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TASK III MILESTONE REPORT
KENNEDY SPACE CENTER (KSC)
LOX LOADING FACILITY ANALYSES

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ACKNOWLEDGEMENTS

Contributions to the Kennedy Space Center (KSC) facility and the Space Shuttle system configuration and operational input data for the KSC facility analyses were made by:

Sterling Walker (NASA, KSC)
Roy Johanson (NASA, KSC)
Tom Winstead (NASA, MSFC)

Contributions to modifications of the Transient Cryogen Transfer Program (TCTP) and documentation of the KSC facility analyses were made by the following Boeing personnel:

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1.0 INTRODUCTION

Transient thermodynamic analyses have been made for the Kennedy Space Center (KSC) LOX loading system proposed for the Space Shuttle. The primary objective of these analyses is to predict the sensitivity of system performance to operating procedures, flow rate, temperature, and quality at the Orbiter (ORB)/Ground Service Equipment (GSE) interface. A further objective is to establish required system chill-down times. These analyses also include the prediction of transient thermodynamic conditions for the facility vent line, Shuttle Main Engine (SSME) feed line entrance, ORB/ET interface, and the ET entrance (tank bottom).

The KSC/Shuttle system, shown in Figure 1-1, is made up of the GSE LOX loading system; which includes the LOX storage tank, 1000 GPM pumps, pump drain and LOX by-pass lines, LOX fill and vent lines, flow control valves between the storage tank and the ORB/GSE interface; the Space Shuttle fill system; and the SSME chill-down bleed system. The system analyses are based on continuous flow through the Orbiter, SSME engine bleed, and ET during the LOX loading facility chill-down, orbiter chill-down and slow fill and vehicle slow fill. Following the LOX loading system tank head flow chill-down, the flow is diverted to the facility LOX vent line during the pump start-up to chill-down the vent line for a brief period. The flow is then switched back to the vehicle for the Orbiter chill-down and vehicle slow fill. The results of these predictions may be used as a technical basis to establish the expected degree of similarity between the NSTL and KSC LOX loading facilities and for further development of the system configuration or operating sequence.

Additional modifications and improvements of the Transient Cryogen Transfer Program (TCTP) were required for simulation of the KSC system and operations proposed for the Space Shuttle LOX loading. These TCTP improvements provide a more generalized capability to perform transient analyses of various cryogenic transfer system configurations and operations with various known boundary conditions.

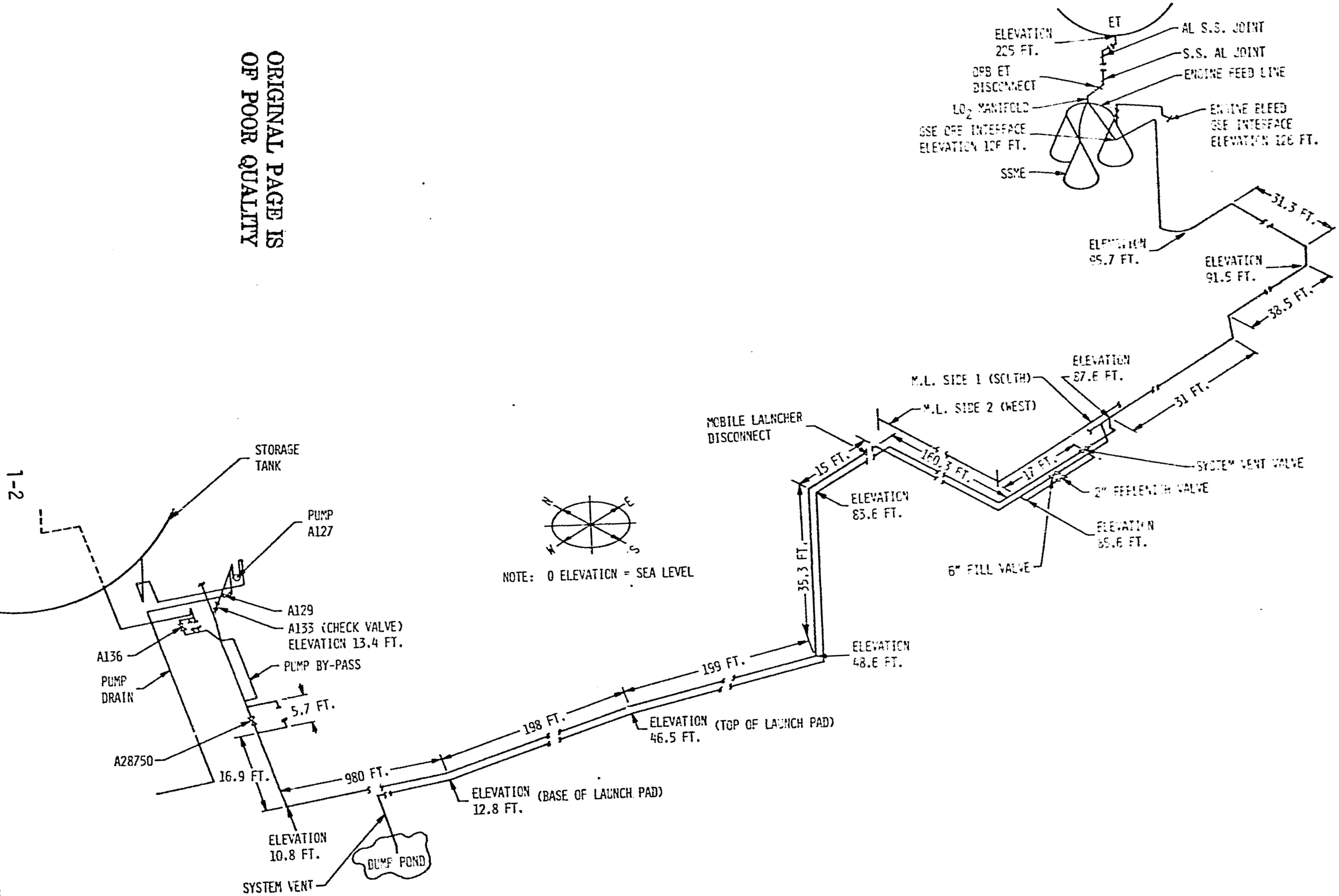

FIGURE 1-1. KSC/SHUTTLE LOX LOADING SYSTEM

2.0 KSC/SHUTTLE SYSTEM SIMULATION INPUT DATA

The KSC LOX loading system combined with the Space Shuttle LOX fill system is shown schematically in Figure 1-1. More detailed configuration input data for these analyses are presented in the Appendix, Tables A-I and A-II. The KSC facility input data were derived from Launch Complex 39B drawings, Skylab test data, and information provided by Mr. Roy Johanson and Mr. Sterling Walker (KSC). The Space Shuttle configuration, heat capacitance, and maximum external heat load data were derived from drawings and information provided by Mr. Tom Winstead (MSFC).

Pipe friction factors for clean commercial steel as a function of Reynolds Number from Reference 1 were input to the system simulation. Equivalent length-to-diameter ratio data for the system components were derived from References 1, 2, and 3. The maximum steady state external heat flux for the KSC vacuum jacketed line was estimated to be 37.1 $BTU/FT^2 \cdot HR$ based upon Skylab LOX loading system analyses. The KSC LOX loading system is vacuum jacketed from the system inlet (check valve A133) to the ORB/GSE interface with the exception of a 5.7 foot section of line containing valve A28750. The maximum external heat flux input used for uninsulated GSE lines was 465 $BTU/FT^2 \cdot HR$ as suggested by References 2 and 3. The KSC LOX vent line is uninsulated. External heat transfer and work done on the system from the storage tank to the pump discharge was simulated by computing the pump discharge enthalpy as a function of input pump discharge temperature from AS-208 measurement data and computed pump discharge pressure. The external heat flux input data used for the Space Shuttle were: 694 $BTU/FT^2 \cdot HR$ for the GN_2 purged uninsulated Orbiter LO_2 fill and drain line, 55 $BTU/FT^2 \cdot HR$ for the vacuum jacketed LO_2 manifold and duct to the ORB/ET disconnect, and 66.3 $BTU/FT^2 \cdot HR$ for the insulated 17 inch duct to the ET. Steady state heat transfer rates for the combined KSC/Shuttle system are presented in the Appendix, Table A-III. The effective heat capacity of the KSC pipe walls (inner wall for vacuum jacketed lines) was determined with a specific heat of 0.06 $BTU/LB_M/\cdot{}^\circ R$ based

2.0 (Continued)

upon Skylab LOX loading system analyses and a wall density of 501 LB_M/FT^3. The heat capacity of the Shuttle pipe walls was determined by assuming specific heats of 0.091 and 0.208 $BTU/LB_M \cdot °R$ for stainless steel and aluminum and densities of 501 and 169 LB_M/FT^3 for stainless steel and aluminum.

A pump performance curve derived from Skylab data was used as input for the KSC LOX vent line chill-down and Shuttle low fill analyses. This pump performance data as compared to two other sets of data for the 1000 GPM pumps (Byron Jackson and Beach) are presented in the Appendix, Figure A-1. The Skylab launch data agree more closely with the Byron Jackson data than with the independent Beach test data. The Beach data indicate somewhat higher performance than both Skylab and Byron Jackson data. The Skylab data in Figure A-1 differs from the curve presented in Reference 4 in that the curve presented in Reference 4 implicitly included the effect of pump drain line flow during the transient response to the pump start-up (to 60 seconds from pump start). The pump drain flow was not explicitly included in the TCTP at the time of the Reference 4 analyses and the Reference 4 pump curve was used in the simulation to determine system entrance flow ($\dot{m}_{PUMP}-\dot{m}_{DRAIN}$) at valve A133 as a function of pump pressure rise and RPM during the pump start-up. For the KSC/Shuttle system analyses, the pump drain flow as a function of pump discharge pressure is explicitly included in the TCTP. Hence, the Skylab data in Figure A-1 was plotted in terms of the pump discharge flow (measured system flow plus calculated pump drain flow) and used in the system simulation to determine pump discharge flow as a function of pump pressure rise and RPM. For the pump start analyses, the pump speed was assumed to increase to 3060 RPM as shown in the Appendix, Figure A-2. The rate of RPM increase is the same as measured on AS-208. For the tank head flow system chill-down analysis, a pressure drop vs. flowrate curve was derived from measured AS-208 data for the windmilling 1000 GPM pump. The pump pressure drop curve is shown in the Appendix, Figure A-3.

2.0 (Continued)

In order to model the KSC Shuttle LOX loading system inlet flow (valve A133) for a given storage tank ullage pressure and liquid level, AS-208 measured data were used to derive pressure drop vs. flowrate relations for the suction line and pump chilldown drain line. Equivalent 6 inch line loss factors ($\Sigma(L/D)_e$) of 480.15 and 43300.0 were derived for the pump suction line and chilldown drain line respectively. An equivalent 6 inch line length of 151.1 feet was used to simulate the suction line volume and liquid mass. The pump drain line was assumed to be open during the tank head flow period and for one minute after pump start. At the pump start, the LOX by-pass valve (A136) was assumed to be opened to a nominal position which would maintain a 210 PSIG pump discharge pressure with 750 GPM by-pass flow. For these conditions, the equivalent 6 inch line loss factor $(L/D)_e$ was calculated to be 29408.7. The LOX by-pass valve was assumed to be at a constant position during the LOX vent line chill-down. The facility chill-down analyses are based upon an initial storage tank liquid level and ullage pressure schedule similar to that for AS-208 which is considered to be a "worst case". The initial storage tank liquid level is 33.1 feet above the tank bottom. The ullage pressure schedule is shown in the Appendix, Figure A-4. A constant ullage pressure of 23.9 PSIA was used after the 10 minute facility chill-down as was measured on AS-208. The storage tank bulk temperature was assumed constant at -296°F as measured on AS-208 throughout the facility chill-down and slow fill. The system inlet (pump discharge) temperature was assumed to be the same as measured on AS-208 for the 10 minute facility chill-down as shown in the Appendix, Figure A-5. A constant system inlet temperature of -296°F was used after the 10 minute facility chill-down as measured on AS-208. The Shuttle ET ullage pressure was assumed to be constant at 16 PSIA. A valve opening time of 8 seconds was assumed for valve A28750 to initiate flow to the cross country line.

3.0 KSC FACILITY CHILL-DOWN ANALYSES

The facility chill-down analyses include the initial tank head flow period to chill down the LOX loading system followed by a pump flow period to chill down the LOX vent line. Transient analyses of the KSC LOX loading system chill-down include both the Space Shuttle LOX fill system to the external tank (ET) and simulated engine bleed flow.

3.1 KSC SHUTTLE LOX LOADING SYSTEM CHILL-DOWN ANALYSIS

Results of the KSC Shuttle LOX loading system chill-down analysis are shown in Figures 3-1 through 3-5. Steady state conditions are approached at the 6 inch fill valve about 10 minutes after tank head flow initiation (to the cross country line). Previous KSC and NSTL system analyses indicate that neither 100 percent liquid flow at the fill valve nor significantly lower Shuttle duct wall temperatures could be obtained by extending the tank head flow chill-down period. Therefore the tank head flow simulation was terminated and the pump flow simulation was initiated at 10 minutes after tank head flow initiation. Figures 3-1 and 3-2 show that the KSC system pressures and flow rates become relatively stable after 200 seconds of chill-down. At 10 minutes, the system entrance pressure is increasing due to increasing hydrostatic head and the system entrance flow rate is decreasing. These results are similar to the Skylab system entrance pressures and flow rates, as expected, since the systems are the same up to the mobile launcher disconnect tower. The maximum gas flow rate into the ET during the 10 minute facility chill-down is 8.5 LB_M/SEC. At the end of chill-down, the pump NPSH is 46.84 FT. Figure 3-3 shows that the fluid qualities at the 6 inch fill valve and the ORB/GSE interface approach constant values at the end of facility chill-down. Figure 3-4 shows the transient fluid temperatures at the ORB/GSE interface, ORB/ET disconnect, and ET entrance. Figure 3-5 indicates that the Shuttle hardware (fill line walls) will approach minimum temperatures for tank head flow at the end of facility chill-down. Previous NSTL system

3.1 (Continued)

analyses indicate that Shuttle hardware cooling rates would decrease with an extended tank head flow period. This is due to the increasing hydrostatic head which decreases the system flow rates.

3.2 KSC LOX VENT LINE CHILL-DOWN ANALYSIS

Preliminary analyses of the 1000 GPM pump ramp to 3060 RPM (with flow through the 6 inch fill valve to the orbiter) showed that the 2-phase flow rate to the orbiter would reach 22 LB/SEC (133 GPM of liquid) prior to achieving 100 percent liquid flow at the valve complex. Previous NSTL and KSC analyses indicate that the flow rate cannot be effectively controlled by the flow control valve until 100 percent liquid reaches the valve. The planned operating procedure to be analyzed was subsequently changed to include a LOX vent line chill-down period during the 1000 GPM start up transients. The results of the LOX vent line chill-down analysis are shown in Figures 3-6 through 3-10. Figures 3-6 and 3-7 show the transient pump discharge pressure and system flow rates. For the first 28 seconds, the pump discharge pressure and system entrance flow rate very closely match the measured AS-208 data as expected since the RPM ramp is the same and the system hydrostatic head and flow rate are still relatively low at the launch pad. These results indicate that the LOX supply system, including the pump drain and LOX by-pass flow, is correctly modeled. At 44 to 60 seconds with a constant pump speed of 3060 RPM, the pump discharge pressure increases resulting in a decreasing system entrance flow rate due to increasing system hydrostatic head. At 60 seconds the pump discharge pressure and system entrance flow rate both increase due to closing the pump drain valve. The LOX by-pass flow rate (system entrance minus cross country flow rate) increases with increasing pump discharge pressure from 0 to 75 seconds. At 76 seconds the vent line entrance flow rate increases to approximately the same as the cross country flow rate indicating that the system is filled with liquid to the vent line entrance. Figure 3-8 shows that 100 percent liquid

3.2 (Continued)

flow is obtained at the valve complex outlet at 72 seconds after pump start and in vent line at the bottom of the Mobile Launcher (M.L.) disconnect tower at 96 seconds from pump start. Figures 3-9 and 3-10 show vent line fluid and wall temperatures respectively. These results show that 2.5 minutes are required to chill the vent line walls to 200°R or below.

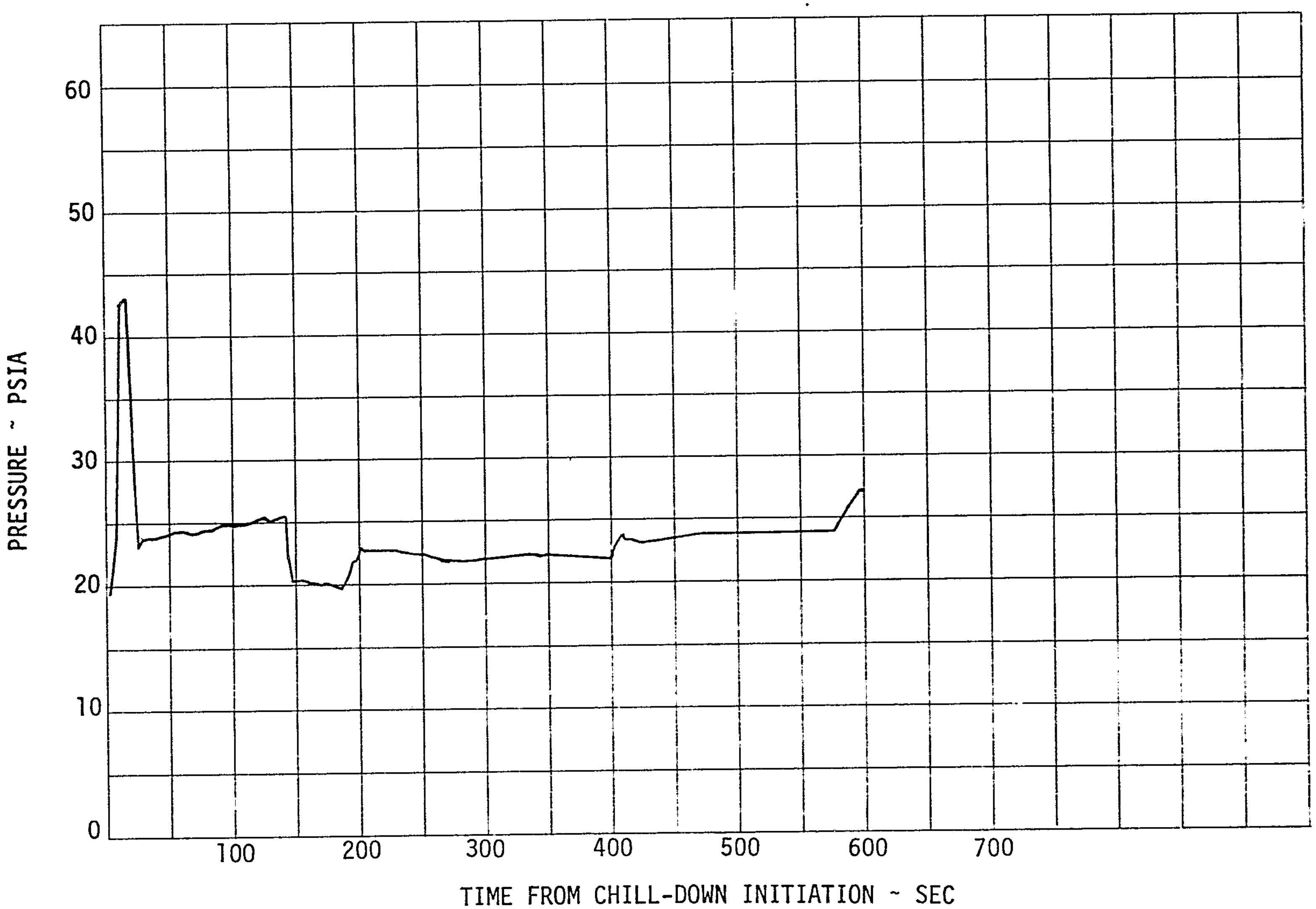

FIGURE 3-1 TRANSIENT SYSTEM ENTRANCE (VALVE A133 DOWNSTREAM) PRESSURE FOR KSC SHUTTLE LOX LOADING SYSTEM CHILL-DOWN

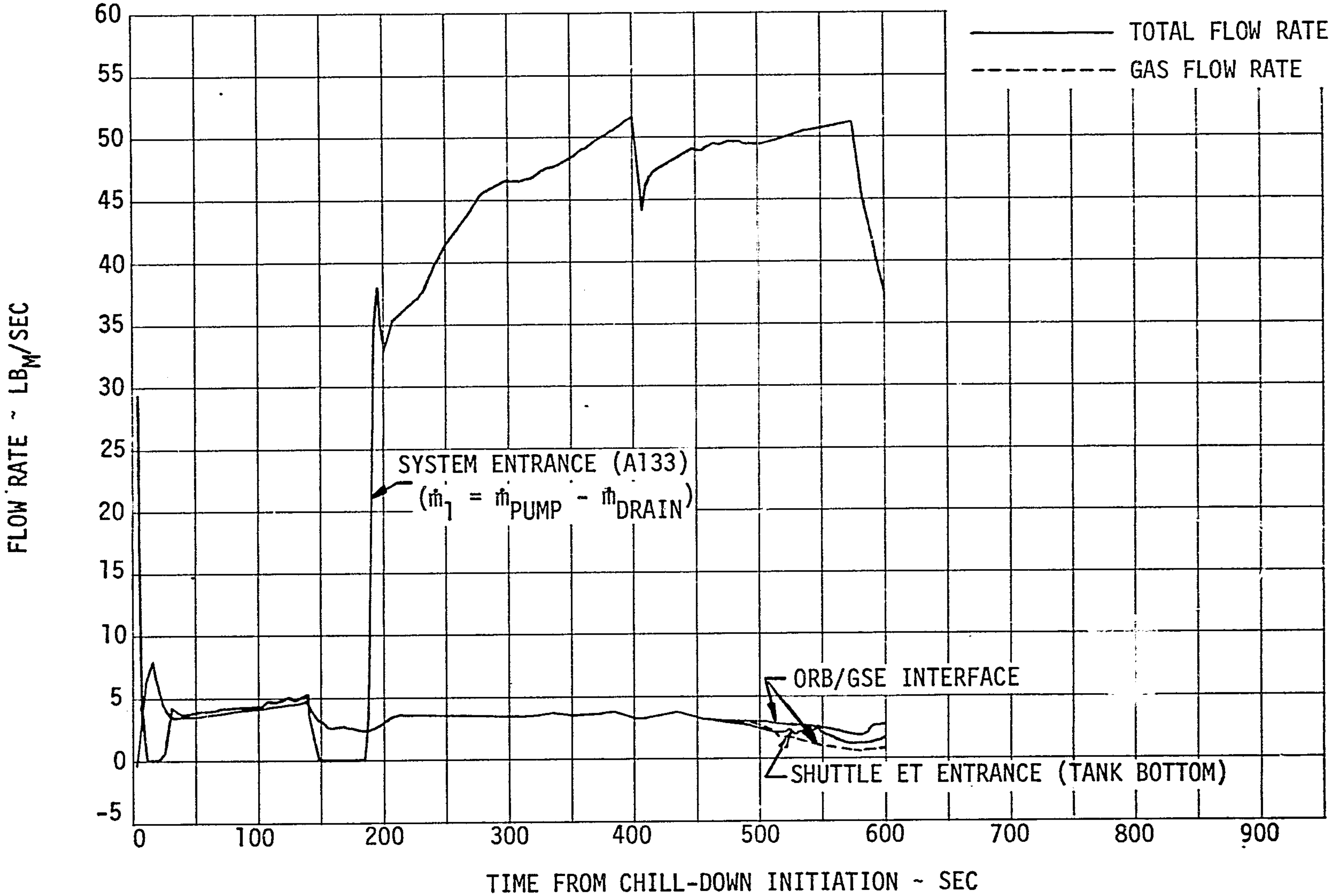

FIGURE 3-2 TRANSIENT FLOW RATES FOR KSC SHUTTLE LOX LOADING SYSTEM CHILL-DOWN

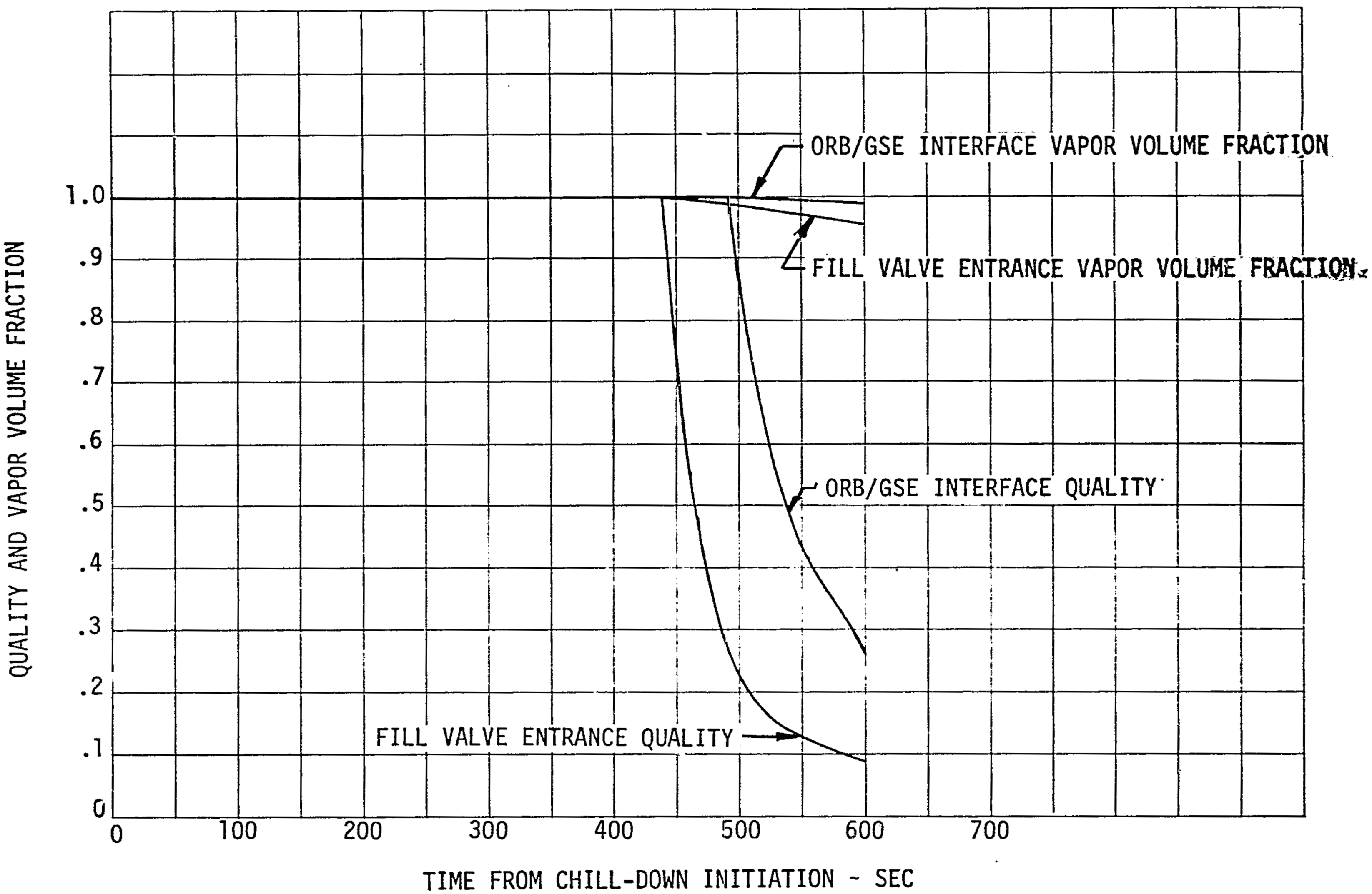

FIGURE 3-3 TRANSIENT QUALITY AND VAPOR VOLUME FRACTIONS FOR KSC SHUTTLE LOX LOADING SYSTEM CHILL-DOWN

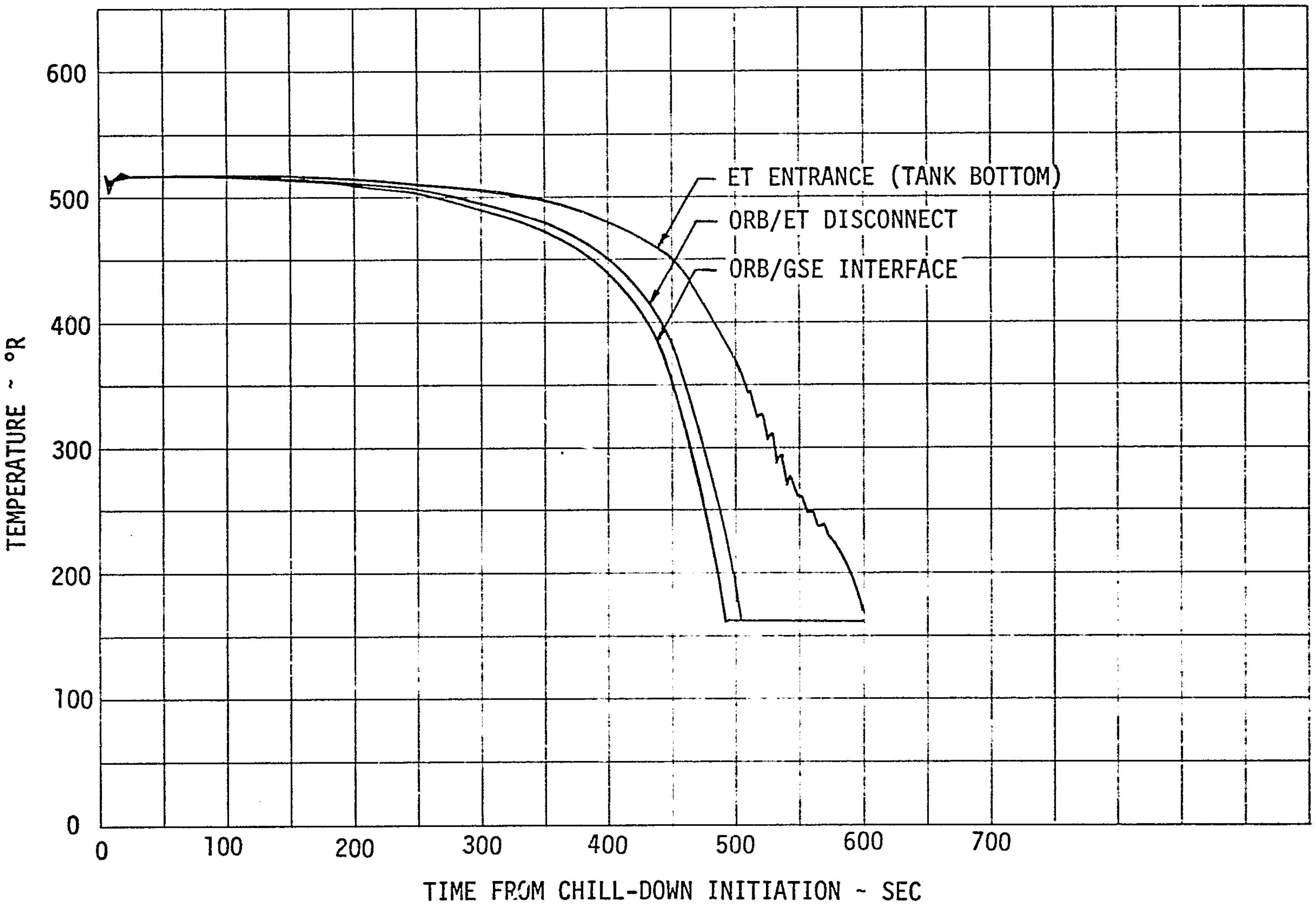

FIGURE 3-4 TRANSIENT TEMPERATURES FOR KSC SHUTTLE LOX LOADING SYSTEM CHILL-DOWN

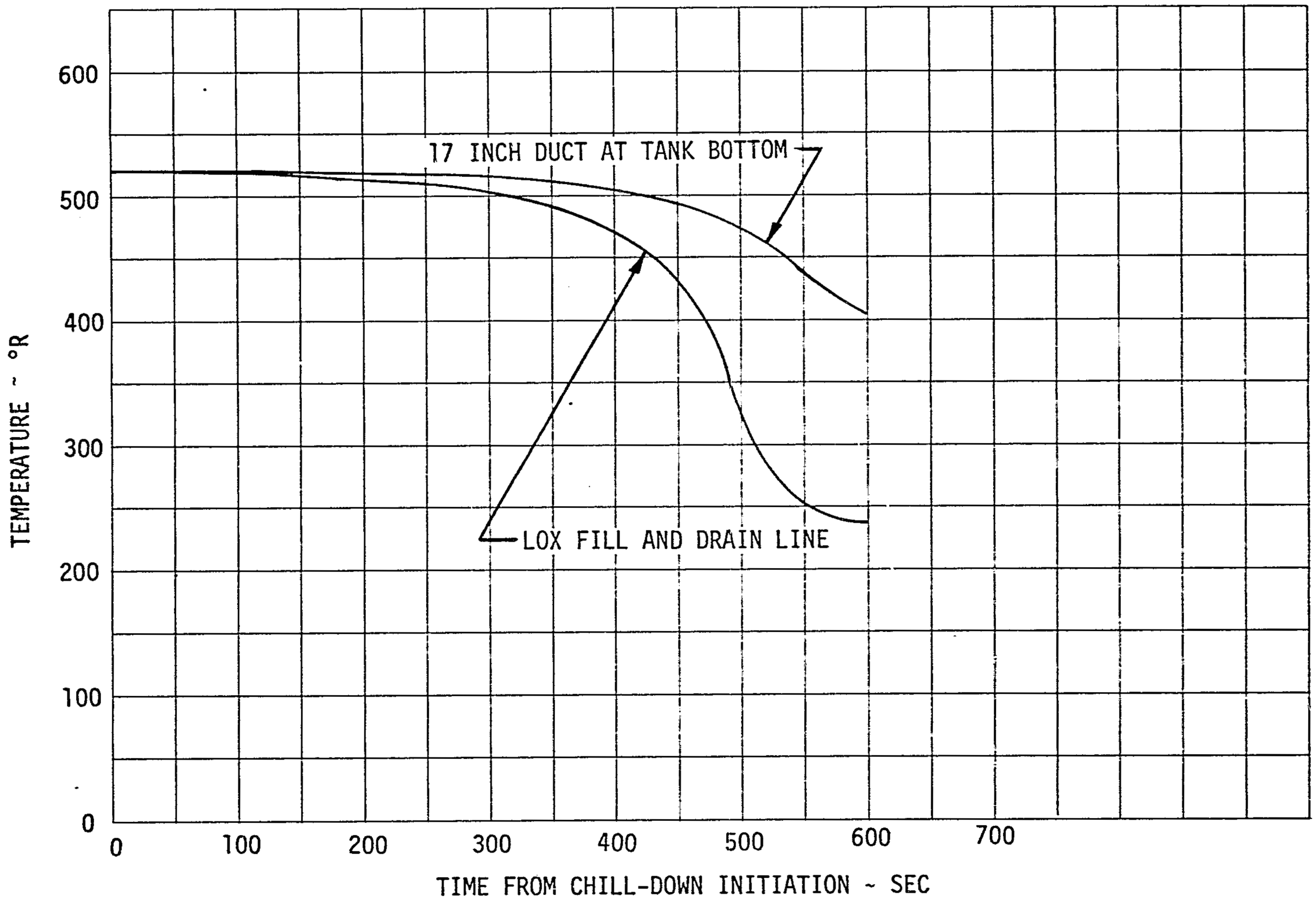

FIGURE 3-5 TRANSIENT WALL TEMPERATURES FOR KSC SHUTTLE LOX LOADING SYSTEM CHILL-DOWN

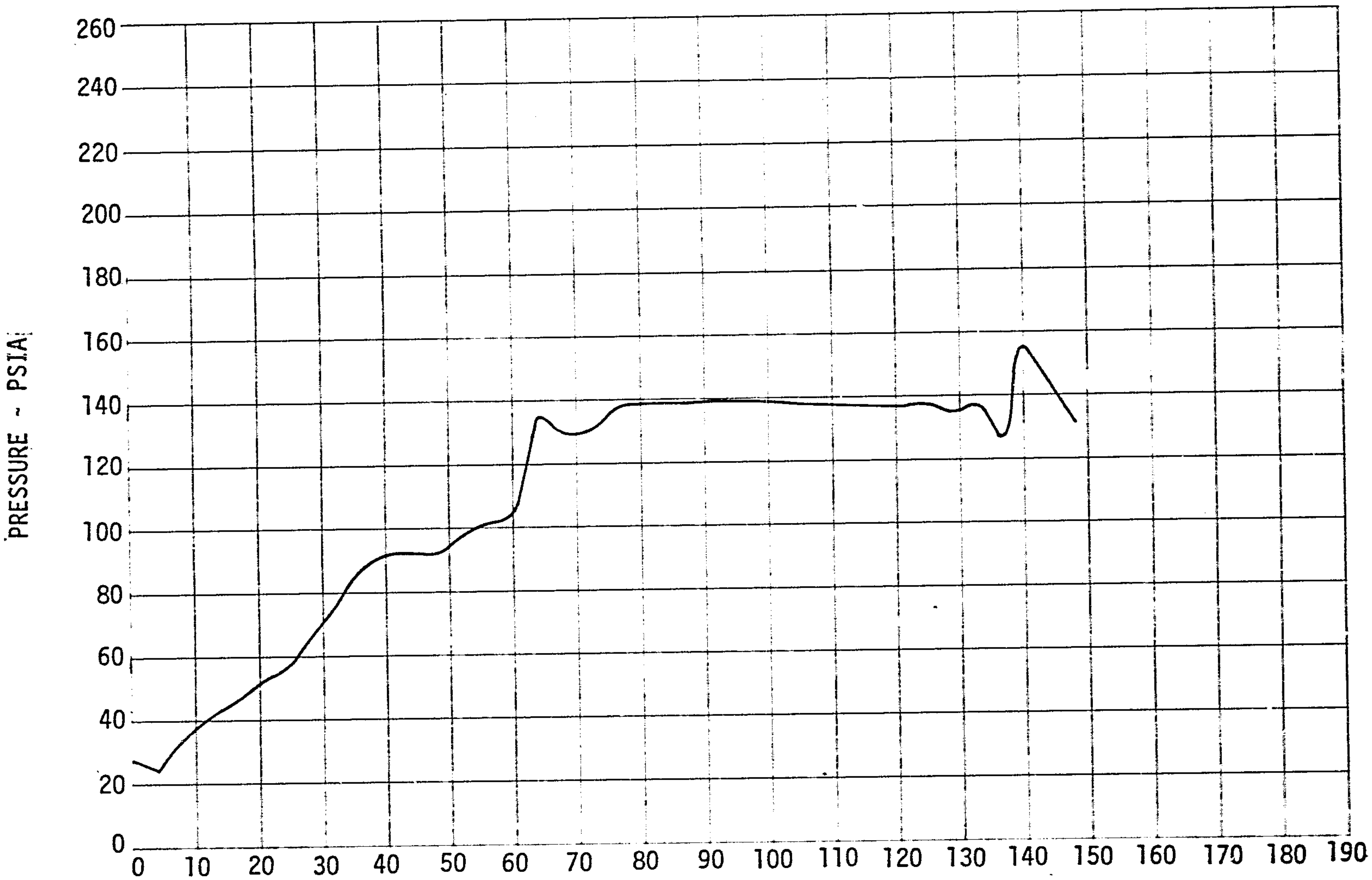

FIGURE 3-6 TRANSIENT SYSTEM ENTRANCE (VALVE A133 DOWNSTREAM) PRESSURE FOR KSC LOX VENT LINE CHILL-DOWN

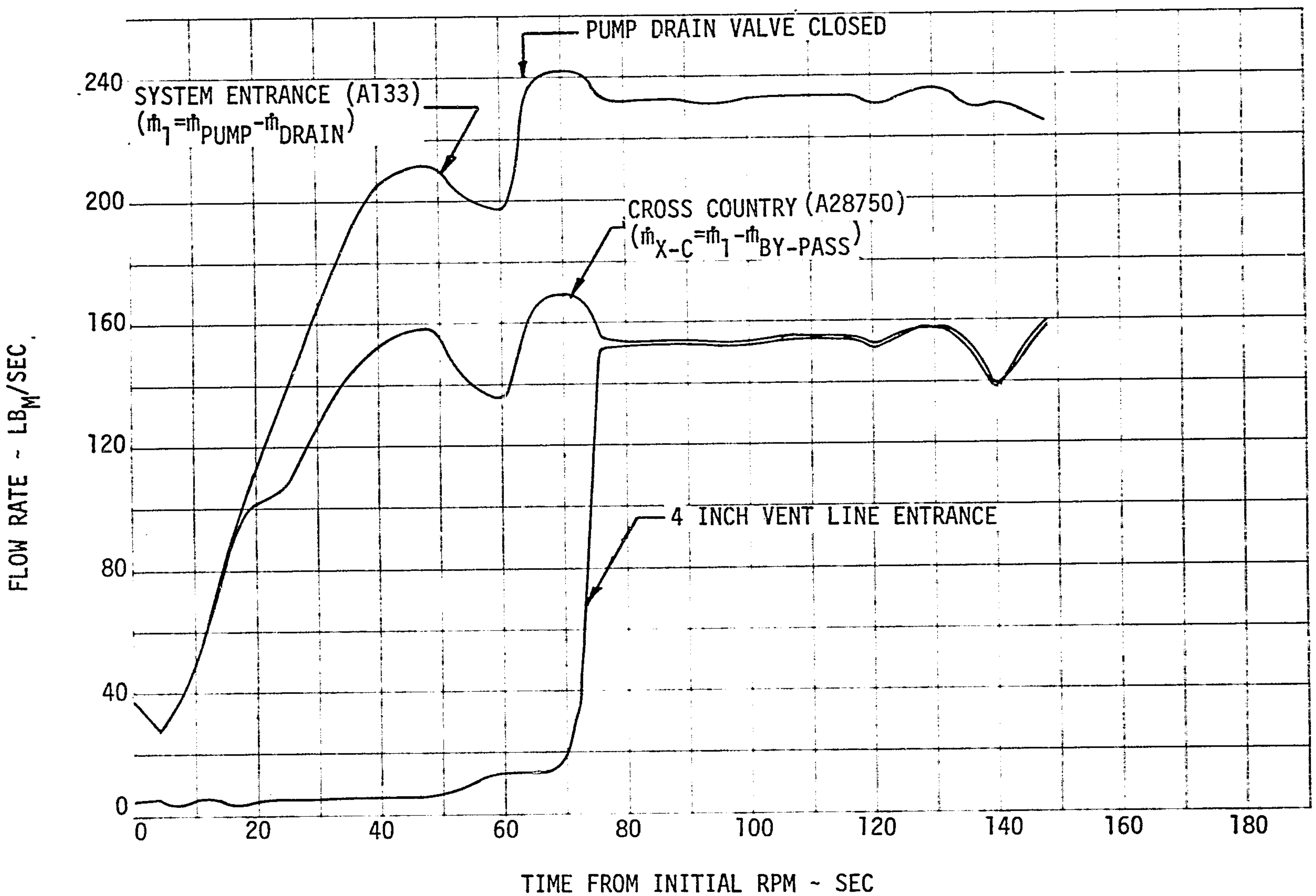

FIGURE 3-7 TRANSIENT FLOW RATES FOR KSC LOX VENT LINE CHILL-DOWN

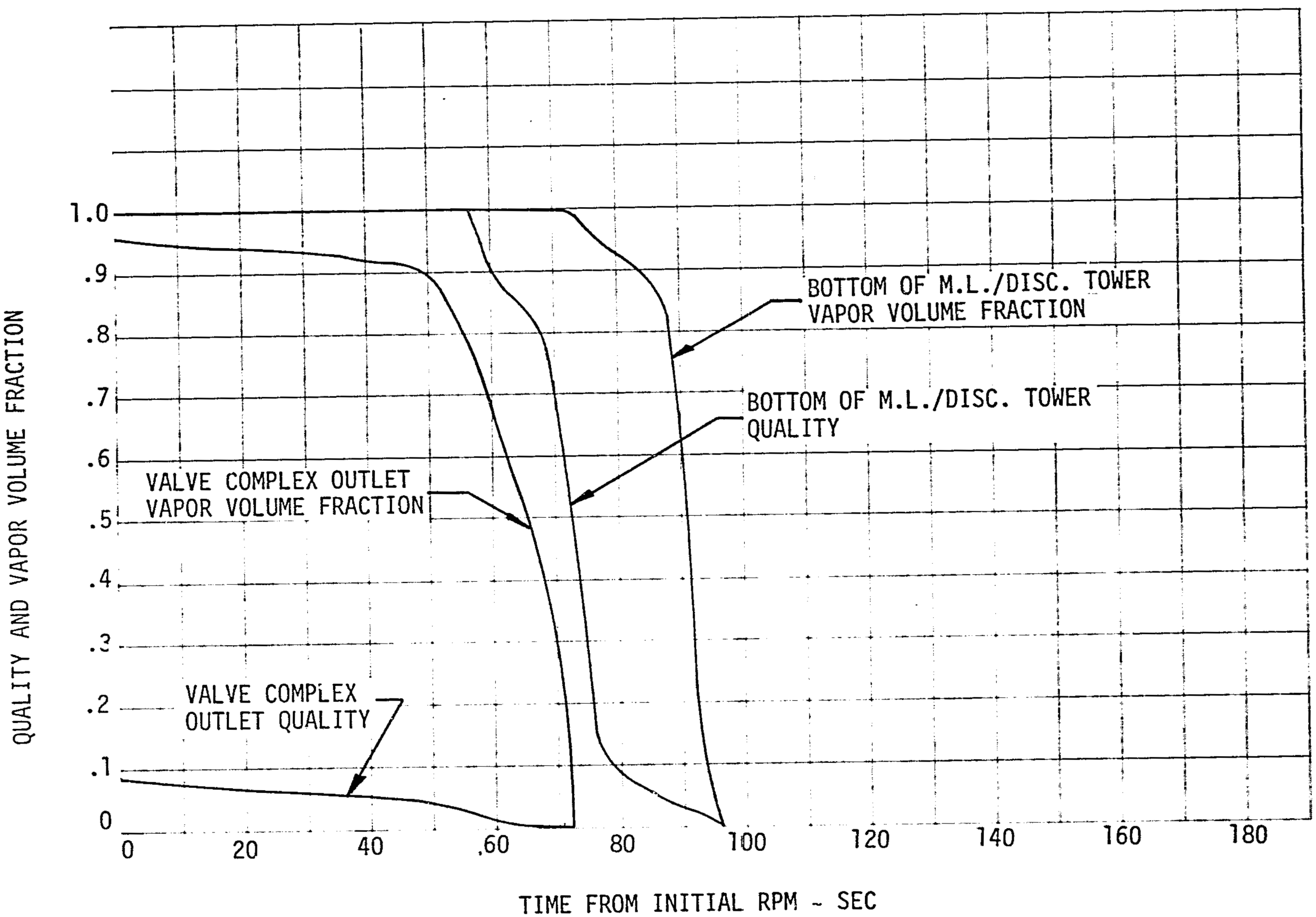

FIGURE 3-8 TRANSIENT QUALITY AND VAPOR VOLUME FRACTIONS FOR KSC LOX VENT LINE CHILL-DOWN

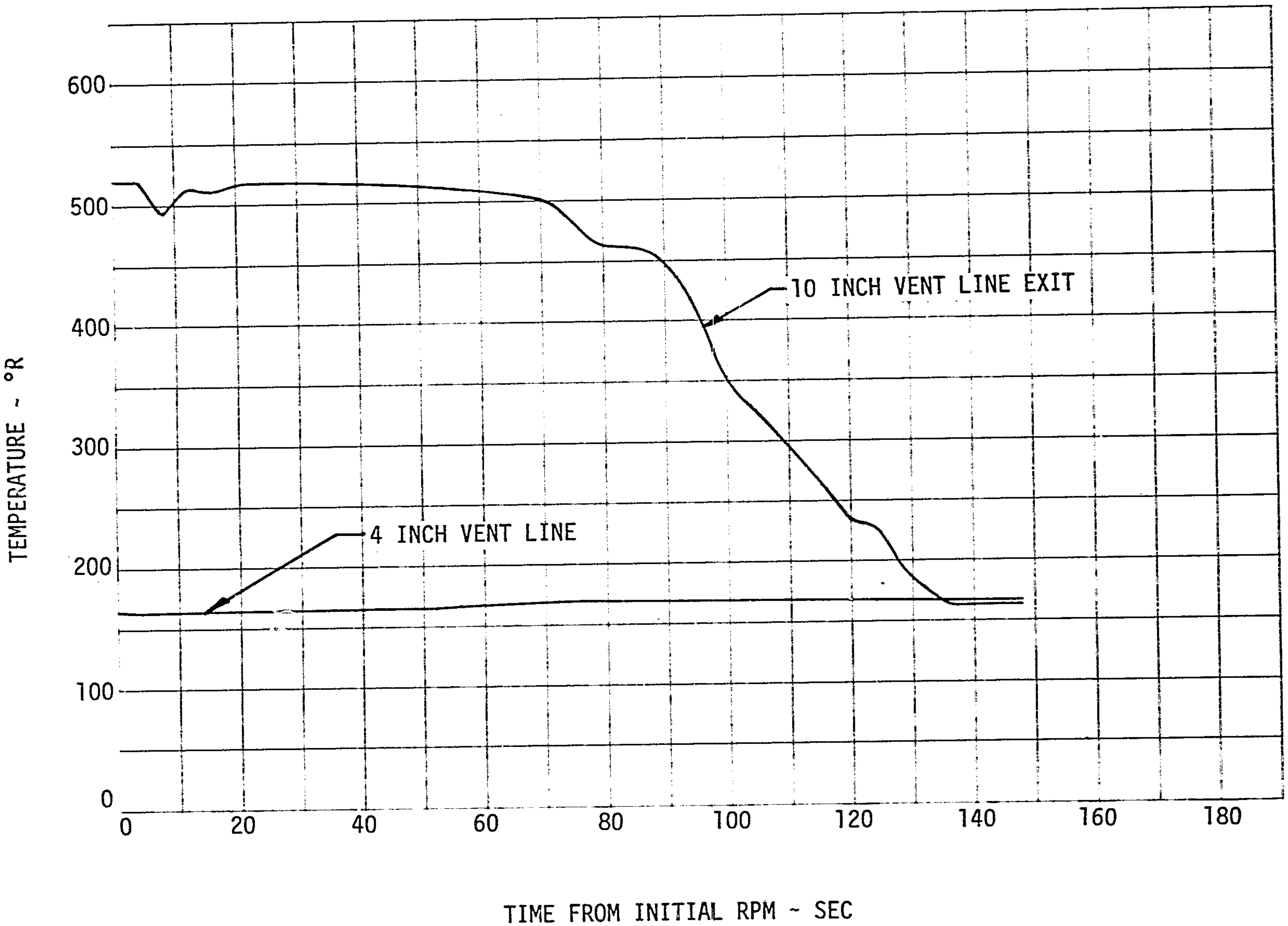

FIGURE 3-9 TRANSIENT TEMPERATURES FOR KSC LOX VENT LINE CHILL-DOWN

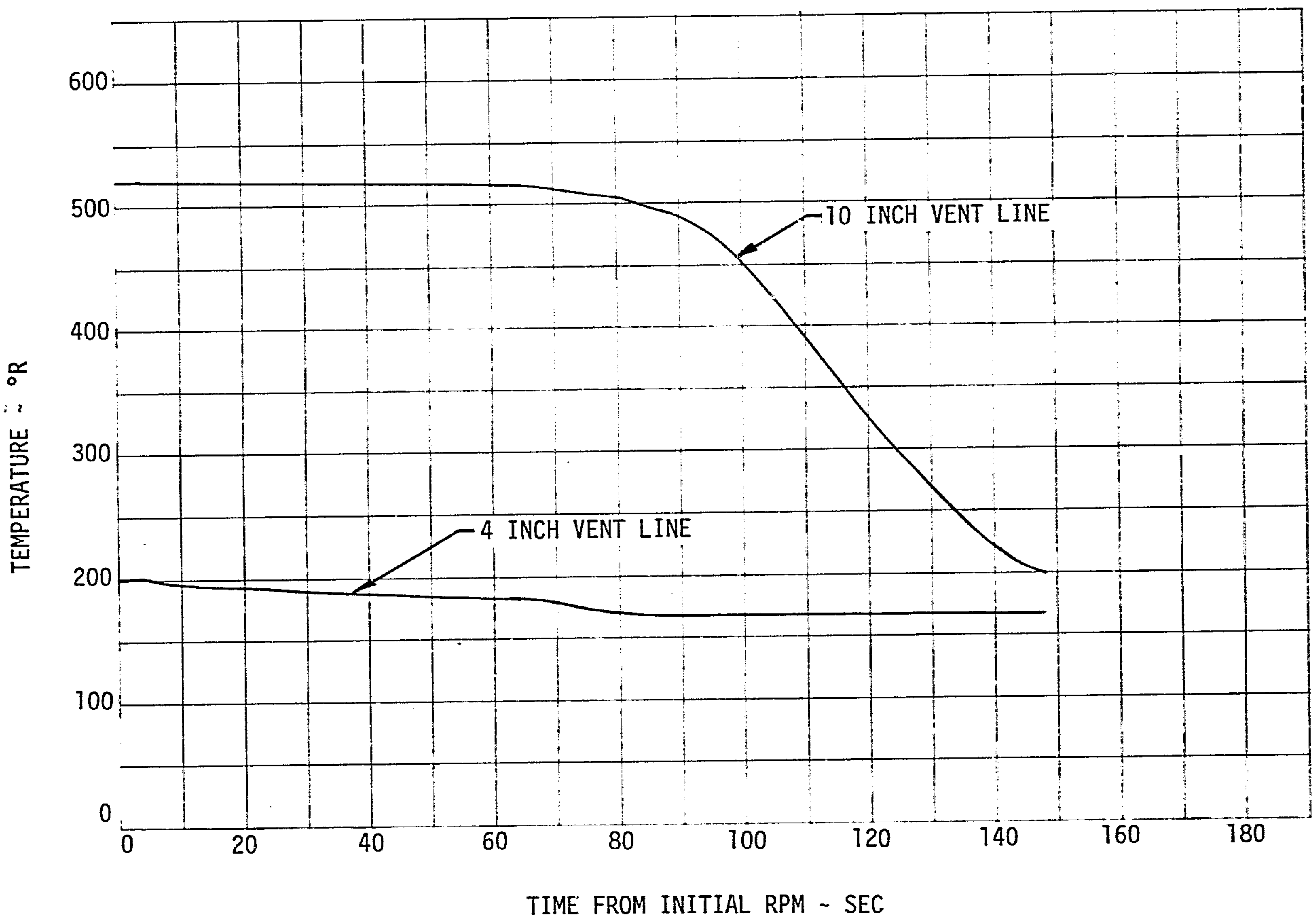

FIGURE 3-10 TRANSIENT WALL TEMPERATURES FOR KSC VENT LINE CHILL-DOWN

4.0 KSC SHUTTLE ORBITER CHILL-DOWN AND VEHICLE SLOW FILL ANALYSES

Various flow rates through the 2 inch flow control valve were initially investigated for the orbiter slow fill to the ORB/ET disconnect. For these orbiter slow fill analyses, the pump by-pass flow control valve was regulated to maintain 210 PSIG pump discharge pressure with a constant pump RPM of 3060. The orbiter slow fill was first analyzed with a controlled flow rate of 50 GPM at the valve complex. Results of this analysis showed that steady state conditions are approached with 2-phase flow downstream of the valve complex 6 minutes from slow fill initiation. The slow fill analysis was then repeated with a controlled flow rate of 150 GPM at the valve complex. For this case, the vapor volume fraction was reduced to 25 percent at the ORB/GSE interface and 73 percent at the ORB/ET disconnect after 6 minutes of slow fill. Extrapolation of results indicate that approximately 10 minutes would be required to fill to the ORB/ET disconnect. The target time to fill the orbiter lines is 5 minutes. Further analysis showed that with 200 GPM, the Orbiter would be completely filled with liquid to the ORB/ET interface in 5.9 minutes. These analyses also showed that 200 GPM is insufficient to fill the 17 inch duct to the ET (tank bottom) and that 200 GPM could not be maintained with the 2 inch flow control valve full open if the 17 inch duct were filled with liquid. Consequently, the system slow fill analyses were repeated with flow through both the 2 inch and 6 inch fill valves with flow rate controlled by pump speed. For these analyses, the LOX by-pass valve was closed and constant system entrance flow rates of 250 GPM for the Orbiter slow fill and 350 GPM for the 17 inch duct slow fill were assumed. The Transient Cryogen Transfer Program (TCTP) was modified to compute the required pump speed as a function of input system entrance flow rate and computed pump discharge pressure. The required pump speed varies from 1000 to 2025 RPM for the KSC/Shuttle slow fill.

4.1 KSC ORBITER CHILL-DOWN AND SLOW FILL ANALYSIS

For this analysis, it is assumed that at the end of the LOX vent line chill-down, the pump speed is ramped down and the flow is switched from the vent line back to the vehicle at a constant pump flow rate of 250 GPM to start the Orbiter chill-down and slow fill. The results are shown in Figures 4-1 through 4-7. Figures 4-1 and 4-2 show the transient pump discharge pressure and system flow rates. The pump back pressure gradually increases as the system hydrostatic head and flow rates increase. The maximum gas flow rate into the ET during the Orbiter slow fill is 2.5 LB_M/SEC. At the end of the Orbiter slow fill, the pump NPSH is 47.83 FT. Figure 4-3 shows the required pump speed to maintain a constant system entrance flow rate of 250 GPM. The initial required pump speed is 1000 RPM and increases with pump discharge pressure. Figure 4-4 shows that the system is filled with liquid to the ORB/GSE interface at 2.8 minutes, and to the ORB/ET interface at 4.2 minutes after slow fill initiation. The target time for orbiter slow fill is 5 minutes. Figures 4-5 and 4-6 show the orbiter pressures and temperatures during orbiter slow fill. Figure 4-7 shows the decreasing orbiter and 17 inch fill duct wall temperatures during Orbiter slow fill. The Orbiter LOX fill and drain line is chilled to 171.3°R during the Orbiter slow fill.

4.2 KSC SHUTTLE 17 INCH DUCT SLOW FILL ANALYSIS

For this analysis, the pump speed was increased as required to maintain a constant system entrance flow rate of 350 GPM. The results are shown in Figures 4-8 through 4-14. Figures 4-8 and 4-9 show the transient pump discharge pressure and system flow rates. The pump discharge pressure and flow rates become relatively stable after about 400 seconds from the 17 inch duct fill initiation. The maximum gas flow rate to the ET during this period is 1.45 LB_M/SEC. The difference between the ORB/GSE interface and ORB/ET interface liquid flow rates shown on Figure 4-9 is due to the simulated engine bleed flow. Figure 4-10 shows the required pump speed to maintain a constant system entrance flow rate of 350 GPM

4.2 (Continued)

with increasing pump discharge pressure. At 20.5 minutes from the 17 inch duct slow fill initiation, the required pump RPM is 2025. The pump NPSH at this time is 46.87 feet. Figure 4-11 shows that the system is filled with liquid to the upper Aluminum/Stainless Steel 17 inch duct joint (10 feet in elevation and 25 feet in length below the ET) at 20.5 minutes from initiation of the 350 GPM 17 inch duct slow fill. The vapor volume fraction at the ET entrance (tank bottom) decreases to 0.62 at this time. The target time for the 17 inch duct slow fill to the tank bottom is 16 minutes. Previous NSTL system analyses, Reference 5, indicates that no further significant decrease in vapor volume at the ET would occur with extended run time, at similar system conditions, until the tank bottom pressure increases above 17.5 PSIA due to tank head or ullage pressure increase. Figure 4-12 shows the Orbiter system pressures during the 17 inch duct slow fill. Figure 4-13 shows the Shuttle LOX fill system fluid temperatures. Figure 4-14 shows the duct wall temperatures at the Orbiter fill and drain line exit and at the 17 inch duct exit.

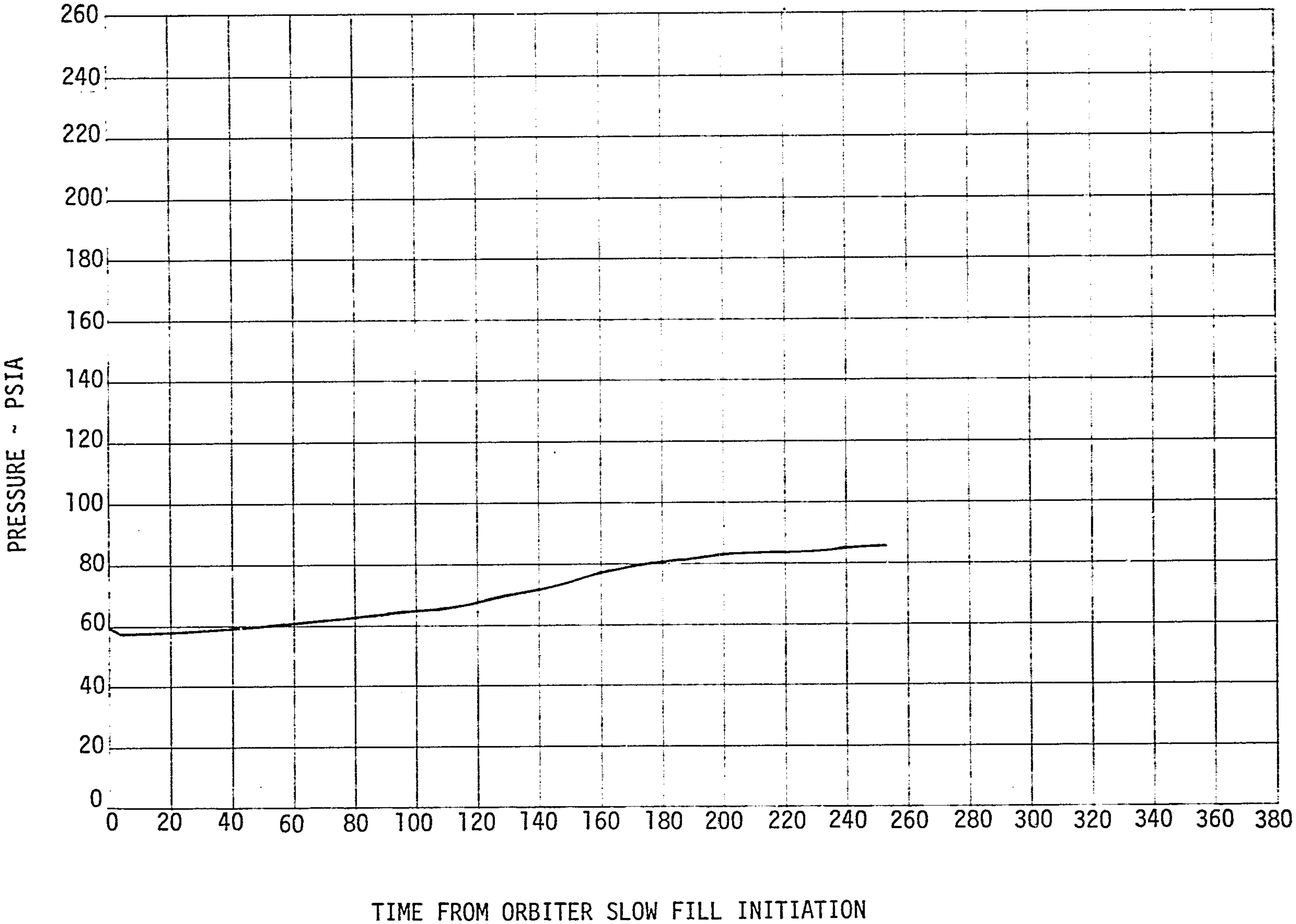

FIGURE 4-1 1000 GPM PUMP DISCHARGE PRESSURE FOR KSC ORBITER SLOW FILL

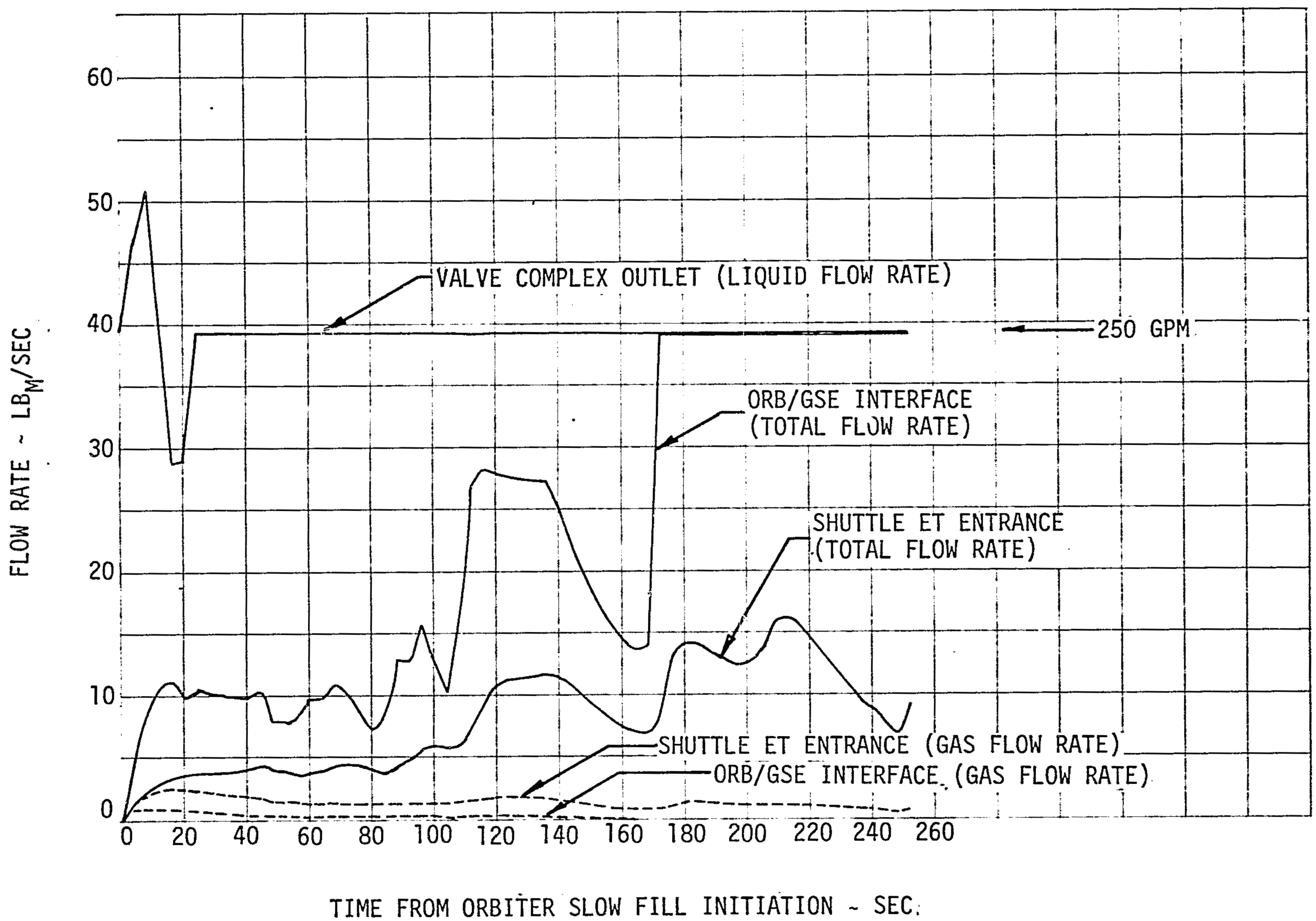

FIGURE 4-2 TRANSIENT FLOW RATES FOR KSC ORBITER SLOW FILL

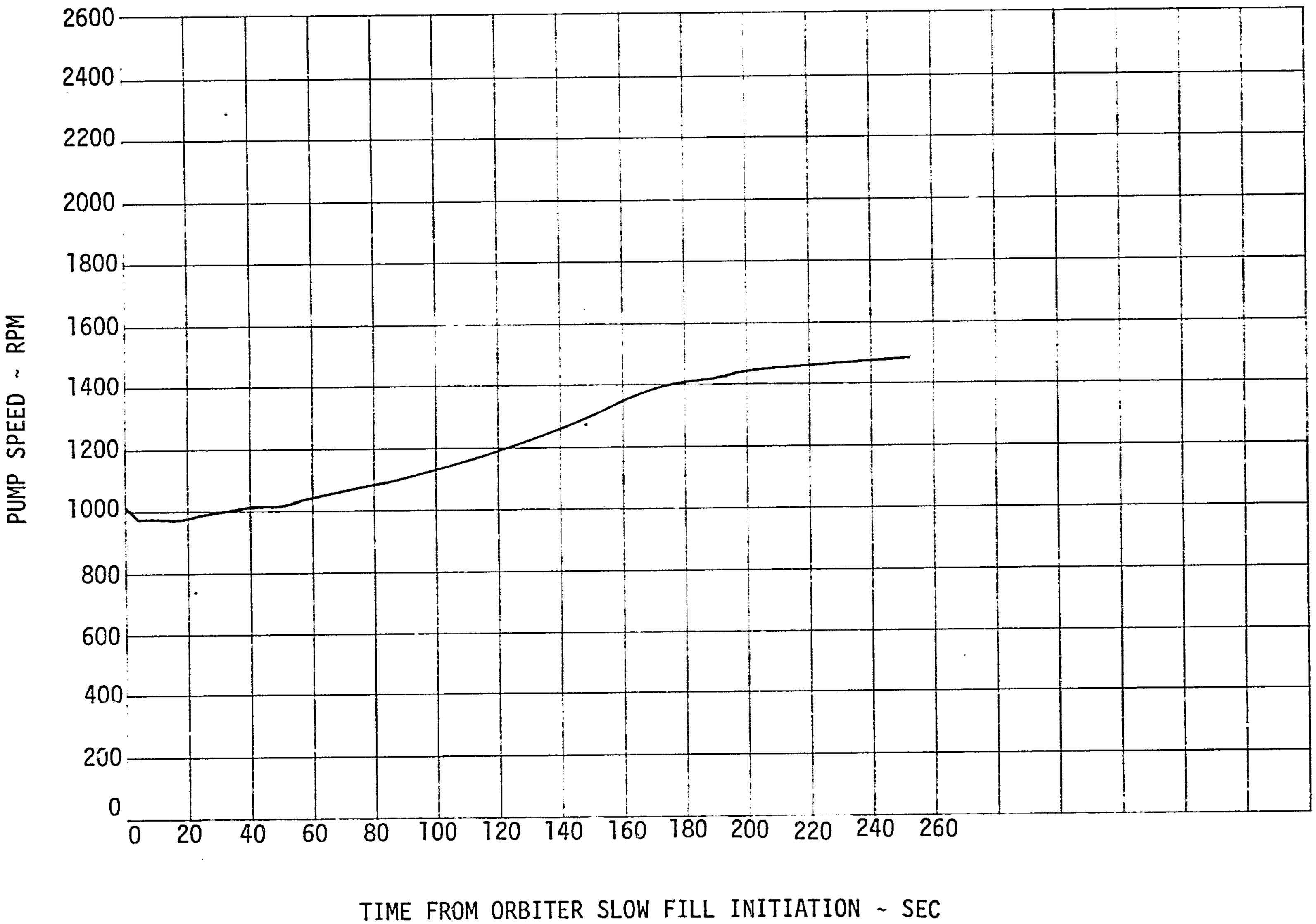

FIGURE 4-3 REQUIRED TRANSIENT 1000 GPM PUMP SPEED FOR 250 GPM TO SYSTEM DURING KSC ORBITER SLOW FILL

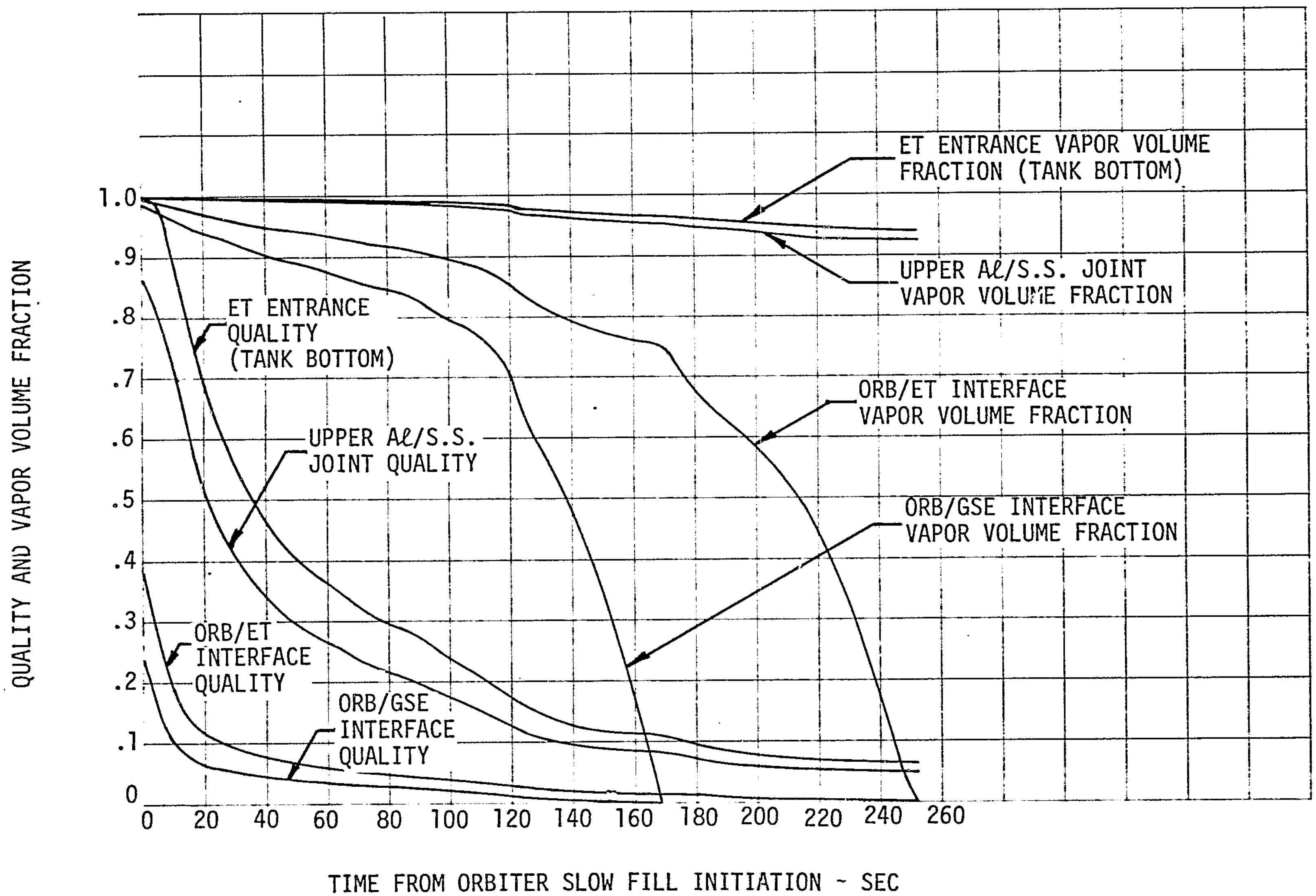

FIGURE 4-4 TRANSIENT QUALITY AND VAPOR VOLUME FRACTIONS FOR KSC ORBITER SLOW FILL

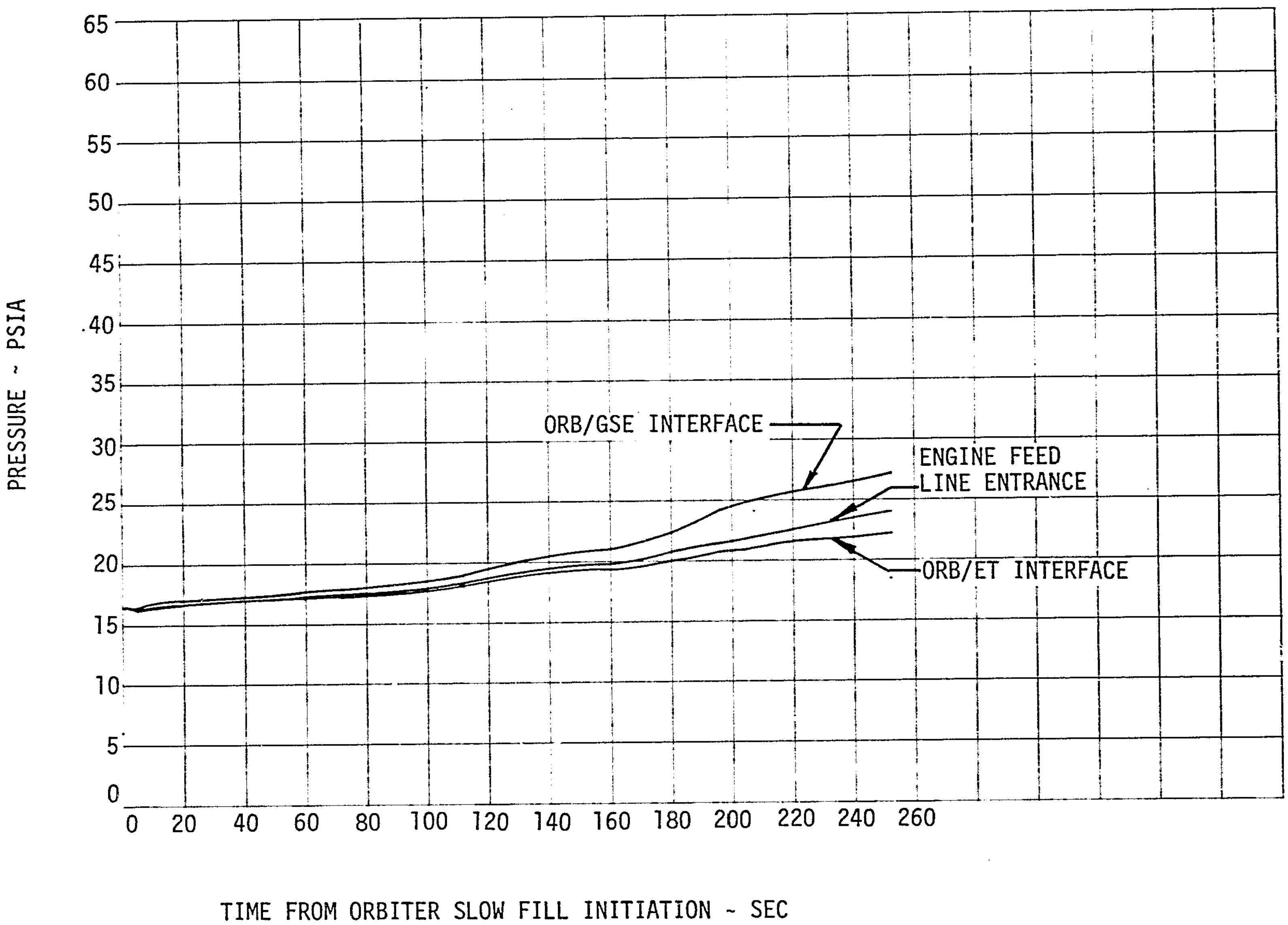

FIGURE 4-5 TRANSIENT PRESSURES FOR KSC ORBITER SLOW FILL

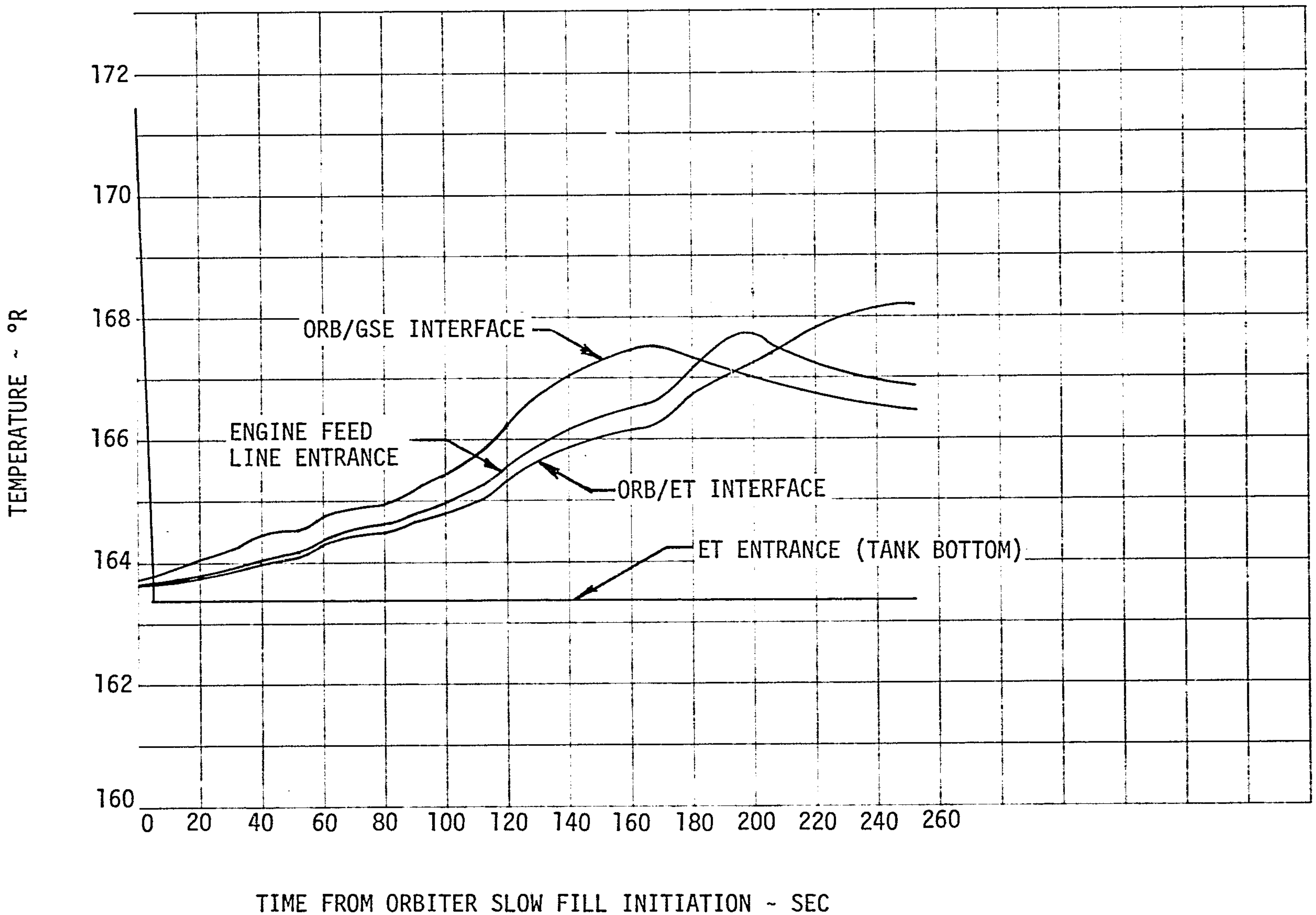

FIGURE 4-6 TRANSIENT TEMPERATURES FOR KSC ORBITER SLOW FILL

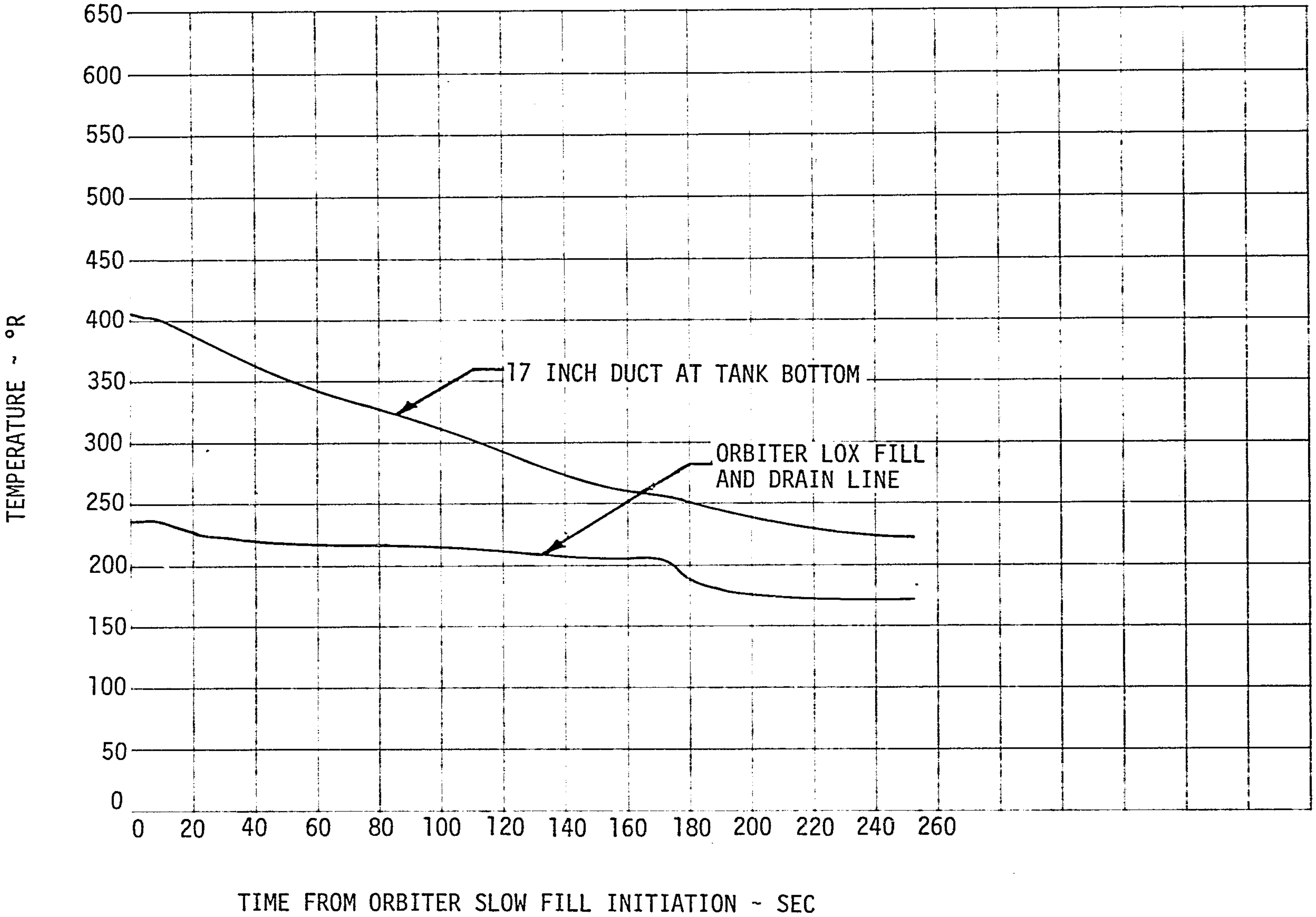

FIGURE 4-7 SHUTTLE LOX FILL SYSTEM TRANSIENT WALL TEMPERATURES FOR KSC ORBITER SLOW FILL

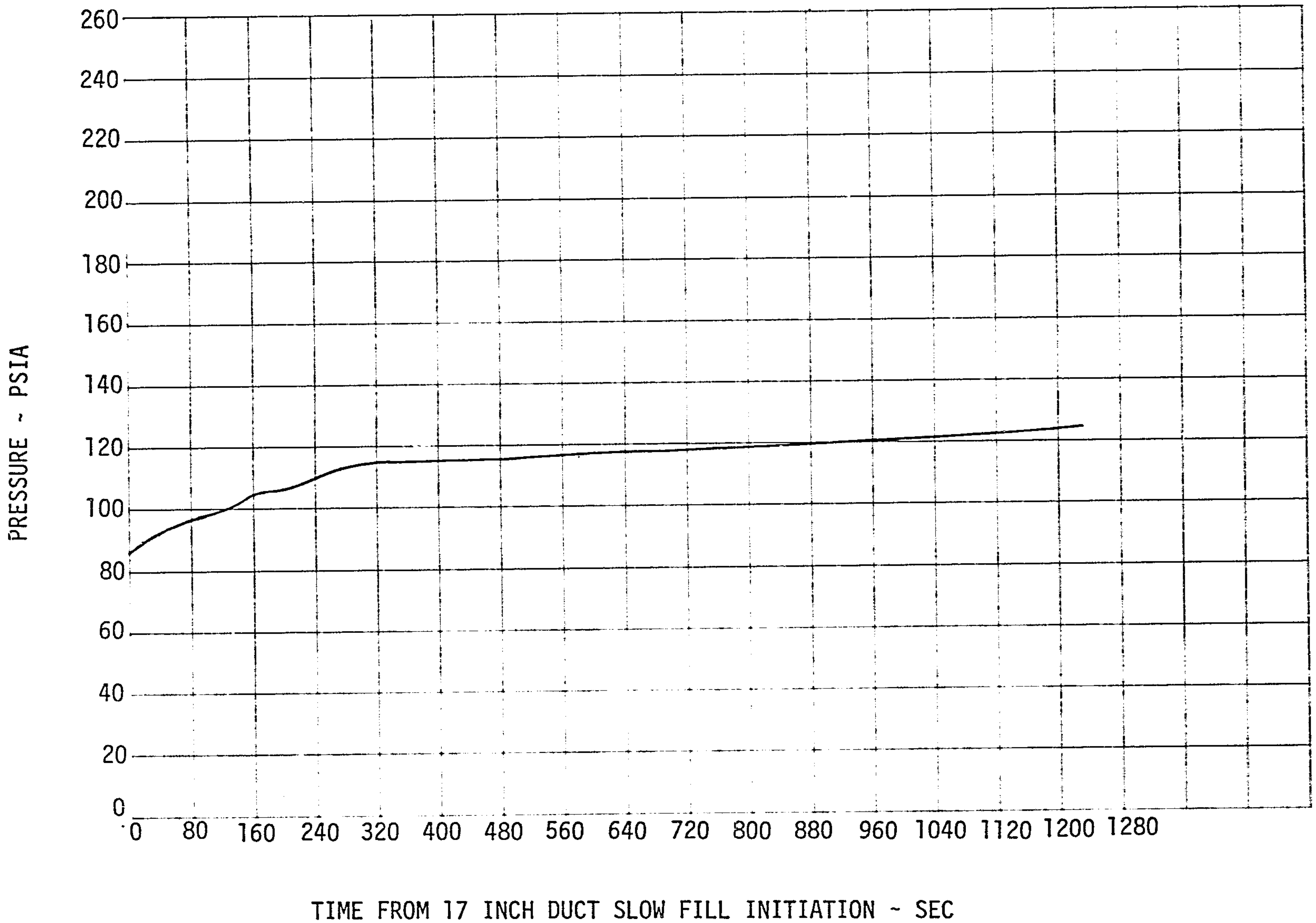

FIGURE 4-8 1000 GPM PUMP DISCHARGE PRESSURE FOR KSC SHUTTLE 17 INCH DUCT SLOW FILL

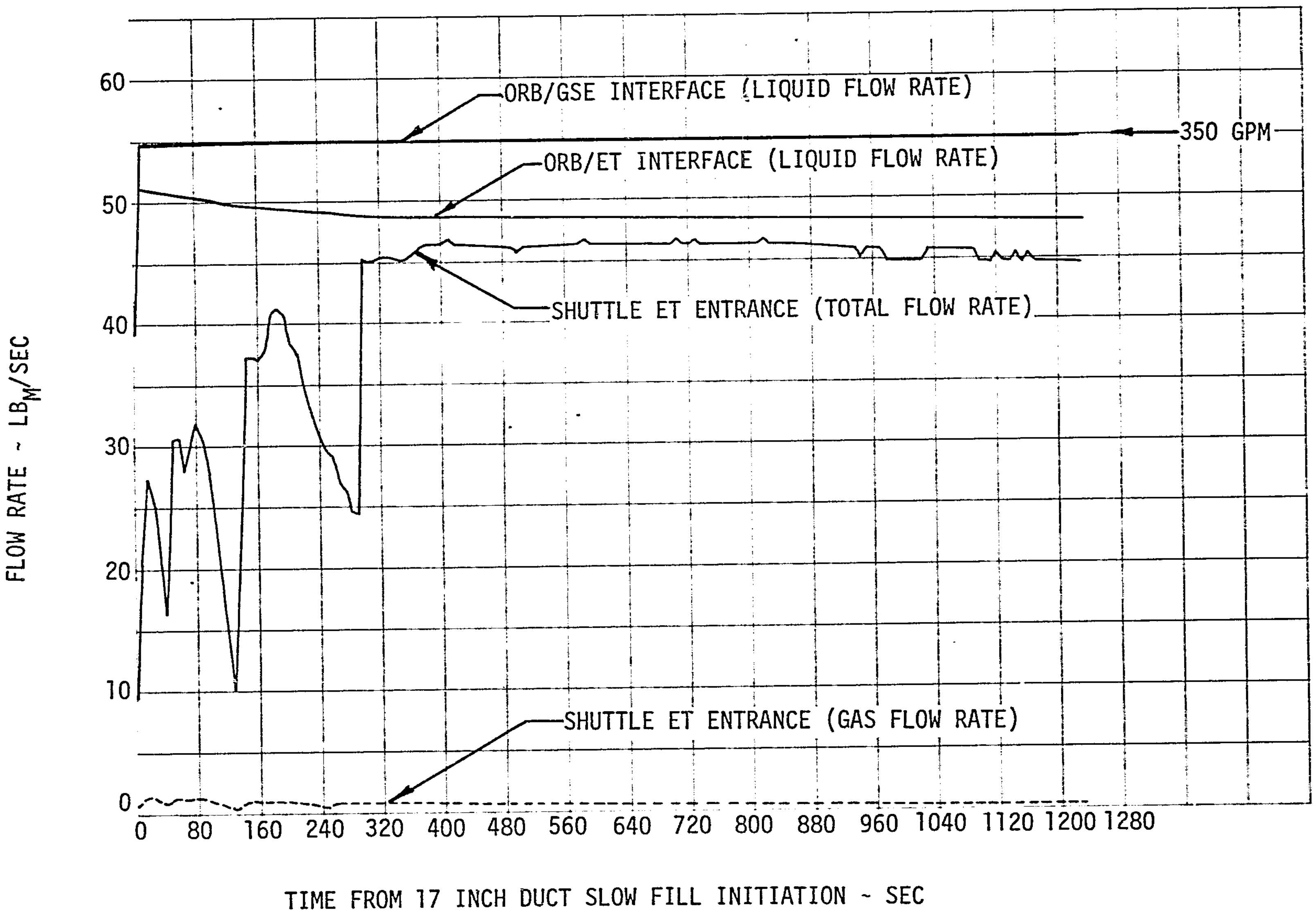

FIGURE 4-9 TRANSIENT FLOW RATES FOR KSC SHUTTLE 17 INCH DUCT SLOW FILL

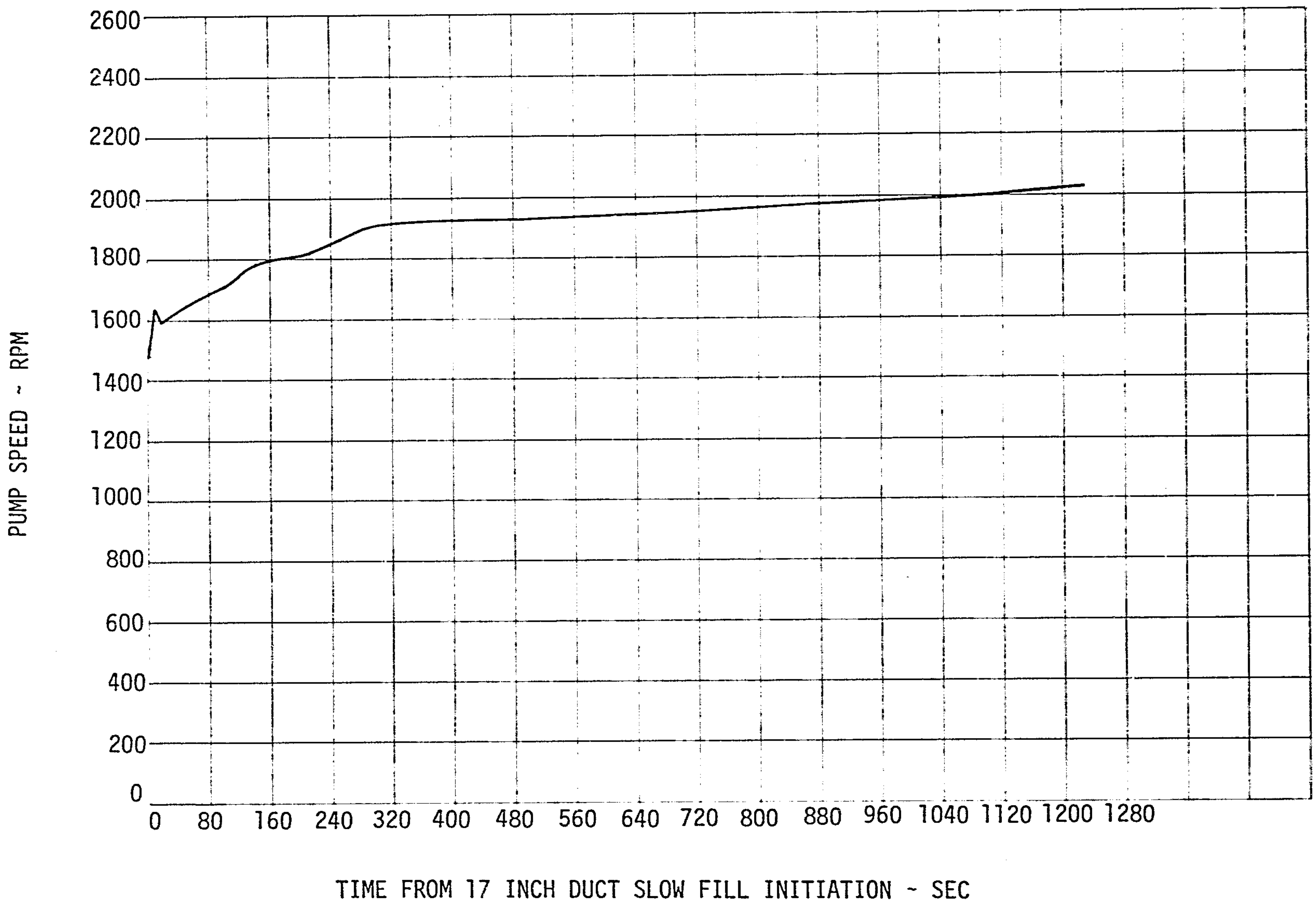

FIGURE 4-10 REQUIRED TRANSIENT 1000 GPM PUMP RPM FOR 350 GPM TO SYSTEM DURING KSC SHUTTLE 17 INCH DUCT SLOW FILL

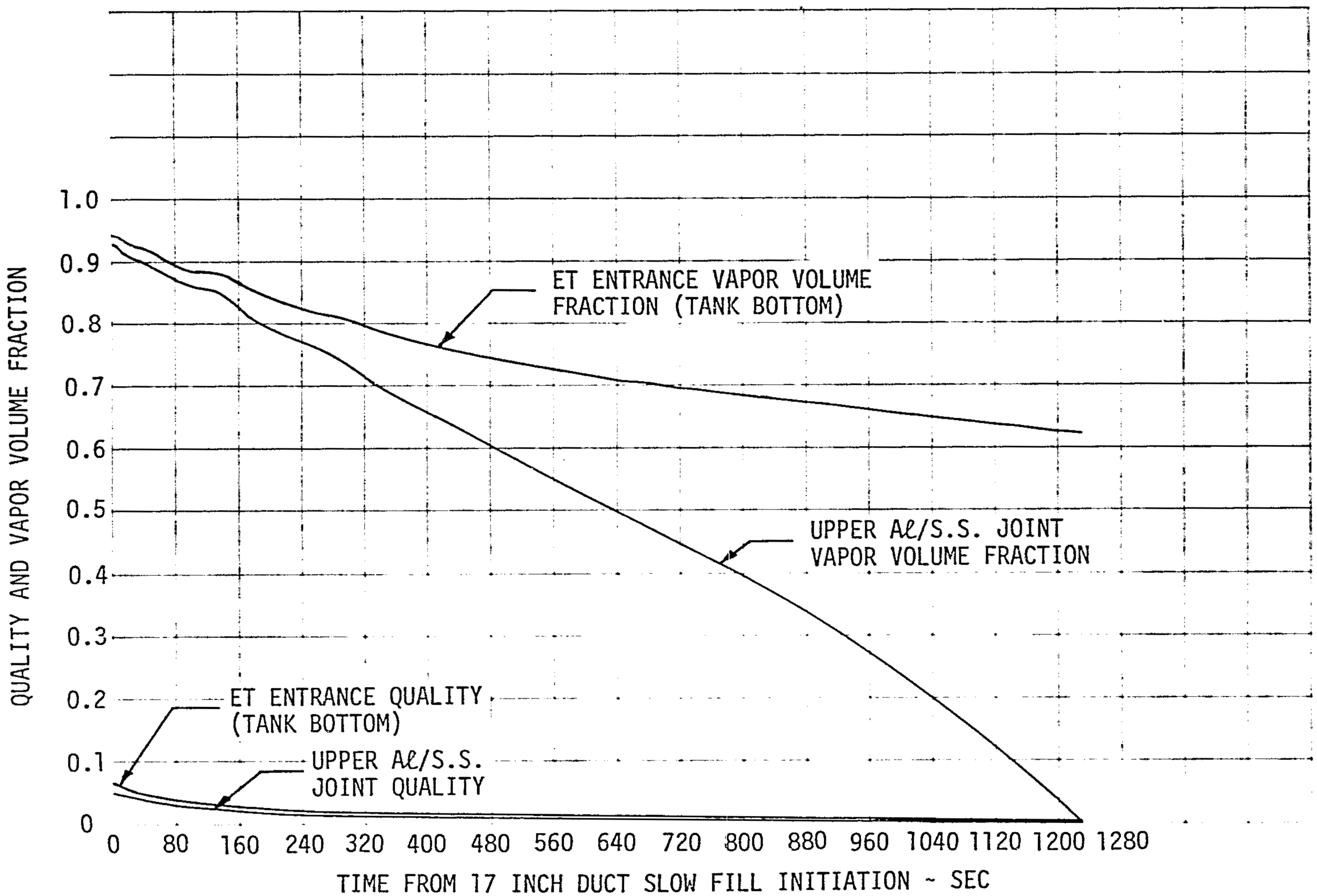

FIGURE 4-11 TRANSIENT QUALITY AND VAPOR VOLUME FRACTIONS FOR KSC SHUTTLE 17 INCH DUCT SLOW FILL

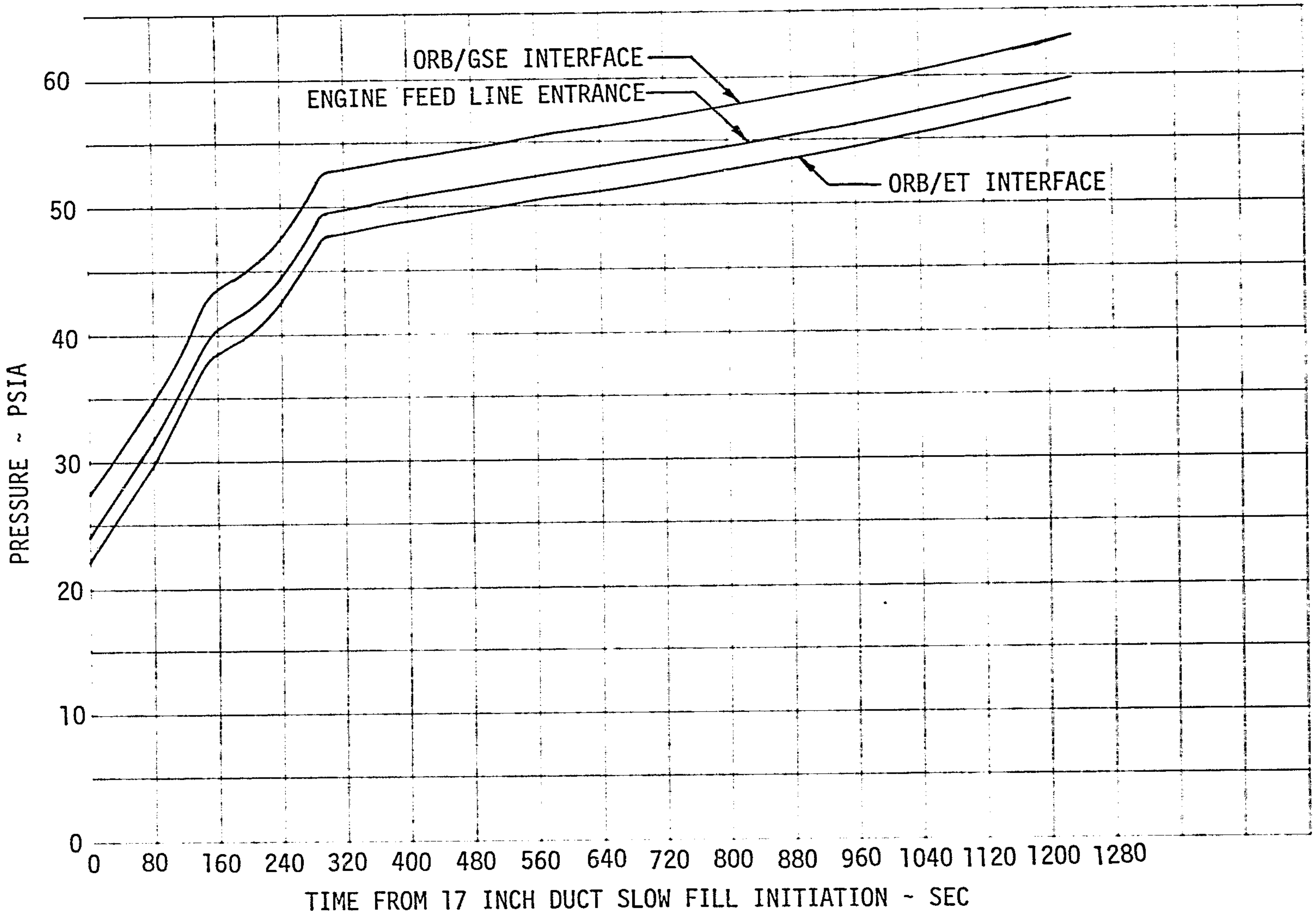

FIGURE 4-12 TRANSIENT PRESSURES FOR KSC SHUTTLE 17 INCH DUCT SLOW FILL

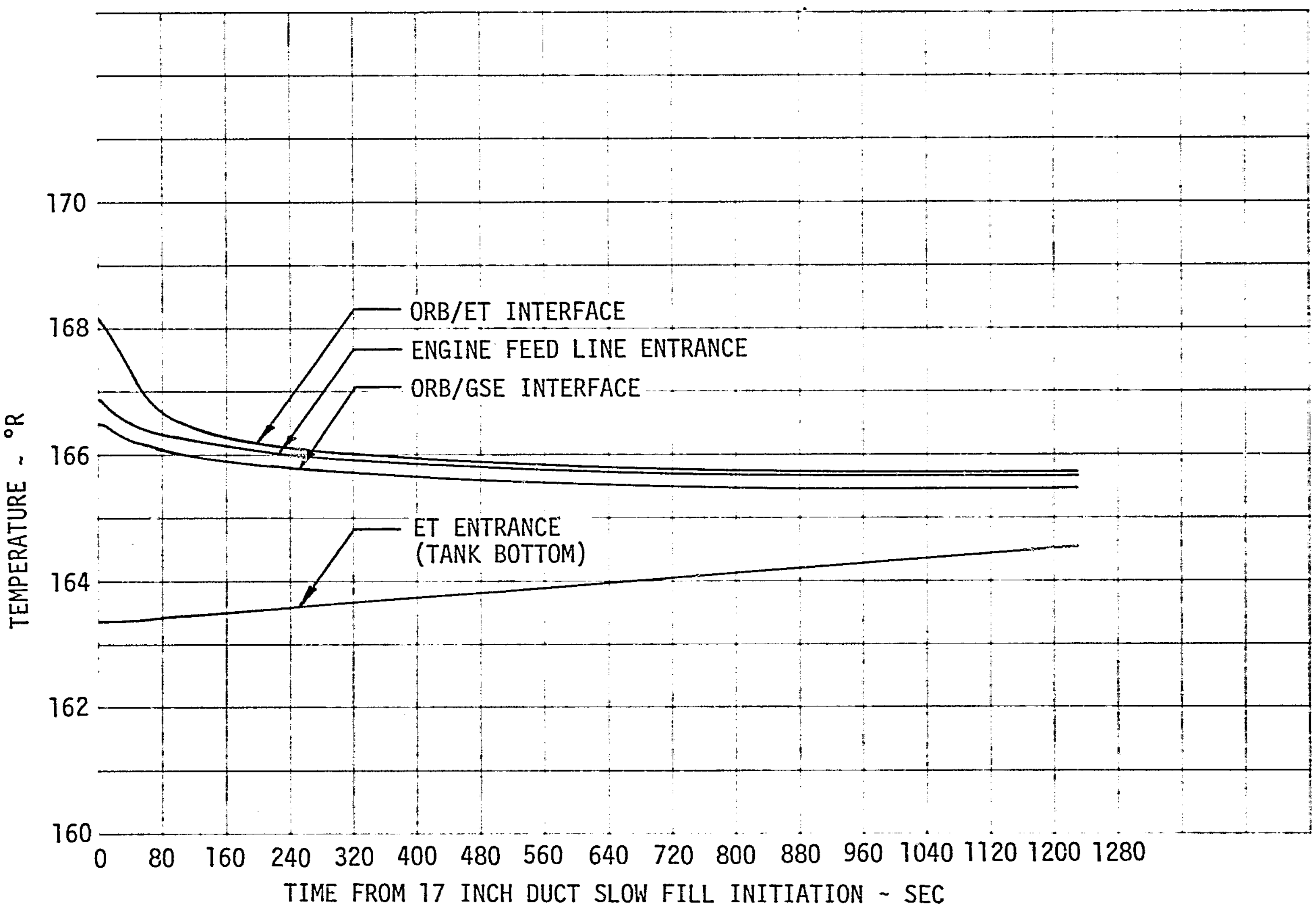

FIGURE 4-13 TRANSIENT TEMPERATURES FOR KSC SHUTTLE 17 INCH DUCT SLOW FILL

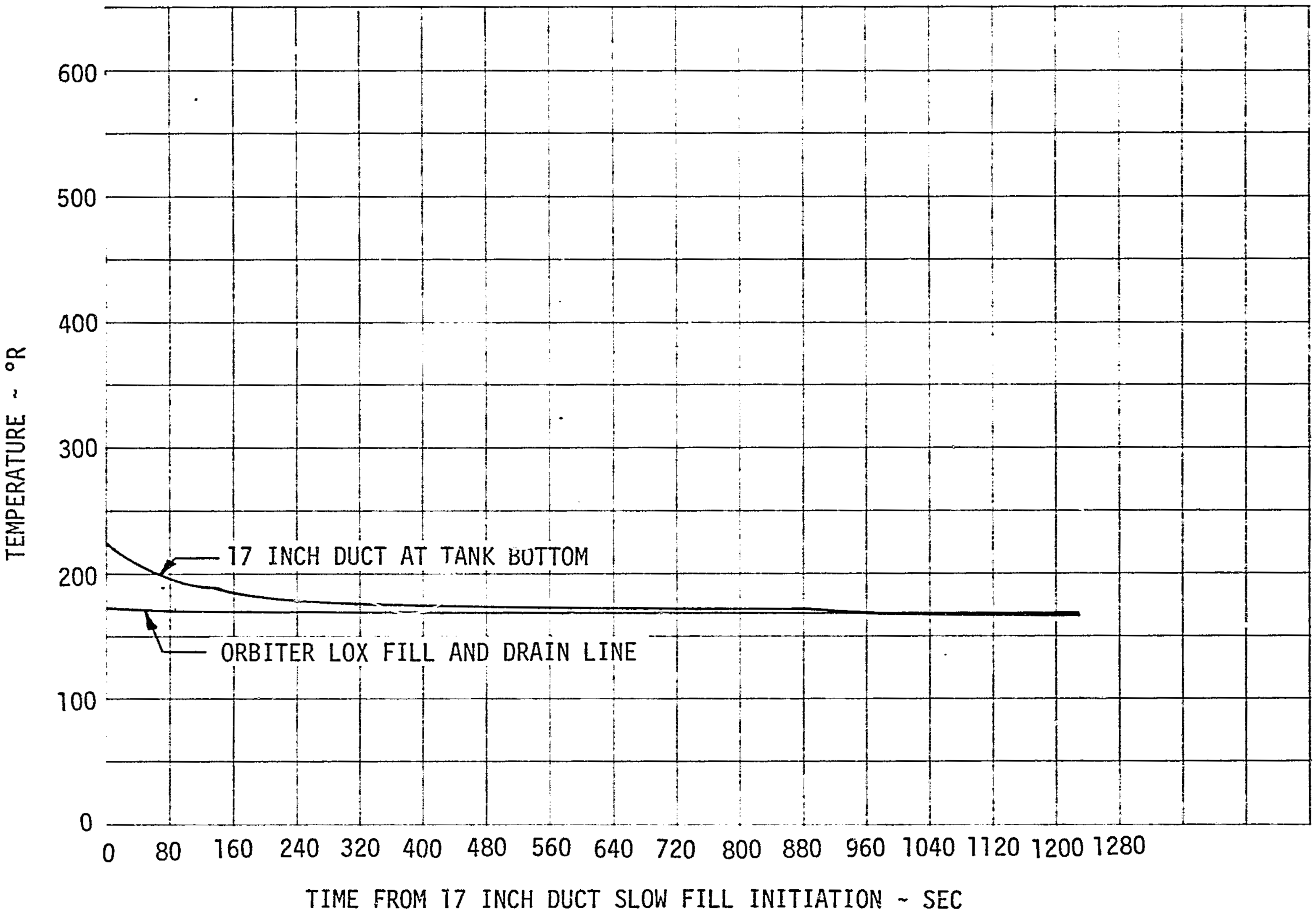

FIGURE 4-14 SHUTTLE LOX FILL SYSTEM TRANSIENT WALL TEMPERATURES FOR KSC 17 INCH DUCT SLOW FILL

5.0 COMPUTER PROGRAM MODIFICATIONS

Additional modifications and improvements to the Transient Cryogen Transfer Program (TCTP), References 4 and 5 were made to simulate the proposed KSC system configurations and operations. These program improvements include the following capabilities:

(1) Throttlable branch flow to the supply tank reservoir (KSC LOX by-pass).

(2) Check valve downstream of pump chill-down drain line.

(3) Improved system bleed flow simulation to compute bleed flow rate as a function of system node pressure and density and bleed system exit pressure.

(4) Option to compute required pump speed as a function of input system entrance flow rate and computed pump discharge pressure instead of system entrance flow rate as a function of input pump speed and computed pump discharge pressure.

These program modifications provide a more generalized capability to perform transient analyses of various system configurations and operations with various known boundary conditions. System entrance flow rates may be simulated for known by-pass valve operation by subtracting drain and/or by-pass line flow rates from the pump discharge flow rate. The user has an option of simulating pump performance by inputing either pump RPM or pump flow rate.

Details of all the computer program modifications made during the NSTL and KSC Shuttle LOX loading transient studies will be incorporated into an updated program user's manual. This updated manual will be attached to the study final report.

6.0 CONCLUSIONS

For the proposed KSC/Shuttle LOX loading system, steady conditions will be approached after 10 minutes of tank head flow. No further benefits can be obtained by extending the tank head flow period. Following the tank head flow period, the pump may be started with the pump chill-down drain and LOX by-pass valves open and flow switched from the vehicle to the facility vent to provide a facility vent line chill-down. This vent line chill-down will require 2.5 minutes with the pump ramped to 3060 RPM and the pump drain closed 1 minute after pump start. During the facility LOX vent line chill-down, the LOX loading system will be filled with liquid to the valve complex. Following the facility chill-down, the flow rate at the valve complex must be greater than 200 GPM to fill the Orbiter within the target time of 5 minutes. With a flow rate of 250 GPM, the Orbiter will be filled with liquid in 4.2 minutes after Orbiter slow fill initiation. A flow rate of 200 GPM could not be maintained with the 2 inch flow control valve full open if the 17 inch duct were filled with liquid. However, an adequate flow rate can be provided through both the 2 inch and 6 inch fill valves with flow rate controlled by pump speed. With a system entrance flow rate of 350 GPM, the 17 inch duct will be filled with liquid to the aluminum/ stainless steel joint (10 feet below the ET) at about 20.5 minutes from initiation of the 17 inch duct slow fill. The target time for the 17 inch duct fill is 16 minutes. However, if the 17 inch duct fill is initiated simultaneously with the planned 15 minute engine chill time, a total of 31 minutes would be available for the 17 inch duct fill. After 20.5 minutes, steady state conditions will be approached with liquid mass flow rate approaching the total mass flow rate (low quality) at the ET entrance. However the 2-phase fluid will be approximately 60 percent vapor by volume at the ET entrance. If it is desired to guarantee 100 percent liquid flow at the ET entrance within the target time, one or more of the following changes should be considered for the planned system configuration or operation:

6.0 (Continued)

(1) Decrease the system inlet LOX temperature.

(2) Decrease the external heat load (improve the system insulation).

(3) Increase the system flow rate.

(4) Maintain a higher ullage pressure (approximately 19.5 PSIA) in the ET to increase the tank bottom pressure above saturation pressure.

7.0 REFERENCES

1. Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings, and Pipe," dated 1972.

2. Boeing Report, SK-DD-MDD-43/507, "Space Shuttle LOX System Servicing Study - LC39 A&B," dated April 26, 1974.

3. Boeing Report, SK/DD-MDD-43/508, "Space Shuttle LOX System MLP Valve Compex Design Proposal," dated April 26, 1974.

4. Boeing Letter Report 5-9030-HT-158, "Cryogen Transfer Computer Program Development and Verification," dated September 3, 1974.

5. Boeing Letter Report 2-1056-HT-082, "National Space and Technology Laboratories (NSTL) LOX Loading Facility Analyses," dated May 8, 1975.

APPENDIX

PROGRAM INPUT DATA

Input data for the KSC/Shuttle LOX facility analyses are presented in this Appendix.

TABLE A-I NODAL INPUT DATA FOR KSC/SHUTTLE LOX LOADING SYSTEM

NODE NO.	DESCRIPTION	LENGTH (FT)	INTERNAL DIAMETER (EQUIV-FT)	NODE EXIT ELEVATION* (FT)	INCLUDED COMPONENTS	EQUIVALENT (L/D)	DUCT WALL MASS (LB_M)
1	Pump	0	0	0	None	0	0
10	V.J. Entrance to Un-insulated Section	15.3	0.5339	-2.6	(2) 45° EL (1) Flow Meter LFM-1 (1) "T" (RUN) 15.3 FT. 6" LINE	14 665.55 20 28.66	118.80
20	Uninsulated Section to Mid Cross-Country	501.38	0.5339	-2.6	(1) "T" (RUN) (1) Hadley Butterfly (1) "T" (RUN) (1) 90° EL 501.38 FT. 6" LINE	20 21.74 20 14 939.09	4125.57
30	Mid Cross-Country to Base of Launch Pad	501.38	0.5339	-0.58	501.38 FT. 6" LINE	939.09	3892.92
40	Base of Launch Pad to Top of Launch Pad	198.35	0.5339	33.11	(1) 10° MITRE 198.35 FT. 6" LINE	2.5 371.51	1540.07
50	Top of Launch Pad to 45° EL	199.00	0.5339	35.18	(1) 10° MITRE (1) LEJ-7 199 FT. 6" LINE	2.5 18.67 372.73	1541.11
60	45° EL to Mobile Launcher Disconnect	35.27	0.5339	70.45	(1) 45° EL (2) 90° EL (2) LEJ-7 35.27 FT. 6" LINE MISCELLANEOUS	7.5 28.0 37.33 66.06 10.00	289.38
70	M.L. Disconnect to Rep. Line Inlet "T"	165.33	0.5339	72.20	(2) 90° EL 165.33 FT. 6" LINE (1) N.O. 6" VALVE	28.00 309.66 21.74	1283.69

*ELEVATIONS ABOVE SYSTEM INLET (VALVE A133)

TABLE A-I NODAL INPUT DATA FOR KSC/SHUTTLE LOX LOADING SYSTEM (Continued)

NODE NO.	DESCRIPTION	LENGTH (FT)	INTERNAL DIAMETER (EQUIV~FT)	NODE EXIT ELEVATION* (FT)	INCLUDED COMPONENTS	EQUIVALENT (L/D)	DUCT WALL MASS (LB_M)
80	Rep. Line Inlet "T" to Rep. Line Outlet "T" (Two Parallel Legs)	17.0 (6"FILL) 20.0 (2"REP.) 19.46** (PARALLEL)	0.5339 (6"FILL) 0.1871 (2"REP.)	72.20	6" FILL LINE: (1) "T" RUN (1) N.C. 6" VALVE 17 FT. 6" LINE 2" REPLENISH LINE: (1) 6X6X2" "T" BRANCH (1) 6X2" ABRUPT CONTRACTION (1) 2" REP. VALVE (1) FLOW METER 20 FT. 2" LINE	 20.00 21.74 31.84 60.00 27.21 631.31 ← OPEN 665.55 106.89	131.99 (6"FILL) 32.84 (2"REP.)
90	Valve Complex Outlet to LOX Vent Line "T"	6.50**	0.70057	74.20	(1) "T" RUN (FLOW THROUGH FILL VALVE) (1) "T" BR. & 2X6" EXP. (FLOW THRU REP. VALVE) 7.75 FT. 6" LINE (1) 6" 90° EL (1) 6X8" "T" BR. (1) ABRUPT 6X8" EXP. 2 FT. 8" LINE	59.30 22091.48 43.04 41.51 60.00 34.29 2.85	80.47
100	Vent "T" to 90° EL North	31.00	0.70058	74.20	(1) "T" RUN (1) 8" V.J. FILTER 31 FT. 8" LINE	20.0 79.88 44.25	314.58

*ELEVATIONS ABOVE SYSTEM INLET (VALVE A133)

**EQUIVALENT LENGTH TO SIMULATE VOLUME AND MASS

TABLE A-I NODAL INPUT DATA FOR KSC/SHUTTLE LOX LOADING SYSTEM (Continued)

NODE NO.	DESCRIPTION	LENGTH (FT)	INTERNAL DIAMETER (EQUIV-FT)	NODE EXIT ELEVATION* (FT)	INCLUDED COMPONENTS	EQUIVALENT (L/D)	DUCT WALL MASS (LB_M)
110	90° EL North to 90° EL Up	42.50	0.70058	78.07	(2) 90° EL 42.5 FT. 8" LINE	28.00 60.66	431.28
120	90° EL Up to 90° EL West	35.08	0.70058	82.32	(2) 90° EL 35.08 FT. 8" LINE	28.00 50.07	355.99
130	90° EL West to Orbiter	48.15	0.70058	112.32	(3) 90° EL (1) 6.5 FT. FLEX-HOSE (1) 90° BEND 41.65 FT. 8" LINE	42.00 82.05 14.00 59.45	489.13
200	ORB Fill and Drain to LO_2 Manifold	12.72	0.667	118.64	(1) 5°18' MITRE (2) MC-284 VALVE (1) 75° BEND (2) 64.6° BEND 12.72 FT. 8" LINE	2.20 26.00 11.67 20.10 19.07	70.68
210	LO_2 Manifold to ORB/ET Disconnect	13.56	1.406	122.53	(3) "T" (RUN) (1) 17" 75.2° BEND (1) 17" 73.9° BEND (1) 17" 5.03° BEND 13.56 FT. 17" LINE	60.00 11.70 11.50 0.78 9.64	158.17
220	ORB/ET Disconnect to S.S./Aℓ Joint	11.38	1.406	130.59	(1) 17" 90° BEND 11.38 FT. 17" LINE	14.00 8.09	132.74
230	Aℓ Duct	23.59	1.406	154.18	23.59 FT. 17" LINE	16.81	117.71

*ELEVATIONS ABOVE SYSTEM INLET (VALVE A133)

TABLE A-I NODAL INPUT DATA FOR KSC/SHUTTLE LOX LOADING SYSTEM (Continued)

NODE NO.	DESCRIPTION	LENGTH (FT)	INTERNAL DIAMETER (EQUIV~FT)	NODE EXIT ELEVATION* (FT)	INCLUDED COMPONENTS	EQUIVALENT (L/D)	DUCT WALL MASS (LB_M)
240	Aℓ Duct	23.59	1.406	177.77	23.59 FT. 17" LINE	16.81	117.71
250	Aℓ Duct/S.S. Joint	23.60	1.406	201.37	23.60 FT. 17" LINE	16.81	117.71
260	Aℓ/S.S. Joint to ET (Tank Bottom)	25.06	1.406	211.55	(2) 90° Bends 25.06 17" LINE	28.00 17.82	292.30

*ELEVATIONS ABOVE SYSTEM INLET (VALVE A133)

TABLE A-II NODAL INPUT DATA FOR KSC LOX VENT LINE

NODE NO.	DESCRIPTION	LENGTH (FT)	INTERNAL DIAMETER (EQUIV-FT)	NODE EXIT ELEVATION* (FT)	INCLUDED COMPONENTS	EQUIVALENT (L/D)	DUCT WALL MASS (LB_M)
140	4" Vent "T" to 4" Vent Valve	10.0	0.3550	72.20	(1) 4" "T" Branch (1) 8X4" Contraction (2) 90° EL 10 FT. 4" LINE	60.00 22.45 28.00 28.17	57.46
150	4" Vent Valve to M.L. Disconnect	181.33	0.6941	70.45	(1) 4" Vent Valve (1) 4X8" Expansion (2) 90° EL 181.33 FT. 8" LINE	317.71 546.79 28.00 261.24	2487.14
160	M.L. Disconnect to Top of Launch Pad	35.27	0.8683	35.18	(1) 8X10" Expansion (1) 90° EL (2) Expansion Joints 35.27 FT. 10" LINE	19.99 14.00 74.66 40.62	673.43
170	Across Top of Launch Pad	199.00	0.8683	33.11	(1) 90° EL (1) Expansion Joint 199 FT. 10" LINE	14.00 37.33 229.18	3799.62
180	Top of Launch Pad to Bottom of Launch Pad	198.35	0.8683	-0.58	(1) 10° MITRE 198.35 FT. 10" LINE	2.50 228.43	3787.21
190	Bottom of Launch Pad to Vent Pond	521.38	0.8683	-2.6	(1) 10° MITRE (2) 90° EL 521.38 FT. 10" LINE	2.50 28.00 600.46	9955.01

*ELEVATIONS ABOVE SYSTEM INLET (VALVE A133)

TABLE A-III STEADY STATE HEAT TRANSFER RATES FOR KSC/SHUTTLE LOX LOADING SYSTEM

NODE NO.	DESCRIPTION	HEAT TRANSFER AREA~FT^2	HEAT TRANSFER RATE-BTU/HR
10	V. J. ENTRANCE TO UNINSULATED SECTION (VALVE A28750)	25.66	952
20	UNINSULATED SECTION ENTRANCE TO MID CROSS-COUNTRY	840.51	35,402
30	MID CROSS-COUNTRY TO BASE OF LAUNCH PAD	840.51	31,183
40	BASE OF LAUNCH PAD TO TOP OF LAUNCH PAD	332.51	12,336
50	TOP OF LAUNCH PAD TO 45° EL	333.61	12,377
60	45° EL TO MOBILE LAUNCHER DISCONNECT	59.16	2,195
70	M/L DISCONNECT TO VALVE COMPLEX INLET	277.31	10,288
80	VALVE COMPLEX INLET TO OUTLET	32.63	1,494
90	VALVE COMPLEX OUTLET TO VENT "T"	14.31	531
100	VENT "T" TO 90° EL NORTH	68.23	2,531
110	90° EL NORTH TO 90° EL UP	93.54	3,470
120	90° EL UP TO 90° EL WEST	77.21	2,864
130	90° EL WEST TO ORBITER	106.09	3,936
200	ORB FILL AND DRAIN TO LO_2 MANIFOLD	26.68	18,519
210	LO_2 MANIFOLD TO ORB/ET DISCONNECT	59.91	3,295
220	ORB/ET DISCONNECT TO S.S./Aℓ JOINT	50.26	3,332
230	Aℓ DUCT	103.94	6,890
240	Aℓ DUCT	103.94	6,890
250	Aℓ DUCT/S.S. JOINT	104.00	6,894
260	Aℓ/S.S. JOINT TO ET (TANK BOTTOM)	110.65	7,335
	TOTAL		172,714

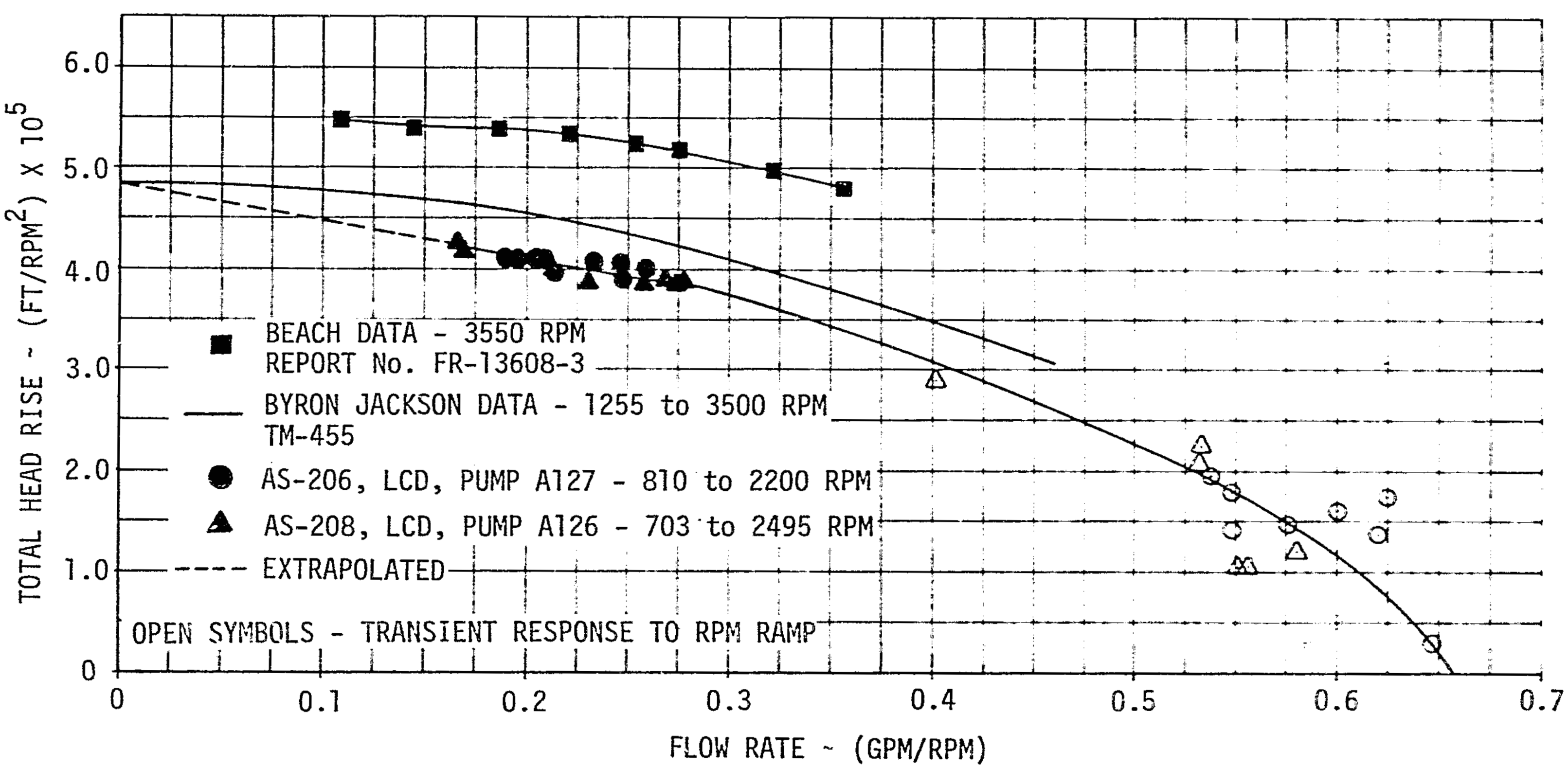

FIGURE A-1 NORMALIZED TOTAL HEAD RISE AS A FUNCTION OF FLOW RATE AND RPM FOR KSC 1000 GPM PUMP

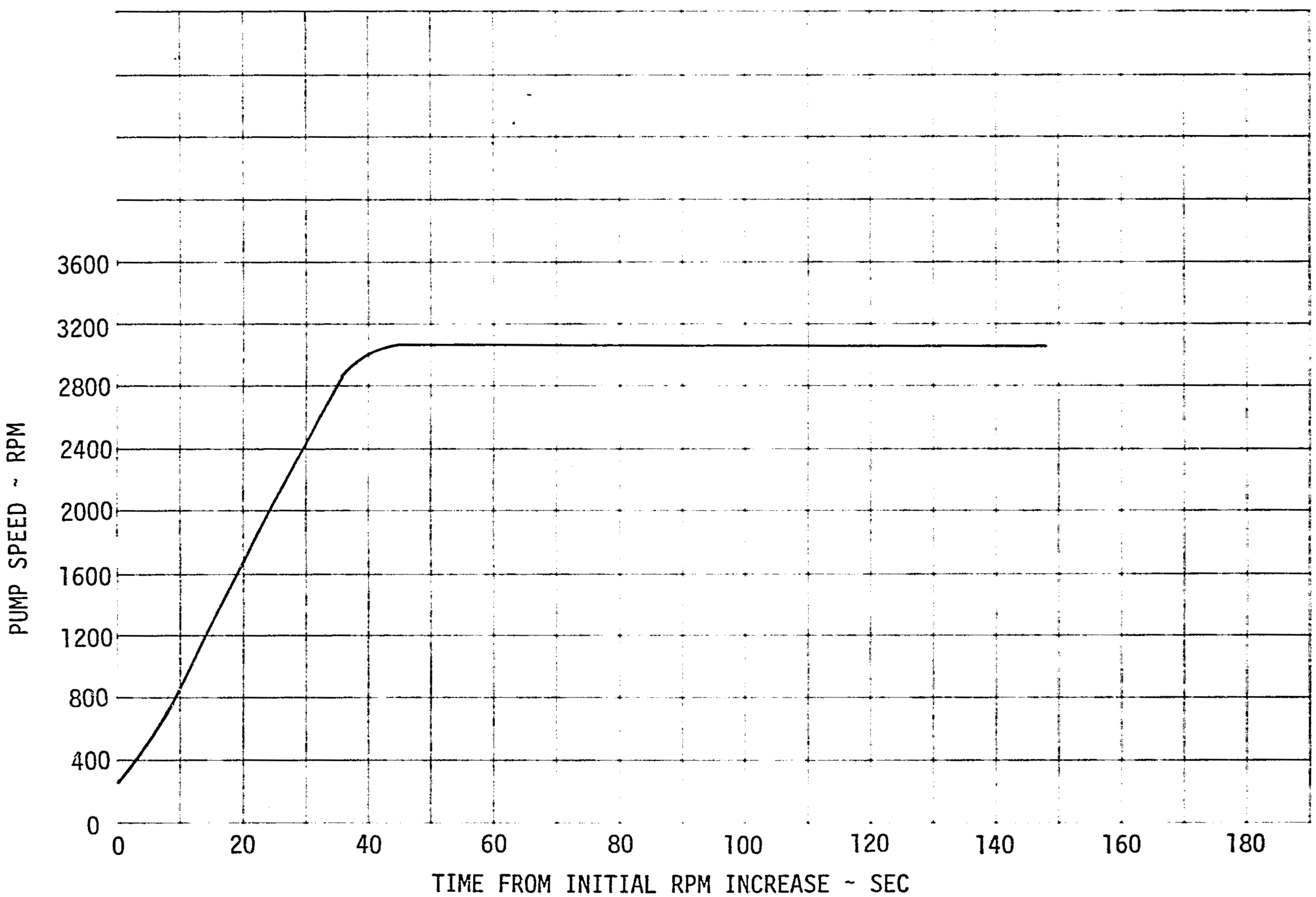

FIGURE A-2 TRANSIENT KSC 1000 GPM PUMP RPM FOR KSC LOX VENT LINE CHILL-DOWN

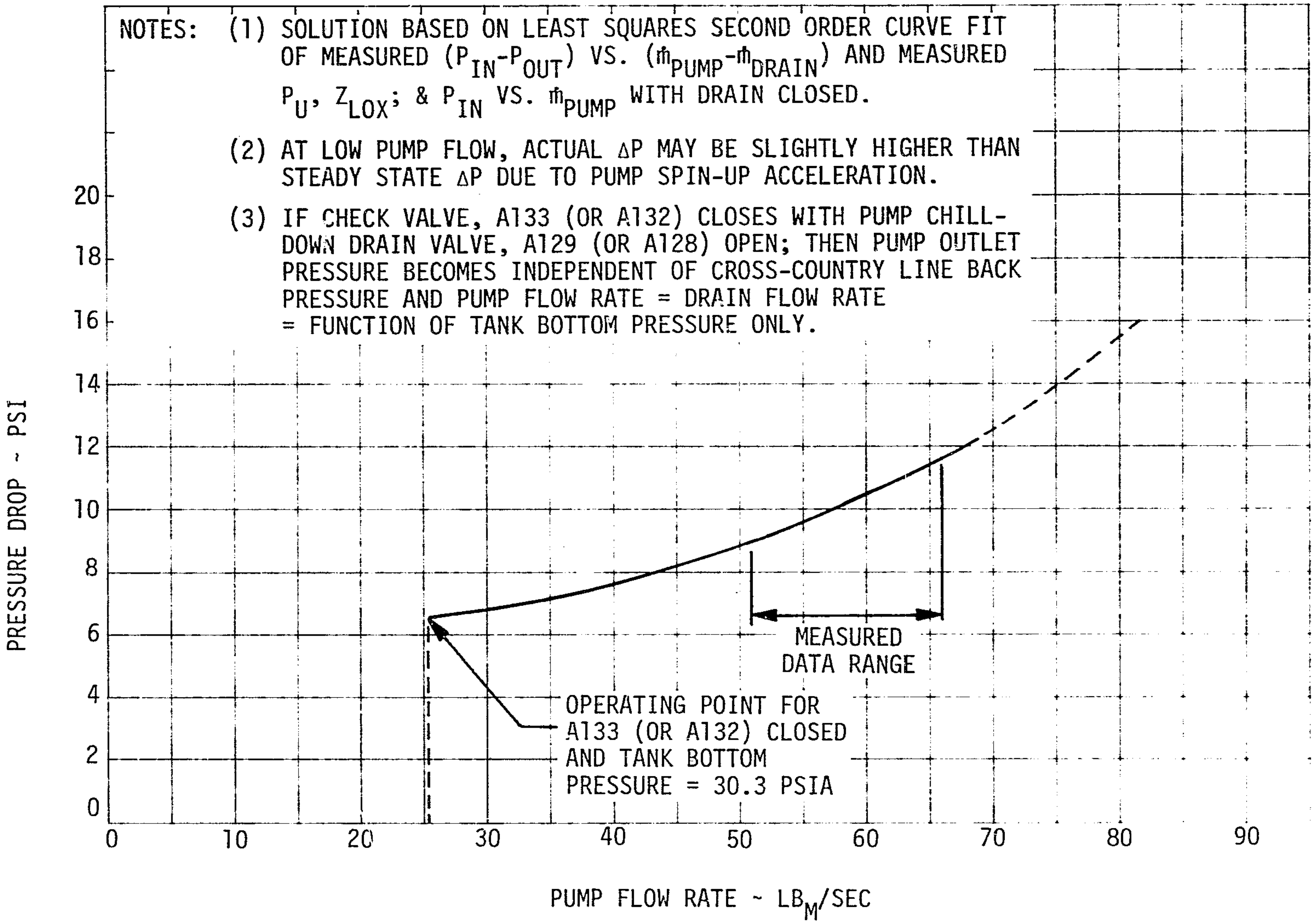

FIGURE A-3 PRESSURE DROP AS A FUNCTION OF FLOW RATE FOR KSC 1000 GPM PUMP

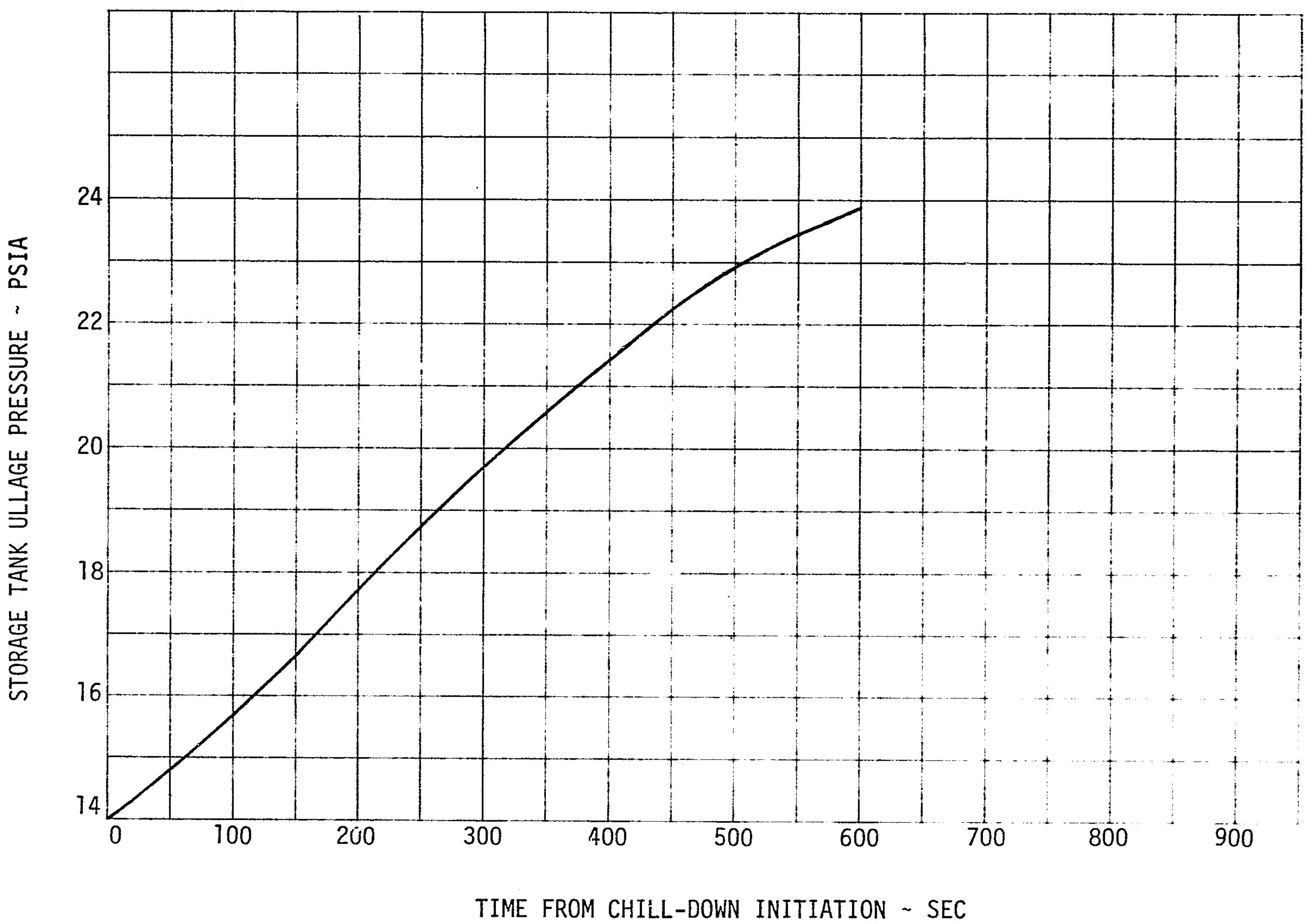

FIGURE A-4 TRANSIENT STORAGE TANK ULLAGE PRESSURE FOR KSC FACILITY CHILL-DOWN

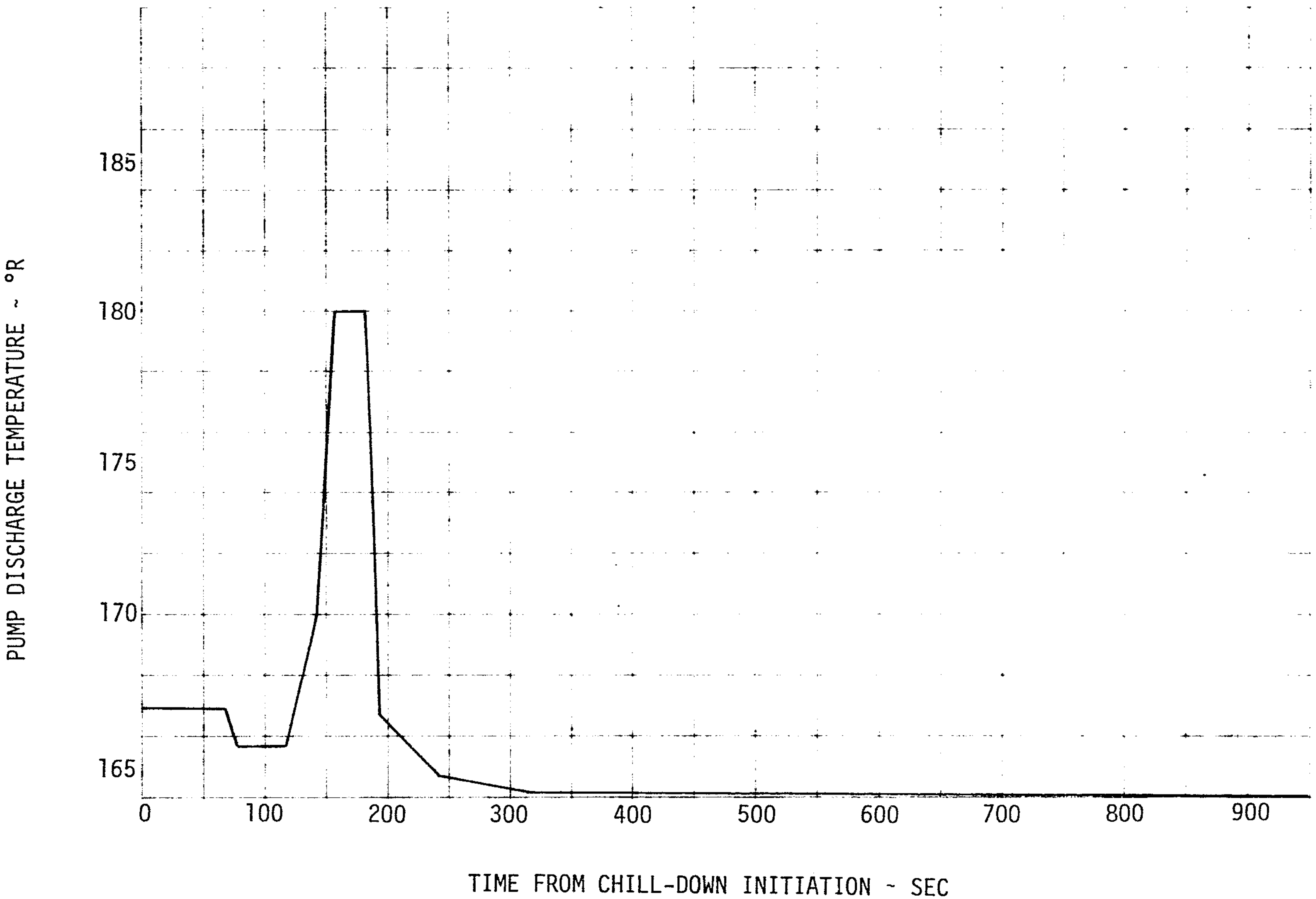

FIGURE A-5 TRANSIENT PUMP DISCHARGE TEMPERATURE FOR KSC FACILITY CHILL-DOWN ANALYSIS