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ALSEP Cask Cooling Performance Summary

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This ATM presents cask cooling performance that was derived from the ALSEP Cask Assembly (ACA) thermal qualification final test results, the Apollo 10 count down demonstration test (CDDT), an Apollo 12 ECS flow test, the Apollo 12 CDDT, and the Apollo 12 count down. By using these results, subsequent cask cooling performance for upcoming Apollo flights can be predicted based on the nominal range of KSC pre-launch conditions.

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1.0 INTRODUCTION

References 1 through 3 presented Apollo 12 expected cask cooling performance based upon the ALSEP Cask Assembly (ACA) thermal qualification final test results, the Apollo 10 count down demonstration test (CDDT), an Apollo 12 ECS flow test, and the Apollo 12 CDDT. The purpose of this memorandum is to include all previous cask cooling test data including that of Apollo 12 count down and to present tabular and graphical results which will allow future cask cooling performance to be predicted based on the expected range of KSC pre-launch conditions.

2.0 SUMMARY

The over-all cask cooling performance during the Apollo 12 count down was excellent. Cask sensor and surface temperatures obtained during the CDDT and launch yielded ACA sensor temperatures of approximately 150°F and external cask surface temperatures below 195°F. The 195°F cask surface temperature was well below the design operational temperature of 350°F established for the cask cooling system.

3.0 DISCUSSION

As was pointed out in Reference 2, the Apollo 12 CDDT ECS flowrate to the cask cooling nozzle was approximately 10 percent higher than had been expected from previous data. In addition, cask cooling air supply temperatures ran lower than those predicted earlier. Flow conditions that existed during the Apollo 12 flow test, CDDT, and the Apollo 12 count down resulted in improved cask cooling nozzle performance over that of the Apollo 10 CDDT as reflected in Figure 1 which illustrates the RTG nozzle pressure as a function of I.U. manifold inlet air flowrate. Using the improved flow conditions and resulting data of the Apollo 12 flow test, CDDT, and the Apollo 12 count down it was possible to widen the cask external surface and band sensor temperature envelopes which include effects of I.U. supply compartment ambient temperatures as low as 62 and 69°f, respectively (Figures 2 and 3). More specifically, cask external surface and band sensor temperatures given in Figures 2 and 3 are presented as functions of RTG nozzle inlet pressure (0.1 - 0.65 psig), manifold inlet total mass flowrate (110-260 lb/min), cask cooling air mass flowrate (14 - 34 lb/min), I.U. supply temperature (62 -130°F), and I.U. compartment ambient temperature (68 - 80°F). All cask external surface and sensor temperatures of Figures 2 and 3 were based upon steady state conditions whereas Figures 4 and 5 present transient data that was recorded during the Apollo 12 CDDT and the Apollo 12 count down.

Figure 4 shows ACA sensor warm-up curves which reflect data recorded during the Apollo 12 CDDT and the Apollo 12 count down. The apollo 12 CDDT data shows that a sensor steady state temperature of 157°F was reached after approximately two hours from the time of capsule insertion. During the two-hour warm-up period, an ECS flowrate of 200 lb/min was supplied at a temperature of 60°F with the I.U. compartment temperature being 68°F.

For the Apollo 12 count down, the ECS flowrate was varied as a function of time as depicted in Figure 4. The major ECS flowrate change from 150 to 200 lb/min occurred at 69 minutes after capsule insertion, with a further increase in flowrate to 210 lb/min being made at 86 minutes after capsule insertion. With an ECS flowrate of 210 lb/min, the ACA sensor temperature varied between temperatures of 148 and 154°F for the time period between 86 and 187 minutes after capsule insertion.

Figure 5 results cover the two-hour cask warm-up period of the Apollo 12 CDDT. In addition to the sensor temperature response, a warm-up curve for the cask external surface is included which shows that the predicted steady state temperature of the surface was 195°F.

Depicted in Figure 6 are cask surface and sensor transient temperature responses that can be expected with the removal of forced cooling air or gaseous nitrogen from the cask assembly. The cask external surface maximum temperature of 623°F and the sensor maximum temperature of 524°F were recorded under free convection equilibrium conditions during the Bendix ALSEP/Cask/LM thermal qualification test. The minimum autoignition temperature of monomethyl hydrazine (MMH) propellant in air, in a 4% oxygen atmosphere, and in a 0.5% oxygen atmosphere are shown in Figure 6. The time for the cask external surface to reach the 380°F minimum autoignition temperature for MMH in air is approximately $4\frac{1}{2}$ minutes after the removal of the forced cask cooling purge. For a 4% oxygen concentration or less, the cask external surface temperature will stabilize at approximately 625°F which is below the autoignition temperature of MMH in the 4% O_2 atmosphere.

Data of Figure 8, recorded during the Apollo 12 CDDT, depicts the ACA sensor cooldown history that resulted when the fuel capsule was removed from the cask. At the time of removal, the I.U. mass flowrate was 150 lb/min at a supply temperature of less than 50°F as shown in Figure 9.

A summary of Apollo 12 CDDT results and series of events is listed graphically in Figures 9 through 11 and tabularly in Table 1. Plots of the cask cooling nozzle flowrate and nozzle outlet velocity as a function of nozzle pressure gradient are given in Figures 12 and 13. Actual recordings and significant events that occurred during the Apollo 12 CDDT and the Apollo 12 count down are given in Tables 2 and 3, respectively.

REFERENCES

(1) McNaughton, J., Bendix Aerospace IM 69-210-205, "Apollo 12 Cask Cooling Data," 24 October 1969.

(2) McNaughton, J., Bendix Aerospace IM 69-210-216, "Trip Report, Apollo 12 Cask Cooling CDDT," 6 November 1969.

(3) Butts, D., Bendix Aerospace IM 69-210-223, "Cask Cooling Performance Predictions for Apollo 12," 11 November 1969.

Table 1

ACA/Cask Cooling Results from Apollo 12 CDDT and Launch C/D

C/D Time	I.U. Flow lb/min	Supply Temp., °F	Comp. Temp., °F	Nozzle Pres., psig	Nozzle Flow, lb/min	Sensor Temp., °F	Cask Temp., °F
1. T-15 to T-9 hrs.							
a. CDDT	200	60	68	0.38	27.5	160	195
b. Launch C/D	211	65	69	0.41	28.7	151	188
2. T-9 to T-0 hrs.							
a. CDDT	210	90-110	66-70	0.42-0.44	28.0	157	193
b. Launch C/D	200-210	64-113	68	0.38-0.45	27.8-28.7	148-154	183-189

Table 2
ACA/NOZZLE COOLING DATA

APOLLO 12/LM-7 27 OCTOBER 1969

Call Letters		RUBM		CECS					KIL-1
For Readout Dial →		7-2332		7-8277	7-4562				7-8065
		RTG Nozzle Pressure		ECS Flow Temp	ECS Flow	Comp. Temp. (IU)	Duct Temp.	% Reheat	ACA Sensor
Countdown Down	EST	IU TM D 0068	Hard Line D 193	12C10 (°F)	2A21 (#/min)	C136 (°F)	12A13 (°F)	(%)	8275T (°F)
	11:45	0.17	0.17	31°	138	68°	60°	8	70°
	12:40	0.17	0.173	59.7°	138	68°	60°	10	70°
	12:50	Pressurizing Swing Arm 7 -- No Access with FCA GSE							
	13:05	0.168	0.171						70°
	13:35	0.170	0.168						70°
	13:45			59.7°		68°	60°		73°
15:00	14:00	0.199	0.197	Capsule Insertion					
	14:06				150	68°			
14:42	14:18				200	68°	58°		106°
	14:26	0.373	0.374						112°
14:27	14:33	0.379	0.379	55.3°					118°
13:56	15:04	0.374	0.379	59.7°	200	68°	62°	20	146°
	15:34	0.375	0.380						
12:00	17:00	0.375	0.375	72.0°	200	68°	60°	16	
9:10	19:50	0.375	0.389	60.8°	200	68°	63°	19	157°
9:00	20:00	0.375	0.375	60.8°	200	68°	62°	16	160°
10/28/69									
9:00	24:00	0.376	0.379	61.9°	200	68°	62°	18	160°
9:00	02:05	0.1-0.5	0.1-0.5	Momentary Transient While Switching to GN_2					
9:00	02:15	.38	.381	62.0°	200	68°	64°	20	157°
8:59	02:23	Resumed Countdown			200	68°	64°	20	
7:30	03:52	.385	.390	62.0°	200	68°	64°	20	157°
6:30	04:52	.415	.410	62.0°	210	68°	65°	21	154°
5:30	05:52	.422	.427	62.0°	210	68°	65°	21	154°
4:30	06:52	.42	.42	62.0°	210	68°	65°	21	151°
4:00	07:22	.435	.421	98.0		65°			148°
3:53	07:29	.435	.421	107°	210	66.5°	138°	81	154°
3:50	07:32	LH_2 Fill							157°
3:45	07:37								160°
3:38	07:44	.445	.445	105°	210	70.0°	111°	65	
2:11	09:11	.432	.440	93°	210	66.5°	100°	52	157°
1:32	09:50	.432	.44	90°	210	68.5°	96°	50	157°
1:00	10:22								157°
0:0	11:22								KIL 1
0:0									
0:0	12:00	.435	.44	93°	210	68.5°	99°	47	
0:00	12:15								
0:45	13:00	.44	.44	64°	210	68°	63°	21	151/154°
1:45	14:00	.425	.425	88°	210	67°	93°	42	154°
2:45	15:00	.380	.381	71°	200	71°	70°	24	162°
	15:10	.33	.33	71°	195	72°	70°	19	165° GN_2 to Air
	15:25	.36	.36						165°
3:45	16:00	.37	.37	53°	200	68°	52°	10	160°
4:45	17:00	.372	.375	52°	200	67°	49°	8	157°
5:45	18:00	.372	.372	51°	200	68°	50°	8	157°
6:45	19:00	.375	.380	52°	200	67°	50°	9	154°
	19:15	IU TM DN							
7:45	20:00								
7:15	7:30	Sandia Trailer Start for Pad							
7:20	7:35	0.0	0.0	49°					154°
7:30	7:45	0.0	0.0	49°	200	67°	43°	5	157°
7:45	8:00	0.0	0.0	49°	200	67°	43°	4	154°
8:04	8:19	0.0	0.0	48°	150	67°	45°	3	160°
8:06	8:21	0.0	0.0	48°	150	67°	45°		165°
8:08	8:23	0.0	0.0	48°	150	67°	45°		168°
8:09	8:24	0.0	0.0	48°	150	67°	45°		174/176°
8:24	8:39	0.0	0.0	48°	150	67°	46°	1	176°
8:40	8:55	0.0	0.0	46°	150	67°	38°	0	
8:51	9:06	0.0	0.0	44°	150	67°	38°	0	182°
8:55									176°
8:57									
8:59:30									174°
9:10	9:25	0.0	0.0	45°	150	67°	35°	0	140°
10:09	10:24								81°
	10:43								76°
	12:25								65°

Table 3
ACA/NOZZLE COOLING DATA

COUNTDOWN FOR APOLLO 12/LM-6   13 NOVEMBER 1969

Call Letters · For Readout DIAL		RUBM Ch 252 7-2332		CECS Ch 244 7-8277		7-4562			KIL-1 Ch 244 7-8065	
		RTG Nozzle Pressure								
COUNTDOWN TIME	EST	IU TM D0068	Hard Line D 193	ECS Flow Temp 12C10 (°F)	ECS Flow 2A21 (#/min)	Comp. Temp. (IU) C136 (°F)	Duct Temp 12A13 (°F)	% Reheat (%)	ACA Sensor 8275T (°F)	Remarks
	5:15	0.21	0.21							
	5:30			65	150	69.5	71	17	70	
	6:09	.21	.21							
	6:15								70	
18:39:30	6:21	Feeler Gage Check prior to Dome Removal								
	6:24	Spline Lock Out								
	6:30	.21	.21			68.3			70	
	6:34			68	150	70	71	19	70	Axial Screws Turn out Hard IDR-002/CSK 029
	6:40	OK to move FCA to 3A Level								
	6:44	FCA into IU							70	
18:15	6:45	FCA in GLFC							73	
	6:47								76	
	6:50	Bands tensioned - tools coming out - spline installed							81	
	6:52								81	
	6:55	FCA installation complete - tool out - photos to be taken								
	6:56	.21	.21						90	
17:59	7:01			68.8	150	70.5	72	17	98	
	7:03								101	
	7:05								104	
	7:08	.205	.205						109	
	7:11	.36	.361		200					
	7:15	.21	.21		150				118	
	7:34			69	150	70	74	18	146	
	7:54	Complete - All photos taken								
	7:56	.37	.375	68.4	200	70	66	16	165-162	High Flow
	8:00	.37	.375	68.4	200	70	66	16	157	
17:00	8:06	Sandia Trailer at Fallback area and secure							151	
	8:12	.415	.420		210				148	KIL-1 to call only if temp Delta is 5° or more
	8:36			65.3	210	68	68	24	148	
	9:07	.415	.42			67.8			–	
	9:35			68.8	210	70	71	25		
17:00	9:52								151	
	10:35	.415	.420	65.7	210	69	65	22	151	
	10:55								151	
17:00	11:35			63	210	69	65	21	151	
	12:00	.412	.416	62	210	69	65	21	151	
Clock started at 14:00 EST	13:08			62	210	68	65	20	151	
16:55	14:05			62	210	68	65	20	151	
	15:00	.415	.415	61	211	68.5	63	19	151	
		525 Platforms coming out KIL-1 to call only if temp Delta is 3° or more								
	15:35	.417	.418						151	
	15:57			67	211	68	70	24		
14:03	16:56	.41	.41	65	211	68	70	24	151	
13:01	17:58	.413	.413	65	211	69	69	23	151	
12:02	18:57	.414	.414	65	211	68.5	69	23		
11:03	19:55	.413	.416	65	211	68.5	68	23		
9:50	21:10	.407	.409	66	210	68.5	69	23	151	
9:01	21:59	.407	.409	67	206	68.5	70	24		
9:00 Hold	22:55	.405	.406	67	206	68.5	70	23		
9:00	23:56	.406	.406	67	206	68	70	24	151	
11/14/69										
9:00	0:50	.41	.41	64	208	68	69	24	151	
9:00	1:05								148	Switch over to GN2 at 1:02
9:00 Hold	1:15								151	
8:56	1:24	.385	.383	67	200	68	69	24	151	
8:20	2:02	.40	.41						151/154	Fluctuating between 151/154
8:12	2:10			67	200	68	70	24	151	
7:46	2:36								148/151	
7:40	2:42								148	Steady
7:16	3:06	.419	.42	66	210	68	70	24	148	
6:47	3:35								148	Steady
6:20	4:02	.418	.421	66	209	68	70	25	148	
5:15	5:07	.418	.421	67	210	68	71	25	148/151	T-5:15 LO_2 Complete
4:54	5:30								151	
4:16	6:08	.43	.435	88						
4:12	6:12	Adding Heat to IU								
4:05	6:17	.436	.44	108	210	68	130	72	154	
Start Hold 6:52										
3:30	6:57								154	
3:30	7:07	.44	.443	112	209	68	126	66		
	7:52 EST Start count at 3:30									
3:27	7:55								154	
3:19	8:03			113.3	210	68.5	124	68		
3:06	8:15	.44	.446						154	
	8:51 Astronauts entered CM									
2:14	9:08	.439	.445	111.7	210	69	130	63		
1:21	10:00	.439	.444	107.1	208	69	115	60	151	
0:24	10:57	.437	.443	108.0	210	68	120	64		

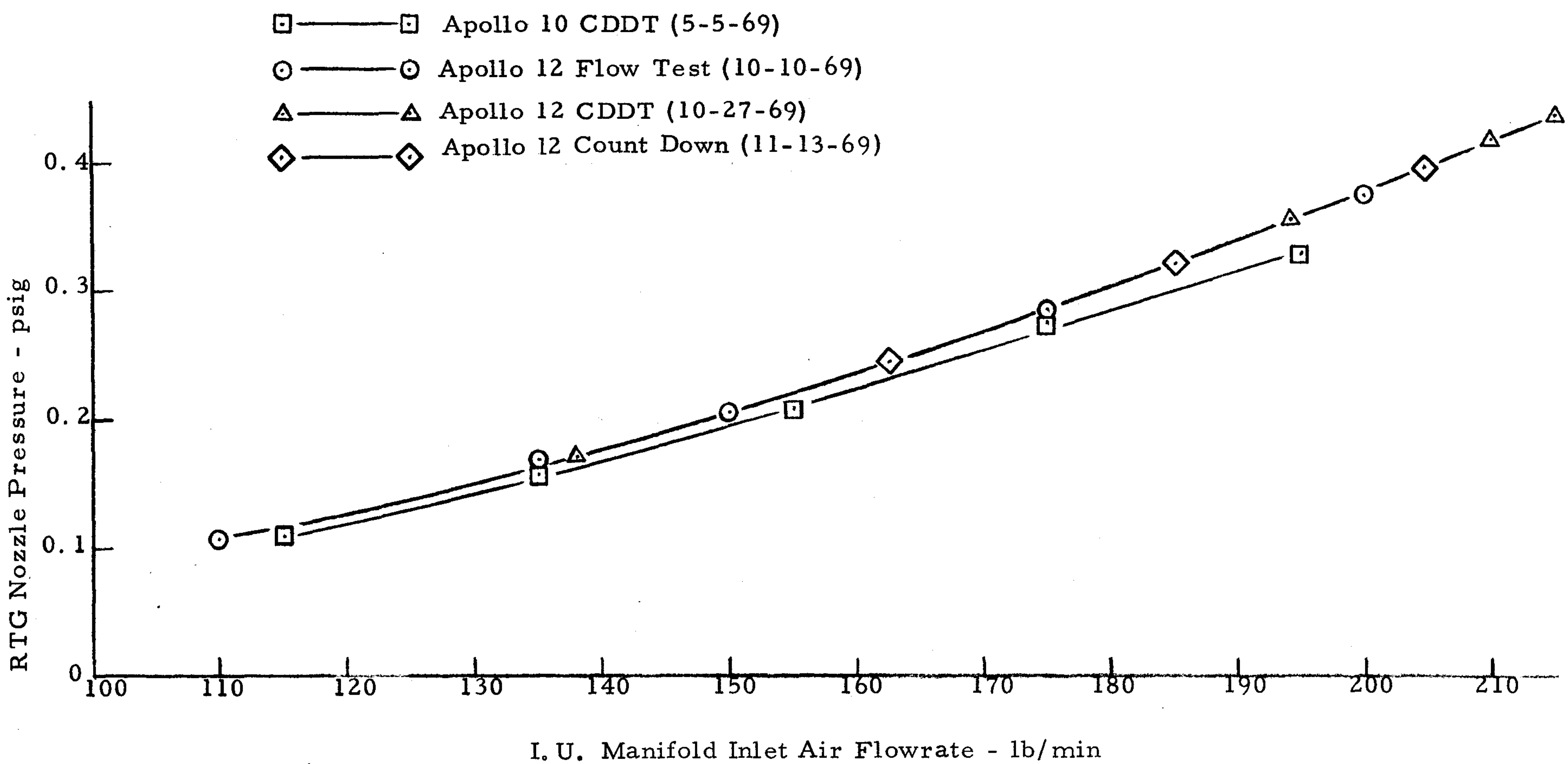


Figure 1. RTG Nozzle Pressure as a Function of I. U. Manifold Inlet Air Flowrate.

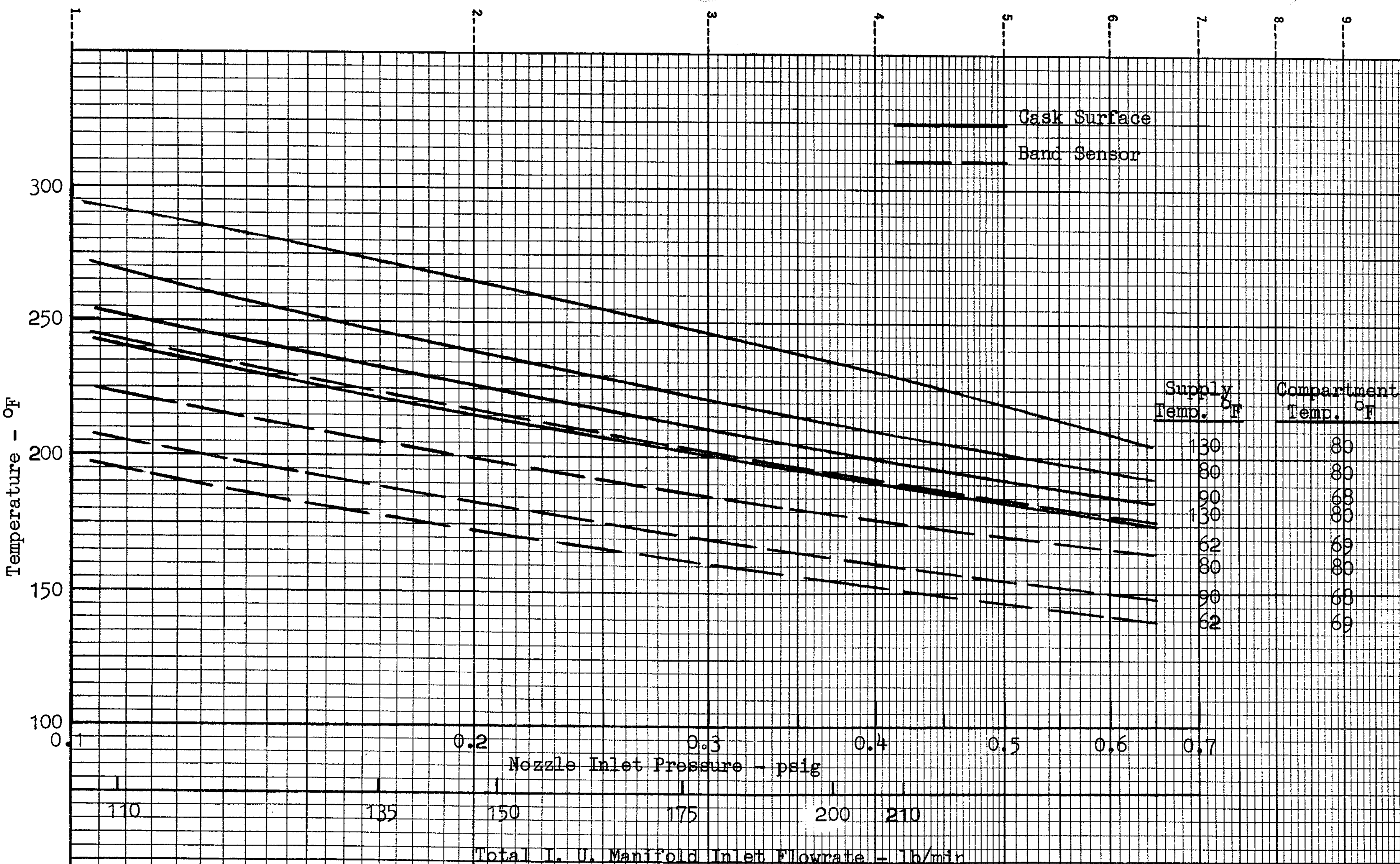


Figure 2. Cask Surface and ACA Band Sensor Maximum Temperatures vs. Cask Cooling Nozzle Inlet Pressure and I.U. Manifold Total Inlet Flowrate

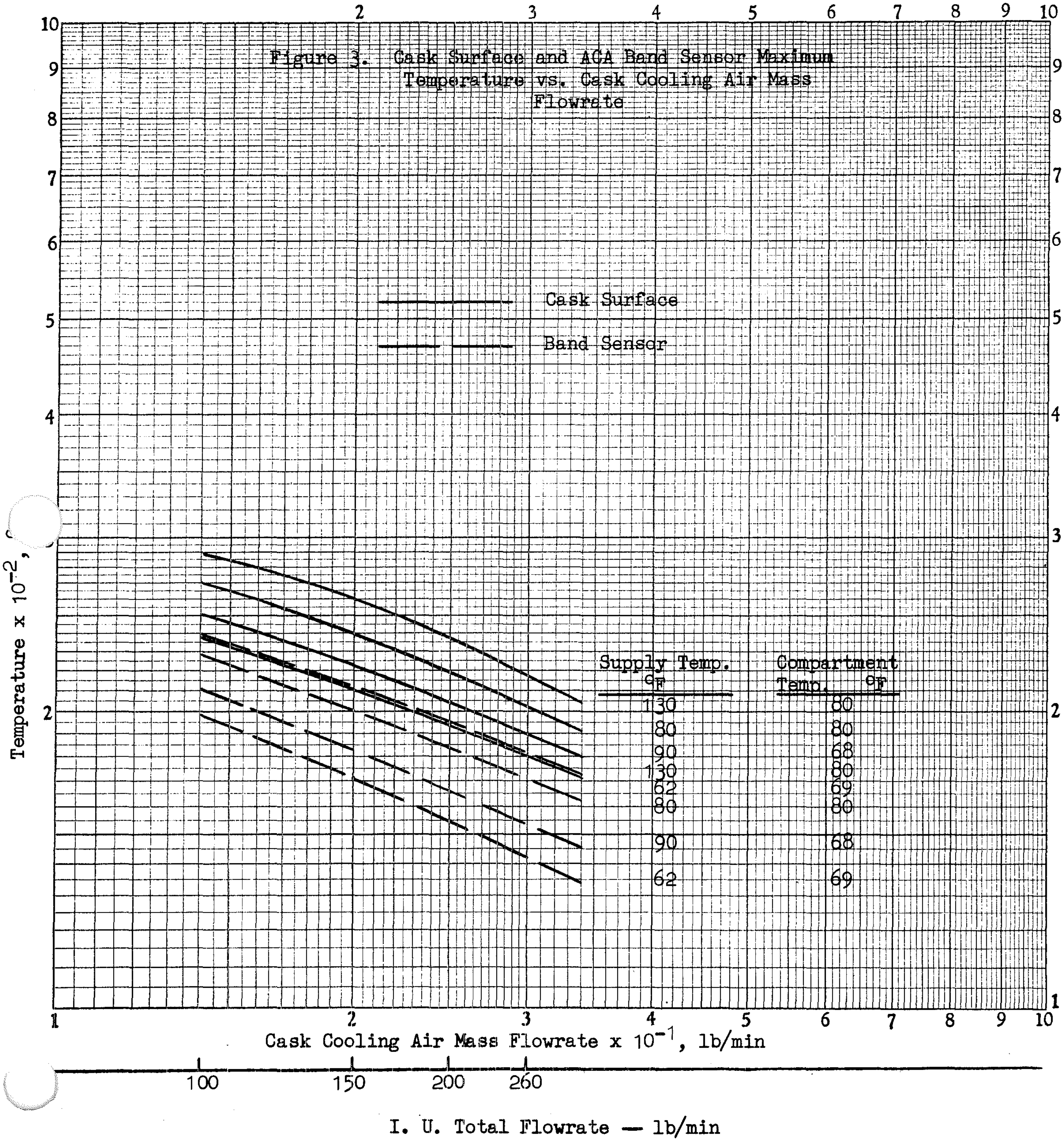


Figure 3. Cask Surface and ACA Band Sensor Maximum Temperature vs. Cask Cooling Air Mass Flowrate

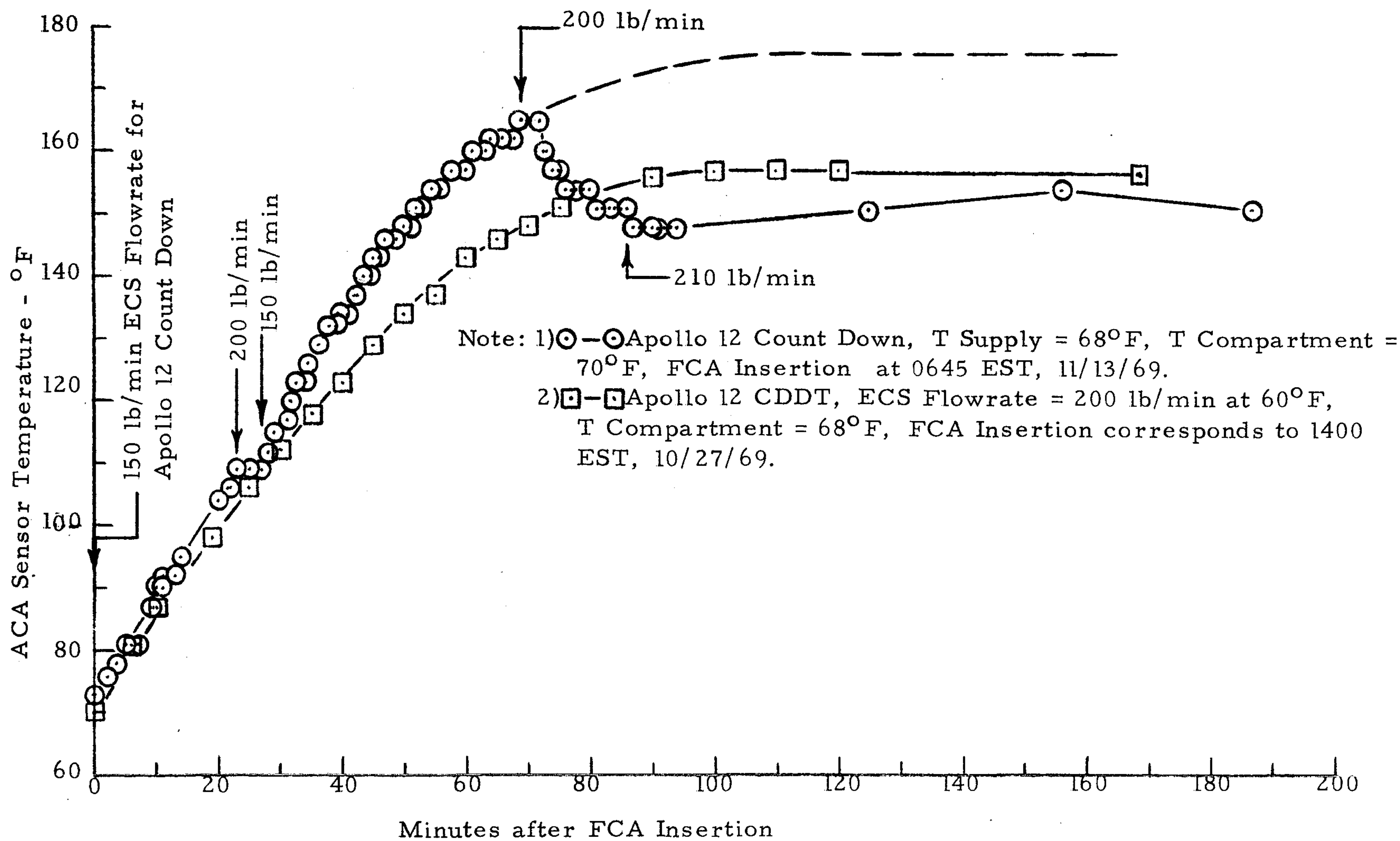


Figure 4. ACA Sensor Temperature Response Following FCA Insertion.

Note: (1) — — — ACA Cask External Surface

(2) ———— ACA Sensor

(3) I. U. Flowrate = 200 lb/min at 60°F

(4) I. U. Compartment Temp. = 68°F

(5) FCA insertion corresponds to 1400 EST, 10/27/69.

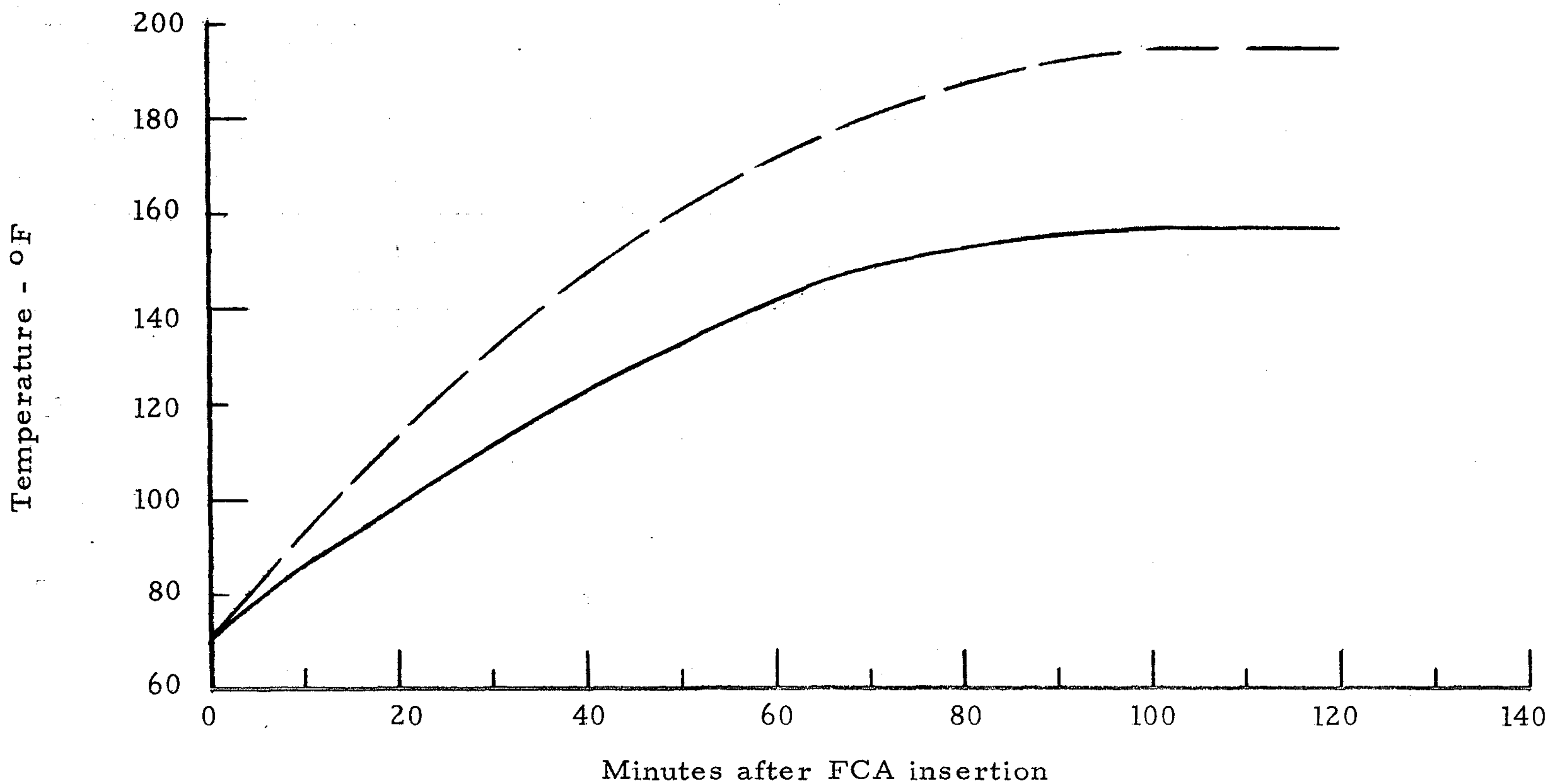


Figure 5. ACA Cask External Surface and Sensor Temperature Response after insertion of Fuel Capsule into cask, Apollo 12 CDDT.

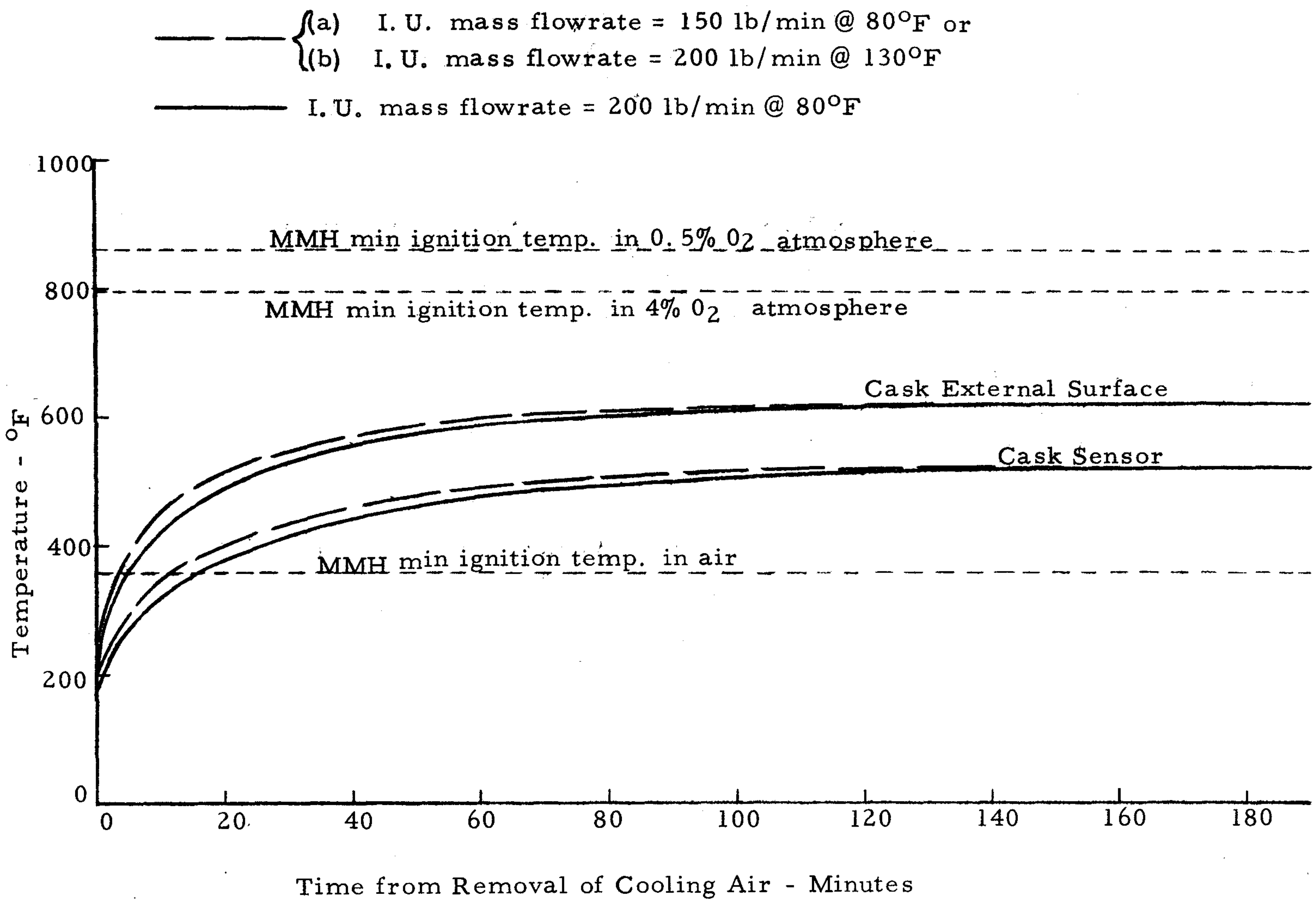


Figure 6. Cask and ACA Sensor Temperature Response After Removal of Cooling Air

Note: (1) ——— Cask External Surface
(2) — — ACA Sensor
(3) Numbers that appear next to warm-up curves correspond to flow conditions that existed prior to cooling air removal:

I. U. mass flowrate (lb/min)/I. U. supply temp (°F)/ambient temp(°F)

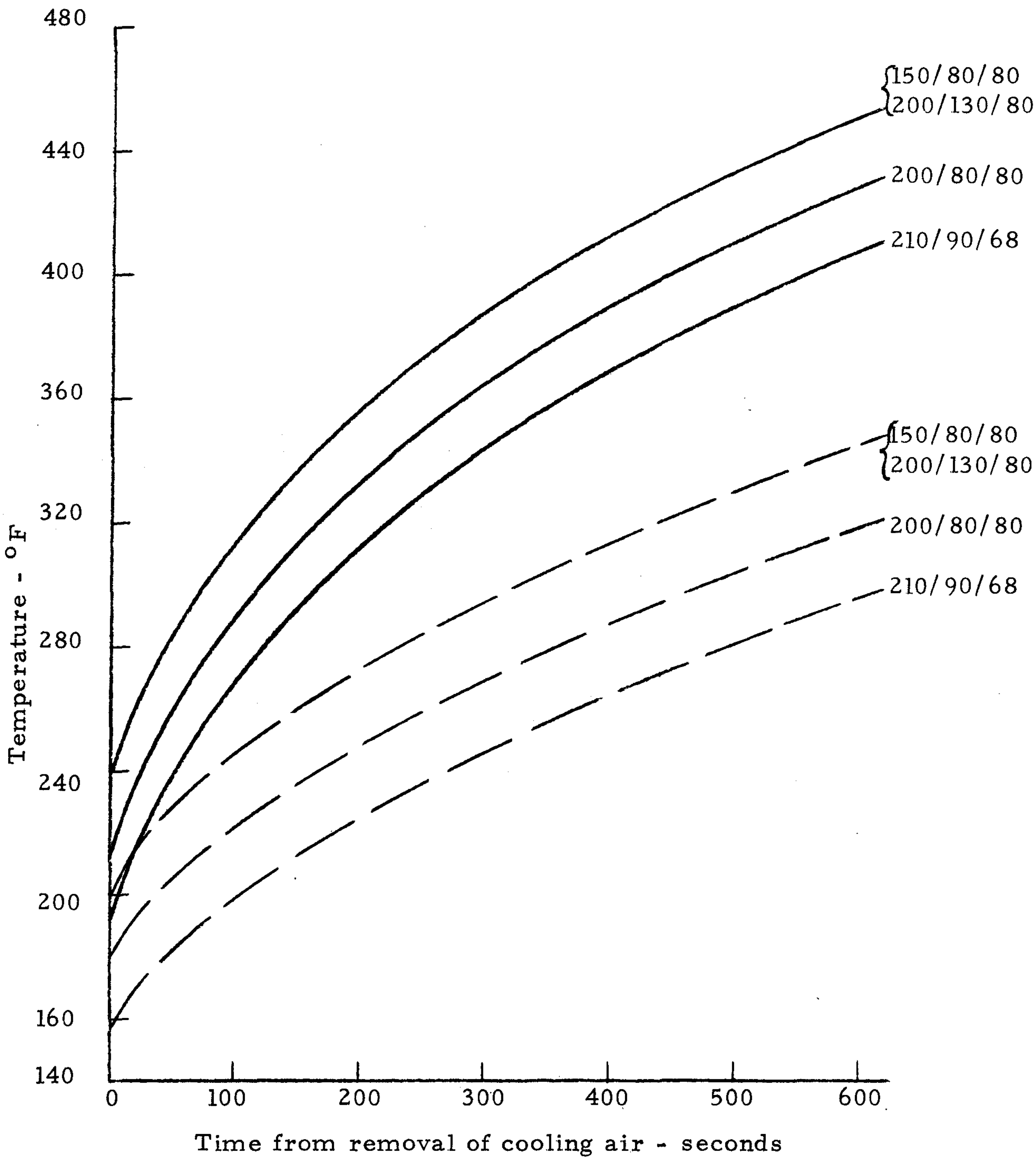


Figure 7. Cask and ACA Sensor initial temperature response after removal of cooling air.

Figure 8. ACA Sensor Temperature Following Fuel Capsule Removal During Apollo 12 CDDT.

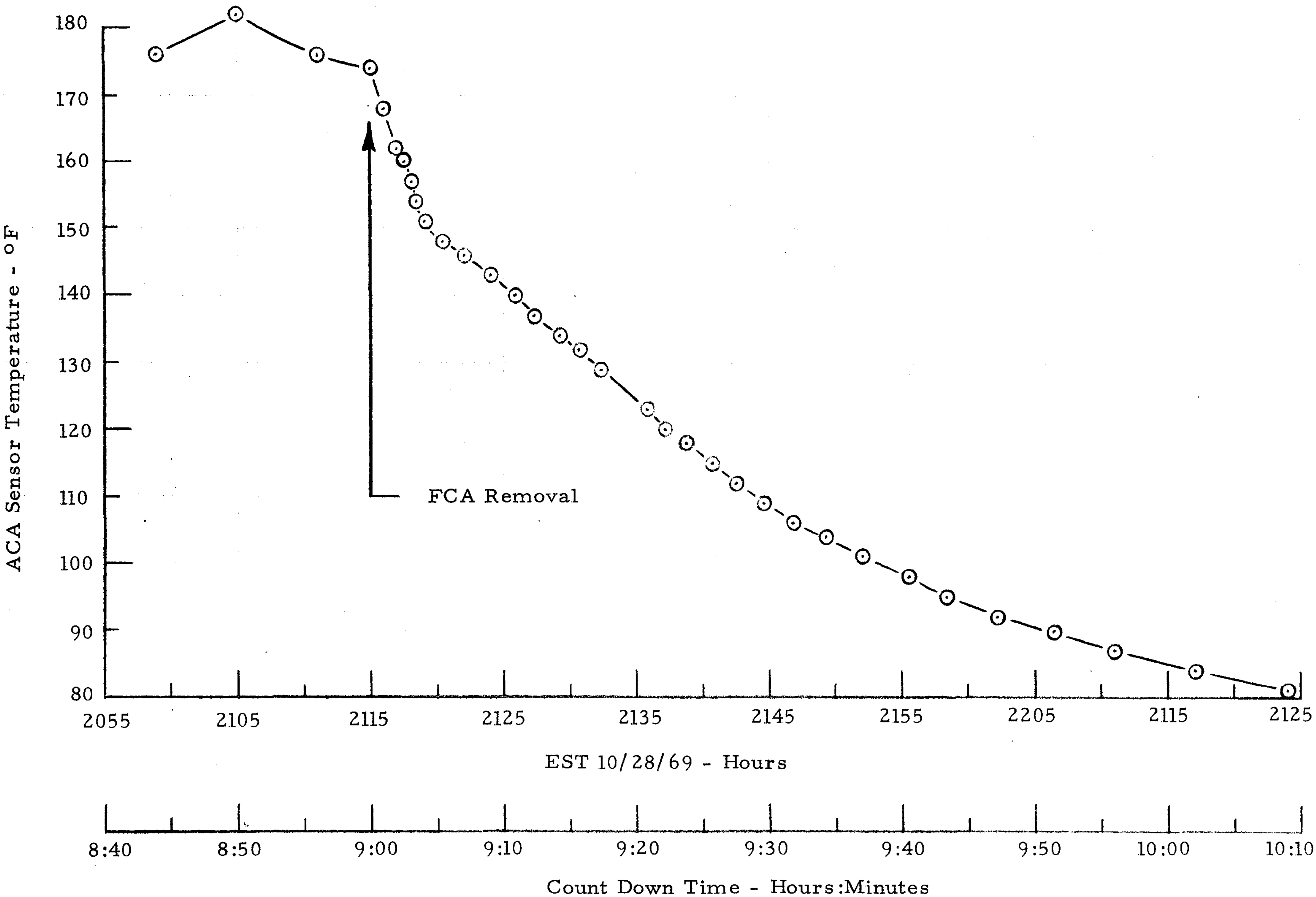


Figure 9. Summary of Apollo 12 CDDT Cask Cooling Performance

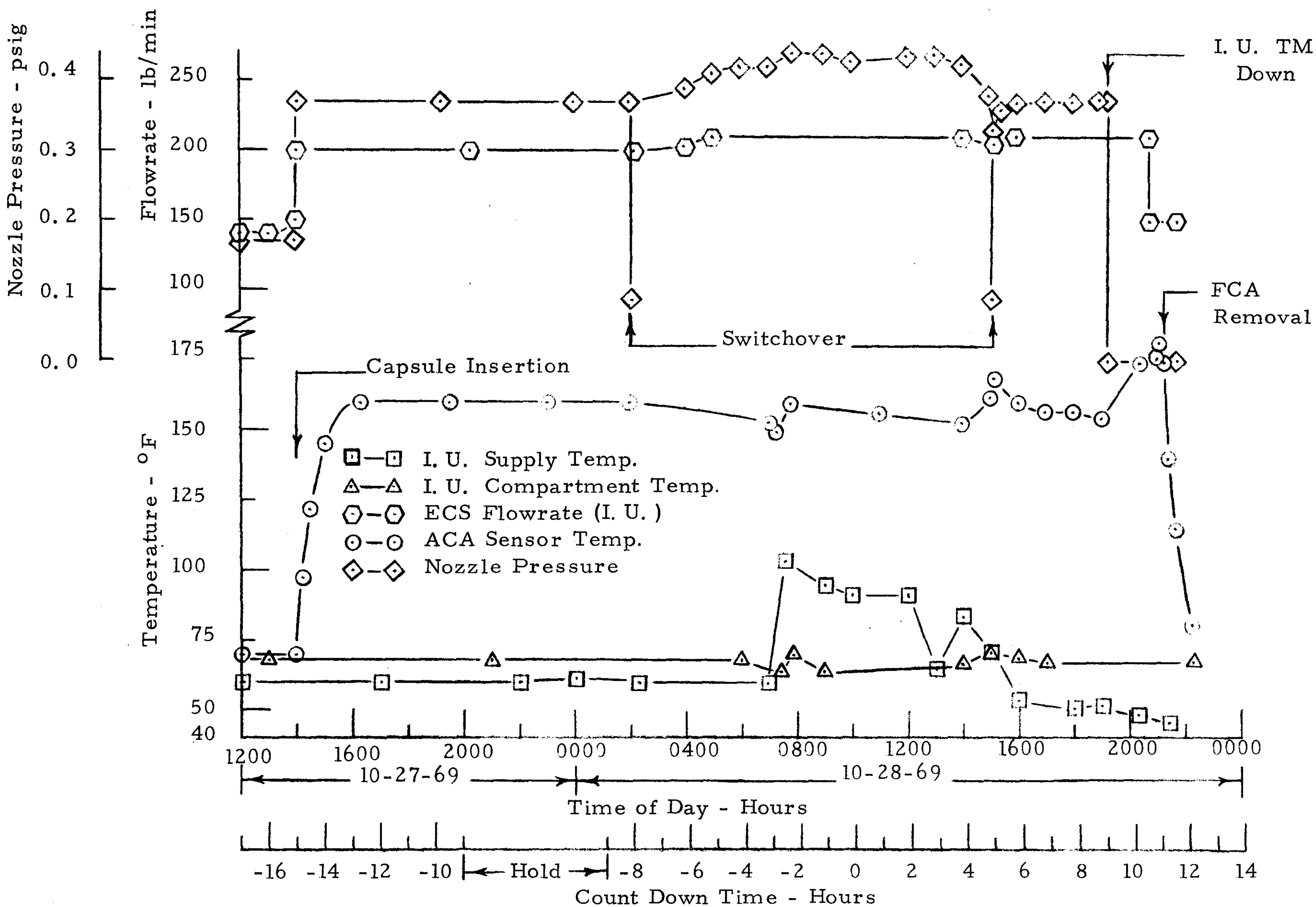
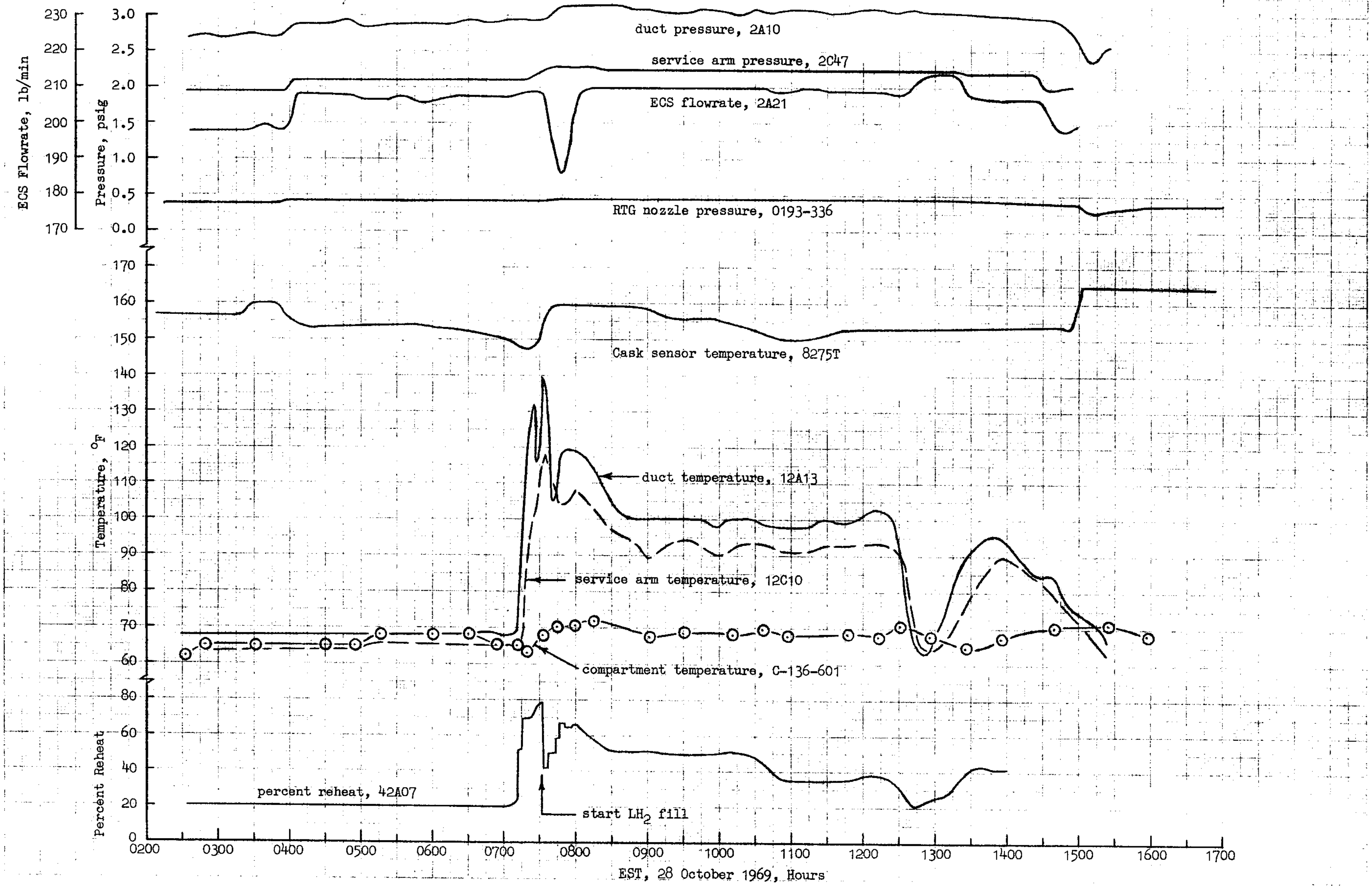


Figure 10. ACA/Nozzle Cooling Data, Apollo 12 CDDT



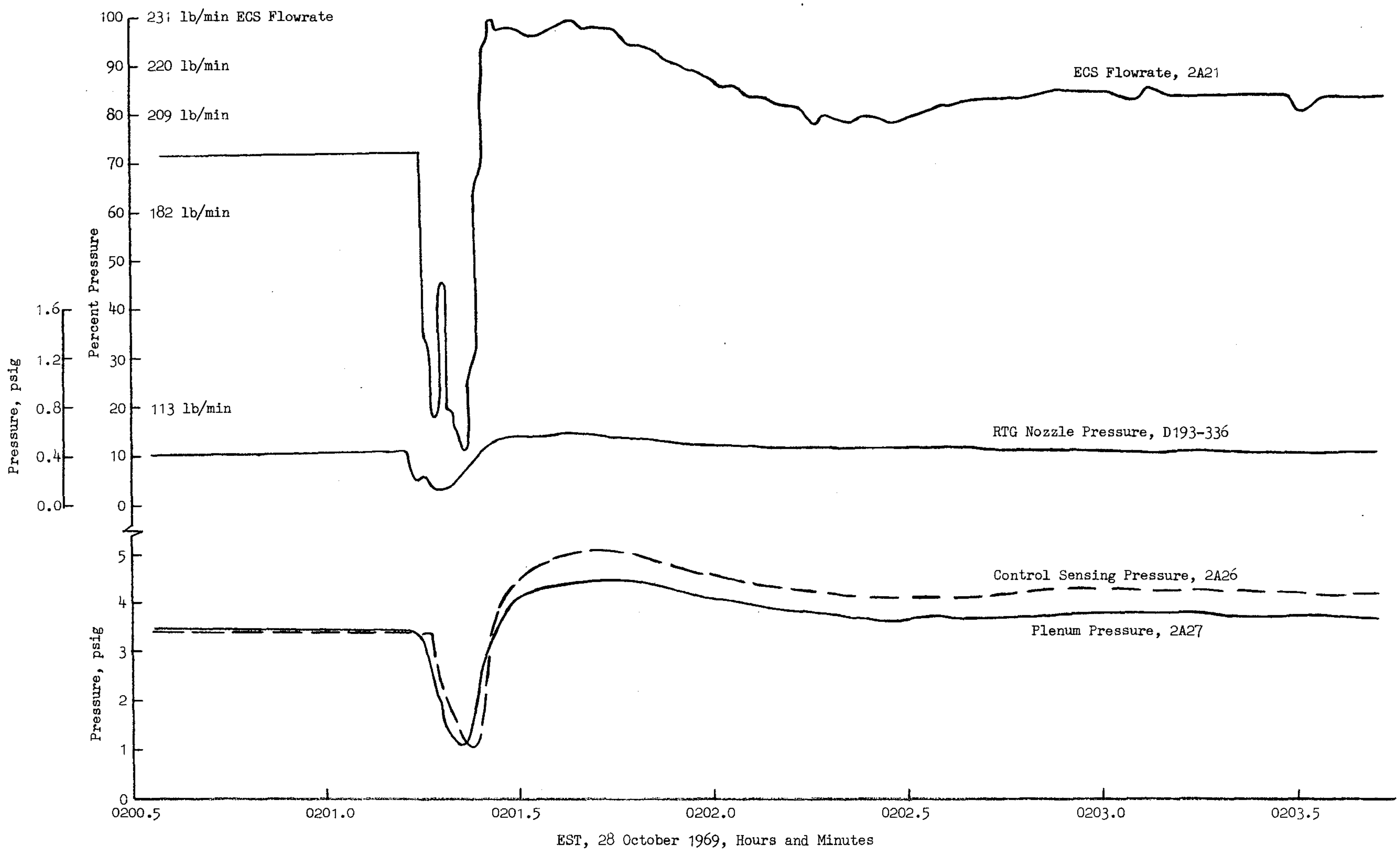


Figure 11. Air/GN_2 Changeover, Apollo 12 CDDT.

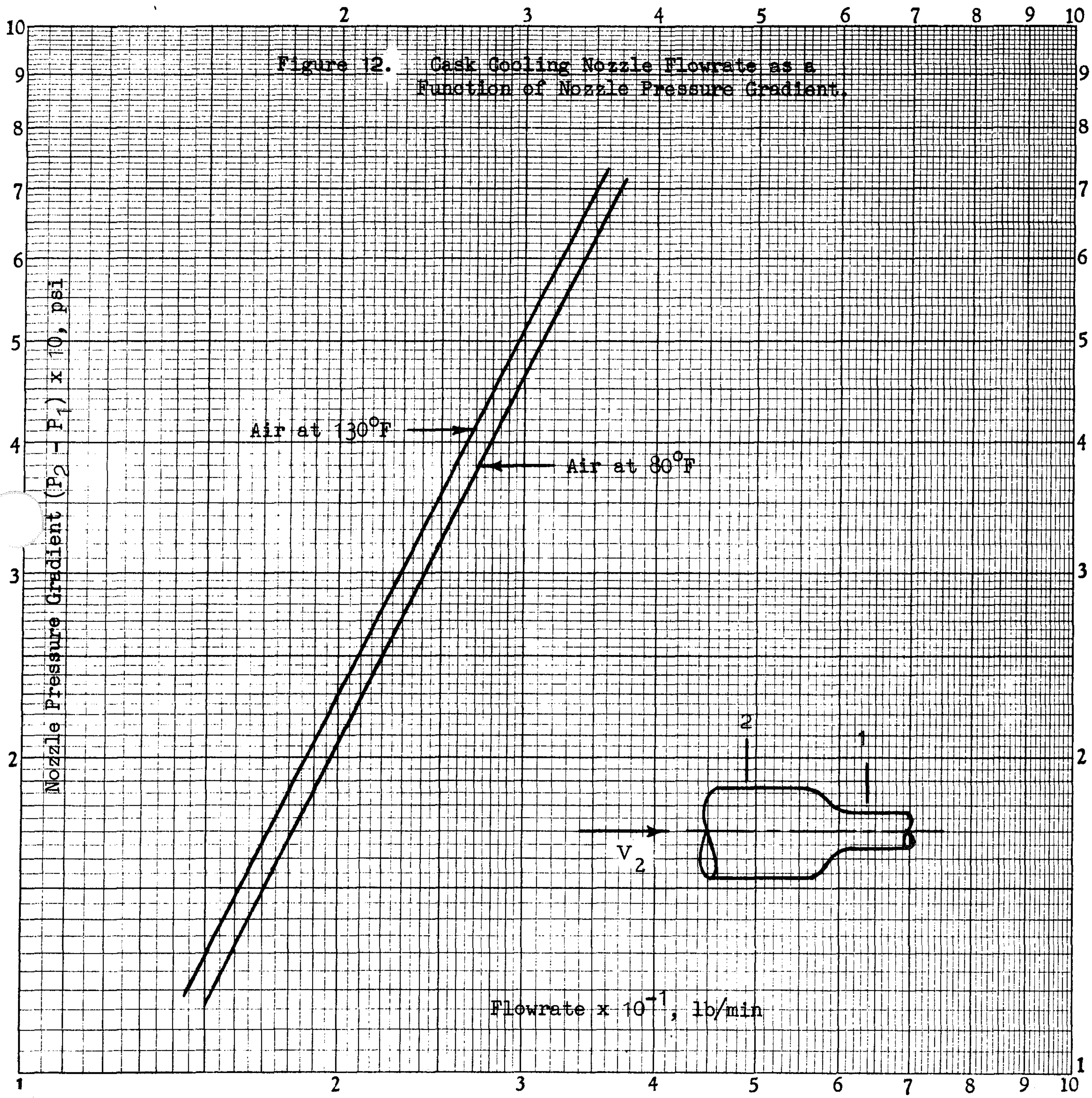


Figure 12. Gask Cooling Nozzle Flowrate as a Function of Nozzle Pressure Gradient.
Nozzle Pressure Gradient (P2 - P1) x 10, psi
Air at 130°F
Air at 80°F
Flowrate x 10-1, lb/min
V2
2
1
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10

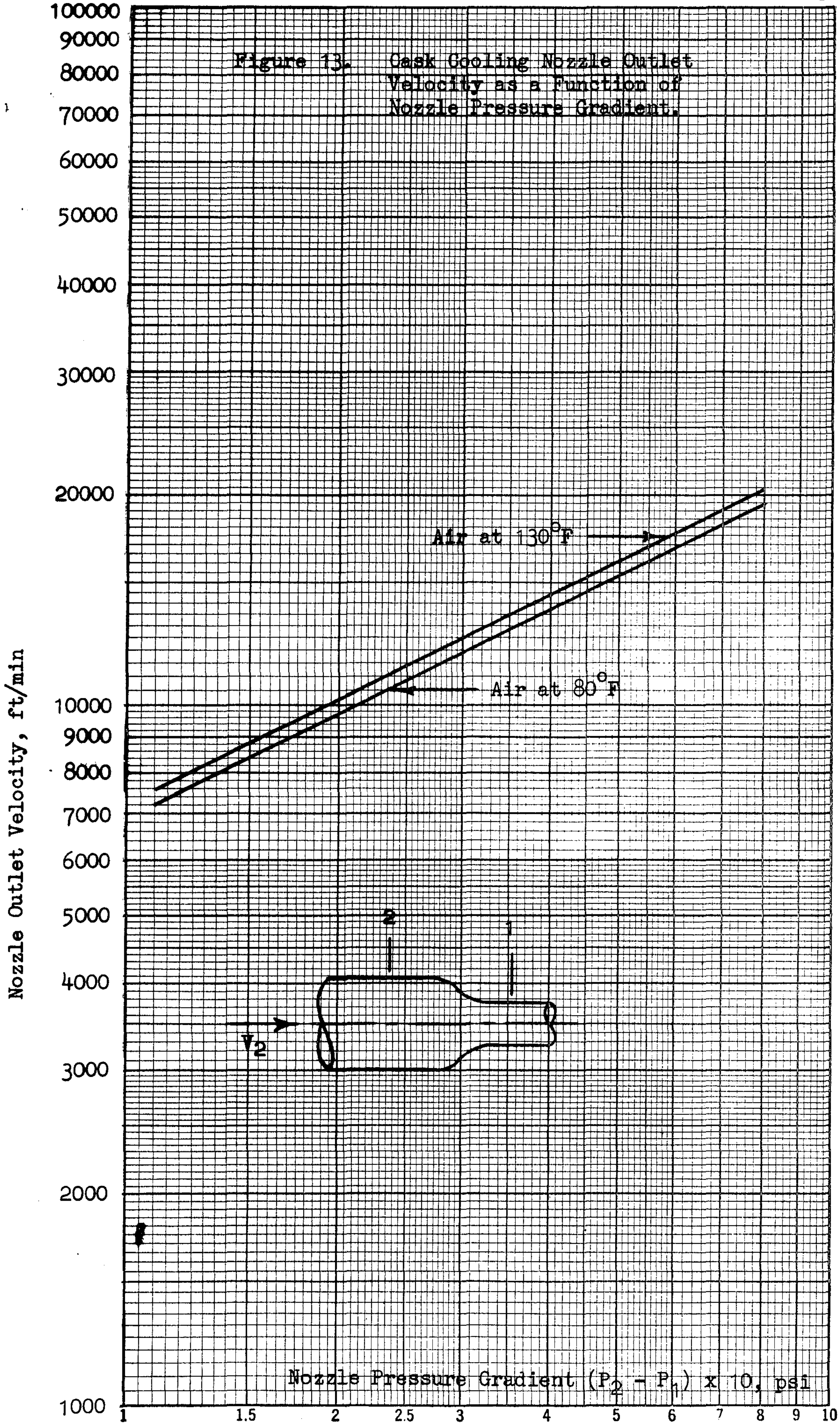


Figure 13. Cask Cooling Nozzle Outlet Velocity as a Function of Nozzle Pressure Gradient.
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Nozzle Outlet Velocity, ft/min
Air at 130°F
Air at 80°F
2
1
V2
Nozzle Pressure Gradient (P2 - P1) x 10, psi
1
1.5
2
2.5
3
4
5
6
7
8
9
10