.5
		PD 174	51.0
		PD 175	51.5
		PD 176	52.0
		PD 177	52.5
		PD 178	53.0
		PD 179	53.5
		PD 180	54.0
		PD 181	54.5
		PD 182	55.0
		PD 183	55.5
		PD 184	56.0
		PD 185	56.5
		PD 186	57.0
		PD 187	57.5
		PD 188	58.0
		PD 189	58.5
		PD 190	59.0
		PD 191	59.5
		PD 192	60.0
		PD 193	60.5
		PD 194	61.0
		PD 195	61.5
		PD 196	62.0
		PD 197	62.5
		PD 198	63.0
		PD 199	63.5
		PD 200	64.0
		PD 201	64.5
		PD 202	65.0
		PD 203	65.5
		PD 204	66.0
		PD 205	66.5
		PD 206	67.0
		PD 207	67.5
		PD 208	68.0
		PD 209	68.5
		PD 210	69.0
		PD 211	69.5
		PD 212	70.0
		PD 213	70.5
		PD 214	71.0
		PD 215	71.5
		PD 216	72.0
		PD 217	72.5
		PD 218	73.0
		PD 219	73.5
		PD 220	74.0
		PD 221	74.5
		PD 222	75.0
		PD 223	75.5
		PD 224	76.0
		PD 225	76.5
		PD 226	77.0
		PD 227	77.5
		PD 228	78.0
		PD 229	78.5
		PD 230	79.0
		PD 231	79.5
		PD 232	80.0
		PD 233	80.5
		PD 234	81.0
		PD 235	81.5
		PD 236	82.0
		PD 237	82.5
		PD 238	83.0
		PD 239	83.5
		PD 240	84.0
		PD 241	84.5
		PD 242	85.0
		PD 243	85.5
		PD 244	86.0
		PD 245	86.5
		PD 246	87.0
		PD 247	87.5
		PD 248	88.0
		PD 249	88.5
		PD 250	89.0
		PD 251	89.5
		PD 252	90.0
		PD 253	90.5
		PD 254	91.0
		PD 255	91.5
		PD 256	92.0
		PD 257	92.5
		PD 258	93.0
		PD 259	93.5
		PD 260	94.0
		PD 261	94.5
		PD 262	95.0
		PD 263	95.5
		PD 264	96.0
		PD 265	96.5
		PD 266	97.0
		PD 267	97.5
		PD 268	98.0
		PD 269	98.5
		PD 270	99.0
		PD 271	99.5
		PD 272	100.0
		PD 273	100.5
		PD 274	101.0
		PD 275	101.5
		PD 276	102.0
		PD 277	102.5
		PD 278	103.0
		PD 279	103.5
		PD 280	104.0
		PD 281	104.5
		PD 282	105.0
		PD 283	105.5
		PD 284	106.0
		PD 285	106.5
		PD 286	107.0
		PD 287	107.5
		PD 288	108.0
		PD 289	108.5
		PD 290	109.0
		PD 291	109.5
		PD 292	110.0
		PD 293	110.5
		PD 294	111.0
		PD 295	111.5
		PD 296	112.0
		PD 297	112.5
		PD 298	113.0
		PD 299	113.5
		PD 300	114.0
		PD 301	114.5
		PD 302	115.0
		PD 303	115.5
		PD 304	116.0
		PD 305	116.5
		PD 306	117.0
		PD 307	117.5
		PD 308	118.0
		PD 309	118.5
		PD 310	119.0
		PD 311	119.5
		PD 312	120.0
		PD 313	120.5
		PD 314	121.0
		PD 315	121.5
		PD 316	122.0
		PD 317	122.5
		PD 318	123.0
		PD 319	123.5
		PD 320	124.0
		PD 321	124.5
		PD 322	125.0
		PD 323	125.5
		PD 324	126.0
		PD 325	126.5
		PD 326	127.0
		PD 327	127.5
		PD 328	128.0
		PD 329	128.5
		PD 330	129.0
		PD 331	129.5
		PD 332	130.0
		PD 333	130.5
		PD 334	131.0
		PD 335	131.5
		PD 336	132.0
		PD 337	132.5
		PD 338	133.0
		PD 339	133.5
		PD 340	134.0
		PD 341	134.5
		PD 342	135.0
		PD 343	135.5
		PD 344	136.0
		PD 345	136.5
		PD 346	137.0
		PD 347	137.5
		PD 348	138.0
		PD 349	138.5
		PD 350	139.0
		PD 351	139.5
		PD 352	140.0
		PD 353	140.5
		PD 354	141.0
		PD 355	141.5
		PD 356	142.0
		PD 357	142.5
		PD 358	143.0
		PD 359	143.5
		PD 360	144.0
		PD 361	144.5
		PD 362	145.0
		PD 363	145.5
		PD 364	146.0
		PD 365	146.5
		PD 366	147.0
		PD 367	147.5
		PD 368	148.0
		PD 369	148.5
		PD 370	149.0
		PD 371	149.5
		PD 372	150.0
		PD 373	150.5
		PD 374	151.0
		PD 375	151.5
		PD 376	152.0
		PD 377	152.5
		PD 378	153.0
		PD 379	153.5
		PD 380	154.0
		PD 381	154.5
		PD 382	155.0
		PD 383	155.5
		PD 384	156.0
		PD 385	156.5
		PD 386	157.0
		PD 387	157.5
		PD 388	158.0
		PD 389	158.5
		PD 390	159.0
		PD 391	159.5
		PD 392	160.0
		PD 393	160.5
		PD 394	161.0
		PD 395	161.5
		PD 396	162.0
		PD 397	162.5
		PD 398	163.0
		PD 399	163.5
		PD 400	164.0
		PD 401	164.5
		PD 402	165.0
		PD 403	165.5
		PD 404	166.0
		PD 405	166.5
		PD 406	167.0
		PD 407	167.5
		PD 408	168.0
		PD 409	168.5
		PD 410	169.0
		PD 411	169.5
		PD 412	170.0
		PD 413	170.5
		PD 414	171.0
		PD 415	171.5
		PD 416	172.0
		PD 417	172.5
		PD 418	173.0
</			

ONE DIMENSIONAL FLOW MODEL OF LRC-3

FIG 4

PRESSURE TAP & THERMOCOUPLE LOCATIONS PRIMARY EJECTOR NO. 9

LRC-2

Function	$\frac{L}{D}$	Function	$\frac{L}{D}$
PD-1	.2	TW-1	.4
PD-2	.6	TW-2	1.1
PD-3	.8	TW-3	1.7
PD-4	1.4	TW-4	10.4
PD-5	2.0	TW-5	10.9
PD-6	10.1	TW-6	11.2
PD-7	10.6	TW-7	11.8
PD-8	11.5	TW-8	12.1
PD-9	12.3	TW-9	12.6
PD-10	13.2	TW-10	13.1
PD-11	14.0	TW-11	13.4
PD-12	.2	TW-12	18.8
PD-13	.6	TW-13	.4
PD-14	.8	TW-14	1.1
PD-15	1.4	TW-15	1.7
PD-16	2.0	TW-16	2.7
PD-17	2.5	TW-17	3.3
PD-18	3.0	TW-18	4.0
PD-19	3.7	TW-19	4.5
PD-20	4.2	TW-20	5.1
PD-21	4.8	TW-21	5.7
PD-22	5.4	TW-22	6.3
PD-23	6.0	TW-23	7.1
PD-24	6.6	TW-24	7.4
PD-25	7.2	TW-25	8.0
PD-26	7.7	TW-26	8.6
PD-27	8.3	TW-27	9.2
PD-28	9.0	TW-28	10.3
PD-29	9.5	TW-29	10.8
PD-30	10.1	TW-30	11.2
PD-31	10.6	TW-31	11.5
PD-32	11.7	TW-32	11.9
PD-33	12.7	TW-33	12.2
PD-34	13.6	TW-34	12.4
PD-35	14.6	TW-35	12.8
		TW-36	13.1
		TW-37	13.4
		TW-38	13.8
		TW-39	14.1
		TW-40	14.3

PRESSURE TAP & THERMOCOUPLE LOCATIONS

PRIMARY EJECTOR NO. 10

LRC-3

Function	$\frac{L}{D}$	Function	$\frac{L}{D}$
PD-1	.2	TW-1	.4
PD-2	.6	TW-2	1.1
PD-3	.8	TW-3	1.7
PD-4	1.4	TW-4	10.6
PD-5	2.0	TW-5	11.4
PD-6	10.1	TW-6	12.1
PD-7	11.0	TW-7	12.4
PD-8	11.8	TW-8	12.8
PD-9	12.5	TW-9	13.0
PD-10	13.2	TW-10	13.4
PD-11	14.2	TW-11	13.6
PD-12	15.5	TW-12	14.1
PD-13	15.7	TW-13	14.3
PD-14	16.1	TW-14	15.9
PD-15	16.5	TW-15	16.3
PD-16	.2	TW-16	.4
PD-17	.6	TW-17	1.1
PD-18	.8	TW-18	1.7
PD-19	1.4	TW-19	2.7
PD-20	2.0	TW-20	3.3
PD-21	2.5	TW-21	4.0
PD-22	3.0	TW-22	4.5
PD-23	3.7	TW-23	5.1
PD-24	4.2	TW-24	5.7
PD-25	4.8	TW-25	6.3
PD-26	5.4	TW-26	7.1
PD-27	6.0	TW-27	7.4
PD-28	6.6	TW-28	8.0
PD-29	7.2	TW-29	8.6
PD-30	7.7	TW-30	9.2
PD-31	8.3	TW-31	10.6
PD-32	9.0	TW-32	11.4
PD-33	9.5	TW-33	12.3
PD-34	10.1	TW-34	12.3
PD-35	11.0	TW-35	12.5
PD-36	11.8	TW-36	12.9
PD-37	12.7	TW-37	13.1
PD-38	13.5	TW-38	13.3
PD-39	14.4	TW-39	13.7
PD-40	15.5	TW-40	13.9
PD-41	15.7	TW-41	14.1
PD-42	16.1	TW-42	14.6
PD-43	16.5	TW-43	14.8
		TW-44	15.0
		TW-45	15.9
		TW-46	16.3

PRIMARY EJECTOR PERFORMANCE LRC - 2

PRIMARY EJECTOR PERFORMANCE LRC - 3

PRIMARY EJECTOR PERFORMANCE LRC-3 STRAIGHT

PRIMARY EJECTOR PERFORMANCE LRC-3 (WITHOUT SECONDARY EJECTOR)

PRIMARY EJECTOR PERFORMANCE
LRC-3 (WITHOUT CONTRACTION SECTION & SECONDARY EJECTOR)

SELECTED WALL PRESSURES VS NOZZLE CHAMBER PRESSURE LRC-3, $P_{sc} = 0$

SELECTED WALL PRESSURES VS NOZZLE CHAMBER PRESSURE LRC-3, $P_{sc} = 24 \text{ ATM}$

SELECTED WALL PRESSURES VS CHAMBER PRESSURE
(RUN 66 & 68 $P_{sc} = 0$)
STRAIGHT LRC-3

MACH NUMBER VS CHAMBER PRESSURE
STRAIGHT LRC-3
RUNS 66 & 68

SELECTED WALL PRESSURES VS CHAMBER PRESSURE (STRAIGHT LRC-3, $P_{sc}=25.93 \text{ ATM}$)

F1618

FIG 19

STARTING PRESSURE AS A FUNCTION OF SECONDARY CHAMBER PRESSURE LRC-3 WITH 24 MN SECONDARY EJECTOR NOZZLE

STARTING PRESSURE AS A FUNCTION OF SECONDARY CHAMBER PRESSURE LRC-3 STRAIGHT EJECTOR WITH 24 MN #1

PERFORMANCE OF LRC-3 WITH H₂-O₂ SECONDARY FLUID & AMBIENT TEMPERATURE HYDROGEN AS PRIMARY FLUID

HEAT TRANSFER COEFFICIENT DISTRIBUTION PRIMARY EJECTOR LRC-2

HEAT TRANSFER COEFFICIENT DISTRIBUTION PRIMARY EJECTOR LRC-3